unicef for every child office of innovation

INNOVATION NODES: INSIGHT REPORT NO. 5

WASH

emerging technologies and innovations

Collaboration with the Institute for Sustainable Futures, University of Technology Sydney and The London School of Hygiene & Tropical Medicine (LSHTM)

OVERVIEW

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Publications produced by the Office of Innovation aim to facilitate the exchange of knowledge and stimulate discussion. The findings, interpretations and conclusions expressed are those of the researchers and authors, and do not necessarily reflect UNICEF policies or approaches.

ACKNOWLEDGEMENTS

This Insight Report is result of an Innovation Node collaboration with the Institute for Sustainable Futures, University of Technology Sydney (UTS-ISF) and The London School of Hygiene & Tropical Medicine (LSHTM). The report was produced by UNICEF Office of Innovation, under the guidance of Tanya Accone, Robyn Lui, and Megan McLaughlin. Authors were Melita Grant, Clare Perry, Alexandra Butler and Melita Jazbec from UTS-ISF with Jane Wilbur from LSHTM.

This work was made possible by the generous support of the Ministry of Foreign Affairs of Denmark and UTS-ISF.

Gratitude is extended to the following reviewers, David Duncan and Esther Shaylor of the Sustainable WASH Innovation Hub in Copenhagen, Denmark, and Thomas Davin of UNICEF's Office of Innovation.

Suggested citation:

Grant, M., Perry, C., Butler, A., Jazbec, M., and Wilbur, J. (2025) WASH: emerging technologies and innovations. Insight Report No.2, UNICEF Office of Innovation, New York, 2023. License: CC-BY 4.0

Abbreviations and acronyms

ABR	Anaerobic baffled reactor
AOP	Advanced oxidation processes
ARB	Antibiotic resistant bacteria
AS	Activated sludge
CBS	Container Based Sanitation
CW	Constructed wetland
GAC	Granular activated carbon
GWP	Global Water Partnership
HCF	Healthcare facility
ICU	Intensive care units
IPC	Infection, prevention, and control
JMP	Joint monitoring program
LMIC	Low- and middle-income countries
MBR	Membrane bioreactor
O&M	Operation and maintenance
PAC	Powder activated carbon
SODIS	Solar water disinfection
SDGs	Sustainable Development Goals
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
UTS-ISF	Institute for Sustainable Futures, University of Technology Sydney
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization
WPR	Western Pacific Region
WRM	Water Resources Management

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SUMMARY

This report explores the role of water, sanitation and hygiene (WASH) emerging innovations and technologies to advance Sustainable Development Goal 6 (SDG6) with a focus on children's rights and universal design principles in the context of a changing climate. Innovations presented in this report are not limited to technologies, but also encompass innovative ways to strengthen the WASH system including Gender, Equality, Disability and Social Inclusion (GEDSI), use of artificial intelligence, behaviour and blended finance. Furthermore, opportunities emerging from circular economy practice and application of circular economy principles are also highlighted and are central to sustainable innovations.

Key messages:

- Safely managed WASH is key to human development and wellbeing. The world is not on track to achieve the Sustainable Development Goal 6 by 2030 - ensuring access to water and sanitation for all. Innovative approaches, underpinned by circular economy and universal design principles are important and needed to help reach SDG6 and other related goals.
- A child rights-based approach to WASH would improve the quality, accessibility and reliability of services including universal healthcare, education, maternal health, while reducing multidimensional poverty and lowering emissions that contribute to the climate crisis.
- Our challenge is to provide affordable, safely managed WASH for all while reducing greenhouse gas emissions and increasing resilience in the face of climate change. Innovative approaches to combining renewable energy and WASH systems are emerging, as well as mitigating emissions caused by sanitation. In addition, circular

economy principles should be considered in relation to use of resources as well as impact of technologies on the environment.

- WASH technologies and infrastructure in many contexts suffer from a lack of operation and maintenance, which limits the effectiveness of many investments in WASH. It also potentially creates wastes and pollution if end-of-life solutions are not considered and in place. A life-cycle approach is needed to ensure operations and maintenance are prioritised and waste is minimised.
- The WASH sector is foundational to all other SDGs. Human and environmental health and wellbeing including gender equality, disability and social inclusion cannot be achieved without WASH. SDG6 is therefore cross-cutting, facilitating acceleration and achievement of other SDGs.

This report canvasses examples of innovations in:

- WASH technologies
- WASH and artificial intelligence (AI)
- Gender Equality, Disability and Social Inclusion (GEDSI)
- Behaviour change in WASH
- Innovative WASH finance

“Technology is not at the heart of system innovation; reframing is.”

Leadbeater and Winhall, 2020

About this Insight Report

This report explores novel and emerging technologies, governance and innovations in the WASH domain with potential to improve WASH accessibility and affordability to all in the future, especially underserved and marginalised communities. The goal of this report is to highlight emerging WASH technology opportunities to accelerate SDG 6 (clean water and sanitation for all), while considering that the innovations are sustainable.

The context for the innovations described in this report is the WASH system - a complex network of actors and processes that contribute to the infrastructure, policies, behaviours, regulation and maintenance of water, sanitation and hygiene infrastructure. Without a deep understanding of the system and its political economy, WASH technologies will fail and/or not be sustained[i]. It is therefore assumed that underpinning any choice of technology, a comprehensive assessment of the local capacity to operate and maintain systems and the governance of the context is undertaken and used to inform choices in innovations.

Scope

The report provides examples of, and explores:

- WASH technologies
- WASH and artificial intelligence (AI)
- Gender Equality, Disability and Social Inclusion (GEDSI)
- Behaviour change in WASH
- WASH finance innovation

Across all these WASH domains, circular economy principles and opportunities are sought and identified where available. Additionally, climate resilient opportunities are prioritised, although this will be contextually specific to each location based on the climate hazards relevant to that location.

1

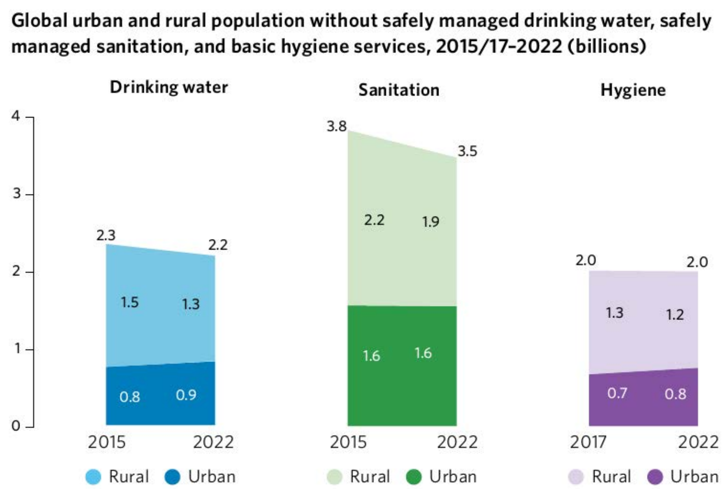
INTRODUCTION

Water, Sanitation and Hygiene (WASH) are foundational to all the Sustainable Development Goals (SDG), because without water and sanitation, no other sector can function optimally. SDG 6 calls to “clean water and sanitation for all”. Despite great progress, billions of people still lack access to safe drinking water, sanitation and hygiene. Achieving universal coverage by 2030 will require a substantial increase in current global rates of progress: sixfold for drinking water, fivefold for sanitation and threefold for hygiene.[ii]

Ensuring access to affordable, reliable, sustainable and safely managed WASH for all will unlock possibilities for millions of people through better health and wellbeing; empowered women, children and youth, and people with disabilities; better education; more sustainable and equitable communities; and greater resilience to climate change. But as Figure 1 illustrates, the world is falling short of achieving the targets set for SDG 6 on WASH. Between 2015 and 2022, the proportion of the world’s population with access to safely managed drinking water services increased from 69 to 73 per cent; safely managed sanitation services increased from 49 to 57 per cent; and basic hygiene services increased from 67 to 75 per cent. [iii]

Figure 1. Global and rural population without safely managed drinking water, safely managed sanitation, and basic hygiene services, 2015/17-2022 (billions).

Source: United Nations, 'The Sustainable Development Goals' Report, 2023.



WASH sector building blocks

The WASH sector building blocks have been identified as essential elements of the WASH system, of which WASH technologies contribute to and depend on. Without these elements being robust, transparent and resourced, WASH technologies will fail and/or not be maintained or sustainable. The building blocks as defined by the Sanitation and Water for All initiative include: sector policy strategy, institutional arrangements, sector financing, planning monitoring and reviewing, and capacity development Figure 2.[iv] These building blocks are underpinned by social and political factors including behaviour change, community engagement and uptake of WASH options.

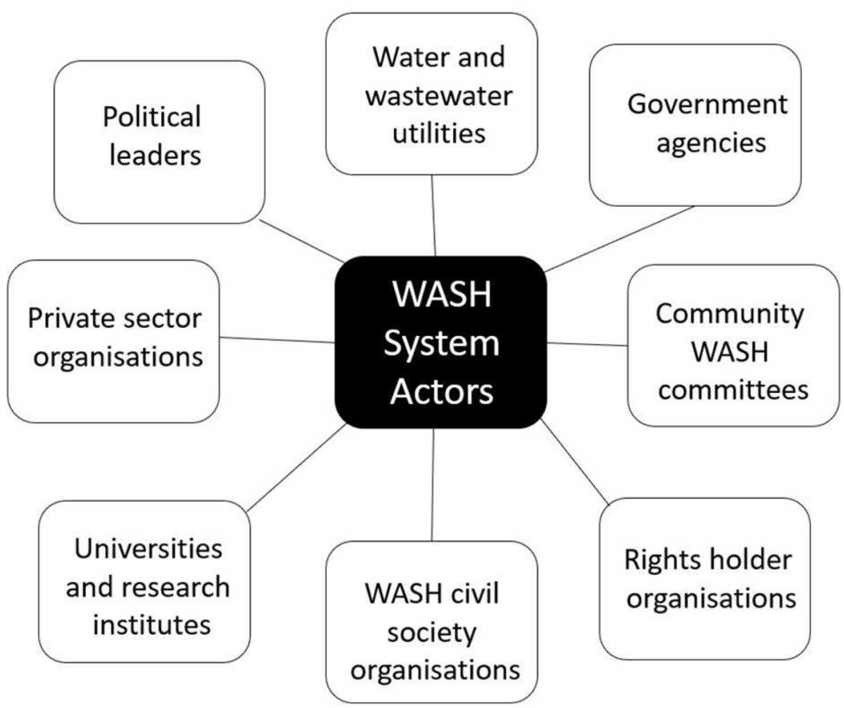
Figure 2. How technologies, behaviour change and WASH sector building blocks fit together.

Source: Adapted from Sanitation and Water for All by Authors.

Governance of the WASH system involves a broad range of actors and systems. Innovations in engaging these actors in new and novel ways are key elements of innovation in the WASH system. Figure 3 provides an overview of some of the prominent actors involved in governing and delivering WASH services. Each of these actors contributes to the WASH system, including WASH technologies choice, financing, governance and uptake

Figure 3. WASH system actors.

Source: Grant *et al* (2023).



> “To understand how decisions are made in WASH systems we need to look beyond formal or visible power to consider who else has influence, and what social and cultural norms constrain or perpetuate power imbalances. Besides the ‘traditional’ WASH authorities, other political, social and economic actors, including CSOs, hold hidden power and influence to set the agenda in WASH decision-making. Working with, and through, these actors is one pathway to advocate for greater diversity and inclusion in WASH systems.”.

Universal design principles

Universal design principles are fundamental to ensuring WASH facilities and services are accessible and usable by everyone, regardless of age, ability, or circumstance. These principles go beyond basic accessibility requirements to create solutions that work better for all users - whether they are children, older adults, pregnant women, people with disabilities, or those with temporary injuries. In WASH infrastructure, universal design means considering features like appropriate height and spacing of facilities, sufficient lighting, non-slip surfaces, clear pathways, easy-to-operate taps and handles, and adequate space for caregivers. For example, a toilet facility designed with these principles might include handrails that serve multiple purposes - supporting people with mobility challenges while also providing a place for others to hang belongings safely off the floor. When universal design is incorporated from the planning stages, it often costs the same or only marginally more than conventional designs while creating more sustainable, inclusive solutions that benefit entire communities. This approach is particularly important in humanitarian and development contexts where retrofitting facilities later can be costly and technically challenging.[v]

Figure 4. The 7 principles of Universal Design applied to a door handle lever.

Source: North Carolina State – The Center for Universal Design: The Principles of Universal Design

Child rights-based approach and child sensitive response

The application of a child rights-based approach to WASH requires the full consideration of all children's rights under the *Convention on the Rights of the Child* and the *Optional Protocols*. The process of realising children's rights is as important as the result. From this perspective, access to safely managed WASH is both a human right itself and necessary for the full enjoyment of a broad range of children's rights such as education, health and wellbeing.

Virtually every child on earth is affected by climate change, environmental degradation and biodiversity loss. At the same time, where WASH is lacking or unreliable, women, children and young people pay the highest price. UNICEF recognises the connection between WASH and the realisation of child rights as outlined in *UNICEF's 2022-2025 Strategic Plan*. UNICEF's strategy emphasises the urgent need to strengthen the services and systems (such as WASH) that children need to survive, grow and thrive in the face of climate and environmental threats, including broader disaster risk reduction.

UNICEF's 2016-2030 Strategy shows where UNICEF is contributing and leading in a range of WASH related development arenas (Figure 5).

Figure 5. UNICEF's Strategy for WASH (2016-2030): A Snapshot [2].

Source: UNICEF's 2016-2030 Strategy

UNICEF's integrated child-sensitive response includes:

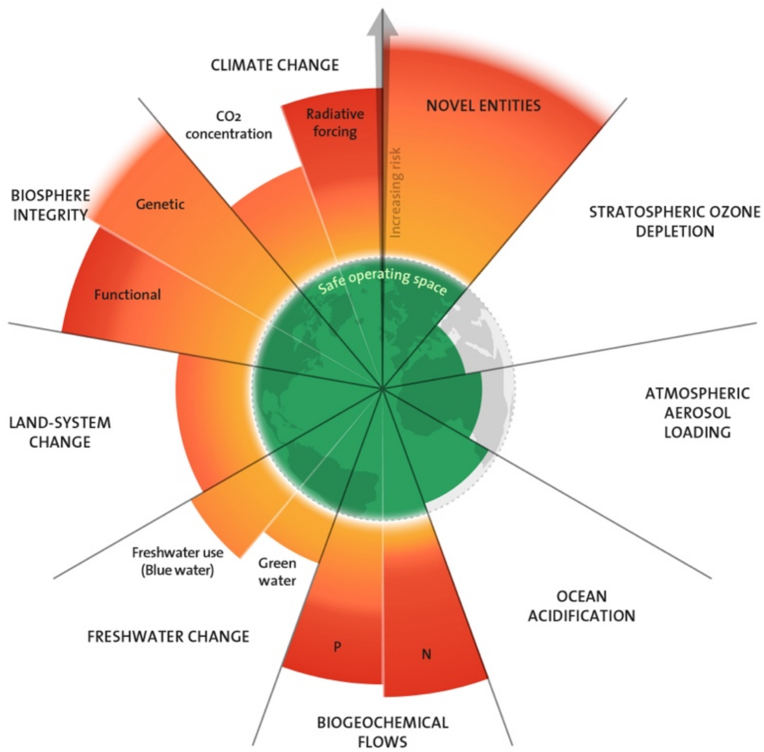
- strengthening the resilience and continuity of social services to climate and environmental impacts, including disasters,
- supporting and empowering children and young people to adapt and create a better world,
- advocating with governments and business partners to put children first in their own sustainability plans, budgets and actions towards a green transition,
- building on UNICEF's strengths in innovation to explore, pilot and scale a range of climate and disaster risk mitigation and adaption solutions,
- generating evidence to support decision-making and prioritisation, and
- ensuring that the organisation embody sustainability within its own global programming, operations, and supply chain.

Circular Economy

Increasing resource use has been the main driver for the triple planetary crisis[vi]: climate change, nature and biodiversity loss, and generation of pollution and waste. The increasing use of unsustainable material and prevailing linear economy practice of take-make-use-dispose has also contributed to the crossing of six of the nine planetary boundaries[vii]. The planetary boundaries are the safe limits for human pressure on the nine critical processes which together maintain a stable and resilient Earth (see Figure below). To reverse these impacts the way we manage resources, make and use products, and dispose of materials needs to be transformed. Circular economy, based on three principals: designing out waste and pollution, keep products and materials in use, and regenerate natural systems[viii], provides and alternative economy model. It aims to redefine growth, focusing on positive society-wide benefits while restoring natural systems. It entails decoupling economic activity from the consumption of finite resources and designing waste out of the system.

Figure 6. The Planetary Boundaries (2023 update)

Source: Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023.

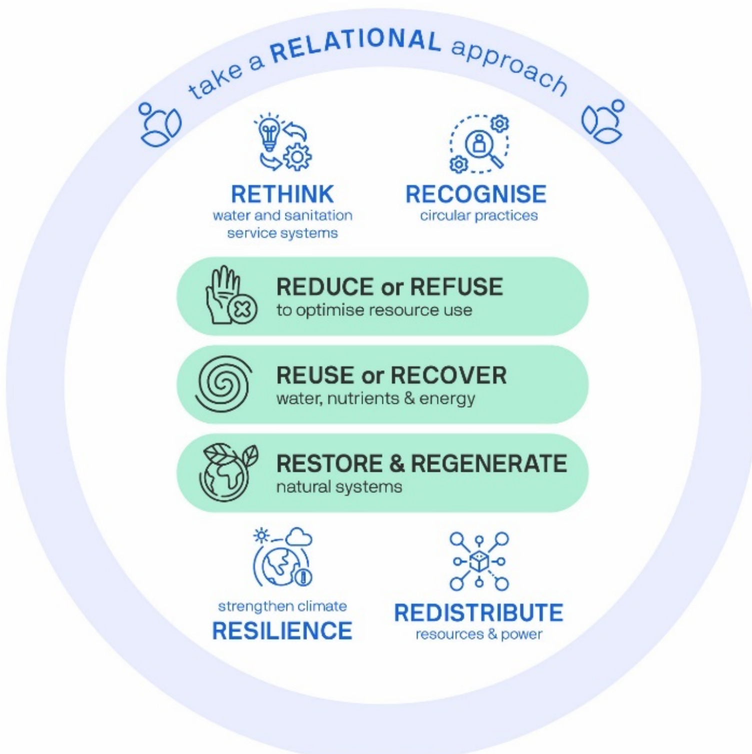


High income countries use six-times more materials per capita and are responsible for ten times more climate impacts per capita than low-income countries. However, it is possible to reduce use of resources in the high-income countries while increasing the use in low-income countries. The policies and actions on resource efficiency, climate and energy, food and land, can also reduce economic inequalities and boost global income growth[vi].

The paper "8Rs for circular water and sanitation systems" presents a conceptual framework designed to apply circular economy principles to water and sanitation services. The framework is structured around eight adapted circular economy 'R strategies': reduce, reuse, restore, rethink, recognise, resilience, redistribute, and relational. The first three strategies focus on practical actions to minimise resource use, promote the reuse of materials, and restore ecosystems. The remaining five strategies emphasise the importance of rethinking traditional approaches, recognising the value of diverse perspectives, building resilience, redistributing resources equitably, and fostering relational connections among stakeholders (Figure 7)[ixx].

