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Ensuring Safe Water and Sanitation for All: A Solution by Science, Technology, and Innovation

Unedited Draft

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Abbreviations

ADB	Asian Development Bank
AfDB	African Development Bank
AI	Artificial Intelligence
AP-PLAT	Asia Pacific Climate Adaptation Information Platform
ATMs	Automatic Teller Machines
BMGF	Bill and Melinda Gates Foundation
CAF	Development Bank of Latin America
CBFEWS	Community Based Flood Early Warning System
CSTD	Commission on Science and Technology for Development
CWDF	China Women's Development Foundation
EUWI+	EU Water Initiative Plus
FAO	Food and Agriculture Organisation
FSM	Fecal Sludge Management
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GWP	Global Water Partnerships
GWSP	Global Water Security & Sanitation Partnership
IMTA	Mexican Institute of Water Technology
INAPA	Dominican Republic National Institute of Potable Water and Sewage
IoT	Internet of Things
ISTP	Independent Sewage Treatment Plant
ITU	International Telecommunications Union
IWRM	Integrated Water Resources Management
LDCs	Least Developed Countries
LLDCs	Landlocked Developing Countries
NGO	Non-Governmental Organization
NOWPAP	Northwest Pacific Action Plan
NPEC	Northwest Pacific Region Environmental Cooperation Centre
OECD	Organization for Economic Co-operation and Development
OHCHR	Office of the United Nations High Commissioner for Human Rights
OLAS	Latin American and Caribbean Water and Sanitation Observatory (OLAS)
POUs	Point of Use Systems
R&D	Research and Development
RDI	Research, Development and Innovation
RVO	Netherlands Enterprise Agency
SCUWO	Schemes of Comprehensive Use and Protection of Water Objects
SDC	Swiss Agency for Development and Cooperation
SDGs	Sustainable Development Goals
SDPI	Sustainable Development Performance Indicator

SFW	Swiss Fresh Water
SHOFCO	Shining Hope for Communities
SIASAR	Rural Water and Sanitation Information System
SIDS	Small Island Developing States
SSA	Sub-Saharan Africa
STI	Science, Technology, and Innovation
SUWASA	Sustainable Water and Sanitation in Africa
SWA	Sanitation and Water for All
TIP	Transformative Innovation Policy
TIS	Technological and Innovative Solutions
UN DESA	UN Department of Economic and Social Affairs
UNCTAD	United Nations Conference on Trade and Development
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
UNICEF	United Nations International Children's Emergency Fund
UNIDO	United Nations Industrial Development Organization
UNRISD	United Nations Research Institute for Sustainable Development
UNWTO	United Nations World Tourism Organization
USAID	United States Agency for International Development
WAH	Water Action Hub
WASH	Water, Sanitation and Hygiene
WfWP	Women for Water Partnership
WHO	World Health Organisation
WHOS	World Meteorological Organization Hydrological Observing System
WMO	World Meteorological Organization
WSIS	World Summit on the Information Society
WWC	World Water Council

I. Introduction

Access to safe water and adequate sanitation is a basic human right. While progress has been made towards the achievement of the Sustainable Development Goal on water and sanitation (SDG 6), the trends and current status of access to water and sanitation provides cause for concern. There is urgent need to devise solutions that accelerate progress and ensure that no one is left behind. Nearly every other Sustainable Development Goal relies in some way on the achievement of SDG 6. For example, together with good hygiene practices, it is essential for the achievement of good health and well-being as well as equality and empowering of women and girls. As a determinant of success in areas including agriculture, energy, and disaster resilience, it has vast socio-economic impacts.

Whilst factors such as improving policies and governance, increasing funding, improving infrastructure, and improving data availability for better decision-making are likely to be central to resolving the water and sanitation issues, there is no doubt that Science, Technology, and Innovation (STI) can play a particularly significant role. The COVID-19 pandemic has demonstrated the vital role of STI in delivering solutions to critical challenges. Countries are more attentive now to the development and deployment of new technologies and processes. New applications of existing technology and techniques have the potential to increase the efficiency of existing water and sanitation systems to secure water and sanitation for all. For example, STI for water has been the centre of attention in much of the discussion at international water policy events.[2] It will be a key focus in the upcoming 2023 UN Water Conference and the 2022 International Water Association Congress in Copenhagen.

This paper explores the role of STI as key enablers for catalytic actions toward achieving universal access to safe water and sanitation. The second chapter will discuss the progress in implementing SDG 6 and challenges in meeting the targets of SDG 6. The third chapter will provide an analytical framework and practical STI solutions in addressing issues in providing water and sanitation services. The fourth chapter highlights the global effort to build partnerships and cooperation in achieving the SDG 6. Finally, chapter five will propose recommendations to be considered by the policymakers and international community.

[2] These include the Stockholm International Water Institute (SIWI) World Water Week in August 2022, the Singapore International Water week in April 2022 and the World Water Forum of the World Water Council, held in March 2022.

II. Persistent challenges of ensuring water and sanitation for all

SDG 6 calls for ensuring universal access to safe and affordable drinking water and sanitation, the provision of hygiene, and ending of open defecation. Important within this goal is the recognition that sustainably managing water goes far beyond simply providing safe water supply and sanitation services. It requires addressing the broader water context, such as improving water quality and wastewater management, improving water use efficiency in order to use freshwater resources sustainably and reduce water stress,[3] water resources management, and the protection and restoration of water-related ecosystems. To this end, it has set multiple targets.

2.1 Global progress in implementing SDG 6

A review of the global status of progress towards meeting the multiple targets indicates that the world as a whole is not on track to achieve SDG 6 (See Table 1) and many countries are even going backwards (UN-Water, 2021).

Table 1: SDG 6 Targets and Indicators

Sub-Goals	**Objectives**	**Indicators**	**Global progress status**
6.1	Universal and equitable access to safe and affordable drinking water.	▪ Proportion of population using safely managed drinking water services.	▪ 74% of the world's population used a safely managed drinking water service in 2020
6.2	Adequate and equitable sanitation and hygiene for all and end to open defecation.	▪ Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water.	▪ 54% of the world's population used a safely managed sanitation service in 2020 ▪ 71% of the world's population had a handwashing facility with soap and water available at home in 2020
6.3	Improvement of water quality through reduction of water pollution.	▪ Proportion of wastewater safely treated; ▪ Proportion of bodies of water with good ambient water quality.	▪ 56% of the world's domestic wastewater was safely treated in 2020 ▪ 72% of the world's monitored water bodies had good ambient water quality in 2020
6.4	Increase of water use efficiency across sectors and reduce number of people suffering from water scarcity.	▪ Change in water-use efficiency over time; ▪ Level of water stress: freshwater withdrawal as a proportion of available freshwater resources.	▪ Water use efficiency has increased by 10% globally between 2015 and 2021 ▪ 2.3 billion people lived in water-stressed countries in 2021 ▪ 19% of the world's renewable water resources were being

[3] Water stress occurs when water demand exceeds available water resources at a specific place and time.

			withdrawn after taking into account environmental flows requirements in 2019
6.5	Implementation of integrated water resource management at all levels.	▪ Degree of integrated water resources management implementation (0-100) ▪ Proportion of transboundary basin area with an operational arrangement for water cooperation.	▪ 107 countries are not on track to have sustainably managed water resources by 2030 ▪ 58% of the world's transboundary basin area had an operational arrangement for water cooperation in 2020.
6.6	Protect and restore the health of water-related ecosystems.	▪ Change in the extent of water-related ecosystems over time.	▪ A fifth of the world's water basins were experiencing rapid changes in the area covered by surface waters in 2020, indicative of flooding and drought events associated with climate change.
6.a	International cooperation and capacity building in developing countries through wastewater treatment, desalination, recycling, and reuse technologies etc.	▪ Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan.	▪ Water- and sanitation-related official development assistance increased by 9% between 2015-2019 stood at stood at USD 8.7 billion in 2020, but there was little change in disbursements
6.b	Participation of local communities for improvement of water and sanitation.	▪ Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management.	▪ Only 14 countries reported having high levels of Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management.

Source: (UN-Water, 2015, 2021)
Note: Not all countries report data on all indicators

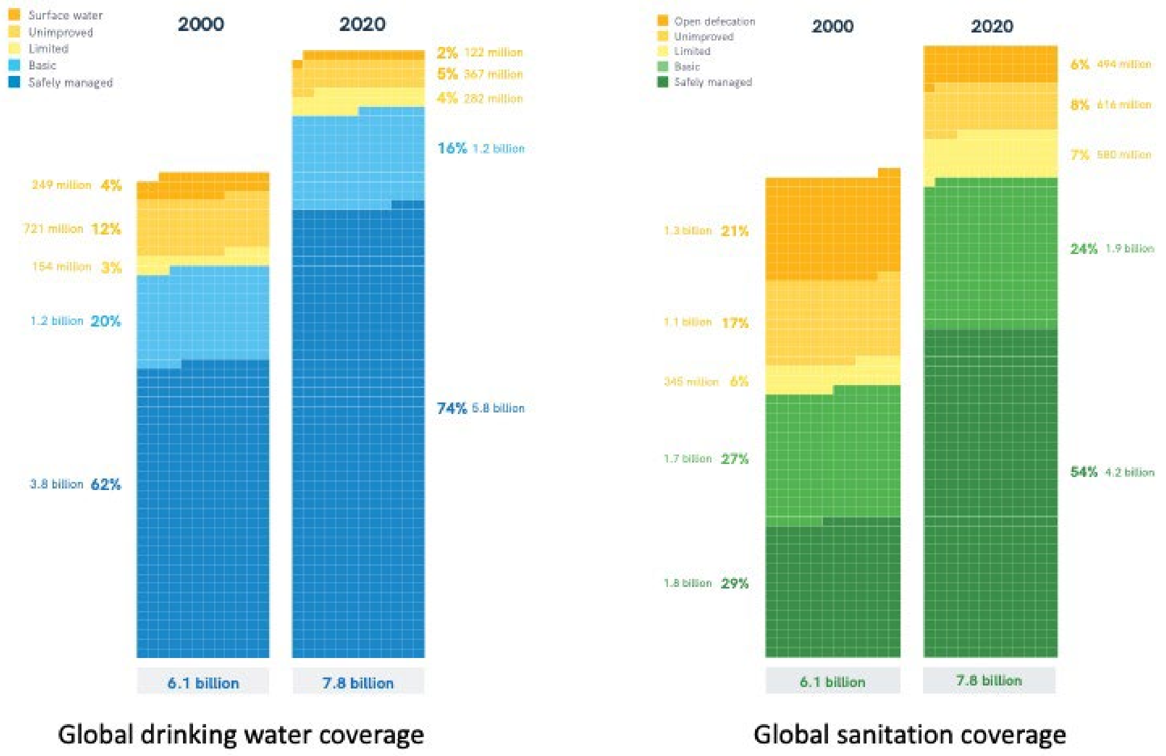
While progress is slow against all sub-goals and targets, there are two areas of particular concern.

The first area of concerns is the universal access to safely managed drinking water services and safely managed sanitation services. While the number of people lacking safely managed services has decreased by significantly in recent years, 2 billion people still lacked access to safely managed drinking water services in 2020 (UN-Water, 2021). Of this, 1.2 billion people could not obtain even basic services, 282 million did not have services when needed, 367 million relied on sources that do not protect against contamination, and 122 million were drinking surface water directly (WHO and UNICEF, 2021).

Limited progress has been achieved in enhancing access to sanitation, with only 2.4 billion people having access to safely managed sanitation services in 2020. Only eight countries had reached universal coverage to safely managed sanitation services, all of which are high-income countries. While 1.9 billion people lacked access to even basic sanitation services, 494 million people continued to practice open defecation (WHO and UNICEF, 2021).

If the current trends persist, only 81% and 67% of the world's population will have access to safely managed water and sanitation services, respectively, by 2030 (WHO and UNICEF, 2021). This means that 1.6 billion people and 2.8 billion people will be left behind, without safely managed water and sanitation services, respectively. Achieving these targets by 2030 will require a fourfold increase in the current rate of progress (UN-Water, 2021).

Figure 1: Trends in access to water and sanitation services, 2000-2020 (% of global population)



Source: (WHO and UNICEF, 2021)

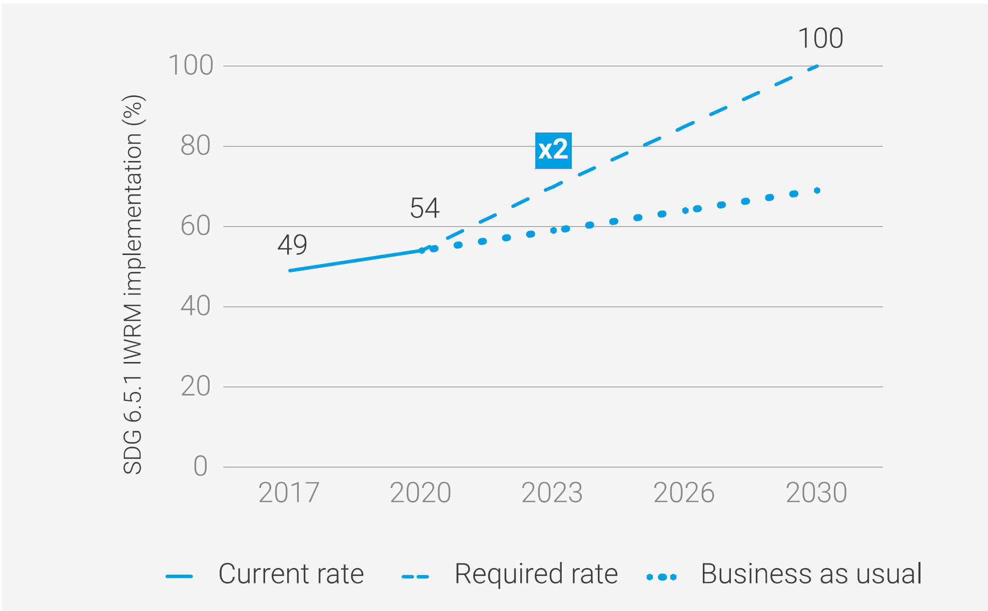
Box 1: Perspectives of national water leaders on achieving SDG6

A recent survey of national water leaders, i.e., those with water leadership responsibility, from 88 countries that are home to over 6 billion people. The survey mapped key issues faced by these countries in improving water outcomes. It was found that only two of the SDG 6 water targets surveyed are considered either 'achieved' or 'not difficult to achieve' by national water leaders of more than half of the surveyed countries. These two targets pertain to transboundary cooperation and participation. The remaining six SDG 6 targets are all considered to be either 'challenging' or 'impossible' to achieve for the majority of surveyed countries. Moreover, the proportion of surveyed countries for which achieving an SDG target is considered 'challenging' or 'impossible' is broadly similar for upper-middle, lower-middle-, and low-income countries. The survey also indicated that while governance related challenges pose the biggest barrier to achieving targets relating to the protection of ecosystems, integrated water resource management, local participation and transboundary cooperation, the lack of financing holds back progress on the targets relating to drinking water, water use efficiency, water quality, and water scarcity.

