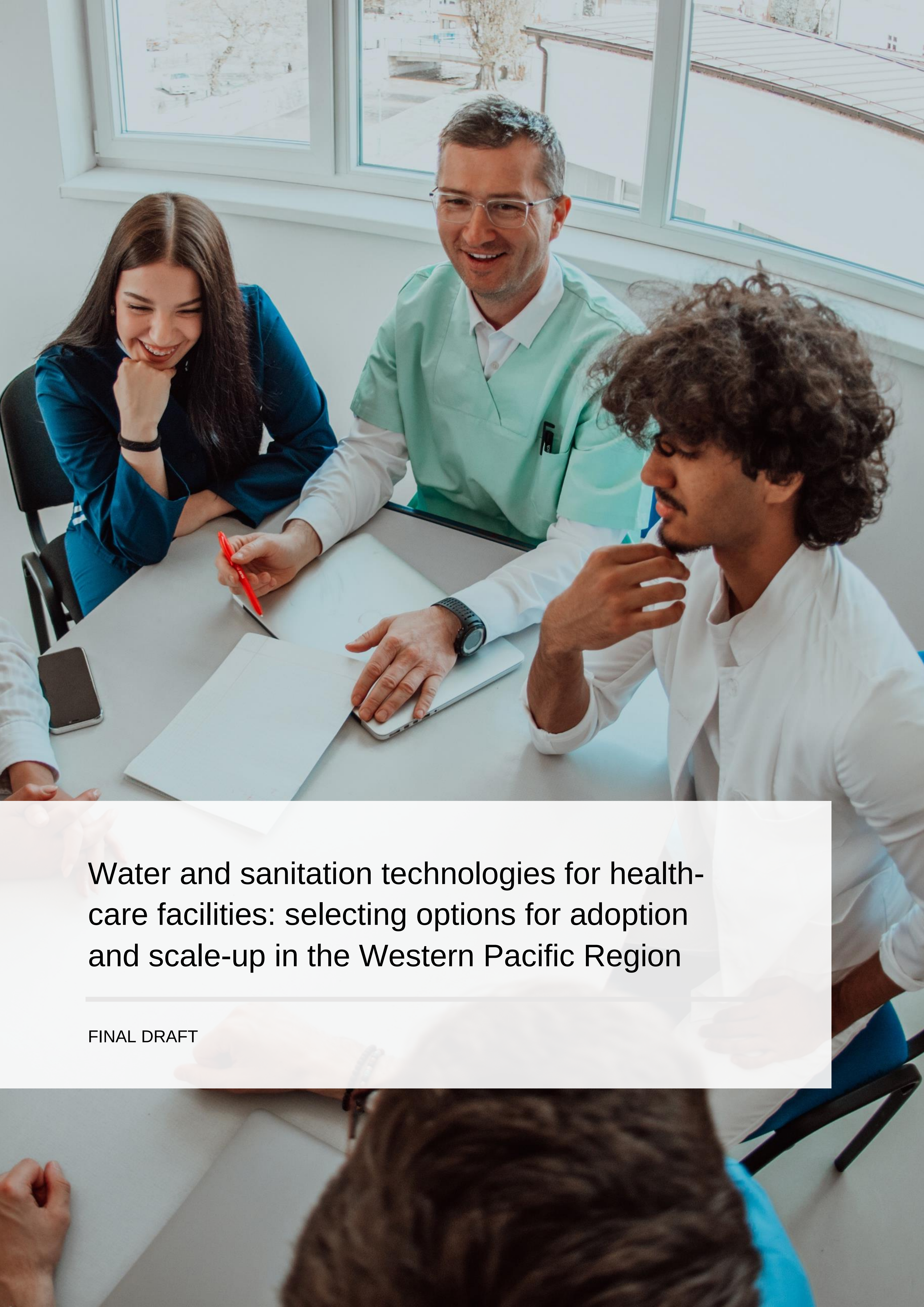


Water and sanitation technologies for health-care facilities: selecting options for adoption and scale-up in the Western Pacific Region

FINAL DRAFT

Acknowledgements

This guidance document was authored by Dr Benny Zuse Rousso, Professor Juliet Willetts, Dr Tim Foster and Dr Nuhu Amin of University of Technology Sydney, Institute for Sustainable Futures (UTS-ISF).

The document benefited from the participation of and key contributions from Dr Oyuntogos Lkhasuren and Ms Souvanaly Thammavong of WHO Lao Health and Environment office, Ms Nellie Ham of Vanuatu's Ministry of Health, and Ms Altazangas Badrakh of WHO Mongolia Health and Environment office, as well as inputs from WHO WPR staff including Genandrialine Peralta, Sally Edwards, Bonifacio Magtibay and Ton Tuan Nghia.

Review was provided by Guy Howard from the WHO Climate Change and Environment Technical Advisory Group; Kencho Namgyal and James Robertson from UNICEF; Bilal Akbar from the Australian Department of Foreign Affairs and Trade; and Ed Ramsay, Madeleine Edgeworth and Ruth Kennedy-Walker from the WASH in Institutions team, Water Global Practice, World Bank Group. Review was also provided by WHO headquarters staff Margaret Montgomery and Arabella Hayter.

JinWon Yi and Akeem Ali of WHO Asia-Pacific Centre for Environment and Health in the Western Pacific Region provided overall guidance, direction and technical oversight in the preparation of this report.

Images: Adobe Stock Images and Juliet Willetts

Executive summary

Access to **clean water and safe sanitation services** in health-care facilities (HCFs) is fundamental for public health, economic progress and delivery of quality health care. In low- and middle-income countries and areas (LMICs), particularly in the Western Pacific Region (WPR), ensuring a safe water supply and wastewater treatment in HCFs is still a challenge, and improvements are critical to prevent infections, reduce avoidable deaths and uphold sterile environments. The World Health Organization (WHO) recognizes the urgency of advancing knowledge about appropriate technologies for water and sanitation in LMIC HCFs.

This guidance document aims to support **informed decision-making** in the selection of suitable water and sanitation technologies in HCFs in the WPR. It was developed through: (i) a literature review of current scientific evidence on current and emerging technologies, and (ii) engagement with stakeholders in selected WPR countries regarding in-place technologies including co-design of a framework to support technology selection.

This document is focused on **water supply and wastewater treatment technologies**. It does not cover other important HCF topics – waste management, environmental cleaning or design of internal facilities such as washbasins and toilets – which are dealt with in existing resources.

This document provides:

- **a decision-support framework** covering three groups of factors that warrant consideration in the technology selection process, namely: (i) site and environmental factors (HCF facility, surrounding human environment and natural environment including water resources); (ii) institutional factors (financial and human resource capacity, regulations and standards); and (iii) technology factors (treatment performance, energy requirements, climate resilience, etc.); and
- **technology fact sheets**, which describe key relevant water and sanitation technologies, each accompanied by information about their strengths and potential challenges for specific scenarios. Summary tables also provide a quick reference of the characteristics of key technologies.

The target audience for this document is **health sector staff** with responsibility for HCFs. It is expected that an assessment group which includes relevant water and sanitation expertise will be assembled to make use of the decision-support framework. The aim is to ensure that the technology selection process is not limited to technical elements but incorporates other factors essential to ensure long-term effectiveness in terms of safety, ongoing operation and maintenance, and climate resilience.

This guidance document also includes information on key principles for improving water and sanitation systems in HCFs through water and wastewater **management practices.** A dedicated section on **climate resilience** highlights where climate resilience is embedded in the decision-support framework, as well as targeted approaches to improve the climate resilience of technology through design adaptations.

It is accompanied by **two supporting documents** setting out the underpinning evidence base:

- a literature review of current and emerging water and sanitation technologies; and
- water and sanitation technologies in HCFs in the Western Pacific Region: current status and context.

This guidance document can serve as **a resource for the health sector** and other stakeholders to strengthen their understanding of water and sanitation technologies suitable for HCF requirements and the key factors that impact their effectiveness, and to make informed choices that will improve the overall services provided by HCFs. This in turn will improve outcomes for the populations of priority countries in the WPR where improvements to water and sanitation in HCFs are paramount to safeguard staff and patient health and protect the wider environment.