Figure 7. 8Rs for circular water and sanitation, comprising three practical R strategies (reduce, reuse, restore) and five strategies related to dimensions of purpose and process (rethink, recognise, resilience, redistribute, relational).[1]

Source: Carrard et al. (2024). 8Rs for circular water and sanitation systems, Environmental Development, 52, Article 1010893



By integrating the eight strategies (as shown in Figure 7), the framework seeks to drive multiple outcomes relevant to water and sanitation programmes, including safe management, social inclusion, and climate resilience. The approach highlights the potential of circular economy concepts to facilitate regenerative resource flows and enhance sustainability in water and sanitation systems. The framework can be used for ideation of locally appropriate circular economy water and sanitation opportunities, and as a guide for assessing and planning implementation[xi].

There is value in adopting a circular economy approach in servicing water and move away from linear approaches in extracting freshwater, treatment, use and disposal practices, where biosolids are disposed to landfills and or oceans and the services delivered discretely and in isolation.[xii] Adopting circular economy principles for water, considers waster use and associated resources (energy, nutrients and minerals) together, reducing the impacts and delivering restorative and regenerative outcomes Figure 7. Therefore, there is an opportunity in the technological development and innovation to implement the circular economy principles while transitioning to innovative practices.

Methods

Technologies and innovations were identified following a broad exploration and review of published literature sources. In addition to novelty and potential impact, technologies and innovations were selected based on adaptability, affordability and scalability. However, many technologies are at the early stages of research and development and their impact is unpredictable and cannot be guaranteed. We have drawn on Technology Readiness Levels (TRL) scale to consider the level that the technology is at in terms of research and development through to adoption (Appendix 2). The technologies in this report were also informed by WASH researchers at the Institute for Sustainable Futures and The London School of Hygiene & Tropical Medicine (LSHTM) through co-authorship and a collective workshop activity.

A literature review informed the sections related to GEDSI, behaviour change, AI and innovative finance.

Structure of this report

2

OUR WASH CHALLENGE

The world is not on track to meeting SDG 6 – “clean water and sanitation for all”. Notably: [xiii]

- Globally, 1.8 billion people live in households without water supplies on the premises.
- Globally 3.6 billion people do not have safely managed sanitation.
- Women and girls aged 15 and older are primarily responsible for water collection in 7 out of 10 such households, compared with 3 in 10 households for their male peers.
- Girls under 15 (7 per cent) are also more likely than boys under 15 (4 per cent) to fetch water. In most cases, women and girls make longer journeys to collect it, losing time in education, work, and leisure, and putting themselves at risk of physical injury and dangers on the way.

- Households with people with disabilities have less access to water and sanitation, with young children with disabilities twice as likely to suffer severe diarrhoea than those without disabilities[xiv], 7 out of 10 schools had basic water services, but 15% had no water service at all (Figure 8).
- In 2021, 7 out of 10 schools had basic sanitation service, but 13% had no service at all (no latrines at the school) (Figure 8).
- Data from 30 countries reveals that 30-40% of children with disabilities are not attending school.[xv]

Figure 8. Global and regional coverage of drinking water services in schools for 2025-2021.

Source: © UNICEF/WHO 2022

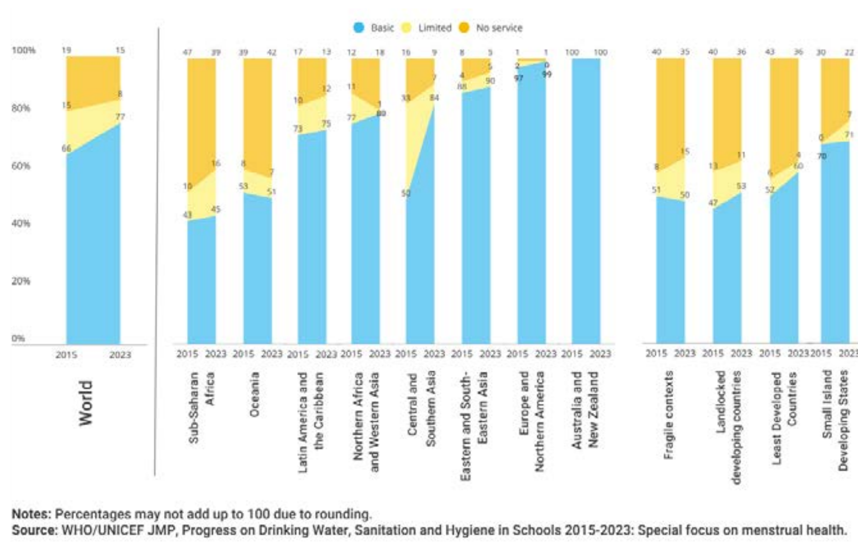
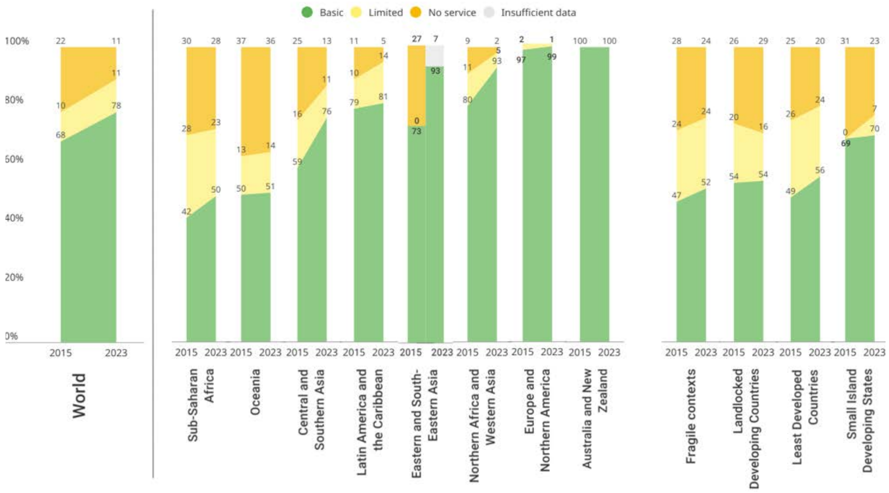


Figure 9. Global and regional coverage of basic sanitation service in schools in 2021.

Source: © UNICEF/WHO 2022



Notes: Percentages may not add up to 100 due to rounding; In Eastern and South-Eastern Asia, currently no data for 2030
Source: WHO/UNICEF JMP, Progress on Drinking Water, Sanitation and Hygiene in Schools 2015-2023: Special focus on menstrual health.

From challenge to opportunity

Our challenge as a global community is to provide accessible, affordable, safely managed water, sanitation and hygiene for all, while building climate resilience, reducing greenhouse gas emissions and reliance on fossil fuels operating within Planetary Boundaries. This needs to be achieved with gender equality, disability and social inclusion in order to ensure that no one is left behind.

Given the foundational nature of WASH, and the gap between SDGs and the current rate of achievement of targets towards these goals, acceleration in action, including uptake and maintenance of new and emerging technologies is required. For example, uptake of artificial intelligence (AI) and blended/innovative finance could support the novel technologies, but as explained above, the fundamental building blocks of governance and political commitment are also required to sustain these technologies.

The development of innovative WASH technologies presents significant opportunities to apply circular economy principles across water's multiple roles - as a vital resource, nutrient carrier, energy source, and service provider. Population growth, rapid urbanization, and climate change will dramatically increase demands on these water systems, making circular approaches increasingly critical. By viewing water through this multifunctional lens and designing technologies that maximize resource recovery and reuse, we can create more sustainable and resilient WASH solutions for the future.

The SDG 6 Global Acceleration Framework is a unifying initiative that aims to deliver fast results, at an increased scale, towards the goal of ensuring the availability and sustainable management of water and sanitation for all by 2030. Business as usual will not achieve SDG 6. The existing and future water-related challenges we face require the rapid development and deployment of innovative and transformative ideas. Launched in 2020, as a part of the United Nations Secretary-General's Decade of Action to deliver the SDGs by 2030, *The SDG 6 Global Acceleration Framework* mobilises UN agencies, governments, civil society, private sector, and other stakeholders around five cross-cutting and interdependent 'accelerators':

- **Financing** - Optimised financing is essential to get resources behind country plans.
- **Data and information** - Data and information targets resources and measures progress.
- **Capacity development** - A better-skilled workforce improves service levels and increases job creation and retention in the water sector.
- **Innovation** - New, smart practices and technologies will improve water and sanitation resources management and service delivery.
- **Governance** - Collaboration across boundaries and sectors will make SDG 6 everyone's business.[xvi]

Safely managed WASH will help improve the accessibility and quality of services, such as education, health and nutritional outcomes that children rely on for their survival, development and wellbeing. This is especially the case for children who are displaced by conflict or environmental and climate disasters. Without access to safely managed WASH, children cannot go to school safely, study to improve their opportunities in life, reach their potential especially if they suffer from WASH related stunting, and particularly girls and women.

What we want to know

The following questions have guided the development of this report:

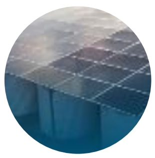
- What kind of technologies and innovations could advance WASH for all, particularly for children and communities in low-resource rural/remote settings?
- How might we accelerate SDG 6 and decelerate the climate and environmental crises through harnessing novel and emerging technologies, AI and blended finance in the climate resilient WASH domains while considering and applying circular economy principles?
- What is the potential impact of novel and emerging renewable WASH sector innovations (including GEDSI, technologies, governance and finance) for children and the humanitarian and development sectors?

Types of innovation

This report draws on the categories of innovation as developed by UNICEF including:

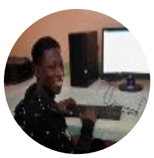
Digital innovation

New or existing digital technologies that are adapted into real-time monitoring, apps and online platforms.



Physical products

New or improved physical goods created to meet the needs of children and young people.



Innovative finance

Non-traditional mechanisms of raising resources to meet children's needs e.g. bridge funds, blended finance, innovation funds, blended finance, cryptocurrency, transactional financing.

Programme approaches

Different approaches, processes and ways of working to improve effectiveness/efficiency (e.g., human-centered design and systems thinking, GEDSI and governance approaches).

Data innovation

Use of new or non-traditional data sources and applications of data science to gain new insights including through predictive analytics.

Frugal innovation

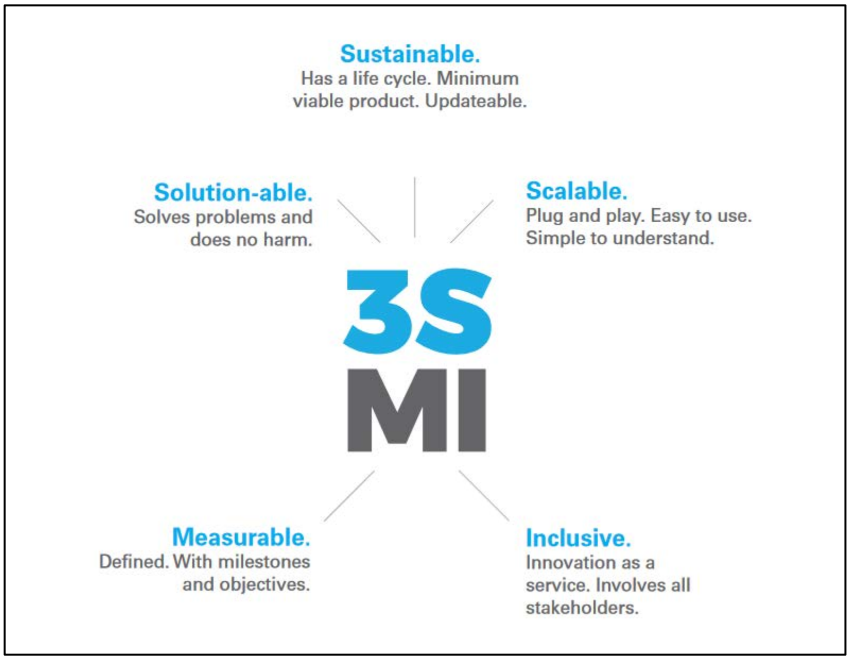
Simple products or services that dramatically cut costs, outperform alternatives and can be scaled up (e.g., soapy water and rainwater tanks in certain contexts).

Social innovation

New solutions that simultaneously meet a social need (more effectively than existing solutions) and lead to new or improved capabilities and relationships and better use of assets and resources. Social innovations are both good for society and enhance society's capacity to act.

Figure 10. 3SMI

Source: UNICEF 2020



UNICEF uses the 3SMI lens (above) to scrutinise and prioritise innovation activities throughout the organisation. This lens allows UNICEF to assess innovations based on common criteria, and is aligned with existing principles.

3

OPPORTUNITY: WASH TECHNOLOGIES

There are many dimensions and contexts for WASH technologies and innovations, and in the following chapters each example is categorised based on which WASH element it relates to in terms of water, sanitation and hygiene. The proceeding sections outline some of the underpinning and enabling innovations necessary to support and bring effect to technologies. These include artificial intelligence (AI), Gender Equality, Disability and Social Inclusion (GEDSI), Behaviour change in WASH and WASH finance innovation.

While consideration for the carbon footprint is increasingly considered in the water sector, an aspect often not considered in the water sector innovations, particularly delivering solutions for the developing countries, is the circular economy and its principles. Circular economy is still associated predominately with material recycling, therefore even in the water context applies to water recycling or in some wastewater treatment cases generation of energy. There is however an opportunity for the developing countries to adopt resource efficient and circular practices in innovation and not just implement solutions that have been developed for developed counties, specifically when they are complex to operate and introduce a waste stream for which are no local end-of-life solutions.

Action required to align the circular economy with climate actions and SDGs agenda in the developing countries include[xvii]:

- integration of circular economy with the existing policy priorities, assuring resilient economic growth with opportunities for vulnerable people
- investments that also support transition to the circular economy, ensuring sustainable and circular waste management
- inclusive in the global circular economy efforts with trade and cooperation

Table 1 presents a summary of the technologies and innovation canvassed in the following sections.

Table 1. Technologies and innovation canvassed from WASH aspect.

WASH aspect	Technologies and innovations canvassed in this report
Water technologies	• Augmented reality for water system planning • Solar stills and humidity catchments • Non-lab water quality monitoring methods • Internet of Things (IoT) for monitoring water levels • Real time water tank and bore monitoring • Deep water drilling • Solar chlorine production • Hydropanels (atmospheric water generation) • Ultrafiltration • Managed Aquifer Recharge (MAR) • Professionalised maintenance • Opportunity: sanitation technologies
Sanitation technologies	• Sky Latrine • Net zero toilet device • Vacuum toilets • Gates Reinvent the Toilet • Container-based sanitation • Urine diversion

	• Modern dry composting toilets • Sanitation in cold climates • Nature based solutions • Self-care and incontinence products
Hygiene technologies	• Reusable period underwear and products • Handwashing with soapy water • Health and hygiene disposal mechanisms
Climate change mitigation and WASH	• Solar desalination • Mitigating sanitation emissions
WASH and artificial intelligence	• AI and Water supply • Smart sanitation systems • Continual operation and maintenance • Water quality monitoring and public health protection • Climate resilience and water security • Education and behaviour change • WASH AI
Gender Equality, Disability and Social Inclusion (GEDSI)	• Intersectionality • Transformative approaches • Partnerships with Rights Holder Organisations • Innovations in inclusion within the WASH sector itself

"Incontinence products are essential for my child's independence, relationships and self-esteem."

George, Democratic Republic of Congo

Behaviour change in WASH	• Nudge theory in handwashing • Behavior-Centreded Design (BCD) • mHealth Interventions • Social marketing approaches • Participatory Hygiene and Sanitation Transformation (PHAST)
Innovative and Blended WASH Finance	• Project Wave • Supporting entrepreneurs with blended finance • Revolving Fund for Sanitation (RFS)

4

OPPORTUNITY: WATER TECHNOLOGIES

This section examines water technologies across three key domains: digital systems, water quality testing, and water quality improvement solutions. While these technologies offer promising solutions, their effectiveness and appropriateness depend heavily on local contexts and enabling environments such as governance structures, technical capacity, and infrastructure.

These technologies align with circular economy principles through their focus on resource efficiency and sustainability enhancement. However, a significant challenge lies in their end-of-life management, particularly for digital components that become electronic waste. Many of these technologies contain complex materials and components that are difficult to recycle or safely dispose of in resource-constrained settings. To address this challenge, implementing robust product stewardship schemes and extended producer responsibility (EPR) programmes is crucial. Such frameworks ensure manufacturers and suppliers take responsibility for the entire lifecycle of their products, including proper disposal or recycling, thereby reducing environmental impact and promoting more sustainable technology choices.

Augmented reality for water system planning

Augmented reality (AR) technology offers a unique way to provide communities and WASH organisations with an "x-ray" view of underground water and sewerage networks. It could also be used for visioning new WASH infrastructure by bringing designs, options and WASH concepts to life visually. This innovative approach not only helps communities understand the specifics of water and sanitation projects but helps people to imagine what they would look like in context. AR could serve as an educational tool to inform people about the long-term functionality and maintenance of water and sewerage infrastructure. Urban Utilities has recently trialed this technology in Brisbane, Australia in a mall context to educate local people about water and sewerage works happening underground and the benefits of these to the community.[xviii xix] To access the augmented reality experience, users scan a QR code on local signage with their smartphone or tablet, download the relevant application, and begin exploring the hidden infrastructure beneath them.

AR technology has a broad range of applications, including urban and rural water management, sanitation projects, schools, and healthcare facilities. It is currently at Technology Readiness Level 9, indicating early adoption on a small scale.

There are several potential benefits of this technology. It can enhance community engagement and education by providing a clearer understanding of underground or planned/designed infrastructure, which in turn could improve the management and maintenance of these systems, reducing the need for disruptive excavation work. In developing contexts, AR could help inform both planners and communities about infrastructure options, allowing for valuable feedback on which options are most acceptable and sustainable. This feedback can ensure that the chosen solutions are more likely to be used, operated, and maintained effectively.

However, there are also potential challenges to the widespread adoption of AR technology. Access to smartphones and tablets can be a barrier in certain areas, particularly in low-income regions. In many of UNICEF's operational contexts, limited access to technology could constrain the effectiveness and reach of augmented reality solutions. [xx] Additionally, these technologies potentially also contribute to the increasing e-waste stream for which there are limited recycling opportunities, so the whole lifecycle of these products needs to be considered along with operational and maintenance aspects.