Source: Water Policy Group, 2021

The second area of particular concern is the implementation of integrated water resource management (IWRM) which has four components: Enabling environment, Institutions and participation, Management instruments and Financing. 107 countries are not on track to meet this target (UNEP, 2021). The global call for IWRM implementation is not new: it was formalized in 1992 during the International Conference on Water and the Environment in Dublin, Ireland. Yet, 87 countries continue to report "low" or "medium-low" levels of IWRM implementation (UNEP, 2021). In the absence of coordinated policy, legislative and regulatory frameworks, financing, transparent management of data and information, and multi-stakeholder planning across all sectors and at all levels, it is difficult to balance competing water demands from across society and the economy to achieve SDG6. Globally, the rate of IWRM implementation needs to double (UN-Water, 2021).

Figure 2: Current and required global IWRM implementation rate



Source: UNEP, 2021

2.2 Inequality in access to water and sanitation

The trends above in access to water and sanitation hide important inequality or inequities in access to water and sanitation that manifest themselves at different levels.

The first level of disparity is between regions, with Sub-Saharan Africa (SSA) falling furthest behind. Coverage of safely managed drinking water services stood at 96% in Europe and Northern America in contrast to 30% in SSA. Similarly, 78% of the population in Australia and New Zealand had access to safely managed sanitation services in contrast to 34% in Latin America and the Caribbean, and 21% in SSA (WHO and UNICEF, 2021). In fact, the number of people lacking basic sanitation services in SSA increased between 2000 and 2020, as the population grew by 73% over the same time period, although 290 million gained access to at least basic sanitation services during this time (WHO and UNICEF, 2022).

Nearly half of those without access to basic drinking water services in 2020 lived in the Least Developed Countries (LDCs). The disparity can also be seen in the quality of facilities and services across regions. Almost the entire population in Europe and North America has generally contaminant-free water available on premises and on demand. Conversely, only 36% of the population in Oceania had access to water when needed, while only 36% of Sub-Saharan Africa had access to contaminant-free water (WHO and UNICEF, 2021). Countries characterised as LDCs, Small Island Developing States, or Landlocked Developing Countries and countries in Sub-Saharan Africa and Central and Southern Asia have a greater share of population using on-site sanitation facilities.

For LDCs, where the highest priority is to simultaneously close the large gaps in access to water and energy, ensure food security, and promote growth in other economic sectors, the nexus of water and other systems could lead to constraints in ensuring water for all when needed. Low-carbon energy sources can support both energy and water security goals (through a reduction in water demand and wastewater) as long as the low-carbon fuel comes from a less water intensive alternative to higher carbon fuels (Kerres et al., 2020). It is worth noting that some future energy options which may be key to some countries' goals under the Paris Agreement, such as carbon capture and storage, could worsen water stress in regions already experiencing water scarcity (Rosa et al., 2020). Increased demand for water may have to be met by using coastal waters or non-traditional sources, such as treated wastewater, which in turn could use more energy.

Second, coverage also varies widely within regions. For example, in Eastern and South-Eastern Asia, coverage of safely managed drinking water services stood at 99% in Malaysia, while that in Lao People's Democratic Republic and Cambodia was 18% and 28%, respectively. Furthermore, while northern American countries enjoy access to clean water, countries in Latin America such as Ecuador, still has a large proportion of households who does not live in a hygienic environment and, for example, does not have accessible drinking water, cannot dispose of their excrement adequately, or do not have handwashing facilities.[4] Similarly, in sub-Saharan Africa, national coverage ranged from 94% in Reunion[5] to a mere 6% in Chad and nearly half of those without access to basic drinking water services in 2020 lived in the least developed countries. (WHO and UNICEF, 2021).

[4] Contribution from the Government of Ecuador.
[5] Reunion is part of France overseas territory.

On the sanitation side, in North Africa and Western Asia, Kuwait exhibited 100% coverage in comparison to Lebanon, Algeria and Yemen where coverage ranged between 16% and 19%. The level of disparity is within countries and is related to urban and rural coverage, with rural populations having significantly lower levels of access to safe water and improved sanitation as compared to their urban counterparts. Globally in 2020, 86% of the urban population had access to safely managed water services, compared to only 60% of rural inhabitants (WHO and UNICEF, 2021). However, due to rapid and unplanned urbanisation, has meant that the number of urban residents without access to safely managed drinking water has nearly doubled since 2000. Of those who lacked access to basic water services, the overwhelming majority (8 out of 10) lived in rural areas (UN-Water, 2021).

Rural access to safely managed sanitation services (44% of the population) also lagged behind urban areas where safely managed sanitation services reached 62% of the population. Urban areas also experience better quality of services, where two thirds of the covered urban population had sewer connections as opposed to one in seven people in rural areas, where on-site sanitation facilities are more common (WHO and UNICEF, 2021). For example, Romania is among the lowest ranking countries in European Union regarding the rate of connection of the population to water services (72.4%), and for sewerage services (57.4%). The differences between urban and rural areas in Romania are huge, with smaller communities in rural areas lagging considerably.[6]

The fourth level of inequality occurs to the people belonging to vulnerable, marginalised, and disadvantaged groups including women, and the disabled. They face additional barriers to accessibility, availability and quality of services in comparison with those of ordinary citizens (Van de Lande, 2015). For example, persons with disabilities, especially those living in developing countries, are disproportionately affected by challenges to access water and sanitation. Although data is scarce, evidence from a small set of developing countries indicates that more than one in seven persons with disabilities finds the toilet at home hindering or not accessible. Most public toilets in developing countries are also not accessible for wheelchair users, although the figure remains low even in developed countries with only 69% of public toilets being accessible for wheelchair users (UNDESA, 2020). A survey of 20,000 households in Bangladesh found that 79% of people with disabilities were unable to collect water while 47% of people with disabilities were unable to access sanitation facilities without coming into contact with fecal matter (Scherer et al., 2021).

Women and girls experience discrimination and inequalities in access to water and sanitation in various ways. In developing countries, socially and culturally induced gender responsibilities result in water management activities being assigned to women and girls. Studies indicate that in some countries such as Mauritania, Somalia, Tunisia and Yemen, a single trip takes longer than an hour. A 2016 study of 24 sub-Saharan countries indicates that an estimated 3.36 million children and 13.54 million adult women were responsible for water collection (UNICEF, 2016). Limited access to water and sanitation facilities and services leads to a deterioration of physical and psychological health outcomes. Fetching water from long distances or using water and sanitation facilities that are not on premises expose girls and women to physical and sexual violence (Scherer et al., 2021; Assefa et al., 2021). With 1 in 3 schools globally lacking access to basic water and sanitation (WaterAid, 2017), girls in particular stand to lose out on access to education.

[6] Contribution from the Government of Romania

2.3 Increasing challenges posed by climate change

Climate change impacts the earth's water system, posing substantial threats to ensuring safe water and sanitation for all. This adds challenges for countries to achieve SDG 6. According to a 2021 survey of national water leaders from 86 countries, the greatest perceived risk to maintaining or achieving good water management was climate change which was classed in the 'top three' for 80% of surveyed countries. At the same time, the water sector is the most essential sector for improving the climate resilience of communities and ecosystems (Kerres et al., 2020). Water demand management, reduction of water losses, and reuse of treated wastewater are key to mitigating and managing the risks from climate change.

Water scarcity affects more than 40 per cent of the global population and is projected to rise due to climate change. Over 1.7 billion people are currently living in river basins where water use exceeds recharge (United Nations, 2022). For example, even major developing countries such as Türkiye still face a challenge of water shortage. When the annual usable water amount per capita in Türkiye is calculated using the address-based population data of 2017 published by TÜİK (Turkish Statistical Institute), it is estimated that this value will decrease to approximately 1.120 m3 in 2030 from its 2017 value 1.400 m3. Unless water resources are used more effectively and efficiently, Türkiye is likely to become a water-scarce country during the 2030s.[7]

More and more severe floods and droughts resulting from climate change, which are affecting all continents as manifested in the summer of 2022, are among the most critical events that influence the availability of water resources – and hence the adequate supply of clean water for drinking and sanitation purposes. For example, Cameroon has been facing an abnormal recurrence of extreme weather events such as wind violence, high temperatures, long periods drought or heavy rainfall that endangers human communities, ecosystems and the services they provide.[8]

Additionally, rising water temperatures create ideal conditions for bacteria and viruses to thrive, resulting in concerning surface water and groundwater contamination. The poorest countries suffer the most from this as they also have a lower coverage of freshwater bodies which cover 1.4% of their land on average compared to developed countries' figure of 3.5% (Favre and Oksen, 2020). Worsening water conditions undermine these countries' efforts to reduce poverty, increase food security and develop a diversified economy.

Developing countries need to strengthen their efforts and commitment to address the challenge in water supply due to the climate change. Brazil, for example, has highlighted specific public policies and initiative at reducing the loss in the water supply system, in their fourth national communication to the climate convention[9]. Moreover, it is equally important for national climate planners and decision-makers to integrate water management into their climate responses set out in National Adaptation Plans (NAPs) and Nationally Determined Contributions (NDCs) (Timboe et al., 2020).

[7] Contribution from the Government of Türkiye
[8] Contribution from the Government of Cameroon
[9] Contribution from the Government of Brazil

III. Science, technology, and innovation for ensuring safe water and sanitation for all

Water science, technology and innovation is one of the longest standing human enterprises. Some of the oldest forms of infrastructure in recorded history relate to the harnessing of water, with the supposedly oldest wooden water well from the neolithic period dated from the age of the wood to 7200 years old (Wu, 2020). Irrigation systems have been dated around the same period, for instance those of the Jordan Valley which date from 6000BC (Sojka et al., 2002). These early successes resulted in local water security, enabling the development of agriculture and human settlement that has become the basis of human civilization as we know it.

STI is pronounced in every part of the water value chain (see Figure 3), from abstraction of surface or groundwater to treatment for safe use, to effective reticulation to end-users, to return flows of polluted waters, to wastewater treatment back to stream, and all over again (Kerres et al., 2020). The different parts of this value chain correspond to the different targets in SDG 6. In general, the global water community has not been a sufficient beneficiary of the knowledge of STI.

Figure 3: STI - Water value chain

Source: Authors

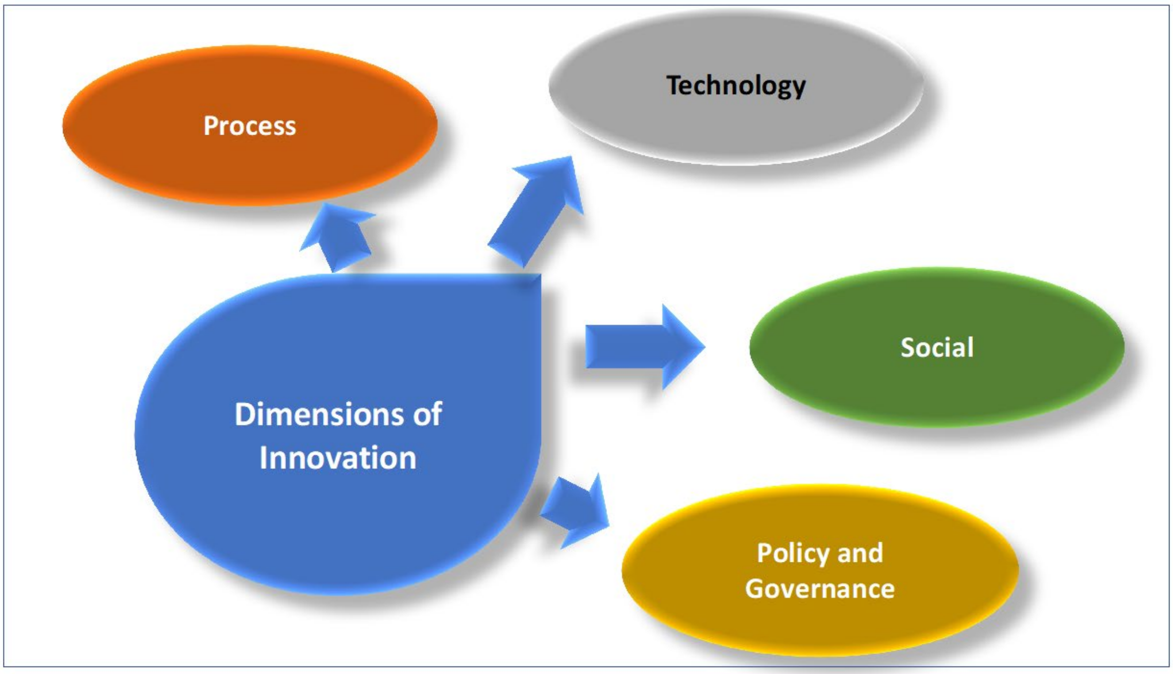
The contribution of the STI enterprise to achieving SDG 6 including universal access to safe water and sanitation can be divided into three realms. The first is analytical science that focuses on research and knowledge augmentation. The second is developing solutions through technological invention and innovations to attend to the problems and improve the ways in which solutions are rolled out. The third is the embedding and upscaling of solutions in the water value chain so that these solutions become the dominant and improved way in which water and sanitation challenges are managed.

