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Engineering for Sustainable Development

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Engineering for Sustainable Development

Delivering on the Sustainable Development Goals

SHORT SUMMARY

Engineering the SDGs

The report highlights the crucial role of engineering in achieving each of the 17 SDGs. It shows how equal opportunities for all is key to ensuring an inclusive and gender balanced profession that can better respond to the shortage of engineers for implementing the SDGs. It provides a snapshot of the engineering innovations that are shaping our world, especially emerging technologies such as big data and AI, which are crucial for addressing the pressing challenges facing humankind and the planet. It analyses the transformation of engineering education and capacity-building at the dawn of the Fourth Industrial Revolution that will enable engineers to tackle the challenges ahead. It highlights the global effort needed to address the specific regional disparities, while summarizing the trends of engineering across the different regions of the world.

By presenting case studies and approaches, as well as possible solutions, the report reveals why engineering is crucial for sustainable development and why the role of engineers is vital in addressing basic human needs such as alleviating poverty, supplying clean water and energy, responding to natural disasters, constructing resilient infrastructure, and bridging the development divide, among many other actions, leaving no one behind.

It is hoped that the report will serve as a reference for governments, engineering organizations, academia and educational institutions, and industry to forge global partnerships and catalyse collaboration in engineering so as to deliver on the SDGs.

It is essential that more young people, especially girls, consider engineering as a career

UNESCO

'Since wars begin in the minds of men and women it is in the minds of men and women that the defences of peace must be constructed'

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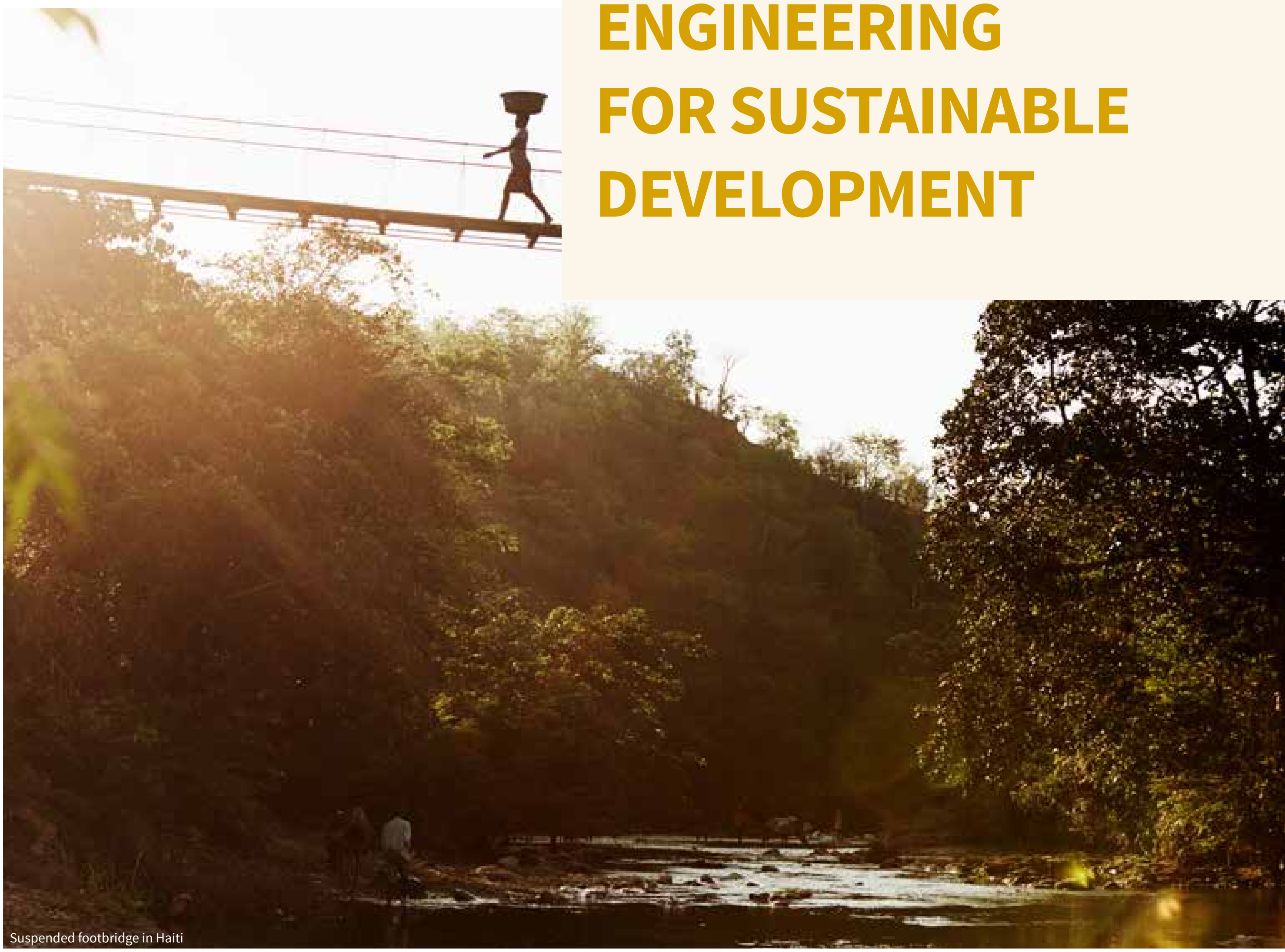
José Vieira[8]