Solar stills and humidity catchments

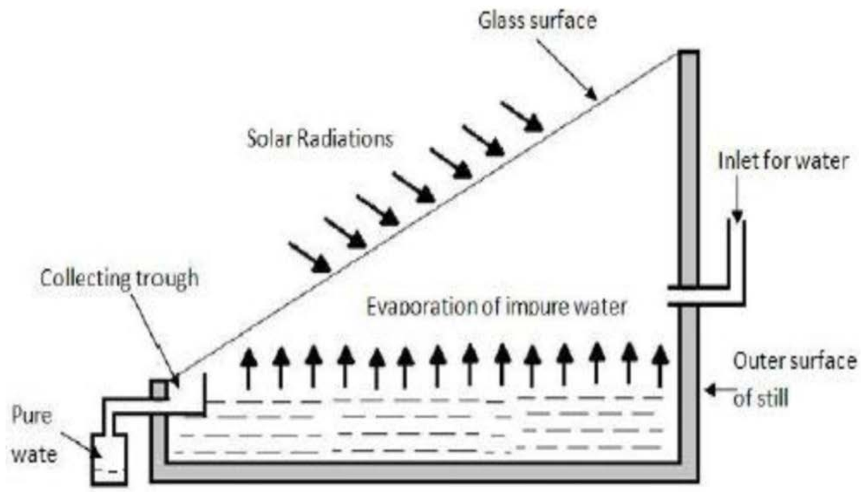
Solar stills are designed for distilling contaminated water, such as salt water, using solar energy. These devices function by creating an enclosed environment with a basin of contaminated water at the bottom. The sun heats the area as it shines on the angled top surface. This causes the water to evaporate and then condense on the inside of the top surface, from where it flows down the angled surface into a catchment area, producing clean, drinkable water (Figure 11)[xxi].

Solar stills have a range of applications, including urban and rural water management, sanitation, schools, and healthcare facilities. Currently, the technology is at the commercial trial stage on a small scale.

There are several potential benefits of using solar stills, depending on the design chosen. Generally, these devices do not produce pollution during the production phase and do not involve any moving parts, making them relatively low maintenance. They are also suitable for use in arid areas and, depending on the setup, can have an operational life of up to 30 years.

However, there are some challenges associated with solar stills. The production cost can be relatively high, estimated at around $0.015 per litre for a system with a 10-year operational life. Additionally, the productivity of solar stills, or the amount of distilled water produced, varies significantly depending on the setup, ranging from 7% to 87%, which is considered low compared to other water purification options. Solar stills also require a large amount of space, which can be a limiting factor in many contexts.[xxii]

Figure 11. A horizontal cross section of a single slope single basin solar still (one of several variations of solar stills



Non-lab water quality monitoring methods

Modern methods of monitoring water quality encompass a range of digital, physical, and data-driven technologies, including the Internet of Things (IoT), virtual sensing, cyber-physical systems (CPS), and optical techniques. These advanced methods are being developed to address various needs across different contexts, such as urban and rural water management, sanitation, schools, and healthcare facilities. Currently, these technologies are at Technology Readiness Level 9, indicating a high level of maturity and readiness for early adoption.

The use of cyber-physical systems for water quality monitoring offers several potential benefits. Traditional monitoring methods often struggle to provide accurate, real-time measurements of water quality parameters in a cost-effective manner. In contrast, CPS technologies enable continuous data measurement and real-time detection while simplifying the monitoring process, even though they can be expensive. The combination of physical systems with computational algorithms makes CPS particularly well-suited for water quality monitoring. Research by Zainurin et al. in 2022, suggests that CPS is a relevant and acceptable solution for water quality monitoring in Malaysia and similar contexts. Looking ahead, there is potential to enhance CPS technology by integrating it with advanced optical techniques, which could improve reliability and sensitivity.[xxiii]

Despite its advantages, the implementation of CPS for water quality monitoring presents several challenges. The high cost of these technologies can be prohibitive. Additionally, engineers and scientists need a solid understanding of advanced concepts such as artificial intelligence, machine learning, neural networks, and other modern online technologies to effectively apply CPS. Furthermore, the development of CPS requires collaboration among professionals from diverse fields, including software engineering, electrical and electronic engineering, computer science, and others. This interdisciplinary approach can lead to communication challenges, as various tools and abstractions are used in each field, complicating the development process.

Internet of Things (IoT) for monitoring water levels

The Internet of Things (IoT) technology for monitoring water levels represents a digital innovation that uses portable sensors (Figure 12), computing devices, and internet communication infrastructure to manage various systems remotely, without spatial limitations. This technology has a wide range of potential applications, including smart cities, municipal waste recycling, aquaculture, agriculture, healthcare, education, and flood monitoring. Currently, IoT for water level monitoring is at Technology Readiness Level 8, indicating it is in the final stages of system development before full deployment.

The IoT offers several potential benefits for monitoring water levels. It enables automatic monitoring of water levels in tanks and the automatic detection of leaks from tanks and nearby supply pipes. Additionally, it facilitates automated tank refilling while preventing the dry running of motors or pumps, which can cause damage. Furthermore, IoT systems provide end-users with remote access to control and monitor relevant activities, enhancing operational efficiency and oversight.

Figure 12. Example of a remote tank/bore/dam level monitoring device being used in the Pacific by UTS-ISF.

Some of the challenges associated with adopting IoT technology for water monitoring include that transitioning to new IoT systems requires time and the adoption of new approaches, which can be difficult for organisations and communities. Integrating different systems is also time-consuming and demands a high level of technological expertise. There are cybersecurity concerns, as the sensitive information managed by IoT systems can be vulnerable to security breaches. Reliability is another concern, as IoT systems depend on consistent internet connectivity, stable energy supply, and reliable system operations, which may be compromised by low internet connection, power outages, or system failures. Moreover, IoT cloud servers, which are essential for the system's functioning, often come with costs and may require licenses, adding to the overall expense of implementation.

Table 2 presents some of the limitations and challenges of IoT-controlled water tanks and some of the ways these limitations can be managed.[xxiv]

Table 2. Limitations and challenges of IoT controlled water tanks with recommendations for mitigation.

Source: Jan et al. (2022), p. 29.

S. No.	Limitations/Challenges	Recommendations
1.	Development of biofilms on sensors	Search market for reliable products
2.	Most IoT gadgets do not have built-in security	Search for IoT kits that are equipped with the latest security threats or embedded chips
3.	Most contemporary IoT cloud servers are not free of cost	It is best to develop a private IoT cloud server if possible
4.	Public IoT could servers are not considered secure due to third party involvement	It is best to develop a private IoT cloud server if possible
5.	Implementation of AI/ML schemes on IoT gadgets	Select at least 32-bit IoT devices with higher clock beats
6.	Overall system cost	Cost should be minimized to make IoT products accessible to all consumers
7.	Developing secure Apps for smartphone	It is wise to develop a private App if possible

Real time water tank and bore monitoring

Remote level monitoring for tanks, bores, and dams is a technology that combines physical and digital innovations to provide real-time monitoring of water levels. These devices can send text and email alerts when water levels are low, high, or rapidly falling. Currently being used in research in the Pacific by UTS-ISF[xxv], this technology is highly adaptable for various contexts, including urban and rural water management, sanitation, schools, and healthcare facilities. It has reached

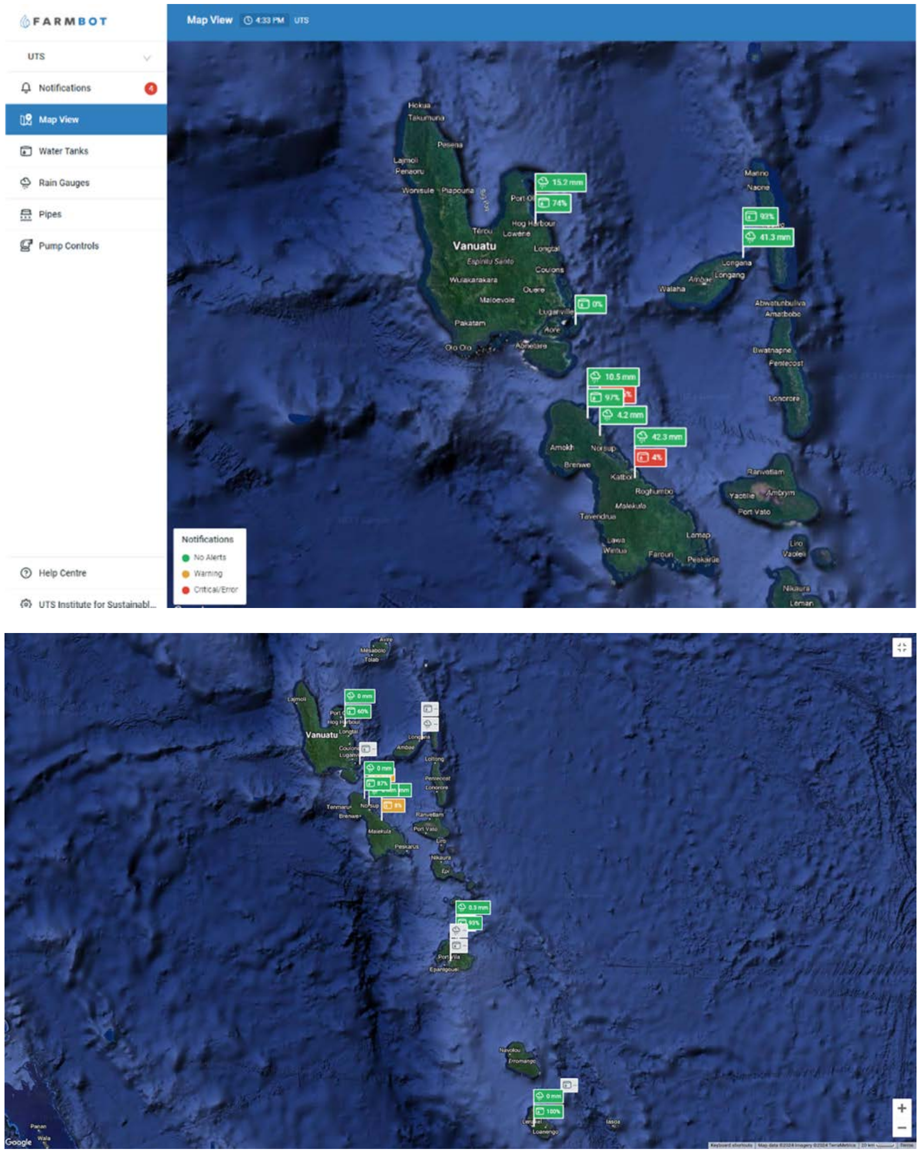
Technology Readiness Level 9, indicating it is ready for widespread adoption.

Remote level monitoring devices can help save time and reduce fuel costs by eliminating the need for frequent physical checks of remote water storages. Additionally, they provide valuable data that can inform decision-making and improve water conservation efforts. The data collected can also help users understand seasonal changes in water availability and consumption patterns. The system's reliance on satellite communications ensures reliable network coverage, making it effective even in remote areas.

Challenges of remote devices include the upfront cost of purchasing, which is relatively high, approximately AUD $1,200 (USD $790) per device for tank monitoring. While the system generally relies on satellite communications, areas without satellite coverage may experience issues with mobile data reception or network coverage. The devices occasionally require rebooting or troubleshooting, which can be inconvenient. Maintenance tasks, such as keeping the solar panels clean, are also necessary to ensure optimal operation. Additionally, there is an ongoing cost associated with the transmission of data and access to the monitoring portal, typically in the form of a monthly subscription fee.

Figure 13. An example of remote data on water tank level sensor.

Source: Farmbot via UTS-ISF. Farm Bot https://farmbot.com.au



Deep Water Drilling

Deep Water Drilling is an approach designed to address water shortages in East and Southern Africa, where millions, particularly children, are vulnerable to the impacts of water scarcity. Without access to clean water, communities face increased risks of conflict, disease, and food insecurity. The More Water More Life groundwater drilling project utilises satellite data to map deep aquifers—permeable rock formations that can hold water—improving drilling accuracy by 90-95%.[xxvi] This enhanced precision directly improves water access for approximately 1.2 million people, including 740,000 children.

This technology is primarily used in rural water contexts and has reached Technology Readiness Level 9, indicating it is ready for widespread adoption. The key benefit of deep-water drilling is the improved access to reliable groundwater sources, which can be more dependable than surface water or rainwater.

The high cost of drilling deep wells can be a significant barrier, and there is a risk of over-extraction, which could deplete the groundwater resources if not carefully managed.

Use of high-quality materials and durable drill bits extends the lifespan of equipment, reducing the need for frequent replacement. Using sharing/leasing models for the project also lowers waste generations from the equipment.

Solar chlorine production

Chlorine production using solar energy is an innovative product that aims to harness renewable energy to produce chlorine for water disinfection. The process begins by separating salt from seawater. Water is placed on sand and left to evaporate in the sun, leaving salt behind. This salt is then subjected to electrolysis using solar power, which generates chlorine gas. This chlorine can be used for disinfecting water, making it a valuable tool for urban and rural sanitation, schools, and healthcare facilities. Some sources suggest that this process can also produce hydrogen as a by-product, which could have additional applications. Currently, this technology is at Technology Readiness Level 2, indicating it is still in the early stages of development.

There are several potential benefits to this approach. It uses renewable solar energy, making it an environmentally friendly as well as closed-loop system. Additionally, the production of both chlorine and hydrogen could provide multiple useful outputs from a single process.

The efficiency of chlorine production using solar energy is currently low, with less than 10% efficiency reported. There is also limited information available about the technology in this specific form, indicating that further research and development are needed to fully understand its potential and to optimise the process.[xxvii]

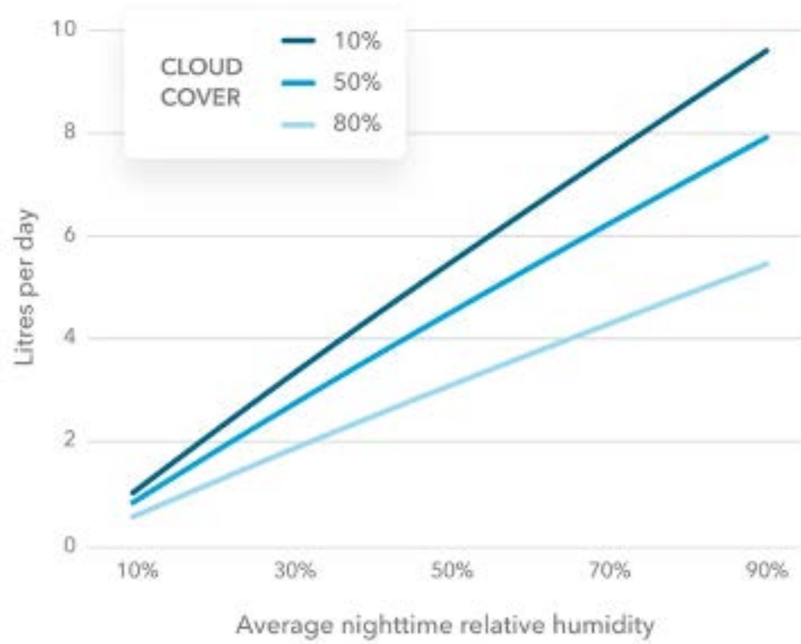
Hydropanels (atmospheric water generation)

Atmospheric Water Generation (AWG), also known as hydropanels, is a physical innovation that extracts clean water directly from the air. AWG operates as an off-grid, stand-alone technology capable of producing water at the location of installation, eliminating the need for transportation from other sources. According to a paper by Moghimi et al. (2021), AWG could be an "attractive substitute" for bottled water and therefore eliminate plastic bottles pollution, although it is not currently considered an economically viable alternative for potable tap water.[xxviii] By providing a clean water source without depleting natural water bodies, AWG also help preserve natural ecosystems[xxix].

AWG technology is primarily used in rural water contexts and has reached Technology Readiness Level 9, meaning it is ready for widespread adoption.[xxx] The potential benefits of AWG include its capability to produce water on-site and its economic attractiveness in regions where it could compete with bottled water. Yet, the efficiency of water generation varies significantly based on factors such as humidity, temperature, and the specific technology used in the membrane system. The amount of water produced is relatively low given the size and cost of the system; while a panel can theoretically produce up to five litres of water per day, actual production can drop to less than two litres under cloudy or low humidity conditions and can cease altogether in freezing temperatures. This variability can limit the practicality and economic viability of AWG in certain regions.[xxxi]

Figure 14. Source reports that "each Hydropanel will produce approximately 180 standard bottles of water per month. We recommend at least one panel for every two people living in the home."

Source: https://www.source.co/



Ultrafiltration

Ultrafiltration (UF) membranes mechanically separate materials from a mixture by means of hydrostatic pressure. Their application in addition to water treatment and wastewater reclamation spans to chemical recovery, cell harvesting, dairy production, chemical use and juice concentration[xxxii].

Ultrafiltration offers a high removal rate of macromolecules, less energy consumption, lower footprint, and mild conditions than conventional practices. It is also easy to scale-up. However, one of the main problems of the UF membranes is fouling, which requires chemical cleaning and increases operational cost. There are a number of research studies in the literature addressing the fouling developing fouling-resistant UF membranes[xxxiii]. In addition, a range of selective UF membranes are being developed to address the complex composition of wastewater, including catalytic UF, micellar enhance UF, tight UF and adsorptive UF[xxxiii].

This technology is seen to play an important role in addressing the increased demands for energy, providing adequate supplies of water in both developed and developing countries[xxxiv].

Case study: SkyHydrant Water Filtration Systems[xxxv]

This gravity-fed membrane filtration system uses hollow fiber membranes with 0.04 µm pore size to filter water without electricity or chemical treatment. A study in rural southern India found the system achieved log reductions of approximately 0.86 for total coliforms, 1.14 for fecal coliforms, and 0.79 for E. coli in field conditions. The system can produce 500-700 litres per hour when installed with appropriate head pressure, making it suitable for community-scale applications. The units have been deployed in emergency situations including the 2004 tsunami relief efforts in Sri Lanka, India, and Indonesia, as well as in 16 other low-income countries. The technology requires minimal technical expertise to operate and maintain, though adherence and long-term acceptance remain important factors for successful implementation in resource-limited settings.

Figure 15.
SkyHydrant

Managed Aquifer Recharge

Managed Aquifer Recharge (MAR) compliments surface water storage with aquifer storage. This technology has applications in both urban and rural water contexts and has reached Technology Readiness Level 9, indicating its readiness for widespread adoption. By balancing waster extraction with recharge, it promotes long-term water sustainability and can help restore natural groundwater levels and support the ecosystems dependant on groundwater.

A study by Ross (2022) analysed 21 MAR schemes across 15 countries, evaluating their levelised costs, benefit-cost ratios, and qualitative social and environmental impacts. The study revealed strong returns on investment for the reported MAR schemes.[xxxvi] Specifically, MAR schemes using infiltration basins or riverbank filtration were found to be relatively inexpensive with high benefit-cost ratios. While MAR schemes using recycled water or requiring substantial drilling infrastructure and water treatment were more costly, they still offered positive benefit-cost ratios. Most MAR schemes demonstrated positive or neutral effects on aquifer storage and condition, water quality, and environmental flows. Additionally, the energy requirements for MAR were found to be competitive with alternative water storage methods.

In Timor-Leste, UNICEF has scaled up the use of MAR in response to climate change challenges, such as rising sea levels and extreme weather events that threaten WASH facilities and contribute to saline intrusion of coastal freshwater aquifers. The MAR technique implemented there involves collecting and treating water from ponds and rooftops (rainwater) and injecting it underground for storage and future use. Each MAR system is designed to be maintained by local communities, with periodic external support as needed.

One of the key benefits of this approach is its potential to counteract saltwater intrusion into freshwater aquifers, thereby protecting local water supplies from contamination by seawater. However, MAR also faces some challenges. While schemes using recycled water and stormwater can be more costly, they can still be substantially cheaper than alternative water supplies. The technology may require community education and acceptance, especially if recycled water is used for potable purposes. Additionally, community support and understanding are necessary for any construction and catchment management activities to keep water clean and develop underground infrastructure.

