Is there a water crisis on the blue planet?

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1. Introduction

Water is a miraculous substance. It occurs in abundance throughout the Universe, appearing within the first billion years after the Big Bang. Water is also common in our Solar System - in comets, the major planets Uranus and Neptune, moons like Europa and Enceladus, and of course on Earth, the Blue Planet.

Water is threaded through so many aspects of our world, firstly and foremost being essential for the creation, support and evolution of all living things. Earth's oceans appeared some 4.4 billion years (By) ago, soon after the planet's formation, and are thought to have initially covered the whole planetary surface. Whilst we don't know exactly how or when life formed, it is likely that life began in the oceans. The first ocean lifeforms emerged at least 3.5 By ago as single-celled ***microorganisms***. Around 2.5 By ago, ***cyanobacteria*** that produced oxygen during ***photosynthesis*** appeared, fundamentally changing the Earth's atmosphere and ultimately powering higher life forms. However, it was a long time later before the first complex ***multicellular organisms*** appeared - just 600 million years (My) ago.

The history of life in the oceans is long and complex, responding to constant change from many different factors. The first plants colonised land around 460 My ago, followed by animals some 360 My ago. Our direct ancestors, the first ***hominins***, arose in Africa, some 7 My ago, constantly facing challenges and existential threats from water, whether by climate change, droughts, or Ice Ages. Anatomically modern Homo sapiens, who all of humanity is today, arose some 100,000 years ago, before slowly colonising most of the planet. Again, they faced huge water challenges, especially with Ice Ages. But since around 12,000 years ago, at the end of the last Ice Age and the beginning of the ***Holocene***, Earth's environment has been favourable for humans, resulting in the dawning of modern civilisations and an explosion in the human population.

Humanity's relationship with water today is a complex one. We know water is essential for all life forms and vital for our own survival, but, by and large, we don't manage our available water resources as well as we should. It is commonly claimed that in fact we face a global water crisis, despite living on the 'blue planet' with a vast ocean reservoir covering 70% of the planet's surface. Whilst ocean water is too salty to drink without treatment, the planet has large amounts of freshwater in its ice caps and mountain glaciers, as well as in rivers, wetlands, and groundwater. Of course, plenty of the planet's land is relatively arid, with 3 billion people living in '***drylands***', needing to make the most of the scarce water available.

To understand the meaning of a water crisis, a broader perspective on water is needed, one that recognises the critical importance of water in providing food, maintaining ecosystems, and supporting spiritual and cultural wellbeing; one that notes that water isn't always our friend, causing amongst the largest loss of human lives through natural disasters; and one that understands how climate change is creating unprecedented risks to global water security and vulnerable communities.

In this Insight, we focus on the question 'is there a water crisis today'. In answering this question, we take for granted many of the critical roles water plays in our daily lives, in shaping our planet, and maintaining the functioning of our own bodies, as well as all other lifeforms, noting these aspects are well covered through the disciplines of hydrology, climatology, oceanography, and biology. Here we focus on how past civilisations have risen and fallen on the back of water; what aspects of water are contributing to a potential crisis today; our efforts to manage water crises; and the risks we face in the future.

Mangrove ecosystem in the Philippines. By Alex Traveler. Adobe Stock

2. History of human-water interactions

2.1 Early humans and water

The oldest hominins currently known date back some 6-7 My, but by far the best-known early hominin is Ardipithecus ramidus, a 4.4-million-year-old species from Ethiopia, which spent much of its time in the trees but walked bipedally whenever it ventured to the ground in the mixed woodland and savannah environments they inhabited. The oldest member of the genus Homo, H. habilis, lived in East Africa 2.3-1.5 My ago, while its descendant, H. erectus, is found throughout Africa and Eurasia, persisting from 1.9 My ago to 100,000 years ago. The earliest hominins in Africa were able to access water from rivers, lakes, and springs and from the food they ate, especially fruits.

Evidence of hunter-gatherer culture dates back as far back as 2 My, persisting until the agricultural revolution 12,000 years ago. Hunter-gatherers were nomadic, using mobility as a survival strategy, hence requiring access to large areas of land to find the food and water they needed to survive. Hunter-gatherer groups, ranging in size from extended families to larger bands of 100 or so, had a subsistence lifestyle that relied on hunting and fishing animals and foraging for plant foods and other nutrients like honey. Hunter-gatherer culture accelerated 1.9 My ago with the larger brain, longer-walking and meat-eating H. erectus pushing into Asia and Europe. Hunter-gatherers had several ways of accessing water; besides staying within reach of natural sources of fresh water such as rivers, lakes and wetlands, they dug wells and trenches while they were hunting or travelling. They could transport water in eggshells, animal hides and bladders. If streams stopped flowing due to droughts, these humans would move upstream or look elsewhere for other local water sources; and if the drought persisted, they migrated further in search of water.

Our own species, H. sapiens, evolved in Africa around 300,000 years ago, moving across the African continent. Around 50,000 to 60,000 years ago, a large human migration out of Africa coincided with lower sea-levels, giving access to the Arabian Peninsula and the Middle East, and eventually the whole globe. Most living people outside Africa can trace their ancestry back to this migration, meaning other hominids associated with earlier migrations out of Africa were displaced, or in some cases assimilated, leaving just one human species.

One of the greatest water challenges for early humans was Ice Ages. The most recent Ice Age spanned 40,000 to 10,000 years ago, covering one third of the planet, including North America and Europe, at its peak 24,000 to 21,000 years ago. Despite migrating from warm African climes, H. sapiens thrived in the harsh icy conditions by using more sophisticated weapons and tools and building shelter. Their fluent speech and language enabled the sharing of knowledge between tribes and generations through storytelling, music, dance and art. Critical knowledge about the natural world included the seasons, edible plants, and animal migrations. They used bone needles to fashion warm clothing, built weather-proof rock shelters, and used spears for hunting vast numbers of woolly mammoths

and bison. With ice glaciers absorbing ocean water, sea levels dropped some 120 metres below today's levels, opening up the opportunity for some humans to move to warmer regions.

Hunter-gatherer culture persists in pockets around the world today, including the Bushmen of southern Africa and the Sentinelese of the Andaman Islands in the Bay of Bengal. The oldest living culture today is Australian aborigines who have a close physical and spiritual relationship to water (Box 1).

Box 1: Aboriginal Australians and water

(Partly based on article by Waterwise Queensland, 2023)

Aboriginal Australians entered Australia some 60,000 years ago, before becoming physically and genetically isolated until the 1700s, making them the world's oldest civilization. Aboriginal peoples, often considered nomadic hunter-gatherers, also farmed and built large villages, meaning many groups stayed in one place. Whether nomadic or in villages, understanding water was essential for aborigines to survive in the often arid and harsh Australian conditions – the driest inhabited continent. Aborigines learnt to identify certain bird, animal and plant species that needed access to water. They also followed the seasonal movements of some animals which led trackers directly to water. Birds such as the zebra finch, striated pardalote and red-browed pardalote, for example, are excellent at finding water in the desert.

Aboriginal traditional knowledge about locating and using water included mapping of water sources, setting up markers and identifiers such as scar trees, as well as oral instruction. Adult aborigines memorised the locations and sequences of water supplies and taught their children while travelling along the chains of water sources. In some areas, artwork and carvings on trees thousands of years old pointed the way to water sources that were difficult to find. Landscape markers also denoted the custodianship of water sources and the rights and responsibilities of visitors to these sites.

Water is also highly significant in Aboriginal culture and identity, helping define language boundaries and ceremonial places. Dreaming stories highlight the role of spirits in creating sources of water—rivers, creeks, rock wells, lakes, lagoons, seas and springs—and the ongoing supply and control of these water bodies by ancestral spirits and creation beings.

Evidence of Aboriginal people using and protecting precious water sources can still be found in many places throughout Australia. Traditional hunting and fishing activities are still practiced by many Aboriginal people outside urban areas today. Colonisation of Australia in the 1700s alienated aborigines from their traditional lands and European settler land clearing destroyed many trees and artwork signposts. Today, aborigines living in remote locations are more reliant on western means for their water supply, such as groundwater wells and small-scale desalination plants that treat local brackish ground water. Despite these technologies, the quality of water for some remote aboriginal communities is far from meeting modern standards (Wyrwoll, P.R. et al. 2022), resulting in serious health issues.

