WBGU

German Advisory Council on Global Change

Summary

Water in a heated world

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Summary

In a climatically and geopolitically heated world, the challenges surrounding water are becoming substantially more acute. Uncertainty is becoming the norm; the limits of controllability could be exceeded. What is needed is a climate-resilient water-management regime with a long-term view that combines thinking about blue and green water and is able to react flexibly to changes. It must incorporate existing, self-organized structures and needs to be accompanied and supported by science. An International Water Strategy with regional platforms should be developed.

Where there is water, there is life. Water is powerful yet fragile – an object of conflict and, at the same time, a unifying medium. Continuing, accelerated changes in the global water cycle are to be expected in the future. The effects of climate change, the overexploitation of water resources, the unequal distribution of water, the loss of ecosystem services, and threats posed by water-related health risks will continue to intensify. The assumption of stationarity – i.e. the idea that natural systems exhibit predictable variability within a defined time window on the basis of empirical observations – is no longer valid in the face of climate change. This will increasingly lead to threatening situations that are beyond the spectrum of human experience and could escalate into regional water emergencies. In extreme cases, situations arise in which the limits of controllability are exceeded, societal structures and ecosystems are substantially destabilized, and there is no longer any room for manoeuvre. These are threatening patterns with a planetary dimension.

A water-mapping initiative consisting of a scientific platform and a panel of experts should be launched internationally in order to recognize crisis developments at an early stage and avert regional water emergencies with a planetary dimension. Furthermore, there should be a systematic international exchange on effective adaptation and resilience strategies. These challenges face all countries, and an International Water Strategy should be sought to meet these challenges as a global community.

Climate-resilient, socially balanced water management worldwide, in which infrastructure and management approaches adapt to changes in local hydrological balances and increasing extreme events, is of key importance. This also includes the protection of water quality by consistently implementing the zero-pollution approach and the guiding principle of a circular water economy, incorporating ecosystems and the active management of green water in the form of soil moisture.

Moreover, sustainable water policy can only succeed if progress is also made in other policy areas. A stringent climate-change-mitigation policy, spatial planning for the conservation and restoration of ecosystems and the implementation of international biodiversity targets are essential to maintain room for manoeuvre. They must be closely linked to global social, economic and trade policies to make a peaceful "WaterFuture" possible. Private investment must be mobilized and public revenues stabilized in order to finance the adaptation to a changed water supply and increasingly frequent extreme events. Access to funding should also be improved for local actors.

Science is an important resource for enabling climate-resilient water management. It has an obligation to supplement empirical knowledge with projections of future changes and their uncertainties. At the same time, innovative approaches for dealing with large-scale and disruptive changes in water availability and increasingly frequent extreme events must be developed and scientifically monitored. Decision-making processes can be accelerated by providing real-time data and forecasts.

A sustainable WaterFuture requires goals and responsibility to be borne not only by the state but also by business and society. The state must create the conditions for this and lay down a political and regulatory framework that promotes self-organized structures and supports an education campaign for the responsible use of water. As a valuable resource, water should be priced consistently and in a socially balanced way in order to promote its efficient and sustainable use worldwide.

It is therefore of the utmost urgency to place the issue of water higher on the international agenda. The current strong momentum created by the UN Water Conferences in 2023, 2026 and 2028 should be used by governments to maintain a sufficient distance from the limits of controllability worldwide by taking comprehensive precautions. In the short term, effective strategies for resilient water management should be developed that will strengthen global cooperation in the medium term and lead to a water agreement supported by the international community in the long term.

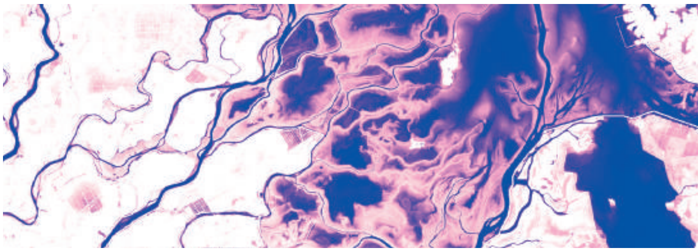
International water policy must adapt to the progressive and accelerated changes in the global water cycle. To this end, water should be considered a cross-cutting issue in many forums, but it also needs its own process and political attention. The WBGU recommends developing an International Water Strategy by 2030. The objectives and measures of the Strategy should also be incorporated into intergovernmental economic and trade relations to enable synergies between the protection of water resources and support for climate-neutral development and food security. In the long term, the strategy should be developed into a separate international agreement for water – comparable to the Rio Conventions.

Box 1 provides an overview of the WBGU's key messages.

Box 1

Core messages

- Keep the limits of controllability at a safe distance
- Anticipate and avert regional water emergencies with a planetary dimension
- Implement climate-resilient water management and maintain near-natural water quality
- Integrated climate policy, biodiversity policy and social policy are effective water policy
- Transformative water knowledge: forward-looking practice supported by science
- With society, not against it: the proactive state and self-organized society take up responsibility
- Take responsibility internationally – develop an International Water Strategy
- Use the national water strategy to foster the international discourse on water



How we use water today

On Earth, water passes through a continuous, global cycle, which constantly provides fresh water in the form of precipitation over land. This is then available as blue or green water: blue water includes all water resources in rivers, lakes, reservoirs and groundwater; green water refers to the water held in the subsurface as soil moisture; through plants it can productively promote the formation of biomass (Rockström et al., 2023). Ecosystems and their biodiversity are an important part of the global water cycle. Humans now greatly influence the natural water cycle – both regionally and globally – by abstracting, using and discharging water in many ways which have changed and continue to change evaporation, precipitation, groundwater recharge, runoff behaviour, water quality, etc. Furthermore, the massive impact of climate change and ecosystem degradation can already be felt today.

Globally, agriculture accounts for 72 % of all freshwater abstraction, industry for 15 % and municipalities and households for 13 % (AQUASTAT, 2024). However, the amount of water abstracted for agriculture as a percentage of total abstraction varies considerably by region and income level. In high-income countries it is on average only 41 % of the total withdrawals, whereas in low- and middle-income countries water abstracted for agriculture accounts for 80–90 % (Ritchie and Roser, 2017). The expansion of irrigated agriculture, the area of which more than doubled between 1961 and 2018 (UNESCO, 2024), and the water requirements of a growing urban population have led to the overuse of non-renewable groundwater (deep groundwater), and water tables have been falling further and further in many regions and cities around the world. The Middle East, North Africa, India, northern China and the Southwest of the USA are particularly affected. In most of these regions, water consumption for agricultural irrigation accounted for an average of over 90 % of total water consumption between 1960 and 2010. At least around half of this came from non-renewable groundwater (Wada and Bierkens, 2014).

About 2.2 billion people have no safe access to clean drinking water – low- and middle-income countries are particularly affected (UNESCO, 2024). The supply situation is especially difficult in rural areas, where four out of five people do not have safe access to clean drinking water. About 3.5 billion people have no access to an adequate, hygienic water supply. Official Development Assistence (ODA) to the water sector in 2022 was US$ 9.1 billion, more than 4 % below its 2018 peak (UN Water, 2024).

Between 2002 and 2021, 1.6 billion people were affected by flooding and about 100,000 lost their lives. In the same period, 1.4 billion people suffered from droughts, with about 21,000 deaths (UNESCO, 2024). Approximately half of the world's population currently suffers from severe water shortages for at least part of the year (IPCC, 2023).

In many regions of the world, efforts to ensure a safe water supply and disposal system have made significant progress, yet a substantial proportion of the world's population still does not have adequate access to these services: for at least three billion people, water quality is uncertain because of a lack of monitoring (UN, 2022). The threat caused by pathogenic microorganisms in drinking water still affects two billion people worldwide.

In addition to local effects, there can also be telecoupling effects via trade in goods whose production requires water. The water required for producing goods and the water contained in the goods can be tracked as virtual water flows across the globe. Approximately 65–90 % of global virtual water flows originate from trade with agricultural products, followed at a considerable distance by industry and the energy sector. Countries exporting agricultural goods in particular thus indirectly export their own water.

Water is wasted, overused and unfairly distributed in many places. Use patterns are shaped by political framework conditions and the existing water infrastructure which involve considerable path dependencies that make course corrections and substantial changes difficult.

Exacerbated water-related challenges in the future

Humanity, ecosystems and the planet are moving towards a future in which the quantities and quality of water available to humans and nature are subject to increasing change. The assumption of stationarity is no longer valid, particularly as a result of climate change.

Climate change and pollution

Climate change is intensifying the global water cycle: water is evaporating ever faster from the animal and plant world, as well as from soil and water surfaces, and the amount of water stored in the air is increasing – the air can store 7 % more water for every 1 °C of warming, making more and heavier precipitation events possible.

Progressive warming is driving global and regional changes in precipitation and evaporation, shifting the balance from frozen to liquid water, increasing the water content in the atmosphere and leading to an increase in extreme events such as floods and droughts. One billion people currently live near a coast and are directly affected by rising sea levels and correspondingly higher storm surges (IPCC, 2019). Precipitation is rising on a global average; every 1 °C added to global warming increases average precipitation worldwide by 1–3 %, whereby the extent and direction of the changes – and therefore their effects – vary greatly from one region to another. The amount of precipitation could increase by up to 13 % by the end of the century compared to the period 1995–2014. Since warming also leads to potentially higher evaporation, there are regional differences in the effects on the total amount of water available. Soil moisture and thus green water will decrease more and more in many regions. If global warming reaches 4 °C, this could mean a reduction in soil moisture of up to 40 % in Amazonia, southern Africa and western Europe, for example – while continuing to increase in other regions. In response to climate change, groundwater abstraction, e.g. for irrigation, can be expected to increase and could deplete the non-renewable groundwater resources worldwide. The combination of further rising temperatures, changing precipitation patterns, retreating glaciers and reduced snow cover means that average runoff volumes will increase as global warming progresses, albeit with regional differences. Increasing runoff volumes are predicted in particular for the northern high latitudes and regions in Central and East Africa, while decreases in the Mediterranean region and parts of Central and South America will lead to considerable shortages of blue water, especially in the summer months (Douville et al., 2021).