A primary concern associated with MAR is the potential pollution of groundwater, which could occur if the recharged water is not adequately treated or if contaminants enter the aquifer during the recharge process. This risk underscores the importance of careful management and monitoring of MAR systems to ensure water quality and safety. Despite these challenges, MAR remains a promising technology for addressing water storage and quality issues in various contexts.[xxxvii]

Professionalised maintenance

Professionalised maintenance is aimed at improving the sustainability and quality of water services, particularly in rural areas. This approach has reached Technology Readiness Level 9, indicating it is ready for widespread adoption across various contexts including urban and rural water and sanitation systems, as well as in schools and healthcare facilities.

Despite substantial capital investments by governments, donors, and NGOs over the years, the continuity and quality of water services in many rural areas globally remain poor. By professionalising maintenance, there is potential for greater sustainability of WASH services and improved incentives for maintaining them.

The concept of professionalised maintenance is defined by a comprehensive set of criteria that ensure clear accountability, legal recognition, and performance-based service delivery. These criteria include clearly defined responsibilities between asset owners, water operators, maintenance providers, customers, and government bodies. Maintenance providers must be constituted as legal entities capable of contracting with various stakeholders and be registered with relevant sector authorities. They operate within defined service areas and are subject to formal contracts that outline roles, activities, and expected outcomes.[xxxviii]

An important aspect of this approach is the focus on performance-based targets and measurable indicators, which may be linked to incentive payments or penalties. This performance is subject to oversight by local government offices or independent regulators. Transparency in fee structures and price regulation is emphasised, with consideration given to local economic factors. In cases where tariff revenues are insufficient, subsidy mechanisms with transparent funding sources and governance oversight are implemented.

One primary difficulty in professionalised maintenance lies in isolating maintenance functions from broader aspects of operations, management, and overall governance. Successfully implementing professionalised maintenance requires building the capacity of service providers and ensuring the ability and willingness of users to pay for services. In cases where user payments are insufficient, alternative funding sources must be secured.

Continuous training for maintenance providers is an integral part of this approach, financed either internally, by government agencies, or through professional associations. Additionally, community customers receive support and are incentivised to fulfill their obligations, fostering a collaborative environment for sustainable water service management. Overall, while professionalised maintenance presents some challenges in implementation, its potential to significantly improve the longevity and quality of water services makes it a promising approach for addressing persistent issues in water service delivery, particularly in rural areas.[xxxix]

Case study of professionalised maintenance: SafePani in Bangladesh

The SafePani model, developed by REACH in collaboration with UNICEF and the Local Government Division (LGD) of the Government of Bangladesh, represents an innovative approach to professionalised maintenance in the context of rural water professionalised maintenance we discussed earlier, aiming to reform existing institutional design and move towards a more professional, performance-based water service delivery system.

Launched in 2021, the SafePani pilot programme has been implemented in 171 schools and 33 healthcare centres in the Khulna district of Bangladesh. The model's effectiveness has been demonstrated through several key outcomes:

1. Improved water safety: The programme has implemented regular monitoring and prompt remedial actions when contamination, particularly E. coli, is detected.

2. Timely maintenance: The model ensures rapid response to infrastructure issues, with waterpoint repairs completed within 48 hours of reported breakdowns.

3. Cost-effectiveness: The estimated costs are less than 100 Bangladeshi Taka (approximately USD 1) per student or patient per year, making it an economically viable solution.

The SafePani pilot phase comprises three main work packages - infrastructure maintenance, water safety assessment, and data management which are now outlined.

Infrastructure maintenance: This includes the rehabilitation and ongoing maintenance of all water supply infrastructure. A key performance indicator is the ability to repair any reported breakdowns within 48 hours, ensuring consistent water availability.

Water safety assessment: This involves comprehensive water quality monitoring, including sanitary inspections, baseline tests for arsenic, manganese, and chloride, as well as seasonal tests for E. coli. Notably, the programme includes prompt disinfection of sources upon detection of faecal contamination, addressing a critical health risk.

Data management: The development and maintenance of a data storage platform is an important component. This platform highlights key performance metrics related to water quality, service reliability, volumetric use, and costs. This aligns with the professionalised maintenance principle of using measurable indicators for performance evaluation.

The SafePani model exemplifies several key aspects of professionalised maintenance:

1. Performance-based approach: The model uses independently verified performance metrics to unlock results-based funding, creating strong incentives for maintaining high service quality.

2. Comprehensive service provision: By combining infrastructure maintenance, water quality monitoring, and data management, the model addresses multiple aspects of water service delivery.

3. Emphasis on water safety: Regular water quality testing and prompt remediation of contamination issues directly contribute to public health outcomes.

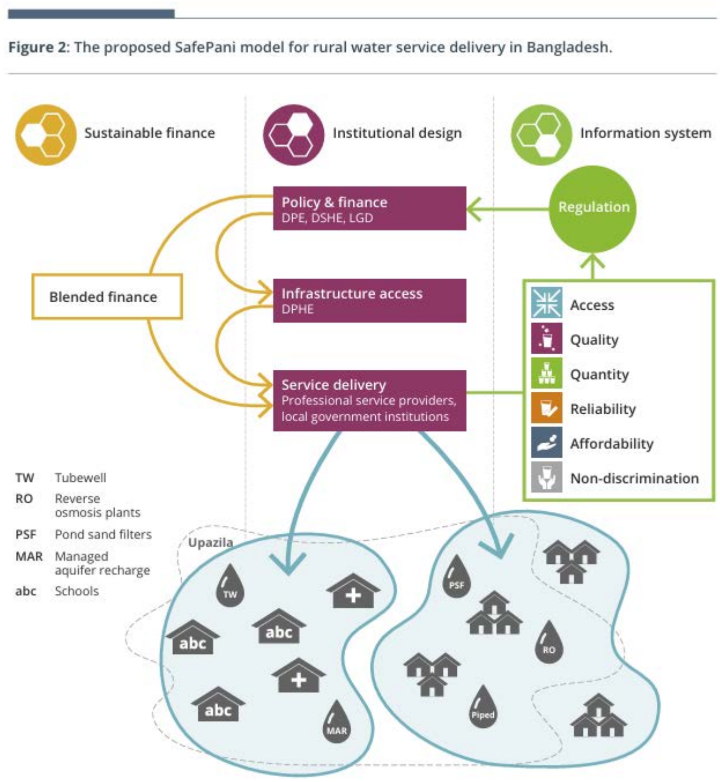
4. Transparency and accountability: The use of a data storage platform with key performance metrics allows for clear tracking of service quality and efficiency.

5. Cost-effective service delivery: The low per-capita cost demonstrates the potential for sustainable, affordable water service provision.

The SafePani model in Bangladesh provides a practical example of how professionalised maintenance principles can be applied to improve rural water service delivery.[xl]

Figure 16. SafePani model in Bangladesh.

Source: https://reachwater.uk/wp-content/uploads/2024/01/SafePani-story-change-v3.pdf



5

OPPORTUNITY: SANITATION TECHNOLOGIES

Innovative sanitation technologies must be specific to the context in terms of soil, water sources, housing density and consider GESDI from the pre-design and design stages through to implementation. Sanitation technologies have evolved over centuries, though many of the innovations and technologies invented hundreds of years ago are still not in place in many contexts.

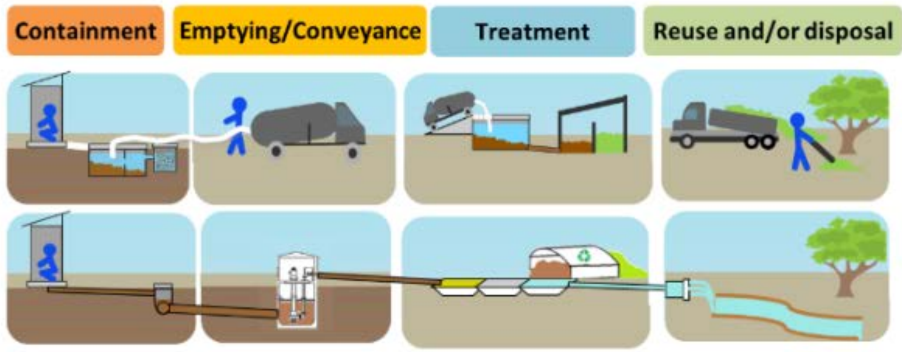
Figure 17. Timeline for sanitation developments.

Source: International Conference on Nutrient Recovery from Wastewater Streams (Vancouver, 2009)

Figure 17 is one representation of how sanitation systems have evolved from being used in land applications and for composting from 3000 BC, to now being considered as part of the circular economy in 2023 and beyond. While this representation is Euro-centric, it captures a number of the common innovations that are still used today, though which are not appropriate in all contexts such as composting toilets, wetlands for wastewater treatment, and septic tanks.

Figure 18. Sanitation service chain.

Source: UTS-ISF (2022) Urban sanitation and climate change: A public service at risk – Landscape study. Prepared for the Bill and Melinda Gates Foundation by University of Technology Sydney - Institute for Sustainable Futures



Sanitation technologies covered in this section may be at any point of the sanitation service chain such as those shown in the citywide inclusive sanitation framework as shown in Figure 18.

Sky Latrine

iDE's Sky Latrine is a climate-resilient elevated latrine developed specifically for seasonally flooded communities along Cambodia's Tonle Sap Lake. This innovative sanitation technology enables sanitation access year-round and prevents contamination of nearby water sources, upon which seasonally flooded fisher communities often rely for their livelihoods. With a toilet pan fixed inside stilted homes, above the high-water mark and waste safely contained in the ground, households can maintain access to sanitation year-round with dignity and mitigate the climate risk of seasonal floods. The Sky Latrine, which prevents the need for individuals to leave and re-enter their highly stilted homes via step ladder to defecate, provides an accessible option for those with mobility impairments to relieve themselves, an impact in quality of life that has been highlighted by people using the latrines (and reported to iDE).[xli]

Figure 19. iDE Sky Latrine

Net Zero toilet device

The Net Zero Aquonic is an innovative physical product that may represent a significant advancement in sustainable sanitation technology. This device, pioneered in Vietnam, is the country's first net-zero toilet system, designed to address water conservation and sanitation needs simultaneously. The core functionality of the Net Zero Aquonic revolves around its ability to treat and recycle wastewater for toilet flushing purposes. The system utilises solar energy, harnessed through integrated solar panels, to power the water treatment process. This approach not only reduces the device's reliance on external power sources but also contributes to its net-zero energy profile.[xlii]

Currently, the primary application context for the Net Zero Aquonic is in schools, where it can improve water conservation and sanitation practices. By implementing this technology in educational institutions, it serves the dual purpose of meeting immediate sanitation needs while also educating students about sustainable water management and renewable energy use.

The Net Zero Aquonic is at the commercial trial stage, indicating that it's being tested on a small scale in real-world applications. This Technology Readiness Level suggests that while the basic functionality has been proven, further testing and refinement may be necessary before large-scale deployment.

The key benefit of this technology lies in its water reuse capability. By treating and recycling wastewater for toilet flushing, the Net Zero Aquonic significantly reduces the demand on other water sources. This is particularly valuable in areas where water scarcity is a concern or where reducing the overall water footprint of buildings is a priority.

Challenges related to the Net Zero Aquonic revolve around operations and maintenance. As a complex system combining water treatment and solar energy technologies, it may require specialized knowledge for proper operation and upkeep. This could potentially limit its adoption in areas without access to appropriate technical expertise or resources for ongoing maintenance.

Despite these challenges, the Net Zero Aquonic represents a promising step towards more sustainable sanitation solutions. Its innovative approach to combining renewable energy with water recycling addresses multiple environmental concerns simultaneously. As the technology continues to be refined and tested, it has the potential to make a significant impact on water conservation efforts, particularly in institutional settings like schools.[xliii]

Vacuum toilets

Vacuum toilets are an innovative physical product designed to significantly reduce water consumption in sanitation systems. This technology uses suction to remove urine and faeces from the toilet bowl, offering a more efficient alternative to traditional gravity-based flush systems.[xliv]

Currently, vacuum toilets are at the commercial trial stage, being tested on a small scale. While they have been widely used in specific commercial environments such as airplanes and boats, their application in other settings is still limited.

The potential benefits of vacuum toilets are numerous:

Water conservation: The DualFlushVac model uses 25-50% less water compared to other vacuum toilets and 2-11.25 times less water than traditional gravity toilets.[xlv]

Space efficiency: Unlike other toilet systems, vacuum toilets do not require holding tanks or venting, making them ideal for retrofits in existing structures.

Air quality improvement: These toilets remove small particles from the air during flushing, potentially improving indoor air quality.

Resource recovery efficiency: The higher concentration of black water due to less water usage makes resource recovery more efficient, aligning with circular economy principles.

Energy efficiency: Vacuum toilets require less energy to operate compared to traditional systems.

Potential for closed-loop systems: This technology can be integrated into closed-loop water systems, further enhancing sustainability.

However, vacuum toilets also face several challenges including:

Electricity dependence: Being reliant on electricity, they may not function reliably in areas with inconsistent power supply - a common issue in many countries where UNICEF operates.

User awareness and behaviour: The water-saving feature's effectiveness is highly dependent on user awareness and needs. Improper use or double-flushing due to dissatisfaction with cleaning effects can negate water-saving benefits.

Regulatory compliance: In some regions, these toilets may not comply with local plumbing standards. For instance, they do not comply with AS3500 in Australia, preventing them from receiving WaterMark status.

Limited widespread adoption: While common in specific commercial environments, vacuum toilets are not yet widely used in residential or public settings, which may affect user acceptance and maintenance infrastructure.

The potential applications for vacuum toilets span various contexts including urban and rural sanitation, schools, and healthcare facilities. However, their implementation would need to consider the specific challenges of each setting, particularly regarding power supply reliability and user education. While vacuum toilets offer potential for water conservation and improved sanitation efficiency, their widespread adoption faces hurdles related to infrastructure requirements, user behaviour, and regulatory compliance. As the technology continues to develop and adapt to various contexts, it could play a useful role in future sustainable sanitation solutions, particularly in areas where water conservation is a priority and reliable electricity is available.

Gates reinvent the toilet

The Nano Membrane Toilet (NMT) is an innovative physical product developed as part of the 'Reinvent the Toilet Challenge' funded by the Bill and Melinda Gates Foundation. This waterless toilet system represents a significant advancement in sustainable sanitation technology, particularly for areas with limited water resources or inadequate sewage infrastructure. The NMT operates on a principle that combines membrane separation and combustion processes. It separates urine and faeces on-site, treating them through different methods: (1) Urine is purified using a nanostructure membrane, with the process aided by heat generated from the faeces combustion. (2) Faeces are burned on-site, producing energy and ash as byproducts.[xlvi]

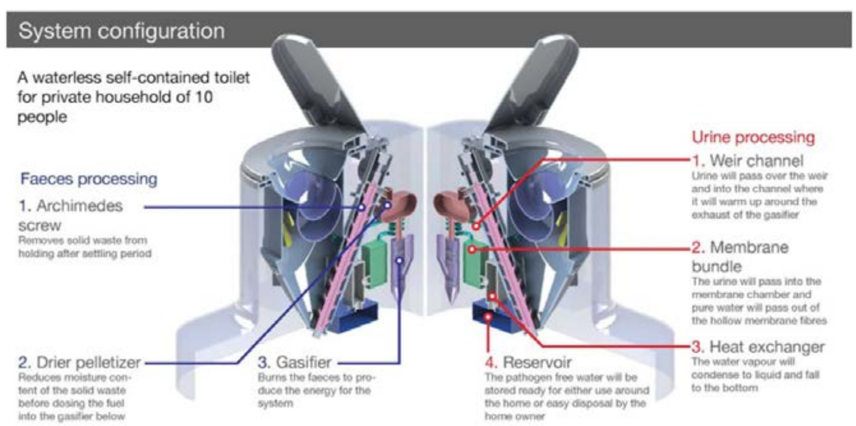


Figure 20. The Nano Membrane Toilet was developed by Cranfield University to enable those without plumbing to have access to safe and hygienic facilities.

The Nano Membrane Toilet represents a promising innovation in sustainable sanitation. Its ability to treat waste on-site, recover resources, and operate without water input addresses multiple challenges in global sanitation. However, further development and adaptation will be necessary to overcome current limitations and make it a viable solution for widespread adoption, particularly in the developing contexts where UNICEF operates. As research and development continue, the NMT could play a significant role in improving sanitation and resource management in challenging environments.

The technology is currently at Technology Readiness Level 4, indicating it has progressed beyond basic research but is not yet ready for widespread commercial application. Potential benefits of the NMT include:

Reduced transportation costs: By treating waste on-site, the NMT significantly lowers the need for waste transportation, which can be a major expense in traditional sanitation systems.

Resource recovery: The ash produced from faeces combustion can be used in fertilizers, promoting a circular economy approach to waste management.

Economic feasibility: Studies suggest that the NMT is economically viable, which will be helpful for its potential adoption in other contexts.

Water reuse: The purified water from urine can be reused for purposes such as gardening, contributing to water conservation efforts.

Energy production: Excess energy from the combustion process can potentially be used for other purposes, such as generating electricity for households.

However, the NMT also faces several challenges including cost, social acceptance and lifespan. Despite being economically feasible, the initial cost of the NMT system remains a significant barrier to scaling, particularly in resource-constrained settings. While the purified water can be used for domestic cleaning, there may be social barriers to its acceptance, limiting the technology's full potential.

The NMT system has an estimated lifetime of 7 years, which is considerably shorter than traditional toilets. This is particularly significant when compared to the 10–15-year lifespan of toilets in developing contexts where UNICEF typically operates.

Strategies to address these challenges might include exploring ways to reduce production costs or implement subsidies to make the technology more accessible. Additionally, community engagement and education programmes to increase acceptance of water reuse and investigating ways to extend the system's lifespan or design for easier maintenance and part replacement are warranted.