2.2 Agricultural revolution, early civilisations and war

One of the most radical changes in human societal evolution occurred just 12,000 years ago when hunter-gatherer tribes began converting to agricultural settlements, commencing in the Fertile Crescent, a region that includes parts of modern-day Iraq, Syria, Lebanon, Israel and Jordan. This transformation, known as the ***Agricultural Revolution*** (or ***Neolithic Revolution***), which coincided with the end of the last Ice Age and the beginning of the current geological epoch, the Holocene, paved the way for modern civilisation. The first settlements formed on the banks of rivers – including the Ancient Egyptians, who were based on the Nile, the Mesopotamians on the Tigris/Euphrates rivers, the Ancient Chinese on the Yellow River, and the Ancient Indians on the Indus. Rivers provided many services to the first civilisations, as they still do today. These services included drinking water, food from fish and other aquatic plants and animals, and fertile floodplains for growing irrigated crops. Rivers were also used for transporting people and goods, and disposing of wastes. Animals that came to drink at the river's edge also presented easy prey.

Although each civilisation was unique, there are common patterns amongst the first centres based around rivers. Most notably, they were all ***hydraulic empires*** - a social or governmental structure which maintains power through exclusive control over water access. This system of government arises through the need for water supply, flood control, and irrigation, which requires central coordination and a specialized bureaucracy. The political structure was commonly characterised by a system of hierarchy and control based around class or caste. Power, both over food, water, energy, and a means of enforcement, such as the military, were vital for the maintenance of control.

Most early civilisations became sophisticated users of water. Below we describe some water management skills and innovations developed by the Ancient Egyptians and Romans as examples of the water management sophistication of many early civilisations.

Ancient Egypt and its water management

Ancient Egypt was the preeminent civilisation in the Mediterranean world for almost 30 centuries—from its unification around 3100 BCE (Before Common Era) to its conquest by Alexander the Great in 332 BCE. The Egyptian civilisation was established in the northeast corner of the African continent on the banks of the river Nile – to which it owed much of its success. The Greek historian Herodotus wrote that "Egypt was the gift of the Nile". Whilst most of Egypt was desert, it had a slender strip of fertile land subject to annual Nile floods that deposited new layers of silt, thus maintaining high soil fertility. This enabled agriculture to become the main source of wealth in the region, with the Ancient Egyptians cultivating and trading wheat, flax, papyrus, and other crops.

The Nile floods are driven by an annual monsoon between May and August, causing heavy precipitation upstream in the Ethiopian Highlands, which rise to 4,550 metres. Based on the flooding, the ancient Egyptians invented a three-season calendar:

1. Akhet (Inundation or Flood): roughly from September to January.

2.Peret (Emergence or Winter): roughly from January to May.

3.Shemu (Low Water or Harvest or Summer): roughly from May to September.

The Ancient Egyptians are well known for their innovative irrigation designs used for growing crops. Utilising the natural rise and fall of the River Nile, they built a criss-cross network of earthen banks parallel and perpendicular to the river, thus forming irrigation basins of various sizes. Flood water was directed into these basins, saturating the soil, with excess water drained into more distant basins. As the waters receded, the floodwaters left behind rich silt. At its peak of 13 metres, the flood would cover the entire Nile floodplain. Farmers planted wheat and other crops just as the winter was beginning and harvested them from mid-April to early May. The Egyptians also built reservoirs to hold water supplies in case of drought.

Specific technological innovations included the Shadoof, a hand-operated device for lifting water using a weight to counterbalance a bucket of water suspended from a long pole and pivoted over a beam (Figure 1). The bucket could be lowered into a canal, filled, raised and rotated to the desired location. Another innovation was the nilometer, used to predict flood levels. This instrument recorded the height of the Nile over years and then could identify water levels above or below normal at any given time, acting as an early warning system for floods and droughts.
The Egyptians provided the earliest documentation of water treatment in Sanskrit writings and inscriptions in ancient Egyptian tombs, dating back to about the 15th century BCE. Many different water treatment methods are mentioned, including boiling of water over fire, heating of water under the sun, dipping of heated iron into water, filtration through gravel and sand, as well as the use of the Strychnos potatorum seed and a stone called “Gomedaka.” In ancient Egypt, aluminium sulphate, iron sulphate, or a mix of the two were used to remove suspended solids.
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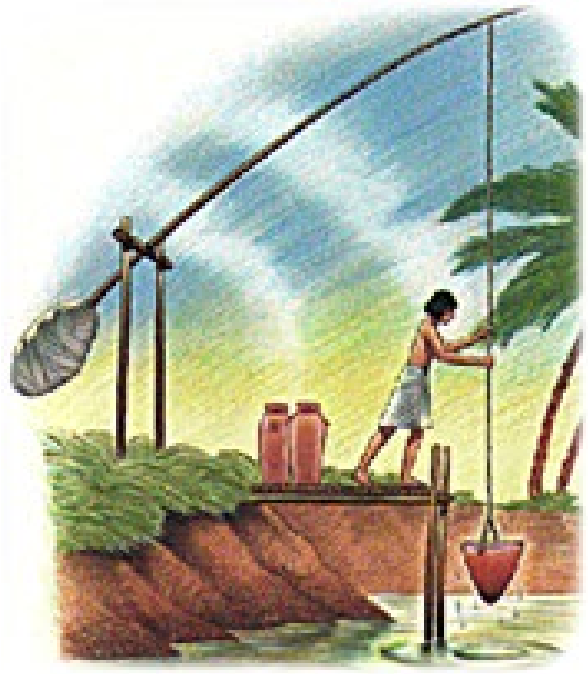

Figure 1. The Shadoof.
Source: http://waterhistory.org/histories/nile/t1.html

Romans and water

The Romans are also well known for their innovation in managing water. It is generally accepted that Rome was founded in 753 BCE, while the Roman Republic began in 509 BCE as a representative democracy, until 27 BCE. At this time the Republic was superseded by the Roman Empire until its demise in the 5th century CE (Common Era). By about 300 BCE, Rome had a population of more than half a million and could no longer rely on local rivers or groundwater alone, so they began building an intricate system of canals, aqueducts and pipes for importing water and distributing it around the city. Romans also recognised the need to flush away waste, which led them to create the first sewers. At its peak, the Roman Empire stretched over three continents and was home to an estimated 70 million people, requiring the extensive deployment of its water management methods. Some notable Roman water innovations are:

Aqueducts: The Romans constructed aqueducts throughout the Republic and Empire eras to bring water from outside sources into cities and towns. Rome's first aqueduct was built in 312 BCE and, by the 3rd century CE, 11 aqueducts supplied water to a population of over a million to provide public fountains, public baths, latrines, and wealthy private households. The first supply priority was constantly running public fountains from which most Romans accessed their water. Aqueducts also supported mining operations, milling, farms, and gardens. Aqueducts were built from stone, brick and concrete and were designed with a small downward gradient so water could be moved by gravity. Aqueducts were built above ground, and below ground by tunnelling, with water flow controlled by sluices, stopcocks and storage cisterns. Sedimentation tanks were used to settle out large debris and particles. Cities and towns throughout the Roman Empire emulated this model.

Figure 2: Pont Du Gard Roman Aquaduct, France Pont du Gard (Roman Aqueduct) - UNESCO World Heritage Centre

Roman baths: as many as 900 baths were built over the Roman Empire. The largest 'Thermae' could accommodate 1500 people. Built on hot springs and heated by under floor air circulation, the baths were said to have healing powers. Their impressive designs included libraries, galleries, shops, eateries, gardens, courtyards, gymnasiums, and marble statues. They were lively meeting places but were restricted to Roman citizens, while children were forbidden, and slaves only entered to serve their masters. Separate hours during the day were allotted for use by men and women.

Roman public toilets date back to the 2nd Century BCE, consisting of dark, long rooms lined with benches dotted with key-shaped holes placed rather closely together. To clean themselves, Romans used a sea sponge on a stick called a tersorium kept in a shallow gutter below the toilets. Not everyone carried around their own sponge, so shared sponges inevitably passed on diseases such as dysentery. Beneath the public toilet houses, a sewer system made of terra cotta piping drained sewage away from Rome, along with public bathwater, stormwater and the marshy swamp areas of the city. The main sewer of Rome was the Cloaca Maxima which emptied into the Tiber River. The sewerage system relied on a regular supply of water from aqueducts. Rome's sanitation system became essential to the growth of Rome and was replicated across the empire. The public toilets though were dark and dirty places and rarely visited by women and certainly never by rich women. Instead, private latrines were built in upper-class homes, over cesspools. These latrines probably smelt awful and so wealthy Romans just used chamber pots, emptied by slaves, sometimes onto the streets, a practice that persisted despite laws written to control this behaviour. After the fall of the Roman Empire, the idea of sewers was essentially lost to Europe for 1,300 years.

Public fountains: Rome's first aqueduct was built in 312 BCE and supplied a water fountain at the city's cattle market. For nearly 2000 years, water fountains both provided public drinking water and decorated the piazzas of Rome. In 98 CE, a Roman consul was named curator aquarium, or guardian of the water of the city. His task was to administer nine aqueducts supplying 39 fountains, 591 public basins, private villas and the Imperial household. In modern-day Rome around 2,500 public fountains called nasoni (big noses) still supply water safe for drinking.