Water quality, too, will continue to decline in the future if the discharge of inadequately treated wastewater – currently about 80 % of the world's wastewater – and with it pathogens, persistent chemicals, nutrients and solid waste continues. As a result, groundwater, many freshwaters, coastal zones and seas are becoming dead zones uninhabitable for animals and plants due to a lack of oxygen and toxic blooms; the self-purifying power of water bodies is being lost. The complexity of pollution is increasing as a result of modern, newly developed substances, as well as mixtures of substances and possible interactions, e.g. with the microorganisms present (EEA, 2022). The long-term risks are yet unknown and are the subject of ongoing research. Micro- and nanoplastics, for example, can act as a vector for additional harmful contaminants with potentially serious consequences for the environment and health. In a future scenario without countermeasures, the amount of plastic – and therefore also microplastics and nanoplastics – released into the environment is expected to double globally to 44 million tonnes per year by 2060 (OECD, 2022). Climate change is further exacerbating the situation: during periods of drought, for example, the concentration of pollutants in surface waters can no longer be sufficiently diluted. Flooding and melting snow and ice mobilize pollutants, making them bioavailable. Rising water temperatures during heat waves influence the physical, chemical and biological processes in surface waters, which can affect the concentration and chemical properties of transported substances. Together with unabated climate change, this results in an extreme, barely controllable burden for global water resources.

The capacity for adaptation decreases continuously as climate change progresses – this affects people, technological and institutional systems as well as nature (IPCC, 2022). In order to largely maintain adaptability, there is no alternative to limiting climate change to 1.5 °C global warming in accordance with the precautionary principle and – if possible – even reversing it in the long term. This requires an end to anthropogenic CO_2 emissions and a sharp reduction in emissions of other greenhouse gases, as well as the removal of CO_2 from the atmosphere.

Socio-economic and geopolitical developments

In future, unless effective actions are taken, water use – and thus the risk of overuse – will continue to grow, depending on the region. UNESCO (2023) estimates that the global demand for water will increase by about 1 % per year and thus by 20–30 % by 2050. However, the margin of error for this assessment is more than 50 %. A large proportion of the expected increase in demand will happen in low- and middle-income countries, especially in emerging economies. Increases in demand by municipalities and households are strongest in regions where the water supply and disposal are being expanded. Increases in industrial water demand generally go hand in hand with advancing industrialization; demand can also fall again if there are improvements in the efficiency of water use. The demand for water in agriculture is driven primarily by irrigation. Projections on the development of water demand vary considerably, depending on the underlying assumptions on socio-economic, technical and climatic developments. The IPCC estimates that the demand for water for irrigation could double or even triple by the end of the century (Caretta et al., 2022). Projections show that rising irrigation requirements and increased evaporation as a result of climate change will contribute to accelerating the depletion of groundwater resources by the end of the century.

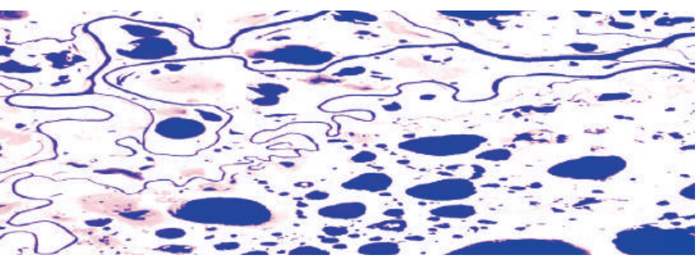
Global geopolitical and societal developments are likely to exacerbate the situation. A lack of water availability and extreme events such as droughts or floods can hinder growth, development and poverty alleviation. Multidimensional poverty and social inequalities, as well as autocratization and polarization processes, weaken societal cohesion, promote the fragmentation of governance systems and reduce societal resilience to water-related crises like droughts and floods. Water management is often a task that transcends political boundaries; like water-related multilateral negotiations it is therefore being made more difficult by current geopolitical tensions. Moreover, water crises are frequently caused not by a lack of availability but by unequal distribution. Climatically and ecologically induced resource availability and distribution deficits reinforce each other.

Damage to the health of species, ecosystems and humans

Increasing pollution, the growing climate crisis and their impact on hydrological processes and, not least, biodiversity will have direct and indirect consequences for human health and that of other organisms. This has an impact on the functioning and species composition of ecosystems. Water availability is fundamental to plant growth – and therefore to the functioning of ecosystems like forests or grasslands. Conversely, healthy ecosystems are essential for locally stable freshwater availability and quality. Water is therefore not only important for biodiversity; biodiversity is also important for water.

The interaction of climate factors can also change human living conditions so unfavourably that local livelihoods and food supplies are no longer guaranteed. Changes in water quality and quantity and the associated lack of safe water are only part of the threat situation. Water scarcity, pollution and flooding affect people both directly and indirectly. They can lead to the permanent loss of health and the loss of many human lives. Social structures and health facilities can also be lost. Irregular or insufficient water supplies impair not only the vitality of individual people and their performance in society but ultimately also the performance of society as a whole, with corresponding economic and socio-political consequences.

The emerging global exacerbation of challenges and their interaction can lead to emergencies that can hardly be controlled by humans. Examples of regional water emergencies that can also occur in the same or similar ways in other regions of the world are illustrated in Box 2.



Maintain a safe distance from the limits of controllability

Water emergencies can reach the limits of controllability, beyond which societal structures and ecosystems destabilize: humans and ecosystems in the affected region are deprived of their livelihoods (Box 2). In view of the predicted climatic, ecological, socio-economic and geopolitical developments, such boundary conditions and regional water emergencies can be expected to become increasingly common worldwide.

In order to maintain a safe distance from the limits of controllability, measures are required at the global, regional and local level (Fig. 2):

First, it is important to limit the exacerbation of challenges which, as global drivers, have a direct impact on the global water balance: this requires an ambitious climate policy, including compliance with the goals of the Paris Agreement, as this is the only way to limit the changes to the global and local hydrological balance caused by climate change. Equally important is the implementation of the Kunming-Montreal Global Biodiversity Framework in order to protect the fundamental role of nature in the global hydrological balance. The earlier action is taken, the more options there are.

Second, regional water emergencies must be avoided as far as possible. If the exacerbated water-related challenges cannot be controlled, the likelihood of regional water emergencies on a planetary scale will increase. Transformative adaptation measures and climate-resilient, socially balanced water management are needed as defence against such emergencies, since incremental adaptation measures will no longer be sufficient. This requires a willingness to radically change course, in particular by shaping structural change, for example in land-use, industrial, settlement and infrastructure policy – both nationally and in the context of international cooperation.

As it is not always possible to maintain a safe distance from the limits of controllability, regions at risk must prepare for a plan B at an early stage. If transformative measures no longer help, an orderly and timely withdrawal may be the only option left. Where the limits of controllability are crossed, the options for action are acutely reduced to reactive crisis and disaster management accompanying the retreat. Which risks are considered intolerable and which individual adaptation paths should be pursued is also the subject of societal negotiation processes.

Establish principles of action

The WBGU recommends climate-resilient, socially balanced water management based on the following principles:

- *Safeguard water as a common good for people and nature:* Water must be distributed and stored as a global, life-giving common good according to the needs of all people and nature. Nature-based, technical and institutional solutions for ensuring a resilient water supply with impeccable water quality must take into account and balance multifunctionality for humans and ecosystems.
- *Increase adaptability in the face of continuous change:* Systems for the provision and use of water should be kept resilient in the face of hitherto unknown fluctuations and ongoing changes that cannot be precisely predicted; they should be re-coordinated on a scientific basis. Administrations, operators and users must

Box 2

Regional water emergencies with a planetary dimension

Droughts and extreme precipitation will increase worldwide due to climate change. Melting glaciers will massively change the availability of water in many places. Added to this is the degradation and destruction of ecosystems that support valuable water storage, e.g. as green water. Water pollution will also increase significantly in some regions of the world. These exacerbated water-related challenges can mutually reinforce each other and, in the medium and long term, escalate into regional water emergencies with a planetary dimension. The extent and dynamics of these water emergencies can exceed hitherto manageable risks. Here, the WBGU describes five examples of regional water emergencies whose patterns can also be found in other regions of the world.

Water scarcity in cities

› 933 million
urban dwellers today are affected by water shortages

30–50 %
of the world's population will be affected by 2050

approx. **80 %**
growth in urban demand for water expected by 2050

In the last twenty years, over 80 large cities and metropolitan regions worldwide have been affected by severe water shortages (Rusca et al., 2023). The number of reports about cities threatening to run out of water is growing. In 2016, over 30 % of the urban population lived in areas where water was scarce. Lack of surface water, soil sealing, excessive groundwater use and the increase in the demand for water caused by (rapid) urbanization and rising per-capita demand are the main drivers of urban water shortages. Leaks in the water infrastructure and mismanagement are exacerbating the water shortage. The number of people living in cities facing water scarcity worldwide could increase from more than 933 million in 2016 to 1.6-2.3 billion people in 2050; that is between a third and almost half of the global urban population (He et al., 2021). The megacity of São Paulo (Brazil) experienced a severe water shortage in 2014-2016, while in 2019, Chennai (India), one of the world's wettest megacities, was affected by the worst water shortage in 30 years. Barcelona, Cape Town, Bogotá, Montevideo and Mexico City are further examples of cities where a water emergency has had to be declared in the recent past.