3.2 WATER ENGINEERING FOR SUSTAINABLE DEVELOPMENT



© Bridges to Prosperity

Suspended footbridge in Haiti

8 President-elect, World Federation of Engineering Organizations.

The United Nations Sustainable Development Goals (SDGs) are supported by scientific and technological advances in the implementation of policies and actions for peace and prosperity, for people, and for the survival of all forms of life on Earth.

Water, as a prerequisite for life, assumes a special focus in terms of sustainable development. Global water problems, including droughts and floods, pollution caused by natural and anthropogenic-driven events such as extreme rains, rising sea and river levels, bushfires and untreated domestic and industrial effluents, are key challenges globally which require adequate and efficient water management in order to meet the growing demand for clean water.

The hydrological changes induced by climate change will present challenges to the sustainable management of water resources, which are already under severe pressure in many regions of the world, aggravating the situation of regions that are already experiencing water stress, while at the same time generating water stress in regions where water resources are still abundant today.

SDG 6 on clean water and sanitation includes the 'water goal', which aims to provide universal access to clean water and sanitation by 2030. According to United Nations statistics from 2017, and despite the progress made, an estimated 2.2 billion and 4.2 billion people still lack safely managed drinking water and decent sanitation, respectively. In recent years, a new approach – known by the acronym WASH (water, sanitation and hygiene) – includes handwashing as a main element of good hygiene practices, which has shown to be an effective method to prevent the spread of COVID-19. However, an estimated 3 billion people still lack basic handwashing facilities at home, which may have negative consequences for the prevention of COVID-19.

Universal access to WASH will not be achieved for a long time in a great number of developing countries at current rates of progress. These countries also experience rapid and often unplanned urbanization which has put a strain on clean water supply and sanitation services. As access to clean safe water and decent sanitation is recognized as a basic human right by the United Nations, there is pressure on local and national authorities to meet their political and social commitments in this regard. Engineering can help explore innovative solutions for physical infrastructure to deliver water supply and sanitation, combining traditional approaches of large centralized systems with decentralized non-sewered solutions, ranging from more effective design of septic tanks through to waterless toilets.

Water engineering is multidisciplinary and benefits from progress in technological innovation in areas such as microelectronics, nanotechnology, fine chemicals, biotechnology, data acquisition, satellite-based earth observation, hydro-environmental modelling and remote sensing.

This chapter presents examples of engineering contributions that address these global challenges and seek to achieve the SDGs, in particular SDG 6, which emphasizes the mutually integrated advances made in hydrology concerning clean water and human health.

3.2.1. Clean water and human health

José Vieira[9] and Tomás Sancho[10]

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Abstract. The close relationship between human health and the well-being of communities with access to clean water is a determining factor for economic and societal development. Despite the human right to safe, clean drinking water and sanitation, as recognized by the United Nations in 2010[11], there are still major challenges to implementation, particularly in less developed countries. Currently, clean water has garnered unprecedented focus in public policy in efforts to contain the spread of COVID-19. Historically, civil and environmental engineers have played a prominent role in the design and construction of large infrastructure projects to provide clean water and adequate sanitation systems. Significant progress in water and environmental engineering in recent decades has led to the development of new and more efficient water technologies, such as advanced oxidation, adsorption, reverse osmosis, and nano- and ultra-membrane filtration, which are used in the removal of priority substances in advanced water treatment. In addition, innovations in engineering disciplines, such as aerospace, satellite technology, hydro-environmental modelling, electronic and computer engineering as well as remote sensing technologies, all contribute to identifying trends in the water cycle, which is of paramount importance for comprehensive assessment of quantitative and qualitative water-related climate change impacts.