Contents

Abbreviations

AOP	advanced oxidation processes
ARB	antibiotic-resistant bacteria
AS	activated sludge
CW	constructed wetland
GAC	granular activated carbon
GWP	Global Water Partnership
HCF	health-care facility
ICU	intensive care unit
IPC	infection, prevention and control
LMICs	low- and middle-income countries and areas
MBR	membrane bioreactor
O&M	operation and maintenance
PAC	powder-activated carbon
SODIS	solar water disinfection
UNICEF	United Nations Children's Fund
WASH	water, sanitation and hygiene
WASH FIT	Water and Sanitation for Health Facility Improvement Tool
WHO	World Health Organization
WPR	Western Pacific Region

1 Introduction

Water and sanitation are vital for public health, economic growth and health care quality. Clean water and appropriate sanitation and wastewater management in health-care facilities (HCFs) are crucial for delivering quality care, controlling infections and reducing avoidable deaths. However, global challenges persist in providing adequate water and sanitation access in HCFs.

According to World Health Organization (WHO) estimates, approximately 15% of patients develop infections during their HCF stay, attributed to insufficient water, sanitation and hygiene (WASH) practices (Allegranzi et al., 2011). These infections have severe implications, causing thousands of deaths each year, especially in low-resource settings, where the risk of sepsis is 34 times higher than in other settings (Oza et al., 2015). HCFs are integral parts of national health-care systems, offering a diverse range of medical services to the population.

Despite the critical role of HCFs, there is a significant global challenge to ensure appropriate access to water and sanitation in these facilities. Worldwide, approximately 20% of HCFs lack basic water services and 10% lack sanitation services, affecting roughly 1.7 billion and 800 million people's respective access to water and toilets in HCFs (WHO and UNICEF, 2023).

> Globally, one in five HCFs lacks basic water services, and one in 10 does not have access to sanitation services. Hence 1.7 billion people attend HCFs without proper water services and 800 million people utilize HCFs without toilet facilities (WHO and UNICEF, 2023).

Low- and middle-income countries and areas (LMICs) face a more significant issue, with half of their HCFs lacking water services and 60% lacking sanitation services, making them a priority for improvement (WHO and UNICEF, 2023). The provision and effectiveness of such services in HCFs are further complicated by specific requirements determined by the type of activities conducted in HCFs. Compounding the issue is the lack of comprehensive monitoring data, resulting in an incomplete understanding of the actual situation in many LMICs (WHO and UNICEF, 2023). Moreover, climate change is an additional challenge to be addressed.

This situation underscores the need for significant investment in water and sanitation in HCFs. According to estimates, achieving full coverage of basic WASH services in HCFs across the 46 United Nations least developed countries would require a total investment ranging from US$ 6.5−9.6 billion (Chaitkin et al., 2022). According to the same source, capital investments are projected to constitute 30–74% of the total costs, while recurrent costs are expected to make up 38–74% of the investment.

1.1 Global targets for water and sanitation services in health-care facilities

In response to the urgent need for improved water and sanitation services in HCFs, WHO and the United Nations Children's Fund (UNICEF) have set global targets for the provision of basic WASH in HCFs (WHO and UNICEF, 2020a). These targets are designed to ensure a progressive increase in WASH services to HCFs, aiming for a coverage rate of 80% of basic WASH services by 2025 and universalization of services by 2030.

To facilitate water and sanitation services in HCFs, eight key steps are outlined **(WHO and UNICEF, 2019**):

(1) **conduct situation analysis and assessment;**
(2) set targets and define road map;
(3) establish national standards and accountability mechanisms;
(4) improve and maintain infrastructure;
(5) monitor and review data;

(6) develop the workforce;
(7) engage with communities; and
(8) conduct operational research and share learning.

As suggested in the first key step above, it is fundamental that site-specific characteristics, such as the availability of natural, economic and human resources, are considered when selecting, designing and implementing water and sanitation services in HCFs. These factors ultimately dictate the long-term success of the implemented technology and its sustainable and safe operation. From among the large number of water and wastewater treatment technologies, decision-makers need support to select the most suitable technological alternatives for HCFs in any given locality or region.

1.2 Water and sanitation technology requirements in health-care facilities

HCFs have unique water supply and sanitation needs due to the priority of maintaining a safe and sterile environment in the presence of medical-related hazardous compounds. The requirements for water supply in HCFs, including higher water consumption and an imperative reliance on continuous supply, often exceeds that of residential or commercial buildings, requiring the installation of backup water supply and storage systems. HCFs must also adhere to high water quality standards to ensure patient safety and prevent infections. This involves addressing potential risks from external sources of pollution, such as pathogens (e.g. faecal contamination) and heavy metals, as well as minimizing internal contamination within the HCFs themselves, such as the proliferation of antibiotic-resistant bacteria (ARB) within plumbing systems. Given that certain activities within HCFs may require ultra-pure or sterile water, the inclusion of point-of-use treatment at taps is a common practice in HCF water supply systems.

Proper sanitation requires treatment of wastewater and faecal sludge from HCFs including the removal of hazardous compounds prior to disposal. Hospitals in particular demand more advanced technologies due to the greater diversity and higher concentration of emerging pollutants (4–150 times) compared to municipal or domestic wastewater (Verlicchi et al., 2010; Rodriguez-Mozaz et al., 2015). These pollutants can include chemicals, biological agents including ARB, and radioactive substances, which in some cases may require advanced treatment technologies in comparison to the conventional treatment methods commonly employed for municipal and domestic wastewater. Although ARB and pharmaceuticals also occur in municipal wastewaters, HCFs are a major source of these pollutants and, wherever possible, treatment at source is preferred. In addition, HCFs generally generate a large volume of wastewater per capita compared to domestic sources, increasing in proportion to the number of beds (D'Alessandro et al., 2016; Khan et al., 2021).

1.3 Challenges in the Western Pacific Region

In addition to the HCF's distinct technical water and sanitation needs, specific socioeconomic, political and cultural factors within the Western Pacific Region (WPR) require consideration, as does climate change.

Data from the WHO and UNICEF Joint Monitoring Programme reveal that most countries in the WPR (27 out of 37) lack comprehensive information on water and sanitation coverage within HCFs. Available data indicate that approximately 60% and 85% of countries have not attained the 80% coverage goal for basic water and sanitation services, respectively (WHO and UNICEF, 2023). Among the 37 Member States in the WPR, eight LMICs – American Samoa, Cambodia, Kiribati, the Lao People's Democratic Republic, Mongolia, Papua New Guinea, Solomon Islands and Vanuatu – have not yet reached the 80% coverage target for households (WHO and UNICEF, 2023).

Based on that finding, WHO acknowledges the urgent need to improve water and sanitation services in HCFs, especially in LMICs. A key barrier to this improvement − identified in an unpublished comprehensive review performed by the World Bank Group in 2021 and made available to WHO − is the lack of appropriate tools to support well-informed decisions about which water and sanitation technologies options are suitable for the local context. Hence the importance of this guidance document.

1.4 Guidelines and standards for water and sanitation technologies in health-care facilities

Several countries worldwide, including some WPR Member States, lack established national standards for water and sanitation technologies within HCFs. In their absence, international guidelines, such as those published by WHO, and national guidelines from other countries, can and should be used as reference. The latest report by WHO on the progress of WASH in HCFs identified that 53% of all countries worldwide have completed national standards for WASH in HCFs and that further dissemination of these standards was needed (WHO and UNICEF, 2023). WHO guidelines developed in 2008 on environmental health standards in health care provide a comprehensive overview of water and sanitation requirements in HCFs (WHO, 2008).

The primary guidelines addressing hospital effluents are those published by WHO in 1999 and later updated in 2014 as *Safe management of wastes from health-care activities* (Chartier et al., 2014). These guidelines offer comprehensive recommendations for the proper management of liquid wastes and wastewaters in health-care settings. They classify different types of wastewaters and liquid wastes based on their content (faeces, pathogens, pharmaceuticals, medicines, solvents and radioactive substances).