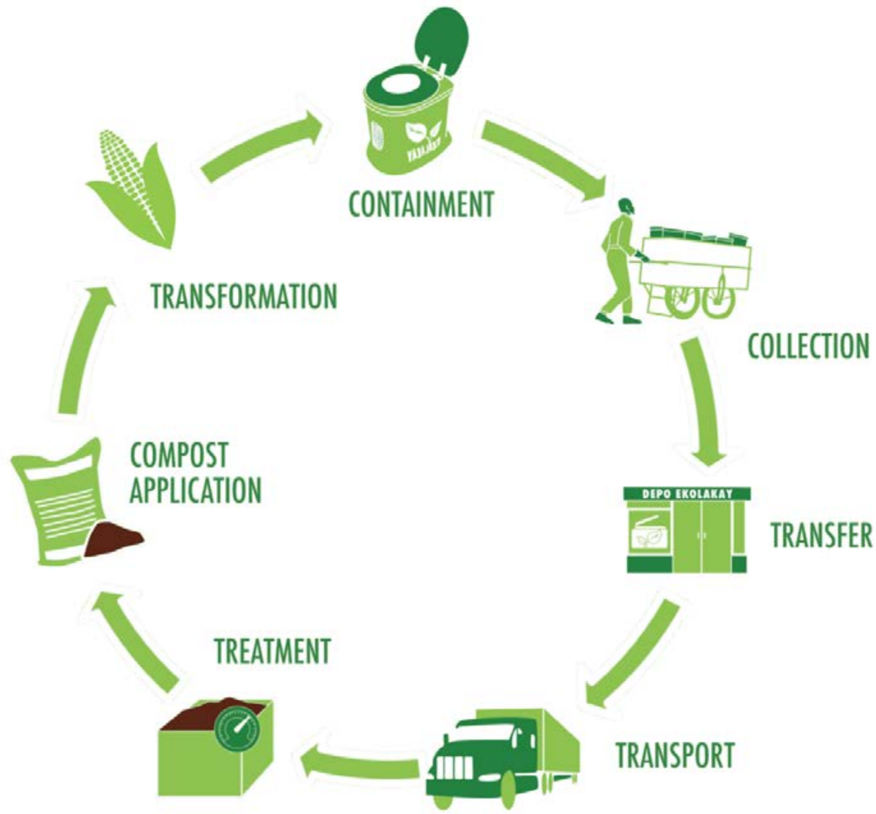
Container-based sanitation

Container-based sanitation (CBS) is an innovative approach to managing sewage that has reached Technology Readiness Level 9, indicating it is ready for widespread adoption. CBS systems typically involve the use of sealable, removable containers for the collection of urine and faeces, which are then transported to a treatment facility. These systems are modular in nature and adaptable to various contexts, generally consisting of a toilet interface designed to fit local preferences and space constraints, removable containers for waste collection, and a service model for regular collection and transport of filled containers to treatment facilities.[xlvii]

As CBS schemes grow in scale, companies and organisations are addressing the significant challenge of collection and transport through several strategies. These include using GPS and data analytics for optimised route planning, establishing decentralised treatment facilities closer to service areas, implementing transfer stations for waste consolidation, adopting modular scaling approaches, employing community-based collectors, partnering with existing waste management systems, and developing technological innovations specific to CBS systems.[xlviii]

Figure 21. SOIL's CBS system.

Source: SOIL



CBS has proven particularly effective in urban sanitation contexts, especially in densely populated, low-resource environments, areas prone to flooding, and regions with limited freshwater availability. It has also been successfully implemented in some rural sanitation contexts and could potentially be adapted for use in schools and healthcare facilities.[xlix]

The potential benefits of CBS include adaptability to challenging environments, improved sanitation access in dense urban areas and those who experience incontinence or people with disabilities who cannot access a household latrine, resilience to climate-related challenges, water conservation, and potential for resource recovery through proper waste treatment. Self-care and incontinence products like commodes, bedpans, and mattress protectors are essential but often overlooked sanitation technologies. For people with disabilities and their caregivers, these products can significantly improve dignity, independence and hygiene. Without access to appropriate assistive technologies, both caregivers and people with disabilities face increased direct contact with human waste, raising the risk of infection and disease transmission. However, having the right equipment is only part of the solution - it must be paired with proper waste disposal practices and hygiene behaviors, and CBS could be an effective mechanism in some contexts for people with disabilities.

However, CBS also faces challenges such as the need for evidence of user acceptance and public demand, the requirement for effective behaviour change initiatives, the necessity for regular and high-quality collection services, potential scalability issues, and the need for sustainable business models to cover operational costs.

While CBS offers a promising solution for improving sanitation in challenging environments, its success depends heavily on effective management of collection and transport logistics, as well as on gaining user acceptance and governmental support. As the technology continues to be implemented and refined, addressing these challenges will be essential for its widespread adoption and long-term sustainability.[l]

Urine diversion

Urine diversion (UD) is a physical product innovation that has reached Technology Readiness Level 9, indicating its readiness for widespread adoption. This technology focuses on collecting nutrients such as phosphorus and nitrogen from urine without conventional wastewater treatment, allowing these nutrients to be used as fertilizer. The system works by separating urine from other waste products, such as faecal matter, directly in the toilet bowl.[li]

UD systems have potential applications in various contexts, including urban and rural sanitation, schools, and healthcare facilities. They offer several significant benefits, including the opportunity to close the nutrient cycle by directing urine towards agricultural use. Implementation of UD systems can lead to a reduction in greenhouse gas emissions by 29-47%, decrease the chance of water body eutrophication by 25-64%, and reduce energy consumption by 26-41%. Urine contains approximately 80% of the nitrogen and 50% of the phosphorus found in domestic wastewater, so using UD systems could potentially eliminate the need for methanol and ferric chloride in wastewater treatment processes, as these chemicals are typically used to remove nitrogen and phosphorus, respectively.[lii]

Despite these advantages and the technology being available for decades, UD systems have not seen significant uptake due to several challenges. Developing a market for UD products has proven difficult, and the technology's success depends on simultaneous changes in socio-cultural and institutional structures. There are also gaps in regulations regarding how UD systems should be installed, moved, and used, as well as how effluent from these systems should be utilised as fertilizer. This lack of regulatory framework has hindered the development and adoption of UD systems. Additionally, the need for associated infrastructure to support UD systems presents another hurdle to widespread implementation.[liii]

While urine diversion technology offers promising environmental and agricultural benefits, its adoption faces significant socio-cultural, regulatory, and infrastructural challenges. Addressing these issues will be important for realising the full potential of UD systems in improving sanitation and resource recovery across a range of contexts.

Modern dry composting toilets

Dry composting toilets utilize naturally occurring aerobic processes, in which micro-organisms convert biodegradable organic matter into a humus-like product. There are two main types of composting toilets: those with urine diversion and those without. In both designs, the initial step involves dewatering the content to enhance the decomposition of organic material and accelerate hygienisation.[liv]

Dry composting toilets have applications in various contexts, including urban and rural sanitation, schools, and healthcare facilities. They offer several significant benefits, such as providing a source of fertilizer and soil conditioner. Composting toilets can replace the need for conventional chemical fertilizers, which are becoming increasingly expensive due to high energy inputs (for nitrogen) and scarce deposits (for phosphorus and sulphur). The combination of urine and faeces in these systems constitutes a well-composed fertilizer with a range of micro-nutrients such as magnesium and selenium. Additionally, composting toilets can help avoid the chemical pollution caused by conventional fertilizers.[lv]

Despite these advantages, composting toilets face several challenges in their implementation and adoption. In some cultural and religious contexts, there are concerns about human wastes being accessible and potentially used in magic to the detriment of people, or the systems being considered unclean.

Affordability has been noted as a major barrier to the adoption of composting toilets. The technology also requires the incorporation of plant matter into the toilet for effective composting.

There are also health considerations to address. Sludge from toilet facilities can pose health risks, necessitating measures to manage these risks in accordance with WHO recommendations for the safe management of urine and faecal matter. Furthermore, the complexity of operating the facilities and handling excreta requires basic training on the management of composting toilets.

While dry composting toilets offer promising environmental and agricultural benefits, their adoption faces significant socio-cultural, economic, and operational challenges. Addressing these issues, particularly through education, cost reduction strategies, and adherence to health guidelines, will be essential for realizing the full potential of composting toilets in improving sanitation and resource recovery in a range of contexts.

Sanitation in cold climates

Small-scale wastewater treatment facilities designed to operate at below freezing temperatures represent an innovative physical product addressing a critical need in extremely cold climates, such as Mongolia. This technology has been developed to tackle the unique challenges posed by harsh winter conditions where temperatures can plummet to as low as -50º Celsius, and permafrost persists throughout most of the country for a significant portion of the year.[lvi] [lvii]These specialized treatment facilities are primarily intended for use in rural sanitation contexts, particularly in remote communities and public institutions such as schools, kindergartens, and health centres. Their development and implementation assist in areas where traditional sanitation methods are rendered ineffective or inoperable due to extreme cold. The potential benefits of these small-scale wastewater treatment facilities include:

Improved sanitation access: By functioning in sub-zero temperatures, these facilities can dramatically increase access to improved sanitation in rural areas where it is critically low. In Mongolia, for instance, only 6.8% of the rural population has access to improved sanitation facilities.

Reduction of open defecation: The availability of functional sanitation facilities even in extreme cold can help reduce the high rates of open defecation in rural areas (25.2% in Mongolia), which poses significant health and environmental risks.

Year-round operation: Unlike traditional systems that may freeze or become inoperable in winter, these facilities can function continuously throughout the year, ensuring consistent access to sanitation.

Adaptability to remote locations: The small-scale nature of these facilities makes them suitable for installation in remote communities that may not have access to centralized wastewater treatment systems.

Support for public institutions: By enabling the installation of functional sanitation facilities in schools, kindergartens, and health centres, this technology can improve public health and education outcomes.

Environmental protection: Proper wastewater treatment, even in extreme conditions, can help protect local water sources and ecosystems from contamination.

Potential for scalability: As a demonstration technology supported by UNICEF[lviii] in Mongolia, these facilities have the potential to be scaled up and implemented more widely if proven successful.

Improved quality of life: By providing reliable sanitation facilities in extreme conditions, this technology can significantly enhance the quality of life for people in remote, cold-climate communities.

The technology likely faces challenges related to installation costs, maintenance in remote areas, and the need for specialized knowledge to operate these systems. However, the ability to provide improved sanitation in areas previously underserved due to climatic constraints represents a significant step forward in addressing global sanitation challenges.

Nature-based Solutions

Nature-based Solutions (NbS) represent an innovative approach that encompasses both physical products and programme approaches to address various societal challenges, including water and sanitation issues. As defined by the International Union for Conservation of Nature, NbS are actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits.[lix]

Although both NbS and circular economy principle of regenerating nature both aim to leverage natural processes for environmental and societal benefits, have distinct focuses and applications. Regenerating nature (third circular economy principle) focuses on redesigning economic system to support natural regeneration, but NbS involves direct interventions in natural or modified ecosystems. Both approaches are complimentary and essential for achieving SDGs and environmental resilience.

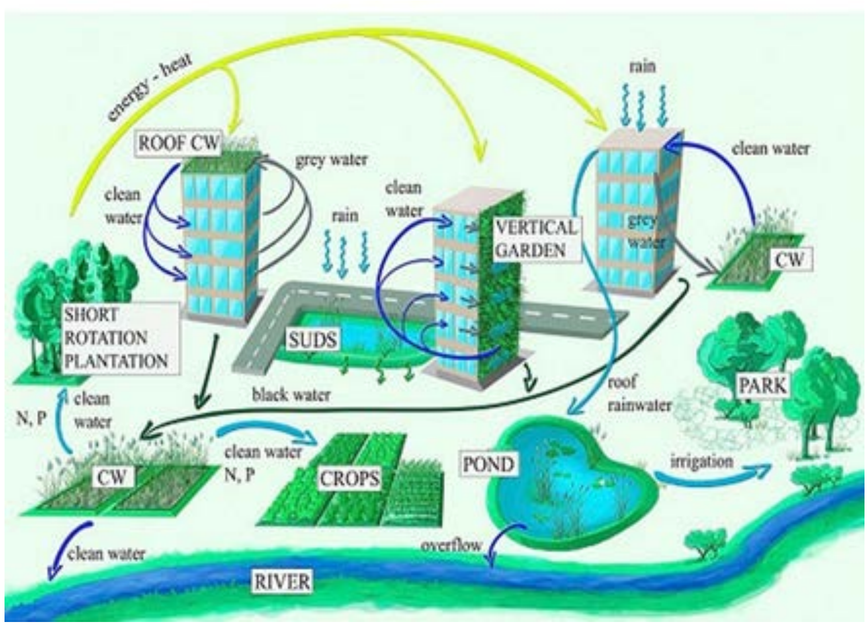
In the context of wastewater management, the International Water Association defines NbS as engineered systems that leverage or mimic ecosystems, utilising plants, soil, porous media, bacteria, and other natural processes to remove pollutants. These solutions can be applied across various contexts, including urban and rural water and sanitation systems, schools, and healthcare facilities. The Green Climate Fund is exploring the integration of urban water management, sanitation, and drainage in green city projects, particularly focusing on small cities. The Technology Readiness Level of NbS varies from 6 to 9, depending on the specific solution, indicating that many of these approaches are either in advanced stages of development or ready for widespread adoption.

NbS offer numerous potential benefits, making them particularly attractive for addressing complex environmental and social challenges. They can simultaneously address biodiversity conservation, urban cooling, water treatment, liveability improvement, livelihood creation, carbon capture, and sanitation treatment. These approaches often gain government support, especially around informal settlements, as they don't require extensive 'hard' infrastructure. NbS contribute to the restoration and protection of natural ecosystems and help communities adapt to climate change impacts. In many cases, they can be more cost-effective than traditional engineered solutions and often involve and benefit local communities directly. NbS can effectively treat wastewater and improve overall water quality in an area, while in urban settings, they can create green spaces that improve air quality and provide recreational areas.

Despite these benefits, NbS also face some challenges. Many nature-based solutions can be land-intensive, which may be a constraint in densely populated urban areas. Like any infrastructure, NbS require ongoing operation and maintenance, which needs to be factored into long-term planning and budgeting. Some NbS, particularly those involving plant growth, may take time to reach full effectiveness. The effectiveness of NbS can vary based on local conditions and may change with seasons or climate shifts. There may be a lack of local expertise in designing, implementing, and maintaining some NbS. Existing regulations may not adequately address or support the implementation of NbS, and some stakeholders may perceive NBS as less effective or reliable compared to traditional engineered solutions.

Figure 22. NBS based concepts for urban sanitation.

Source: F.Masi, A.Rizzo, M.Regelsberger (2018). The role of constructed wetlands in a new circular economy, resource oriented, and ecosystem services paradigm. Journal of



6

OPPORTUNITY: HYGIENE TECHNOLOGIES

Reusable period underwear

Reusable menstrual underwear, also known as period underwear, is an innovative physical product that has reached a Technology Readiness Level of 9. This garment resembles typical women's underwear but incorporates a built-in menstrual pad. It can be used in various contexts, including urban and rural sanitation, as well as in schools.[lx][lxi]

Reusable/washable period underwear strongly aligns with circular economy principles. Its reusable design and durable materials reduce need for single use alternatives which have poor end of life options and mostly finish in landfills. Some of the underwear brands use natural fibres such as cotton or bamboo, which are biodegradable and can be composted reducing the environmental impact further.[lxii]

The technology offers several potential benefits. Users may experience long-term cost savings and increased comfort compared to traditional menstrual products. While further research is needed, emerging evidence suggests that period underwear may be easier for people with disabilities to use, including individuals with intellectual and physical disabilities and those with limited dexterity.[lxiii] This product can also simplify menstrual care for caregivers, and can be hung out and dried in more usual ways (with other washing) because it looks like normal underwear. Period underwear is reusable, requiring only washing and drying between uses. This feature contributes to a reduced environmental impact when compared to disposable alternatives, which generate more waste through product and packaging disposal. Innovation around reducing purchasing cost and reuse is an important and emerging area. Menstrual washing bags are designed to wash period underwear discretely, without touching them, and with minimal water. After washing, the underwear can be placed in fast-drying bags that are discreetly hung to dry, even in hot and humid conditions.[lxiv][lxv]

The higher upfront cost of reusable underwear can be a barrier, particularly as multiple pairs are needed for one period. If someone is concerned about the product's effectiveness, it's unlikely that they'd buy more than one to start with, but people would need to buy at least two for one period so this may be an initial hesitancy for some people.

Another obstacle is the potential lack of support from resource-constrained organisations, such as schools, which play essential roles in menstrual education and providing menstrual hygiene management (MHM) products to girls. Further research into examples from developing contexts, including cost considerations, would provide valuable insights into the feasibility of widespread adoption in these areas.

Handwashing with soapy water

Soapy water is an innovative physical product that offers a low-cost solution for hand hygiene, particularly in low- and middle-income countries (LMICs) and humanitarian settings. This simple yet effective handwashing agent is created by mixing a 30-gram commercially available powdered detergent packet with 1.5 Liters of water. The technology has reached a Technology Readiness Level of 9, indicating its full market readiness.[lxvi] The applications of soapy water are diverse, ranging from public spaces and institutions such as schools, hospitals, garment factories, and shopping malls to informal settlements and shared handwashing stations in low-income areas. Its effectiveness has been recognized, with the EAASi Soap dispenser for soapy water showcased at the UNC Conference 2023.

One of the primary benefits of soapy water is its affordability, making hand hygiene accessible to those who cannot afford traditional soap. It can be easily prepared at home and is microbially effective. Additionally, other types of soap powder, such as laundry soap, may be used if they do not cause skin irritation, further increasing its versatility.

However, from circular economy perspective bars of soap is (no plastic) are more sustainable due to their lower environmental impact, they use less energy and water during production, less packaging and contain fewer synthetic chemicals.

Soapy water faces the challenge that as it is not a commercial product, it can be difficult to integrate into traditional business models. Furthermore, the lack of large soap dispensers in the market necessitates frequent refilling, which can be an inconvenience in high-traffic areas. Despite these challenges, soapy water represents a significant innovation in promoting hand hygiene in resource-limited settings, offering a practical and affordable solution to a critical public health need.

7

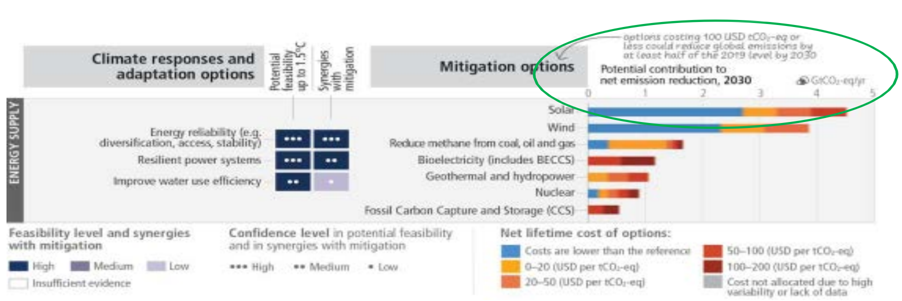
OPPORTUNITY: CLIMATE CHANGE MITIGATION AND WASH

The IPCC AR6 Synthesis Report: Climate Change 2023

The latest IPCC Synthesis Report has modelled pathways and opportunities for scaling up climate action and the feasibility of climate responses and adaptation for the near term. The report is based on scientific understanding, and key findings can be formulated as statements of fact or associated with an assessed level of confidence using the IPCC calibrated language.

Figure 23. Responses and adaptation options

Source: IPCC Sixth Assessment Synthesis Report, SPM Figure 7, p.69



Solar energy is considered a highly feasible and impactful mitigation option, and has huge potential in the water and wastewater sectors given that emissions from wastewater are on a par with those from aviation (ADB, 2023). Figure 30 presents a snapshot of the potential impact and relative cost of transitioning the energy supply and deploying solar for emission reduction and adaptation by 2030. Costs are net lifetime discounted monetary costs of avoided greenhouse gas emissions calculated relative to a reference technology. Solar energy as a core component of an energy generation diversification strategy will help reduce climate-related risks, but the potentials and costs will vary by place, context and time and in the longer term compared to 2030.[lxvii]

A study conducted for the Gates Foundation on urban sanitation and climate change found five key challenges related to infrastructure and service delivery. These range from understanding, to access to data, to a lack of guidance and standards with respect to climate resilient sanitation technologies and services as shown in the following figure.

Solar desalination

Solar desalination is an innovative physical product that harnesses the power of the sun to purify water, making it particularly suitable for rural water supply. This technology has reached a Technology Readiness Level of 9, indicating its full market readiness and commercial viability.