Introduction

It is relatively safe to say that throughout human history serious public health problems have frequently been due to the transmission of infectious diseases through pathogenic microorganisms (bacteria, viruses, protozoa and helminths), related to an absence of safe water. In fact, through various routes of infection, either by ingesting food or water, by inhalation or aspiration of aerosols, as well as by exposure to contaminated water and carried by arthropods or molluscs, these waterborne diseases have been responsible for serious widespread public health crises (Vieira, 2018).

From the middle of the nineteenth century, following the devastating epidemics of cholera and other gastrointestinal diseases in Europe, there was a gradual and definitive change in thinking and attitude towards the economic, social, environmental and health aspects of daily life with regard to public policies. The creation of the Poor Law Commission in Great Britain in 1834, and the studies developed within the scope of its activity (Chadwick, 1842), were decisive for medicine and public health engineering. This act from an intervention perspective aimed to help find technical solutions for the supply of cleaner water supply and sanitation in the urban environment with the aim of preventing and controlling disease. It was thus believed that disease would be combated more effectively if technical solutions that were preventative in nature were implemented, rather than relying on interventions by the individual for the promotion of health. In this context, steam – the new energy source – enabled the development of revolutionary drinking water networks and sanitary sewer systems in buildings, introducing new technological advances in the fields of wastewater collection and treatment, and assuming a strategic role in promoting health in the urban setting.

Progress in medicine and microbiological sciences was first needed to identify and isolate the pathogens before 'safer' water could be envisaged by advances in engineering. The disinfection of drinking water, introduced at the end

9 President-elect, World Federation of Engineering Organizations.
10 Chair of Working Group on Water, World Federation of Engineering Organizations.
11 In its Resolution 64/292, on 28 July 2010 the United Nations General Assembly recognized water and sanitation as a human right, and acknowledged that clean drinking water and sanitation are essential to the realization of all human rights.

of nineteenth century, considerably reduced the spread of cholera and typhoid fever (Rose and Masago, 2007).

Currently, water pollution continues to exert pressure on public health due to growing industrialization, urbanization and the intensive use of chemical products in agriculture. Learning from the past, it is vital to use engineering advances to address the issue of global clean water, which is crucial to controlling emerging and re-emerging waterborne diseases, as well as to enhancing the quality of life in modern societies.

The human right to water and sanitation, and the focus of water for sustainable development

In 2010, the United Nations General Assembly recognized the right to safe, clean drinking water and sanitation as a human right essential for the full enjoyment of life, reflecting the fundamental nature of these basic needs. It was agreed that the lack of safe, accessible, sufficient and affordable water and sanitation and hygiene facilities has a devastating effect on the health, dignity and prosperity of billions of people worldwide with significant consequences for the realization of other human rights (UNESCO/UN-Water[12], 2020). This was a political act of high strategic significance, contributing decisively to significant investments worldwide for the construction and maintenance of the infrastructure needed to support drinking water supply and sanitation systems.

On the occasion of the United Nations Summit for Sustainable Development in 2015, an ambitious document, the 2030 Agenda for Sustainable Development, presented a strategic vision for the orientation of national policies and international cooperation activities until 2030. It proposed 17 Sustainable Development Goals (SDGs) with the aim of implementing the specific principles of health, and human and social dignity in various areas of activity. For example, SDG 6 establishes the principle of ensuring 'availability and sustainable management of water and sanitation for all'. Beyond SDG 6, several other goals are closely related to water, namely SDG 1 (End poverty in all its forms), SDG 2 (End hunger and achieve food security), SDG 3 (Ensure healthy lives and well-being for all), SDG 7 (Ensure affordable, reliable, sustainable and modern energy), SDG 11 (Make cities and human settlements inclusive, safe, resilient and sustainable), SDG 13 (Combat climate change), and SDG 15 (Protect and restore biodiversity, forests, and halt deforestation).

However, despite the advances made in the last decade, there are still major challenges to overcome before the Agenda is fully implemented, particularly with regard to less developed countries. In fact, recent estimates regarding the coverage of water supply, sanitation and hygiene systems among the world's population (UNICEF/WHO, 2019) reveal relatively slow progress that casts doubt on whether the proposed objectives will be achieved by 2030.

- *Drinking water*: 5.3 billion people have access to safely managed services. An additional 1.4 billion have at least access to basic services, 206 million people have limited services, 435 million have unimproved sources and 144 million still use surface water.
- *Sanitation*: 3.4 billion people have access to safely managed services. An additional 2.2 billion have at least access to basic services, 627 million people have limited services, 701 million have unimproved facilities and 673 million still practise open defecation.
- *Hygiene*: 60 per cent of the global population have basic handwashing facilities with soap and water available at home. Three billion people still lack basic handwashing facilities at home, 1.6 billion have limited facilities lacking soap or water, and 1.4 billion have no facilities at all.