Internationally, hospital wastewater is often categorized as an industrial wastewater or a hazardous waste. European regulations (e.g. European Directive 91/271/EEC; Directive 2008/98/EC) require a pre-authorization before discharge of hospital effluents into centralized sewerage systems, and pre-treatment is usually required for such cases. Some liquid wastes cannot be discharged into sewers and must be treated as a waste product. In Italy, hospital wastewater may also be classified as industrial wastewater, depending on the number of beds (Legislative Decree No. 152/2006). In Viet Nam, Article 72 of the Law on Environmental Protection No. 55/2014/QH13 states that all hospitals and medical facilities are obliged to collect and treat medical wastewater in accordance with environmental standards. For this reason, it is critical to select appropriate treatment technologies for each HCF, particularly for hospitals that are likely to have effluents with a wider range of contaminants compared to smaller HCFs providing limited health services.

1.5 Purpose, scope and audience

The purpose of this document is to facilitate informed decision-making on the selection of suitable water and sanitation technologies for HCFs in contexts similar to those in WPR priority countries (i.e. those that have not yet achieved 80% coverage of water and sanitation services). Despite this focus on priority WPR countries, the principles employed in the technology selection process are applicable to similar contexts in other countries globally.

The scope of the document is limited to water supply and wastewater technologies, and does not include broader health-care waste management or environmental cleaning. This document also does not cover details of the user interface aspects of WASH in HCFs, such as specific types of handwashing facilities for staff and patients, gender and disability considerations in water and sanitation facility design, and appropriate toilet-to-user ratios. Rather, the focus is on technologies to ensure safe supply of the appropriate quantity and quality of water, and safe treatment methods for human and other liquid waste.

The document was developed based on:

- a **literature review** to identify scientifically endorsed technological options for water supply and wastewater treatment that meet the unique requirements of HCFs, including the strengths and weaknesses of these options, which covered more than 100 sources (supporting document: *A literature review on current and emerging water and sanitation technologies for health-care facilities*); and
- an analysis of **water and sanitation in HCFs in the WPR context**, by review of available data and consultation with WPR WHO staff, and engagement with stakeholders in three WPR Member States (Lao People’s Democratic Republic, Mongolia and Vanuatu) to understand their current technologies and decision-making processes (supporting document: *Current status and context*).

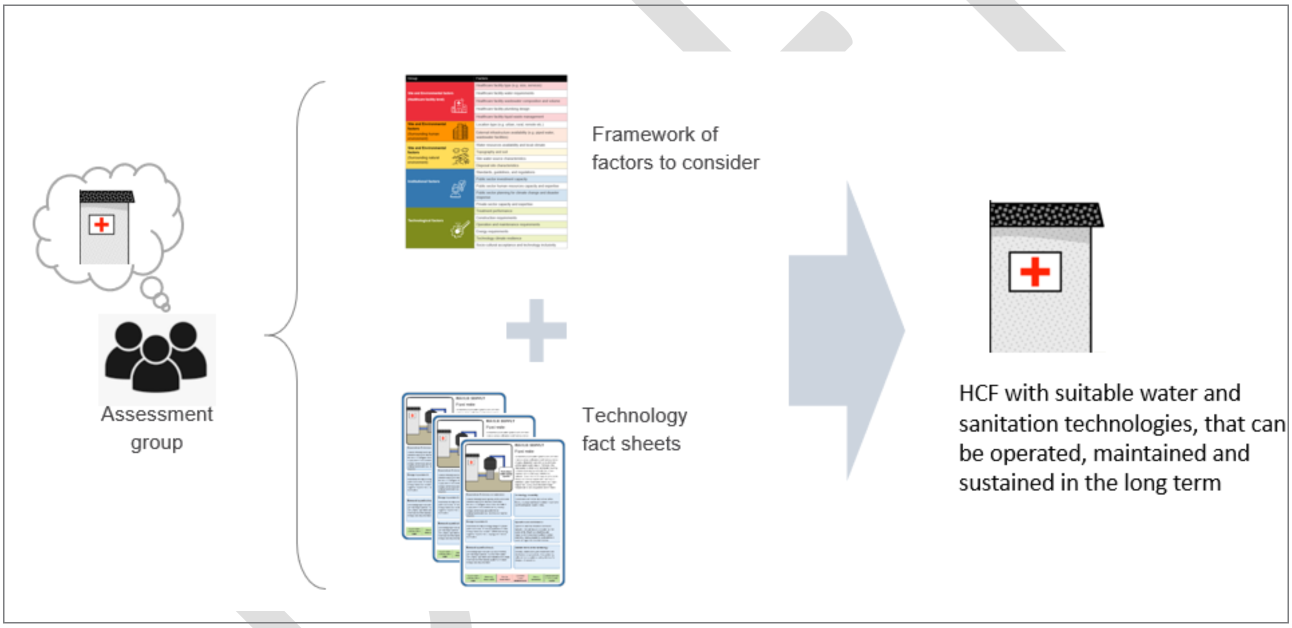
The intended audience for this document is the health sector, including HCF administrators and relevant ministries responsible for HCFs. It is expected that the proposed selection process will be implemented by a multisectoral assessment group that includes water and sanitation expertise. The process can be used for new HCFs, as well as to consider ways to upgrade water and sanitation technologies in existing HCFs.

1.6 Guidance for users of this resource

The document presents a framework to support decision-making along with fact sheets on key technologies. It can be used by an assessment group comprising health sector actors and others with water and sanitation expertise as a tool to guide specific, case-by-case analysis of a specific HCF in a specific site (see Fig. 1).

- The **framework** aims to ensure that the technology selection process is not limited to technical elements but incorporates other factors essential to ensuring its long-term effectiveness, ongoing operation and maintenance, and climate resilience.
- The **technology fact sheets** describe key relevant water and sanitation technologies, each accompanied by information about their strengths and potential challenges for specific scenarios. These draw on the findings of the literature review, and further information on many of the technologies can be found in the respective supporting documents.

Fig. 1. Assessment group process when deciding on suitable water and sanitation technologies for HCFs



In addition, this document provides two sections covering **management practices** and targeted **climate resilience** considerations and technology design features to supplement the framework. Its aim is to facilitate a comprehensive evaluation process and guide the selection of robust, sustainable and resilient water and sanitation systems in HCFs.

1.7 Complementary resources

The scope of this resource is limited to water supply, wastewater technologies, and does not cover internal facilities such as handbasins, bathrooms and toilets. Other important resources, such as the WHO and UNICEF Water and Sanitation for Health Facility Improvement Tool (WASH FIT) document (WHO and UNICEF, 2022), provide a practical guide to improve WASH in HCFs, and include a broader set of aspects than just water and sanitation technologies.

WASH FIT is a risk-based management tool for HCFs that covers key aspects of water, sanitation, hand hygiene, environmental cleaning and health-care waste management, as well as selected aspects of energy, building and facility management.

WASH FIT provides a framework to develop, monitor and continuously implement an infrastructure improvement plan, while supporting prioritization of specific WASH actions. It facilitates multisectoral solutions by bringing together those who share responsibility for providing WASH services, including legislators/policy-makers, district health officers, hospital administrators, water engineers and environmental and climate specialists.

This document complements WASH FIT by offering more detail on specific choices, considerations and trade-offs concerning the suitability of various water and sanitation technologies.

2 Framework for water and sanitation technology selection

To evaluate water and sanitation technologies for specific HCFs that are safe, sustainable and resilient, a range of technical, financial, institutional, cultural, socioeconomic and environmental dimensions must be considered. These can be organized into three groups: (i) site and environmental factors; (ii) institutional factors; and (iii) technology factors.

The **decision-support framework** includes these three groups and their component factors (see Fig. 2 and Fig 3). For each factor, a description and set of question prompts are provided (see Tables 1−5).

An assessment group, comprising health staff and water and sanitation experts, should consider each factor, identify factors with high relevance for context, specific HCF and site, and respond to the question prompts for those factors. Responses can then be considered in the light of available technologies (see section 3) to facilitate technology selection. A tool in the Annex serves to document the assessment.

