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#HydrolinkMagazine

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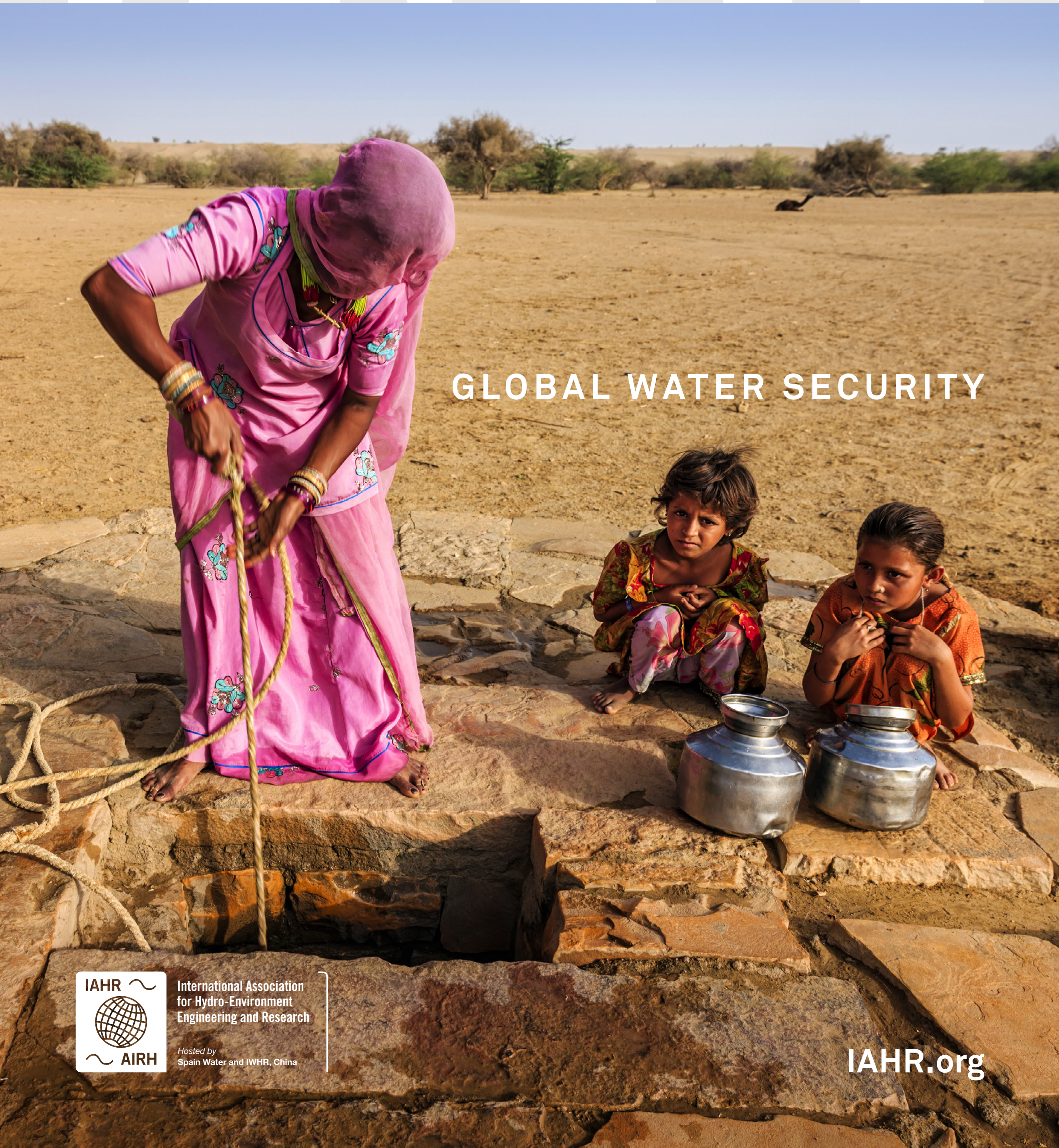

GLOBAL WATER SECURITY

IAHR AIRH
International Association
for Hydro-Environment
Engineering and Research

Hosted by
Spain Water and IWHR, China

IAHR.org

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EDITORIAL

Water security has been gaining acceptance as an all-encompassing descriptor of the water challenges faced around the world. The first broadly publicized definition of the term was in the 2000 ministerial declaration at the Second World Water Forum in The Hague, which outlined the basic dimensions of water security, including meeting basic needs in safe/sufficient water and sanitation, securing the food supply, protecting ecosystems, sharing water resources through peaceful co-operation, managing risks, valuing water, and governing water wisely. These principles were expressed also in the Millennium Development Goals of the United Nations and were elaborated more later in the Sustainable Development Goals of Agenda 2030 adopted by the United Nations in 2015.

The first article of this issue introduces IAHR's various activities focusing on global water security. An early milestone in this work was the forum organized at the 2013 IAHR Worldwide Congress in Chengdu, which led to a Global Water Security Declaration signed by the Presidents of five other associations (IAHS, ICOLD, IWRA, ICID and WCCE) besides IAHR. This document identified the factors threatening water security and stressed that water security means minimizing water related risks and that demand management is essential for water security. To strengthen water security the declaration called for action on different fronts including (i) informing policy makers about current and emerging threats, and promoting solutions and strategies that ensure water security, (ii) promoting formal education on water issues at all levels and raise capacities among key stakeholders and the general public, (iii) promoting thematic research in critical areas, and (iv) calling engineers and other professionals to work on sustainable designs and enhanced water use efficiency in agriculture and the industry.

The present issue of Hydrolink includes several articles that discuss different issues and aspects of water security, and report on efforts to strengthen IAHR's activities in this field. A major issue among those is the impact of climate change on water security at different levels through its effect on infrastructure, decision-making, governance, and water justice. In response to this challenge engineers and scientists are called to work harder to contribute to adaptation and mitigation measures and help improve governance.

Achieving water security requires policies supporting the sustainable use and management of water resources. It is essential that these policies are coherent with those in other sectors depending on, or affecting water use (e.g., agriculture, industry, energy, health) and develop intersectoral decision making, which is a fundamental element for the success of all sectors. Lack of financing, governance issues and fragmented water institutions often stand in the way of implementing policies ensuring water security. Overcoming these barriers is necessary for the water security of any country.

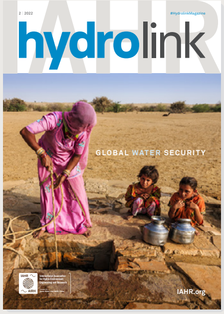
Among the ways of dealing with various threats to water security, such as floods, droughts and water contamination are management strategies such as Nature-based Solutions. Examples include the reduction of flash floods in cities using blue-green infrastructure such as green roofs, and urban parks facilitating water storage and the restoration of wetlands which reduce peak flows, improve baseflows, create additional habitats for wildlife, and enhance biodiversity values and ecosystem services.

One of the tools for reducing and mitigating water security risks is the digitalization of the water services to the agricultural, domestic, industrial and commercial sector. Hydroinformatics, artificial intelligence and machine learning, digital twins, extended reality, serious gaming, digital portals, and advanced processing of remote sensing satellite and unmanned aerial vehicle imagery are among the many new tools. To fully realize the benefits offered by these technologies and hydroinformatics solutions, cultural changes would also be necessary with emphasis on the role of the human factor.

Many countries have assessed their water security concerns and have taken steps towards improving water resources and quality. For example, China has focused on three water security concerns, drought conditions and water scarcity, flooding and sea level rise, and water pollution. In response to these concerns new policies for demand management have been introduced, in parallel with efforts to augment supply. Engineering and non-engineering measures, such as the sponge city program, are used to address the issue of flooding. Point and non-point pollution source control, improved wastewater treatment, and nature-based solutions are used to deal with pollution. In addition, institutional reforms make river and lake management the responsibility of local governments.

Spain, another country where water security is a concern, has developed a water governance system based on the concepts of legal certainty, basin river organizations, water users associations, participatory water management, hydrological planning, technical and scientific knowledge, and investment in water infrastructure. The goals of the system are to balance supply and demand at the river basin level and provide flood and drought management.

Many studies and investigations on specific hydro-environmental problems contribute directly or indirectly to improving water security. Three articles in this issue discuss such topics. These include the monitoring, control and treatment of emerging contaminants, the forecasting of the occurrence of detrimental algal blooms, and the use of artificial intelligence methods in a system for hydro-ecological and environmental modeling. With this issue and the recent and planned activities of its Technical Committee on Global Water Security, IAHR is aiming at raising awareness and mobilize those who can contribute to improving water security around the world.



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Cover picture: *Indian woman drawing water from the well meanwhile two of her children waiting for her. Thar Dessert, Rajasthan, India* | ISTOCK BY GETTY IMAGES

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Introduction to Global Water Security

By Roger Falconer and Arthur Mynett

The topic of Global Water Security (GWS) came to the foreground during the various World Water Forum events taking place in the years 2006 (WWF Mexico), 2009 (WWF Istanbul), and 2012 (WWF Marseille). Based on the outcomes of these events, UN-WATER drafted a document and working definition, as illustrated in Figure 1[2]. This definition includes all aspects of the water cycle from 'source to sea', and includes topics of relevance to IAHR members with an interest in: floods, droughts, water pollution, ecosystems services, water trading (through virtual water) etc.

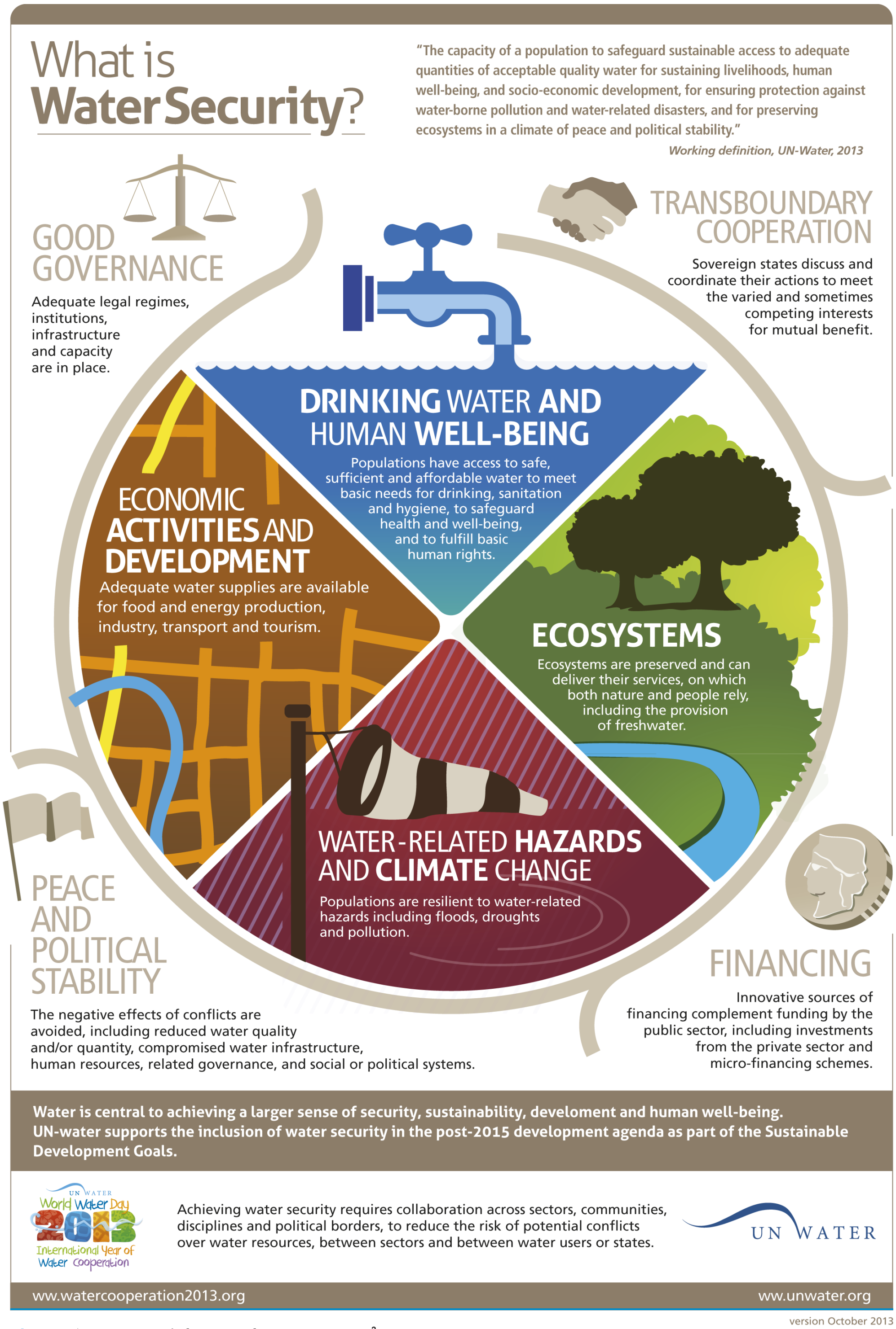

Figure 1 | UN Water definition of water security[2].

Because of the relevance of this topic for IAHR as a professional association, the authors launched an IAHR Working Group on Global Water Security in 2012. The aim was to address, through hydro environmental research, the many practical issues related to GWS and in doing so, making IAHR more appealing to practitioners. This corresponded to the worldwide paradigm shift at the time, where academics were encouraged to collaborate more with practitioners[1]. For example, in the UK 7-year Research Assessment Exercise cycle (now Research Excellence Framework, or REF), 'research impact' was introduced in REF2014 to assess the impact of academic research, in addition to the quality of publications, peer reviewed grant income, etc. Such emphasis on impact has increased further over the past decade and the authors of this article have been mindful of trying to engage practitioners more with the IAHR community by revitalising the Global Water Security Working Group to a level where it is now a Technical Committee within the IAHR organisation.

By developing and building on the UN-WATER definition, and by its commitment to engage with practitioners, the IAHR Technical Committee on GWS was able to raise considerable interest in the topic again, and from 2020 until today has organised 6 highly successful webinars (see Committee on Global Water Security (iahr.org)), including over 50% of the speakers from practitioner organisations, and a total viewing audience of well over 40,000. The Committee is currently preparing the inaugural IAHR Conference on Global Water Security, to be held in Nanjing, 30th October to 2nd November 2023 (see: 1st IAHR International Conference on Global Water Security https://icgws2023.iahr.org/en/web/index/).