This stark analysis brings to light the hygiene-sanitary reality of billions of people around the world, revealing the enormous global inequalities between developed and less developed countries with serious social, economic and public health repercussions for those populations.

To accelerate the realization of SDG 6, which is alarmingly off course, the United Nations launched the SDG 6 Global Acceleration Framework[13] to assist countries in raising their ambition to rapidly move towards national targets for SDG 6 and, in doing so, contribute to progress across the 2030 Agenda in areas such as poverty reduction, food security, good health and well-being, gender equality, peace and justice, sustainability and climate resilience of communities, ecosystems and production systems.

The Framework contributes to realizing the human rights to water and sanitation. It builds on ongoing processes, including the Water Action Decade 2018–2028, as well as the United Nations Secretary-General's global call to action for water, sanitation and hygiene (WASH) in all healthcare facilities, and the Agenda for Humanity[14].

12 UN Water official website: https://www.unwater.org
13 Read more about the SDG 6 Global Acceleration Framework at https://www.unwater.org/publications/the-sdg-6-global-acceleration-framework
14 Read more about Agenda for Humanity at https://agendaforhumanity.org

Engineering responses to clean water challenges

In order to ensure water security, realize SDG 6 and build resilience to climate change engineering must provide the necessary knowledge and technology to lead efficient water governance and management.

Almost one-tenth of the total burden of waterborne diseases worldwide could be prevented by improvements to drinking water, sanitation, hygiene and water resources management. The following examples refer to global diseases that are preventable if these conditions are met: diarrhoea (1.4 million preventable child deaths annually); malnutrition (860,000 preventable child deaths annually); intestinal nematode infections (2 billion infections affecting one-third of the world's population); lymphatic filariasis (25 million seriously incapacitated people); schistosomiasis (200 million people with preventable infections); trachoma (visual impairments in 5 million people); and malaria (half a million preventable deaths annually) (WHO, 2019).

In addition to these well-known waterborne diseases, emerging and future biological threats can be anticipated, for example: i) other known diseases that can re-emerge; ii) 'new' diseases identified due to new, more sophisticated laboratory methods; iii) real new diseases; iv) changes in disease behaviour; v) changes in environmental conditions; and vi multidrug-resistant microorganisms that may emerge.

Anticipated climate change can make these numbers even more dramatic, though their possible spread is so far unlikely. However, the ability to spread infectious diseases via vector arthropods increases with rising water temperatures. Regions such as Europe and North America, which were previously too cold to support transmission, may experience an inversion of this trend as the rise in water temperature creates favourable conditions for the reproduction of the aforementioned vectors.

New and emerging chemical pollutants are ubiquitous in water resources and the environment, and include: i) pharmaceutical waste; ii) endocrine disrupting compounds; iii) nitrosamines; iv) pesticides; v) biocides; vi) algal toxins/cyanobacteria; vii) personal hygiene products; viii) fragrances, and so on. For the majority of these pollutants, there is no information on their effects on human health, and their ecotoxicology is not included in official lists of parameters for regular water quality monitoring. Moreover, there is no evidence regarding the behaviour of these priority substances during water and wastewater treatment processes.

Solutions to the complex issues related to clean water have been addressed in a multidisciplinary way by engineers from different disciplines, applying scientific knowledge and providing innovative solutions to global water problems. Historically, civil engineers have played a prominent role in the construction of large infrastructure projects and water resources development. Other engineering disciplines, such as mechanical, chemical, biological, environmental, agricultural, electronic and computer engineering, have also contributed by offering new technological solutions and enhancing options for sustainable water management policies (see Box 1).

In addition to the design of water infrastructures (dams and reservoirs, channels, pipelines, pumping stations, water treatment plants), engineering contributions include the technification of systems, providing them with 'intelligence' that enables better operation and management through research and development, and knowledge transfer (Trevelyan, 2019). Some examples include:

- supporting water governance with an integrated water resources management approach;
- improving water-use efficiency and reducing losses in municipal distribution networks and industrial and energy cooling processes;
- implementing nature-based solutions in rivers, aquifers and sustainable urban drainage;
- protecting and restoring water-related ecosystems;
- introducing alternative water sources, such as safe wastewater reuse (a significant untapped resource for industry and agriculture), storm runoff and desalination, which can also relieve water stress; and
- assessing and managing risks of extreme events (floods and droughts), which are natural phenomena that cause major human and economic losses.