Water and agriculture, mining and construction: The Romans built dams and cement-lined reservoirs and used aqueducts to deliver water for irrigated cropping. Water-driven mills were used in agriculture, mining and construction, replacing slave and animal labour by the last century BCE. Breakthroughs in milling technology expanded their use to crushing ores in mining and cutting wood and marble. Mills dramatically increased productivity, enhancing the Roman economy. Their water-smart agricultural practices allowed Romans to thrive in the Mediterranean climate. Eventually, though, population growth made the Empire vulnerable to varying grain yields responding to changing climate.

Property rights: a lesser-known story about water in the Roman world is property rights that were used to allocate water as a "common pool resource". In the Republic period, Romans created a servitude for water, representing a right that an owner of a "dominant" property would exercise over a resource associated with a "servient" property. The servitude for water was strongly protected in Roman law since it was attached to the land in question rather than the person who owned it or cultivated it. When the land changed hands, the new owners would acquire the same rights and obligations as the previous owners.

2.3 Industrial revolution and water

The Industrial Revolution introduced new technologies for treating both drinking water and wastewater. The advent of engines allowed the pressurising of water so that it could be delivered through pipes into any building. The water was used for cleaning, bathing, and toilets, as well as drinking, before being returned to the water supply system. The need to eradicate waterborne diseases led to the development of water treatment technologies. One of the earliest forms of water treatment was riverbank filtration whereby water was pumped from a line of wells in the sand, which filtered out some of the waterborne pathogens that made people sick. Sand filtration was developed further into the slow percolation of contaminated water, effectively removing many pathogens from drinking water. Another breakthrough came in the early 20th century with the use of chlorine to purify water.

In the 20th century, wastewater dumping in rivers and oceans became unacceptable in advanced countries. Regulations, combined with new treatment technologies, made wastewater treatment the norm. Three levels of water treatment were developed and deployed to varying degrees: primary treatment – removal of larger material in settling ponds; secondary treatment – use of micro-organisms to break down waste in ponds in addition to primary treatment; and tertiary treatment – removal of nutrients and other compounds using technologies such as carbon filtration, ozonation, ultraviolet treatment or biological nutrient removal systems, in addition to primary and secondary treatments.

Beyond water and wastewater treatment, many industrial uses of water were developed during the revolution, including in fabrication, processing, washing, diluting, cooling, transporting a product, or incorporation into a product. Some industries use large amounts of water to produce commodities such as food, fibre, paper, chemicals, refined petroleum, or primary metals. Water is used as a solvent, a catalyst, or a vapour in some industrial processes. Water fabrication uses water in the production of electrical, photonic, or optical circuits on semiconductor wafers. Water is also used in nuclear and other cooling towers, and for cooling machines and equipment that generate heat during industrial operations.

2.4 Water management today

Water management in the 21st Century is diverse, with differences in the level of sophistication practiced. Advanced economies employ a wide range of specialised methods to achieve a high degree of water security, perhaps with the exception of environmental water security. Anyone living in these economies can expect clean water on tap for drinking and domestic uses; ready and safe disposal of human effluent and industrial wastes; water for gardens and swimming pools; water for food and energy production; and wetlands, rivers and lakes suitable for recreation and aesthetic enjoyment. In recent times there has been a growing appreciation of the social, cultural and spiritual values of water.

By contrast, in least developed countries, some developing countries and war-torn regions, water management is rudimentary, subsistence or survival focussed. Access to clean water is fraught, and treatment of wastewater minimal. In these countries there is a devastating loss of human life linked to poor water quality. Today billions of people face the ignominy of a lack of basic water services.

Of course there are exceptions, with some poor communities in least developed countries living healthily and sustainably off of nature, whilst in rich countries minority groups can be marginalised from the high quality services available to wealthier communities.

3. What can we learn from past water crises?

Civilisations were usually located where there was good access to reliable water and on or near floodplains where fertile soils were regularly replenished by silt deposited in floods. However, water has also played a key role in the demise of civilisations, with droughts in particular undermining societies by limiting the availability of water for drinking, food production, ecosystem functioning and other purposes.

While the fall of a great empire is usually due to a complex set of factors, drought has been identified in a surprising number of collapses. In their book Drought, Sheffield & Wood (2011) identify more than ten civilizations, cultures and nations that collapsed, in part, because of drought. In Table 1, we present some well-known civilisations that have ended or been diminished through water impacts, presented chronologically.

Table 1. Civilisations where water has played a key role in their demise (adapted in part from Sheffield and Wood 2011)

CIVILISATION	CAUSE OF DEMISE RELATED TO WATER
Akkadian Empire (2334 BCE - 2193 BCE). As the first ancient empire of Mesopotamia, the great Akkadian Empire 4200 years ago united all the indigenous Akkadian-speaking Semites and the Sumerian speakers, and controlled Mesopotamia, the Levant, and parts of Iran. It thrived along the banks of the Tigris and Euphrates where extensive agriculture supported the highest population density of the time.	Cullen et al. (2000) discovered a large increase in dust 4,200 years ago that likely coincided with a 100-year drought that brought a 30% decline in precipitation to Syria. This led to a sudden drop in river water levels, which combined with soil salinisation from over-irrigation, contributed to the collapse of the Akkadian empire.
Old Kingdom of Egypt (c. 2700–2200 BCE) was the first of three so-called 'Kingdoms' which mark high points in civilisation in the lower Nile valley. Also known as the "Age of the Pyramids", the Old Kingdom was noted for its monumental pyramids, centralised government, and rule by the pharaohs.	The same drought that brought down the Akkadian empire in Syria severely shrank the normal floods on the Nile River in ancient Egypt. A terrible famine caused by the drought reduced both harvests and tax revenue, hastening the collapse of the Old Kingdom.
The **Late Bronze Age civilisation** (1200 BCE) in the Eastern Mediterranean hosted some of the world's most advanced civilizations. The Mycenaean culture was flourishing in Greece and Crete. The chariot-riding Hittites had carved out a vast empire encompassing a large part of Asia Minor and the Middle East. In Egypt, the New Kingdom was at its height.	Around 1200 BCE, the Late Bronze Age Eastern Mediterranean civilizations declined or collapsed. Kaniewski et al. (2013) showed that this collapse coincided with a 300-year drought which caused crop failures, famine, socio-economic crises and forced migrations.

CIVILISATION	CAUSE OF DEMISE RELATED TO WATER
Indus Valley Civilisation (2700-1900 BCE) was located around the Indus River in India and Pakistan, and was considered an advanced water manager. The Harappans built impressive water infrastructure including drinking water supplies, sewerage networks, water storages and public baths.	Most theories of the collapse of the Indus Valley Civilisation involve water in some way. Evidence of silt deposits in ruins suggests destruction by floods, whilst another theory points to the river changing its course, leading to desertification.
The **Maya civilization** (2000 BCE to 1000 CE) was an **advanced and influential culture** spanning five countries – southeastern Mexico, Guatemala, Belize, and the western portions of Honduras and El Salvador. It is known for its temples, architecture, sophisticated writing system, mathematics, astronomical system and calendar.	Haug et al. (2003) documented substantial multi-year droughts coinciding with the collapse of the Maya civilisation. These droughts likely led to severe famine and lack of water, causing many deaths. A cascade of progressive collapses brought down the civilisation at its cultural peak between 750 CE and 900 CE, although Maya culture persists today.
Tang Dynasty, China (700-907 CE). The Tang Dynasty, known as the golden age of Chinese art and literature and famous for its peace and prosperity, supported a large population of 80 million, with its capital the world's largest city. Trade was conducted with Syria and Rome via the Silk Road.	The Tang dynasty began to weaken in the eighth century CE, and it fully collapsed in 907 CE. Sediments from Lake Huguang Maar in China dated to the time of the collapse indicate a sudden and sustained decline in summertime monsoon rainfall. Agriculture in China depends upon the summer monsoon, which supplies about 70% of the year's rain in just a few months. Agrarian rebellions resulted in mass population loss and displacement, widespread poverty, and further government dysfunction that ultimately ended the dynasty in 907 CE.
Tiwanaku Empire of Bolivia's Lake Titicaca region (300 - 1000 CE) was one of the most important South American civilisations prior to the Inca Empire, dominating the region for 500 years. Tiwanaku influence was attributed to its remarkable agricultural system known as the raised-field system, consisting of raised planting surfaces separated by small irrigation ditches, or canals.	The Tiwanaku Empire ended abruptly between 1000 - 1100 CE following drying in the region as evidenced by a drop of 10 m in nearby Lake Titicaca observable in sediment cores.
Ancestral Puebloan (also known as Anasazi) in the Southwest U.S. (11th - 12th centuries CE) lived in structures ranging from grand pueblos built into the side of cliffs, to small family houses. They had a complex network linking hundreds of communities and population centres across the Colorado Plateau. They held a distinct knowledge of celestial sciences.	Beginning in 1150 CE, North America experienced a 300-year drought called the Great Drought, which some think caused the collapse of the ancestral Puebloan civilisation. Around 1277 CE, a 23-year drought began to ravage the Pueblo community and by 1300 CE, the people abandoned Mesa Verde, a bustling community of around 6,000, including the Cliff Palace. Social strife emerged amongst the 30% of the population who lived on drought-affected land. Lack of food led to brutal conflicts seen at archaeological sites populated with decapitated bodies and mangled skeletons.