Figure 4 : Contribution of the STI enterprise in ensuring access to safe water and sanitation

Source: Authors

Recognising the wide spectrum of innovation is crucial. The general assumption is that innovation is primarily technological. Though technological innovation is an invaluable contributor to progress in water and sanitation and all other SDG6 sub-goals, alone it is insufficient. Where very good technological solutions exist, the achievement of real and lasting impact requires a wider spectrum of innovation: innovation in process, in policy and governance, and in social focus and outcomes.

Figure 5: Dimensions of Innovation



Innovation in provision of water and sanitation similar to other types of innovation takes dimensions of (i) process innovation; (ii) technology innovation; (iii) social innovation; and (iv) policy and governance innovation.

Source: Authors

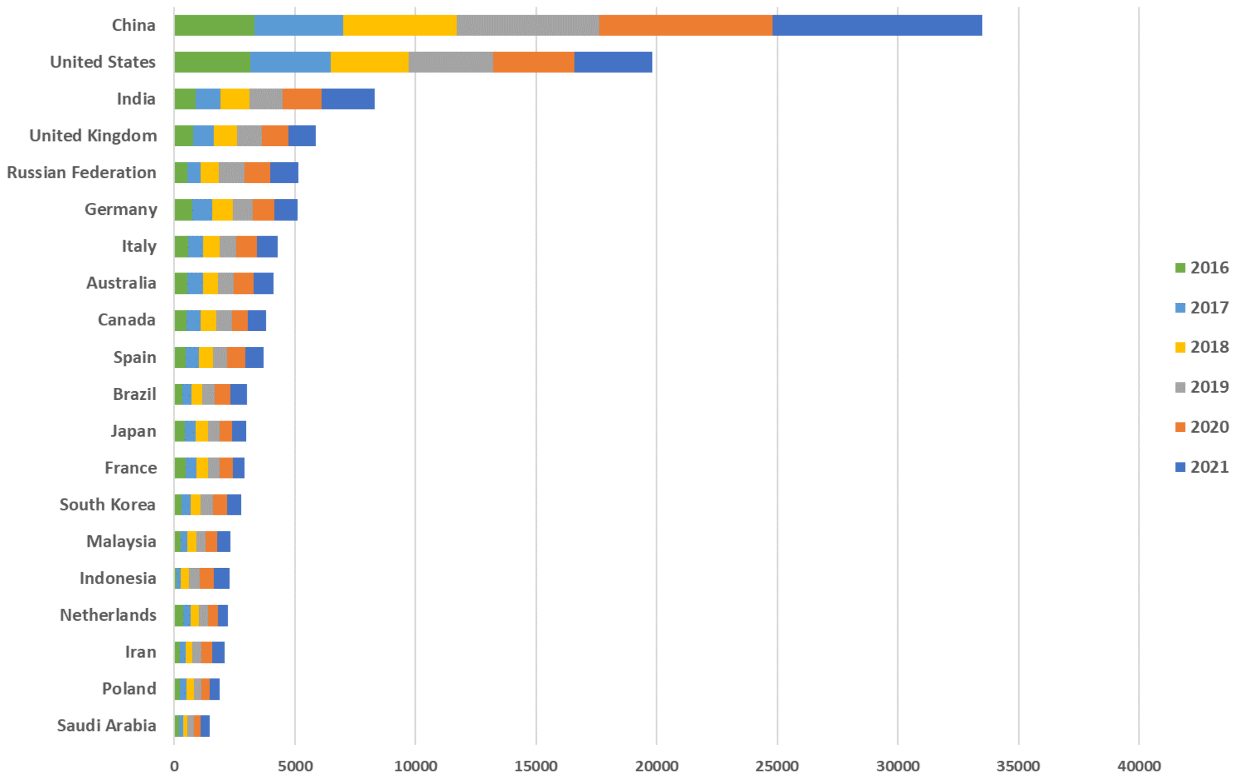
Process innovations are critical to ensure optimisation in both supply processes in operations as well as critical inventions in water demand management as a key tool for water security. Social innovation recognises that modern water management has an acute appreciation that water management is about people and operates in specific social and cultural environments. Innovations in how to facilitate co-designed solutions and are jointly owned with communities and have a tacit appreciation of traditional and cultural knowledge have a better opportunity for sustainable solutions to water security. Policy and governance innovation is characterised by flexibility, data-driven decisions, and a willingness to adopt and help foster the implementation of proven innovations. It is often key to enabling new solutions to be introduced more rapidly and sustainably. The risk mitigation impact of good innovative policy and governance cannot be underestimated.

3.1 Scientific research and knowledge on water and sanitation

The scientific community has been highly productive as evidenced by prolific publication rates over the past decades. Analytical science is a crucial part of the knowledge required to address the water and sanitation challenges and the bedrock of developing solution. There is an overwhelmingly large repository of information and knowledge in various journal publications and reports.

A global snapshot of the bibliometrics of water research over the period 2016 – 2021 shows that global STI-water-related publications are dominated by China and the USA (see Figure. 6). It indicates that while the publications rates are growing rapidly, it is concentrated in developed countries and advanced developing states. Almost 50% of the global publications in this domain is produced by the top 5 countries in the list (China, the United States, India, the United Kingdom, and the Russian Federation).

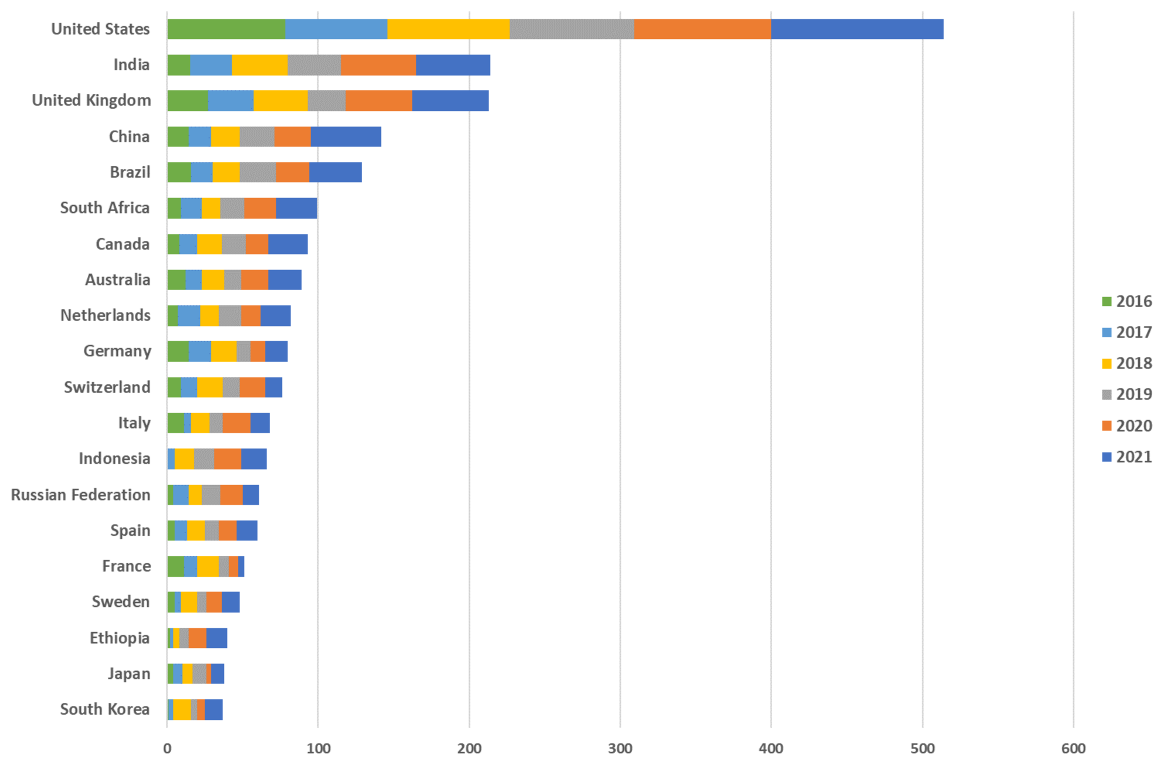
Figure 6: Top 20 countries by the number of STI-water-related publications during the period 2016-2021



Source: UNCTAD based on Scopus.

Conversely, the publication of knowledge product for the domain that links sanitation with science, technology and innovation has been modest compared to STI-water related publications. Globally in 2021, there are only 754 STI-sanitation-related publications, with the United States, India, the United Kingdom, China, and Brazil as the main contributors (see Figure 7). However, developing countries such as Brazil, South Africa, Indonesia, Ethiopia, have given more attention to STI-sanitation-related research, highlighting the urgent needs of improving sanitations in these countries.

Figure 7: Top 20 countries by the number of STI-sanitation-related citations during the period 2016-2021

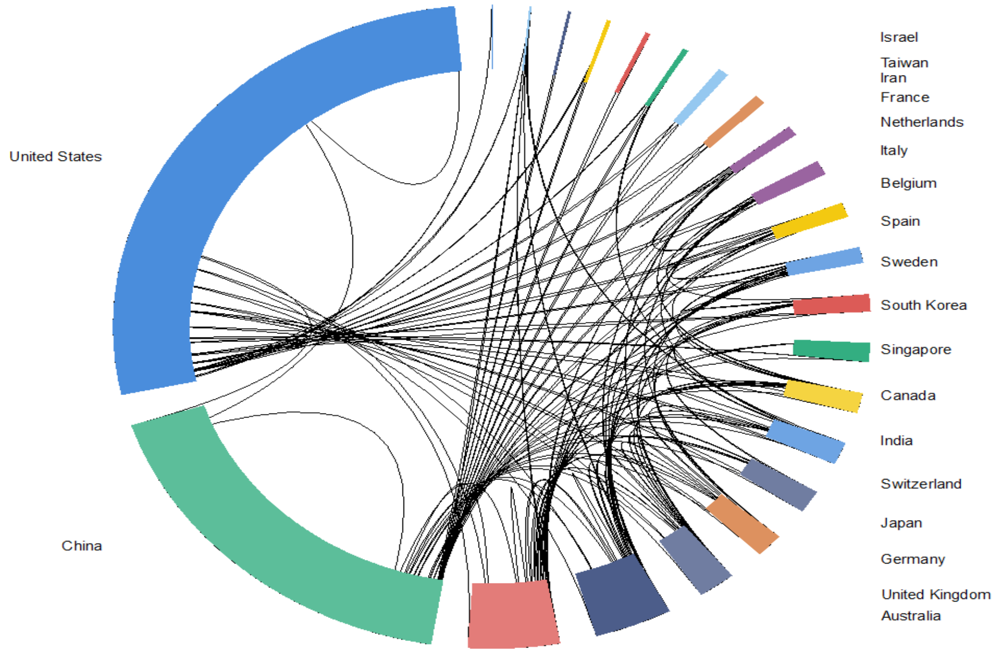


Source: UNCTAD based on Scopus.

Global imbalances in the pattern of production and consumption of knowledge products on STI-water-related are even more profound if we examine the knowledge flows in Figure 8. First, the biggest developing countries like China and India are emerging as knowledge production centres, though their outward knowledge flows are not as prolific as those of traditional Western knowledge producing houses. Second, it confirms that countries with high water knowledge needs in the Global South are neither significant knowledge producers nor consumers. Finally, the knowledge flows' analysis indicates that even when there are significant knowledge production centres in the developing world, as are found in China, India and Brazil, this knowledge is not being accessed by the larger part of the developing world – which is a central theatre of operation for SDG 6 and water and sanitation.

There are several reasons for this mismatch on global knowledge flows between developing countries. The first is limited institutional and individual capacity to monitor and access new knowledge and knowledge products. A second relates to the limited nature of South-South knowledge networks and collaboration, with developing countries still counting on the developed countries as primary collaborators. In the latter case, researchers from developing countries often perform a junior partner role. There is clearly a missed opportunity for better and deeper international cooperation in the generation as well as the use of new knowledge and knowledge products.

Figure 8: Water-research related knowledge flows during the period 2012-2017;



Source: (Mehmood, 2019)

Given that the highest inclines toward the targets are in developing countries, in particular lower income countries, the patterns of knowledge production indicates that they are driven largely, though not exclusively, by the developed world's challenges. Thus there is an urgent need to share the accumulated knowledge in countries like United States, China, India and United Kingdom with countries facing high water knowledge needs in the Global South. International cooperation and multilateral forums can facilitate such knowledge transfer through initiatives aimed at increasing capacity building, funding, and ensuring that the development of science, technology, and innovation will achieve their potential to increase access to clean water and sanitation.

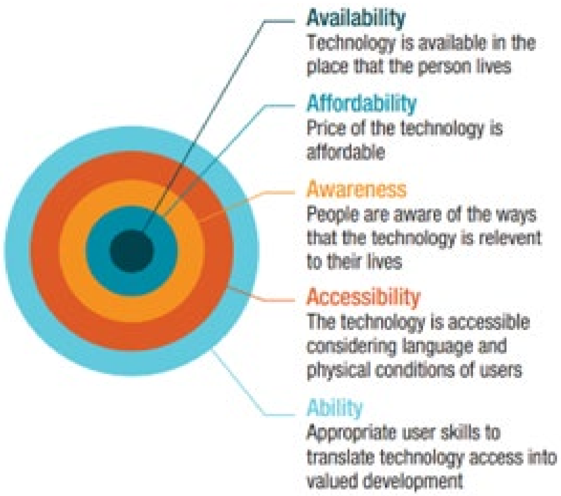
At the same time, translating science into real-world impact is urgent.