Significant progress in water and environmental engineering in recent decades has led to the development of new and more efficient water technologies, such as advanced oxidation, adsorption, reverse osmosis, and nano- and ultra-membrane filtration, which is used in the removal of priority substances in advanced water treatment.

Advances in wastewater treatment processes have been made in removing usable substances (e.g. phosphorus and ammonium) and other products for further processing, for example, using organic matter to produce biogas or base chemicals, which can be used in the pharmaceutical industry, and in promoting a circular economy while also preventing the discharge of harmful substances into water resources and the environment.

The Internet of things (IoT), Artificial Intelligence, new data-driven analysis and control algorithms are currently transforming water systems from passive, single-purpose urban infrastructure elements into active and adaptive units making them more efficient, more innovative and more sustainable.

Innovations in engineering disciplines, such as aerospace, satellite technology, electronic and computer engineering, as well as in remote sensing technologies contribute to identifying trends in the water cycle that are of paramount importance for the comprehensive assessment of quantitative and qualitative water-related climate change impacts.

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Box 1. Innovative engineering contributions to global water problems

Engineering developments offer innovative solutions to global water challenges, provide vital information on sustainable water resources management, support scientific research on new and emerging water issues, and promote science-based decision-making on water issues. Furthermore, engineering advancements can help mitigate and anticipate future water challenges, and contribute to a comprehensive assessment of climate change impacts related to water.

- *Advances in chemical engineering and environmental analysis.* Contributions to the development of wide-spectrum and high-precision analytical tools, which have brought to light the presence of ever greater types of pollutants in water resources, have made it possible to detect and quantitatively assess new pollutants that were not previously known to be present in the environment. With high-precision and high-sensitivity analytical equipment, it has also become possible to detect pollutants at much lower concentrations than those detectable with low sensitivity conventional techniques that were used in the past.
- *Developments in biochemical engineering.* Advanced oxidation and adsorption technologies provide solutions for the pre-treatment of specific pollutants such as pharmaceutical residues and chemicals in wastewater from hospitals and industrial facilities prior to discharge to municipal sewers.
- *Innovations in environmental engineering.* Cutting-edge engineering technologies such as ultrafiltration, nano-filtration and reverse osmosis are used in advanced water and wastewater treatment and have also proven effective for the removal of emerging pollutants from wastewater.
- *Advances in remote sensing.* Wireless sensors for monitoring water consumption have been developed and are increasingly used to allow for remote water metering. Evolutions in the field of data acquisition have been facilitated by high-speed internet networks and global coverage, as well as cloud computing and the enhancement of virtual storage capabilities. Applications of big data analytics can help to obtain knowledge by processing the collection of continuous streams of water-related information and data. Citizen science and crowdsourcing have the potential to contribute to early warning systems and to provide data for validating flood forecasting models.
- *Innovations in hydro-environmental modelling.* Specific and advanced models have been developed for the management of integrated water resources, floods and droughts, precipitation-run off and recharge of aquifers, floodplain estimations, damage previsions, infrastructure resilience, and energy and economic optimizations.
- *Advancements in aerospace and satellite engineering.* Satellite-based Earth observation (EO) can help identify trends in precipitation, evapotranspiration, snow and ice cover/melt, as well as runoff and storage, including groundwater levels. The use of EO imagery coupled with rapid progress in computational engineering has immense potential for water quality monitoring at the basin, national, regional and global levels. The launch of advanced environmental satellites has improved the spatial resolution of satellite images and opened up new frontiers for research on satellite-based water quality monitoring in inland freshwater bodies. Moreover, the open accessibility of most EO satellite images, such as Landsat and Sentinel, further facilitates research and applications, contributing to a better understanding and knowledge of the impacts of climate change and human activities on water resources. Furthermore, the use of EO satellites and drones, makes it possible to monitor water quality and water withdrawals in areas without infrastructure or inaccessibility, especially in developing countries.

The epidemiological context of the COVID-19 pandemic in 2020 and the unknown scientific characteristics of the SARS-CoV-2 virus has resulted in the lockdown of entire cities and the social isolation of billions of people, as well as the closure of vital economic activities. Consequently, civil society has recognized the relevance and value of clean water, safe hygiene and dignified sanitation to protect public health. Never before has the message about the importance of frequent and correct handwashing to prevent infection been so pronounced. The focus on WASH in containing the spread of the pandemic is unprecedented, particularly among the most vulnerable communities that do not have ready access to clean water.