Fig. 2. Framework for informed selection of water and sanitation technologies for HCFs

Group	Factors
Site and environmental factors (health-care facility level)	Health-care facility type (e.g. size, services)
	Health-care facility water requirements
	Health-care facility wastewater composition and volume
	Health-care facility plumbing design
	Health-care facility liquid waste management
Site and environmental factors (surrounding human environment)	Location type (e.g. urban, rural, remote, etc.)
	External infrastructure availability (e.g. piped water, wastewater facilities)
Site and environmental factors (surrounding natural environment)	Water resources availability and local climate
	Topography and soil
	Site water source characteristics
	Disposal site characteristics
Institutional factors	Standards, guidelines and regulations
	Public sector investment capacity
	Public sector human resources capacity and expertise
	Public sector planning for climate change and disaster response
	Private sector capacity and expertise
Technology factors	Treatment performance
	Construction requirements
	Operation and maintenance requirements
	Energy requirements
	Technology climate resilience
	Sociocultural acceptance and technology inclusivity

The **presence of centralized water supply and sewerage systems** significantly influences the selection of water supply and wastewater treatment options in HCFs. HCFs that receive piped water often prioritize increasing water storage capacity to mitigate the risk of water shortages, particularly in LMICs where intermittent water supply is common (Kumpel and Nelson, 2016; Kaminsky and Kumpel, 2018). This is often achieved using a minimum of 48 hours' water supply as a rule-of-thumb for required on-site storage. In addition, point-of-use treatment is commonly implemented to minimize the potential for contamination, which may arise from water intrusion in the piped system or irregular cleaning of storage tanks. Furthermore, the presence of sewerage systems connected to municipal wastewater treatment plants impacts the management of HCF effluents. In such cases, it is crucial for HCFs to align the characteristics of their effluents with those of domestic and municipal wastewater to ensure proper functioning of the municipal treatment plants. For hospitals or HCFs providing more diverse services, this entails a focus on removal of emerging contaminants and resistant pathogens instead of targeting the removal of organic matter, suspended and dissolved solids and nutrients, which is typically the objective of municipal treatment plants.

The **socioeconomic context** is important to assess the affordability and cost recovery of the chosen water supply and wastewater treatment technologies, as well as their acceptance and ownership by the population, which is crucial for the long-term effectiveness of such systems. For instance, some water sources may be perceived as unsafe by the population despite rigorous treatment before water supply, thus compromising the delivery of health-care services due to population mistrust (Dolnicar and Schäfer, 2009; Pierce and Gonzalez, 2017). Regarding wastewater treatment, some technologies such as treatment ponds may result in odours that are considered offensive by the local population, while other energy-intensive technologies may be perceived as not sustainable by the population (Fu et al., 2022).

Public sector capacity, both in terms of financial resources and human resources, is an essential determinant of the effectiveness of chosen water and sanitation technologies. Water and sanitation are not just a "technology" but an ongoing service that requires operation and maintenance to continue functioning and providing the amenities required of an HCF. Often decision-making processes focus on the initial infrastructure investment, without due consideration of ongoing costs, supply chains and the expertise needed to support sustainable operation in the long term. In addition, the public sector varies in terms of its existing capacity and expertise to select and provide appropriate water and sanitation technologies.

While the public sector holds the responsibility for ensuring water, sanitation and health-care services, it often relies on the **private sector** for specific products, technologies and construction of water and sanitation facilities. In the context of water and sanitation in HCFs, the local private sector's expertise in implementing, operating and maintaining relevant water and sanitation technologies becomes crucial for understanding the suitability and applicability of different technologies. The private sector's capacity and expertise vary across different locations. While conventional, simplified, on-site and centralized water supply and sanitation technologies are available in most contexts, the availability of specialized services for emerging water and sanitation technologies relevant to HCFs may be limited, particularly in LMICs. This limited availability hampers the adoption and long-term sustainability of emerging or not yet consolidated technologies in HCFs.

Key technical performance characteristics of the water supply and wastewater treatment technologies must be suitable for the local context. Factors such as the characteristics of the water source and disposal environment are key determinants in the appropriateness of technologies. Some water supply technologies may not be effective in treating water with specific compositions, such as saltwater, while some wastewater treatment technologies may not be able to adequately remove contaminants or meet environmental guidelines for sensitive environments, such as natural wetlands. Furthermore, it is important to assess the requirements of each technology in terms of area, energy, maintenance and operation. Assessment should consider the available resources, including the available area for construction, funds for capital investment and ongoing operation, and the availability of trained personnel to maintain and operate the system. This ensures that the selected water supply and wastewater treatment technologies are not only effective in the short term but also sustainable and feasible in the long term, given the HCF's available resources and capabilities.

Management practices and **climate resilience** are other considerations of relevance to decision-making about sanitation technologies, and are covered in Sections 4 and 5, respectively.

Fig. 3. Decision-support framework for informed selection of suitable water and sanitation technologies for health-care facilities

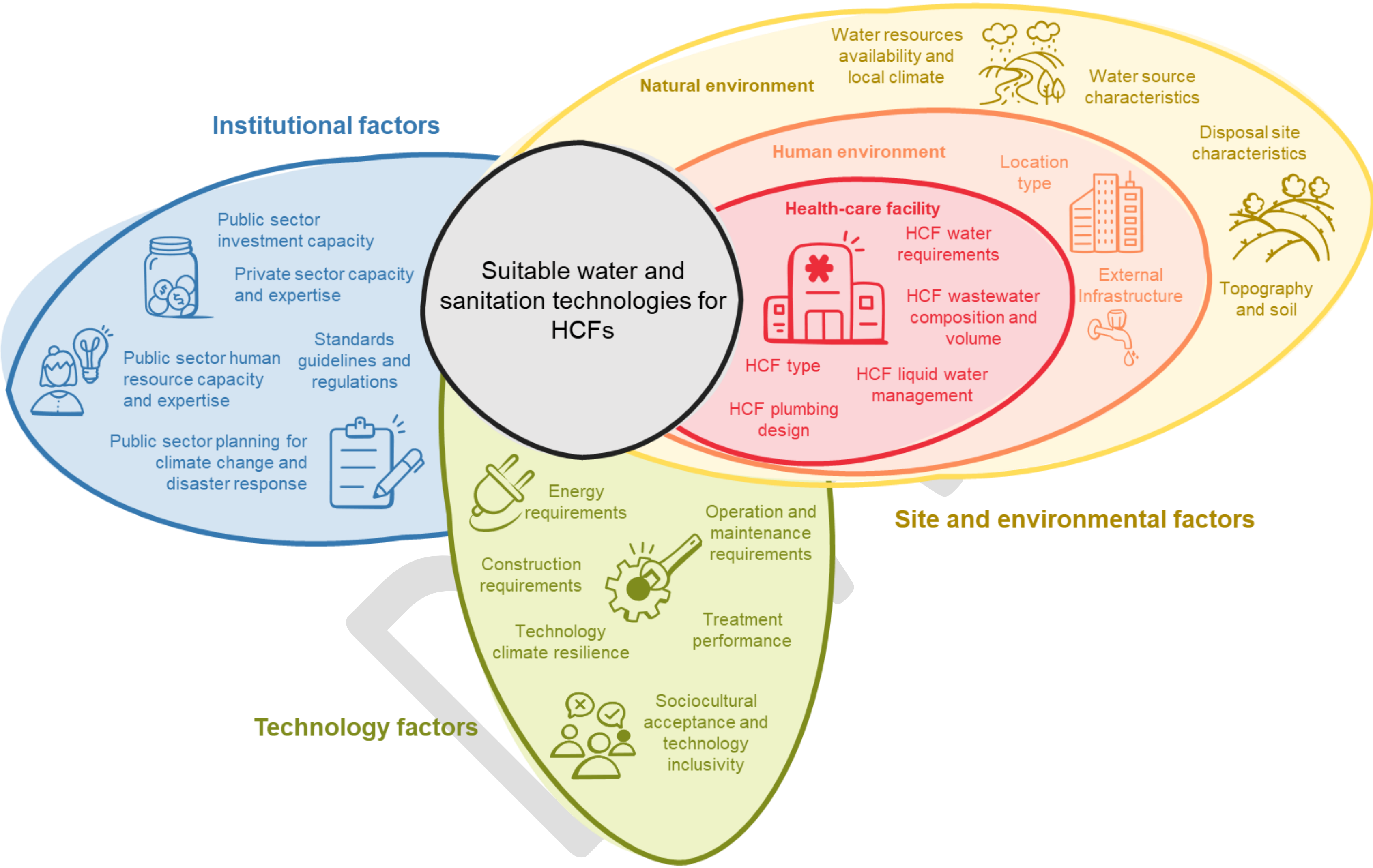


Table 1. Definition of the decision-support framework’s factors and leading prompts (site and environmental factors, health-care facility level)