The process of solar desalination can be implemented in various ways. One approach uses solar-generated electricity to power reverse osmosis systems. Another design relies on the natural convection of water, while a third method employs concentrated solar power (CSP) to convert water into steam using the sun's heat.[lxviii]

This technology offers several potential benefits. It can be adapted to treat wastewater, demonstrating high performance in water purification. Unlike some similar systems, solar desalination prevents salt accumulation, addressing a common challenge in desalination processes. The flexibility to use either solar photovoltaic (PV) panels or solar thermal energy for powering reverse osmosis adds to its versatility. Furthermore, the current emphasis on renewable energy projects has made funding more readily available for such initiatives. The growing focus on regional business and manufacturing has also expanded the market for solar desalination technologies.[lxix]

However, solar desalination is not without challenges. In areas with high temperatures and significant air pollution that obstruct solar rays, PV panel-based systems may operate less effectively. The broader implementation of solar energy technologies requires more strategic planning and goal setting. Additionally, most solar desalination systems cannot operate at night, which can limit their continuous use.[lxx]

Despite these challenges, solar desalination represents a promising solution for providing clean water in rural areas, particularly in regions with abundant sunlight and limited freshwater resources. As the technology continues to evolve and improve, it has the potential to play a significant role in addressing water scarcity issues worldwide.[lxxi]

Mitigating sanitation emissions

Despite being essential for health and wellbeing, sanitation systems are increasingly recognised as contributors to global greenhouse gas (GHG) emissions and climate change.[lxxii] Recent estimates suggest that wastewater and sludge management, along with non-sewered sanitation, account for approximately 1.3% of global GHG emissions - comparable to the global aviation sector. Sewage primarily produces nitrous oxide and methane, which have global warming potentials 273 and 28 times that of carbon dioxide over a 100-year period, respectively.[lxxiii]

Poudel et al (2023) discuss the challenges in measuring GHG emissions from on-site sanitation systems (OSS), particularly in Low and Middle-Income Countries (LMICs). Through a systematic review of English-language literature, the authors found only eight studies that used field-based methods to measure GHG emissions from OSS, all focusing on septic tanks in middle- and high-income countries.[lxxiv] The most common measurement technique is the flux chamber (FC) method, with various modifications. However, the review highlights several limitations, including insufficient information on calibration and validation, complex designs, resource-intensive operations, and potential unsuitability for LMICs due to unstandardized OSS designs and limited resources. The authors conclude that there is a need for a simple, adaptable, and well-calibrated field-based method to reliably quantify GHG emissions from diverse OSS in LMICs.

The importance of addressing emissions is further emphasised by projected trends, particularly in rapidly urbanising regions of South Asia and sub-Saharan Africa. The number of people relying on non-sewered sanitation technologies is expected to reach 5 billion by 2030.[lxxv] This expansion of sanitation infrastructure presents opportunities for mitigation strategies. In some urban contexts, such as Kampala, Uganda, sanitation-related emissions could account for over 50% of the city's total emissions. [lxxvi] Lowering emissions from sanitation can be done in a range of ways, though evidence is lacking for most technologies in a range of contexts. Some options canvassed by Lambiasi et al, (2024) include:

- **Alternative technologies** to pit latrines, which can be significant sources of methane emissions. Options presented in this report above such as container-based sanitation, composting toilets, or urine-diverting dry toilets may have lower emissions.

- For existing pit latrines, implement **more frequent emptying** to reduce anaerobic conditions and methane production. Direct collected sludge to proper treatment facilities rather than on-site disposal.
- Improve **pit latrine design** to promote more aerobic conditions, which produce less methane. This could include better ventilation.
- For septic tanks, ensure **proper maintenance and regular desludging** to reduce methane emissions. Consider connecting septic tank effluent to sewers or leach fields rather than direct discharge.
- Implement **resource recovery and reuse** where possible, such as composting of excreta or use of urine as fertilizer to offset emissions from fertilizer production.
- Consider **decentralised ecological sanitation systems**, which can have lower energy requirements and emissions compared to centralised systems.
- For any treatment systems, **optimise operations** to run efficiently and minimize direct emissions of methane and nitrous oxide.
- Implement **monitoring of greenhouse gas emissions** from sanitation systems to identify opportunities for targeted improvements.
- Consider **local environmental conditions** like temperature and water table depth when designing systems, as these impact emissions.
- Take a **whole system approach**, considering emissions across the entire **sanitation chain** from containment to treatment and end-use/disposal.
- Explore innovative **low-emission technologies** and approaches suitable for rural contexts, such as container-based systems with off-site composting.
- Provide **training and capacity building** to ensure proper

operation and maintenance of sanitation systems to minimize emissions.

8

WASH AND ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) has the potential to address complex global challenges and improve water, sanitation, and hygiene (WASH) outcomes while also considering circular economy principles. With its ability to process vast amounts of data, recognise patterns, and make predictions, AI could support a number of WASH challenges, especially in relation to data management, using data to inform decision making, and in communications. The AI driven optimisation improves the resource efficiency, reducing waste and regenerating natural systems. It also increases resilience with predictive maintenance in addition to the efficient resource management while delivering reliable WASH services.

Terminology

Many concepts are often used interchangeably in this sphere.

Terms such as machine learning, cognitive computing, and digital monitoring are often conflated and confused with the umbrella term “AI”.

These terminological distinctions matter, as Leonard D'Avolio, Harvard Medical School professor and CEO of Cyft, a healthcare machine learning company, notes: "*If I describe what I do as cognitive computing, but a competitor describes what they do as AI or machine learning or data mining, it's hard to even understand what problems we are trying to solve*."[lxxvii]

Key definitions relevant to AI in WASH:

Artificial Intelligence (AI) – A broad field which refers to diverse technologies that aim to simulate human intelligence. This enables them to perform tasks that typically require human cognition, such as decision-making, problem-solving, and learning from data.[lxxviii] AI technologies may include robotics, deep learning, machine learning, speech recognition, image recognition, computer vision, natural language processing and analytics.[lxxix]

The following terms are considered subsets of AI.

- **Machine Learning (ML)** – Training algorithms to recognise patterns and make decisions or predictions based on data. Instead of being explicitly programmed to perform tasks, ML models "learn" from the data they are provided, improving their performance over time.[lxxx] An example of this is the ML-based platform BlueDot. BlueDot analyses global health data to predict outbreaks of waterborne diseases such as cholera and typhoid, helping WASH programmes focus efforts on at-risk populations.[lxxxi]
- **Cognitive computing** – Systems developed to work alongside humans to enhance decision making by simulating reasoning, interpretation and learning abilities.[lxxxii] Many smart water metering companies, such as Australian based SUEZ Smart Solutions, use cognitive

computing to help water utilities optimise operations through analysing water network data, customer reports, and environmental data to recommend actions such as adjusting water pressure or scheduling maintenance activities.[lxxxiii]

- **Digital monitoring** - The use of Internet of things (IoT)-enabled sensors, devices, and software to observe, track, and collect data about a process or system in real-time, often for the purpose of surveillance or operational management.[lxxxiv] Loowatt, a UK-based company, uses digital sensors in its off-grid toilet systems to monitor waste levels, providing real-time data to operators for efficient waste collection and disposal.[lxxxv]

SDG6 and AI

Artificial intelligence (AI) is increasingly being leveraged to tackle some of the world's most pressing challenges, including the 17 United Nations' Sustainable Development Goals (SDGs). [lxxxvi] AI specifically promotes SDG9, to build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.

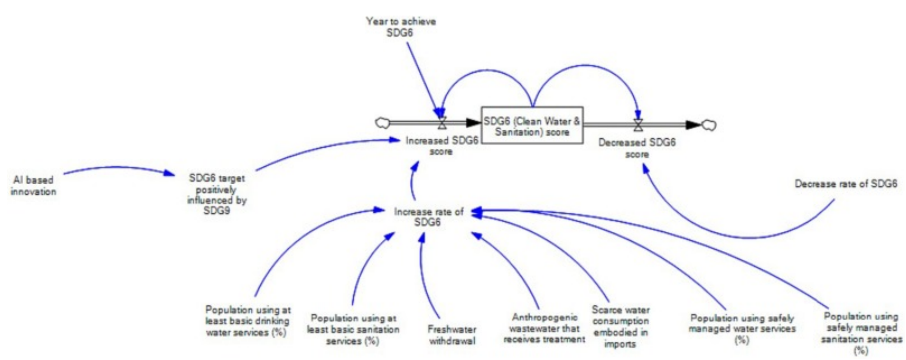
In the context of SDG6—ensuring clean water and sanitation for all—AI-driven innovations can improve water resource management, enhance sanitation infrastructure, and expand access to water globally. [lxxxvii] [lxxxviii]

AI-based innovation could transform global water and sanitation challenges, though the degree of its impact will vary across different countries over this decade. Nahar (2024) comments on this variation through a system dynamics modelling-based simulation undertaken from 2022 to 2023.[lxxxix] Developed nations such as Australia, France, Germany, Japan, Russia, Saudi Arabia, and the UAE as well as some developing countries like Egypt, Iran, Nigeria, and Pakistan are projected to experience continuous growth in AI advancements impacting the water and sanitation sector. For some developing nations including Vietnam, Kenya, Bangladesh, China, and India, the impact of AI is expected to dip in the short term but then rise steadily through the decade. Conversely, the UK and Turkey are expected see a temporary increase in AI's impact, followed by a gradual decline.

Nahar outlines the factors contributing to these variations between countries in the following visual ‘SDG6 stock-flow diagram’. It represents the global status of water and sanitation facilities, where the 'stock' is the SDG6 score. The model incorporates two streams: 'inflow,' indicating improvements in water and sanitation, and 'outflow,' representing challenges faced. AI-based innovation is the primary factor driving inflow, supported by variables such as the time to achieve SDG6 targets, the influence of SDG9, access to basic drinking water, effective sanitation services, freshwater withdrawal rates and wastewater treatment levels.

Figure 24. Stock-flow diagram assessing the impact of AI-based Innovation on SDG6 (Environmental Pillar)

Source: Nahar 2024



AI innovation areas for WASH

From predicting water shortages and optimising sanitation networks to real-time monitoring and behaviour change initiatives, AI is enhancing the efficiency and sustainability of WASH services by improving resource management, system maintenance, and public health protection.

It is relevant to note that industry experts caution against digitising for its own sake, which can often lead to 'digital fatigue' amongst organisations and customers. Instead, AI should be integrated into existing systems strategically, starting with smaller projects that deliver measurable results.[xc] The WASH sector's risk-averse nature requires a balanced, incremental approach to adopting AI, aligning digital efforts with long-term goals like decarbonisation and customer-centric services.

This section explores how AI can be and is being applied across WASH areas, driving more effective, resilient, and equitable outcomes for communities globally.

AI and Water supply

AI has the potential to enhance water supply management by improving availability predictions, demand forecasting, network optimisation, and leak detection. Through digital twins of supply networks and the automated analysis of satellite imagery, weather patterns, and historical data, AI can refine water availability predictions and identify potential shortages or supply failures.[xci] AI models have been developed to forecast groundwater levels in water-scarce regions and to model nitrate contamination in groundwater sources, aiding in more proactive water resource management.[xcii] [xciii] AI can also evaluate the best times of day to move water between reservoirs and consumers to avoid evaporation or freezing in high and low temperature zones.[xciv]

AI-driven models are able to improve water demand forecasting. By analysing historical usage data, hybrid machine learning models can provide short-term, probabilistic forecasts, helping to guide water efficiency measures and infrastructure planning.[xcv] These models can incorporate long-term climate projections into demand scenarios, enabling more sustainable decision-making and contributing to the resilience of water systems in the face of climate change.

By analysing data in real time, then adjust water flow and pressure, AI systems can minimise losses and enhance network performance. [xcvi] This will also allow for the efficient allocation of water, particularly during periods of scarcity. This is especially important for maintaining equitable distribution across communities, with particular benefits for vulnerable populations. AI-powered sensors and monitoring systems additionally enhance the maintenance of water infrastructure by predicting, detecting, and reporting leaks. This proactive approach extends the life of assets, reduces water loss, and ensures that clean, safe water is reliably delivered to communities.[xcvii]

Smart sanitation systems

AI can impact sanitation systems by optimising the placement of sanitation facilities and the design of sewage networks through the analysis of demographic data, satellite imagery, and topographic information.[xcviii] By improving the strategic planning and distribution of resources, AI facilitates more efficient management of sanitation infrastructure and enhances access to clean water and sanitation services. A recent study using machine learning tools demonstrated the link between ineffective sanitation management and the prevalence of diarrhoeal infections, highlighting AI's role in addressing public health concerns related to sanitation. [xcix]

In waste treatment, AI can optimise processes by incorporating smart bin systems, route optimisation algorithms, dynamic scheduling, and demand prediction models. Waste sorting is a critical step in the waste management process, AI integration in these processes (through automated sensor or robotic sorting techniques and image recognition or machine vision) is improving accuracy, speed and efficiency.[c] In China, AI-driven recycling facilities have achieved up to 95% accuracy in sorting recyclable materials.[ci]

Plants that process drinking water and wastewater are among the largest consumers of energy. Making these plants more energy efficient can significantly reduce running costs. AI-driven optimisation algorithms can help optimise treatment processes, adjust aeration rates and minimise energy-intensive operations to reduce overall energy consumption.cii This enhances the efficiency of waste treatment facilities while simultaneously reducing environmental impact, leading to cleaner and more sustainable waste management practices.

Continual operation and maintenance

AI-driven solutions can improv the continual operation and maintenance of WASH infrastructure, leading to enhanced system reliability and more efficient service delivery. AI-powered predictive maintenance systems use real-time monitoring to forecast equipment failures in critical infrastructure such as water treatment plants and pumping stations. By anticipating maintenance needs, these systems help reduce downtime, avoid costly repairs, and ensure more consistent water services for communities. [ciii] [civ]

In addition, AI-enabled citizen reporting platforms allow users to report service disruptions or issues in real-time, such as the mWater app used globally.[cv] These platforms create a direct line of communication between the public and service providers, enabling quicker responses to problems and promoting accountability in maintaining reliable water and sanitation services. This increased transparency strengthens community trust and contributes to more effective service delivery.

Water quality monitoring and public health protection

AI's ability to processing large datasets and predicting potential risks can lead to the improvement of water quality monitoring and safeguarding of public health. Machine learning algorithms analyse data from sensors and water quality tests to detect contamination and predict trends in water conditions. This enables rapid responses to contamination issues, ensuring welltimed interventions and precise targeting of treatment efforts. [cvi]

AI also enhances disease prediction and surveillance by integrating environmental data with health records to identify and forecast outbreaks of waterborne diseases, such as cholera and dysentery.[cvii] By anticipating outbreaks, AI enables authorities to take preventive measures, ultimately protecting communities. This proactive approach allows for quicker, more targeted public health interventions, reducing the spread of diseases associated with unsafe water conditions.

Climate resilience and water security

AI technologies are increasingly important in enhancing climate resilience and water security, particularly in managing risks related to sea level rise, floods and droughts. In sea-level rise and flood management, AI models analyse weather patterns, hydrological data, and environmental factors to provide accurate forecasts. These predictions support the design and planning of more resilient WASH infrastructure, helping communities and governments mitigate the impacts of climate-induced disasters.[cviii] By minimising disruptions to infrastructure, AI-driven disaster management ensures continued access to clean water and sanitation, reducing health risks during events.

In drought management, AI can improve the allocation and use of limited water resources in regions prone to water scarcity, as discussed in the previous 'water supply management' sections. By analysing data on water consumption, climate trends, and local conditions, AI optimises water distribution to ensure access to drinking water and sanitation even during periods of drought.[cix] This proactive approach supports long-term water security.

During natural disasters, AI-technologies can provide leaders vital and time-sensitive information to help responders prevent loss of life. After an event, they can also help governments restore water quality and repair damage to more quickly improve the quality of life for citizens. [cx]

Education and behaviour change

AI has the potential to transform education and behaviour change initiatives in the WASH sector through personalised communication and localised learning. AI-powered tools, such as chatbots and messaging systems driven by natural language processing and machine learning, can deliver tailored WASH-related information in local languages.[cxi] Engaging and accessible AI-driven hygiene education platforms, such as mobile apps and digital platforms teach individuals about key hygiene practices, such as effective handwashing.[cxii] These tools promote essential hygiene practices and provide individuals with the knowledge needed to improve water and sanitation behaviours, critical in preventing spread of disease.

In addition, AI supports localised learning by adapting educational materials to reflect the local context, culture, and language of the communities it serves.[cxiii] This approach ensures that children and their families are better equipped to protect water resources and maintain sanitation, fostering long-term sustainability in water and hygiene practices.

Challenges of AI in WASH

It is important to note that the full integration of the above 'AI innovation areas' in existing systems is not the current reality of the WASH sector. While AI holds significant potential to improve WASH services, several challenges must be addressed to ensure its effective and ethical application, particularly in low-income contexts. A key challenge is the lack of comprehensive data as well as the capacity and capability to implement required system changes. AI models require large, high-quality datasets to generate accurate predictions and inform decision-making. However, many low-income countries lack sufficient WASH-related data, making it difficult to effectively train AI systems.[cxiv] Enhancing data collection processes and ensuring data quality are therefore essential steps for AI to make a meaningful impact on WASH services.

Another obstacle is limited internet connectivity and access to digital devices. In many low-income regions, the necessary infrastructure—such as reliable internet and access to digital tools—is underdeveloped, impeding the application of AI technologies.[cxv] Additionally, there is an urgent need to build local expertise in AI and data science to ensure the long-term sustainability of AI-powered WASH initiatives. Without sufficient local capacity, AI solutions may not be effectively implemented or maintained over time.

Ethical considerations are also to be considered. AI systems must be designed to respect privacy rights, avoid reinforcing biases, and ensure that marginalised communities and individuals are not further disadvantaged by AI-driven decision-making. The lack of robust data protection and AI policies in the Global South could potentially lead to greater levels of misuse as AI grows in reach.[cxvi] It is important to ensure that AI does not exacerbate existing inequalities and that all communities benefit from these innovations. Furthermore, AI solutions developed in high-income countries may not be directly applicable to low-income settings, necessitating adaptation and localisation to meet specific local challenges.

To fully harness AI's potential in WASH services, collaborative efforts among governments, NGOs, technology companies, and local communities are essential. Addressing challenges related to data availability, infrastructure, capacity-building, and ethical concerns will allow AI to contribute to more targeted, efficient, and sustainable WASH interventions.

WASH specific AI tool

WASH AI is an innovative artificial intelligence tool specifically tailored to address the unique challenges of the water, sanitation, and hygiene (WASH) sector.[cxvii] Unlike general AI models, WASH AI is designed to provide real-time, contextual knowledge by continuously updating its database with the latest sector-specific information, including published research and grey literature. This allows it to offer more accurate, relevant insights to help improve decision-making in areas such as water resource management, sanitation infrastructure, and hygiene education. Additionally, its ability to analyse diverse datasets ensures that critical insights from underserved and low-resource regions are included in its recommendations.

WASH AI states that it has a focus on accessibility and inclusivity. The platform supports over 20 languages, making it a valuable resource for WASH professionals and communities across the globe. By delivering personalised, localised information, WASH AI ensures that language barriers and digital access limitations don't prevent individuals from benefiting from essential water and sanitation knowledge. The tool is designed for seamless integration into various communication platforms, including WhatsApp, Telegram, and Slack, which broadens its reach and enhances user engagement.