Despite the availability of huge amount of scientific knowledge, water and sanitation practitioners generally either don't find the knowledge accessible or find that it is not in a sufficiently usable form to inform their decision-making. In general, the quantum of knowledge available is uneven in the innovation value chain as upstream knowledge dominating and diminishing as one moves into the domains of upscaling, commercialization and impact.

A key component of the challenges is a lower availability of knowledge solutions closer to implementation. Many factors may influence this, including the higher costs of innovation projects, the difficulty of attracting potential investment partners due to the higher risk profiles of new solutions, and a lack of capacity to support new solution platforms. It is also important to recognize the general market failure wherein new solutions supported by excellent analytical science encounter the challenge of the 'valley of death' phenomenon. There is a need for investment in the 'science of implementation' to examine accelerated mechanisms to harvest the solutions developed by the STI enterprise with higher frequency and regularity as the world's water and sanitation challenges become increasingly 'wicked' problems.[10]

One of the most critical aspects to implement scientific knowledge or technological solutions that can address challenges in water and sanitation is access. Access in turns, can be considered to comprise a combination of "five A's": availability, affordability, awareness, accessibility, and ability for effective use (see Figure 9). Therefore, practical approach to implement technological solutions need to first address the more mundane and non-tech barriers to access the technology. A solar-powered water pumping system, for instance, is of little use if it is too expensive, if people are not aware of its existence, or if it must be operated by a trained individual where no training is given. Access to technology can also be restricted by social norms (e.g., for women, ethnic minorities, etc) or people who lives in geographically remote area.

Figure 9. The 5 A's of technology access



Source: UNCTAD, 2019

The second component is trans-disciplinarity. Even where we have completed solutions from a science and engineering perspective, behavioural, cultural, policy, governance and other challenges become obstacles to implementation. While the physical science and engineering toolboxes are crucial to finding water solutions, their implementation and sustainability rely heavily on social sciences, economic and governance knowledge, interventions, and strategies. A capable 21st century Water Team has to possess both repositories of knowledge and science-based solutions in these domains, but also skilled non-technical expertise which can ensure successful implementation.

The third component is investing in nexus approaches. It is increasingly clear that embracing connectivity between water and other sectors is essential to the development of sustainable and efficient solutions with multiple beneficiaries. It is also true that a failure to sufficiently appreciate the inter-dependencies of different sectors may lead to positive outcomes in one

[10] A wicked problem is a problem that is difficult or impossible to solve because it is a symptom or result of multiple, contingent, and conflicting issues. Interdependencies mean that the effort to solve one aspect of a wicked or complex problem may reveal or create other problems (Ramalingam et al., 2014).

sector but have unintended negative consequences in others. A nexus approach helps to mitigate this while also raising the possibilities of attracting a larger investment community and benefiting from more attractive cost-benefit ratios. The concept is an old one in the water sector and has gained a reputation over time of being a building block to socio-economic development.

One of the rising examples is an extension into the water-energy-food nexus as a major strategy to ensure global food security in addition to water and energy access and security being enhanced (FAO, 2014). Water-centred nexus approaches with other sectors are fundamental to implement STI application to achieve SDG 6 in water and sanitation while simultaneously contributing to the achievement of other SDGs such as zero hunger, clean energy, climate action, and partnerships for the goals.

3.2 Technological and innovative solutions (TIS) and their implementation

Along with the high production of analytical science, technological and innovative solutions (TIS) in water and sanitation have made great strides over the years. With rapid rates of production of new knowledge that is responsive to the genuine needs of people for safe water and sanitation, many technology developers and innovators, in both the formal and informal sectors, continue to be busy and highly productive. Rapid advances in frontier technologies including the bioeconomy, big data and the Internet of things and nanotechnology all have the water and sanitation sector as a potential primary beneficiary.

These technologies have the potential to powerfully assist us in the attainment of targets in SDG 6. The following sections present a number of TIS and their implementation, which could contribute to the achievement of SDG6, particularly its targets of universal access and integrated water resources management.

3.2.1 Accessibility of safe water and sanitation, including distribution and delivery

Access to clean water, most notably in the developing countries, is hindered by factors including the lack of adequate infrastructure, limited water resources, global warming, pollution in water sources, high-water stress due to excessive extraction, and wasteful behavior. However, different trends predominate region to region. Some areas in developing and least developed regions struggle to find adequate resources to access clean water and lack infrastructure. In others, developing countries' primary challenges relate to obsolete infrastructure assets and excessive levels of water consumption. Access to sanitation, on the other hand, requires establishment of proper sanitation facilities, which can be costly.

Multiple currently available technologies and innovative practices can help address such water and sanitation challenges.

Easy and low cost decentralized clean water delivery

Swiss Fresh Water (SFW) has developed a small sized low-cost desalination system for salt or brackish water. It uses ultra-filtration, carbon filter and reverse osmosis filtrations while the energy source can be solar or grid. It allows for the small-scale production of drinking water (4'000 liters drinking water / day) which is sold at a price 3 to 10 times cheaper than the mineral water available in 10L bottles, depending on the area (peri-urban or rural). The system has been designed with easy use and maintenance and low energy consumption in mind, alongside sensor- and IoT-based remote monitoring, making it suitable for use in developing countries, notably in Africa. A pilot project started in 2012 in the Sine Saloum Delta in Senegal, home to 225,000 people suffering from brackish and fluorinated water has proven to be successful from 2012 to 2019. In addition, SFW has set up more than 120 water kiosks on a franchise model in urban and peri-urban areas, around which small craft and service development centres have developed, generating more than 500 jobs through this income generating activity.[11] Following its success in Senegal, SFW is now beginning plans to replicate the model in West Africa, South America, and Asia through partners including REPIC.[12]

Similarly in Kenya, GivePower - a non-profit organization that develops clean water and energy systems - is converting sea and brackish salt water into clean and healthy water. GivePower is using advanced filtration systems and new solar powered desalination technology to provide fresh water in Kiunga, a small fishing community of about 3.500 people in area that is extremely dry. Each solar water farm produces enough fresh drinking water for 35.000 people every single day. Compared to most ground well systems, the GivePower solar water farm produces a higher quality of water over a longer period of time with no negative environmental impact.[13]

Innovation to address water availability and delivery

The challenge of getting water services into underdeveloped, rural, remote, slums, and informal settlements presents a major conundrum. China provides a successful example in addressing water access in the remote and rural area, after recognizing that difficulty to access water is a key constraint to rural development in general and to women's progress in particular as the burden of water fetching falls mainly on women. Since 2000 the China Women's Development Foundation (CWDF) has rolled out the "Water Cellar for Mothers" project to address water shortage in poor and arid areas in rural China. This is the first nation-wide and women-specific water project in China. The central activity was the construction of concrete water cisterns to store rainwater for use during dry spells. In addition, centralized water supply facilities were built to ensure safe drinking water and provide the villagers with easy access. By 2021, 139 900 cellars were built, supplemented by 1941 centralised water facilities and 1045 safe drinking water projects. The project covered 30 provinces, autonomous regions and municipalities and eventually afforded increased water access to 3.3 million people.[14] It has enabled women to have more time and energy, which they spend on gaining new skills and economic activities to improve their financial conditions. Thanks to the cellar project, many of them have been able to grow vegetables and raise poultry and livestock, hence improving their family income.

Approximately one quarter of the world's urban population live in slums area (Habitat for Humanity, 2017). In Kenya, Kibera in Nairobi, widely known as East Africa's largest slum, comprises 13 villages with an estimated population of 250 000 people within a peri-urban area spanning only 2.5 square kilometres. Most families here live on less than USD 1 per day. With water provision from vendors and cartels becoming increasing unaffordable, the NGO, Shining Hope for Communities (SHOFCO) developed an innovative process of water delivery using an aerial pipeline (Wesangula, 2016). This system was conceptualised as a circumnavigation of the complicated and costly logistical hurdle of distributing water across a settlement where

[11] https://www.swissfreshwater.com/en/la-machine/
[12] Contribution from the Government of Switzerland
[13] Contribution from the Government of Kenya
[14] Contribution from the Government of China

space is at a premium. With buildings overlapping with one another, leaving only narrow pathways to navigate through the slums, classically ground laid water pipes are an impossibility.

The core concept involves piping water from the Nairobi Water and Sanitation Company into a 100 000-litre storage tank via an aqueduct composed of an aerial mounted pipeline. This creates a water network capable of providing water access to 84 000 people. The idea was to enable access to water with a maximum 8-minute walk to vending points which is achieved through a networks of water kiosks, many built in partnership with a private sector partner, the mobile company SafariCom.

Figure 10 : Shining Hope for Communities (SHOFCO) Aquaduct in Nairobi

Photograph by Daniel Wesangula (Wesangula, 2016)

While this is a state-of-the-art intervention in a country that is a global leader in water management, various interventions at smaller more accessible scales are equally possible. A particularly relevant example is electronic payment for clean water through ATMs (automatic teller machines), as implemented in the Karatu District of Tanzania (Lawson, 2017). The Water ATM is a partnership between the NGO Catholic Relief Services, the Danish Water Company Grundfos and the Diocese of Mbulu Development Department aiming to resolve the issues of water governance and increase access to clean and safe water. Similar projects are in operation across a number of African and Asian countries. This technological intervention addresses issues relating to governance, payment and security matters as the ATM are in strategic locations in neighbourhoods and no physical money changes hands.

Water treatment to ensure water safety

Cities and towns in developing countries generally benefit from safe potable water on tap thanks to centralised water treatment plants that purify the water to a potable standard before it enters the reticulation system. The same cannot be said for many peri-urban slums and rural communities around the world, home to an estimated 2 billion people (Centers for Disease Control and Prevention, 2022). With an estimated 80% of wastewater returns to stream untreated, risks of water borne diseases and harm due to chemical and other contaminants are greatly increased. (UNEP, 2022). With a growing population and ever-increasing industrial activity producing ever-more wastewater, this risk is growing manifold.

While remarkable progress has been made to better water treatment through technologies and innovations through nanotechnology development, ceramic filters, smarter process design and higher energy and chemical use efficiencies, many parts of the world lack access to reticulation systems fed by these systems. One important solution for this challenge is Point of Use Systems (POUs) (Pooi and Ng, 2018). These use a combination of flocculation, coagulation, filtration, and distillation to deliver safe and clear water for consumptive and other uses. With increasing demand and the challenges of classical centralised water treatment, POUs are finding increasing uptake even in developed countries (Wu et al., 2021). Point of use systems have been in use for centuries and the indigenous knowledge associated with filtering systems and choices of clays for storage vessels are an important opportunity to combine new and older science for sustainable and trusted culturally acceptable solutions (see Box 2).

Box 2: Example of a Point of Use System

POUs increase access to clean and affordable water, particularly compact and portable POUs which are increasingly being relied upon to decentralize water treatment for drinking water and the treatment of wastewaters for recycling and reuse. One successful example of a POU is the Vulamanz Microfilter from South Africa. It uses a nanotech solution in a textile scaffolding, known as fabric microfiltration, to filter contaminants including suspended solids, colloids and bacteria without using any water treatment chemicals (VulAmanz, 2022).

Source: (UNEP, 2022)

Water saving toilets

Toilet flush accounts for 30 percent of water consumption in households (Madzia, 2019). All sewered sanitation solutions require processing in water-based treatment plants. Waterless toilet technologies, on the other hand, can generate substantial water savings, avoidance of waterway pollution, and the opportunity of turning human waste into energy or organic fertiliser for crops.

The *Bill and Melinda Gates Foundation* (BMGF) launched a global partnership campaign in 2011 to reimagine the sanitation value chain by using the best STI available to reinvent the toilet so as to provide new sanitation solutions appropriate for the 21st century context (Bill and Melinda Gates Foundation, 2020). A key requirement for candidate solutions was low or no water use so that systems were non-sewered. Local safe treatment of the waste was crucial, which in turn promoted solutions enabling waste beneficiation by creating opportunities for employment and business development. In addition, combined with the water saving technology is the use of solar panel, as illustrated in the EcoSan toilets installed in a 'toilet block' for girls at Gugulethu Primary School in KwaMashu, City of eThekwini South Africa (See Figure 11).

This partnership has grown from China, India, and South Africa to include many more developing countries and some developed countries as well. While the reinvented toilets and installations show great promise as an accelerated solution for the SDG sanitation deficit, their low or no water use also resonates well with most countries as water scarcity becomes an important phenomenon worldwide. They represent a key adaptation measure to a world experiencing increasing water stresses as climate change's impacts are increasingly felt. Additionally, they offer a low-carbon alternative to classical sanitation, thus additionally resonating with the quest to increase global Climate Resilience.

Figure 11. Water and energy saving toilets for girls in a school, Kenya

Source: Bill and Melinda Gates Foundation / Samantha Reinders

Portable toilets

Portable toilets have been often used on the occasion of events as temporary toilets. However, the benefits of portable toilets, such as less water use or water free, proper waste disposal, which have come along with the advancement in constructing portable toilets, increase their attraction in implementing universal access to sanitation.