Increase in droughts and flash floods in the MENA region

6 %
of the world's population live in the MENA region

only **1 %**
of global freshwater resources is available there

24 %
decline in per-capita renewable freshwater availability between 2007 and 2018

By global comparison, the MENA region (Middle East and North Africa) will be one of the most severely affected by the negative effects of climate change (Hajat et al., 2023). Between 2007 and 2018, the availability of renewable fresh water per capita in the region fell by approximately 24 % (SIWI and UNICEF, 2023). Changing precipitation patterns, increasing aridity and droughts, heavy rainfall events and flash floods, and above all overuse, accompanied by major governance challenges in the equitable distribution of the few available freshwater resources are already leading to water shortages and unequal water availability for humans

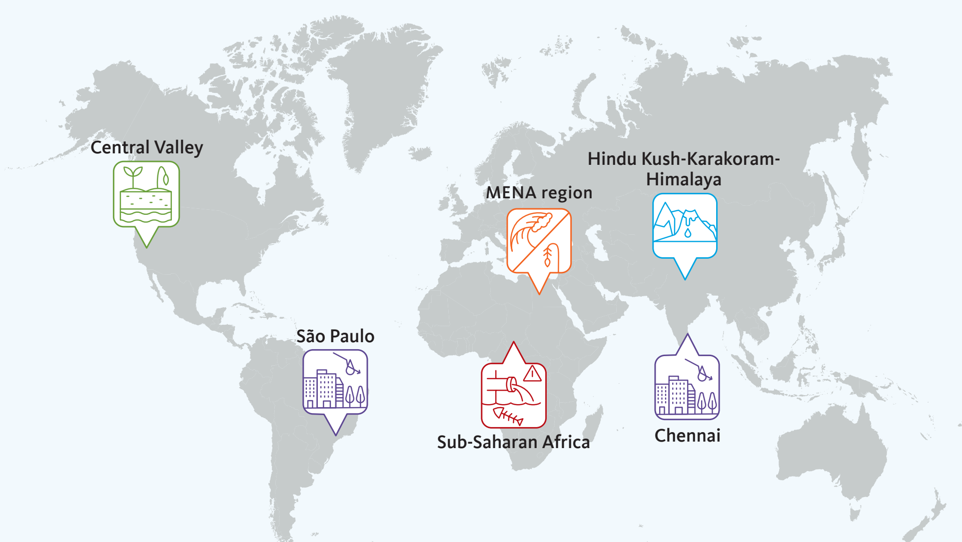


Figure 1
Geographical location of the regional water emergencies with a planetary dimension covered in the report.
Source: WBGU, world map: www.freepik.com

and the environment in the region today. Projections indicate that a significantly more extreme climate can be expected in the MENA region in the future. Heat extremes, more aridity, longer-lasting droughts and more heavy rainfall events, combined with rising pressure of use, will further worsen water scarcity in the region in the future, with negative consequences for people and nature. This trend represents a global pattern: in 2022–2023, a drought emergency was declared in 22 countries worldwide (UNCCD, 2023).

Melting glaciers in the Hindu Kush-Karakoram-Himalayan mountain range: loss of large water reservoirs

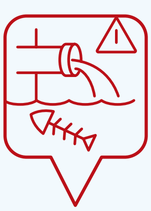
2 billion
people access their water from the region's river basins

200 million
people are already suffering from increased water stress

20 % to 65 %
glacier loss depending on climate scenario

After the poles, the glaciers of the Hindu Kush-Karakoram-Himalayan mountain range are the largest frozen freshwater reservoirs on Earth. The region's river basins supply almost two billion people with water, i.e. a quarter of the world's population. Even without further warming, a loss of more than 20 % of the ice mass and glaciated area in the mountain range is projected by 2100; this proportion increases to up to 65 % under different climate scenarios. Almost 200 million people in the region are already suffering from water stress (Nie et al., 2021) and the situation can be expected to worsen by the end of the century. A reduced supply of water – especially in river basins like the Indus which are largely fed by melting water – is combined here with an increasing demand for water. This development harbours considerable destabilization potential: for example, increased water stress for people and ecosystems can lead to societal and geopolitical conflicts, growing natural hazards can pose a threat to human life and infrastructure, and reduced runoff in the summer months can affect not only regional but also global food production. The region accounts for 61 % of the global rice harvest, 41 % of global potato production and 24 % of the global maize harvest (Hu and Tan, 2018). Melting glaciers also pose water-related dangers in other regions of the world; the southern Andes, western Canada, the western USA (especially Alaska) and the European Alps are particularly affected.

Water pollution in Sub-Saharan Africa



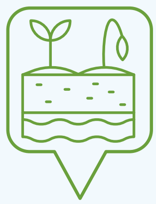
2.7 billion
people are today affected by water pollution

4.2 billion
is their expected number by 2100

38 %
of the world's population affected by organic water pollution will live in Sub-Saharan Africa in 2100

Globally, the number of people affected by water pollution from organic compounds could increase from 2.7 billion to up to 4.2 billion by the end of the century. Similar patterns are predicted for contamination by pathogenic microorganisms, salts and nutrients (Jones et al., 2023). This particularly affects Sub-Saharan Africa: by the end of the century, 25 % of all people – but 38 % of people worldwide affected by water pollution from organic compounds – are expected to be living in Africa. Pathogenic microorganisms pose a direct threat to human health; organic carbon compounds promote microbial growth and oxygen depletion in surface waters, leading to fish kills. Nutrients like nitrogen and phosphorus cause eutrophication, algal blooms and the loss of habitats and biodiversity. In addition to Sub-Saharan Africa, global hotspots of water pollution are also emerging in central and north-western Mexico, northern India and eastern China.

Overexploitation of groundwater and climate change in the Central Valley (USA)



25 %
of fruit and nut production in the USA originates from the Central Valley

10 %
water losses are expected in the region by 2030

75 %
of the wells have suffered a 1.5 metre lowering of the groundwater level 2018–2023

The risk of local water shortages has grown significantly in the Central Valley in recent decades due to rising demand and climate change. Groundwater loss has exceeded the rate of recharge on a multi-year average. As a result, more than 75 % of the wells suffered a lowering of the groundwater table by more than 1.5 m in 2018–2023 (CNRA, 2023). Maintaining the drinking water supply is becoming increasingly challenging in view of high consumption and more frequent dry periods. No alleviation of the situation is in sight. However, as a groundwater-dependent and semi-arid region, the Central Valley is not the only place in the world where there are signs of localized depletion of renewable groundwater resources with far-reaching consequences for people and nature. The north-east of China (Hai He Basin and North China Plain Aquifer), the north of India (Ganges-Brahmaputra Aquifer), the north-east of South America (São Francisco Basin), the southwest and south of the USA (Central and South High Plains), Eastern Europe (Don and Dnieper Basins) and the Middle East (Arabian Peninsula, Iran) are also reaching the limits of their natural carrying capacity as a result of years of intensive crop cultivation and the consequences of global warming.

prepare themselves for a highly dynamic situation. To achieve this, structures, as well as planning and decision-making processes, must be designed to be adaptable and correctable by all actors.

- *Resilience and risk prevention instead of emergency response:* The precautionary principle must be consistently applied to safeguard a climate-resilient water infrastructure and water quality. Risk prevention and risk minimization instead of emergency response should be the basis of planning processes and decisions in the entire water sector and sectors influenced by it.
- *Managing blue and green water across sectors:* Blue and green water must be considered and managed jointly and in all sectors in regional and local solution approaches. Both have strategic, geopolitical relevance: in addition to river catchment areas, transboundary evaporation and precipitation patterns must also be taken into account. Coherence between policy levels and fields is a prerequisite for this.
- *Enable a science-based discourse on challenges and options for action:* The WBGU recommends initiating a science-based discourse on strategy development and options for action in the face of uncertainties, taking the concerns of citizens and stakeholders into

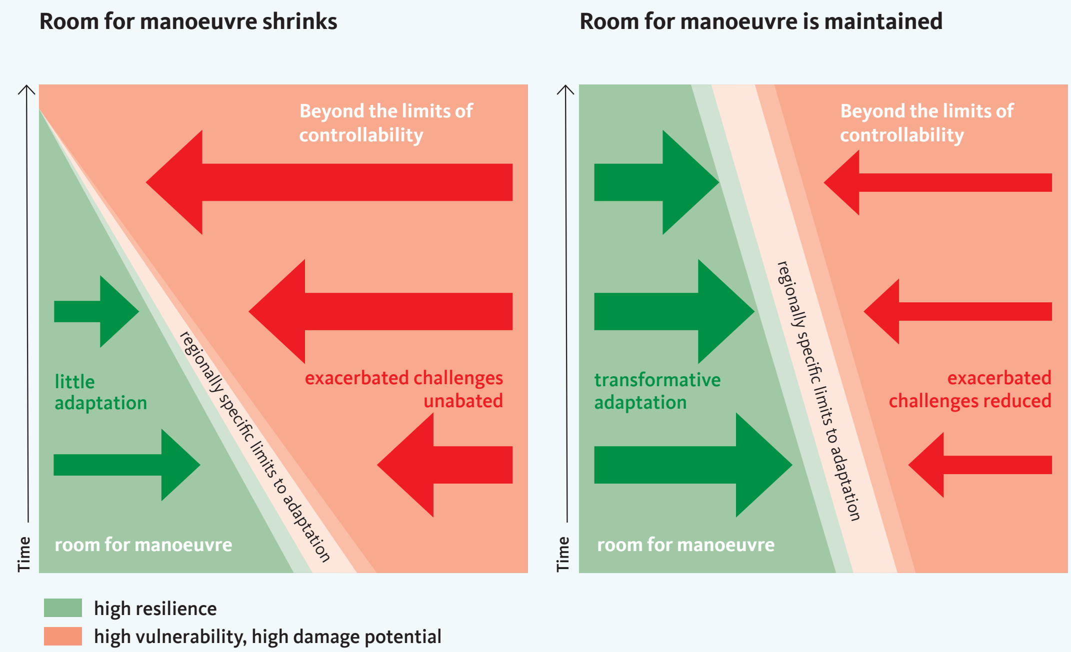
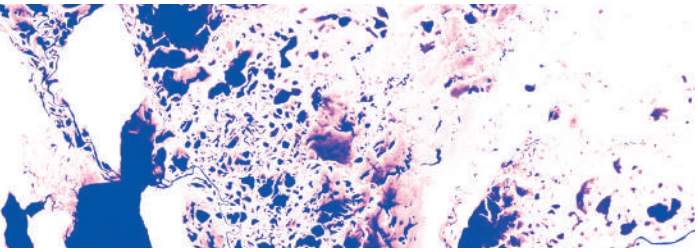


Figure 2
WBGU's concept on the limits of controllability. Unchecked aggravations of water supply, water distribution and extreme events, coupled with inadequate adaptation can lead to regional water emergencies and to the limits of controllability being exceeded. Beyond these limits, which can vary from one region to another, the risks are intolerably high (red area). Which risks are considered intolerable and which individual adaptation paths should be pursued is also the subject of societal negotiation processes.
Left: If only minor adaptation measures are taken, the room for manoeuvre shrinks (green area). Water-related challenges exacerbated by increasing climate change, ecosystem degradation and pollution, as well as socio-economic and geopolitical developments can unleash their full force. Vulnerability and damage potential increase, and the risk of exceeding the limits of controllability grows over time.
Right: Transformative precautions increase resilience and reduce the impact of exacerbated water-related challenges, while at the same time containing the exacerbated challenges themselves. Room for manoeuvre (green area) is also maintained in the longer term.
Source: WBGU

account. To this end, the severity and dynamics of exacerbated water-related challenges and resulting regional water emergencies with a planetary dimension must be identified, understood and options for action researched. Science should continuously inform policy-makers and take on an advisory role, e.g. by scientifically monitoring the instruments used. Political and societal participation, education and collaboration should be promoted.