CIVILISATION	CAUSE OF DEMISE RELATED TO WATER
Khmer Empire based in Angkor, Cambodia (802- 1431 CE) ruled Southeast Asia for over 600 years. It was a Hindu-Buddhist empire centred around hydraulic cities and known for its monumental architecture, trade and road system.	Extreme climate variability in the 14th and 15th centuries, in the form intense decade-long droughts interspersed with heavy monsoons, contributed to the demise of the empire. "The Angkor droughts were of a duration and severity that would have impacted the sprawling city's water supply and agricultural productivity, while high-magnitude monsoon years damaged its water control infrastructure" Buckley et al. (2010).
Ming Dynasty, China (1368- 1644 CE), the last imperial China Han dynasty, was characterised by prolonged social stability and orderly government.	The Ming Dynasty collapsed at a time when the most severe drought in the region in over 4,000 years was occurring, according to sediments from Lake Huguang Maar analysed by Yancheva et al. (2007). An inscription found carved on a wall of Dayu Cave in the Qinling Mountains of Central China dated July 10, 1596, during the 24th year of the MIng Dynasty's Emperor Wanli, said:"Mountains are crying due to drought."
Modern Syria: Since 2011 a civil war has led to the death of 300,000 people, with a further 7.6 million displaced and 4.2 million refugees.	A key factor contributing to the war was a severe drought which began in 1998. The drought led to unprecedented crop failures and consequent migration of millions from rural areas to cities, where conflict began. According to a tree ring study by Cook et al. (2016), this drought was the worst to hit Syria in 500 years (98% probability).

Much can be learnt from the importance water has played in building past civilisations and in their demise. Almost all early civilisations were established close to good water resources. Drought is the predominant water-related contributor to the collapse of civilisations, as without water societies cannot function. Drought has a cumulative impact, especially with successive food crop failures and reduced drinking supplies. Often this socially disruptive event leads to severe conflicts over increasingly scarce water resources, or migration to other centres where they are not welcome or there are insufficient resources for all. Those unable to migrate to safety often die of thirst and starvation, or from conflict.

The collapse of any given society depends on local circumstances and the integrity and resilience of the society itself. Often several factors come together with unfortunate timing, and water is just another contributor. The demise of once bustling societies is a good reminder that even great civilisations can become fragile to the impact of climate variability, often enough to topple what once seemed invincible. Even today, with all our modern science and technology, droughts of different length and intensity, and floods, present serious challenges to many societies, especially vulnerable communities that have limited resources or capacity to respond. Human induced global warming and climate change present a whole new level of threat.

4. Dimensions of the water crisis today

It's tempting to think of a 'water crisis' in just one dimension, for example running short of drinking water as in 'Day Zero' faced by numerous cities and towns in recent years. However, the true nature of our water crisis is that it is manifest in numerous different dimensions and at different scales – some global, some regional and some local. Here we concern ourselves with global and regional water crises that reach many communities. It's also worth defining the term 'crisis' as it is somewhat overused; here we take the meaning of 'crisis' to be a global or regional situation that needs an urgent response to avoid a much worse future outcome.

4.1 Global water crises

The global water crises identified here are associated with climate change, biodiversity loss, pollution, and unsustainable development – each affecting people worldwide. While we analyse these crises individually, they are of course interlinked, and all in a sense result from unsustainable development.

4.1.1 Water and climate change

Global warming and climate change are an existential threat to humanity, as identified in Insight 6, where the topic is dealt with in detail. Here, we summarise the impacts of climate change that are expressed through water, and what that means for humans and the environment.

As the Earth's surface warms up due to emissions of ***greenhouse gases*** from human activities, more water evaporates from land and sea and is stored as additional water vapour in the atmosphere. Typically, our atmosphere can store 7% more water vapour with every 1°C degree temperature rise. One consequence of higher atmospheric water vapour concentration is its occasional release as high precipitation events, seen as storm deluges, often causing local flash flooding as well as more widespread flooding. Flooding causes significant human fatalities, displacement and damage to homes and built infrastructure.

Despite there being more rainfall overall with global warming, droughts are becoming more severe in terms of frequency, intensity, extent and duration, and deserts are expanding. In the decade to 2017, drought affected at least 1.5 billion people and cost US$125 billion globally (UNCCD, 2023a). Forecasts suggest that by 2050 droughts may affect over three-quarters of the world's population. Droughts have contributed to the downfall of past civilisations, as noted in section 3, but these days technical solutions are available, if not always affordable. For example, facing the 13-year Millennium Drought from 1997-2010, the Australian government invested in building ocean desalination plants for most of its major cities, which happen to be located on or relatively close to coastlines. However, in regions like sub-Saharan Africa, drought can mean loss of food, animal death, starvation, migration, and conflict. According to predictions by the United Nations and the World Bank (UN 2023a), drought could put up to 700 million people at risk of displacement by 2030. In many parts of the world, drought is a precursor to wildfires, which are escalating and causing severe damage and health issues. In 2023 Canada and Greece experienced their worst wildfires on record.

As noted in the previous section, a severe drought contributed to the disruption of modern Syria. Hoerling et al. (2011) demonstrated that human-caused emissions of greenhouse gases were a key attributable factor in the reduction of winter precipitation and increased frequency of droughts in the Mediterranean region, including Syria, in recent decades.

Our oceans absorb over 90% of the extra greenhouse heat associated with climate change, leading to both their warming and thermal expansion. At the same time, the warmer atmosphere and ocean are melting the northern and southern ice caps and mountain glaciers – with the additional liquid water flowing into the oceans, adding to sea-level rise globally. The increases in sea level, combined with more severe storm surges, are inundating low-lying coastal regions such as deltas and coral islands, whilst eroding coastlines generally. The ocean is coupled to the atmosphere and hence plays a key role in the behaviour of the ***El Niño–Southern Oscillation (ENSO)***, with El Niño firmly established in 2023, adding significantly to global temperatures.

The ocean is also involved with several important climate system ***tipping points*** such as reducing the strength of the ***Atlantic Meridional Overturning Current*** due to ice melt in the Arctic.

Arctic permafrost thawing, due to global warming and tundra fires, is causing microbes, dormant in the frozen soil for millennia, to begin releasing the key greenhouse gases methane and carbon dioxide. Thawing permafrost triggers a feedback loop, with the vented greenhouse gases increasing warming further, which in turn thaws more permafrost. Where the tipping point lies for runaway permafrost thaw is uncertain, but research shows some permafrost regions are already emitting more carbon than they are absorbing, suggesting we are near that tipping point, if not already over it.

Climate change risks to water is a crisis for all humans and all other species because of devastating effects on societies broadly, and vulnerable communities in particular, with impacts everywhere destined to worsen quickly in coming decades.

Melting permafrost near the Yukon-Alaska border. Photo via National Parks Service. Wikimedia Commons

.4.1.2 Aquatic ecosystems and biodiversity

According to the ***Living Planet Index*** (2022), freshwater species populations have seen an alarming decline of 83% since 1970, more than any other species group. This result is based on 6,617 monitored populations, representing 1,398 species of mammals, birds, amphibians, reptiles, and fish. Habitat loss and degradation, barriers to migration, excessive water extraction, altered flow regimes, species over-exploitation and pollution are well known major threats to freshwater species. Coastal and inland wetlands are experiencing ongoing loss, with more than 80% of wetlands estimated to have disappeared since the pre-industrial era, according to the Sustainable Development Goals Report (United Nations 2023b). Aquatic environments host a rich biodiversity, essential to providing protein and food security, amongst their many ***ecosystem services***.

Climate change also poses specific pressures on all aquatic ecosystems, including oceans and their marine organisms. Rising ocean temperatures and increasing acidification from the dissolution of carbon dioxide from the atmosphere are posing severe threats to coral reefs and phytoplankton. If global warming reaches 2°C, 99% of tropical coral reefs are forecast to disappear, along with the extraordinary biodiversity they support, their human food sources and dependent livelihoods. ***Phytoplankton***, at the base of the marine food chain, are expected to lose diversity and resilience under climate change, with knock-on effects on the productivity and functioning of the marine environment.
It is clear that aquatic species and ecosystems face a crisis of dire proportions, with the outlook worsening.