The effects of climate change, population growth and increasing urbanisation, together with the United Nations Sustainable Development Goals (UN SDGs) and related legislative drivers (such as the European Union Water Framework Directive), have led to increasing global concerns about the sustainable supply and management of good quality water for all. Such concerns form a major part of the targets of the UN SDGs and particularly Goal 6. Furthermore, in many countries worldwide ecosystems services have not been included in the pricing of water, which together with the increasing frequency of both floods and droughts, has necessitated a more systems-based water resources management approach in addressing the growing challenges of water security from source to sea. Very recently, the National Security Council in the USA is discussing releasing a first-ever White House action plan for global water security[3].

It was recognised that, in order to increased Global Water Security, improved water quality in river basins and coastal waters was required, along with a reduction of water pollution. For example, *E. coli (Escherichia coli)* and *enterococci faecal* bacteria levels in rivers and coastal waters are often found to exceed freshwater and bathing water compliance standards, leading to unsafe bacteria levels for recreational swimming, shellfish harvesting etc. Such concerns are increasing in developed countries such as the UK[4], as well as in developing countries. The relationship between faecal bacteria levels in catchments (urban and rural), rivers and bathing or shellfish waters are complex, since multiple processes and driving factors affect the transport and fate of Faecal Indicator Organisms (FIOs) from source to sea. To obtain improved FIO level predictions and better management of river and coastal water compliance for a changing environment and more stringent standards, it is therefore essential to first build a robust and well calibrated hydrodynamic model –governing the main transport mechanisms of bacteria through the system– by collaborating with epidemiologists and other experts to include all relevant dynamic FIO kinetic processes through catchments, gullies, pipes and storage tanks into river networks, estuaries and, finally, coastal waters.

One example worth mentioning here is the UK Ribble River Basin, which includes 28 catchments feeding into the Fylde Coast receiving waters along the North West coast of the UK[5]. The estuary includes shellfish harvesting sites and the coast includes the bathing waters around Blackpool, which is one of the most popular bathing resorts in the UK. Extensive field measurements and laboratory analyses of data obtained on effluents discharging into the estuary were collected, for both wet and dry weather conditions. From this, various model parameters needed for calibration and validation of the integrated modelling system were determined. Model predictions were then used to assess the concentrations and locations of *faecal bacteria* along the bathing and shellfish waters, with the aim to provide planning information for delivering more effective management strategies to meet the EU Water Framework Directive standards, as implemented from 2015.

One of the key findings from this study was that the adsorption and desorption of *faecal bacteria* to and from the suspended and bed sediments proved to be an important

transport mechanism of bacteria from 'source to sea'. However, several key limitations of existing hydro-epidemiological modelling systems remain, particularly regarding the prediction of bacterial levels in rivers and coastal waters, and considerable research opportunities exist for IAHR members to work on with other discipline specialists, such as epidemiologists, biologists etc. to improve water security in river and coastal basin systems.

Similarly, in the Netherlands where more than half of the country lies below sea level and is vulnerable to flooding, water security is a major issue. Not only in terms of flood protection, but also in assuring adequate water supply, both in terms of quantity and quality, throughout the year. Some 60% of the economic value is earned in the lowest lying parts of the country in the West. Apart from rainfall, fresh water supply comes from the three main river systems –Rhine, Meuse, Scheldt— that originate in upstream countries and flow through the industrial areas of Switzerland, Germany, France and Belgium. As a consequence, assuring adequate protection levels and overall water security (quantity and quality) is one of the main driving forces for sustaining the Dutch economy, as laid down in the report from the 2nd Delta Committee of the Government of the Netherlands[6].

Having experienced quite a number of flooding disasters over the past century, the Netherlands developed a number of engineering solutions like the IJsselmeer closure dam, the Eastern Scheldt storm surge barrier, and the Rotterdam Maeslant barrier that all have received global attention. More recently, however, the emphasis has turned to creating so-called Nature-based Solutions (NbS) that are able to achieve more environmentally friendly, but still adequate levels of water security[7]. Key concepts of NbS for sustainable development include: (i) selecting resilient design strategies; (ii) sustaining the natural environment and its ecosystem services; (iii) integrating multiple functions; and (iv) involving stakeholder participation. The overall trend is towards Building with Nature rather than trying to oppose the forces of nature. The concept of NbS is about exploring and enhancing the role of green infrastructure in mitigating the impacts of weather and climate (change) related natural hazards, rather than resorting to grey solutions made out of concrete and steel. New opportunities arise by combining green and grey infrastructure that not only provide adequate safety levels and water security, but also do so in an environmentally friendly and sustainable way. Striving for climate robust agriculture; creating climate adaptive cities; restoring natural water systems; are just a few examples of NbS for water security at the regional and national level. Moreover, these new concepts of Nature-based Solutions for Global Water Security provide a number of business opportunities to make hydro-environment engineering and research (the area of expertise of IAHR) even more relevant to practitioners, as clearly demonstrated by the numerous examples contained in this Special Issue on Global Water Security.

Roger Falconer

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Arthur Mynett

Arthur Mynett is Emeritus Professor of Hydraulic Engineering and Environmental Hydroinformatics at IHEDelft Institute for Water Education and Delft University of Technology (TUD). He received his MSc degree in Civil Engineering from TUD (1976) and ScD degree in Hydrodynamics & Coastal Engineering from the Massachusetts Institute of Technology (1980). He was employed at Delft Hydraulics (1980-2010) and IHE-Delft (1985-2015). He worked in various fields of river, coastal and offshore engineering, and became director of strategic research & development at Delft Hydraulics (1995). Prof. Mynett served as IAHR Council member from 2005-2013 and as vicepresident from 2013-2017. He chaired the LOC of the 36th IAHR World Congress held in The Hague, Netherlands (2015) and was awarded IAHR Life Time Member (2016) and Honorary Member (2019).

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Water Security: Climate change and the great unknowns

By Peter Goodwin and David Wagner

We are on a fast track to climate disaster. Major cities under water. Unprecedented heatwaves. Terrifying storms. Widespread water shortages. The extinction of a million species of plants and animals. This is not fiction or exaggeration. It is what science tells us will result from our current energy policies.

António Guterres
UN Secretary-General
April 4, 2022

This compelling comment was part of a recent statement accompanying the release of the Intergovernmental Panel on Climate Change (IPCC) on the release of the Working Group Reports for the 2022 Sixth Assessment (AR6). The final report AR6 *Climate Change 2022: Synthesis Report* is expected to be released in September 2022.

Climate change is increasing the risk and challenges of designing, operating, and managing water infrastructure. No one in the global community is immune from the potential impacts. Costs, both financial and human, are projected to increase as extreme weather events become more frequent and intense due to climate-related events.

According to the U.S. General Accounting Office, calendar year 2021 was the seventh consecutive year in which the United States experienced 10 or more weather and climate disaster events that cost more than $1 billion each in overall damages. Over the past 5 years, the cost of these disasters has averaged approximately $150 billion each year.

Figure 1 illustrates the rapid increase of such events since 1980. The trends found in the United States are reflective globally. Of importance, the IPCC estimate that about 40% of the world's population is highly vulnerable to the changing climate.

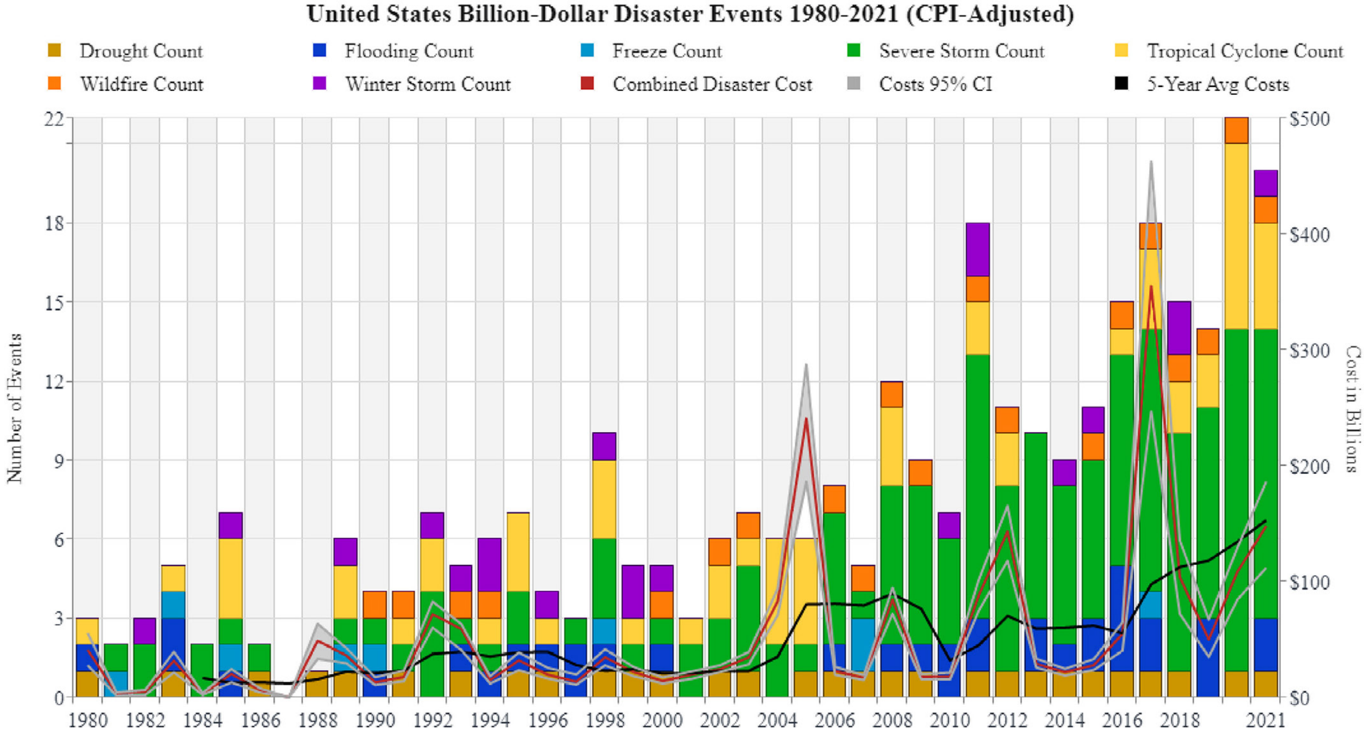


Figure 1 | Increase in climate and weather-related disasters in the United States (1980-2021). The bars indicate the annual number of events (left vertical axis) and the curves the cost in billion US dollars (right vertical axis). CPI stands for Consumer Price Index.

Source: NOAA National Centers for Environmental Information (https://www.ncei.noaa.gov/access/monitoring/billions/).

Water Security and Climate Change

Water security has emerged as a talking point for many decision-makers and politicians around the globe but what is "water security"? We all can agree that implementing decisions and building/operating water infrastructure should embrace a risk reduced approach. Reducing climate-driven risk will increase global, national, regional, and local stability, enhance public safety resulting in maintaining the capacity for transportation, food production, economic capacity, public safety, and ecosystem services.

Water security is characterized through two components, water risk and the stress. *Water risk* is defined as the possibility of experiencing a water-related challenge such as water scarcity from drought, damaging floods, infrastructure decay or trans-boundary disputes. The extent of water risk is a function of the likelihood of a specific challenge occurring and the severity of the impact. *Water stress* refers to the ability to meet human and ecological demand for fresh water. Water stress includes the physical aspects of water availability, quality, and access. Water stress can occur when the demand for water exceeds the supply of water in either the spatial or temporal context.

Why is Global Water Security Important?

The global water supply varies in terms of spatial distribution, availability and quality. The global hydrologic cycle is composed of both surface and ground water connected by infiltration, precipitation, evaporation, and sublimation. Over 90% of the water in circulation is associated with the constant interchange of water between the oceans, seas, lakes, rivers, and streams. Most of the remaining 10% of water in circulation takes the form of water vapor from plant transpiration, evaporation from surface water and sublimation from mountain snowpacks.

While the Earth has a significant amount of water, not all of it is readily available for human consumption. Water is critical for supporting people and the environment, yet fresh water comprises less than three percent of the total global water supply. The remaining 97% is salt water. The majority of the remaining 3% of freshwater is contained either in ice in the polar regions, in glaciers or confined in the underlying geology as groundwater. What remains in the form of freshwater available for humans and ecosystems is being impacted by climate change and is the focus of maintaining global water security.

Available fresh water resources are under constant threat from overuse, pollution, and waste. Protecting the functional capacity of fresh water for public and ecosystems services is critical to the global community. Not having adequate supply of clean water will result in water poverty.

How will Climate Change impact Global Water Security?

Climate change is impacting global water security at multiple levels including infrastructure, decision-making, governance, and water justice.

Infrastructure. The climate and its associated cycles are evident in increased variability and intensity of the global hydrologic cycle. We can see and measure increasing sea levels, extreme rainfall events, drought, and enhanced numbers of coastal storms with resulting surges that move further inland, all of which call for new or upgraded infrastructure. The science is clear – the impacts are increasing at alarming rates and the costs measured in terms of human life and financial impacts.

Decision-making. Determining and funding the construction of water infrastructure has been the responsibility of politicians, agency leaders and local water utilities and public safety offices. Decision makers based their actions on benefit-cost ratios, public safety, and often political support. To the decision-maker water security takes the form of reducing risk.

Governance. Water security for water infrastructure managers has to do with maintaining the capacity to ensure the operations and management of water infrastructure and systems while reducing risk to service disruption and public safety. Managing risk and maintaining infrastructure function is the major driving forces for governance water security.

Water Justice. Historically water infrastructure development occurred at the confluence of political support, financial capacity, and opportunity. Increasingly the global community has become aware that water infrastructure development often left out communities of lower economic standing, indigenous cultures and disenfranchised communities. Whether based on economic standing or ethnic background, some lower income groups are more vulnerable to the immediate impacts of climate change. Water security to these communities means being safe and having access to clean water for survival and, for some communities, ensuring cultural resources dependent on water are sustained.

How can we Address Water Security in a Changing Climate?

Water security is how nations, regions, communities, and individuals need to approach their water future under climate change. Water security is vested in developing and implementing actions that will result in increased climate resilience and reduce the risk to water poverty. There are three areas where the engineering and science communities' expertise and capacity can be applied: adaptation, mitigation, and governance. These actions and the framework that emerges from them need to be built around three guiding principles: information, integration, and incentives.

Adaptation. The initial step in developing a climate resilient –water secure path forward needs to identify and implement actions that provide guidance to develop procedures that allow us to locally adapt to changing climate conditions. Some examples include:

- Land Use and Urban Planning. Identify and protect/restore areas that can serve as buffers from storm induced impacts. This includes restricting and protecting critical coastline areas that can help in buffering storm surges. Approximately 54% of the global population live in cities which is expected to increase to 2/3rds in the next 20 years.