- *Value water and appreciate the value of water:* Policy-makers, public institutions, companies and financial markets should embrace and integrate the value of water and the systemic nature of water risks into their decisions. Economic decisions must be compatible with the long-term goals of sustainable water management.
- *Accelerate implementation – encourage and promote self-organization:* The regulatory framework and all water-management instruments must enable accelerated implementation and involve informal, decentralized governance structures where appropriate. In particular, non-state, self-organized actors need to be involved and empowered.



Climate-resilient water management

In many places, overuse of water resources, unequal distribution, loss of ecosystem services, and water-related health risks are partly caused by misguided and ineffective water management. Management approaches aimed at overcoming shortcomings and deficiencies, such as the established Integrated Water Resources Management (IWRM) approach, do not yet meet the challenges of climate change. The essential features of a climate-resilient, socially balanced form of water management as outlined below, which are based on the principles of action described above, are intended to provide impetus for the further development of existing management approaches (IWRM, Water-Energy-Food-Ecosystem Nexus, adaptive water management) and for the more vigorous implementation of transformative adaptation in the water sector.

Making water management adaptable and resilient

The WBGU recommends establishing a new approach to water management that aims to live with – but also to minimize – uncertainty. Climate-resilient, socially balanced water management established across the board should proactively manage local, regional and global water cycles with foresight, and maintain the various functions of water for humans and ecosystems in the long term. Transdisciplinary and collaborative learning and decision-making processes across sectors and spatial scales are required to make action possible in the face of uncertainty. This is based on empirical data, real-time information and future projections under various climate scenarios on water supply and demand, whereby a rising demand for water in the course of the energy-system transformation must also be taken into account. This requires a digitalization campaign. Management methods must be constantly monitored on this basis and, if necessary, adjusted at short notice. To achieve this, planning and decision-making processes in water management must be adjustable, and infrastructure measures must be designed in a more decentralized and adaptive way.

Water management should moreover be geared towards preserving, strengthening and restoring a climate-resilient landscape water balance. As some of these measures only take effect after a time lag, it is necessary to combine them with short-term measures, but without creating undesirable path dependencies. In line with the integrated landscape approach proposed by the WBGU (2020), an integrated landscape and water-balance approach should be pursued that combines the protection of the climate and biodiversity, the land needed for food security, and the strengthening of natural buffers in the water balance on all types of land, independent of how they are used. The green water stored as soil moisture must be more strongly integrated into water management, taking the effects of climate change into account.

Climate adaptation, water management and ecosystem protection should be better interlinked. In order to enable greater use of regulating ecosystem services for stabilizing the water supply, a key role in water management should be assigned to safeguarding the functions of water for ecosystems.

To make the local drinking-water supply more resilient, it is necessary to utilize various independent blue-water resources that are redundant and mutually complementary. Where necessary and technically feasible, greater use of alternative water resources such as desalinated seawater or effluents from municipal wastewater treatment plants is also recommended, provided that adverse effects, e.g. for ecosystems and human health, can be avoided. Multiple uses of water of different quality levels should be anticipated in the construction of the water infrastructure and buildings. Digital water-information systems should be established across the board which record withdrawals by private households, public institutions and industry, potentially even in real-time, so that the supply can be adjusted by the utility. Artificial intelligence should also be used in the future, although there is still a need for research in this area. Decentralized water storage and water reuse can be established for large consumers, contributing to more flexible water abstraction.

In order to deal in the short term with increasingly frequent extreme events, a broad range of adaptive, fast-acting and resource-efficient measures – from purely technical to more nature-based ones – should be used in combination with long-term effective measures to restore a climate-resilient landscape water balance. The selection and combination of measures should be based on the requirements outlined in Box 3.

In addition, approaches for assessment processes under conditions of uncertainty should be further developed and put into practice. In regions that are particularly at risk from water emergencies, transdisciplinary forums should be created to address the challenges faced and to collaboratively develop adaptation options. In order to promote agile policy adaptation, more research projects should be funded that examine timely technical adaptation measures and policy measures, as well as their (water-) efficacy. Technical adaptation measures, e.g. planning bases for infrastructure measures such as the occurrence of a once-in-100-years flood event (HQ_{100}), must be adapted.

Solution-space ecosystems

The restoration of wetlands such as swamps and marshes, river and floodplain landscapes or peatlands, as well as other water-relevant ecosystems such as forests, plays an important role in climate-resilient water management. Since the pre-industrial era, it is estimated that more than 80 % of the world's wetlands have been lost due to changes in land use and drainage, and most of the remaining wetlands have been degraded (UNEP, 2021). Restoration measures in wetlands can improve the retention of water in the landscape and thus increase local water availability for humans and nature, stabilize supplies of drinking water, contribute to flood protection and improve water quality and nutrient storage. Multiple benefits include e.g. the provision of habitats for diverse flora and fauna, improved soil quality and contributions to the livelihoods and culture of local communities. Furthermore, peatland rewetting is of great importance for climate-change mitigation. Whether the restoration of a wetland is feasible also depends on the regional availability of water with the corresponding water quality. Unintended consequences such as the spread of invasive species or a change in the local hydrological cycle, which can have an adverse effect on agriculture, for example, should be taken into account and avoided.

The WBGU recommends promoting at all political levels the restoration of ecosystems that are of major importance for the water balance. This explicitly includes water-related activities within the UN Decade for Ecosystem Restoration, the UN Water Decade, the 2030 Agenda for Sustainable Development, the Ramsar Convention, the EU Water Framework Directive, the EU Nature Restoration Law and the relevant national strategies. In addition, Germany's Federal Action Plan on Nature-based Solutions for Climate and Biodiversity, and related, relevant strategies such as the German Peatland Protection Strategy should be promoted over the long term and the measures contained therein promptly implemented in the interests of climate-resilient water management.

Box 3

Requirements for climate-resilient water-management measures

The WBGU proposes four requirements that should be taken into account when selecting, implementing and developing climate-resilient, socially balanced water-management measures:

Assess water-related efficacy on different time scales: The efficacy of measures should be assessed on the one hand with regard to specific water-related objectives and, on the other, with regard to their respective contribution to the restoration of a climate-resilient landscape water balance. Against the background of exacerbated water-related challenges, different time horizons, uncertainties, impact delays and adaptation limits must be taken into account.

Analyse feasibility in the respective context: The feasibility of measures should be assessed on a context-specific basis, taking into account the availability of technologies, financial resources, institutional capacities, their acceptance and their requirements in terms of land and resources – also with regard to their long-term operation and any adjustments that may become necessary over time.

Focus more on potential multiple benefits: Possible multiple benefits for climate and biodiversity protection and health, social and economic benefits of measures, and effects on the reduction of inequalities should be anticipated, evaluated and taken into account in the assessment of measures.

Avoid unintended consequences: In order to avoid maladaptation and other unintended water-related, ecological, health, social and economic consequences, all impacts of measures should be identified, evaluated and taken into account using a systemic and transdisciplinary approach.

In the spirit of an integrated landscape approach (WBGU, 2020), it is advisable to enter into a dialogue with land users, residents living near areas to be restored, and other stakeholders at an early stage. In this way, conflicts can be avoided, multiple benefits increased and societal acceptance for restoration enhanced. The measures should be implemented with a view to the multifunctionality of the entire ecosystem (e.g. a river and floodplain landscape) and take into account the mosaic approach in spatial planning (WBGU, 2024). This can result in diverse river and floodplain landscapes with high biodiversity which fulfil various functions such as water-level stabilization, water treatment, groundwater recharge, CO_2 sequestration, and the provision of habitats or recreation areas. Along the entire river catchment, its sustainable use for navigation, fishing, tourism and drinking-water supply, among other things, can be made possible and a near-natural, harmonious appearance restored.

The removal of barriers in river courses should be promoted in order to restore their connectivity and enable far-reaching ecological and water-related multiple benefits. The WBGU recommends entertaining the possibility of creating new ecosystems in restoration measures and spatial planning. This should lead to re-consideration of the legally regulated classification 'good ecological status' (EU Water Framework Directive). Under certain circumstances, this can even mean an addition that takes into account restoration aimed at increasing the resilience of ecosystems. Adaptive management incorporating regular monitoring using scientifically proven methods and robust modelling can help to anticipate the processes of ecosystem restoration and, if necessary, take timely follow-up measures.

In research, the perspective of the water supply and the protection and restoration of ecosystems, especially freshwater ecosystems, should be integrated or given greater consideration, for example in Germany's Future Research and Innovation Strategy. Research on swamp and river landscapes should be expanded: in order to do justice to different usage requirements of river courses and landscapes, more research is needed that analyses their diverse ecosystem services as a function of restoration measures. The findings should be incorporated into multifunctional spatial planning.