Subgroup	Factor	Description	Question prompts to support decisions
Site and environmental factors (HCF level)	HCF type	The type of HCF, often classified in national guidelines, can affect water and sanitation requirements, available budget and human resources. The classification uually relates to the scale and range of services offered by a given HCF. Hospitals and larger health-care centres will have different needs and resources compared with small clinics.	- What is the size of the HCF? What are the numbers of patients (and does this number vary seasonally)? - What types of medical services are provided? - Does the HCF provide inpatient care or any intensive care services requiring an uninterrupted supply of water? - What range and type of toilet facilities are required for staff, inpatients and outpatients, considering gender, disability and any other needs?
	HCF water requirements	The water supply system chosen must consider distinct water requirements, such as quantity and quality, which can differ based on the HCF’s type and size. These factors play a crucial role in the selection of appropriate water supply technologies. Each HCF will require water for a range of different purposes that could include patient care, infection prevention and control (IPC) procedures, cleaning, clinical diagnostics, kitchen, laundry, air conditioning, etc. There may also be a need for ultra-pure or sterilized water. Certain technologies necessitate economies of scale to be financially viable for implementation and operation (e.g. desalination facilities). Conversely, solutions reliant on variable water sources (e.g. rainwater harvesting systems) may be inadequate to independently meet the water needs of an HCF.	- What are the water end-uses within the HCF and what is the minimum water quality required for each? - How much volume of water is required for each end-use within the HCF? - What volume of water would need to be stored locally to ensure that at least 48 hours of supply is available?
	HCF wastewater composition and volume	The nature of medical services affects the wastewater quality and treatment technologies needed, as does the number and type of sanitation facilities. Each HCF may require varying numbers of toilets for staff, patients and their caregivers, and wastewater collection systems (drains/pipes) from all types of water-using devices. HCFs offering surgical procedures and clinical diagnostics may have more complex wastewater characteristics compared to those providing only primary care. Likewise, larger hospitals with a high number of inpatient beds and intensive care units (ICUs) are likely to generate	- What are the numbers and types of toilet facilities in the HCF? - What types of wastewaters are generated within the HCF? How do their compositions vary? - What are current practices for disposal of different types of waste into toilets or drains? - What types of emerging compounds may be present in high concentrations in HCF wastewater?

		significant volumes of wastewater compared to small HCFs and clinics.	- Which wastewater streams may contain high pathogen concentrations? - How much volume of each wastewater stream is generated? How variable are the flows?
	HCF plumbing design	Maximizing water reuse within HCFs can result in reduced water requirements and customized wastewater treatment, provided guidelines for safe reuse are followed. For instance, channelling water from handwashing for toilet flushing or outdoor irrigation via integrated water and wastewater plumbing design within the premises can decrease the daily water consumption in the HCF. Similarly, separating various wastewater streams through integrated plumbing systems – such as greywater, blackwater, and pathogen-rich or chemical-laden effluents – facilitates focused treatment using dedicated technologies for smaller wastewater streams.	- Are there water end-uses requiring non-drinking-water in significant water volumes (e.g. garden, toilet flushing etc.)? - Does the HCF plumbing design allow water reuse for these less strict end-uses? Are measures in place to address potential risks associated with reuse?
	HCF liquid waste management	Partitioning wastewater streams and exercising control over the sources of wastewater generation can affect the choice of necessary wastewater treatment technologies and practices for managing faecal sludge. For instance, substantial quantities of greywater can dilute the organic content in blackwater streams, potentially compromising the efficiency of certain wastewater treatment processes (e.g. anaerobic processes). Similarly, combining wastewater streams with elevated concentrations of emerging substances (such as pharmaceuticals) into other streams characterized by larger volumes, but not at high concentrations, can intensify the demands on wastewater treatment, particularly for advanced technologies, resulting in higher costs.	- Do the activities within the HCF generate effluents with significantly different composition? - Can different wastewater streams be segregated and treated individually? - Is it possible to reduce total wastewater volume through reuse for less strict water end-uses?

Table 2. Definition of the framework's factors and leading prompts (site and environmental factors, surrounding human environment)

Subgroup	Factor	Description	Question prompts to support decisions
Site and environmental factors (surrounding human environment)	Location type	The type of location where the HCF is located – urban, peri-urban, rural, remote or hard-to-reach area – also impacts suitable technologies in terms of capacity for construction, operation and maintenance. Furthermore, the location also indirectly reflects other factors, including the available HCF budget, surrounding infrastructure and type of HCF.	- What is the classification of this location: urban, peri-urban or rural, and is it highly remote or easily accessible? - How much land is available to build? What is the proximity to other buildings and people? - Are there any issues concerning land ownership and access? - Are there expected major climate impacts such as cyclones, drought, flooding or other hazards?
	External infrastructure	Some HCFs are in areas with existing centralized water and wastewater services whereas others are not, and energy services may vary. The availability, quality and consistency of piped water supply and sewerage systems impact the need for contingency water systems and on-site wastewater treatment. Likewise, the dependability and affordability of centralized power supply play a crucial role in determining the choice of water and sanitation technologies.	- Is there a centralized piped water supply? If yes, is this service intermittent and susceptible to cross-contamination? - Is there a centralized sewerage system? If yes, is co-treatment allowed or required and what level of treatment in the HCF is required before disposal in sewers? - What is the existing faecal sludge management system in the area, including both emptying services and faecal sludge treatment and disposal or reuse arrangements? - Is the electricity supply reliable and affordable?

Table 3. Definition of the framework's factors and leading prompts (site and environmental factors, surrounding natural environment)

Subgroup	Factor	Description	Question prompts to support decisions
Site and environmental factors (surrounding natural environment)	Water resources availability and local climate	The presence of dependable, year-round, safe water sources with consistent quality is an important factor in choosing suitable technologies for water supply and sanitation. This can include accessibility of water in terms of groundwater depth or distance to other water sources. The local climate also plays a significant role in shaping the effectiveness of water and wastewater treatment methods reliant on natural processes. Furthermore, climate change may exacerbate various weather-related hazards, impacting the operation and stability of water and sanitation systems, and thereby also influencing the choice of the technology. It may also necessitate utilization of more than one water source, where water shortages or excessively polluted water are a possibility.	- Are the water resources available consistently throughout the year both in quantity and quality? Is that situation expected to remain the same or alter, given climate change? - How might the local climate affect the design, operation or maintenance of water and sanitation services? - Are predicted climate change impacts likely to influence water resource availability and quality now or in the future? Are extreme weather events predicted in this location? - Are there competing activities (e.g. industry, agriculture) besides the HCF that may lead to water scarcity?
	Topography and soil	Assessing the topography and soil composition is essential for determining the technical and financial viability of certain technologies. For example, rocky terrain could escalate expenses for groundwater extraction, whereas sandy soils adjacent to groundwater reservoirs or to coastal areas may demand supplementary wastewater treatment to avoid contamination. Atolls and coastal areas may be vulnerable to sea-level rise and saline intrusion.	- Is the topography a relevant factor for moving water to and from the HCF? - Is the type of soil relevant for construction works of the infrastructure? - If the soil is the disposal environment for HCF wastewater, can it filter and absorb the wastewater generated?
	Site water source characteristics	The characteristics of nearby water sources, including their physical, chemical and biological attributes, strongly influence the selection of appropriate on-site water supply technologies. These attributes can encompass factors such as overall water quality, accessibility, flow rates and risk of local contamination. When choosing the most fitting technology, it is crucial to consider how well the technology aligns with the existing water source's attributes to ensure the best possible outcomes for water supply within the HCF.	- What is the overall quality of the water source? - Is the water source susceptible to specific sources of pollution? - How much water can be extracted from the water source? - Is climate change expected to impact the water source yield or quality?
	Disposal site characteristics	The receiving environment's characteristics influence the choice of appropriate wastewater treatment technologies. Effective treatment should adequately remove pollutants to avoid any substantial impact on environmental balance and public health. For instance, delicate ecosystems such as wetlands or areas with endangered species may require more extensive wastewater treatment measures. Equally important, areas where people are exposed to waterways or	- What is the capacity of the environment to absorb the residual pollution from the treated HCF wastewater? - Is the disposal site a fragile ecosystem, exposed to human contact or likely to pollute the population?