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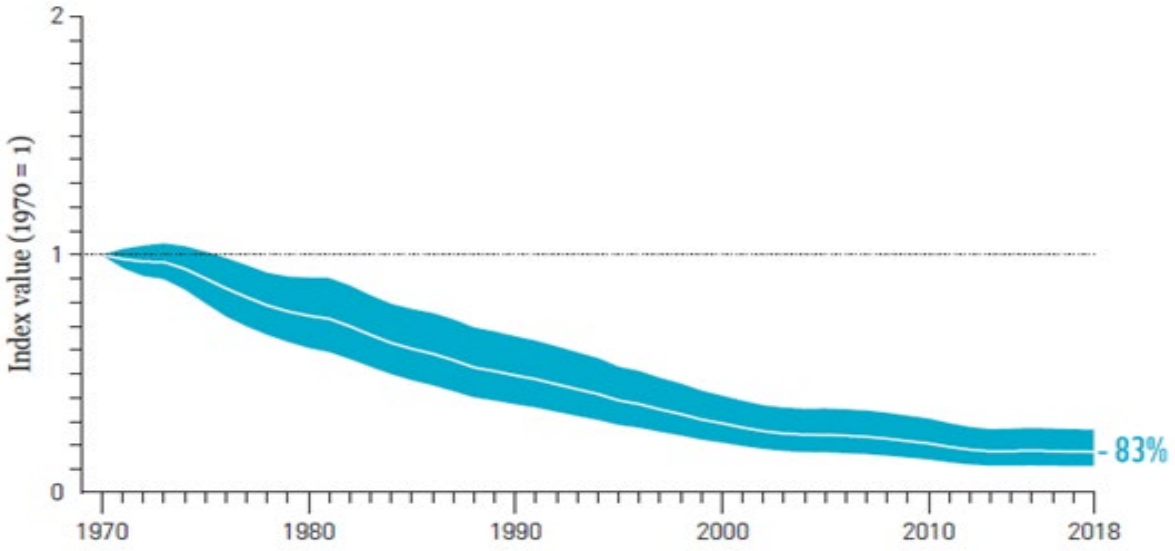

Figure 3: The Freshwater Living Planet Index (1979-2018).
Sourced October 2023 from HOME | WWF (panda.org)

4.1.3 Water pollution

Pollution of water can be observed worldwide, from the ice sheets to oceans to rivers and wetlands. Many human activities lead to water pollution. One of the largest diffuse sources of pollution is agriculture, due to its land conversion, use of fertilisers and pesticides, soil erosion and escape of animal wastes, all on a massive scale, as 40% of global land is devoted to some form of farming. Whilst precision, organic and regenerative farming result in less pollution, their adoption is very low. Other industries such as mining, forestry, manufacturing, and chemical plants, indeed almost all industries, generate a complex mixture of water pollutants of varying levels of threat to the health of humans and other species. The world is also urbanising rapidly, especially in developing countries, adding to the already entrenched problem of lack of wastewater treatment. The treatment of waste is expensive, which is one reason that globally, in 2022, only 58% of known wastewater flows generated by households were safely treated before being released into the environment (United Nations 2023b).

Oceans are also subject to mass pollution from chemicals and trash, mostly manufactured plastic products from land sources. There is estimated to be more than 150 metric tons of plastic in the ocean, increasing by around 10 tons every year, and making up some 80% of marine pollution. Plastics over time break down into highly mobile microplastics, which are eaten by many different marine animals, producing deleterious effects such as loss of nutrition, inhibition of growth and development, tissue damage, intestinal blockage, neurotoxicity, behavioural abnormalities, and mortality.

Water pollution is an age-old crisis, and while there are some clean-up success stories, globally the crisis remains unabated.

Environment pollution. By overcrew. Adobe Stock

4.1.4 Unsustainable development and water

The concept of ***Sustainable Development*** was defined in the Brundtland Report (1987) as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". Sustainable development imagined a society where living conditions and resources meet human needs without undermining planetary integrity, by carefully balancing economic development, environmental protection, and social wellbeing. Whilst sustainable development has been promulgated for 36 years and widely adopted by governments and businesses, its success in practice is highly questionable, as unsustainable development has been mostly the norm, as for example noted in the ramping up of climate change due to human activities since the 1980s, and the massive loss of species populations since the sustainable development concept was launched.

Why has development been allowed to severely compromise the integrity of the biosphere and exact increasingly severe impacts on societies? Principally because development has been generated through the widely adopted capitalist economic model which focuses on human consumption to drive increasing wealth and welfare. In this economic paradigm, improvements in human welfare have been impressive, with many indicators of positive outcomes, although notably wealth inequality is a growing issue. Our advancing science and technologies have also allowed a massive human population explosion, now reaching 8.1 billion, an increase of 4.4 billion since 1970, and still increasing by around 80 million a year. This 120% increase in human population occurred while wildlife populations dropped 70% globally over the same period.

Alongside human population increase has come dramatically higher consumption demands and expectations, driven by the capitalist system. These demands in advanced economies include consuming exotic foods, living in large homes, owning one or more cars, access to goods and services of all kinds, and global travel. Developing economies aspire to the same high consumption living standards, despite the Earth lacking sufficient resources. Rapidly increasing human population and per capita consumption have required a re-engineering of the planet's terrestrial surface and exploitation of oceans to provide the necessary goods. Today we use 75% more resources than what the planet's ecosystems can regenerate — or 1.75 Earths (Global Footprint Network 2022). The materials used by the global economy have quadrupled since 1970, and in recent years consumption has jumped while reuse of resources has fallen (Circularity Gap Report 2020).

Water has been an integral part of the unsustainable human development enterprise. Demand for freshwater has climbed over time and that trend continues. This demand has led to the construction of over 50,000 large dams worldwide to store water for drinking, irrigation and hydropower purposes, which at the same time have fragmented rivers, disturbed flow regimes and reduced sediment flow, with negative impacts on river fish and downstream ecosystems. Irrigated agriculture has grown at about 1% each year since the 1980s (UN-Water, 2019) to meet human food requirements but has resulted in over-exploitation of groundwater, with levels falling dramatically in some regions. Agriculture, involving the mass conversion of forests and other native vegetation, has altered hydrological regimes, and, along with most other industrial developments, has severely polluted waterways and oceans.

Unsustainable development is the fourth ongoing water crisis, with aquatic systems affected by many forms of development, including unsustainable water development itself.

4.2 Regional water crises

4.2.1 Access to safe drinking water and sanitation

Although not affecting advanced economies, one of the ongoing human tragedies today is over 800,000 people in low and middle-income countries die each year because of inadequate water, sanitation, and hygiene (WHO 2023). Contaminated water is linked to the transmission of diseases like cholera, diarrhoea, dysentery, hepatitis A, typhoid, and polio.

In 2022, 2.2 billion people still lacked drinking water services that were accessible on premises, available when needed and free from contamination (United Nations 2023b). Of this, 1.3 billion people live in rural areas, but the figure is declining, whereas in urban areas the figure is growing due to an urbanising world.
As of 2022, 57% of the world's population used a safely managed sanitation service (United Nations 2023b) but approximately 1.5 billion people still lacked even basic sanitation services, two thirds of whom lived in rural areas. An estimated 419 million people still practised open defecation. In 2022, nearly 2 billion people lacked a basic handwashing facility with soap and water at home.

4.2.2 Water stress

When a territory withdraws 25% or more of its renewable freshwater resources, it is said to be "water stressed". An estimated 18% of the world's total renewable freshwater resources was withdrawn in 2020, after considering environmental flow requirements, suggesting overall the globe is not water stressed (FAO, 2022). The picture is different at a subregional level - in 2020 Southern Asia and Central Asia had high levels of water stress and Northern Africa had critical water stress. It is estimated that 2.4 billion people lived in water-stressed countries (level of water stress equal to or greater than 50%) of which almost 800 million lived in high and critically high water-stressed countries (level of water stress equal to or greater than 75%) (FAO, 2022).

Looking ahead, nearly 6 billion people could suffer from clean water scarcity by 2050 according to the United Nations World Water Development Report (2018). This is the result of increasing demand for water, reduction of water resources, and increasing pollution of water, driven by population and economic growth.

Indian man collects water in Puttaparthi, Andhra Pradesh, India. Adobe Stock.

4.2.3 Water and conflict

'Water wars' is a conflict between countries, states or societal groups over access to water resources. Water conflicts also include deliberate military or terrorist action to destroy or damage water infrastructure or contaminate water sources. Throughout history droughts have been an underlying contributor to conflicts, as noted previously. Climate change is driving more severe droughts, and combined with population increase, competition for increasingly scarce water is on the rise, leading to more water conflicts.

Tensions and conflicts over water now occur more frequently at the subnational, rather than the transnational, level – for example violence between pastoralists and farmers in sub-Saharan Africa are rising. By contrast, water resources that span international boundaries are more likely to be a source of collaboration and cooperation than war.