Long-term studies, research and monitoring projects have an important role to play and should be promoted: examples include studies on the diverse effects of dam removal, on comparing the initial state with the ecological state after dam construction and after removal, or on water input into upland bogs. There is a need for research into the typification and mapping of peatlands in order to effectively monitor, protect and restore peatlands and their contribution to climate-change mitigation and the conservation of specific biodiversity. Socio-ecological research should also be strengthened. For example, ecosystem services and the impacts of management and restoration should be comprehensively studied, and methods for the effective implementation of the integrated landscape approach for ecosystems of major importance for the water balance should be researched and made available.

Solution-space agriculture

On the one hand, climate-resilient water management in agriculture means adapting crops and cultivation methods (and irrigating where or when necessary) in order to deal with fluctuations in water supply and climate change as a whole. On the other hand, agricultural practices in turn also influence the water balance and water supply; agriculture must therefore contribute to a climate-resilient landscape water balance. Approaches to reducing water-related risks are diverse and locally specific, their effectiveness declines as climate change increases and is subject to uncertainties. Among the approaches under consideration, measures to maintain soil moisture and agroforestry are relatively effective even if warming intensifies. Often, however, individual measures will no longer be sufficient and combinations will be necessary (Caretta et al., 2022). In its report entitled 'Rethinking Land in the Anthropocene: from separation to integration', the WBGU made extensive recommendations for ecologically sustainable agriculture and its incorporation into an integrated landscape approach (WBGU, 2020). In addition to this, the following recommendations are made for climate-resilient, socially balanced water management in agriculture:

First, data and projections on water use and water supply should be improved and more knowledge made available on water-related adaptation measures in agriculture. Many measures are in the individual farmer's self-interest and, in principle, also within its sphere of influence. Advisory and training programmes or regional support teams should therefore provide farmers with knowledge and skills for climate-resilient water management and involve them in its practical further development. For overarching planning and regulation, abstraction and consumption data should be collected in real time wherever possible, data on water supply, groundwater aquifers, etc. should be improved and made available together with corresponding projections. This should be part of a broader digitization campaign for agriculture. Capacities should be built up for improving publicly available local projections and scientific monitoring of adaptation measures. Experience should be exchanged in international networks, including with low-income countries. In these countries, for example in Sub-Saharan Africa, the potential of local knowledge systems should be better used in local adaptation and transformation strategies for agriculture. Corresponding advisory services and networking activities could be further expanded internationally, for example by the GIZ, and in Germany by the Federal Agency for Agriculture and Food.

Second, agriculture should also be appreciated as 'green water management' and incorporated into integrated landscape and water-management approaches: adaptation measures that influence the water balance and water quality – e.g. by creating buffers, increasing groundwater recharge or maintaining ecosystem services – also benefit other water users or the general public. Land users should therefore be seen more as water actors, and farmers should be given more support in their role as 'green water caretakers'. This should be reflected in the political and societal treatment of agriculture, in its appreciation, in education and training and in its integration into water-management processes – such as an integrated landscape and water-balance approach and climate-adaptation strategies – and in financial incentives.

Third, financial incentives for farmers are required and transformation efforts should be safeguarded; in some cases, sufficient access to resources and capital must first be created in low- and middle-income countries. Compensating mechanisms, such as water funds, should be established between land users and water users for measures affecting water. Here, water-related agricultural subsidies can be integrated. In the EU, this concerns the next cycle of the common agricultural policy, which should be reorganized into a 'common ecosystem policy' (WBGU, 2020). As cooperation between farmers and the public sector is essential when it comes to water risks, new scope for negotiation could arise here. This should be flanked by the creation of transition programmes that secure livelihoods and mitigate the risks of the transformation for agriculture, e.g. by means of temporary income support or partial protection against possible reduced yields when testing new cultivation methods. Possible regulation or pricing of actual water abstraction and consumption (based on improved data) should be facilitated by the above-mentioned supporting measures, also with a view to social balance.

Research should develop new guiding principles for agriculture. The focus here is on learning from practical experience with adaptation strategies. Tools and metrics for evaluating adaptation measures should also be further developed. Options such as changes in behaviour or capacity-building measures often cannot be covered by current climate and impact models. Appropriately scaled models are needed that take into account economic, social, cultural and management aspects for different adaptation options, as well as multiple benefits and trade-offs for sustainable development. There are still knowledge gaps regarding the potential effectiveness of adaptation measures to reduce water-related risks, especially for climate scenarios predicting warming of 2 °C and more. In particular, the potential and limits of irrigation as an adaptation option should be better researched, since global modelling often does not sufficiently take local water availability into account. Tools also need to be developed to improve our understanding of interrelationships in the water-energy-food-ecosystem nexus and to project changing sectoral expectations in climate change.

Solution-space cities

By 2050, the global urban population will have grown to an estimated 6.6 billion people, with two thirds of humanity living in cities (UN, 2019). At the same time, the effects of climate change are being felt more and more acutely in many cities around the world. In addition to increasing pressure on natural resources, more frequent and longer periods of drought are leading to increasing water shortages, and the number of cities worldwide where a water emergency has already had to be declared is rising. More frequent and heavier extreme precipitation, intensified by urban surface sealing and overburdened drainage systems, is causing more and more flood damage. Increasing heat stress, exacerbated by the urban heat-island effect, is leading to a rising number of heat-related deaths.

The WBGU recommends establishing climate-resilient urban water management across the board in accordance with the guiding principle of water-sensitive urban development. Together with access to affordable, climate-adapted housing, it is of key importance for a sustainable urban design for all in the future. In this context, the urban infrastructure must be designed in such a way that it is more resilient to the effects of extreme events and strengthens the local hydrological cycle, enabling it to act as an efficient buffer against growing water extremes. Urban infrastructure should be integrated into the natural landscape water balance. It is essential to take medium- and long-term climate projections into account here. Synergies between water-sensitive urban development and the mitigation of the urban heat-island effect should be specifically targeted. In addition, the guarantee of urban quality of life and the reduction of social inequalities should always be considered and anticipated as essential contributions to improving urban climate resilience.

In view of the growing number of exacerbated challenges in the water sector in many places, there is an urgent need to accelerate adaptation to climate change in cities around the world. In addition to establishing climate-resilient water management, this includes in particular the development and expansion of a climate-resilient urban water infrastructure. It must be significantly accelerated, especially in fast-growing cities, in order to keep pace with rapid, often informal growth (especially in Africa and Asia). Special consideration should be given to informal neigbourhoods, where decentralized and non-piped sewage systems can be used, for example. The local population should be involved in planning and implementing these systems, informed about health benefits, and the capacities of previously informal service providers should be strengthened. Financing the development and expansion of climate-resilient urban water infrastructure in low- and middle-income countries should be increasingly promoted in bilateral and multilateral development cooperation.

In order to prevent maladaptation and an increase in vulnerability and existing inequalities, care should be taken to avoid negative social, health and environmental consequences when constructing and expanding a blue-green infrastructure in cities. Preventive measures should be taken to avoid displacement effects. The vegetation should be suitable for expected changes in the climate and have a low allergenic potential. Urban green spaces should be easy to reach, accessible and tailored to the needs of the local population.

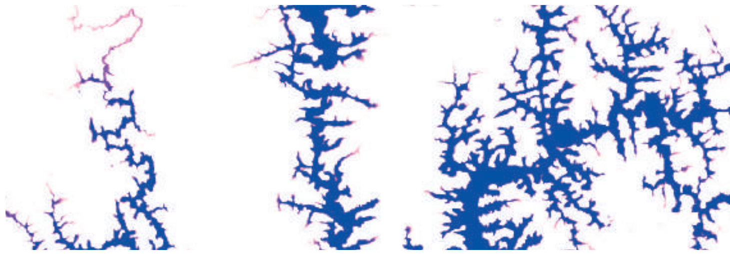
The WBGU further recommends developing emergency plans for urban water shortages. The number of cities that have declared a state of emergency due to water shortages is rising worldwide. If left unresolved, this growing global problem has considerable destabilization potential and therefore deserves greater attention in international sustainability policy.

Furthermore, it is important to recognize the water-related limits to urban growth. Climate change will confront many cities with existential challenges in connection with water, many of which are barely being addressed today. In particular, cities that will not be able to effectively solve the problem of water scarcity in the medium and long term with infrastructure measures alone should, after exhausting all other means, examine options for limiting urban growth or, in extreme cases, options for an orderly retreat in good time.

In this age of urbanization, more and more cities are facing seasonal or permanent water shortages. There is a need for research on the effective implementation of known adaptation measures, but also on how to deal with the above-mentioned hydrological boundary conditions.

Given the existing urban infrastructure, innovative approaches are needed for the integration of resilience-enhancing solutions in existing buildings in order to implement transformative adaptation measures. This raises the question of how new water-supply concepts can be realized in existing systems with as little invasiveness as possible and at low cost.

Especially in regions where the water supply is under pressure, there is a need for better temporal and spatial mapping of private and commercial demand, ideally in real time. To this end, research is needed into identifying the proper resolution of capturing water abstraction locations, ethical aspects of data collection, data processing, data security and provision, as well as possibilities for using artificial intelligence.



Protection of water quality

The quality of water resources is severely impaired worldwide by the release of pollutants and pathogens. In many cases, the use of water as a transport medium leads to considerable concentrations of pollutants in the water. This regularly over-stresses nature's self-purifying power. It is therefore essential to protect water quality in order to counteract the scarcity of water resources as a result of the exacerbated challenges described above. The European Green Deal already includes the goal of 'zero pollution' by 2050 (European Commission, 2021). Zero pollution means that pollution is reduced to a level that is no longer harmful to human health and the health of ecosystems. The zero-pollution objective is of great importance and requires the implementation of a circular economy.