Table 3. Definition of the framework's factors and leading prompts (site and environmental factors, surrounding natural environment)

Subgroup	Factor	Description	Question prompts to support decisions
		drainage systems receiving wastewater require that wastewater should meet specific safety standards.	- Is the disposal site near local waterways or drains, allowing people to come into contact with wastewater? Or where flooding might cause potential for exposure?

Table 4. Definition of the framework's factors and leading prompts (institutional factors)

Subgroup	Factor	Description	Question prompts to support decisions
Institutional factors	Standards, guidelines and regulations	Standards, guidelines and regulations significantly influence the selection of appropriate water and sanitation technologies. In many countries these directives serve as critical drivers, guiding the choice of technologies that adhere to established norms and regulations, and thus promoting responsible and sustainable practices. Non-compliance repercussions further drive the practical implementation of these standards, with more severe penalties encouraging investment in technologies to ensure compliance. In places where standards do not exist, standards in similar countries or minimum international standards can be consulted. Beyond technology standards, guidelines for monitoring water quality, wastewater discharges and IPC procedures may be relevant. Approaches to ongoing monitoring water and sanitation operation and standards in HCFs also require consideration.	- Are there any guidelines for design, operation and maintenance of water and sanitation systems suitable for HCFs? - Are there any restrictions for on-site water supply and wastewater treatment and disposal in HCFs? - Are there any regulations that penalize non-compliance? - What systems are in place for ongoing monitoring of water supply and wastewater treatment in the facility?
	Public sector investment capacity	Financial resources allocated to water and sanitation infrastructure in HCFs are crucial for enabling the adoption of technologies that meet HCF requirements. Investment capacity refers to the availability of funding for supporting water and sanitation technologies, encompassing government sources as well as access to donor funds for system design and construction. An important consideration is not just investment capacity for capital investments, but also budgets required to support ongoing operation and maintenance costs, without which any technology is likely to fail.	- What is the available budget to design, construct, operate and maintain water and sanitation systems in the HCF? Is a budget available for both capital expenditure as well as recurrent expenditure? - What are potential resources for implementing water and sanitation systems?
	Public sector human resources capacity and expertise	The proficiency and capabilities of public sector personnel are crucial for evaluating, overseeing, enforcing and providing guidance on suitable water and sanitation technologies for HCFs, including their familiarity with various technologies. For instance, if government staff responsible for approving water and sanitation projects are unfamiliar	- What is the familiarity of the public sector with the water and sanitation technological alternatives? Are technologies that might require additional time and resources to be approved?

Table 4. Definition of the framework's factors and leading prompts (institutional factors)

Subgroup	Factor	Description	Question prompts to support decisions
		with a specific technology, this could impede its adoption and hamper timely project advancement. In addition, where public sector staff are responsible for operating, maintaining and testing the efficacy of water and sanitation technologies, the number of staff, their skills and expertise are important considerations in technology selection.	- Are there skilled personnel in the public sector to assess advanced and non-conventional water and sanitation systems? - Where required, does the public sector have the human resource capacity and relevant skills to operate and maintain water and sanitation technologies in HCFs? - Do public sector staff have the capacity to oversee or manage private sector actors with regard to procurement and contracts, etc.?
	Public sector planning for climate change and disaster response	Public sector systems for vulnerability and risk identification, budget allocation, and responsive protocols for climate change risks and disaster management can influence the choice of apt technologies for a given situation. For instance, specific technologies that are more resilient to the possible hazards facing an HCF may prompt the public sector to endorse their adoption. Then again, climate mitigation efforts may prompt a focus on low-energy solutions or alternative energy sources, such as solar. In addition, understanding available disaster response mechanisms can influence the presumptive robustness of a technology, or the ability to arrange for backup water supply or sanitation systems should an event occur.	- Are there any national guidelines for climate change risk and disaster response? If yes, are there any endorsed technologies or considerations regarding climate adaptation or climate mitigation? - What is the relevant disaster preparedness or response mechanisms, and do they include consideration of HCFs and relevant water and sanitation technologies?
	Private sector capacity and expertise	Local private sector companies with expertise in water and sanitation can support the public sector's duty of ensuring a safe water supply and clean environment in HCFs. The availability, quality and affordability of their water and sanitation products and services – and the related technical expertise – greatly impacts the feasibility of implementing, operating and maintaining specific technologies for a given location. Equally crucial is the availability of affordable and accessible spare parts in the private market when choosing technologies.	- What water and sanitation technologies, products and services are available from the local private sector? Are there also international technologies that should be considered? - Is there locally available expertise to perform relevant feasibility studies, design, operation and maintenance? - Are the spare parts and materials required for the water and sanitation system easily accessible?

Table 5. Definition of the framework's factors and leading prompts (technology factors)

Subgroup	Factor	Description	Question prompts to support decisions
Technology factors	Treatment performance	The anticipated technology performance, encompassing water quality and quantity, is pivotal in the choice of appropriate alternatives capable of fulfilling HCF needs or disposal mandates. For example, certain wastewater technologies may lack the ability to eliminate emerging substances like pharmaceuticals and ARB. Similarly, some water technologies may offer heightened purity levels in alignment with more stringent water use demands, whereas their optimal operation is contingent upon specific volume production ranges, making them suitable for larger or smaller HCFs. For any technology, monitoring processes required to ensure efficacy should be considered. In addition, consideration of potential climate risks for system performance is critical in view of climate change.	- What treatment level and compounds removal are expected from the technology? - What type of water end-uses can be achieved by the technology? - In what environments can the treated effluent be evacuated from the technology? - Does the treatment technology meet the local regulations? - How is the technology expected to perform under relevant climate risks?
	Construction requirements	The construction of some technologies requires skilled professionals and materials that might or might not be locally accessible, thereby impacting the feasibility and affordability of their implementation.	- Are there local resources to construct the proposed technology, including human resources, materials, and equipment? - What is the capital cost to construct the water or sanitation technology?
	Operation and maintenance requirements	The complexity and resource demands for operating, maintaining and repairing technologies are vital considerations, as they directly influence the long-term effectiveness and durability of the implemented system. For example, technologies reliant on imported parts can face extended interruption periods after repair failures due to lack of available stock.	- Does the technology require dedicated staff to operate and maintain the system? - What level of skills is required to operate and maintain the system? - Does the technology require ongoing materials or reagents for operation? - In case of failure or damage, is the repair easily done in terms of required materials and personnel?
	Energy requirements	The energy demands of water and sanitation technologies should match the availability of reliable and affordable energy for continuous operation. For instance, energy-intensive systems relying on continuous pumping and aeration may become expensive to operate with rising energy costs. Equally, some technologies require a continuous energy supply, and hence	- What are the energy requirements to operate the system? - What are the consequences for the system if the power supply is interrupted?

Table 5. Definition of the framework's factors and leading prompts (technology factors)

Subgroup	Factor	Description	Question prompts to support decisions
		would be unsuitable in locations where there are frequent energy blackouts or intermittent supply.	- What is the cost of energy consumption to operate the system? - Are there renewable and cheap energy sources in the HCF to support energy-intensive technologies?
	Technology climate resilience	Technologies vary in their ability to withstand or adapt to hazards driven by climate change and to continue operating during or after events. Alterations in design, and in operation and maintenance requirements, can enhance the resilience of a given technology. For example, design features can be modified to protect a technology from hazard exposure, help it withstand exposure, enable flexibility or adaptation during events, contain and limit the impact of failures, or facilitate fast recovery.	- Can climate-related hazards damage or compromise the operation, function or effectiveness of the technology? - Does the technology incorporate design features that support improved resilience to climate-related hazards? - Can climate-related hazards negatively affect or compromise the supply chain of materials and services, affecting the effectiveness of the technology?
	Sociocultural acceptance and technology inclusivity	Local perceptions of technologies, by either HCF staff or the wider population, play a crucial role in their enduring success and acceptance. For example, there may be a local inclination towards using water sources perceived as cleaner and a preference for technologies that minimize environmental impact by reducing reliance on chemicals or energy. There may also be a tendency to prefer technologies that are familiar, although not the most suitable technology based on other criteria. Equally important, inclusivity requires consideration of whether people with diverse and varying abilities and age, such as persons with disability or older individuals, are able to use different facilities and technologies.	- Are staff and the wider population supportive of the proposed technology and perceive it to be a good solution? - Is the technology able to cater to the needs of diverse groups of people while ensuring environmental protection and public health?