- Protocols on the use of freshwater systems. Include developing conjunctive use programs for managing ground and surface water systems.

Mitigation. Mitigating for future water security requires understanding the global future scenarios for climate change and developing policies and actions that can increase resilience. Examples include:

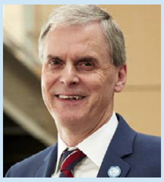
- Develop and improve models and observations to implement policies to address the global impacts on water security
- Develop information distribution systems to provide knowledge and approaches on climate and water security to the global community

Governance. Water security based on useful adaptation and mitigation methods can only succeed if the decision-makers and policy developers implement and support decision making that is based on information, integration of actions, incentives and monitoring. An example is:

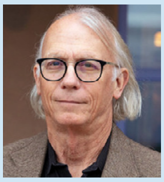
- Implementing an adaptive management approach that ensures that new information, whether for science or lessons learned, is rolled back into the decision framework.

Global Water Security and IAHR

Globally the costs in human safety and impacts to infrastructure are increasing. Implementing actions to reduce impacts and institute science and engineering-based climate resilience protocols requires coordination and an understanding of the risk associated with following the traditional approaches to the design, construction, and operation of infrastructure. IAHR and its knowledge base can provide the global community important resources to approach maintaining water security to the climate challenges ahead.



Peter Goodwin
Dr. Peter Goodwin is professor and president of the University of Maryland Center for Environmental Science. He is an internationally recognized expert in ecosystem restoration, ecohydraulics, and enhancement of river, wetland and estuarine systems, and he has spent 30 years in higher education. He has participated in the river restoration, coastal wetland sustainability, flood control, and sediment management projects around the world, including Chile and Guatemala, and estuarine and tidal wetland restoration projects on the East, Gulf, and West Coasts of the United States, from Delaware Bay to California.



David Wegner
Professor David Wegner is an Experienced Biological Scientist with a demonstrated history of working in the environmental services industry. Skilled in Analytical Skills, Government, Natural Resources, Environmental Awareness, and Environmental Consulting. Strong engineering professional with a Master's Degree focused in Hydrologic and natural resources from Colorado State University.

The link between Policy and Water Security

By Angelos N. Findikakis and Tom Soo

Water security in the context of several broadly accepted high-level water management principles

Recognizing old and new threats to water security has changed the way we think about water over the last few decades. In many parts of the world water security is threatened by a combination of factors, such as water scarcity caused by growing populations, economic growth, and climate change; extreme weather and climate conditions, such as floods and droughts; water pollution; and the degradation of aquatic and terrestrial ecosystems.

Several high-level principles and concepts related to the response to these threats emerged over the years. These ideas included the recognition that water resources are limited, the concept of sustainable development, the need to shift from supply augmentation to demand management, the human right to water, the economic value of water and the role of women in water management. The high-level principles around these ideas have been expressed in many documents and declarations by international bodies, such as the the ministerial declaration of the Hague on water security in the 21st century, the Millennial Development Goals and later the Sustainable Development Goals of Agenda 2030. Even though the high-level principles and goals of these declarations have been embraced almost universally and their language can be found in many water policy documents of most countries, the challenge of how to translate these principles to action remains.

A range of solutions consistent with these principles are available to improve water security. They include the re-evaluation of water-dependant economic activities (e.g. growing water thirsty crops in dry climates); balancing supply augmentation (e.g. building new large infrastructure projects) with demand management (e.g. conservation and public education, use of smart meters, and pricing with equity considerations); the use of non-conventional water sources (treated wastewater, desalination, rainwater harvesting, etc); increased water use efficiency (reduction/elimination of leaks/losses, efficient irrigation methods, water efficient household appliances, etc); nature based solutions and smart land use planning.

Obstacles on the road to the implementation of these high-level principles to improve water security include conflicts with different policies whose success depends on water, legal and institutional barriers, financial constraints, opposition to regulation by those benefiting by the lack of regulation and in some cases the lack of political will of elected officials, driven often by the short-term interests of their constituents, ignoring the consequences of inaction. As pointed out in an OECD report[1] a special challenge for water security is to properly consider the nexus between water, energy, food, climate and biodiversity and ensure coherence between the policies in all these sectors. It is essential that nations have coherent policies in all these sectors and develop intersectoral decision making as an essential ingredient for the success of all sectors (agriculture, industry, energy, health). Water security is not only closely related to food security, but also to national security. A recent report on water policy based on interviews with national water leaders from 88 countries concluded that the greatest challenges in most countries are related to governance issues and fragmented water institutions[2]. The same report found that the highest water risks are related to climate change which threatens water supplies, the increasing demand, and increases in extreme events such as floods and droughts. Policy challenges between richer and lower income countries do however present different priorities. In Africa for example, water leaders also place a high priority on their need to overcome inadequate and inaccessible data and information, as well as inadequate infrastructure.

Policy incoherence undermines water security

One way to understand how specific policies may undermine water security is to distinguish between:

A | Policies aiming at short-term benefits ignoring their long-term consequences.

B | Policies introduced in the past for a specific purpose and remain almost frozen in time, even though the original purpose has long been achieved.

C | Policies establishing water rights, often codified into law long time ago, which, when exercised today, undermine sustainability.

Many of these policies are related directly or indirectly to other sectors such as energy, industry and agriculture, the largest water user around the world. Visioning the future, projections from a global think tank, the OECD as well as others, point towards significant shift in global withdrawal and water consumption patterns, with thirst from energy production and manufacturing set to become proportionally much more significant than in the past. Increasing demand and potential rising competition for water calls for policy coherence across time scales, and between sectors that incentivizes and guides decision makers and practitioners to improve the use of fit-for-purpose water.

There are many examples of shortsighted agricultural policies that lead to the depletion of non-renewable water resources, undermining long-term water security. Such policies are sometimes aimed at achieving food security or to provide socio-economic development in rural areas, where farming may be the only employment opportunity and where many depend on subsistence farming. Even though they may provide short-term social benefits, they can be short-sighted if they don't consider the long-term sustainability of irrigated agriculture in these areas. This is the case of the agricultural policy of Saudi Arabia in the 1980's. Motivated by the need to diversify the country's

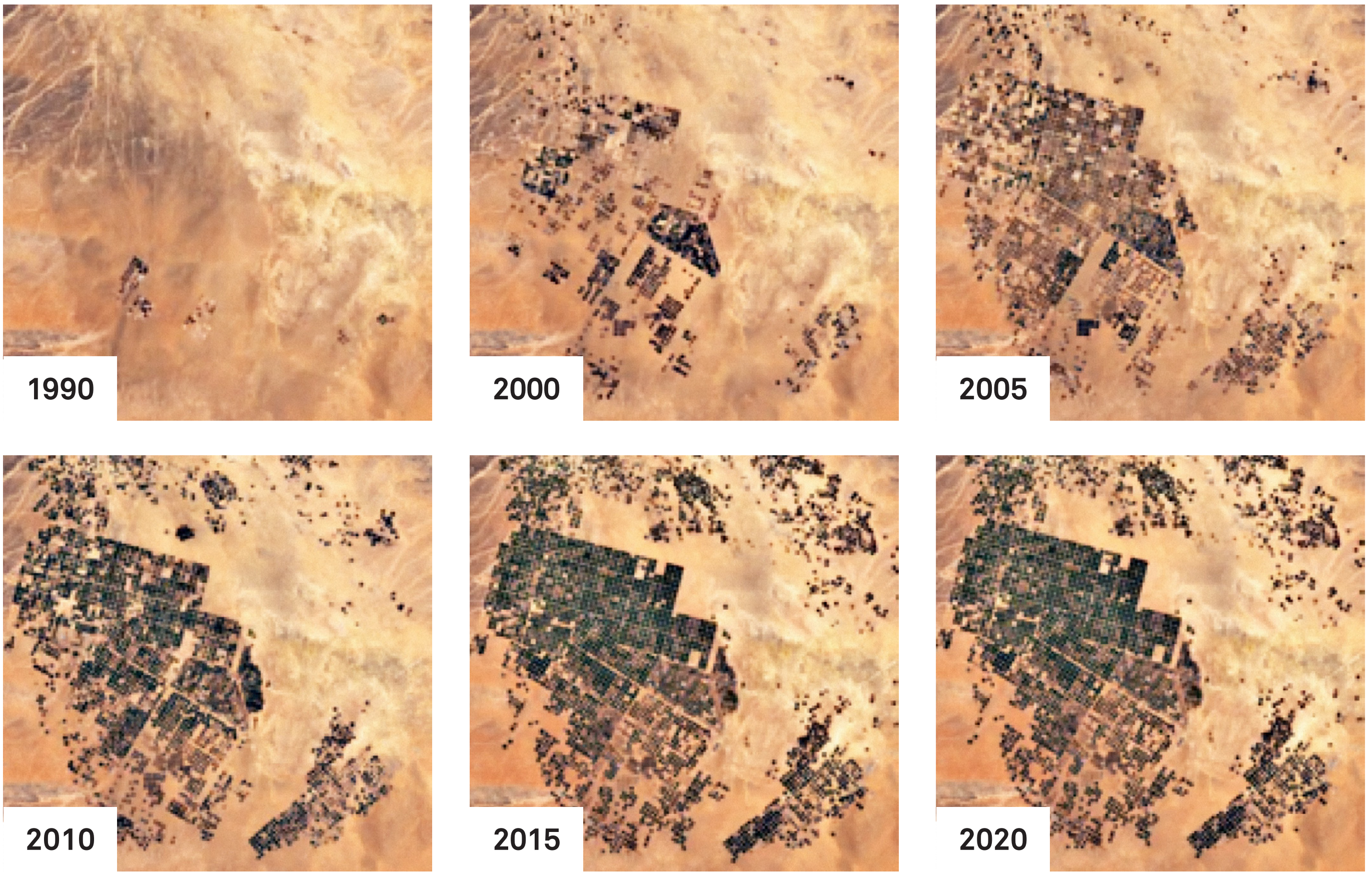


Figure 1 | Expansion of irrigated farms in the desert using non-renewable groundwater: an example of agricultural policy undermining long-term water security.

economy and achieve food self-sufficiency it introduced several measures such as crop price support, and subsidies for wells, pumps, and energy to use fossil groundwater making in few years a desert country an exporter of wheat by rapidly using a good part of its non-renewable water resources. Realizing that such groundwater use is not sustainable, this policy was abandoned few years later.

An example of a policy that was adopted more than a hundred years ago, but remained in place long after its goal was achieved, is the policy of the United States government of providing heavily subsidized water in the American West, introduced early in the twentieth century as part of the effort to develop and populate the region. Several large water infrastructure projects continued to subsidize irrigated agriculture long after the goal of this policy had been achieved. This encouraged farmers to continue growing some very thirsty crops, such as cotton and alfalfa, in arid and semi-arid parts of the region.

Water security can also be threatened by policies codified in some types of water rights. Among those are groundwater rights based on the doctrine of absolute ownership, according to which landowners have the absolute right to the water beneath their property, without any restrictions on the amount of water that they can abstract. The uncontrolled exercise of such groundwater rights in some parts of the world has led to the severe depletion of local aquifers.

Equally threatening to long-term water security is the lack of government intervention or enforcement of regulations aimed at protecting valuable water resources. The unsustainable use of water resources is supported by those with vested interests in continuing existing practices, such as, for example, large and small farmers benefiting in the short term from the overexploitation of groundwater. An example is the absence for years of any controls in groundwater abstraction in many parts of the High Plains aquifer in the United States, especially in North Texas.

Financing, infrastructure and engineering: essential policy for water security

Traditionally policies for securing adequate water supply were focused on water resources development through engineering infrastructure projects. In many parts of the world this is not an option anymore. This is not because all available water resources have already been developed (even over-developed) in some countries, but also because water policy must recognize the interdependencies that infrastructure solutions have with the environment, geo-political stakes and socio-economic well-being.

In some cases, the only alternative is to adopt policies aimed at balancing water supply limitations with demand management for sustainable water use. An example is the Sustainable Groundwater Management Act (SGMA) introduced in California in 2014 to address the severe overexploitation of many of its aquifers. The SGMA mandated the formation of local agencies with the responsibility to develop and implement plans for the sustainable use of groundwater within a 20-year timeframe. Each of these agencies has the authority to require registration of groundwater wells, mandate annual water extraction reports and impose limits on the rate of groundwater extraction.

Water infrastructure and engineering solutions that are multi-purpose and work in harmony with the environment and other sectors are absolutely essential for water security. Newer hydraulic solutions need to urgently be engineered and implemented in order to realize the development potential of many countries around the world. In Africa for example, two thirds of the sub-Saharan population still lack access to safely managed drinking water[3], irrigation potential is largely under-developed, and almost 90% of hydropower potential is not yet harnessed. Many developed countries such as Korea, Singapore or Spain are orienting public policy towards complementing traditional hydraulic works with digital infrastructure. A 3 billion Euro program has recently been launched by the Spanish Government, aiming at digitalizing water management in the country and involving new technologies in urban and industrial settings, digitalizing irrigation, transforming administrative settings and catalyzing training, research and innovation.

Policy must also incentivize the renewal, replacement or decommissioning of existing hydraulic works. A study by the United Nations University-INWEH[4] alerts us to the fact that most of the 58,700 large dams around the world were constructed between 1930 and 1970 with a design life of 50 to 100 years. Understanding that by 2050, a good part of the population of the planet will live downstream of one of these infrastructures; and that climate change scenarios in the coming decades present deep uncertainty, there is an urgent need for policy makers and designers to integrate future scenarios that are not simply based on historical data, but follow a holistic approach for planning, design and construction of the water works that will assure global water security.

A critical path towards ensuring water security for all is the financing of water-related infrastructure. A partial estimate of the scale of global economic losses related to water insecurity amount to a USD 260 billion per year from inadequate water supply and sanitation, USD 120 billion per year from urban property flood damages, and USD 94 billion per year of water insecurity to existing irrigators[5]. Despite this, projections for future investment needs far outweigh current financing measures, with global estimates ranging from 6.7 trillion by 2030 to 22.6 trillion by 2050[6]. To meet these needs, the High-Level Panel on Water, made specific policy recommendations to: maximize the value of existing assets for water-related investments; design investment pathways that maximize benefits over the long term; ensure synergies and complementarities with investments in other sectors; attract more financing by improving the risk-return profile of water investments[6].