As we face these challenges, technological innovation, knowledge management, advanced research and capacity development will generate new tools and approaches, and equally importantly, will accelerate the implementation of existing knowledge and technologies across all countries and regions (UNESCO/UN-Water, 2020).

Recommendations

1. Clean water is at the heart of any public health policy and an integral part of sustainable development. Governments and policy-makers should take urgent action to accelerate the realization of SDG 6 and solve the problem of inaccessibility to clean water which creates vicious cycles of poverty, inequality, food shortage and forced migration, particularly in less developed countries.
2. Anticipated global water challenges related to the impacts of increasing water pollution and climate change need to be addressed, while benefiting from advances in science, technology and innovation in areas such as hydro-environmental models, decision support systems, microelectronics, nanotechnology, fine chemicals, biotechnology and information technology.
3. The social and environmental relevance of clean water and the holistic nature of the 2030 Agenda for Sustainable Development demand an integrated and systematic approach when dealing with the specificities of each of the 17 SDGs which require intensive interdisciplinary analysis and multi-sectoral expertise in their implementation.

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3.2.2. Hydrology for the SDGs

Anil Mishra,[15] Will Logan,[16] Yin Chen,[17] Toshio Koike,[18] Abou Amani and Claire Marine Hugon[19]

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Abstract. The science of hydrology provides practical knowledge and information for society about water fluxes, transport and management, and thus has intertwined linkages with engineering applications. In the four decades after 1930, the development of hydrological science as a separate field of scientific inquiry (Horton, 1931) coincided with an enormous increase in engineered water infrastructure development. Furthermore, the rapid increase in hydro-infrastructure development triggered engineering applications across the globe. Hydrology and engineering thus essentially developed in tandem. In this section, the mutually integrated development of hydrology and engineering towards meeting global challenges, including the implementation of the Sustainable Development Goals (SDGs) is presented from the programme perspective of UNESCO's Intergovernmental Hydrological Programme (IHP).

Global water challenges

The world's population is projected to grow from 7.7 billion in 2017 to nearly 10 billion by 2050, and two-thirds of the population is expected to live in urban areas (UNDESA, 2017). This will lead to a corresponding increase in water demand in sectors such as agriculture, energy and industry, and will be manifested in engineering applications for water-related infrastructure development. In addition to population growth and economic development, climate change is also a major factor in water security. Climate change adaptation and mitigation through water management is therefore critical to sustainable development and necessary to achieving the goals of the 2030 Agenda for Sustainable Development, the Paris Agreement and the Sendai Framework for Disaster Risk Reduction (UNESCO/UN-Water, 2020).

In addition to water supply and sanitation, the management and reduction of uncertainty and the risks associated with flooding, sediment erosion, transport and deposition, and droughts are also key challenges globally. Since these fields mutually integrate hydrology and engineering, case studies in these areas are presented in this section.

How hydrology and engineering address the SDGs

Water is explicitly addressed in Goal 6 of the SDGs (clean water and sanitation). However, goals related to poverty reduction, food, health, gender and education, and targets for water-related disasters and climate change adaptation are also linked to water. The original role of hydrology in addressing water goals has thus evolved from a primarily engineering approach to an integrated approach involving natural sciences, the social and human sciences, and engineering. Engineered and nature-based infrastructure needs to be combined with water management approaches involving stakeholder engagement and bottom-up climate adaptation. These activities require the mobilization of international cooperation for research, the strengthening of the policy-science interface and capacity-building. Through its various programme sectors (education, science, culture, and communication and information), UNESCO has a unique mandate to address these interlinkages among the water-related SDGs.

15 Division of Water Sciences, UNESCO.
16 International Center for Integrated Water Resources Management (ICIWaRM).
17 International Research and Training Center on Erosion and Sedimentation (IRTCES).
18 International Centre for Water Hazard and Risk Management (ICHARM).
19 Division of Water Sciences, UNESCO.

UNESCO's unique role in hydrology and addressing the SDGs

UNESCO played a crucial role in this development by sponsoring the International Hydrological Decade (IHD 1965–74), which provided a mechanism for a global study of water resources available for engineering works, including social aspects, water quality and land use. The objectives of the IHD, and the Intergovernmental Hydrological Programme (IHP) that followed, were to strengthen hydrology's scientific and technological bases through the development of and training on the methods, techniques and guidelines for sustainable water management.

IHP is the only intergovernmental programme of the UN system devoted to water research and management, and related education and capacity development. The main objective of IHP's eighth phase (2014–2021) entitled, 'Water Security: Responses to Local, Regional and Global Challenges', is to mobilize science for water security. All of its activities support the SDGs. The upcoming ninth phase of IHP (2022–29) will reflect even stronger links for the realization of the SDGs, the Paris Agreement and the Sendai Framework.