ECOLOO, a Swedish-Malaysian start-up invented an odour-free, water-free (water can still be used for hygiene purposes), sewage-free, energy-free, and hassle-free portable toilet solution, which was a winner of UNWTO's SDGs Global Startup Competition. It is easy to install, maintain, and can be used permanently or temporarily. It employs special formulated bacterial culture to treat and vanish human waste and transform the urine into natural liquid fertilizer.[15]

[15] Contributions from UNWTO

Smart Sanitation for Water Settlements

In developing countries, it is common that sanitation and wastewater treatment systems are not in place in every village. Hence there is a need for easy- to- install sewerage treatment facilities. In Malaysia, independent sewerage treatment plants (ISTP) were developed by a team of researchers from Universiti Putra Malaysia. The ISTP is a 360-liter modular wastewater treatment technology that discharges treated wastewater according to the country's highest regulatory standard into water bodies after 7 hours of treatment time. A "Smart Sanitation for Water Settlements" project has been designed to tackle pollution and reverse the degradation of marine and coastal ecosystems due to lack of sanitation and wastewater treatment in the Lok Urai water village near the Sabah Marine National Park. The project involved the installation of 10 ISTP tanks with 10 residents trained to install and maintain them. The technology brings innovation where no sanitation and wastewater treatment systems are in place, with benefits for the environment and human health (Special Project with United Nations Environment Programme (UNEP), 2022).[16]

Ending open defecation

Ending open defecation is a crucial determinant to the successful implementation of both the water and sanitation targets of SDG 6. It is a challenging task in many developing countries, particularly their rural areas, due to lack of financing to build properly equipped toilets as well as lack of awareness of the health and environmental implications of open defecation. But it is not unachievable as evidenced in India, the second largest populous country in the world.

The Swachh Bharat Mission (SBM) is an example of combination of a modern technology and innovative governance and leadership commitments from the highest political level. The Indian government began SBM in 2014 to end open defaecation across the country within five years by constructing both public toilets and toilets at the household level, besides enhancing solid waste management. The campaign effectively utilized modern technology for comprehensive monitoring of the progress in building toilets to avoid corruption and duplication of toilets in the individual households under this program. For instance, each toilet in every village was mapped on an integrated management information system to track progress in real time. Moreover, every toilet was mandatorily geotagged for to help people find the toilet using Google Maps (Karelia and Bhaskar, 2018).

By October 2019, over 95 million new toilets were installed in India's 27 states and Union territories (Chaudhery, 2019). Consequently, far-reaching impacts have resulted from SBM as the number of people engaging in open defecation decreased from 550 million to 50 million (India Ministry of Drinking Water & Sanitation, 2019) and the number of deaths from diarrhoea due to poor sanitation decreased from 140,000 in 2014 to 50,000 in 2018 (WHO, 2018).

Though much still needs to be done to engage that last mile of implementation and reinforce ODF behaviours, various studies have verified positive this programme's impacts through a range of indicators including and improvement of health status on the back of the SBM (Dandabathula et al., 2019). This could be seen as one of the most impressive successes in providing a basic service in human history.

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[16] Contribution from UNEP

Innovative Fecal Sludge Management (FSM)

Fecal Sludge Management (FSM) is an integrated system that is decentralized for safe treatment and disposal of wastewater and human body waste from dwellings and businesses close to their sources. It is being developed in Thailand with support from the Gates Foundation. The stages of the FSM process involve the emptying, collecting, transporting, treating, and disposal of fecal sludge. Hence the system engages many stakeholders to address fecal sludge problem using innovative solutions, because a functioning FSM service chain requires strong awareness and understanding of the consequences of misconduct by households, fecal sludge collectors, fecal sludge treatment operators, related local government officers, and policymakers at local, provincial, and national levels.

Three innovative products are being developed, namely Cess to Fit, the Solar Septic Tank, and the Zyclone Toilet. A major benefit of the "Cess to Fit" system is that it is designed to be retrofitted into existing cesspool systems. The "Solar Septic Tank" collects solar energy, which is used to eliminate pathogens, enhance the biodegradation of organic matters, and produce better quality septic tank effluent. The "Zyclone Toilet" is able to separate solid and liquid waste through the clever use of gravity and the cyclone concept. Key considerations in the development of innovation to improve this process focus on designing technological solutions that enhance the user interface or reduce sludge volumes by creating better onsite collection and storage methods (Koottatep et al., 2021).

Fecal sludge management also offers sustainable solutions by transforming sanitation waste into more valuable materials. Sanivation, a Kenyan social enterprise, is partnering with local governments to help meet growing waste processing needs by transforming fecal sludge from septic tanks and pit latrines into biomass fuels. Sanivation designs, builds, and operates fecal sludge treatment plants whose biomass fuel sales cover operational costs, making the project financially viable. Each plant ensures waste is safely managed, creates local employment, prevents environmental pollution, and saves trees by promoting biomass fuels.[17]

Mitigation and adaptation of climate change impact on safe water supply

Climate disasters in the form of extreme weather events are becoming an increasingly frequent phenomenon throughout the world. The impact of climate change on water by increasing the prevalence of droughts and floods puts significant stress on both water supply and water quality. To address the grave challenges presented by climate, hydrogeology must gain a stronger climatological reference.

Austria is exploring the combination of meteorological-climatological and geological-geophysical competences through its GeoSphere program. Geoelectric analysis measuring the electrical resistance of subsoil can inform surveyors about the latter's water content. Thus, lateral and temporal changes in subsoil water flow can be measured. Geoelectrics can be used in all those areas where knowledge of the subsoil water supply and its changes is relevant. This includes the demarcation of landslide areas, the development of early warning systems, groundwater exploration, the monitoring of flow movements (using fed-in salt tracers), tightness monitoring of dams, and more. The intersection between weather and climate data

[17] Contribution from the Government of Kenya

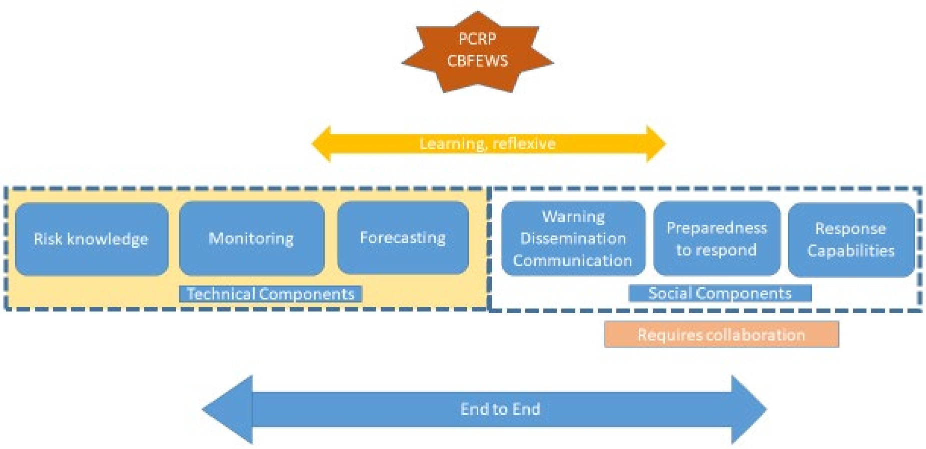
with subsoil saturation data promises great potential for innovation, especially when assessing the effects of climate change on the future availability of groundwater resources.[18]

In India, the government implements Water Technology Initiative (WTI) to promote technology development to provide water from sustainable sources; augmentation of water quality for specific applications; and recycling and reuse of water. The initiative has vast social impact, and its field interventions have benefitted 200 000 people to date.[19]

Early warning system is fundamental in preparing response to natural disasters which have become more frequent due to climate change. For example, in Latvia, the government has implemented an early warning system involving high technology and deeply integrated earth observation systems such as mobile pipe flushing water flow devices for data collection on water flow, pressure, and turbidity, or 3D river flood models capable of predicting flood threats 24 hours in advance.[20]

At local levels, low-tech innovative systems involving community participation with higher levels of community agency and effective partnerships are already proving to be highly impactful. A recent example is the work of Community Based Flood Early Warning System (CBFEWS) in an informal settlement or slum in eThekwini in KwaZulu-Natal, South Africa that ensured a zero loss of life in a community that lived on the banks of a river in the April 2022 'rain-bomb' event in the city.

Figure 12: End to end community-based flood early warning system in the Palmiet Catchment Rehabilitation Project in Durban



Source: The Community Based Flood Early Warning System (https://www.icimod.org/mountain/cbfews/)

The CBFEWS is an example of bottom-up innovation based on the co-production of knowledge in a local governance platform (state, university, civil society organizations, local Enviro-champs, and Quarry Road West community members). Real-time information from CBFEWS flood warning system includes municipal weather and river data, risk warnings translated by

[18] Contribution from the Government of Austria
[19] Contribution from the Government of India
[20] Contribution from the Government of Latvia

researchers, and on-the-ground conditions provided by community members. By providing residents of the informal settlement with real-time, accessible, and context-specific information, safe and life-saving evacuations are made possible in the event of floods.

Water-related disasters often have cross-border elements and challenges which require strong regional cooperation. On this front, in the United Nations system, regional commissions and several agencies have programmes to promote STI solutions to contribute directly to building resilient against water related disasters. For instance, the Economic and Social Commission for Asia and the Pacific (ESCAP) highlights regional cooperation through a space-based drought monitoring mechanism which provides timely and free access to space-based data. Relevant products and services as well as training and capacity-building support are provided to participating countries.

Similarly, The World Meteorological Organization (WMO) provides online information on extreme weathers (i.e., tropical cyclones, heavy rain and snow, thunderstorms) and aim to give the entire global population access to early warning systems in five year, namely by 2027 (WMO, 2022). Meanwhile, the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) makes available space-based scientific knowledge and technologies for disaster management. The United Nations Office for Disaster Risk Reduction (UNISDR) remains the focal point in the United Nations system for the coordination of disaster reduction, to ensures synergies among the disaster reduction activities, including to provide early warning system in the event of flooding and drought that affects water supply in national and regional level (UNCTAD, 2019).

Data gathering and forecasting for water security and sanitation

Inadequate water quality continues to pose major threats to human health. Water quality is ensured only if it is continuously monitored. This allows for the control of water characteristics, identification of patterns and trends, identification of emerging problems, determination of whether pollution control programmes are working, and the design of better pollution control efforts and respond to emergencies such as floods and spills. Traditional monitoring of water quality involves on-site sampling of water and subsequent laboratorial analyses. While this provides accurate measurements, it is costly, time-consuming, and indicative only of the situation at the points where samples are obtained. Alternative TIS offer important ways to ensure water quality and safety, but also to increase efficiency and reduce costs in doing so.

The information revolution has empowered policymakers by giving them a far greater capacity to understand the situations they are addressing or seeking to address. It empowers policymakers to make more informed decisions while simultaneously enhancing governance through transparency and accountability.

The SIASAR joint initiative between several South and Central American states is an example of this[21]. The initiative establishes an up-to-date and verified information tool on existing rural water supply and sanitation services and increases transboundary cooperation in water among members. It is designed to be applicable by countries with similar rural water and sanitation systems (low levels of coverage, limited self-sustainability, little information, etc.).[22]

[21] Sistema de Información de Agua y Saneamiento Rural (SIASAR). See more at: https://globalsiasar.org
[22] Contribution from the Government of Dominican Republic

In most developing countries, rapid population growth without parallel development of urban water treatment infrastructure is challenging those utility companies that are unable to maintain their systems properly. To tackle this, Egypt has established an online system to monitor wastewater discharge from major polluting enterprises to measure wastewater pollution load. The system is expanded annually to ensure a strict control over the main wastewater dischargers so as to maintain the quality of ambient water in the main watersheds that feed water treatment plants for safe water supply. The system eases burdens on competent authorities performing regular drinking and ambient water quality monitoring. It also facilitates the forecasting and management of potential incidents affecting the quality of watersheds.[23]

Hungary, through its Water Science and Water Security National Laboratory, is seeking to broaden the knowledge base on fluvial and lacustrine systems (e.g., River Danube, Lake Balaton, and Lake Neusiedl) by studying the complexities and interactions in their hydrology, hydrodynamics, morphology, water quality and ecology with the aim of informing the establishment of more advanced wastewater treatment technologies. This initiative has resulted in the development of a high-resolution 5G-based urban precipitation monitoring system encompassing the drinking water supply network and hydrodynamic models to control biological wastewater treatment processes.[24]

Water source protection is essential to ensure water quality. China has worked out a systematic approach to protect water source for ensuring water quality. With technology in the center, it comprises (a) environmental survey of the water source zone; (b) analysis of pollution origins; (c) risk analysis; (d) water source zone delineation methods and plans, and (e) site delineation. At water source, the "satellite remote sensing + APP" technology is deployed, which offers high-resolution detection, precise prevention and control of environmental risk factors. It also generates precise information on the spatial distribution of risk factors in water source zones. Through the automatic water quality monitoring system at water sources, real-time online early warning and monitoring of water quality are carried out for the particular pollutants of risk sources, including heavy metals and volatile organic compounds, apart from the conventional water quality control parameters such as pH and dissolved oxygen.[25]

The capacity to develop highly accurate models and indicators increases policymakers' capacity to anticipate the effects their decisions may or will have. For instance, UNRISD has funded and initiated the development of a context sensitive Sustainable Development Performance Indicator (SDPI) for sustainable use of water at the facility level. Published in February 2022, the indicator provides a low-cost and scalable method for providing a sustainable water allocation for enterprises based on the hydrological, economic, and demographic contexts of their facilities. This means the indicator can easily be upscaled and widely disseminated among enterprises, perhaps by governments, in the form of a digital tool.[26]

In a similar vein, the social innovation was also the central focus of the partnership between the Development Bank of Latin America (CAF) and local NGO Agualimpia which have partnered to delivered an innovative technological and social intervention to improve access to clean water of 13 rural villages in Peru (Agualimpia ONG, 2020). Besides using digital solutions to diagnose, identify gaps, prioritize, and budget interventions in water and sanitation, the project adopted social innovations such as the inclusion of social elements and community

[23] Contribution from the Government of Egypt.
[24] Contribution from the Government of Hungary
[25] Contribution from the Government of China
[26] Contribution from the UNRISD

management in the optimization process, the revamp and improvement of social organizations involved in the provision of drinking water, and the organization of socialization workshops to foster conducive conditions for replication of the intervention. The intervention resulted in a 22% increase in the supply of water to the targeted drinking water systems (Agualimpia ONG, 2020).