The policy options to support much needed infrastructure and engineered solutions are difficult to achieve. Complex demands for sustainable financing and "bankable" investments, that align with the appropriate technical solutions, geo-politics, societal demands and environmental protection represent a challenging task for policy makers. Sharing common challenges, approaches and solutions amongst decision-makers can provide a "policy scaffolding" to support difficult decision making that is adapted to local contexts.

The role of learned societies

The language of water security has been widely adopted in policy declarations around the world, but there are many barriers to turning it to action. Learned societies of researchers and practitioners, scientists and engineers can help overcome some of the barriers to linking policy to water solutions. They can start by trying to communicate to the public the findings of scientific and technical studies using plain language and increase efforts to inform/educate political leaders and other decision makers, possibly by preparing policy briefs. They should also foster cross-disciplinary collaborations with different societies joining forces to launch joint initiatives, prepare information briefs, and organize join meetings or conferences. International platforms create space and opportunity for practitioners and innovators to freely exchange ideas with policy makers and scientists to catalyse change for a more water secure future.

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Using Nature-based Solutions to address water security changes

By Ellis Penning

Global water security challenges are many, and relate to either too much, too little, or too polluted water in relation to societal and environmental needs. A vast range of management solutions is available to mitigate the potential negative impacts of floods, droughts and contaminated waters. In recent years, more and more attention is being paid to the potential role of Nature-based Solutions (NbS) as part of the overall strategies for managing water security challenges. This article aims at giving an overview of the range of topics related to NbS for addressing water security challenges and the role of science in facili tating the uptake and implementation of these solutions in practice.

An introduction to Nature-based Solutions

On the 2nd of March 2022, the United Nations Environmental Assembly agreed on the definition of Nature-based Solutions as '*actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits.'* This is an adapted version of the IUCN definition[1] and an important milestone in maturation of the concept of NbS in the widest sense, indicating their potential application in a multitude of different ecosystems and for a wide range of social, economic and environmental challenges. Yet, using NbS is not new: already in the early 1970s H.T. Odum acknowledged the role of eco-engineering[2]. Other terms such as Building with Nature, Engineering with Nature and Blue-Green infrastructure are and have been used for methods in which 'working with nature, rather than against it to mutually solve societal and environmental challenges. Using natural processes is a key aspect of NbS, for example, the smart use of hydrodynamic processes may aid the transport of strategically placed sediment nourishments along coasts to reduce erosion in wider areas[3]. Many NbS are inspired by ancient, ecologically sound technologies, such as permeable dams to trap sediment for salt marsh and mangrove restoration[4] and the use of small-scale wadis and natural water retention in catchments to mitigate floods and droughts.

Co-benefits of NbS

In contrast to 'single-objective', traditional engineering solutions, often referred to as 'grey solutions', NbS often provide multiple co-benefits next to a primary objective, that can be of high relevance in overall and integrated management strategies. For example, NbS for reduction of flash floods in the urban environment (e.g. through implementation of blue-green infrastructure such as green roofs, and urban parks where water storage is facilitated) also provide human well-being through higher-quality public urban spaces and reduce the impacts of heat islands during droughts. Another example is the restoration of wetlands to improve sponge functioning in catchments, in which the wetland itself not only reduces peak flows and improves baseflows, but also creates additional valuable habitats for wildlife, improves biodiversity values and related ecosystem services such as the provisioning of food and drinking water to local populations. Increasingly also the potential role of multiple types of NbS for carbon sequestration is mentioned as a co-benefit of relevance, although their exact contribution to this particular topic is highly dependent on the local context, scale and correctness of implementation.

Adaptiveness of NbS

Many NbS are characterized by being adaptive to change as ecosystems can adapt to slowly altering conditions over time. For example, sedimentation in saltmarshes and mangroves can enable long-term adaptation to Sea Level Rise, provided that enough sediment input is available for this vertical growth. Large-scale ecosystem restoration provides more resilient buffers to climatic instabilities and using a catchment approach to flood management using NbS can also contribute to better resilience for droughts and improves biodiversity in the area. At the same time, there are boundaries to what ecosystems can resist, as is clearly demonstrated by e.g. the sensitivity of coral reefs to bleaching due to high seawater temperatures, and the risk of forest fires during heat waves which diminishes the potential of forests to contribute to reduced soil erosion and landslides on hillslopes.

Increasing the evidence base of NbS

The evidence base for the functioning of different types of NbS for various water security challenges is growing. Research in field pilots, large-scale implementation projects, experimental settings and modelling of long-term dynamics contributes to the trust and successful implementation of NbS, especially when this is done in close interaction with stakeholders. This evidence base provides the fundamental system understanding that is needed for proper NbS design and implementation and is always of a multi-disciplinary nature. For example, the role of vegetation dynamics in hydromophological processes is of crucial importance to the long-term dynamics of ecosystems, such as mangrove coasts, salt marshes, riverine floodplains and vegetated banks, wetlands in upstream catchments and forests on hillslopes that affect rainfall runoff processes. This ecological knowledge is combined with engineering knowledge to quantify the dynamics of ecosystems and related NbS in time and space. The resilience to extreme events, such as extreme storms is being tested in large-scale experimental settings[5] and via remote sensing after events. Increasingly, system understanding for proper design is combined with life-cycle cost-benefit analysis and business cases requiring further cooperation with economic, social and political science are essential.

Drawing on in-depth experience from planning, implementing and governing NbS in research and innovation projects of inter-and transdisciplinary character. Successful NbS amplification may be achieved by [1] using multi-scalar action to balance differing interests and reconcile governance levels, [2] providing financial and other institutionalized incentives and strategies for integrated participation processes, [3] using appropriate governance and management scales effectively integrating mediators, [4] using opportunities for transformative change offered by crisis, and [5] learning from worldwide amplification experiences.

System understanding as a key feature taking a landscape approach as the basis for working on water security challenges

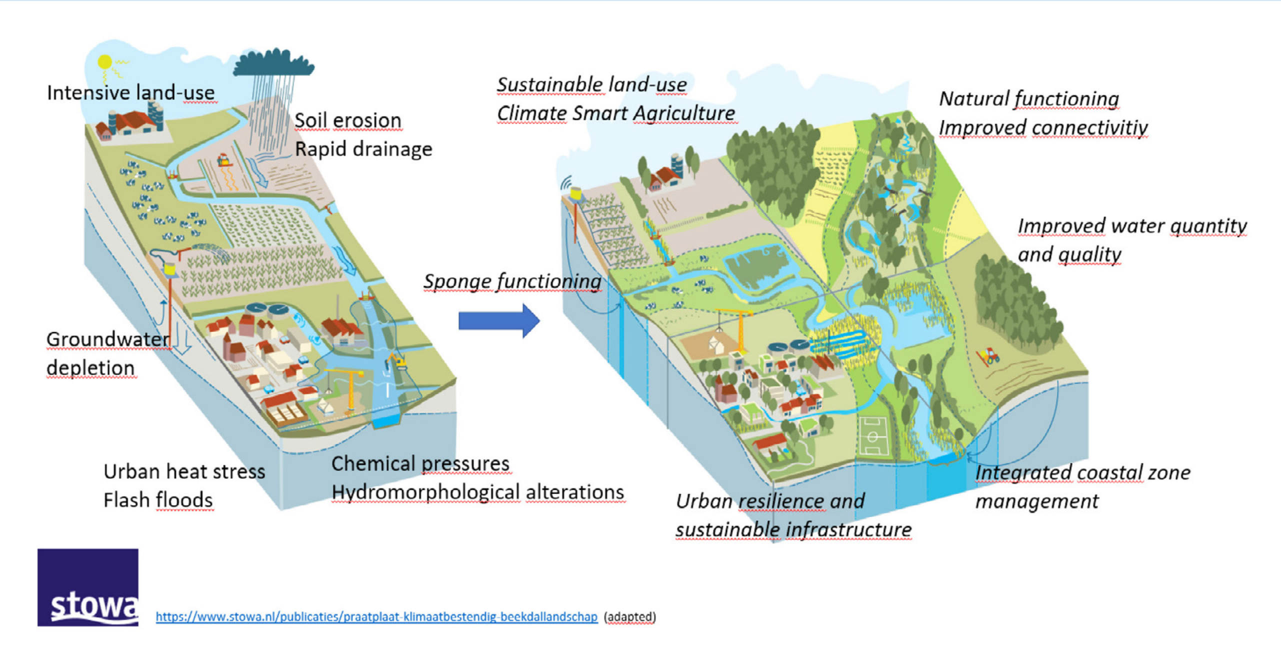

Figure 1 | From a current impacted catchment towards a sustainable and resilient catchment taking a landscape approach as a basis.
Adapted from: https://www.stowa.nl/publicaties/praatplaat-klimaatbestendig-beekdallandschap

Water management challenges are most often related to the dynamics and use of water in a landscape context. Human interference in landscapes has reduced their natural functioning and dynamics, resulting in a wide variety of water security challenges, such as depleted groundwater, soil erosion and accelerated drainage, chemical and hydromorphological pressures, heat stress, and flash floods, especially, in densely populated zones. When working on improvements for water security challenges, the interplay between these different aspects calls for integrated strategies that work on improvements of all aspects within a catchment approach, all the way from source to sea.

Various individual NbS should be combined (together with 'grey measures' where needed) into integrated strategies considering these integrated linkages.

A good example of this is the 'Room for the Rhine' project in the Netherlands[6], where a combination of 43 individual measures, both green and grey, were implemented along the entire Rhine river in the Netherlands to provide room for the river during floods and improve natural values of the floodplains, simultaneously providing increased landscape values, recreational opportunities and upgraded infrastructure where needed.

A new working group on Nature-based Solutions in IAHR

In order to exchange knowledge and scientific advance related to NbS, IAHR has initiated a new working group on Nature based Solutions. This working group will have its first live meeting during the IAHR World Congress 2022 in Granada, Spain.

IAHR-members interested in joining this initiative are more than welcome to contact the leadership team, which consists of Ellis Penning, Jochen Hack, William Nardin, Leon Kapetas, Julia Mullarney, YuJun Yi and QiuWen Chen.

Ellis Penning
Dr. Ellis Penning is an expert in the field of Nature Based Solutions and ecohydraulic research. She leads the research programme on Nature Based Solutions and carries out a variety of projects related to this subject. An ecologist by training, Ellis Penning is specifically focussing on the role of vegetation in aquatic systems, both from a flood risk and environmental quality point of view. Ellis Penning active in various EU projects such as the MARS and Hydralab projects and has extensive experience in international cooperation both in Europe and Asia. At present she is the co-chair of the International Steering Committee of the River Experiment Centre of the Korean Institute of Civil Engineering and Building Technology and leads the Deltares contribution to the joint project on vegetated flows in this unique large outdoor flume facility.

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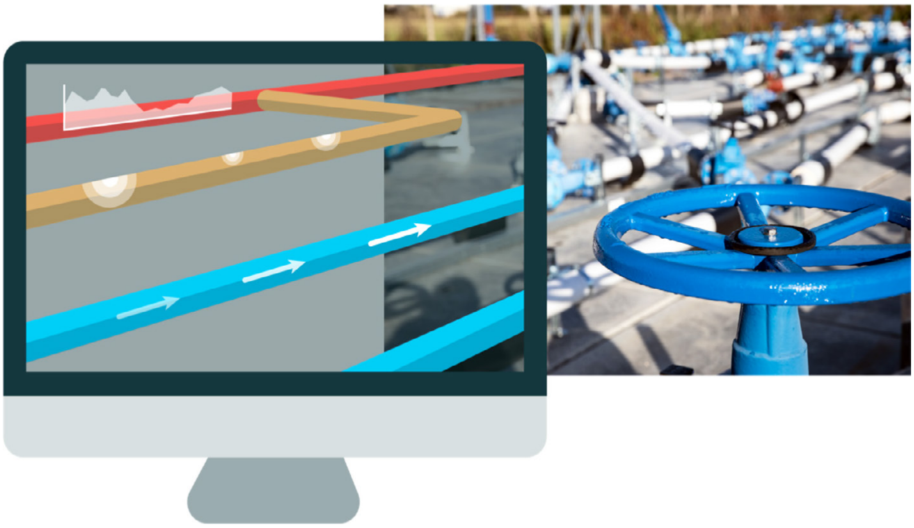
Hydroinformatics: Solutions for global water challenges

By Dragan Savić

Global water security is a multi-dimensional and enduring human goal. These multiple dimensions reflect human desire to manage risks related to water, including droughts, floods, landslides, desertification, pollution, epidemics and diseases, as well as disputes and conflicts.



Over the last 30 years, we have been whitenesses to modern digital technologies transforming our society (e.g. banking, transportation, tourism, entertainment). However, while digital banking (e.g. payment apps), transport apps (e.g. Uber), tourism platforms (e.g. AirBnB), and video and music streaming services (e.g. Netflix, Spotify) have disrupted traditional sectors, improving planning and management of those global water-related risks through digital transformation has been slow. With 90% of the data in the world today that has been created in the last two years alone, the quantity of information available is unprecedented in human history. We can measure, sense and monitor the condition of almost anything. The question is then, what is the situation with the digital transformation of the water sector?

The field of *hydroinformatics* has been at the forefront of the digital transformation of the water sector. Although in the past hydroinformatics was often identified by its technological dimension through applications of information and communications technologies (ICT) and artificial intelligence (AI) methods to solving complex water and societal challenges, it is much more than that – *it is a management philosophy developed to respond to global water challenges and made possible by rapidly advancing technologies!*

Digital technologies and hydroinformatics

Hydroinformatics is not a completely new concept. It has its roots in computational hydraulics (Abbott, 1991) and simulation modelling dating even before digital computers, e.g. electric-analogue groundwater models of the late fifties and early sixties. Hydroinformatics began to flourish with digital technologies afforded by the advent of desktop computers in the early eighties.

Modern digital technologies include various forms of AI and Machine Learning, such as data-driven modelling for leakage detection and localization, where machine learning methods are used to predict future signal values and deviations from those values indicate a potential leak. Another AI technology that has found its application in the water sector is nature-inspired computing (e.g. genetic algorithms, particle swarm optimization, etc.) for planning and management of complex water networks.

A Digital Twin is a digital copy of a physical system, which has roots in modelling and simulation. Classical offline models can be enhanced by bringing in real-time (and/or near real-time data) to update a model, making it a dynamic replica of the physical system. This type of modelling has the potential to change decision support and management of water systems from being reactive to becoming proactive.