Key elements for implementing these guiding principles are (1) the rapid implementation of the EU Urban Wastewater Treatment Directive, (2) contemporary testing procedures and methods for substance assessment that can better detect persistent and (water-) mobile pollutants and must be given more preventative consideration in the official approval process, (3) integrated approaches for recovering raw materials from wastewater, and (4) the flexible use of centralized and decentralized wastewater-disposal systems in the expansion of sanitary infrastructure in low- and middle-income countries.

Extend producer responsibility in the EU

The EU Urban Wastewater Treatment Directive is a significant landmark regulation for the preservation of water quality and should be implemented swiftly in the EU Member States once it has been adopted. The WBGU particularly welcomes the concept of integrated extended producer responsibility, according to which producers of pharmaceuticals and cosmetics should bear at least 80 % of the costs of constructing and operating an advanced treatment step in wastewater treatment plants required to remove trace organic chemicals. It should be examined to what extent it is possible to expand extended producer responsibility to cover further pollutant classes (e.g. toxic and persistent household chemicals and pesticides) and substance properties (not only toxicity but also persistence in the aquatic environment). When implementing the EU Urban Wastewater Treatment Directive, it is crucial to provide incentives to reduce the emission of environmentally hazardous substances, e.g. by grading the participation of companies according to the degree of environmental hazard of the substances placed on the market or produced, or by introducing exemptions for rapidly degradable products.

Expand the recovery of raw materials from wastewater

Wastewater is a valuable resource and should be used in three ways to close gaps in the circular economy. First, in addition to being returned to surface water bodies, wastewater should be treated and reused as required and depending on its intended use, e.g. for irrigation in agriculture. Second, the potential for recovering energy from wastewater treatment processes should be made greater use of. This can also help to achieve the energy neutrality of municipal wastewater treatment plants as envisaged in the EU Urban Wastewater Treatment Directive. Third, wastewater often contains substances that are sometimes considered harmful but can be used as valuable secondary raw materials, e.g. biopolymers and metal ions such as lithium and copper. The recovery of phosphorus, as laid down in the German Sewage Sludge Ordinance, could serve as a model for dealing with these substances. Successful reclamation could potentially reduce the need for primary treatment and the associated negative environmental impacts. However, not all wastewater is equally suitable for recovery in terms of economic efficiency and technical feasibility.

The WBGU sees great potential in technologies for raw-material recovery. Material recovery is becoming increasingly important. The energy transition is also a material transition, which is highly relevant for water. Research is needed into the risks associated with these materials (e.g. lithium), such as their behaviour in the environment and their effects on health.

Avoid the discharge of harmful chemicals

Adverse effects on water quality caused by industrial chemicals that spread along waterways and cannot be recovered can be avoided if substances are tested for health and environmental properties before they are registered and put on the market. Innovative biological high-throughput test procedures and simulations in substance development using artificial intelligence enable the manufacturing industry to carry out significantly faster and more comprehensive risk assessment and labelling. In this way, new substances can be put on the market more cost-effectively and nevertheless more safely; substances already on the market can be better characterized retrospectively. This can make a substantial contribution to achieving the zero-pollution objective and preventively protect water, ecosystems and human health.

Make flexible use of centralized and decentralized wastewater systems

The inadequate treatment of domestic wastewater in low- and middle-income countries is a major cause of the pollution of groundwater and surface waters with pathogenic microorganisms, organic carbon compounds, nutrients, and macro- and microplastics. Historically, the cost-intensive construction of centralized wastewater treatment with extensive sewer networks modelled on the high-income countries was favoured to counter this form of pollution. For many settlements, especially informal settlements in low- and middle-income countries, however, centralized wastewater treatment is not a suitable solution.

By contrast, the flexible use of centralized and decentralized wastewater systems such as the Citywide Inclusive Sanitation (CWIS) concept – which focuses on socially balanced access to water, sanitation and hygiene (WASH) for all population groups and all districts – is very promising. CWIS sees wastewater disposal and treatment as a service concept and not merely as the provision of infrastructure; different technical solutions can be considered on an equal footing and used flexibly. This includes the central sewage system but also decentralized sanitary facilities that are not connected to a sewage network (non-sewered sanitation) such as faecal sludge management. International donors (World Bank, Asian Development Bank) and sector associations (International Water Association) have already taken up the CWIS concept. The WBGU recommends promoting the provision of access to safe water and hygiene based on the CWIS concept instead of focusing exclusively on centralized wastewater treatment concepts. This requires a rethinking on the part of decision-makers, investors, planning engineering offices and universities to promote hygienic, decentralized, non-piped wastewater systems as a real alternative to centralized wastewater systems. Another prerequisite is the improvement and formalization of informal, existing (unsafe, unhygienic) decentralized, non-piped wastewater systems, the prioritization of WASH in political agendas and the assumption of leadership by national governments. As part of research, financing and business models for decentralized, non-piped wastewater systems must be developed and their technical advancement promoted.

Development of climate-resilient water governance

Forward-looking water governance that is capable of learning and adapting is required to avoid harming humans and nature and to prevent distribution conflicts.

Take responsibility internationally – develop an International Water Strategy

The WBGU recommends developing an International Water Strategy as a new impulse for water diplomacy (Fig. 3). The aim here is to contribute to institutionalizing the existing processes on water as an exchange and coordination platform. As there are numerous interfaces with other policy areas, e.g. climate, biodiversity and sustainable land-use governance, as well as regional (e.g. EU) and national water strategies, capacities at the interfaces should be increased. This will enable actors who are already working at the relevant interfaces and have water-specific networks and expertise to play an active role in negotiating and developing an International Water Strategy in the future.

The International Water Strategy should recognize the protection of water as a common concern of humankind and also address the use of green water and its possible regulation under international law. It should endeavour to better interlink the existing water conventions with other international water-related treaties. When organizing the process, care should be taken to begin with the less controversial topics. These include drinking water, integration, education, research and cooperation. To improve the prospects for a consensus, the strategy should initially rely on non-binding instruments. In the long term, the International Water Strategy should lead to an agreement under international law – comparable to the Rio Conventions.

The International Water Strategy could motivate and encourage states to join the existing international water conventions – the UN Water Convention and the UNECE Water Convention. What these water agreements lack is a focus on green water alongside blue water. In the future, their scope of application should therefore be expanded to also achieve a climate-resilient way of dealing with green water. The complex international interactions and interdependencies between green and atmospheric water – e.g. the effects of land-use changes on evaporation flows and precipitation in other countries – urgently need to be researched. The International Water Strategy can serve as a platform for corresponding scientific cooperation with a regular information exchange with a view to subsequent appropriate water governance. Governance of blue and green water could, for example, include information, consultation and approval obligations for projects and extensive land-use changes that have a significant impact on transboundary atmospheric water transport.

The WBGU continues to advocate state recognition and codification of a general human right to water, which includes not only access to clean drinking water but also the participation of civil society in water-related decision-making processes and access to environmental information and legal protection. This recognition should also make it clear that the human right to water is a manifestation of the human right to a healthy environment, which is not yet codified either (WBGU, 2023).

In order to improve the transfer of scientific findings on water to policy-makers, the WBGU advocates establishing a Water Mapping Initiative whose planning and implementation is internationally shared. It should consist of two units: a science platform and an expert panel. The science platform aims to bring together existing scientific expertise in order to identify imminent regional water emergencies. The expert committee governs the platform and feeds the results of its work into political processes (Fig. 4).

In order to recognize and limit water emergencies at an early stage and develop plans for dealing with them, global data and monitoring capacities need to be merged. This includes the IPCC and IPBES forecasts, long-term data series, monitoring and observation data from national monitoring organizations, and the results of regional and national research projects. Furthermore, the platform should integrate data and experience gathered in past emergencies, the results of national and supra-regional water research, and local data and experience of emergencies. This should be supplemented by high-resolution spatial and temporal data from observations and forecasting models at the local (river catchment areas), regional, national, international and global level. As soon as the Science-Policy Panel on Chemicals, Waste and Pollution Prevention called for by the UN Environment Assembly and currently under negotiation has started its work, its findings should also be taken into account.

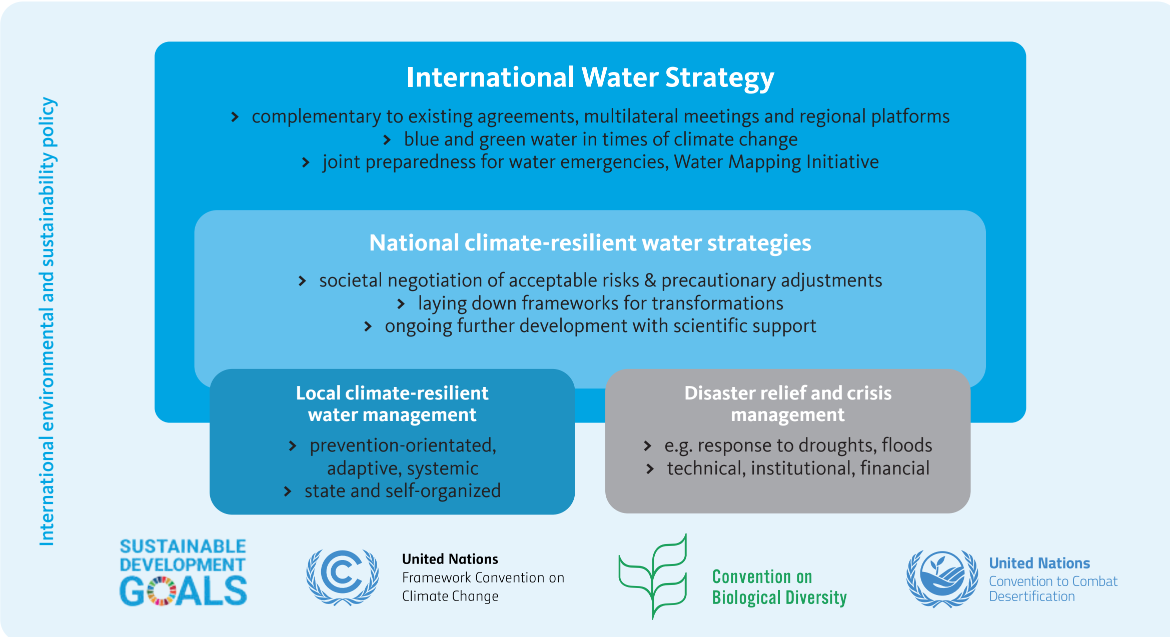


Figure 3
Proposal for an International Water Strategy. The International Water Strategy and national water strategies interact with local water management. Local water management involves the municipalities and all relevant actors, including self-organized structures. National water strategies should be formulated coherently with the International Water Strategy. They should initiate climate-resilient management measures at the local level and include emergency relief and crisis management.
Source: WBGU

An expert committee should be set up to oversee and manage the platform. Once imminent regional water emergencies with a planetary dimension have been identified, the committee would draw up forecasts for regions at risk. At the same time, it could promote the exchange of information between science, politics and stakeholders. At the international level, the expert panel should inform the UN Water Conferences. Moreover, the committee should inform water-related dialogue platforms in different regions of the world and in different country alliances, as well as policy dialogues on designing an International Water Strategy and the UN Water Conferences in 2026 and 2028. Locally, the committee should also support water authorities in the implementation of climate-resilient water management in the event of imminent emergencies.