The potential benefits of WASH AI for the sector could be significant. It can improve the efficiency of resource allocation, optimise water distribution, and enhance sanitation systems, especially in regions vulnerable to climate change and resource scarcity. By facilitating more informed, data-driven decisions, WASH AI may help streamline operations and increase the resilience of WASH services.

9

GENDER EQUALITY, DISABILITY AND SOCIAL INCLUSION

Evidence shows that access to WASH is experienced differently by diverse individuals. In recent decades, there have been significant shifts in how inclusion is considered and implemented in WASH programming. Women and children are often disproportionately impacted by inadequate water and sanitation, despite traditionally being responsible for water collection and management at the household level. Economically marginalised people cannot afford safely managed WASH services. Sexual and gender minorities are overlooked in WASH decision-making, and their needs are seldom considered. Similarly, people with disabilities and their caregivers have diverse needs that must be addressed when designing and maintaining WASH systems, using universal design principles as outlined in the introduction of this document. Inclusive approaches ensure that the immense knowledge and experience related to WASH that diverse groups have, is not untapped or overlooked, thereby increasing the likelihood of WASH delivering on intended health and wellbeing outcomes for all.

To account for this diversity, three areas of innovation in GEDSI are worth particularly highlighting in the context of innovation. These demonstrate how we have moved from simplistic "add women and stir" approaches to more nuanced and complex conceptions of inclusivity:

1. Intersectionality
2. Transformative approaches including partnerships with rights holder organisations
3. Innovations in inclusion within the WASH sector itself

These areas will now be briefly outlined.

Intersectionality

Intersectionality is a concept that recognises how multiple aspects of a person's identity and social categories (such as gender, disability, race, class, sexuality, etc.) intersect and interact to create unique experiences of privilege or oppression.

By considering intersectionality, WASH programmes can better understand and address the complex ways in which factors such as gender, disability, socioeconomic status, age, ethnicity, and sexual orientation interact to create unique challenges and barriers to WASH access. This approach helps to identify and support the most marginalized and vulnerable populations, whose needs might be overlooked by more generalized interventions. For example, a poor woman with disability in a rural area may face compounded difficulties in accessing WASH facilities compared to other community members. By acknowledging these intersecting factors, WASH programmes can develop more inclusive, effective, and equitable solutions that cater to diverse needs and experiences, ultimately leading to more sustainable and impactful outcomes for all community members.

Transformative Approaches

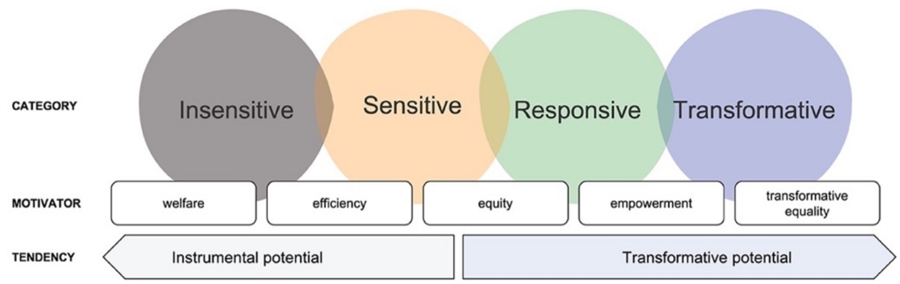


Figure 25. Towards transformative practice.

Source: MacArthur et al (2023)

As summarised by MacArthur et al (2023),[cxviii] transformative approaches to GEDSI in WASH programmes include the following key elements:

A purposeful transformative agenda: These approaches start with the explicit intention to transform harmful norms, dynamics, and structures that perpetuate inequalities.

Addressing structural systems: Rather than focusing on symptoms, transformative approaches engage with the root causes and structural systems of inequality.

Focus on strategic gender interests: The approaches maintain attention on long-term, strategic interests related to gender equality, disability and social inclusion (GEDSI), not just immediate practical needs.

Recognition of diverse identities: Transformative approaches go beyond a gender binary, incorporating concepts of intersectionality to address multiple, interconnected forms of social inequality.

Adoption of transformative methodologies: The approaches use methods and tools specifically designed to foster transformation in gender relations and social structures.

Simultaneous improvement of WASH outcomes and gender equality: Transformative approaches aim to achieve both better WASH results and enhanced GEDSI, recognising that these goals can be mutually reinforcing.

Engagement with relational, collective, and structural inequalities: The approaches work at multiple levels to address gender and social inequalities comprehensively.

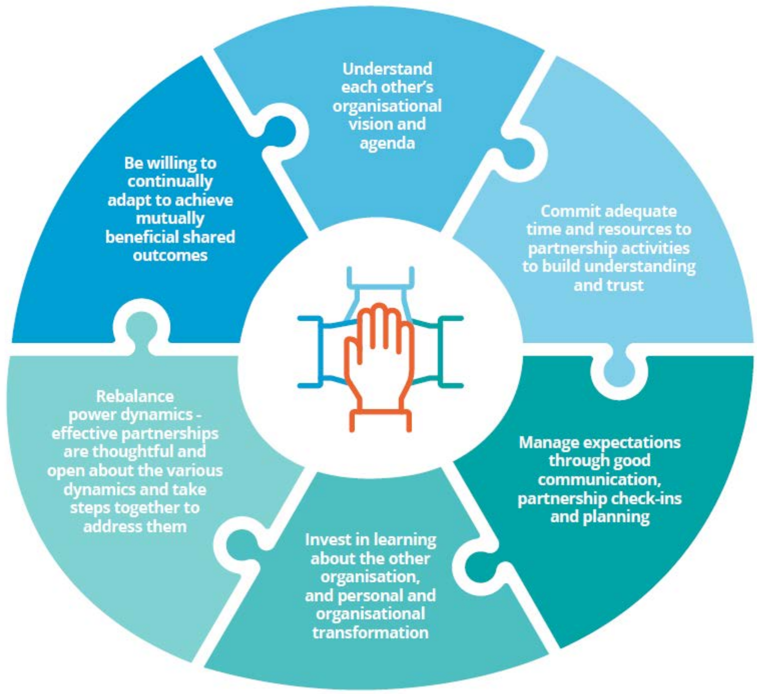
Moving beyond instrumental approaches: While recognising the potential efficiency gains from including the broader community, transformative approaches aim for more fundamental changes in power dynamics and harmful social norms so as to shift underlying discriminatory belief systems, structures and practices.

Partnerships with Rights Holder Organisations

A key strategy to achieve the elements described above, is partnering with rights holder organisations (RHOs) which has been a more common strategy for WASH organisations in recent years as demonstrated by partners within the Water for Women fund in the Asia Pacific region. RHOs are made up of and/or advocate for, and raise the voices of marginalised people and groups, and include women's organisations, organisations of persons with disabilities, sexual and gender minority organisations, ethnic minority organisations, and organisations that represent people who are economically disadvantaged (Figure 34)[cxix]. RHOs make up significant parts of civil society, and focus on amplifying the interests and voices of a broad range of marginalised groups.[cxx] [cxxi]

Figure 26. Top tips for effective partnerships between WASH organizations and RHOs.

Source: Water for Women (2023)

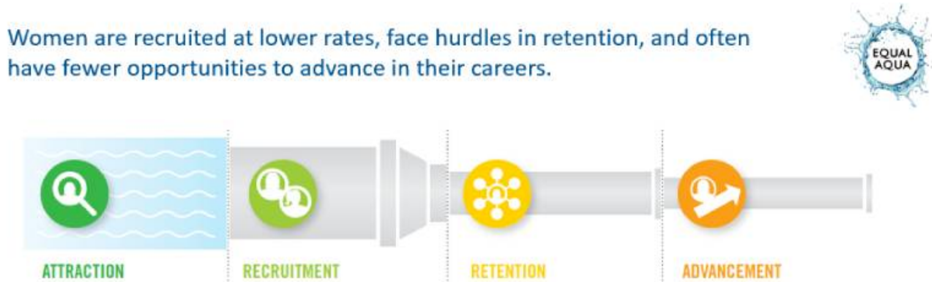


Innovations in inclusion within the WASH sector itself

The WASH sector is increasingly looking at itself and the way it works, as well as the communities it serves. This has led to initiatives such as the Equal Aqua programme [cxxii] of the World Bank which conducts assessments of gender parity, policies and processes within the water sector globally, in order to increase equality (see Figure 35). It's focus on data collection, role models, and uncovering and changing biases in recruitment and societal expectations of women and girls has supported the water sector to be more inclusive. The Equal Aqua framework was further developed by UTS-ISF and a database of diversity and inclusion initiatives developed, along with research conducted in Cambodia and Indonesia. [cxxiii]

Figure 27. Equal Aqua Initiative

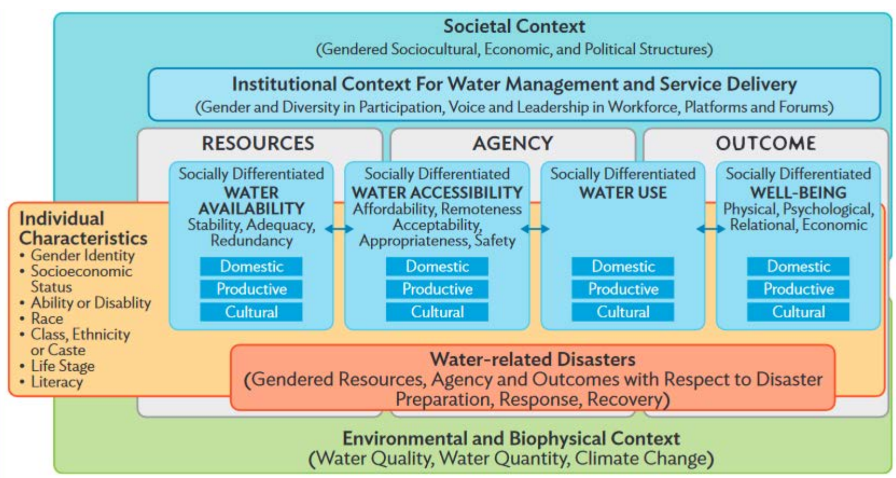
Source: World Bank



UTS-ISF with the Asian Development Bank (ADB) have developed a framework to assist practitioners and policy makers to consider GEDSI in water security and WASH, as shown in the following figure.

Figure 28. Gendered Water Security Framework (ADB)

Source: UTS-ISF and the Asian Development Bank (ADB)



Some of the key recommendations being made by GEDSI researchers and practitioners in the WASH sector include:

1. Embed gender thinking in policy considerations
2. Promote meaningful engagement, co-design, and participation

3. Increase women's voice, leadership, and decision-making
4. Address systemic inequality within organisations
5. Monitor and evaluate gendered outcomes and impacts.

The "Inclusive Pathways Towards Climate-Resilient WASH" study (2025), conducted in Bangladesh, revealed important insights into the challenges faced by people with disabilities in accessing WASH services during climate events.[cxxiv] The research, led by the London School of Hygiene & Tropical Medicine in partnership with icddr,b and World Vision, documented severe disruptions to WASH infrastructure, with 30% of water points and 13% of latrines damaged during extreme weather events. These impacts disproportionately affected people with disabilities, with nearly half unable to access alternative sanitation facilities when their primary options were compromised.

Through participatory workshops in Gaibandha, Satkhira, and Dhaka, the study team collaborated with people with disabilities, caregivers, Organisations of Persons with Disabilities, and sector experts to develop six comprehensive principles for climate-resilient, disability-inclusive WASH interventions. These principles create a framework for practitioners to enhance disability inclusion in climate-resilient WASH efforts.

The **first principle** focused on ensuring WASH services and information remain accessible throughout all phases of climatic events. This includes implementing universal design principles, providing accessible modifications, and incorporating comprehensive disaster preparedness measures. The **second principle** addresses the essential role of caregivers, emphasising the need for proper equipment, training, and social recognition to enable safe and hygienic care delivery during climate events.

Safety and protection form the **third principle**, which calls for addressing specific climate-related risks, incorporating gender-based violence prevention, and establishing robust safeguarding mechanisms. The **fourth principle** tackles affordability, promoting financial accessibility through subsidies, pro-poor tariffs, and the integration of disability considerations in climate finance initiatives.

The **fifth principle** emphasises meaningful participation, ensuring people with disabilities actively contribute to developing WASH solutions and participate in decision-making at all levels. The **final principle** focuses on building capacity among government officials and service providers, calling for standardised guidelines, dedicated budgets, and the integration of disability inclusion indicators in WASH programmes.[cxxv]

These principles, supported by detailed suggested activities, provide a practical framework for practitioners to enhance disability inclusion in climate-resilient WASH efforts. The framework acknowledges that while the suggested activities are not prescriptive, they offer valuable guidance that can be adapted to local contexts and supplemented with additional initiatives as needed. This approach ensures flexibility while maintaining a strong focus on meaningful inclusion and practical accessibility for people with disabilities and their caregivers.

By implementing these principles, prioritising partnerships with RHOs, and considering equity within organisations, the WASH sector can work toward more equitable and resilient WASH services that better serve all people during climate events, ultimately contributing to improved health outcomes and dignity for all.

10

BEHAVIOUR CHANGE IN WASH

Without WASH behaviour change, the uptake and maintenance of WASH technologies are unlikely to succeed. Behaviour change forms the foundation for sustainable improvements in WASH. Innovative approaches to WASH behaviour change has been characterised by community engagement, psychological insights, technology integration, cultural sensitivity, and multisectoral collaboration.[cxxvi] While significant progress has been made, challenges remain in scaling up successful interventions and ensuring long-term sustainability. Some of the most promising innovative approaches in WASH behaviour change in recent years have included:

Nudge theory in handwashing

Nudge theory, which applies behavioural economics principles to subtly influence behaviour without restricting choice, has shown promise in increasing handwashing rates in schools and public facilities across low-income countries. Some innovative applications include:

1. Footpath nudges: Painted footprints leading to handwashing stations
2. Mirrors above sinks: Increase self-awareness and promote handwashing
3. Decorated school bathrooms: Makes handwashing more appealing and memorable

For example, researchers tested a new way to encourage handwashing among school children in the Philippines and instead of just giving information, they used small changes to the environment that remind people to wash hands (nudges).[cxxvii] These included painting footpaths to handwashing stations and putting up posters.

They tested this in 66 schools, comparing them to 66 schools without these changes.

After 4 months, they found that:

1. Handwashing with soap increased by about 17% in schools with the nudges.
2. More soap was available in these schools.
3. The approach worked equally well for all ages and genders and cost less than US$70 per school.

Behaviour-Centred Design (BCD)

Developed by the London School of Hygiene and Tropical Medicine, Behaviour-Centred Design combines evolutionary and environmental psychology with design thinking. Key features of BCD include:

1. Formative research: Deep dive into target behaviours and their determinants
2. Creative process: Generates novel intervention ideas

3. Surprise and disruption: Uses unexpected elements to capture attention and change habits

BCD has been applied successfully in various contexts, offering a comprehensive framework for designing effective behaviour change interventions.

Case Study: Making Menstrual Health Campaigns Accessible for People with Intellectual Disabilities

The Bishesta campaign in Nepal and the Veivanua campaign in Vanuatu demonstrate how behaviour change approaches can be successfully adapted for people with intellectual disabilities and their caregivers. These groundbreaking campaigns show that with careful design and appropriate resources, menstrual health interventions can be both accessible and effective for this often-overlooked group. The campaigns use creative methods such as picture-based stories to explain menstruation and hygienic management, dolls to demonstrate proper pad changing and disposal, and simple visual reminders to communicate key menstrual health concepts. Both campaigns have led to increased confidence and autonomy among participants with intellectual disabilities, with many reporting they can now manage their menstruation more independently. Caregivers also report feeling better equipped to provide support. These initiatives highlight how behaviour change campaigns can successfully integrate accessibility from the outset, rather than treating it as an afterthought. Key to their success was the involvement of people with intellectual disabilities and their caregivers in the design process, ensuring materials and messages were truly accessible and relevant.[cxxviii]

Another example is from Lao PDR emotional motives were drawn upon as explained in the following box.

Case Study: Emotional Motives in Lao PDR

SNV in Lao PDR selected handwashing with soap (HWWS) as the target behaviour to promote. Drawing on learnings from SNV in Bhutan and the SuperAmma intervention in India, they used emotional motives (disgust, nurture, affiliation) rather than germ theory to change behaviours. Key elements of the intervention included:

1. Evoking disgust for invisible dirt through storytelling and demonstrations

2. Engaging parents through the nurture motive, using an adapted illustrated story

3. Promoting proper handwashing stations through games and behaviour trial films

Case study: Using Research to Inform Behaviour Change Communications to Increase Piped Water Uptake

A team of international researchers from Universitas Indonesia and the UTS Institute for Sustainable Futures have developed a behaviour change package aimed at encouraging urban households in Indonesia to transition from private wells or bores to a centralised piped water supply. This initiative promotes a more climate-resilient and safely managed water system than what householders are currently using. The researchers assessed various barriers and incentives that influence people's decisions to adopt piped water, considering factors such as psychological drivers, physiological traits, and the environmental and social context.

The team's approach involved analysing the "behaviour setting," which refers to the physical space where decisions are made, as well as the roles and routines of those involved. By exploring these elements, the team were able to create targeted communication and behaviour change tools designed to increase the uptake of piped water in urban areas. The tools developed include a poster illustrating two life pathways for a young child—one where the family chooses piped water and one where they use hand-pumped groundwater. Additionally, storyboards were created to appeal to various behavioural motivations, encouraging families to connect to a centralised water supply. The package also included a document with six key recommendations for PDAMs (local water utilities) to increase household connections and use of piped water. Lastly, the researchers produced a booklet that addresses common myths and misconceptions about piped water, which may discourage households from making the transition. This was based on insights obtained through the formative research which identified barriers to uptake of the desired behaviour. The booklet provides facts to dispel these myths, further supporting the push towards piped water adoption in Indonesia.

mHealth interventions

Mobile health (mHealth) technologies leverage widespread mobile phone usage in low-income countries to promote WASH behaviours. Innovations in this area include:

1. SMS reminders: Regular messages promoting WASH behaviours
2. Interactive voice response: Provides WASH education through automated calls
3. Mobile apps: Gamified learning experiences for WASH education

Social marketing approaches

Social marketing applies commercial marketing strategies to promote behavioural change in WASH practices. Key innovations include:

1. Aspirational messaging: Links WASH behaviours to social status and success
2. Product innovation: Develops attractive, affordable WASH products
3. Distribution innovation: Creates new channels to reach underserved populations

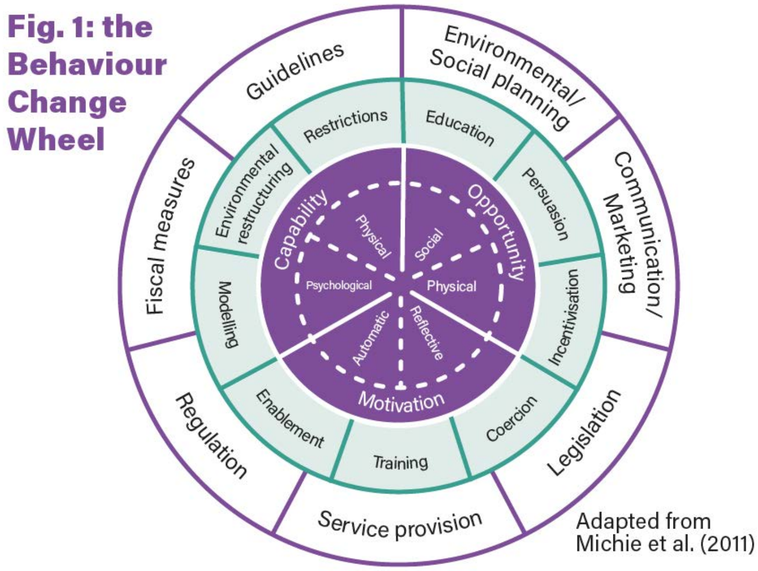
Participatory Hygiene and Sanitation Transformation (PHAST)

PHAST engages communities in a step-by-step process to analyse their hygiene behaviours and design solutions. Innovations include:

1. Visual tools: Uses locally adapted pictures to facilitate discussions
2. Community mapping: Helps identify and prioritise WASH issues
3. Action planning: Empowers communities to create and implement their own plans
4. PHAST has been widely implemented in Africa and Asia, contributing to improved WASH practices and community empowerment.