Extended Reality is another group of digital technologies (including augmented, mixed and/or virtual reality) that is particularly useful for field personnel to, for example, see the augmented view of buried water infrastructure and locate possible problems and solutions, or for the training of personnel in a virtual environment. This risk-free troubleshooting and training technology allows utility personnel to immerse themselves in a virtual environment with a set of superimposed images, thus navigating an augmented reality. Visualisation of data and measurements made by different sensors allows utility personnel to access remote sites virtually and undertake quality control processes with ease.

Serious gaming has also found its way into water management, similar to flight simulator games for training and consensus building among stakeholders. These games, whose main purpose is not entertainment, allow players to experience interactively and visually what it is like to be a water manager facing constant challenges, e.g. droughts, flooding or water recycling.

Digital portals and online dashboards, such as those for monitoring and visualising performance data in a control room could be also enhanced by AI/Machine Learning technologies to analyse and controls the performance of water systems through predictive analytics. Another application of online dashboards helps in engaging water customers and empowering them towards more sustainable behaviour, thus enabling change in attitudes toward resource wastage and supporting demand management.

Remote sensing via satellite and UAV (Unmanned Aerial Vehicle) imagery has become an important source of data for water resource management, particularly for agricultural applications. Small UAVs can carry various sensors including embedded cameras, which are low-cost but have a high spatial resolution. UAV for remote sensing can improve real-time water management and irrigation control in agriculture. Similarly, satellite-based information can help identify trends in precipitation, evapotranspiration, soil moisture, snow and ice cover, melting, as well as runoff and storage, thus supporting and improving water management.

Finally, advances in robotics have brought about the prospect of water infrastructure in which robots are inserted or remain permanently, and are equipped with various sensors providing a continuous stream of data about their condition.

Future water management challenges, including progressing climate disruption, population growth and urbanisation, are increasingly complex and interdependent, which makes it near impossible to make informed decisions without using digital tools. However, using these tools in isolation, i.e. without taking advantage of various data streams will not make disruptive innovation breakthroughs in water management. Hydroinformatics, as a management philosophy, is the key enabler for integrating data across data silos and providing data analytics that improves knowledge and eventually leads to making informed decisions.

Human factor

The impact of digitalisation and automation in the water sector can mainly be felt by people involved in water management. The culture of fear that surrounds digitalisation and AI in particular, spans decades from fear of losing jobs to AI as an existential threat to humanity. However, this attitude is largely to do with media coverage of the topic. Therefore, future progress in digitalisation is not only about technology as equally, if not more importantly, about the human factor that can create more challenges than technology but is often neglected. We can learn from other sectors such as the automotive and aircraft industries, where huge investments in innovation and implementation of automation have happened, about the human factor and its role. For example, operating systems on airplanes or in cars require the highest possible level of safety and still rely on trained airline pilots and vehicle drivers (Savic, 2022). For the water sector this means that despite smart software, including AI and ML solutions, these automation systems will still require a highly-skilled workforce to ensure safe future operation of water systems. In other words, digitalisation and automation require more training for the personnel, not less.

Conclusions

Global water security risks associated with diminished water supply in quantity or quality, increased water demand, and extreme flood events, are only going to grow in future. It is clear that the digitalisation of the water sector (serving agricultural, domestic, industrial and commercial sectors) will help in mitigating those risks. However, digitalisation cannot be the goal by itself and it is not an option anymore, but a necessity. Digitalisation technologies and hydroinformatics solutions are largely available and the water sector is already benefiting from hydroinformatics advancements. However, it is essential not to focus on technologies alone and devote enough, if not more, efforts to cultural change and the human component of the digital transformation. Cultural transformation takes time and effort and should be part of the digital transformation from planning to implementation.

Dragan Savić
Dragan Savić is Chief Executive Officer at KWR Water Research Institute based in the Netherlands. He is also Professor of Hydroinformatics at the University of Exeter in the UK and Distinguished Professor at the National University of Malaysia.

Professor Savić is an international expert in smart water systems with over 35 years of experience working in engineering, academia and research consultancy. His work has resulted in patentable innovation and spinout companies. In addition to innovation and leadership skills, he is known for believing in bridging science to practice in the wider water sector and utilities in general.

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China's water security: Problems, pathways and practices

By Jianyun Zhang, Junliang Jin and T David Zhou

With a vast territory and almost one fifth of the world's population, China's water security is not only an important issue for the country, but also a topic worth discussing in the context of global water security. Under a monsoon climate, China receives ample vapour from both the Pacific Ocean to its east and the Indian Ocean to its southwest, which would subsequently turn into rainfall over the country. However, the vast amount of rainfall isn't taking place regularly over seasons year-round, nor is it evenly distributed over the territory because of various blockages out of huge variations in land elevation and topography, which marvelled the 18th century European travellers as much as they do to the Chinese themselves today. Moreover, China's booming economy and growing population are both making the country increasingly thirsty for water, while bringing about more pollution to the precious resource. Similar to many other places in the world, the country's plight of water security includes, as distilled by some researchers, too little water, too much water, and too dirty water. While water managers endeavour for water security of the country, many of the problems they have come across, pathways they are choosing, and practices they have taken are interesting to share and discuss.

Too little water: droughts and water scarcity

China is not well endowed with water in general. The per capita water availability of China is around 2000 m^3/year, which is less than one quarter of the world's average. Though its monsoon climate brings plenty of rainfall, the annual precipitation, if averaged over the whole country, is around 640mm, which is about 35% less than the global average according to the Global Precipitation Climatology Project (GPCP). Moreover, the majority of China s precipitation takes place during its rainy season between July and September (see Figure 1), which allows rapid rotations between droughts and floods. Apart from the temporal heterogeneity, much of the rain (~80%) falls on its southern part. While annual rainfall in the south could reach as high as 2,000 or even 3,000 mm, the vast northern China could only see 20 to 30 mm of precipitation. Rapid changes taking place in the country means more disturbance to its water system. While China's Meteorological Administration estimates that the country is very sensitive to global warming and expects significant impact from climate change, the country has become the world's biggest Greenhouse Gas emitter and its energy portfolio is still heavily reliant on fossil fuel. The warming climate brings noticeable changes to water. For instance, river flows have been dwindling in the last decades, and the decrease could be up to 70% at some gauge stations on the Haihe River[1]. Meanwhile, as China's urbanisation keeps ramping up, more people are dependent on centralised water supply. The Second National Water Resources Assessment Programme of China in 2012 estimated that China is in shortage of 50 billion m^3 of water even in a year of normal conditions. Of a total of 661 cities, around 400 are in shortage of water and 110 among them are in severe shortage.

Water stress leads to an array of problems related to it. A direct one is drought, the frequency and impact of which have been increasing since the 1990s[2]. Insufficient water means less water for the environment, which degrades ecological systems

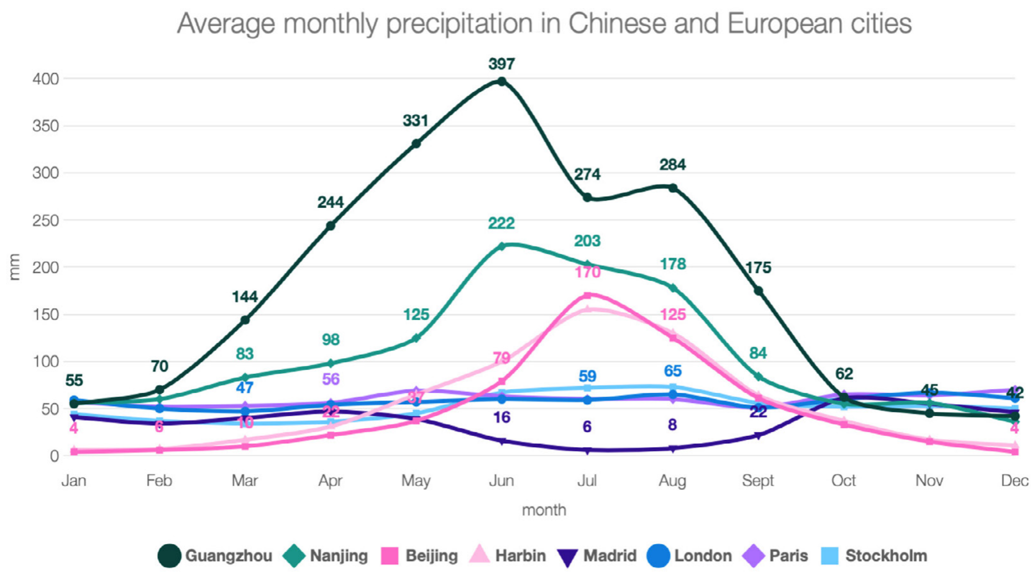

Figure 1 | Average monthly precipitation in Chinese and European Cities. Unlike European ones, cities in China receive the majority of their rain in the rainy season between July and September, and see much higher variation over the year. Data source: climate-data.org. Interactive figure available at: https://s.yicode.org.cn/kzuwxhy

and the invaluable services they provide. In the Haihe River basin where Beijing is located, it is estimated that about 18% of its annual runoff should be reserved for healthy ecosystems, but the region is consuming up to 108% of the basin's available water[3]. Meanwhile, limited water availability also becomes a constraint on socio-economic development. Northern China is home to 46% of its population and has 64% of its arable land, but has to support 45% of the country's GDP with 19% of its water.

The country's response to droughts and water scarcity has been on both the demand and the supply side. To bring water demand under control, in 2012, China s State Council put into force the Most Stringent Water Management policy, which is known as the "Three Red Lines". The policy package caps the quantity and efficiency of water consumption, and raises the bar for water quality. Tiered water pricing is another measure that aims at the demand side. To incentivise water saving, water is priced differently by purposes of consumption, and prices grow as the quantity of consumption grows. On the supply side, the massive inter-basin water transfer project, the South-to-North Water Diversion, now has two routes in operation. By January 2022, the two routes have delivered more than 50 billion m^3 of water to northern China[4]. Non-traditional sources of water, such as flood, recycled or desalinated water, are also being explored.

Too much water: flooding and sea level rise

Flooding is a prominent and recurring disaster in China. Despite the overall water stress, too much water is another problem for the country in some parts, some times. According to China's National Flood Defence Plans, about two thirds of the country is under significant risk of fluvial or flash flooding, and over two thirds of its cities face problems of urban pluvial flooding. Seasonality of precipitation in China makes the country prone to flooding in the rainy season. 2020 saw abundant precipitation and therefore extensive flooding along the Yangtze River, Huai River and in the Taihu Lake Basin. As urbanisation accelerates in China and climate change impacts kick in, cities are becoming more vulnerable to pluvial flooding, especially under extreme precipitation events such as the one in Zhengzhou in July 2021. Other factors that raise the risk of flooding in coastal areas are storm surge and sea level rise. Sea level close to China, although fluctuating, is on a rising trend with an annual average of 3.4 mm, which is higher than the global average[5].

The flood defence system of China consists of both engineering and non-engineering measures. The water engineering system in China consists of around 98,000 reservoirs, 340,000 kms of river dikes, 145,000 kms of sea walls, and 98 retention areas. The National Commanding System for Flood Control, on the non-engineering side, is a decision support system that combines data collection, communication, real-time forecasting, and coordinating emergency responses.

In addition, initiated in 2013, the Sponge City programme aims at streamlining the infiltration, retention, storage, purification, reuse and discharge of rainwater in cities, so as to better manage urban pluvial flooding. The programme prioritises local retention of rainwater, but also engineers artificial infrastructure, such as large-scale underground storage and treatment facilities, for managing excessive rainwater. However, these measures have to be informed by multi-dimensional monitoring, real-time simulation and forecasting, and risk assessment.

Year	Cities
2007	Jinan
2010	Guangzhou, Chongqing
2012	Beijing
2013	Ningbo, Yuyao, Shanghai
2015	Shanghai, Changzhou, Zhengjiang, Nanjing
2016	Wuhan, Nanjing, Zhengzhou
2017	Guangzhou, Changsha, Chongqing, Nanjing
2018	Beijing
2019	Guangzhou, Shenzhen
2020	Guangzhou
2021	Zhengzhou

Table 1 | Pluvial flooding events in Chinese cities according to various news sources.

Too dirty water: pollution

Water pollution is another challenge for China's water security. 2018 data shows that (see **Figure 2**), though the country has invested a lot in improving surface water quality, water quality in 5 of its 10 major river basins is still not desirable. Less than half of the water bodies in the Haihe (northern China) and Liaohe (northeastern China) rivers are suitable for direct human contact. Water quality in estuaries could be even worse. Around 80% of the water in the Yangtze (east China) and Pearl (south China) estuaries is not recommended for direct human contact. About half of the lakes in China are in eutrophic state, and almost half (46.9%) of its shallow groundwater reserves could not be used for water supply even after treatment.

To control water pollution, China's present strategy incorporates [1] controlling sources, which targets diffusive pollution by reducing the use of fertilisers & pesticides, and point sources by regulating industrial effluence; [2] improving wastewater treatment by centralising wastewater treatment, adopting higher standards and improving treatment efficiency; [3] improving river connectivity to replenish clean water and raise loading capacity; [4] adopting nature based solutions through the rehabilitation of wetlands and other ecosystem services; and [5] reforming institutions to put river/lake management under the explicit responsibility of local government heads (the 'River Chiefs').