3.2.2 TIS for integrated water resource management

Though water is a key driver of economic and social development, it also serves a basic function in the maintenance and integrity of the natural environment. That said, it is only one of several vital natural resources, and water issues must imperatively not be considered in isolation. Integrated water resources management (IWRM) takes into account various users and uses of water, with the aim of promoting positive social, economic and environmental impacts at all levels. Government or private sectors need to manage and make difficult decisions on water allocation. Increasingly, they must apportion diminishing supplies between ever-increasing demands. Demographic and climatic changes drive further increases on water resource stress. The traditional fragmented approach is no longer viable, with a more holistic approach to water management now essential. Technological and innovative applications enable different stakeholders, from water utilities and municipalities to businesses and citizens, to develop and implement more efficient data-driven water management practices and policies.

Hydrological observing system

Hydrological data describes hydrological cycles and can be used to better manage water resources by providing information on water quantity and quality, thereby enhancing its delivery and research. Consequently, the World Meteorological Organization (WMO) has developed the WMO Hydrological Observing System (WHOS) to collect reliable hydrometeorological data. In turn, this tool can be used for water resources planning and decision-making including for early warning systems on floods and droughts, integration into hydrological and climate applications and services, and for research (World Meteorological Organization, 2022). WMO is actively advocate the use WHOS among National Hydrological Services and the hydrological communities to share the evidence-based practices on water resource management.

The implementation of the tool in three pilot projects in the La Plata River basin by Argentina, Bolivia, Brazil, Paraguay and Uruguay, the Arctic basin, and in the Dominican Republic have proven its usefulness and effectiveness. These pilot projects have improved national and basin expertise through capacity building efforts and have resulted in the production of more precise hydrometeorological products and services using big data and AI. Moreover, the resulting platforms can visualize data, download it, analyze it, and model it by means of various supported online tools and applications. This was achieved with a strong focus on interoperability that permitted the employment of already available data publication services. These efforts fall within WMO's attempt to promote open-data sources (Boldrini et al., 2022).

The water-energy nexus

The water sector is one of the oldest users and producers of energy. Hydropower, with its non-energy benefits, tends to be an investment of choice wherever possible. Most hydropower projects create water storage and flood control mechanisms and promote water-dependent development through agriculture, industrial production, and urban development. These energy generation projects' potential for good has increased substantively courtesy of STI progress.

Mobilizing the potential of this nexus, UNIDO set up a solar-powered slow filtration system to produce clean water, adopting Japanese innovative technologies in an Ethiopian rural area. The project focused on the provision of clean water through solar-powered water sanitation systems under conditions of equality and gender equity, on the development of community technical capacity to independently operate the systems, and the improvement of public health awareness. It also sought to build local industrial, engineering, procurement and construction capacity in order to strengthen their role in Ethiopia's water and sanitation sectors.[27]

In Latvia, renewable energy resources, notably solar power plants, have been used to produce electricity for self-consumption by water supply enterprises, reducing their energy expenses and thus reducing water prices and enhancing consumer interest in centralized water supply.[28]

TIS for empowerment of women

Issues relating to water and sanitation have an adverse and disproportionate impact on women and girls. The absence of drinking water in household premises generally causes women and girls to be tasked with water collection and treatment. TIS, which brings water closer to the home empower women by freeing them from, or at least alleviating, this duty. An example of this can be observed in the village of Ndombe (Mozambique) where a photovoltaic solar water pumping system to enhance the irrigation system that increase their crop yields. The better yield allows women to sell vegetables and fruits and increase their income and to improve their diets and reduce malnutrition.[29]

Building women's capacity is critical for better water management and for their empowerment. However, doing so in environments with entrenched traditional gendered roles is often challenging. The USAID Passages UPWARD project nevertheless shows it is possible to empower women in decision making process on water management (USAID, 2021). Through a targeted series of workshops supported by appropriate materials, real success was observed in participating villages. Women's participation in decision-making and water management increased significantly. Other successes using different tools include the World Bank's intervention in Bangladesh where micro-financing and sanitation grants for household WASH facilities have had empowering outcomes. (World Bank, 2021). Upscaling and mainstreaming remain a challenge, but these represent encouraging starts.

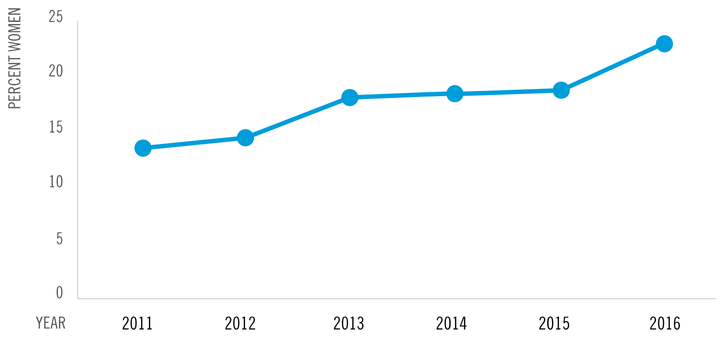
For women and society at large, in addition to now much higher levels of water security, women and girls are freed from the burden of fetching water for the household and are now able to be more active in the local economy or education. Empowered women in turn can enhance the development of their families, economies, and societies.

[27] Contribution from UNIDO
[28] Contribution from the Government of Latvia
[29] Contribution from UN Women.

Box 3: Women in the water system

The World Bank report 'Women in Water Utilities breaking barriers" (World Bank, 2019) engages the key challenges for women in a major operational theatre of the water sector – the Utilities. While the participation challenges prevail, notable movement in women's participation is noted as illustrated in a graph from the report below.

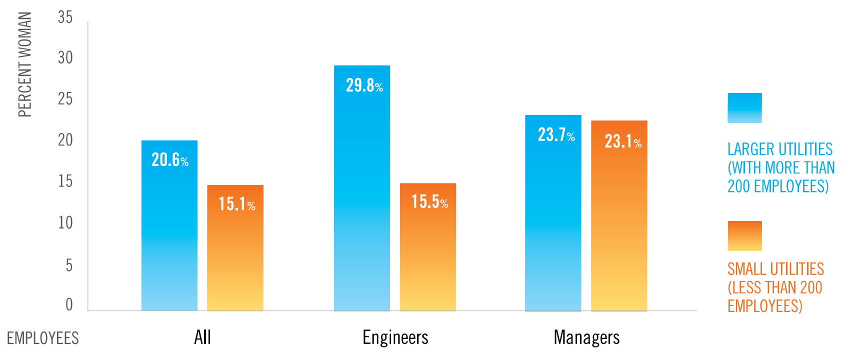
Figure 13: Trends in share of female workers in water utilities



Source: (World Bank, 2019)

Using data for the period 2011-2016, the report finds an increased women's percentage of the total annualised workforce with a steady upward trend albeit from a very low baseline.

Figure 14: Average share of employees in a water utility that are women, 2018-2019



Source: (World Bank, 2019)

The distribution of female employees indicates that larger utilities have a better capacity and willingness to accommodate more female employees in the technical domains, for instance as engineers, compared to smaller utilities. At the management level, the willingness to recruit women to higher echelons is similar across large and small utilities.

The World Economic Forum Gender Gap Report 2022 estimates that gender gap has been closed by 68.1% but finds that at the current rate of progress it will nevertheless take 132 years to reach gender parity (WEF, 2022). Given the current situation in the water sector, its journey to parity is likely to take even longer unless catalytic transformation measures are put in place. Promoting girls' entry into education and the water industry's demand for female workers is likely the most effective remedy.

Sustainable water management for agriculture and food security

Water resource development and management are at the heart of sustainable growth and poverty alleviation. Water is linked to a multitude of pressing global challenges (World Economic Forum, 2022). It is an input to almost all production, being crucial to agriculture, industry, energy, and transport. It interacts with these systems through interdependence, constraints, and synergies. Agriculture, for example, accounts for 70% of water withdrawals worldwide, although this share varies considerably across countries. By 2050, world agriculture will need to produce 60% more food globally, and 100% more in developing countries (UN-Water, 2022). This means either an increase in the amount of water abstracted for irrigated agriculture at an opportunity cost for other uses, notably for drinking but also for industry, or an improvement in the efficiency with which water is used for agricultural purposes. Growing demand for water has already intensified competition for water resources by agricultural, industrial, and domestic users, leading to increased stress on aquatic and wetland ecosystems.

The agrophotovoltaics for Mali and the Gambia (APV-MaGa) project provides a case study in the use of STI in water management for food security. The project is exploring the potential for solar systems to improve access to water not only for drinking but also for agricultural purposes, and thus for food security. The project has explored how efficiency and sustainability in water usage can be maximized via intelligent systems incorporating smart sensors, microcontrollers, and the Internet of things. Real-time data access will aid the monitoring of weather, water demand and water allocation in the agriculture fields.[30]

More efficient and productive use of water is essential to mitigate water scarcity, increase food security and raise the incomes of smallholder farmers. The Food and Agriculture Organization of the United Nations and the Agricultural Water Partnership for Africa are developing evidence-based methods and best practices, and investing sustainable agricultural water management in Burkina Faso, Morocco, and Uganda. They link concrete efforts with national and continent-wide political processes (Swiss Agency for Development Cooperation, 2022).

Inefficient water use, water pollution, climate change and increasing global water demand put agriculture under pressure, for commercial producers and smallholders alike. The Swiss Agency for Development and Cooperation (SDC) is building on successful experiences in this domain in providing 5.5 million CHF to support projects in Africa in ecologically sustainable water management in smallholder agriculture and food systems (Swiss Agency for Development Cooperation, 2022). Similarly, the Russian government has implemented Schemes of Comprehensive Use and Protection of Water Objects (SCUWO) by employing scientific and technological approaches to water management. The project constitutes the basis of the water management of water reservoirs located within the boundaries of river basins. SCUWOs are developed to assess the admissible anthropogenic load on water objects; identify the needs for water resources in the future; ensure the protection of water resources; and specify the main areas of activity to prevent the negative impact on water reservoirs.[31]

[30] Contribution of the UNU-EHS.
[31] Contribution from the Government of Russia

Social innovation for integrated water resources management

While technological innovation is of great significant in assisting countries to efficiently and effectively conduct integrated water resources management, social innovation is important and necessary to ensure a sustainable management. In Kenya, social innovation spurred the development of a participatory solution to improve the access to clean water in Nairobi's informal settlements through community bio-centers (Wamuchiru and Moulaert, 2018).

The initiative is grounded in bottom-linked governance through the collaboration of community-based groups and a human rights organization engaging in negotiations with state agencies for the satisfaction of water and sanitation services. At the same time, community groups carried out grassroots awareness-raising campaigns and mobilization workshops involving technical training and infrastructure construction, while members of the community were integrated into the water and sanitation service management.

3.2.3 Frontier technologies for water and sanitation

In many cases, simple and well-established solutions in water management can be used to address primary access to clean water and sanitation such as delivering drink water solutions to the populations. However, other aspects of management of water and sanitation may require new and emerging technologies. In this part, frontier technologies like drone, artificial intelligence, space application, and other technologies are discussed with respect to their potential for achievement of SDG 6.

Drone technology applications

Drone technologies can provide aerial views to assist in water and sanitation management, notably in the event of natural disasters. In Belize, drones have been used in the hydrological sphere to observe the spatial extent of flooding event. The country has also relied on drone technology as a reconnaissance tool when seeking to identify ideal locations for the placement of monitoring stations. Meanwhile, in Gambia, drones and Early Warning Systems have been used in for pre- and post-flood disaster efforts to help undertake long-term climate risk assessments and to update outdated and inaccurate topographic data.[32]

Drones are also readily used by some countries to monitor water quality and monitor infrastructure. In the Dominican Republic, the National Institute of Potable Water and Sewage (INAPA) relies on drone technology for data management, information exchange and decision making for the design, redesign, treatment, and maintenance of drinking water and sanitation systems. Similarly, Peru's National Water Resources Policy and Strategy proposes the use of drones to monitor and improve water quality and its efficient use due to their key advantages when it comes to providing observations of inaccessible areas of water bodies and vulnerable sites.[33]

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[32] Contribution from the Government of Belize and Gambia
[33] Contribution from the Government of Peru.

AI, big data, Internet of things, and other technological applications

Data and digital infrastructure in water and sanitation management are catalysts for accelerating achievement and monitoring progress on SDG 6. In the Philippines, the Department of Science and Technology (DOST) is leading the effort in harnessing the power of artificial intelligence (AI) and machine learning to help curb water shortages in the east service area of Metro Manila.[34]

Another example comes from Internet of Things (IoT)-Enabled Sanitation Behaviour Monitoring in Indonesia where flow and motion sensors have been used to validate survey responses on handwashing after latrine use. Although survey responses showed relatively high levels of hand washing, the motion and flow sensors confirmed that the behavioural trainings were not having as much of an impact as reported through the survey results (Deloitte, 2020).

Improving water-use efficiency, demand management, and leakage control is one of the most urgent actions needed. Smart technologies using big data such as smart metering can provide the necessary support as they can trigger behavioral change of water users by providing them with real-time information and customized feedback. In Oman, the Leaks Diction System was created in 2020 by Oman Energy Centre to reduce the amount of waste in water resources to a minimum. The system applies the measurement through smart meters, which request no human intervention, to collect the data on water usage which resulting a significant reduction of 15% in water waste[35]. Furthermore, a study also shows that smart metering and automated leakage prevention systems installed in 40,000 households in India have helped save approximately 35% of water consumption on average (Viola et al., 2020).