In the context of global governance, further research is needed as a prerequisite for the work of the Water Mapping Initiative and for the fundamental handling of exacerbated water-related challenges. It is key to replacing or supplementing empirical knowledge in all regions of the world with data from scenarios, as climate change is already significantly altering the hydrological cycle. Data should therefore be generated not only at the local level but also at the level of the world's regions. There is therefore an urgent need for more climate-sensitive water research at the intermediate level. The impacts and interactions of global changes and local measures must also be available as a source of information for decision-making processes.

Climate-resilient planning can only be implemented if capacities for data collection and modelling are built up locally in low-income countries.

In order to consolidate the UN Water Conferences, a UN Water Secretariat needs to be established which, in future, could be headed by a Special Envoy for Water. An International Water Strategy should also include regular meetings both at the UN level and at the level of the various regions of the world. New regional research alliances could inform these regional platforms. The middle-level scenarios described above will be highly relevant here.

Comparable governance approaches have shown that it increases the motivation of countries to deal with global risks if their representatives can regularly exchange information at the regional level on targets, target achievement and imminent dangers and risks in their region of the world. This can be done as part of an International Water Strategy by strengthening regional organizations such as the EU. The strengthened regional organizations could coordinate regional water-governance platforms and thus enable countries to implement global and regional water targets as effectively as possible. Protection measures at the regional level could also be promoted by international funding or international cooperation. In Europe, a water strategy ('EU Blue Deal') could be based on the European Green Deal and relate to the European Biodiversity Strategy.

Create policy coherence internally and externally

As part of their international political actions, Germany and the EU should establish policy coherence between the various external policy fields related to water as well as between the external and internal fields. In the context of their international relations, they pursue a wide range of goals that result, on the one hand, from international agreements on climate and environmental policy and, on the other, from economic interests or geopolitical strategic interests and values. Political measures to promote these goals must be checked for compatibility and coherence. This can affect a wide variety of water-related areas, e.g. covering German energy demand, agricultural subsidies or investment agreements. Particularly against the backdrop of geopolitical power shifts, the importance of trusting partnerships and ensuring Germany's credibility in its own political actions is increasingly becoming the focus of political considerations. In preparation for the upcoming processes to renegotiate a post-2030 agenda at multilateral level, the promotion of European and German credibility in the eyes of strategic partner countries is also of key importance worldwide.

Shape trade and economic relations, hold the private sector responsible

International economic relations and trade policy should promote sustainable water use and not exacerbate water scarcity in regions suffering water stress. This requires better integration of water-related impacts and risks within the framework of international trade policy, for example within the World Trade Organization (WTO), regional trade agreements or investment-protection agreements.

EU trade relations should be analysed specifically for water-related spillover effects. False incentives that exacerbate negative spillover effects – e.g. from regulations in trade agreements or the long-distant effects of European regulation – should be dismantled. Furthermore, trade relations should be used to promote the switch to water-saving production and cultivation methods or alternative sources of income.

The WBGU recommends that the protection of water resources should be more firmly anchored in existing trade agreements. If possible, this should be done under WTO law in order to achieve coherent regulations for a maximum group of countries – but also in bilateral and multilateral agreements, since reforming WTO law is

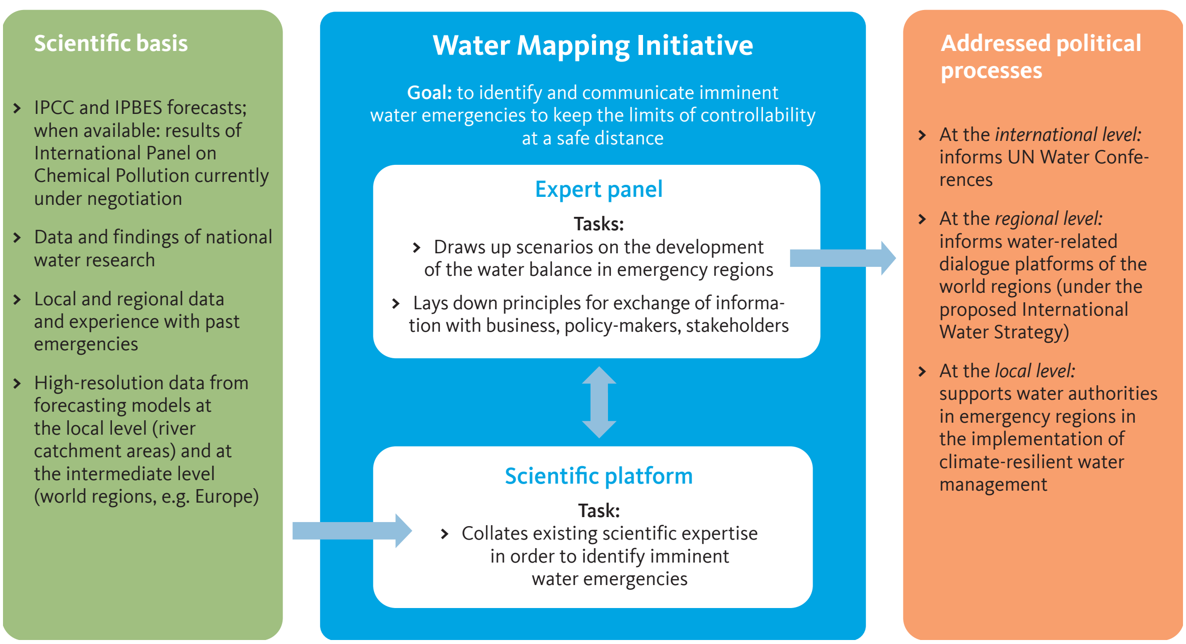


Figure 4
WBGU proposal for a Water Mapping Initiative to prevent imminent regional water emergencies. The scientific platform aims to recognize imminent water emergencies as early as possible by integrating scientific principles. On this basis, the expert panel would inform and support international, regional and local policy processes.
Source: WBGU

likely to be difficult in the short and medium term (Zengerling, 2020).

Companies and investors should also be held more accountable internationally. Based on reporting on water use and water risks, companies and investors should be encouraged to take measures to avoid negative impacts of their activities on water resources. Low- and middle-income countries should be given support with the introduction of reporting obligations, e.g. via capacity-building measures. Germany should also examine the extent to which protecting water resources and recording water risks can be more closely integrated into the German Supply Chain Act.

The proactive state

The state should play a proactive role in the field of water governance. In order to do justice to the precautionary and polluter-pays principles, democratic processes are needed to negotiate, conceive and implement strategies and instruments for water policy. Cooperation with different actors is important ('with and not against society'), but this must not mean that the state withdraws and remains passive vis-à-vis the challenges of water governance. The WBGU recommends increasing administrative capacities and resources so that states can assume their role and responsibilities appropriately.

A future climate-resilient, socially balanced water-management regime requires controlled and planned interaction between the proactive state with all its framework-giving responsibility (top-down) and historically evolved self-organization (bottom-up) in water management, which is already practised in some cases; it does not arise out of necessity but from the opportunity for improved water governance, which can accelerate the implementation of the goals of climate-resilient water management.

Promote self-organization at the regional and local level

Especially in regions of the world that are severely affected by exacerbated water-related challenges, the WBGU advocates the targeted promotion of structures that (1) enable self-organization at the regional and local level (bottom-up), (2) compensate for weaknesses in formal water governance, which is often designed by the state, and (3) also acknowledge and address deficits in informal systems. In the past, the promotion of self-organization, especially in line with IWRM principles, has proved its worth in expanding participatory and inclusive forms of decision-making. Especially in times of growing autocratization processes at the political level in the majority of countries worldwide, this promotion of inclusive governance approaches at the local level and in the area of water management is important.

International alliances for climate-resilient water management

When drawing up funding lines in the field of water management and water research, specific attention should be paid to promoting cooperative research projects with countries facing increasing challenges in water management (e.g. droughts, floods), or affected by social polarization and political autocratization processes – or which are of high strategic relevance as partners and alliances for Germany and Europe at the level of geopolitical negotiation processes.

When supporting confidence-building measures, especially in conflict areas, it is important to pay attention to institutional capacities and a dialogue focused on common goals, and not to concentrate primarily on technological solutions and data availability. All too often, infrastructure projects are prioritized without also considering local needs for their long-term maintenance and for embedding them in both formal and informal societal systems of governance. It is more difficult to change norms, thought patterns and habits. What is needed, therefore, are confidence-building measures in institutions (e.g. on policy coherence, transparency, accountability), long-term partnerships and a genuine dialogue with partners – also in the funding of research projects. All too often, (research) projects are short-term and there is no real dialogue between donors and recipients.

The German and European science-funding landscape should specifically promote interdisciplinary and transdisciplinary projects in the field of sustainable water management in different regions of the world where there are different management challenges. This includes scientific preparation and locally adapted innovation development in the field of irrigated agriculture as well as urban water supply and disposal, waste-water treatment and hydropower generation. It is important to pay attention to transdisciplinary research designs in which the transformative co-production of water-management knowledge is promoted in close cooperation among scientists and practitioners.