3 Key water and sanitation technologies for health-care facilities

This section summarizes the relevant water and sanitation technologies for HCFs into single-page fact sheets with information about each technology regarding: (i) expected performance and end-use suitability; (ii) scale of water production of wastewater treatment; (iii) expected ranges of associated costs; (iv) operation and maintenance requirements including skilled personnel and energy; and (v) current status of the technology as either mature or newly emerging alternative.

3.1 Water supply

In HCFs, water supply must be consistent, reliable and of premium quality to fulfil patient care requirements. HCFs demand more water and a more continuous supply than residential or commercial settings, necessitating backup water systems in addition to the main water system. To ensure patient safety and prevent infections, HCFs must address external pollution risks and minimize internal contamination, including ARB in plumbing. Implementing point-of-use treatments at taps can provide ultra-pure or sterile water for specific activities within HCF water supply systems.

A total of nine key water supply technologies were identified as relevant for HCFs and likely to be commonly applied. These range from established solutions to emerging alternatives and are described in the following pages. These technologies include five that are primarily related to water sources, and four to treatment.

Technologies to access different water sources:

- piped water (with additional storage, backup and additional treatment as required);
- groundwater pumping with motorized pumps;
- groundwater manual extraction with handpumps;
- rainwater harvesting; and
- desalination.

Water treatment technologies:

- granular media filters;
- membrane systems;
- point-of-use (sterilization); and
- point-of-use (high purity).

These technologies can be combined in diverse treatment sequences to suit specific contexts, taking precautions to avoid harmful disinfection by-products. Considering the varied contexts and water uses, technologies are categorized based on treatment levels and scales, ranging from drinking to non-drinking or advanced treatment methods. Recycled water is an additional water supply technology that may also be applicable in certain circumstances; however, it is not covered in detail in this resource.

This resource does not offer exhaustive details about technology design, operation and maintenance. Additional resources, while not specific to HCFs, provide information about water supply technologies. *Guidelines to Planning Sustainable Water Projects and Selecting Appropriate Technologies*, published by the Water and Sanitation Rotarian Action Group (WASRAG, 2012) and the report *Smart Water Solutions* by the Netherlands Water Partnership (NWP, 2004) offer comprehensive information on various water supply technologies, including those mentioned in this report.

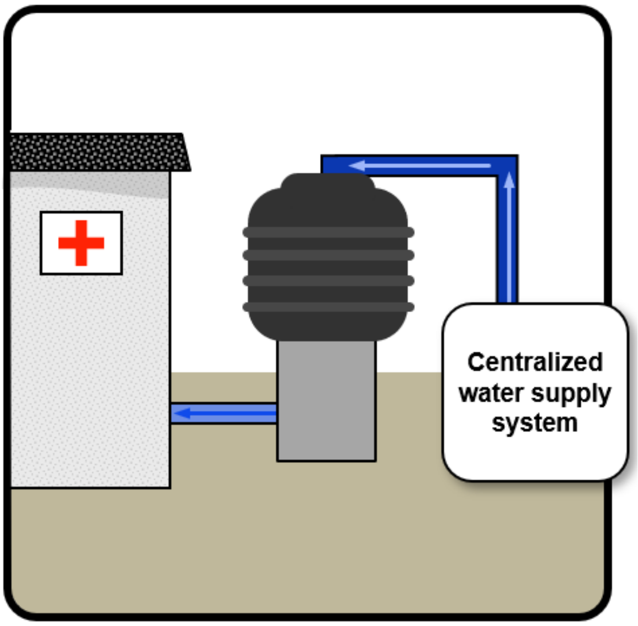
A summary of the technologies and key features concerning cost, scalability, operation and maintenance, energy use and other considerations is provided in Table 6: these correspond to many of the “technology factors” in the decision-support framework. In the technology fact sheets, green cells highlight a technology’s strength, while red cells point to potential challenges. Yellow cells indicate less optimal features that are still applicable.

Table 6. Water supply technology summary

Water source	Water supply and treatment technology*	Cost**	Scale	O&M	Energy use	End-use	Considerations
Piped water	Where needed, additional storage and local disinfection	$-$$	All	L-M	L	Drinking-water	May require additional technologies to address intermittent supply or contamination.
Groundwater (protected wells and/or boreholes)	Motorized pump + [softening] + [filtration] + disinfection] + [storage]	$$-$$$	M-La	M-H	M-H	Drinking-water	Source water quality monitoring is essential to determine treatment level required; pumping can be energy-intensive; and construction may be expensive depending on soil and water depth.
Groundwater (protected wells and/or boreholes)	Handpump	$	S-M	H	M-H	Non-drinking-water	Considerable requirements of manpower and time; highly uncertain water quality; and construction may be expensive depending on soil and water depth.
Rainwater	Harvesting + [treatment] + storage + distribution	$-$$	S-La	L-M	L	Drinking-water	Requires sufficient storage area and may require other water sources due to seasonal variability of rainfall. For drinking uses, will require additional treatment besides storage.
Seawater or brackish water	Desalination (reverse osmosis or nanofiltration)	$$$	S-M	M-La	H	Drinking-water	High costs and technical expertise; requires economies of scale.
Surface water or other source of poor quality	Granular media filters + disinfection	$$-$$$	M-La	L-M	M-H	Drinking-water	May require expert personnel for operation and economies of scale, including sufficient area for system.
Surface water or other source of poor quality	Membrane systems	$$$	M-La	M-H	M-H	Drinking-water	Advanced systems, compact systems suitable for cases with limited area and available financial resources. Materials and parts may not be locally available.

HCF water	Point-of-use (sterilization)	$-$$	S	Lo	L-H	Medical and clinical activities	Valuable for targeted, on-demand supply for onerous activities. Depending on the method it can be energy-intensive and/or require materials not locally available.
HCF water	Point-of-use (high purity)	$-$$	S	Lo	L-H	Clinical activities	Valuable for targeted, on-demand supply for onerous activities. Depending on the method it can be energy-intensive and require materials not locally available.

H: high; HCF: health-care facility; L: low; La: large; M: medium; O&M: operation and maintenance requirements; S: small.
* Steps in square brackets ([ ]) indicate non-mandatory components.
** Life-cycle costs are denoted from relatively low to relatively high ($, $$, $$$).



WATER SUPPLY

Centralized piped water

Centralized piped water systems are common in urban areas and some small towns or even villages, being designed to provide consistent and uninterrupted water supply. However, this ideal scenario often is not achieved, resulting in intermittent supply and potential cross-contamination in the water distribution network. HCFs may therefore require on-site storage or backup supply and additional water treatment before use. Piped supply has usually been treated through multiple steps, such as coagulation and filtration.

Expected performance and outcomes

Ensure drinking-water quality compliance and effective supply for diverse HCFs. To mitigate risks from intermittent supply and cross-contamination, backup storage (overhead, ground level or underground) and local disinfection may be required.

Technology scalability

Piped water can serve HCFs of all sizes. Backup storage and local treatment may have significant space requirements.

Energy requirements

HCF energy usage for piped water use is low. If backup systems or extra storage tanks are needed, additional energy may be required for pumping and internal distribution, and may also be required for heating (e.g. in extremely cold environments).

Operation and maintenance

Operation and maintenance (O&M) needs are typically minimal, largely overseen by the water utility. HCFs are responsible for maintaining their internal plumbing, backup systems, and additional water storage and local disinfection.