Water can be a trigger for conflict, a tool for war, and a casualty of war. As water scarcity grows, physical assaults and cyberattacks on civilian water systems, during wars, are increasing, even if the war started for other reasons. In Yemen, Syria and Iraq, fighting has destroyed water infrastructure, wells and other facilities, leaving millions without safe water to drink or grow crops. In the ongoing Ukraine-Russia war, the Kakhovka Dam was destroyed in the early hours of 6 June 2023, causing thousands to flee the resulting floods which hit settlements and farmland across the region. In the Israel-Palestine war, 2 million people on the Gaza strip have been left desperately short of water for daily survival.

As shown in the infographic below, water conflicts have risen dramatically over the past two decades in Asia and Africa. Severe droughts in India have led to a substantial increase in conflicts over access to irrigation and domestic water and to demonstrations against water diversions from one community to another.

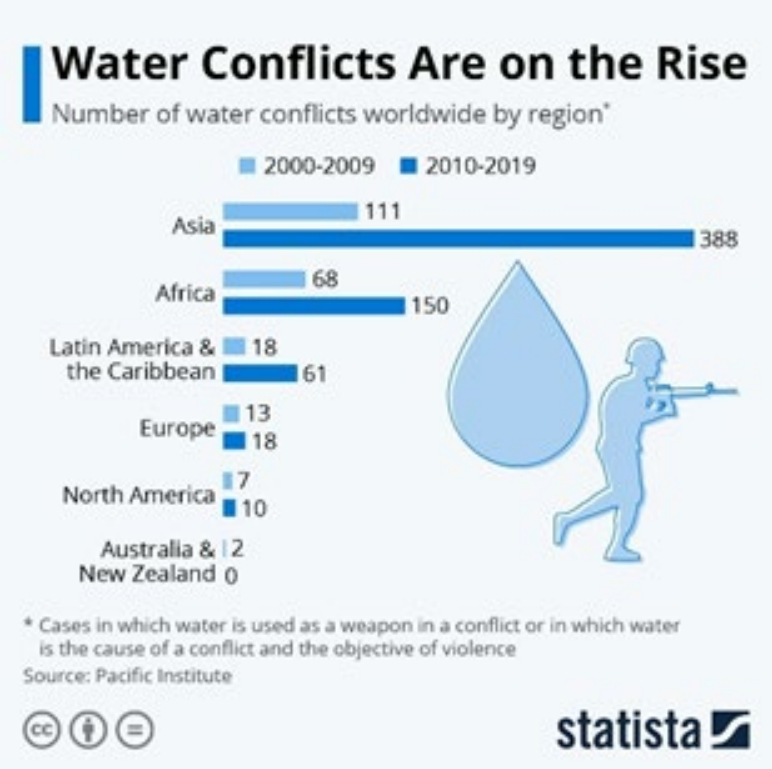

Figure 4. Water conflicts. Sourced October 2023 from Chart: Water Conflicts Are on the Rise | Statista

4.3 Water risks and the global economy

Water-related climate risks will jeopardize growth prospects in the regions worst affected and in some of the poorest countries. The World Bank (2016) predicts that climate-water risks could cost some of the world's regions up to 6% of GDP by 2050 and lock in sustained negative regional growth, as well as spurring migration and sparking conflict. In relation to the global business sector, CDP (2022) found 69% of listed equities are exposed to water risks that could generate a substantive change in their business, with a potential value at risk of US$225 billion. CDP (2021) found that the cost of future inaction on water risks is over five times the cost of action. The WWF Water Risk Filter (2023) estimates that around 10% of global GDP and around 17% of the global population are exposed to high water risks, increasing to 46% of GDP and 51% of the global population by 2050. By contrast, WRI Aqueduct (2023) estimates 25% of the world's population are currently exposed to extremely high water stress annually, and that 31% of global GDP will be exposed to high water stress by 2050, up from 24% of global GDP in 2010.

Grazing cows near the village of Langerak, South Holland. By Ruud Morijn. Adobe Stock

5. Can we manage the water crisis?

We have seen in the previous section that four distinct global water crises exist – climate change, biodiversity, pollution, and unsustainable development. At the regional level, challenges include safe water and sanitation, water stress and water conflicts. One attempt to manage all these crises in a single integrated approach is the United Nations 2030 Agenda - Transforming our World: the 2030 Agenda for Sustainable Development (United Nations, 2015). Given the currency of this global initiative, and the fact it is at its mid-way point, it is worth first understanding the progress being made in the water domain, which is essential for the achievement of numerous other Sustainable Development Goals. We then examine efforts to manage the specific water crises related to climate change, biodiversity and water stress.

5.1 Sustainable development as a solution to water crises

The United Nations has attempted to turn around unsustainable development with the 2015 launch of its Transforming our World: the 2030 Agenda for Sustainable Development (2030 Agenda) and associated 17 Sustainable Development Goals (SDGs). At the current mid-point of the 2030 Agenda in 2023, progress towards many goals, including SDG 6 - Ensure availability and sustainable management of water and sanitation for all - is alarmingly off track (United Nations 2023b,c). For most water indicators, the current rate of progress is not fast enough to close the gap before 2030.

In some regions and countries, for some indicators, progress is even relapsing. Lack of progress on SDG6 and other water-related SDG targets can threaten hard-won development gains in other areas. Whilst SDG6 reporting is substantial, the SDG Progress Report noted that in too many countries, policymakers lack credible and timely data for decision-making due to inadequate monitoring and reporting systems, and insufficient resources, meaning reported progress against targets is not always globally representative. The progress on individual SDG6 targets and additional actions needed are summarised in Table 2.

Soto de ribera combined cycle thermal power plant in Asturias, Spain. By Stockphotoastur. Adobe Stock.

Table 2. Progress on SDG6, based on United Nations (2023b,c)

SDG6 TARGET	2023 UPDATE	2030 EXPECTATIONS / ACTIONS NEEDED
Target 6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all.	Between 2015 and 2022, the proportion of the world's population with access to safely managed drinking water services increased from 69% to 73%, an additional 687 million. 2.2 billion people still lacked drinking water services that were accessible on premises, available when needed and free from contamination. In rural areas, the number of people lacking safely managed drinking water decreased from 1.5 billion in 2015 to 1.3 billion in 2022. In urban areas, over the same period, it increased from 784 million to 857 million, highlighting the challenge of urban growth.	At current rates of progress, the world will reach 77% of people with safely managed drinking water services by 2030, leaving 2 billion without. Gaps in the water workforce capacity are growing due to limited access to education, weak supportive frameworks, and poor rates of recruitment and retention of skilled staff, particularly women.
Target 6.2: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.	Over 2015-2022, safely managed sanitation services increased from 49% to 57%; and basic hygiene services increased from 67% to 75%, with 911 million and 637 million people respectively gaining access to these essential services. Approximately 3.5 billion people still lacked safely managed sanitation services in 2022 – of which two out of three people lived in rural areas. In 2022, 2 billion people lacked a basic handwashing facility with soap and water at home. Open defecation decreased from 715 million to 419 million during 2015-2022.	At the current rates of progress, the world will reach 65% safe sanitation coverage by 2030, leaving 3 billion without safely managed sanitation, and 1.4 billion without basic hygiene services.
Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.	Based on data from 140 countries and territories, in 2022 about 58% of household wastewater was safely treated before being released into the environment. There was insufficient data to measure industrial wastewater. Data from 2017–2020 indicate that 60% of assessed water bodies in 97 countries had good ambient water quality. However, water quality data are not routinely collected in many countries, meaning that over 3 billion people could be at risk because the health status of their freshwater systems is unknown.	Agriculture and untreated wastewater are major threats to water quality, with nitrogen and phosphorus measurements frequently failing to meet targets. Efforts are needed to improve farming practices and wastewater treatment, especially in regions with high population growth.

The SDG Progress Reports also noted that water governance is ineffective due to institutional weaknesses and fragmentation, and poor regulation, accountability and transparency. Moreover, inclusive governance was found to be recognised but often not implemented, despite national policies and laws increasingly recognising participatory procedures. Of particular concern, financing needs have gone up while official development assistance (ODA) disbursement is going down.

In summary, progress on SDG6 water goals and targets is being made overall, but with notable gaps and some relapses. In its midterm review, UN (2023b) noted that progress towards achieving SDG 6 is 'severely falling behind, and that a much higher pace of implementation and increased cooperation and partnerships are needed across all targets'. To meet the global target of universal access by 2030, the United Nations (2023c) Blueprint for Acceleration: Sustainable Development Goal 6 Synthesis Report on Water and Sanitation 2023, declared that progress needs to 'increase six times faster for safely managed drinking water, five times faster for safely managed sanitation and three times faster for basic hygiene'. Access to safely managed drinking water, sanitation and basic hygiene services is still out of reach for billions of people, particularly in rural areas and least developed countries. With Target 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes, unmet by a long way and now expired, it is uncertain what happens next for monitoring and achieving this component of SDG6.