The three case studies below were undertaken by IHP and three UNESCO Category 2 Centres: ICHARM[20], IRTCES[21] and ICIWaRM[22]. These centres host the secretariats for the International Flood Initiative (IFI), the International Sediment Initiative (ISI) and the Global Network on Water and Development Information for Arid Lands (G-WADI), and focus on water management and engineering applications based on hydrological services (flood control, sediment transport and drought, respectively).

Flood control, dam operation and water management in Asia and West Africa

ICHARM has developed the Water and Energy Budget-based Rainfall-Runoff-Inundation (WEB-RRI) model to analyse water-related hazard phenomena with a high level of accuracy. The model integrates the Hydro-SiB2 model, which is capable of calculating the dynamics of water and energy balance, with the Rainfall-Runoff-Inundation (RRI) model that is able to perform 2D runoff/inundation calculations. Use of the new model in combination with atmospheric models has enabled the evaluation not only of flood hazard impacts but also of drought hazard impacts due to future climate changes. By applying an integrated optimization scheme to the current operation procedure for hydroelectric dams, ICHARM is working together with electric companies to reduce ineffective dam discharges, improve power generating efficiency during a flood, and secure the storage capacity of a dam reservoir after a flood.

Real-time flood forecasting systems for the Kalu River in Sri Lanka and the Pampanga River in the Philippines were developed using the Data Integration and Analysis System (DIAS) in collaboration with ICHARM and the University of Tokyo, which has started to provide flood forecasting information to related organizations in both countries. Similarly, as part of an Asian Development Bank (ADB) project on climate change impact evaluation, ICHARM applied a series of forecasting methods, which take into account uncertainty, to three cities of Viet Nam: Hue, Ha Giang and Vinh Yen. In this study, four general circulation models (GCMs) were selected for their high responsiveness in regard to meteorological factors. The uncertainty originating in GCMs concerning future prediction was evaluated by applying statistical downscaling, while, future climate scenarios were created using dynamic downscaling, and flood risk evaluation was conducted using the RRI model.

In West Africa, flood disasters often occur in the Niger and Volta river basins resulting in deaths and hindering economic development in the region. In an effort to reduce human damage, UNESCO proposed to develop flood monitoring and prediction systems for these basins and their surrounding areas. After concluding a partnership agreement with UNESCO within the framework of the Water Disaster Platform to Enhance Climate Resilience in Africa, ICHARM developed a flood early warning system for the Niger and Volta river basins to help reduce water disaster risks. Simultaneously, ICHARM invited engineers from AGRHYMET, a specialized institute of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) and the Volta Basin Authority (VBA), to Japan and provided training on the system.

Application of hydrological services to flood control and sediment management in the Three Gorges Project

Located in the middle reach of the Yangtze River, the Three Gorges Project (TGP) in China is one of the world's largest hydraulic projects. Since 2003, the TGP has been producing comprehensive flood control, navigation, power generation and

20 International Centre for Water Hazard and Risk Management official website at https://www.pwri.go.jp/icharm/
21 For more information on International Research and Training Center on Erosion and Sedimentation (IRTCES), see https://uia.org/s/or/en/1100024285
22 International Center for Integrated Water Resources Management official website at https://iciwarm.info

water resource benefits. Its annual average power generation capacity is 84.88 billion kWh, equal to about 50 million tonnes of coal. Average annual runoff and sediment loads of the river at the dam site are 451 billion m^3 and 530 million tonnes, respectively. The total and flood control storage capacities of the TGP are 39.3 billion m^3 and 22.15 billion m^3. Long-term and real-time hydrological records are used to determine its operational flood control and sediment management modes.

The TGP controls 96% of the inflow to Jingjiang – the most dangerous river section during floods – and over two-thirds of the inflow to Wuhan. The flood control standard of the Jingjiang section is raised once every 100 years by storing flood water, decreasing the flood peak flow rate and flattening the flood peak. Between 2003 and 2019, the TGP has stored a total of 153.3 billion m^3 in flood water inflow, and plays an indispensable role in mitigating floods overall and reducing massive flood levels in the Yangtze River basin.

In the summer of 2020, serious flood events occurred in the basin. Through flow regulation of the TGP, the peak discharge was reduced from 70,000 m^3/s to 40,000 m^3/s, and the water level along the main stem of the middle reaches of the Yangtze River decreased by 0.45–2.55 m. According to the Chinese Academy of Engineering, the TGP's annual flood prevention benefits alone amount to RMB 8.8 billion yuan.