Dialogue forums with deliberative elements should be institutionally established and interlinked as an instrument of sustainable climate-resilient governance. Participation has a preventative effect and helps to reduce the potential for conflict between different actors. This also promotes democratic practice and can contribute to peacekeeping both within countries and internationally. Dialogue forums also offer an opportunity to involve diverse forms of knowledge and actors (e.g. cities, associations, religious communities and companies) in the search for solutions.

Mobilize and organize funding also for local approaches

Safe access to drinking water and sanitary facilities, as agreed in the UN Sustainable Development Goals (SDG 6), has been improved worldwide, but even today 2.2 and 3.5 billion people respectively still have to make do without them. In 140 countries, investments would have to be tripled to a total of over US$100 billion per year in order to achieve SDGs 6.1 and 6.2 by 2030 (Hutton and Varughese, 2016), plus expenditure on water-resource protection and the reduction of water-related risks (including those caused by climate change). However, the respective benefits are estimated to be two and a half to seven times the costs (UNESCO, 2024; GCA, 2019).

Public and private investment is needed to finance this. More private capital in particular must therefore be mobilized, especially in low-income countries, where, for example, only 1.4 % of the private financial resources leveraged with development cooperation funds in 2012–2017 were allocated to the water and sanitation sector (OECD, 2019). Many strategies (e.g. of the World Bank, of the German Federal Ministry for Economic Cooperation and Development (BMZ) as well as the German National Water Strategy) are already aimed at making investment in the water sector more attractive and raising the creditworthiness of water suppliers. Skills and capacities need to be built up, especially in public companies and institutions for efficient planning, investment management and operation, as well as for supervision and regulation. However, because of the exacerbated water-related challenges described above, more attention must also be paid to the following three fields of action.

First, water-related risks should be made transparent in order to mobilize private and public investment. Only if companies, investors and municipalities pay more attention to the water-related risks and impacts of their activities will they invest more in mitigating them or participate in efforts such as the International Climate Adaptation Fund. The German government should work for a harmonization of non-financial reporting on SDG 6, for example by supporting the International Platform on Sustainable Finance, and with its own activities. Building on experience with EU taxonomy and the design of 'blue' financial instruments, Germany can play a pioneering role in this respect. Moreover, information and support services for assessing water risks should be improved. Better data and long-term projections on water availability, forms of water use and regional and sectoral linkages should be collected and made available in line with demand; the skills needed for the use of these data and projections should be taught, and other countries should also be supported in this endeavour. Climatological, meteorological and hydrological public services and research institutions must be strengthened and networked for this purpose. The establishment of a digital and free European access portal (European Access Point, ESAP) should be supported. Public support programmes such as the German Sustainability Code should be expanded and relevant experience exchanged with other countries.

Second, the water sector should be made more attractive by ensuring stable sources of income. The users of water or specific infrastructures (e.g. flood protection) should bear more of the costs, as should those who cause damage. On the one hand, the pricing of water should be comprehensive but socially balanced and cover environmentally related costs. Exceptions to water-abstraction charges should be abolished. On the other hand, distributors and users of water-polluting substances should participate more in waterbody protection. In Germany and the EU, there are already proposals of this nature within the framework of extended producer responsibility; these should be extended to other substance and product groups and properties. Germany should also advocate an EU-wide pesticide levy that takes environmental and health risks into account and charges more for substances with higher risks. The revenue can be used for waterbody protection, to mitigate exceptional burdens, e.g. for farmers, and for advice on alternative plant-protection techniques. The German government should support capacity building in low- and middle-income countries for the planning and implementation of price reforms as well as the introduction of producer responsibility and water-related environmental levies.

In addition, measures with multiple benefits for the general public should be better remunerated. Public co-financing, tax relief or subsidies can create more incentives for private investors. The EU's Common Agricultural Policy (CAP) should be reformed as from 2028 in such a way that it promotes the conservation of water resources and nature-based measures with multiple benefits and avoids disincentives. The eco-schemes provided for in the first pillar of the CAP should be expanded at the expense of the existing area-based direct payments. Indirect water-related subsidies should also fulfil minimum water-related standards and could, for example, be screened on the basis of the do-no-significant-harm principles of EU taxonomy. In the introduction of climate-resilient water management, low- and middle-income countries can be supported by water-related debt swaps, provided they fulfil the necessary institutional conditions.

Finally, revenue generation and use should be given a boost at the local level. However, revenue from centrally levied charges, e.g. on water-polluting products, should also flow to municipalities and cities on a pro-rata basis to enable them to carry out the tasks made necessary by these product (e.g. water treatment). This can be supplemented by horizontal equalization mechanisms if the costs and benefits of local measures are incurred in different municipalities. In low- and middle-income countries, more efficient revenue collection and use often requires institutional and structural reforms, a fight against corruption, and greater transparency and accountability.

Third, mediating institutions (intermediaries) and local cooperation platforms should be strategically strengthened or established: specialized banks, revolving water funds, NGOs or research institutions can 'pool' smaller projects or water and land actors as well as public and private investors, mediate between them and structure suitable financing. With the help of these intermediaries, the EU, national and sub-national governments should institutionalize local exchange and cooperation formats between stakeholders and donors across the board. These can be used to create a common knowledge base, coordinate strategies and measures, and organize financing. This should be accompanied by the development of public capacities and best-practice networks for implementing results-orientated blended-finance approaches and the planning, review and scaling of remuneration models for projects with environmental and social multiple benefits.

Research is required on (1) projections of potential water-related damage, adaptation costs and multiple benefits and on the modelling of uncertainties; (2) impacts of potential water-related damage on national economies and the financial sector; (3) opportunities for more participation of institutional investors in financing water-related objectives; (4) hybrid financing instruments and new business models for nature-based approaches; (5) the efficient assessment of local multiple benefits of nature-based approaches and their systematic use; (6) effects of an extended reform of levies and charges, including e.g. unintended burdens on third parties or the relocation of pollution-intensive economic activities.

Science and education for a sustainable WaterFuture

The science system has a key role to play in dealing with exacerbated challenges. Especially the non-stationarity of hydrological regimes caused by anthropogenic climate change requires the continuous production of knowledge and data, which must be taken into account in innovations to ensure that the water requirements of humans and ecosystems are secure. Non-stationarity means that the assumption that a system exhibits predictable variability that can be derived from empirical observations is no longer tenable. Furthermore, science has a growing advisory and supporting role to play in the political process. The complexity and speed of changes in socio-ecological processes, exacerbated by climate change, simultaneously demand forward-looking, reflexive and adaptive local and global water governance. Independent, critical science is essential as a basis for this.

Scientific capacities in low- and middle-income countries should be strengthened. International research collaborations can contribute to their development. Up to now, the legal framework for international scientific cooperation has stipulated that all personnel, material and travel funds are managed in the scientific institutions of the donor countries. As a way of boosting scientific capacities, the WBGU recommends creating the legal conditions for direct fund management, including accounting and auditing in partner countries. This strengthens the role of the scientists conducting research there and generates skills in the administration of funds. Another measure would be to create the legal conditions for on-lending funds, with shared liability between the partner institutions involved and the donor.

Citizens can actively participate in scientific research projects in citizen labs. By involving the population in the decision-making process, citizen labs, like deliberative participation processes, can contribute to more resilient structures in municipalities; they can find customized solutions to local challenges – such as water shortages – which are accepted thanks to transparent decision-making. Citizen labs also improve the protection of water resources. The WBGU regards this form of public participation as very important for the protection of water and biodiversity and advocates its further expansion.

Education is essential for the transition to a sustainable society in general and for the prevention of water crises in particular. Measures such as information provision, education, and knowledge acquisition through practical experience or public dialogue raise people's awareness of the importance of water as a resource. Self-determined action and active participation in political processes are promoted by a better understanding of the connections between lifestyles, the economy and water quality, as well as by knowledge of the new, climate-change-related challenges in water management and the complex interrelationships of global governance. The WBGU recommends initiating more educational programmes at national and international level and launching an international discussion on new forms of economic activity and the appreciation of ecosystem services. Furthermore, advisory and training programmes – also based on the results of knowledge exchange – should be carried out at the regional level and tailored to local conditions in order to raise awareness of local water problems and enable actors to rethink and take targeted action. Real-life lessons on the topic of water enables children and young people to learn more about water cycles, the water supply, water's importance for people and nature, and the consequences of climate change. There is already a considerable amount of teaching material for all ages and school types. Because the topic of water is of such paramount importance, the WBGU recommends that it becomes obligatory for curricula to take up the topic on an interdisciplinary basis across the entire school spectrum.

Outlook

The issue of 'water in a heated world' has gained new international momentum with the UN Water Conference 2023 and the establishment of the G7 Water Coalition in 2024. The aim must now be to capitalize on this. In particular, the UN Water Conferences scheduled for 2026 and 2028 should be used to place the global importance of water higher on the political agenda and to adopt resolutions to anchor the topic more firmly in international sustainability policy. This report aims to make a contribution to this end.

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The German Advisory Council on Global Change

(Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen – WBGU)

The WBGU is an independent, scientific advisory body to the German Federal Government set up in 1992 in the run-up to the Rio Earth Summit. The Council has nine members appointed for a term of four years by the German Federal Cabinet. The Council is supported by an interministerial committee comprising representatives of all ministries and the German Federal Chancellery. The Council's principal task is to provide scientifically-based policy advice on global change issues. The Council:

- analyses global environment and development problems and reports on these,
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- provides early warning of new issue areas,
- identifies gaps in research and initiates new research,
- monitors and assesses national and international policies for the achievement of sustainable development,
- elaborates recommendations for action, and
- raises public awareness and heightens the media profile of global change issues.

The WBGU publishes flagship reports every two years, making its own choice of focal themes. In addition, the German government can commission the Council to prepare special reports and policy papers.

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