Sustainable Development Goals icons. Adobe Stock.

5.2 Managing climate change risks to water

One of the most challenging water crises at present is climate change, with much worse impacts expected by scientists in coming decades. In terms of managing climate change, unfortunately, despite scientists ringing the alarm bell on global warming for more than three decades, society has been slow to respond, and greenhouse gas emissions from human activities have risen sharply over this period. As a result, the water crisis has escalated significantly, affecting vulnerable communities mostly – often the ones who have contributed least to climate change. Climate-water risks are global, and even the most economically advanced nations are being affected, as seen by recent floods and wildfires around the world.

As to the question of whether climate-water risks can be managed, the answer is yes and no. Most critical is the mitigation of global warming through reducing greenhouse gas emissions. There is some cause for optimism here, as the rate of increase of human generated greenhouse gas emissions has slowed dramatically over the last decade due to the transition from fossil fuels to renewables in the energy sector. Some analysts are hopeful greenhouse gas emissions will peak soon and then start a decline to 'net zero' by 2050 – but based on past performance, many are sceptical too. However, in the water sector, no matter what happens to greenhouse gas emissions, some ongoing water challenges will worsen for centuries and millennia to come – the most obvious being ice melt and sea-level rise.

Some level of risk management can be achieved through planned adaptation – such as building desalination plants or adopting recycling to secure water supplies; raising the height of levees for flood protection; building sea walls to limit coastal erosion; constructing barrages to protect coastal cities; or applying nature-based solutions such as reviving wetlands in floodplains to accommodate floods, or replanting mangroves to assimilate carbon whilst protecting shorelines. Technical adaptations, in particular, can be expensive and sometimes contested and may only be affordable on scale by wealthier countries. The alternative to planned adaptation is 'forced adaptation', such as giving up building homes in flood-prone areas, withdrawing from eroding and inundated coastlines, or moving for better water and food access. Forced adaptation can involve mass migration, already occurring in regions like Syria and sub-Saharan Africa due to severe droughts, leading to social unrest, distress, and conflict. The United Nations High Commissioner for Refugees (UNHCR 2021) stated that the number of people displaced by climate change-related disasters since 2010 has risen to 21.5 million, pointing out that, in addition to sudden disasters, climate change is a complex cause of food and water shortages. Further, over the past 30 years, the number of people living in coastal areas at high risk of rising sea levels has increased from 160 million to 260 million, 90% of whom are from poor, developing countries and small island states.

Climate-water risk also plays into financial risk, as at-risk property and infrastructure is devalued and becomes either uninsurable or exposed to ultra-high insurance premiums. Governments may provide some financial support, but by-and-large owners will suffer the consequences. Hence, one societal response to increasing climate-water risks, and future perceived risks, will be prioritising 'climate and water-safe locations', which will both be highly sought after and become much more expensive.

Whilst the water sector must combat its own greenhouse gas emissions, one 'clean energy' water solution is hydropower, which currently accounts for 7% of global energy use. Although considered clean energy, hydropower dams are expensive to build, use a large amount of concrete, are damaging to the environment in terms of flooded areas and as disturbed river flow regimes, and can be disruptive for local communities.

5.3 Managing the aquatic biodiversity crisis

The SDG6 Target for managing the aquatic biodiversity and ecosystem crisis is Target 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes. As noted above, this target, with a date of 2020, was not met – in fact it does seem this target was highly unrealistic given the scope of damage and massive restoration needed.

The Living Planet Report (2022) shows aquatic species populations are still in decline (Figure 3), and as aquatic habitats are destroyed or degraded, biodiversity loss ensues. Humans have changed the face of the Earth for their own immediate benefits but at the same time have severely compromised the ability for other species to survive. Despite the environmental movement emerging mid last century, and the enactment of environmental legislation by most governments, the human onslaught of nature has been relentless and is ongoing.

Solutions to save aquatic ecosystems and biodiversity have been around for many decades, focusing on conservation and sustainable development. Conservation measures have seen the growth of protected areas, both aquatic and terrestrial, but unfortunately these areas are still far too small, and inadequately managed, to prevent species loss. Hence the United Nations, through its Convention on Biological Diversity, enacted in 1993, set out to increase protected areas to sustain biodiversity, on land and sea. Unfortunately, the global loss of biodiversity and ecosystems has accelerated at an unprecedented rate, reaching the highest extinction rate in human history, with 1 million animal and plant species currently threatened with extinction, many within decades.

Climate change is also having a growing impact on aquatic species, with shallow water tropical coral reefs expected to disappear by 2050 on current trends, losing a myriad of species and source of food and livelihoods for millions of people. As a result of the growing biodiversity threats, in late 2022, the United Nations adopted "30x30" - a worldwide initiative for governments to designate 30% of Earth's land and ocean area as protected areas by 2030, as part of the Kunming-Montreal Global Biodiversity Framework (United Nations 2022). This target is hugely ambitious considering only 16.64% of land and inland water ecosystems, and 7.74% of coastal waters and the ocean, lay within documented protected and conserved areas in 2020 (UNEP 2020), and the quality of protection within these areas is questionable. On a more positive note, international organisations and investors are increasingly recognising that solutions to climate change and biodiversity are closely intertwined, allowing multiple benefits for conservation actions.

5.4 Overcoming water pollution

As we saw in section 4, water pollution is a massive global issue. Despite significant progress in advanced economies, with some remarkable

stories of the clean-up of major river systems like the Thames, Danube and Rhine in recent decades, generally water pollution is on the increase, with the world's oceans becoming the latest casualty. There are many tools for dealing with water pollution, including improved agricultural practices that can minimise farm escape of pesticides, nutrients and sediments into rivers, wetlands and oceans. Point source pollution from industrial activities, like manufacture of blue jeans, is again technically easy to resolve but requires strong regulation and enforcement to ensure companies adopt the necessary clean-up technology and factor that into their pricing. As for human effluent from 8.1 billion people, again sanitation technology is advanced and available but expensive to buy, run and maintain, including requiring significant technical capacity. Many of the megacities in developing countries were built without sewerage systems, limiting easy options for human effluent treatment.

Plastics are a new frontier of pollution, ending up in our waterways and oceans, compromising marine life and food systems. At this stage most regulatory focus is on managing plastic use and disposal at source, but, while having some small successes in some locations, plastic disposal into waterways is normal practice in many communities adjacent to rivers and oceans.

5.5 Managing water stress

Future growing populations, rising incomes and per capita consumption, and expanding cities, resulting in the demand for water rising exponentially, will collide with more erratic and uncertain water supply due to climate change. The impacts of climate change will be channelled primarily through the water cycle, cascading through food, energy, urban, and ecosystems, with large and uneven consequences across the globe. A common fear is that communities, including major urban centres, will run out of water in the future – indeed, more and more towns and cities have been exposed to Day Zero and the need for water to be trucked in from other areas for people to survive.

Whilst water stress is likely to increase, there is a lot that can be done to manage the risk. One side of the equation is to improve water use efficiency, and to use water for its most productive purposes. This can be achieved through technical innovation such as more water efficient domestic appliances and on-farm irrigation technologies; economic methods such as water pricing signals based on 'more use means higher costs', and cap and trade water markets encouraging higher value water uses; regulation such as bye-laws restricting specific water uses during droughts; licenses for groundwater extraction to remain within sustainable yields; behaviour modification such as educating people to value and conserve water; or establishing community-based water monitoring, allocation and management with technical support.

The other side of the equation is improving water supply through multi-sourcing. This could include desalinating ocean water or brackish groundwater; increasing surface water storage in dammed reservoirs; treating and recycling wastewater and stormwater for uses on outdoor parks and sporting facilities; treating human effluents to a potable standard for drinking and domestic use; treating wastewater and storing in aquifers for later groundwater extraction and use; and even extracting water from humid air. These and other methods provide an armoury of solutions to water stress, but as they are mostly technological in nature, they can be expensive and hence better suited to wealthier countries or sectors. In least developed and lower income developing countries, local innovations to achieve water security will be more cost-effective.

In very poor remote communities under severe water stress, solutions are typically limited to the provision of external water by government or donors, using for example trucked or bottled water. This can provide short term relief, but longer-term water stress is likely to end these communities, causing death or migration to better lands, as it did with numerous ancient civilisations.

Drought's Grasp: Reservoir Bed Revealed. By isuru. Adobe Stock.

6. Concluding remarks

The fundamental question of this Insight is whether our Blue Planet is suffering a water crisis today. With 70% of the Earth's surface covered by water, it seems inconceivable that a water crisis would be possible. However, using our definition of a crisis as a global or regional situation that needs an urgent response to avoid a much worse future outcome, we conclude that several water crises exist, at both global and regional scales. This does not take away from the magnificent achievements in improved water management that has been achieved in numerous countries and locations by a highly motivated workforce.