Figure 29. Behavior Change Wheel

Source: Michie, S., van Stralen, M. M., & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. Implementation Science, 6, Article 42



Case Study: The Behaviour Change Hub

The SNV behaviour change hub offers expert central support to diverse organizational teams working on behaviour challenges.[cxxix] This approach improves the effectiveness of interventions, optimises resource use, strengthens organizational capacities, and reduces carbon footprint. Benefits include:

- Improved effectiveness through a common approach rooted in behaviour science

- Optimized resources through central support and collective learning

- Strengthened organizational capacity through practical application of theory

As the field of WASH behaviour change continues to evolve, future innovations will likely focus on integrating multiple approaches, leveraging emerging technologies, and addressing the specific needs of vulnerable populations. By combining these innovative strategies and tailoring them to local contexts, we can make significant strides in improving WASH practices and, ultimately, public health outcomes in low-income countries.

11

INNOVATIVE AND BLENDED WASH FINANCE

Global costs of achieving SDG 6 exceed US$ 1 trillion annually, while only a fraction of this amount is currently being spent to close the service gap.[cxxx] It is widely recognised that traditional foreign aid and public sector resources alone will not suffice to meet this investment gap. Consequently, private capital is deemed essential to address this shortfall. However, complex reasons and market failures have hindered the flow of private capital into this sector.

The concept of blended finance emerges as a potential solution to this funding challenge. The rationale behind blended finance lies in the varying levels of cost, time, risk tolerance, and financial return requirements among different types of capital providers. This diversity gives some providers a comparative advantage over others at different stages of a market's development lifecycle. In the WASH context, particularly in low-income settings, blended finance presents both clear utilities and limitations. Innovative and blended finance can be defined as follows:

Figure 30. WASH Blended Finance

Source: Volta Impact (2022) Water for Women | WASH Blended Finance Research Report

The WASH sector has distinctive features that pose challenges to market-based solutions and blended financing approaches. These challenges can be broadly categorized into three areas. Firstly, there are demand-related issues, where the lack of fundamental demand and prioritisation for WASH goods and services makes market-based models difficult to implement. Secondly, challenges arise from the supply side of goods, services, and absorptive capacity. Both private and public sector providers may have low capacity, limiting their ability to absorb funding and use it productively. Lastly, there are challenges associated with the supply of WASH financing, including characteristics of the development finance market for WASH and complexities in cultivating blended finance opportunities (Volta Impact, 2022). Despite these challenges, the WASH sector presents numerous opportunities for blended finance. The study identifies four prevalent categories of blended finance applications in WASH.

WASH infrastructure finance: This involves investments in installing or refurbishing reservoirs, treatment facilities, and pipe networks. These projects are typically financed through project finance vehicles, which allow for the pooling of different funding sources with varying risk, return, and impact preferences.

Microfinance for WASH: This addresses the need to facilitate both household ability to pay for WASH assets or services and microenterprise delivery of such products and services. Microfinance is a well-established model capable of reaching vulnerable populations not served by commercial lenders.

WASH SME finance: Local WASH SMEs, such as product suppliers, distributors, masons, and desludging operators, often face significant challenges in accessing finance. Blended finance can help address this gap.

Results-based financing for WASH: This approach provides financial payments based on the achievement of agreed-upon results. While it doesn't necessarily involve blended finance, it can be structured to incorporate different types of capital.

Traditional grants, donor and government funding will always play a necessary role in the WASH funding ecosystem. These funding sources are essential for reaching the most vulnerable and marginalized populations, safeguarding consumer interests, providing public goods with long-term and diffuse benefits, and strengthening institutions to transition WASH markets towards greater self-sufficiency.

However, blended finance can be a valuable tool under the right conditions. It can help crowd in additional financing from new sources and assist in transitioning a given WASH context or market to a steady state. In this ideal scenario, either the public sector, the private sector, or a combination of both can sustainably deliver inclusive WASH goods and services.

The success and suitability of blended finance in WASH depend on various factors. These include the maturity of the market, the scale of the project, local capacity, and the specific challenges being addressed. As such, careful consideration of each of these elements is needed for the effective implementation of blended finance strategies in the WASH sector.

In conclusion, while blended finance offers promising opportunities to address the WASH funding gap, it should be viewed as a complementary tool rather than a replacement for traditional funding sources. Its application requires a nuanced understanding of local contexts, market dynamics, and the specific needs of the WASH sector in different regions.

In their report, Volta Impact (2022) identified a range of general suitability and success considerations for blended and innovative finance in the WASH sector, as shown in the following Table 3.

Table 3. General suitability and success considerations for blended and innovative finance in the WASH sector

Source: Volta Impact (2022) Water for Women | WASH Blended Finance Research Report

Key suitability considerations	Description	Potential risks otherwise
1) The intervention being funded envisions and helps facilitate the market's transition towards a sustainable steady-state	The underlying intervention design is sound and based on a clear vision for the market development objective, e.g. establishing viable private markets, capacitating public sector service delivery, etc.	Financial engineering cannot solve for interventions that are fundamentally unsustainable and the blended finance approach may only be a temporary fix
2) Users of the financing demonstrate sufficient absorptive capacity	Neither donors nor investors should fund actors that lack sufficient capacity to make productive use of their funds	Access to finance and financial engineering cannot solve for lack of capacity, and funding such actors may lead to underutilization of reserved capital, over-indebtedness, etc.
3) It is feasible for stakeholders (e.g. funders, implementers, local government) to see the blended finance initiative through	The providers and users of the capital should have sufficient organizational buy-in and capacity to engage with novel financial concepts, legal/regulatory requirements, stakeholder negotiations, monitoring & evaluation requirements of a given blended finance initiative	Insufficient capacity by any one party may lead to asymmetrical cost/benefit-sharing being negotiated and/or lack of feasibility of the initiative over time
Key success factors		
4) The blended finance structure makes use of the comparative advantages of each funder's different risk-return-liquidity-impact appetites	The key rationale for blended finance v. conventional finance approaches is the ability to pool resources from different funder profiles, making it important that the structuring intentionally takes advantage of their comparative strengths	Blended finance is not needed, and a conventional financing approach involving less multi-stakeholder coordination, would have been an easier, less costly, quicker at achieving the same results
5) The blended finance structure aligns incentives appropriately	The financial structure results in sufficiently attractive cost/benefit for each party within the structure, while at the same time ensures equitable sharing of costs/benefits across all parties	If one party bears disproportionate risk/burden or nets disproportionate gain, the full benefits of a blended structure may not be realized, or intractable conflict between parties is more likely if there is underperformance
6) The provision of blended finance is supported by complementary interventions to address market bottlenecks other than lack of financing, such as lack of demand, lack of capacity, lack of appropriate policies/regulations, etc.	Provision of finance, blended or otherwise, is most effective when lack of finance is the key bottleneck	Underlying market failures remain unaddressed, and provision of financing is a superficial stopgap and/or further distorts the market

Examples of innovative and blended finance initiatives

Project Wave

Project Wave is an innovative blended finance initiative designed to support and expand water utilities in Cambodia's rural and semi-rural communities. This project focuses on a Cambodian water utility holding company that currently operates five private water stations serving households and businesses in these areas. With ambitions to grow, the holding company aims to increase its operations to nine stations, requiring additional investment to achieve this expansion.

The project demonstrates the viability of private commercial investment in the rural water sector. However, recognizing the inherent risks and challenges in such ventures, Project Wave employs a blended finance approach. This strategy combines private investment with grant funding, creating a more attractive and secure investment opportunity. The grant component is specifically allocated to provide technical assistance, which plays a vital role in building and enhancing the technical, operational, and financial expertise of the private water operators. This support is essential in ensuring that these operators can run their businesses effectively and sustainably.

In this initiative, SNV, a civil society organization, plays a significant role. Having previously collaborated with the holding company on a safe drinking water project, SNV now extends its involvement to Project Wave. The organization's primary contributions include providing technical assistance and supporting the scale-up efforts of the project.

Project Wave is particularly tailored for rural water contexts, addressing the unique challenges and opportunities present in providing water services to rural and semi-rural areas. By combining commercial investment with targeted technical support, the project aims to improve and expand water access in these communities, contributing to broader goals of sustainable development and improved quality of life in rural Cambodia (Volta Impact, 2022).

Supporting entrepreneurs with blended finance

The Centre for Advocacy and Research (CFAR) has developed an innovative faecal sludge management programme aimed at addressing the sanitation needs of urban poor communities living in informal settlements in India. This comprehensive initiative focuses on connecting these underserved populations with affordable, responsible, and safe desludging services provided by local small and medium-sized enterprises (SMEs).

CFAR's programme encompasses a range of activities designed to improve sanitation practices and support local businesses. These efforts include raising awareness and stimulating demand for proper sanitation services among community members. Additionally, CFAR provides training to SMEs involved in desludging operations, enhancing their skills and capacity to deliver high-quality services.

To optimize service delivery, CFAR has developed efficient route maps for desludging operations. This strategic planning helps to streamline services and improve coverage across different areas. Furthermore, the organization has created a centralized digital platform that integrates information from various municipal wards, facilitating better coordination and management of sanitation services.

Building on its success, CFAR is now looking to scale up its operations. A key focus of this expansion is to support entrepreneurs in acquiring the necessary desludging equipment and machinery. This step enhances the capacity and reach of local SMEs in the sanitation sector.

Currently, CFAR manages this programme through grant funding, which allows them to support targeted SMEs effectively.

However, recognizing the potential for greater impact and sustainability, CFAR has identified the opportunity to apply a blended finance approach to SME finance. This innovative financing strategy could combine grant funding with other forms of capital, potentially attracting more investment into the sector and enabling more rapid scaling of these essential sanitation services.

By bridging the gap between urban poor communities and sanitation service providers, while also exploring innovative financing mechanisms, CFAR's programme represents a holistic approach to improving urban sanitation in India. This initiative not only addresses immediate sanitation needs but also contributes to building a more robust and sustainable local sanitation economy (Volta Impact, 2022).

Revolving Fund for Sanitation (RFS)

The Rotating Sanitation Fund (RSF) is an innovative blended finance model developed to address the critical sanitation challenges in West and Central Africa. In this region, a staggering 372 million people lack access to basic toilet facilities, with financial barriers significantly exacerbating the issue. Households struggle to afford sanitation improvements, while businesses face prohibitively high interest rates of up to 30 percent, hindering their ability to provide affordable sanitation solutions.

Initially launched in 2017 by UNICEF as the Revolving Fund for Sanitation (RFS), this innovative financing mechanism was first implemented in Ghana and Nigeria, later expanding to Togo. The fund's structure and operation are tailored to suit the unique ecosystem of each country, ensuring its effectiveness and relevance to local contexts.

The primary goal of the RSF is to accelerate the availability of basic sanitation services to households from lower wealth quintiles and vulnerable groups, with a particular focus on ending open defecation. To achieve this, the fund strategically targets sanitation loans towards these households, making a significant impact where it's most needed.

The Sustainable WASH Innovation Hub has further developed this model, leveraging microcredit funds for both households and small- and medium-sized enterprises. This approach not only improves access to sanitation at the household level but also promotes the development of community-based sanitation businesses. The success of this model is evident in the impressive repayment rates of 73-90 percent, demonstrating its sustainability and effectiveness in addressing the region's sanitation financing challenges.

Implementing and scaling the RSF is a complex undertaking. The model provides a four-stage pathway that serves as a guide for those responsible for enhancing existing funds or establishing new ones. This structured approach helps establish milestones and reference points, facilitating a more organized and effective rollout of the fund.

The experiences gained from the initial years of the RSF in Ghana, Nigeria, and Togo underscore the need for revolving financing mechanisms as a key tool in extending access to basic sanitation services through market-based approaches. However, to play a significant role in bridging the sanitation financing gap and contribute meaningfully towards achieving Sustainable Development Goal 6.2, the RSF must evolve to become financially viable and build a compelling investment case. This is essential to leverage additional philanthropic and commercial resources for sanitation financing.

To achieve this, a scaling model has been developed focusing on four key performance indicators: cost coverage, loan recovery, market reach, and clear impact orientation. Recognizing the complexity of sanitation financing, ongoing efforts are required to enhance performance across these indicators, establishing a sustainable mechanism that can have a systemic effect on sanitation markets.

The optimization of the RSF demands systematic performance monitoring, testing, and evaluation of context-specific strategies and tactics. It also requires continuous learning from both the experiences of the RSF and engagement with other actors involved in sanitation financing in West Africa and globally. This approach ensures that the fund remains adaptive, effective, and capable of making a lasting impact on the sanitation challenges facing the region.[cxxxi]

Innovative and blended finance initiatives that include circular economy principles in the WASH

Circular economy principles are often included in the innovative and blended finance initiatives in WASH. For example,

- WaterEquity[cxxxii] (philanthropic capital with private investments providing microloans for water and sanitation projects) supports projects that focus on resource efficiency and waste reduction, e.g., rainwater harvesting systems and eco-friendly solutions
- Sanergy Collaborative in Kenya[cxxxiii] (grants, equity and debt) strives to solve the sanitation crisis through the power of the circular economy: safe sanitation systems, upcycling into reuse products (e.g. fertilizers, fuels and animal feed) and waste services

12

CONCLUSION: INNOVATIONS FOR CHILD-SENSITIVE AND CLIMATE-RESILIENT DEVELOPMENT

Over one billion children face increased risks from environmental hazards and climate change, including heatwaves, floods, and droughts. These impacts threaten to undermine decades of progress in child health, education and wellbeing. Where WASH is lacking or unreliable, children and young people - especially those from marginalised groups - are disproportionately affected.

This report has highlighted emerging and frontier technologies and innovations that could help accelerate progress toward SDG 6 while building climate resilience and driving equality. From solar desalination to container-based sanitation, and from smart sensors to circular economy approaches, there are promising solutions that could transform WASH service delivery. However, technology alone is not enough. Success depends on considering the full ecosystem in which these innovations operate - including governance structures, financing mechanisms, behavioural factors, and critically, the principles of universal design and accessibility.

Several key themes have emerged from this exploration:

- The most promising innovations often combine multiple approaches - such as linking renewable energy with water treatment, or integrating digital monitoring with community management systems.
- Circular economy principles are increasingly central to WASH innovation, promoting resource recovery and reuse while reducing environmental impacts.
- Successful implementation requires careful consideration of local contexts, including operation and maintenance capabilities, cultural factors, and existing infrastructure.
- Universal design and accessibility must be considered from the outset, not retrofitted afterwards, to ensure solutions work for all users including children, people with disabilities, and their caregivers.

Looking ahead, water security and WASH actors should prioritise innovations that:

- Are climate-resilient and environmentally sustainable
- Promote equity and universal access
- Can be maintained and operated locally
- Consider end-of-life management from the design phase

- Build on existing systems and knowledge
- Support child-sensitive development

The path to achieving safely managed WASH for all requires both technological advancement and systems strengthening. By taking an integrated approach that considers sustainability, equity, and local capacity, we can accelerate progress toward SDG 6 while ensuring no child is left behind. The innovations showcased in this report represent important steps toward this goal, but their success will depend on thoughtful implementation that considers the broader context in which they operate.

The urgency of the climate crisis, combined with persistent WASH access gaps, demands bold action. By supporting promising innovations while maintaining focus on sustainability and equity, we can work toward a future where every child has access to safely managed water and sanitation services, regardless of their circumstances.

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APPENDICES

Safely Managed Ladder

Source: Joint Monitoring Program, WHO & UNICEF (2017)

SERVICE LEVEL	DEFINITION
SAFELY MANAGED	Drinking water from an improved water source that is located on premises, available when needed and free from faecal and priority chemical contamination
BASIC	Drinking water from an improved source, provided collection time is not more than 30 minutes for a round trip, including queuing
LIMITED	Drinking water from an improved source for which collection time exceeds 30 minutes for a round trip, including queuing
UNIMPROVED	Drinking water from an unprotected dug well or unprotected spring
SURFACE WATER	Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal

Note: *Improved sources include: piped water, boreholes or tubewells, protected dug wells, protected springs, and packaged or delivered water.*

SERVICE LEVEL	DEFINITION
SAFELY MANAGED	Use of improved facilities that are not shared with other households and where excreta are safely disposed of in situ or transported and treated offsite
BASIC	Use of improved facilities that are not shared with other households
LIMITED	Use of improved facilities shared between two or more households
UNIMPROVED	Use of pit latrines without a slab or platform, hanging latrines or bucket latrines
OPEN DEFECATION	Disposal of human faeces in fields, forests, bushes, open bodies of water, beaches or other open spaces, or with solid waste

Note: *improved facilities include flush/pour flush to piped sewer systems, septic tanks or pit latrines; ventilated improved pit latrines, composting toilets or pit latrines with slabs.*

SERVICE LEVEL	DEFINITION
BASIC	Availability of a handwashing facility on premises with soap and water
LIMITED	Availability of a handwashing facility on premises without soap and water
NO FACILITY	No handwashing facility on premises

Note: *Handwashing facilities may be fixed or mobile and include a sink with tap water, buckets with taps, tippy-taps, and jugs or basins designated for handwashing. Soap includes bar soap, liquid soap, powder detergent, and soapy water but does not include ash, soil, sand or other handwashing agents.*

Technology Readiness Levels (TRL)

The TRL Scale is a globally accepted benchmarking tool for tracking progress and development of a specific technology from basic research to systems demonstration in expected operating environment.

Technology development stage	TRL	Definition
Green field research	0	Initiated with a novel idea, guiding question, or poking at a problem from new angles.
Fundamental - basic Research	1	Basic principles observed and reported. The work is analytical with the emphasis on understanding the science better.
	2	Technology and/or application concept formulated. Scientific research begins to be translated into applied research and development.
Research and Development	3	Research to prove feasibility. Analytical and experimental critical function and/or characteristic proof of concept.
	4	Technology development. Validation of component(s) in a laboratory environment
	5	Validation of semi-integrated component(s) in a simulated environment
Pilot and Demonstration	6	Technology demonstration. Engineering/pilot-scale, similar (prototypical) system and/or process validation in relevant simulated environment.
	7	Prototype system ready (form, fit and function) demonstrated in an appropriate operational environment. Final design is virtually complete.
	8	Actual technology completed and qualified through tests and demonstrations.
Early Adoption (small scale)	9	Actual technology proven through successful deployment in an operational environment. The technology is in its final form and operated under the full range of operating mission conditions.
Commercial trail (Small scale)		

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