The TGP is operated in 'Storing Clear Water and Releasing Muddy Water' modes. In the flood season, the water level is kept low to allow the large sediment concentrations to be transported through the reservoir and discharged downstream; during the rest of the year, the reservoir operates at the water level of 175 metres. From 2003 to 2019, the amount of sedimentation in the reservoir was 1.8 billion tonnes, and the sediment delivery ratio of the reservoir was 24%. According to current predictions of sediment inflow, the reservoir sedimentation balance period can be extended from 100 years to more than 300 years.

International training workshops have been organized by the International Research and Training Center (IRTCES) to develop practical design and management strategies that will facilitate the sustainable development of hydropower and dams through reservoir sedimentation management. For example, the 'International Training Course on Integrated Sediment Management' and the 'International Workshop on RESCON 2 and Numerical Modelling for Assessment of Sediment Management Alternatives' were held in Beijing in 2018 and Chengdu in 2019, respectively.

Drought, water scarcity and water management in California

Southern California is a leading agricultural producer, a major manufacturing centre and home to 23 million people. With an average annual rainfall of only 375 mm/year, water must be imported from outside the region in most years. In fact, on average, Southern California receives over half of its water through aqueducts from Northern California and the interstate Colorado River. Engineered infrastructure includes pipelines that convey water, dams that store it and protect major cities, distribution plants that supply drinking water, facilities that treat and distribute wastewater for reuse, and injection wells that form a hydraulic barrier to seawater intrusion.

The task of the water resources engineering community is always challenging, but in drought years, every drop of water counts. Some of the starkest trade-offs involve balancing flood risk management and water supply during droughts. From about 2011–2017, California's worst drought in a millennium placed intense pressure on water managers. However, hydrologists of many sub-disciplines have contributed to alleviating some of this pressure. First, hydrometeorologists estimated the volume and distribution of the scarce precipitation using satellites (including systems co-developed by UNESCO), ground-based Doppler radar and precipitation gauges. Second, snow hydrologists measured the meltwater equivalent in snowpack in the mountains using snow surveys assisted by satellite and airborne imagery. Third, land-surface and surface-water hydrologists translated the rainwater and melt-water runoff into inputs to reservoirs. Finally, groundwater hydrologists analysed the safe yield of the state's aquifer systems, which many irrigators turned to as surface water sources dried up, as well as the potential for managed aquifer recharge. These studies together helped prevent a major disaster.

Still, more can be done by hydrologists to improve the management of engineered infrastructure in the next drought. Field experiments are underway to test Forecast-Informed Reservoir Operations (FIRO) using data from watershed monitoring and weather and water forecasting to help manage releases in a manner that reflects both current and forecasted conditions. At the Prado Dam in Southern California for example, FIRO could be used during inevitable future droughts to allow greater capture of scarce stormwater for managed aquifer recharge, while maintaining acceptable flood risks for the highly urbanized regions downstream.

The path forward

Neither engineering nor hydrology are static. Both have been impacted by technology and societal needs (Sivapalan and Blöschl, 2017); a trend that will likely continue in the future (Blöschl *et al.,* 2019). To respond to these drivers, the International Association of Hydrological Sciences (IAHS) has identified 23 'unsolved problems in hydrology' (Blöschl *et al.*, 2019). Recent studies also highlight advances in hydrological science and innovation, and engineering in water management, as well as solutions to improve this relationship, particularly with a view to contributing to the 2030 Agenda for Sustainable Development, the Paris Agreement and the Sendai Framework.

Despite the many advances in engineering and hydrology achieved to date, comprehensive integrated data and multidisciplinary approaches are required to provide solutions for the implementation of the SDGs and their water-related targets. The breadth of UNESCO's mandate in the natural and social sciences provides it with unique strengths to respond to these challenges. By bringing innovative, multidisciplinary and environmentally sound methods and tools into play, while fostering and capitalizing on advances in water sciences, IHP and the UNESCO water family act at the science-policy nexus to help meet today's global water challenges.

Recommendations

1. Recent research should highlight advances in hydrological science and innovation, and engineering in water management, as well as solutions to improve this relationship, so as to contribute to the 2030 Agenda for Sustainable Development, the Paris Agreement and the Sendai Framework.
2. Engineered and nature-based infrastructure need to be combined with water management approaches involving stakeholder engagement and bottom-up climate adaptation.
3. Engineers need to be trained in recent advances in hydrology, intertwined with externalities such as technology and societal needs, in order to develop approaches for the implementation of the SDGs and other water-related goals.

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