Whilst integrated thinking for water problems and solutions has merit, it is more instructional to consider the water crisis in its different forms. This is because each crisis has different causes, drivers, and characteristics, and can be solved independently, as well as in combination with other crises.

Four water crises are recognised as being global – climate change driven water impacts, aquatic biodiversity and ecosystem decline, water pollution, and the water consequences of unsustainable development.

Climate change, an existential risk for humanity, expresses most of its impacts on human societies and ecosystems through water, and hence creates a water crisis. Climate change is accelerating and every day we hear of more extreme floods, droughts, intense storms, cyclones, inundation from sea-level rise and storm surges, marine heatwaves, loss of corals and melting of the polar caps and glaciers. In terms of managing the climate-water crisis, political and societal responses to date have been far from adequate.

As global warming increases, the water cycle will be energised further, the cryosphere will melt more rapidly, tipping points will be crossed, and extreme climate-water events will pose even greater risks for humans and ecosystems.

An aquatic biodiversity and ecosystem crisis is evident from the dramatic decline of 83% of aquatic species populations, 80% loss of wetlands, widespread river degradation, a 50% decline in marine animal populations, and loss of seagrasses and mangroves since 1970. Combined with the increasing threat of climate change, there is potential for the complete loss of tropical corals this century, with large consequences for biodiversity, as well as humans dependent on coral systems. Driving this biodiversity and ecosystem crisis is habitat destruction and degradation, modification of natural flow regimes, barriers to fish movement, invasions of exotic species, overexploitation of both water and organisms, water pollution, overfishing, coastal development, and high greenhouse gas emissions, all linked to human activities. Aquatic species the world over are in crisis. Management efforts to protect terrestrial aquatic species and marine species to date have fallen well short of what is needed to prevent a mass extinction event unfolding over the next few decades.

The water pollution crisis emerged from the agricultural and industrial revolutions combined with a human population explosion. In the most advanced economies, the introduction of pollution controls in the 20th century have been fairly effective, requiring treatment of all human effluent and industrial wastes before safe disposal into water environments.

Non-point source agricultural pollution has generally been more difficult to control. In least developed and many developing countries, most effluent and wastes are disposed to the environment untreated, posing great risks for downstream users. This ongoing crisis has been supplemented by the global pollution of waterways and oceans by plastics – with solutions painfully slow to implement.

Sustainable development, initiated at the 1992 Earth Summit in Rio de Janeiro, was at the time considered imperative for a better planetary future. Instead, unsustainable development, the fourth global water crisis, continues apace in most countries, skewing economic development massively in favour of humans, at least in the short-term, and against other species, leaving the Earth's biosphere imperilled. Completely contrary to original intentions, unbridled development has also occurred across parts of the water sector itself, exemplified by over-extraction of surface and groundwater, in-filling of wetlands, isolation of and development on floodplains, and unrelenting dam construction causing river fragmentation and disturbed flow regimes.

In addition to the above global water crises, regional level water crises include increasing water stress in towns, cities, catchments and remote communities; unsafe drinking water and unsafe sanitation in least developed and some developing countries; increasing internal conflicts over access to water; and damage to water services and infrastructure in war zones.

Solutions to the multiple water crises are available, some technical, some political and some community based, but have been difficult to implement because of the massive adjustment required to the existing socio-economic paradigm. The case for effectively managing water is strong in that it could achieve universal access to clean water and sanitation, provide additional clean energy, address food insecurity, help control disease pandemics, allow preparedness for disasters and enable recovery, minimise conflicts, and help eliminate extreme poverty and gender inequality.

There is room for optimism in managing water crises, as exemplified by countries that have built high water security and/or restored some aquatic ecosystems. Furthermore, the United Nations has risen to the challenge with three crucial initiatives: Transforming our World: the 2030 Agenda for Sustainable Development; the Framework Convention on Climate Change; and the Convention on Biological Diversity. These initiatives bring together the world's best minds across multiple disciplines and sectors to formulate the actions needed for a better future. In terms of water, the United Nations is making significant progress with Sustainable Development Goal 6 - Ensure availability and sustainable management of water and sanitation for all, although positive results are uneven, and a significant acceleration and increased funding is needed to achieve 2030 targets.

In summary, the world is facing multiple water crises, some global and some regional. On the positive side we have the know-how and tools to solve the water crises, have key global initiatives in place, and some inspiring success stories. On the downside societal behaviours and intransigent economic systems, have, by and large, realised far too limited responses to overcome these crises, despite scientists' warnings. It remains to be seen if there is sufficient societal willpower to redress the worsening water crises in the coming decades.

Appendix A: Earth's water inventory today

The distribution of Earth's water by volume is shown in Table A1.

Table A1: Distribution of Earth's water

SALINE WATER	**% OF TOTAL WATER**	**% OF SALINE WATER**
Oceans, seas and bays	96.5%	99.03%
Saline groundwater	0.94%	0.964%
Saline lakes	0.006%	0.006%
FRESHWATER	**% OF TOTAL WATER**	**% OF FRESHWATER**
Ice caps, glaciers and permanent snow	1.74%	68.7%
Fresh groundwater	0.76%	30.1%
Ground ice and permafrost	0.022%	0.83%
Freshwater lakes	0.007%	0.25%
Soil moisture	0.001%	0.045%
Atmospheric water vapour	0.001%	0.036%
Swamp water	0.0008%	0.031%
Rivers	0.0002%	0.0059%
Biological water	0.0001%	0.0031%

Glossary

Agricultural revolution: The transition of human culture from hunting and gathering to agriculture and settlement, during the Neolithic period, making an increasingly large human population possible.

Atlantic Meridional Overturning Circulation (AMOC): The main current system in the South and North Atlantic oceans, transporting warm upper-ocean water northwards and cold, deep-water southwards, as part of the global ocean circulation system. (IPCC glossary)

Biodiversity: The variety and variability of life on Earth.

Cyanobacteria: A group of photosynthetic prokaryotes capable of oxygenic and anoxygenic photosynthesis.

Drylands: Land characterized by a scarcity of water, which affects both natural and managed ecosystems and constrains the production of livestock, crops, wood, forage and other plants and affects the delivery of environmental services (FAO).

Ecosystem services: The many and varied benefits to humans provided by the natural environment.

El Niño–Southern Oscillation (ENSO): An irregular periodic variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting the climate of the tropics and subtropics. The warming phase of the sea temperature is known as El Niño and the cooling phase as La Niña, and the Southern Oscillation is the accompanying atmospheric component, coupled with the sea temperature change.

Global warming: an increase in the Earth's atmospheric and oceanic temperatures due to an enhanced Greenhouse Effect resulting from the emission of greenhouse gases by human activities.

Greenhouse gases: Gases in Earth's atmosphere that trap heat.

Holocene: The current geological epoch commencing approximately 11,700 years ago.

Hominin: A primate of the taxonomic tribe Hominini, which comprises those species regarded as human, directly ancestral to humans, or very closely related to humans.

Hydraulic empires: A social or governmental structure which maintains power through exclusive control over water access.

Hypocaust: A Roman system of central heating in a building that produces and circulates hot air below the floor of a room.

Microorganism: A minute, unicellular organism invisible to the naked eye, also known as microbes or microscopic organisms, making up almost 60% of the Earth's living matter.

Multicellular organisms: Organisms composed of cells performing different functions and having different characteristics.

Neolithic Revolution (also called the Agricultural Revolution): The transition in human history from small, nomadic bands of hunter-gatherers to larger, agricultural settlements and early civilization, starting in the Fertile Crescent about 12,000 years ago.

Photosynthesis: The process by which green plants and some other organisms use sunlight to synthesise nutrients from carbon dioxide and water, generating oxygen as a by-product.

Phytoplankton: The autotrophic components of the plankton community and a key part of ocean and freshwater ecosystems.

Sustainable Development: Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

Thermae: large imperial Roman bath complexes.

Tipping point: A critical threshold beyond which a system reorganises, often abruptly and/or irreversibly. (IPCC glossary)

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About the author

Professor Nick Schofield is the Founder and Director of Global Future Research, established in 2021. Nick has a broad range of national and international experience across academia, private sector, government and non-government organisations. He has specialist expertise in theoretical astrophysics, hydrology, water resources, natural resources management, climate change, international development, futures and global issues. Nick has a BSc (Hons) in Physics from Imperial College, London University, a Doctor of Philosophy in Astrophysics from York University, UK, and additional tertiary qualifications in hydrological modelling, business management and futures methods. He is a Visiting Professorial Fellow at the University of NSW (Sydney), an Adjunct Professor at Murdoch University (Perth) and Fellow of the Royal Society (NSW).

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