In Latin America and the Caribbean, the Inter-American Development Bank has created Hydro-BID, an integrated and quantitative online system to simulate hydrology and water resources management using a combination of smart metering and the Internet of things (IoT). Under scenarios of change (e.g., climate, land use, population) the technology helps to evaluate the quantity and quality of water, inform infrastructure needs, and the design of strategies and adaptive projects in response to these changes.[36]

Nevertheless, most developing countries still require assistance and capacity building to capitalize on the technology. It is thus key that developed countries support the development of infrastructure and human capacity building in using such technology. In this respect, Japan sets an example through its commitment to sharing technology and building capacities for countries that are willing to utilize technological solutions it has developed.[37] Among others, Japan uses the advanced technologies of AI and Internet of things to support development and provide "Quality Infrastructure" in Asia and the Pacific which implements climate change adaptation and mitigation measures with various infrastructure projects such as "Quality Dams", "Quality Sewerage Systems", and "Quality Agricultural Infrastructure Improvement and Rural Development." Using AI and IoT, Japan has developed precipitation forecast and flood analysis technologies to visualize changes in local water-related disaster risks to enable the advanced operation of "Quality Infrastructure" installations.

[34] Contribution from the Government of the Philippines
[35] Contribution from the Government of Oman
[36] Contribution of the Inter-American Development Bank
[37] Contribution from the Government of Japan.

Satellite-based solutions

Satellite data enables the development of innovative to improve lives and accelerate sustainable development in many areas, water and sanitation key among them. Wider coverage of water quality observations can be obtained by satellite-based remote-sensing technology, which is suitable for near-real-time geographical coverage of water quality of inland freshwater systems, such as lakes, reservoirs, rivers, and dams, and which can detect lake eutrophication, light penetration, phytoplankton bloom, chlorophyll levels, turbidity, alongside other parameters.

Examples of good uses of such solutions are provided by Madagascar and Ethiopia. In both countries, a new methodology developed by the European Union's Joint Research Centre using both satellite remote sensing to scan and identify high potential sites for the extraction of groundwater and on-the-ground geophysics investigations has substantially improved drilling success rates. In Ethiopia, success rates rose from less than 50% to over 90%.[38] Meanwhile, in the Philippines, the Remote Sensing and Data Science (DATOS) Project developed a GIS-plugin to train and implement AI models to extract features from satellite imagery. The technology uses the agency's High-Performance Computing which can be used by public users from academic institutions as well as government agencies.

Regional Seas Conventions and Action Plans have adopted satellite-based monitoring methodologies for chlorophyll. In 2021, the Northwest Pacific Region Environmental Cooperation Centre (NPEC) successfully developed the 'Global Eutrophication Watch' for mapping coastal eutrophication on a global scale using satellite remote sensing. Eutrophication is an emerging global issue associated with increasing anthropogenic nutrient loading. The methodology applied in the Global Eutrophication Watch is part of the Common Procedure for the eutrophication assessment of the NOWPAP Special Monitoring & Coastal Environmental Assessment Regional Activity Centre (CEARAC). It will produce an interactive map of potential eutrophication area over the global ocean to help the NOWPAP Member States and countries around the world to manage eutrophication and report their progress under the 2030 UN Sustainable Development Agenda.[39]

Digital twinning

Rapid improvements in the frontier technologies have led to the deployment of a range of technologies from this toolbox to help overcome scarcity, improve safety, enhance reliability and efficiency in the provision of services through real-time management and monitoring of water and sanitation infrastructure and operations, and provide data and analytics. One interesting case study comes in the form of intelligent water management through digital twinning. Digital twinning refers to the concept of creating a virtual twin of the real asset. For instance, the Singaporean wastewater treatment plant recently completed its digital twin (Jacobs, 2020). This digital twin is a virtual replication of the installation used for real-time monitoring and thereby enabling intelligent and dynamic management and simulating scenarios for business continuity and process optimisation.

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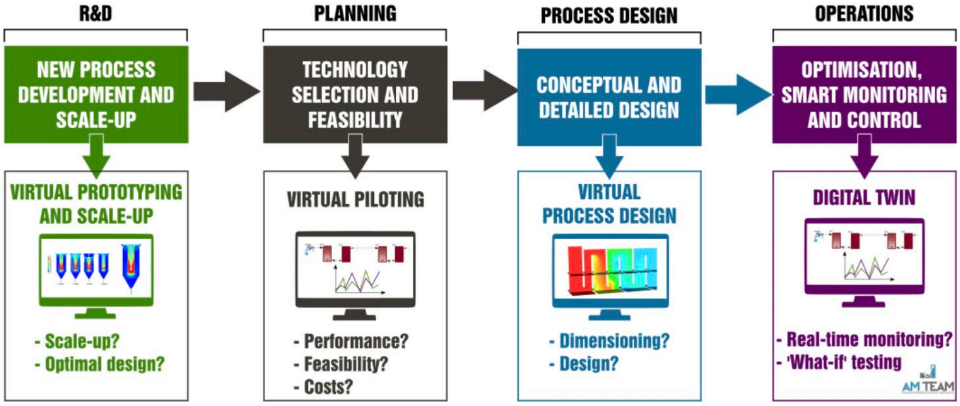
[38] Contribution from WHO
[39] Contribution from UNEP

Figure 15: Technology lifecycle and the use of digital twin model in the water industry



Source: (Audenaert, 2022)

IV. Role of knowledge and technology sharing among countries to effectively address water and sanitation challenges

In recent years, knowledge sharing has assumed the same level of importance as financial and technical assistance in the global development agenda (Janus and Karp, 2019). This is also the case when it comes to addressing water and sanitation challenges wherein the goal of achieving universal access to water can only be achieved if stakeholders from different sectors and different backgrounds come together in an inclusive way and find collective solutions to the challenge (See *Box 4*). The sharing of insights and learning from the experience of others is also important for enhancing the quality and efficiency of the formulation and implementation of water supply and sanitation initiatives. At the same time, enhancing capacities and competencies at all levels, including leveraging and building on traditional knowledge of communities, is crucial for effectively addressing water and sanitation challenges.

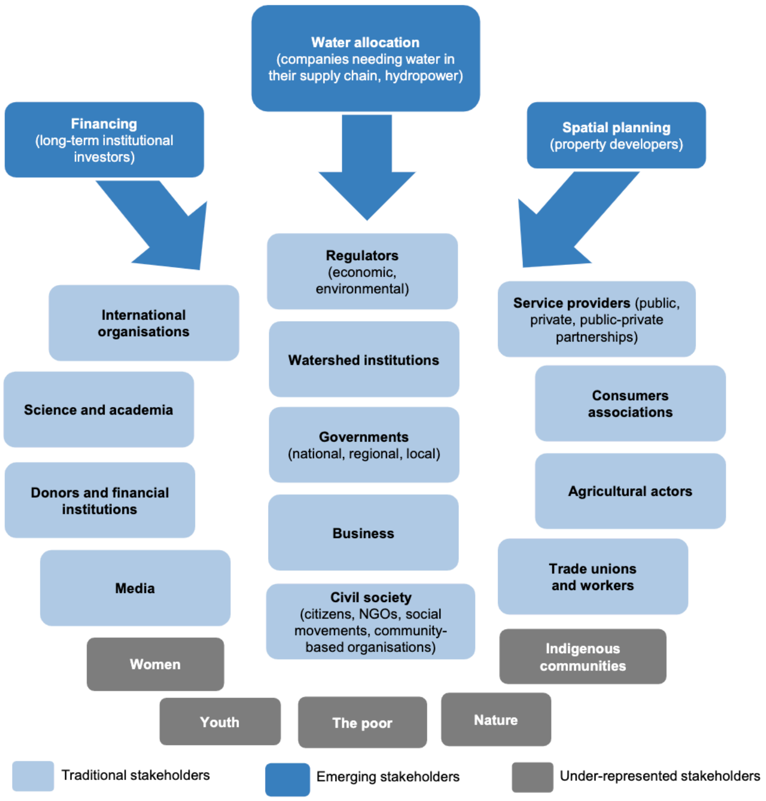
Stakeholders in the sector already understand this need. A range of global partnerships, platforms, or cooperation models have been set up under North-South and South-South, and triangular regional and international cooperation not only to support access to STI but also to enhance knowledge-sharing that fosters the scaling up of good practice domestically, and inspires replication and adaptation of successful technological, social, and financial innovations internationally. The focus of these platforms and networks includes but is not limited to facilitating learning among countries and among public and private actors in the water and sanitation sector, sharing traditional and scientific knowledge, enhancing capacity, raising awareness, reinforcing the science-policy interface, and encouraging effective partnerships.

Several actors including multilateral organisations, development agencies, and dedicated water and sanitation networks have taken an active role in developing and promoting these platforms and networks. Usually, these platforms involve partnerships and combines a web platform with an extensive network that may reach from global to local level (UN-Water, 2015). Additionally, they share knowledge and build capacity through their own programmes.

Box 4: Role of the various stakeholders in water and sanitation management

Ensuring water and sanitation for all will require greater multi-stakeholder efforts. Water supply and sanitation management cuts across hydrological and administrative boundaries and involves multiple stakeholders, from end users to local and national authorities, regulators, and civil society at large. Moreover, balancing the competing demands for water resources will have the greatest chance for success if undertaken at the relevant scale, inclusive of, and resonating with, all stakeholders (OECD, 2014). The number and type of actors varies across countries and across the public, private and third sectors of countries based on local context (see *Figure 16*). As seen from the mappings of international and national water governance frameworks in a range of countries in different parts of the world, stakeholders involved in decision-making and implementation processes related to water and sanitation vary across countries and across water governance functions from policy making, regulation and water resources management to service delivery and financing, and across national, intermediate and local levels (Human Right 2 Water, 2021: 2).

Figure 16: Major stakeholder groups in the water and sanitation sectors



Source: (OECD, 2015)

4.1 Multilateral organizations

Agencies of the UN and multilateral development banks collect resources and promote knowledge and practices, including those of STI, not only from their programmes but also from the global community. The problem of water and sanitation is an international issue, therefore, the UN is well placed to play the role of main outlet for debating and achieve agreements, and international cooperation should be strengthen to contribute to the development of infrastructures, capacity building in the area of water management, climate change adaptation, and technology transfer.[40] UN-Water, which comprises over 30 UN agencies, has the broadest thematic scope, sharing its own experiences as well as those of others. It runs the UN-Water Activity Information System (UNW-AIS), an online platform to present and share information on water-related projects and learning initiatives run by itself and its members and partners. They include UNICEF, UNESCO, UNDP, UNEP, UN-Habitat, Office of the United Nations High Commissioner for Human Rights (OHCHR), UN Department of Economic and Social Affairs (UN DESA), and UN Refugee Agency (UNHCR), and UNCTAD.

The UN Commission on Science and Technology for Development (CSTD) acts as a multilateral platform dedicated to science and technology for development in the UN system, where country can share their lessons and best practices in leveraging STI to address water and sanitation related challenges they face. Additionally, CSTD promotes international cooperation through technical assistance programmes to help developing countries in particular least developed countries, small island developing countries and land-locked developing countries to access knowledge and technology that other member States are willing to share.

The World Summit on the Information Society (WSIS) Forum and other WSIS-related processes and activities have been providing a platform to share knowledge and information, promote best practices in all segments of life, including matters of sanitation and safe water. Co-organized by ITU, UNESCO, UNDP, and UNCTAD, the WSIS Forum has create a meaningful WSIS Action Lines and SDGs, including the SDG Goal 6 that linked with WSIS Action Lines on access to information, capacity building, ICT applications e-Science, and cultural diversity and local context.[41]

The Word Bank administers the Global Water Security & Sanitation Partnership (GWSP) that supports countries to meet the targets related to water and sanitation under the Sustainable Development Goals (SDGs), particularly those of Goal 6. GWSP provides countries, other development partners, and World Bank staff with global knowledge, innovations and country-level technical support while also leveraging World Bank Group resources and financial instruments. Its mandate covers water supply and sanitation, water resources management, and water in agriculture and a broader range of themes related to inclusion, resilience, financing, institutions, and sustainability which has allowed learning and sharing on a range of topics relevant to water and sanitation including climate change; inclusion; urban sanitation; service provision in situations affected by fragility, conflict, and violence; and water supply, sanitation, and hygiene in healthcare (World Bank, 2021).

[40] Contribution from the Government of Cuba.
[41] Contributions from the ITU.

4.2 Development agencies

A number of countries focus on water and sanitation under their international and bilateral cooperation agenda. Consequently, a range of development agencies focus on knowledge and technology sharing, with knowledge sharing based both in their own experiences from development projects and in knowledge centres. Development actors such as the UK Foreign, Commonwealth and Development Office (FCDO), the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the Swedish International Development Cooperation Agency (Sida) facilitate sharing of knowledge and lessons through their publication hubs as well as programmes.[42]

But the capacity to share important knowledge and technology is not limited to developed countries: South Africa, for instance, through its Water Research Commission (WRC), has engaged deeply with multiple international partners to share its extensive expertise in water and sanitation.[43]

Another example is cooperation between the Mexican Institute of Water Technology (IMTA) and the Dominican Republic's National Institute of Potable Water and Sewage (INAPA) to provide water and sanitation in rural and marginalized communities. IMTA trained INAPA staff in the adoption of technologies for the collection, treatment, supply, consumption, and disposal of water.[44]

The United States Agency for International Development (USAID) has both programmes and a dedicated knowledge platform. It runs a knowledge platform called Globalwaters.org that acts as a knowledge hub from its water security, sanitation, and hygiene activities. Examples of its programmes devoted to generating and sharing knowledge and evidence to influence policy and practice both include the Water, Sanitation and Hygiene Partnerships and Learning for Sustainability (WASHPaLS). WASHPaLS identifies and shares best practices for achieving sustainability, scale, and impact of evidence-based sanitation interventions (USAID, 2021).