Conclusion

China's water security is a challenging issue for the country because of its unique meteorological, geological, and hydrological features. Therefore, the country is highly susceptible to droughts,

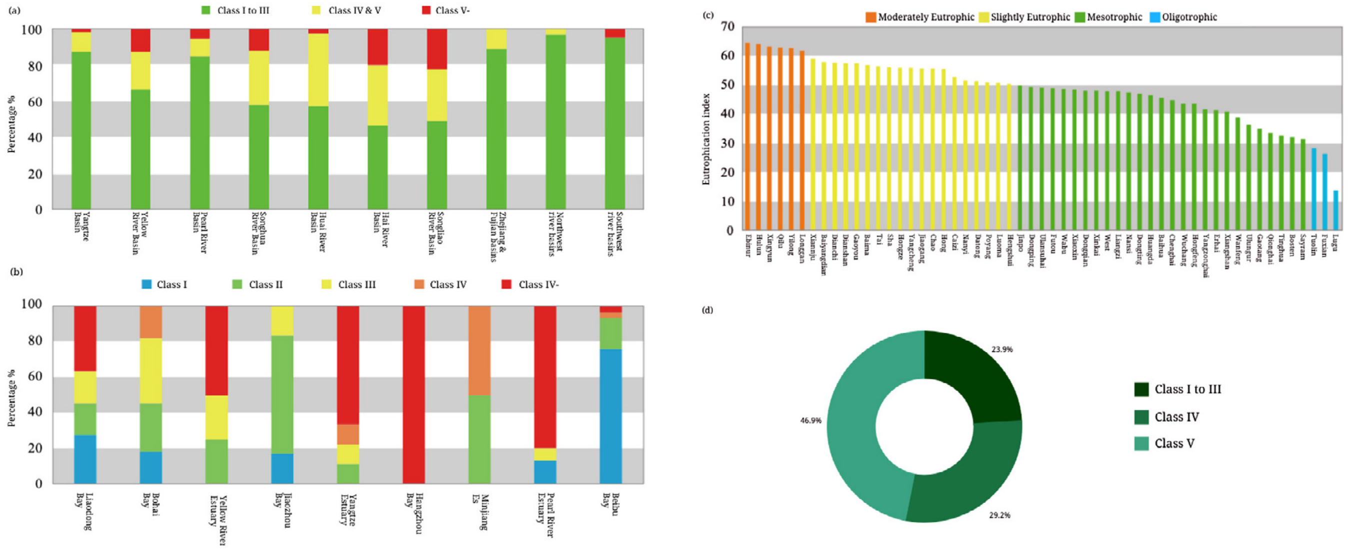

Figure 2 | 2018 water quality data of China, (a) water quality by basin, (b) water quality at major estuaries, (c) eutrophication of major lakes, and (d) shallow groundwater quality. China classes surface water quality into six classes (from good to poor, Class I, II, III, IV, V and V-). Water quality below Class III is not recommended for direct human contact. Groundwater quality below Class IV is not recommended for water supply even after treatment. Source: State of the Environment Bulletin of China 2018

flooding, water pollution and ecological degradation. The impact of climate change and rapid urbanisation further challenges the country by bringing higher risks and more uncertainties. To build a water-secure future, it is necessary to combine both engineering and non-engineering measures, the former of which enhances the robustness of the overall system of water management, and the latter develops its capacity for better resilience.

The ‘too much’, ‘too little’ and ‘too dirty’ water problems may not be unique to China only, and therefore China’s experience and practices could be valuable for other countries challenged by similar issues. However, this does not mean that China’s strategies are universally applicable, nor that they are flawless. First, the approach to water security taken by China relies heavily on massive engineering. Though nature-based solutions are gaining popularity and influence, there is still a need for more attention in the country on how to make best of them to build a **resilient infrastructure system** under growing uncertainties. Second, it is not difficult to see that China’s current strategies are mostly top-down and government-centric. For a **resilient institutional framework,** it would be better for the country to diversify the current framework by introducing more contributions from other institutions including the market and local communities. Third, as the most vulnerable communities are often hit the hardest by global warming and natural disasters, tipping the policy scale towards their water security would be a necessity for the country to mould a **resilient society** and realise, to quote its leadership, common prosperity.

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Facing the challenges of water security: the Spanish Water Governance System

By Teodoro Estrela and Tomás A. Sancho

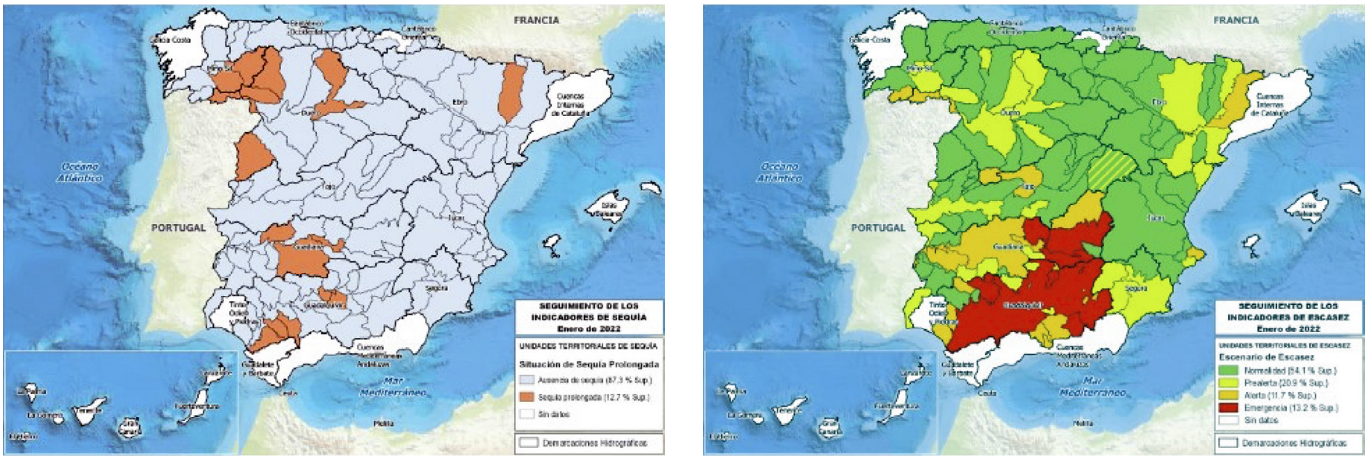
Due to the climatic and geographic peculiarities of Spain, with great spatial and temporal irregularity in the rainfall, and the severity of water scarcity and periodic droughts (**Figure 1**) the country a singularity in the European context- needed to develop a Spanish Water Governance System (SEGA) to achieve sustainable development, providing 35,000 hm^3 of both surface water and groundwater to the users (when in the natural regime, i.e. prior to the development of any water infrastructure, only 7,000 hm^3 of guaranteed resources would be available). SEGA is based on 7 pillars: [1] legal certainty; [2] basin river organizations; [3] water users associations; [4]; participatory water management; [5] hydrological planning; [6] technical and scientific knowledge; [7] investment in water infrastructure. However, everything is not solved, and now, when we must face climate change, SEGA's resilience is being analyzed to test if it is able to continue offering water security, in a compatible way with the preservation of the environment linked to water ecosystems. Considering three fundamental factors of water security, we can highlight the main actions and the tools used to study it (see table).

Regarding water security in terms of water supply to the population and to different productive uses, Hydrological River Basin Plans (incorporating coastal waters) have been developed and approved in order to ensure a proper balance between water supply and demand. Here water supply excludes ecological flows, necessary for the preservation of aquatic habitat and associated ecosystems, such as riparian forests. Ecological flows are defined based on technical criteria. Their scope ('always reaching good states for water bodies') is nowadays also taking into account socioeconomic effects through a process of concertation.

These Plans are based on rigorous technical studies and are prepared by a Water Council, in which all the agents involved participate. They contemplate the necessary measures, both to achieve a good status of the water bodies and those necessary to be able to supply water with adequate guarantee to users, including the construction of new hydraulic works to achieve the objectives set in quantity and quality goals. These plans are reviewed every 6 years and those that are currently in the

Goal	Actions	Tools
Supply and Demand Balances	• River basin management plans: Balance sheets and resource allocation. Programme of Measures • Participatory management in the Reservoir Commission and Exploitation Boards of the River Basin Organizations	• Simulation rainfall-runoff models • Model AQUATOOL[1] • Feasibility studies of hydraulic works • Non-conventional resources (desalination and reuse)
Drought management	• Special Drought Management Plans (for each River Basin Organization)[1]	• Drought indicators (for each Drought Technical Unit) • Scarcity indicators (for each Technical Exploitation Unit) • Management measures associated with indicator thresholds • Implementation of measures by river basin bodies and users
Flood management	• Plan de Gestión del Riesgo de Inundación (PGRI) Flood Risk Management Plans (for each River Basin Organization)[1] • National Cartographic System of Flood Zones	• Bidimensional flow models • Structural measures and Nature based Solutions (NbS) • Land use management in flood zones • Technical guidelines for Prevention, Adaptation and Self-Protection • SAIH - Automatic Hydrological Information Systems[4] • Standing Committee on Floods (controlled reservoir and flood management decisions) Coordination with Civil Protection Services

2022. Drought situation **2022. Scarcity situation**



Monitoring every month facilitates to apply adequate measures. So, we are now implementing measures in Spain in order to face drought and scarcity this summer in south and southeast areas, restricting irrigation demands and facilitating to supply water with non conventional resources (desalinitation) from now on.

Figure 1 | Assessment of drought and water scarcity conditions in Spain in 2022.

process of approval already include the effect of climate change, based on detailed and particularized studies developed by the Centro de Estudios Hidrográficos (CEH) – Center for Hydrographic Studies – of the Centro de Estudios y Experimentación de Obras Públicas (CEDEX), the technological center of reference in Spain for water issues – applying to our territory the scenarios contemplated by the Intergovernmental Panel on Climate Change (IPCC).

Once the Plans are approved, those responsible for their implementation program the necessary measures to achieve the agreed goals, and establish an allocation of water resources with a normative character. Their effective application, and the integrated management of water year after year, is carried out by the River Basin Organizations (Spain was a worldwide pioneer in the creation of such organizations in 1926) through their management bodies in a participatory regime, mostly integrated by the water users of each exploitation system, distributing the available water within the framework of what is approved in the Hydrological Plans. The AQUATOOL package has been used in both the planning and in the determination of the optimal exploitation curves of each resource source. Developed by the Polytechnic University of Valencia, this tool allows to simulate each exploitation system with its topology adapted to that of the real system and by introducing algorithms that allow to assess, at a monthly level, the optimal resources that guarantee meeting – in quantity and quality – the annual water demands.

A test of the resilience of each exploitation system, and a determination of the management measures that can be adopted gradually, are those that define the Special Drought Management Plans (PES), which have been demonstrating, since their implementation, a great effectiveness in reducing the socioeconomic and environmental effects of droughts. The selection of indicators and the definition of drought and scarcity thresholds in each part of the river basins allows, through their monthly monitoring, to detect droughts in time and anticipate the adoption of measures to mitigate their effects. The indicators include reservoir volume, water levels in aquifers, measured flows at selected points, rainfall collected, or snow stored.

Temporary exceptional measures are adopted that allow an increase in resources and the limitation and restriction of uses in an equitable and supportive manner among all those affected. The conditions of using the public hydraulic domain are temporarily modified including: reduction or suspension of endowments; modification of priority criteria for the allocation of resources; substitution of all or part of the concessional flows by others of different origin; the use of drought well batteries; modification of the established conditions in the discharge authorizations; adaptation of the exploitation regime of the hydroelectric plants to the needs and the ex officio constitution of the Central Boards of Users that are necessary.

On the other hand, and to manage flood risks and protect goods and people from them, the PGRI studies all the river sections with flood risk and analyse all the properties and other assets in danger of being affected, based on two-dimensional flow models, and determine the structural actions and the most appropriate NbS. A National Cartographic System of Flood Zones has been developed and it is publicly available. And when the floods really occur, the SAIHs have proven to be a very profitable investment, due to the real time information they provide (rainfall, flow measures and situation of reservoirs in strategic points of each river basin), which combined with the experience of the managers of the Standing Committee on Floods of the River Basin Organizations allow to decisively alleviate the damage that would occur in the absence of the adopted measures.

Research centres, private companies and public administration continue making progress and adopting innovations aimed at improving the Decision Support Systems currently available, integrating climate predictions and probabilistic rainfall and hydraulic models.

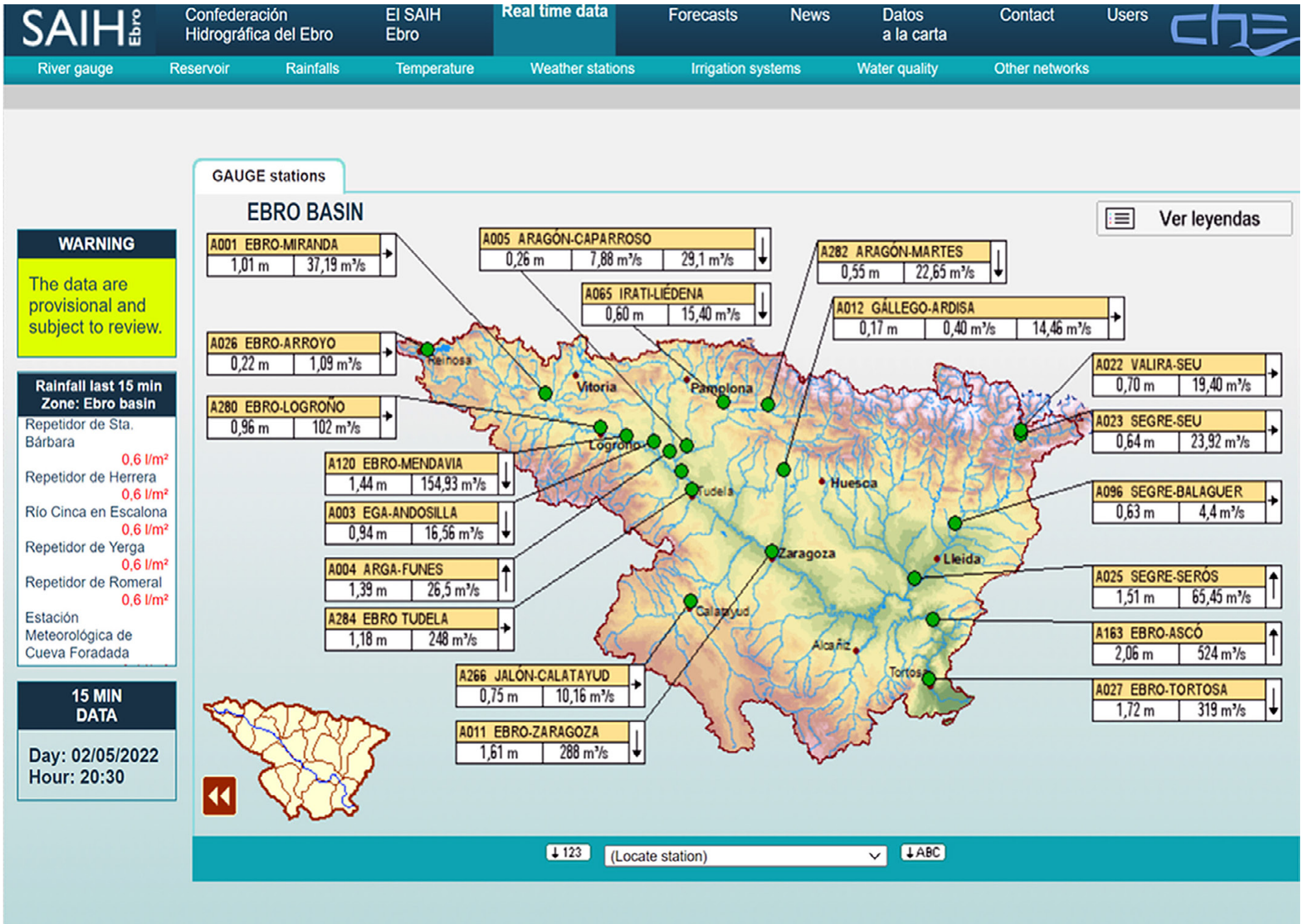


Figure 2 | SAIH web page – for the Ebro River Basin Organization (CHE- Confederación Hidrográfica del Ebro) http://www.saihebro.com/saihebro/index.php

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Data assimilation and deep learning in lake algal bloom forecasting

By Cheng Chen, Yuqing Lin, Tao Feng and Qiuwen Chen

Due to the combined impact of human activity and the effects of climate change, harmful algal blooms (HABs) have become a serious socio-ecological problem for sustaining water and food security in many parts of the world. Oxygen depletion from the decay of biomass and higher organisms are aggravating global water shortages and can cause serious ecological disasters, that are often detrimental to food security. The outbreak of HABs in Lake Taihu, about 80 km west of Shanghai, in 2007 caused a drinking water crisis and impacted on the health of millions of people in the nearby Wuxi city. Although eutrophication control strategies have already been in place for decades, the challenge of avoiding HABs remains largely unresolved. Forecasting and early warning of potential HABs have therefore become essential for risk management in eutrophic lakes, aimed at providing adequate water security. This article shares some of the techniques that have been developed for this purpose.

A variety of data-driven and process-driven models is available to forecast the occurrence of HABs in lakes[1]. The performance of these models highly depends on the spatial-temporal resolution of available measured data. The process-based models have the potential to track the entire development of a bloom event, allowing early warning of timing, position, magnitude, and duration[1]. However, the intensive computation time and complex configuration as well as adequate calibration, limit their applicability.

Data acquisition technologies, online monitoring and remote sensing are nowadays being widely used for HAB management, although it may be difficult to obtain high-resolution and high frequency measurements. Since both model predictions and multi-source observations have their advantages and shortcomings, it remains a hot topic and challenging task to effectively synergize different technologies to improve the capability of forecasting HABs, thereby securing water and food supply in the region.

The ecohydraulics research group at the Nanjing Hydraulic Research Institute (NHRI) has recently developed a robust system for HABs prediction, by fusing data-driven and process-based models as well as assimilating multi-sourced data (**Figure 1**).

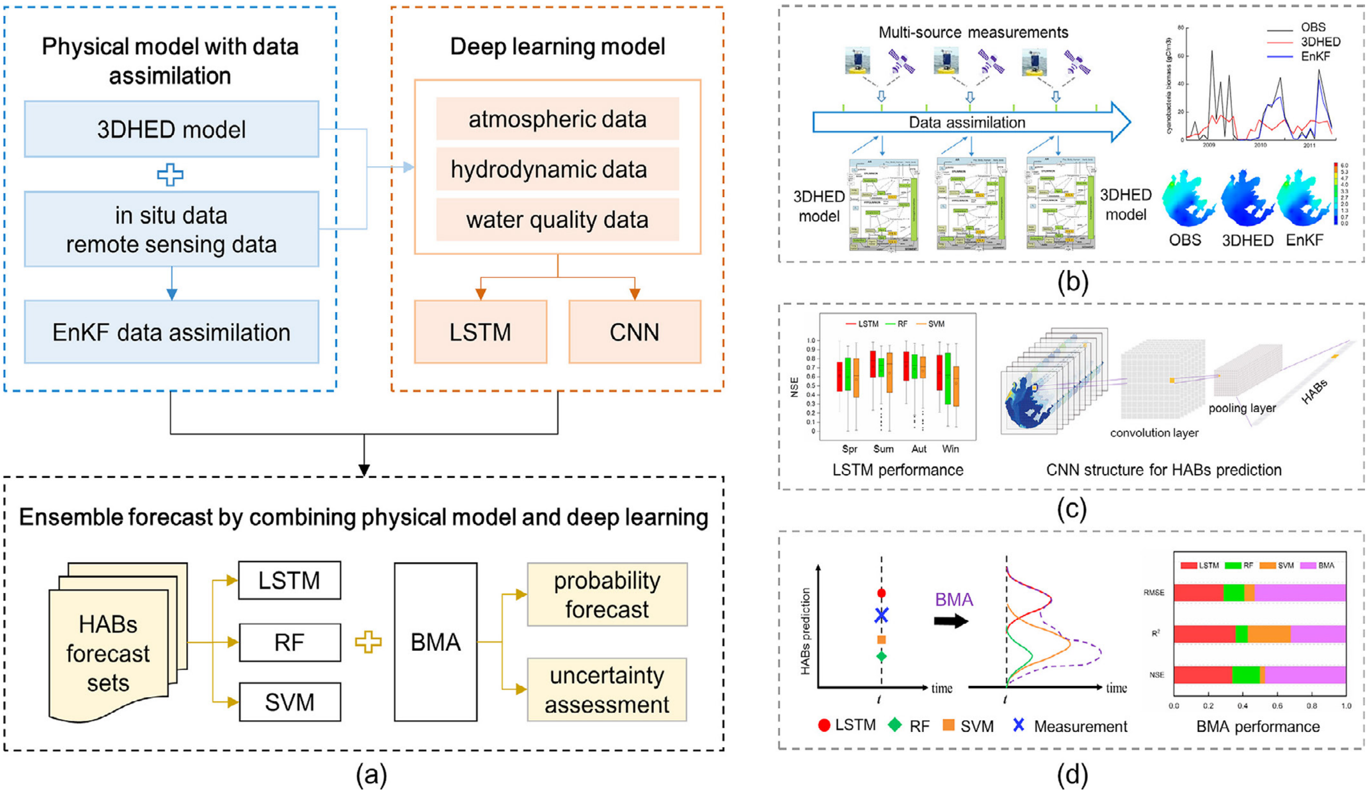

Figure 1 | (a) flowchart of data assimilation and deep learning in lake algal bloom forecasting; (b) schematic diagrams and results of physical modelling with data assimilation; (c) deep learning model; (d) ensemble forecast by combining physical models and deep learning.

Physical-based modelling with data assimilation

A physical-based three-dimensional hydro-ecological model (3DHED) was developed to predict cyanobacteria biomass by coupling the models SALMO (Simulation by means of an Analytical Lake Model) and SELFE (Semi-implicit Eulerian-Lagrangian Finite Element model). Such a combination avoids solving the complex 3D partial differential equations for both mass and momentum conservation and thereby improves computational efficiency. Moreover, the 3DHED model can distinguish different functional groups of algae. Based on careful calibration and validation, the 3DHED model is able to adequately simulate the spatial-temporal dynamics of DO, PO_4-P, NO_3-N and green algae concentrations. However, the cyanobacteria biomass, especially the peak values, were not well captured in the initial application of the model.

Data assimilation is one of the best ways to improve the simulation accuracy of physical modelling by merging measured data into model predictions. Multi-source data (i.e., in situ observations and remote sensing data) are assimilated into 3DHED to update the simulated cyanobacterial biomass (**Figure 1b**). Assimilating *in situ* measurements not only better simulates the dynamics of cyanobacterial biomass, but also better captures the peak values. Using multi-source data assimilation further improves the simulation accuracy of the model with respect to the spatial-temporal distribution of cyanobacteria. However, continuously updating parameters from different data sources could trigger oscillations in the model predictions, leading to occasionally unexpected model performance. These problems can be remedied by filtering and fusing data to obtain high-quality data sources[2, 3].

Deep learning model

LSTM (long short-term memory) is an Artificial RNN (regression neural network) architecture frequently used in the field of deep learning. Compared with ordinary machine learning models, LSTM can take into account the influence of historical information on current state variables. Chlorophyll-a concentrations are usually selected as the indicator for predicting HABs due to their close relationship to the abundance and biomass of aquatic phytoplankton[2]. The data dislocation processing method is used to establish the relationship between chlorophyll-a before and after the moment, and the known monitoring data at the current time is substituted into the established relationship to obtain short-term forecast predictions in the future. LSTM usually has a better performance when compared to the Random Forest (RF) and Support Vector Machine (SVM) learning models (**Figure 1c**).

CNN (convolution neural network) models mainly include a convolution layer and a pooling layer (**Figure 1c**). The convolution layers induce the input's internal features by performing dot-product multiplication of the input vector and the learnable weights and biases. The pooling layers, usually located between two convolution layers, are then used to extract distinctive spatial dimension to reduce the number of parameters and the amount of computation in the network. CNN models utilize the kernel matrices of convolutional layers to capture the rich features of the input data, leading to the substantial consideration of both the spatial and spectral information of the multi-dimensional image. The physical-based model can provide input maps of atmospheric, hydrodynamic, and water quality variables. The in situ observations or remote sensing data can then be used as the output true value[4]. A point-centred approach is used for CNN regression, in which a small image window patch scans the in situ observations or whole remote sensing image pixel by pixel to generate the training datasets.

Ensemble forecast by combining physical model and deep learning

The physically-based model could provide long-term and relatively high frequency chlorophyll-a data. NHRI have developed three machine learning-based short-term forecast sets of HABs by using the results from the physically-based model. In addition, considering the uncertainty of single model forecast results, a multi-model ensemble forecast method for HABs was established based on Bayesian Model Averaging (BMA). The overall performances of the four models are in the order BMA > LSTM > RF > SVM (**Figure 1d**). In general, a BMA multi-model ensemble forecast can effectively integrate the forecast results for a single model. Meanwhile, the uncertainty of forecast results can also be quantified.

Practical implications

A modelling approach can well simulate the hydrodynamics, water quality and algae dynamics of Taihu Lake, but the predicted results of peak values of cyanobacterial biomass are not satisfactory. By assimilating multi-source data, the accuracy of spatial-temporal patterns and peak values of cyanobacterial biomass were eminently improved. The LSTM deep learning approach takes into account the influence of historical information on defining current state variables, outperforming other conventional techniques like SVM and RF for time-series HABs prediction. A short-term Bayesian ensemble forecast method combing physical-based model results and deep learning techniques can be used to further improve model performance, providing better ways to issue advanced warnings for possible disasters, thus helping to secure adequate water and food security.

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New challenges of water security: China's actions on emerging contaminants

By Nan Xu and Weiling Sun

As China's water pollution control strategies have achieved preliminary progress and traditional water pollutants have been effectively controlled, emerging contaminants in the aquatic environment become a key concern of water security. Here, we address the latest practices in the control and treatment of emerging contaminants in China, including monitoring, risk assessment, and control strategies. The prospects for future studies were suggested from a multidisciplinary perspective including environmental science, hydrology, ecotoxicology and engineering.

Background

With rapid economic development and urbanization, various kinds of pollutants have been discharged into the water environment in the last few decades, many threatening human health. Therefore, to strengthen the control of water pollution and ensure national water security, the Chinese government formulated and issued the Action Plan for Water Pollution Prevention and Control (also known as "Water Ten") in April 2015, the Guidelines for the Remediation of Urban Black and Odorous Water Bodies in August 2015, and the Opinion on Comprehensively Implementing the River Chief System in December 2016. Ever since then, China has intensified efforts in the treatment of water bodies. The goal of the first stage has been basically achieved, i.e. black and odorous water bodies in built-up areas of cities at prefecture-level and above were reduced by the end of 2020 to less than 10% of what they were in 2015. The next phase calls for the overall elimination of black and odorous water bodies in urbanized areas by 2030.

In this context, traditional water pollution has been effectively controlled, and common water quality indicators (such as: chemical oxygen demand, NH_4-N, etc.) have reached the Chinese national environmental quality standards for surface water, while another problem, the pollution of emerging contaminants (ECs) or contaminants of emerging concern, has become a major threat to water security. The concept of ECs can be traced back to the early 21st century[1], although some of these contaminants have already been listed as priority pollutants by the State Environmental Protection Administration of China, the US Environmental Protection Agency (EPA), the Stockholm Convention, etc. Therefore more recently ECs have become the focus of environmental science studies aiming at supporting good water security. Generally, ECs can be defined as any synthetic or naturally occurring chemicals that are not commonly monitored in the environment (and largely unregulated) but are known or suspected to pose ecological and/or human health risks[2]. Although they are present as trace levels in the environment, they can still be detrimental to ecosystems and humans due to their bioaccumulation, persistence and toxicity, therefore posing a major challenge to water security. Different countries and organizations, e.g. the US EPA, EU, and UNESCO, have listed the various types of ECs that are of particular concern to them. Currently, the ECs that are recognized globally include persistent organic pollutants (POPs), endocrine disrupting chemicals (EDCs), pharmaceuticals and personal care products (PPCPs), nanomaterials (NMs), microplastics (MPs), and antibiotic resistance genes (ARGs).

Occurrence of typical ECs

Among various ECs, antibiotics and per- and polyfluoroalkyl substances (PFASs) are typical contaminants which have attracted considerable attention in academia and government in China. Antibiotics are extensively consumed by humans and animals and frequently detected in the aquatic environment worldwide. Vast surveillance data on antibiotics are available in China's surface water (**Figure 1**). Their median concentrations were generally below 35.5 ng/L in river waters, but a small fraction of the samples have shown different levels of potential ecological risk to aquatic organisms[3]. Residual levels of antibiotics (e.g. cipro-floxacin 9.1 ng/g and sulfamethoxazole 1.6 ng/g wet weight, median concentration) were also reported in fish and shellfish from aquaculture[4]. Based on maximum residue limits and acceptable daily intake, the health risks presented to humans via seafood consumption were found to be negligible. However, the increase in antimicrobial resistance associated with antibiotic usage may be of great environmental concern.