In Kenya, the World Bank has supported sanitation project in Nairobi to provide greater water and sanitation access for people in urban settlements, especially for the low-income residents.[45] Water is also a priority sector in technical assistance programmes in Africa, offered by the Swiss Agency for Development Cooperation. Concrete activities have been undertaken through Swiss Fresh Water in West and Central Africa.[46]

Regional initiatives also play important role in ensuring access to safe water and sanitation. For example, Belarus has benefited from the international and regional cooperation in this specific area through the EU Water Initiative Plus (EUWI+) for the Eastern Partnership Programme, as well as in partnership with the UNECE and WHO Regional Office for Europe and with the use of mechanisms of the Protocol on Water and Health to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes. Through the

[42] In the case of the FCDO, this hub is called Research for Development Outputs.
[43] Contributions from the Government of South Africa
[44] Contribution from the Government of Dominican Republic
[45] Contribution from the Government of Kenya
[46] Contribution from the Government of Switzerland

regional initiatives, Belarus has been intensively participating in topical national and regional reviews and capacity-building activities.[47]

Some donors, such as the Netherlands, have directed their contributions through public private partnership initiatives. The Netherlands Water Partnership is now a networking platform of companies, NGOs, government agencies, knowledge institutions and other entities in the Netherlands that actively engages in sharing knowledge and expertise from the Dutch water sector. Combined with the Netherlands Enterprise Agency (RVO), it is implementing a Water Support Programme which provides expert advisors to share policy and financial knowledge with 10 partner countries (Netherlands Water Partnership, 2022). Furthermore, in partnership with the government of India, the Netherlands supports three Indo-Dutch bilateral consortium projects under the Bilateral call on Cleaning the Ganga and Agri Water Nexus, focusing on the Hindon sub-basin region. The supported consortia are led by premier Indian and Dutch research institutions engaging in collaborative research studying the impact of agriculture on water quality and quantity in the Hindon basin of the Ganga river system.[48]

Besides donor countries, regional development banks such as the Asian Development Bank (ADB), the African Development Bank (AfDB) and the Inter-American Development Bank (IADB) support knowledge sharing and capacity building. For latter's Latin American and Caribbean Water and Sanitation Observatory (OLAS) is a digital platform that compiles qualitative and quantitative information; technical, institutional, and regulatory documents on the water and sanitation sector for each country and at the regional level; and a research and development network. Similarly, the ADB's Asia and the Pacific Water Resilience Hub is an open, online platform that brings together water experts, policy makers, resource managers, and utilities to facilitate partnerships, provide training, develop and share knowledge products, and facilitate innovation in the sector, tools, data, and digital technology.

4.3 Water and sanitation actors' networks

Several actors and networks with global, regional, and sub-regional focuses act as knowledge centres and active hubs of exchange for policy makers, utilities, and practitioners. Besides facilitating capacity development, some of these networks also lead on advocacy to enhance political commitment and governance to address water and sanitation challenges as well as to promote participation of disadvantaged and vulnerable groups in decision-making on water and sanitation issues. Partnerships and networks with such a focus include the Sanitation and Water for All (SWA) partnership, Global Water Partnership (GWP), World Water Council, Women for Water Partnership (WfWP), and the Water Action Hub.

The Water Action Hub, for instance, seeks to raise awareness, catalyze collaboration, and scale critical lessons on water sustainability and climate resilience through collaboration and knowledge sharing. Likewise, the WfWP is a partnership of women's organizations and networks from around 134 predominantly low and middle-income countries that provides knowledge exchange and learning platforms alongside regional workshops and peer-to-peer support.

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[47] Contribution from the Government of Belarus
[48] Contribution from the Government of India.

STI-based initiatives are an increasingly central focus among water and sanitation actors as they seek to effect better regional water governance. For example, the Kumamoto Initiative for Water, a regional Asia Pacific programme launched at the 4th Asia Pacific Water Summit 2022, uses the Asia Pacific Climate Adaptation Information Platform (AP-PLAT) to advise the development of climate resilient quality infrastructure.[49] Similarly, the transnational and multidisciplinary Danube River Regional Resilience Exchange co-ordination and support action network, which seeks to strengthen flood resilience in the Danube region, presents a regularly updated RDI Roadmap highlighting promising innovation opportunities for its Partners.[50]

Innovation in the form of institutional and financial mechanisms is at the heart of the Latin America Water Funds Partnership (Allianza Latin Americana de Fumdos de Agua) as it promotes public-private participation in the conservation of watersheds to improve water security. With core partners[51], it now has 26 funds operating in several Latin American countries including Brazil. Columbia, Cost Rica, Ecuador. Mexico and Peru and has benefitted over 105 000 families and has leveraged USD 240 million in Green infrastructure.[52]

Beside these major global networks, examples of successful smaller-scale international cooperation networks seeking to strengthen STI capacities are plentiful. One of these is the Transformative Innovation Policy Consortium, whose nine members are China, Colombia, Ghana, Finland, Kenya, Norway, Senegal, South Africa, and Sweden. It brings together science, technology and innovation researchers, policymakers, and funding agencies from the above countries with the aim of giving substance to a new framing for Science, Technology, and Innovation (STI) policy which it terms “Transformative Innovation Policy” (TIP). It seeks to conduct largescale policy experimentation: for instance, in South Africa, it has positioned two big water sector projects as strategic niche global experiments in innovation in sanitation and ecological water infrastructure security.[53]

Others can be found within the European Union’s Horizon Europe scientific research initiative, co-funded by the European Union and several third countries. The Water Security for the Planet (Water4All) partnership aims to reduce water stress, better protect water resources, and ensure the adaptation of water resources to global changes by 2030. The AQUACOSM-plus project is an example of an innovative project benefitting from Horizon Europe funding as it seeks to advance mesocosm-based aquatic RI by integrating the leading mesocosm infrastructures into a coherent, interdisciplinary, and interoperable network covering all ecoregions of Europe.[54]

There are thus a multitude of initiatives facilitating knowledge sharing. However, in order to accelerate our progress in the Decade of Action with the Global Acceleration Framework’s five pillars to achieve SDG 6 by 2030, there is a need to facilitate much higher levels of technology access, knowledge transfer and capacity and capability building, and to make such opportunities better structured, more organised, and less haphazard.

[49] Contribution from the Government of Japan.
[50] Contribution from the Government of Hungary.
[51] The InterAmerica Development Bank (IDB), the FEMSA Foundation, the Nature Conservancy (TNC), the Global Environmental Fund (GEF), the International Climate Initiative (IKI) and the German Government
[52] Contribution of the Inter-American Development Bank.
[53] Contribution from the Government of South Africa.
[54] Contribution from the Government of Türkiye.

V. Policy Recommendations

Water and sanitation are basic and essential human needs, hence access to water and sanitation is a human right. The SDG6 has taken a broader and integrated approach in addressing the issue of water and sanitation, going beyond simple access to these services, with a view to ensuring the sustainability of water supply and good sanitation services.

This issues paper has examined how countries in particular developing countries could utilize innovative STI solutions to address challenges in meeting the targets of SDG 6 on water and sanitation, which include improving access to and delivery of safe water, increasing the quality of water treatment, and making general advances in water and sanitation management. The process can be accelerated not only through scientific and technological approaches, but also through other forms of innovation, including social innovation, innovative policy or governance or enabling laws that encourage the practitioners and users of these services to find effective solutions. A number of policy considerations have the potential to assist countries in their efforts to harness science and technology in ensuring access to safe water and sanitation for sustainable development.

In this regard, national governments, particularly from developing countries are encouraged to:

Cultivate and empower local innovation ecosystems. A functioning local innovation ecosystem requires public and private actors to build technology acceptance and given the increasing use of digital tools, the capacity around digital mindsets and skills to use them. When choosing technology and innovation to ensure safe water and sanitation for the population, consideration should be given to the financial and geographical conditions in a community and the ability of the community to operate and maintain the technology. Given the acute and wide financing gap facing governments, priority could be given to the STI actions that can ensure value for money.

Develop close partnership with local actors on water and sanitation. Water sanitation management requires a fruitful partnership between practitioners and users. Water governance is key to water security. Building agency and capability of all actors, in particular non-state actors and vulnerable and marginalised groups that includes women, youth, disabled and indigenous peoples is of paramount importance. Governments and local authorities should encourage and assist the blossoming of grassroot- and community-led participatory initiatives to strengthen local ownership of water and sanitation services. In doing so, they should engage with community groups including indigenous and youth groups, human right associations, and environmental organizations, and foster collaboration among them.

Transform infrastructure and service delivery for gender equality. Lack of access to water and sanitation impact most negatively women and girls. Continuous piped water at the household level has the greatest health benefits and reduces women's and girls' burden of unpaid care and domestic work. Also critical for women and girls are safely managed sanitation facilities in private households, but also in public spaces – schools, transportation hubs, publicly accessible government offices, health clinics, markets, and workplaces. As such, countries should take affirmative action to alleviate gender-based burdens and discriminations, design policies and projects that include a gender lens, and partner with women rights organizations. Gender roles that may be embedded in local environments should also be addressed by promoting adequate and effective workshops.

Design sustainable and climate-friendly water and sanitation systems. Lack of wastewater management or solid waste disposal have detrimental effects on the environment. However, solutions to these issues can also have adverse environmental effects if sustainability aspects are not taken into account. It is therefore essential to consider sustainability and climate resilience when designing policies and projects. Moreover, global warming is increasingly posing substantial challenges to the provision of drinking water especially in developing countries, and long-term consideration that are cognizant of climate change should be incorporated in government action.

Revamping data infrastructure in water and sanitation. Developing countries often faces insufficient and paucity of reliable data that undermines decision-making within the sector. Therefore, there are needs to transforming existing data governance structures to ensure a more systemic, human-centric, and multi-stakeholder collaborative system to support a more comprehensive water resources assessment in planning and decision-making process.[55] Frontier technologies, such as big data, cloud, satellite, and Internet of Things, could open an opportunity in providing a reliable data collection and decision-making process in water and sanitation management.

Campaign for the use of effective low-tech tools for water and sanitation. Developing countries often do not have the means to access high-tech and costly technology to provide clean water and sanitation. Nevertheless, evidence has shown that recent developments in water and sanitation services can provide cost-effective solutions. To minimise water losses and waste, they must accept the value of, and transition to, water-smart technologies such as waterless and low water use toilet systems, more efficient irrigation, technology-based optimisation of industrial water use, and real-time operations and maintenance. This approach may also help address water and sanitation challenges in remote communities or in informal settlements.

Introduce new and more equitable financing mechanism. Finance innovation is critical to ensure water security status. Blended financing models at the macro-level combined with micro-financing for small scale operators are imperative for the creation of an enabling environment for sustainable water businesses. Micro-financing has also proven to be an effective to provide grants for households to address WASH issues. Moreover, governments should take advantage of opportunities provided by sustainable and green finance. Increasing donors' attention to water and sanitation is another means of financing. There are competing needs within a country when listing items for cooperation with donors. Given the essential role that water and sanitation plays in the economic, social and environmental spheres of a country-water is life-, priority should be given to them.

Boost scale-up of good practices. Good practices for universal access to water and sanitation and IWRM should be scaled up with support from the governments, fiscally or non- fiscally. Governments could conduct an assessment of the various factors that hinder or accelerate local scale-up of good practices. They should also encourage local actors to participate in international networks of cooperation where they can learn from successful actors from other countries.

[55] Contribution from the Government of Dominican Republic, Latvia, and the Philippines.

The international community, meanwhile, should consider the following:

Promote knowledge transfer and capacity building. There exist abundant knowledge and technological and innovative solutions to address the challenges in meeting SDG 6. Multilateral organizations, development agencies, and global networks of actors on water and sanitation should actively work to direct and increase the global flow of water and sanitation STI knowledge from current production centres to all member states. This should be accessible through knowledge portals, knowledge exchanges, online learning platforms, practitioner networks, and smart dissemination mechanisms.

The sharing of STI practices will also help forge new local and international collaborations, strengthening the innovation ecosystems worldwide. In addition to each organization's own platform, the CSTD, as the focal point in the UN system on science, technology and innovation for development, provides a central platform to share knowledge, build consensus and synergies between organization-wise initiatives. Moreover, capacity building efforts should also be carried out in order to ensure the long-term functioning of water and sanitation solutions. During this process, regard of the local context and respective adaptation should be taken into consideration.

Technology transfer and upgrading. The international community should promote technology transfer between developed and developing countries in managing water and sanitation. Such transfers must represent complete packages including the building of local capacity and capability to operate, maintenance, and, where needed, information as to how such technology ought to be adapted for the relevant local context. Furthermore, developed international community should support the upgrading of water and sanitation infrastructure and the development of appropriate water management in developing countries, through technology transfer, financial support, and the sharing of expertise. This might for instance involve benchmarking and sharing best practices and technologies through North-South or South-South cooperation.

Improve data on gender and WASH. To effectively monitor progress on the SDGs, the international community must cooperate to build awareness and technical capabilities to measure gender-specific indicators and disaggregated WASH data. Indicator 6.1.1 which monitors progress towards target 6.1 on safe drinking water for all is not disaggregated by gender. Conversely, target 6.2 does explicitly recognize that women and girls have specific sanitation and hygiene needs. However, indicator 6.2.1 does not currently track whether efforts to expand access to safely managed sanitation respond to those needs by disaggregating by gender. If progress towards safe water and sanitation is to be monitored for all, improved gender-disaggregated data and gender statistics are needed.

Strengthen international network and provide financing for developing countries, especially countries in special situation (LDCs, LLDCs, and SIDS). The international community must be supportive of stakeholders' participation in international networks and programmes to build their capacity in addressing challenges in ensuring safe water and sanitation. The network is also best placed to pool and provide financing to countries in need, to develop their national capacity and relevant technology in the effort to ensure safe water and sanitation to all population.

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