PFASs are representative of emerging persistent organic pollutants. Due to their superior physicochemical properties, PFASs are widely used in various industrial and commercial products. Therefore, they have been widely detected in different environmental matrices, including surface water, groundwater, sediments, soils, and atmospheric particulate matter[5]. As a result of the recent strict regulation on legacy PFASs, the dominant PFASs detected in the Chinese aquatic environment are currently changing from long-chain perfluoroalkyl acids (PFAAs) to short-chain PFAAs and polyfluoroalkyl substances (e.g. F-53B

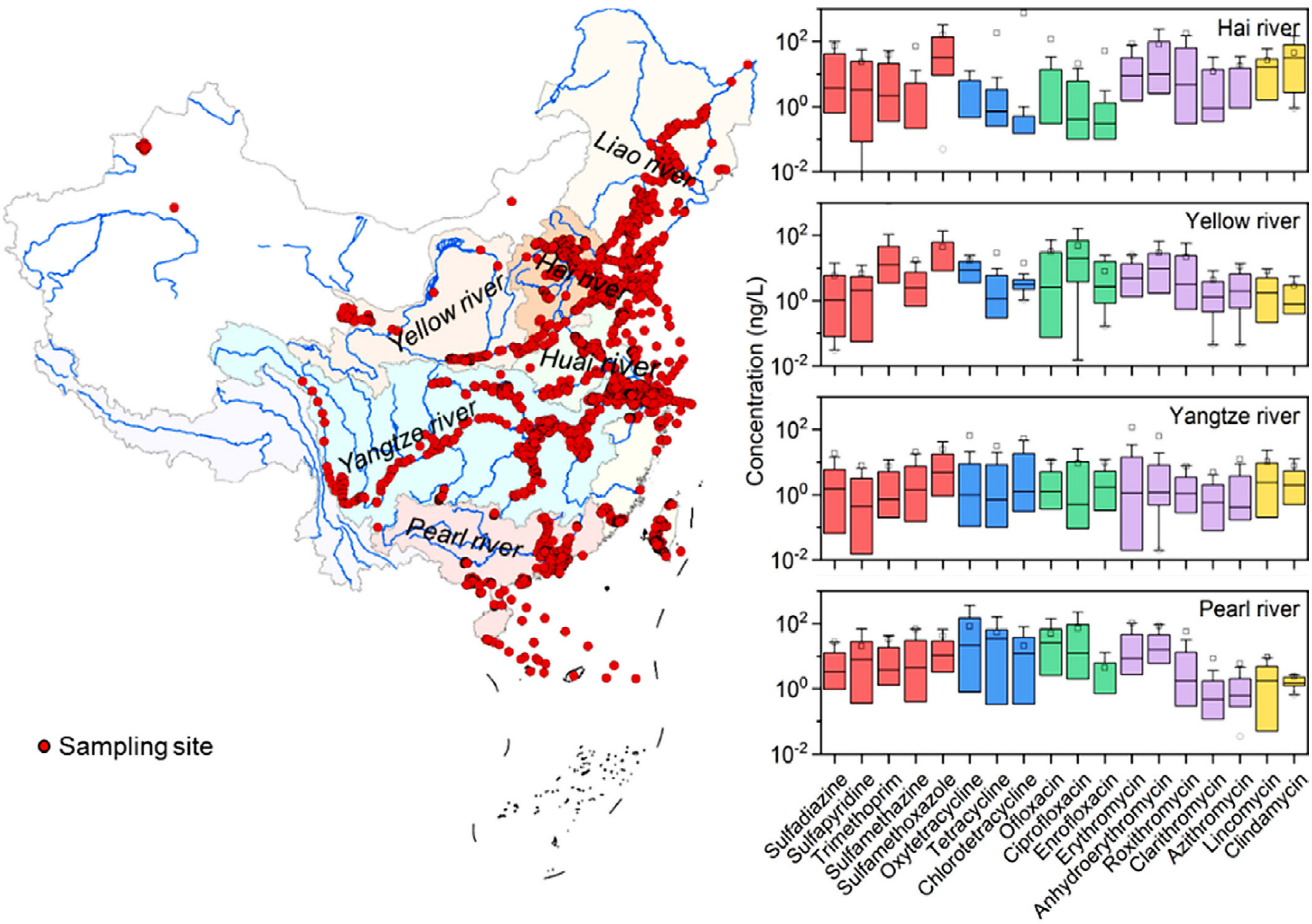

Figure 1 | Regional distribution of sampling sites and concentrations of representative antibiotics in China's major rivers.

(primarily 6:2 Cl-substituted perfluoroalkyl ether sulfonic acid) and 6:2 fluorotelomer sulfonic acid). However, as diverse substitution strategies are being applied to deal with the phase-out of legacy PFASs in the fluorine chemical industry, more than several thousand substances have been registered in the PFAS category. However, there are still a large number of PFASs with unknown structures present in the water environment. Thus, exploration of the screening, occurrence, and potential risk of these unknown PFASs has become a new challenge.

National actions on ECs

In view of the pollution status of ECs in the water environment, the Chinese government has paid unprecedented attention to these contaminants, and the treatment of ECs has become one of the foci of ecological and environmental protection in the 14th Five-Year Plan. The general guidelines for emerging contaminant control can be summarized as "screening, evaluation, control" and "banning, reduction, treatment". That is, conducting systematic surveys and risk assessments to identify priority ECs, dynamically issuing the list of key ECs under regulation, implementing life cycle management, including banning, restricting production and use at source, reducing emissions during the process and strengthening end-of-pipe treatment, and increasing the R&D investment in ECs.

with relevant sectors, has made efforts on environmental risk management of toxic and harmful chemicals, i.e., establishing a system of legislation and standards, strengthening point source regulation, promoting environmental risk control of toxic and harmful chemicals, and actively participating in the global chemical compliance action. On this basis, the Ministry of Ecology and Environment is taking the lead in establishing an action plan for the treatment of ECs. In the draft (for comments) of the Action Plan, 28 chemicals or groups of chemicals have been listed as the Key ECs under Regulation (2021 edition), including antibiotics and perfluoroalkyl substances. For listed pollutants, specific regulations are stipulated, including the fields with specific exemption, discharge standards and management measures of in-use stocks.

The development of advanced technologies for screening and control of ECs is also one of the priority fields funded by the Ministry of Science and Technology (MST) and the National Natural Science Foundation of China. For example, the National Key Research and Development Program of the MST has supported a large number of projects on integrated governance of the water environment, involving efficient pollution control and risk management of ECs in major river basins such as the Yangtze and Yellow Rivers.

Perspectives

In response to the new challenges of water security, considerable emphasis and effort has been devoted to the monitoring, risk assessment and control of ECs in China. The control of ECs is a systematic and long-term project, which requires close multisectoral and regional collaborations. There are still some scientific issues that need to be addressed, which require the joint effort of scientists from multidisciplinary fields, including environmental science, hydrology, ecotoxicology, and engineering. Although the compositions and concentrations of ECs have been frequently reported in various river basins, data on the fluxes of these pollutants into the sea are still lacking, particularly the fluxes transported by water and sediment in large rivers. Systematic studies are still lacking on how the suspended solids and sediments affect the distribution, transport, transformation and risk assessment of ECs in the aquatic environment. In addition to intensive monitoring of target contaminants, non-target screening of ECs remains a challenge. Regarding the pollution control of ECs, there is an urgent need to develop cost-effective technologies and evaluate their performance, especially the upgrading of existing treatment processes in wastewater treatment plants, and assess the persistence of ECs in water basin systems.

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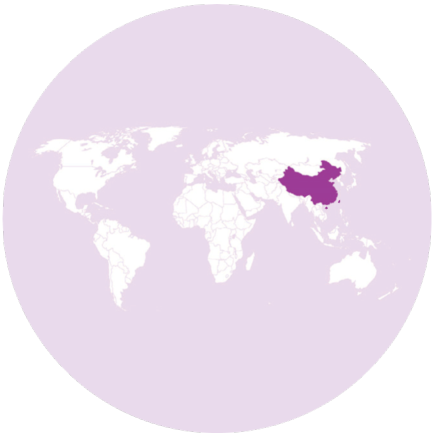
FAMOUS WOMEN IN HYDRAULICS

The IAHR task force on Strengthening Gender Equity intends to raise the profile and visibility of women who made major contributions to hydraulics.



Li Guifen
1931–2020, China

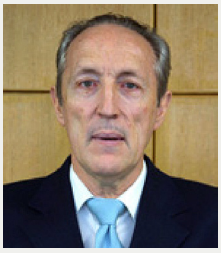
Graduated from Shandong University, China, in 1952, Li Guifen started her career working for the Chinese Ministry of Water Resources. After a visiting scholarship in the Department of Hydraulics of VNIIG, Leningrad, U.S.S.R., she joined the Institute of Water Conservancy and Hydropower Research (IWHR, now the China Institute of Water Resources and Hydropower Research) where she was the Director of the Department of Hydraulics and Director of the Division of International Cooperation.

Professor and Senior Engineer, Li Guifen's research covered a wide range of topics that include hydraulic structures, high speed flow, flood discharge and dam safety, energy dissipators, wind-induced waves in reservoirs, river ice, effects of plant-barriers on debris flow, and prototype measurements.

She also acted as a consultant for many water engineering projects in terms of planning, assessment, laboratory design and construction, and capacity building. Due to her excellent work and achievements, she received many awards at national and ministerial levels. Over the first two decades of the 21th century, she had been very active as a member of various Chinese scientific associations, as well as a prominent member of IAHR, until she passed away in 2020 at the age of 89.

Damien Violeau
EDF, IAHR member

IN-MEMORIAM



Cristóbal Mateos Iguacel
1938–2022

On May 14, 2022, our friend and colleague Cristóbal Mateos Iguacel passed away after a long illness. The IAHR would like to convey to his family our deepest condolences for their loss.

Cristóbal, beyond his extraordinary academic and professional career, was an endearing and down-to-earth person, who was always accessible and who amassed encyclopedic knowledge, not only in engineering but also in the sciences in general and the humanities. His solutions were always pragmatic and convincing and he never sought to impose them on others. Working with Cristóbal or being under his supervision was always a privilege and an honor and what he transmitted has left an unforgettable mark, both humanly and professionally.

Cristóbal was Doctor of Civil Engineering (1965) from the Polytechnic University of Madrid (UPM) and Graduate in Mathematical Sciences (1963) and in Statistics (1964) from the Complutense University of Madrid (UCM). He was Professor of Mathematics Applied to Civil Engineering from 1970 to 2009 at the Higher Technical School of Engineers of Roads, Channels, and Ports of the UPM, becoming Professor Emeritus of said center in 2010, after his retirement. He was also a professor at the Colegio Libre de Eméritos of Spain (a private non-profit cultural association).

Over the course of his career at the Center for Hydrographic Studies (CEH) of the Center for Studies and Experimentation of Public Works (CEDEX), where he began working in 1961, he took on multiple responsibilities, reaching the prestigious position of Director of the CEH Hydraulics Laboratory, where under his direction hundreds of physical model tests of hydraulic structures were carried out, as well as numerous numerical studies.

He was involved in the design and/or construction of some 300 projects in Spain and abroad, mainly in relation to dams, canals, river works, and other hydraulic infrastructures, as well as nuclear and thermal power plants, cooperating with research centers worldwide to produce patents.

Cristóbal was interested in high-speed flows, shock waves, air-water mixtures, stratified flows, energy dissipation, hydraulic dam structures, river works, sedimentation in reservoirs, natural disasters caused by floods and the safety of hydraulic infrastructures. He published nearly a hundred articles, presenting numerous papers at congresses and symposiums, both nationally and internationally (IAHR, ASCE, ICOLD, CEDEX, JIA,...) and is the author of several books, written individually or in collaboration with others, including: *Linear Algebra, Hydraulics, Structural Mathematics Problems and Hydraulic Works in Illustration.*

He also received numerous national and international prizes and awards, including the following: the "Gómez Navarro" from the Juan March Foundation and the Ministry of Education, the research award from the Japanese Ministry of Construction, the Medal of Professional Merit from the College of Civil Engineers, Canals and Ports of Spain, the Commendation of the Order of Isabel La Católica, and was appointed Honorary Member of the International Association for Hydro-Environment Engineering and Research (IAHR).

He was an active member of the IAHR for many years, participating in many of its congresses and symposiums. When the IAHR moved its World Secretariat to CEDEX in Madrid (Spain) from Delft Hydraulics in Delft (Holland) in 2001 and until 2005 he was its Secretary General, a position from which he adeptly facilitated the smooth and seamless transition between the two headquarters.

Likewise, he was the founding member of the Spanish Chapter of the IAHR in 2009 and its first President until 2015; he was later named Honorary President.

We cannot underscore enough Cristóbal's wonderful charisma and exceptional career. All those of us who had the good fortune to know and work with him consider ourselves profoundly grateful and we deeply regret such a tremendous loss.

Ramón Gutiérrez Serret, José Dolz, Luis Balairón, Jose María Grassa and Christopher George

Prince Sultan Bin Abdulaziz International Prize for Water

Recognizing Innovation

Winners for the 10th Award (2022)

Creativity Prize

1) The team led by Thalappil Pradeep (Indian Institute of Technology, Madras, India)
for the creation and successful deployment of environmentally friendly "water positive" nanoscale materials for the affordable, sustainable and rapid removal of arsenic from drinking water. Team members include Avula Anil Kumar, Chennu Sudhakar, Sritama Mukherjee, Anshup, and Mohan Udhaya Sankar.

Dr. Thalappil Pradeep

2) The team led by Dionysios D. Dionysiou (University of Cincinnati, USA)
for the development of innovative advanced oxidation technologies and nanotechnologies for environmental applications, particularly in the removal and monitoring of emerging contaminants. Team members include Wael H.M. Abdelraheem, Abdulaziz Al-Anazi, Jiong Gao, Ying Huang, and Vasileia Vogiazi.

Dr. Dionysios D. Dionysiou

Surface Water Prize

Dennis D. Baldocchi (University of California Berkeley, USA)
for the development and implementation of effective models to understand, evaluate and predict evapotranspiration and water-use efficiency in various environments under climate change conditions.

Dr. Dennis D. Baldocchi

Groundwater Prize

Linda M. Abriola (Brown University, USA)
for pioneering research on toxic Dense Non-Aqueous Phase Liquids (DNAPLs) in groundwater, ranging from the simulation of their fate to effective methods for cleaning contaminated sites.

Dr. Linda M. Abriola

Alternative Water Resources Prize

The team of Menachem Elimelech (Yale University, USA) and Chinedum Osuji (University of Pennsylvania, USA)
for wide-ranging advances in nanostructured materials for next-generation water purification, focusing on implementation issues like manufacturing, sustainability, self-assembly, and biofouling.

Dr. Menachem Elimelech

Dr. Chinedum Osuji

Water Management and Protection Prize

The team led by Matthew McCabe (KAUST, Thuwal, Saudi Arabia)
for employing CubeSat constellations in the sustainable management and security of linked water-food systems, along with estimates of agricultural water use at unprecedented spatial and temporal resolutions and with global coverage. Team members include Bruno Aragon (KAUST) and Rasmus Houborg (Planet Labs, USA).

Dr. Matthew McCabe

Invitation for Nominations

11th Award (2024)

Nominations open online until 31 December 2023

www.psipw.org e-mail: info@psipw.org