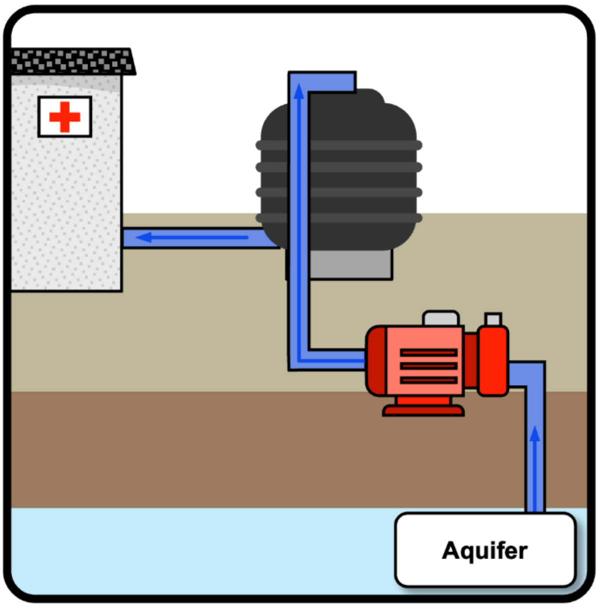
Expected associated costs

Continuing expenses are typically modest, with the major portion incurred from water utility rates. O&M costs can rise if extra backup systems or water storage are implemented.

Current status of the technology

Globally, centralized water treatment and distribution are prevalent, often guided by national-level standards and guidelines for design and operation.

Usually clean and abundant water	**Relatively cheap water**	**Can be intermittent**	**Can show cross-contamination**	**Mature technology**	**May require water quality testing**



WATER SUPPLY

Groundwater pumping

Groundwater accessed via wells, boreholes or springs with motorized/manual pumps can supply large volumes of water. Motorized pumps need power, maintenance and skilled personnel. Safe water for HCFs requires groundwater that is free from microbial contamination. Treatment options include chemical removal of minerals, softening, aeration and disinfection for boreholes/wells, which will greatly vary based on the natural water quality of the groundwater source.

Expected performance and outcomes

Groundwater generally offers better quality than surface waters, though variations exist, impacting treatment demands. It is expected that, in absence of local pollution, drinking-water standards can be achieved after simplified treatment.

Technology scalability

Extracted water quantities can fluctuate seasonally; careful management and collective planning with other large water users (e.g. agriculture, industry) is crucial to prevent overextraction.

Energy requirements

Groundwater pumping requires a reliable energy supply, with energy consumption varying based on pumped volume and groundwater level. Unless using solar power, energy for pumping often is the largest energy requirement based on the usual need for only simplified treatment processes.

Operation and maintenance

Pump operation, upkeep and repair demand technical know-how. Replacement parts and disinfecting agents are typically accessible in urban areas but may be scarce in remote or rural regions, such as the electricity required for system operation.

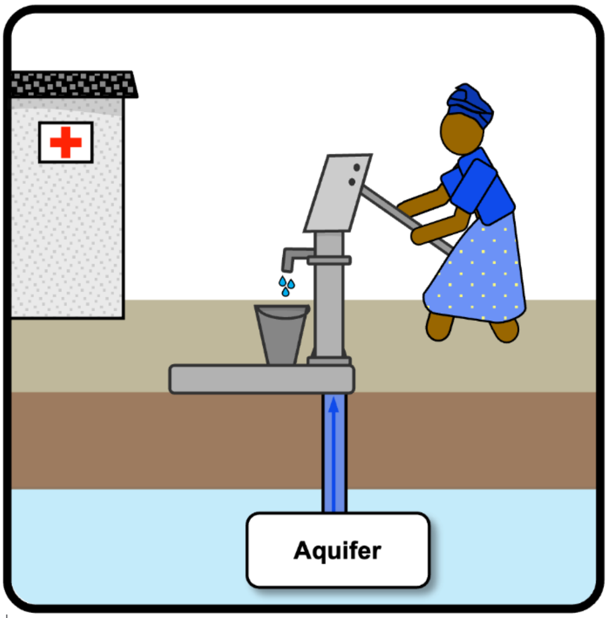
Expected associated costs

Anticipate moderate costs, subject to variation based on pumping needs. Additional treatment, such as disinfection, may add expenses. Well excavation or drilling, pump installation and solar panels can constitute a notable share of capital costs, contingent on soil type, groundwater depth and capacity.

Current status of the technology

Groundwater pumping is a widespread practice, with service providers available in many locations.

Usually clean water source	**Usually reliable source**	**Can require lots of energy**	**Can be costly to construct**	**Mature technology**	**Should provide drinking-water quality**



WATER SUPPLY

Groundwater manual extraction

Groundwater manually extracted from wells, boreholes or springs can supply limited volumes of water not requiring power or skilled personnel. Often this solution requires extra storage and proper treatment to avoid contamination. Treatment is performed on a small scale, often at the point-of-use level, and depends on the natural water quality of the groundwater source.

Expected performance and outcomes

Groundwater generally offers better quality than surface waters, though variations exist, impacting treatment demands. It is expected that, in the absence of local pollution, drinking-water standards can be achieved after simplified treatment.

Technology scalability

Handpumps or manual extraction with containers restrict scalability. Manual extraction followed by storage can reduce reliance on manpower during medical emergencies. Patients may need to fetch their own water, limiting accessibility (e.g. for those with disability/poor health, older individuals).

Energy requirements

Energy requirements are minimal since water is transported using human power.

Operation and maintenance

Operation is simple but time-consuming. Additional storage may increase the risk of contamination, requiring monitoring and treatment of stored water. Repair and spare parts may be required, and hence must be available. Some installations such as deep well pumps may require specialist tools.

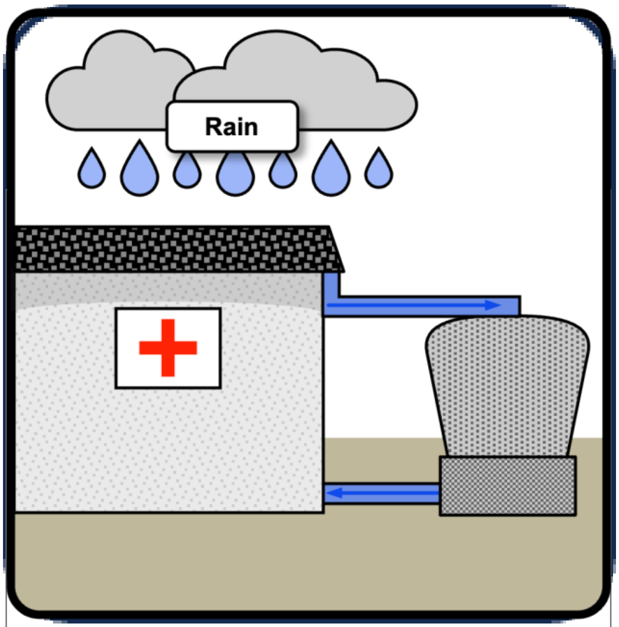
Expected associated costs

Apart from the opportunity cost for operators who could otherwise use the time required for other activities, financial costs are generally low for this solution. Most expenses derive from construction, ongoing maintenance and ongoing treatment, if applicable.

Current status of the technology

Groundwater manual extraction has been practised for centuries worldwide, and system operation requires no expertise; however, maintenance does.

Clean water source	**Operationally simple**	**May require large storage tanks**	**Low scalability**	**Mature technology**	**Requires staff time**



WATER SUPPLY

Rainwater harvesting

Rainwater harvesting collects rain from roofs via gutters to storage tanks that are treated for debris and contamination through first flush diversion, gross and fine filtration, and disinfection. Adapting to rainfall fluctuations, rainwater tank size must match drought needs. Sole reliance on rainwater may demand impractical tank sizes and may not be resilient to climate change. Combining rainwater with other sources can overcome these challenges.

Expected performance and outcomes

Rainwater, typically clean, requires quality assurance measures for drinking purposes. First flush diversion, gross and fine filtration, and disinfection are needed to eliminate debris and pathogens from collection and transport from roofs to storage tanks.

Technology scalability

Variable rainfall and limited catchment and storage space can restrict the scalability of this solution for smaller to medium-sized HCFs. Rainwater harvesting can be a feasible supplementary system for larger hospitals in locations of low air pollution.

Energy requirements

Energy demands are minimal due to gravity-driven processes. Water pumping, whether to elevate water for subsequent gravity-based supply or for on-demand use, can facilitate convenient access to stored water.

Operation and maintenance

O&M are simple. Key tasks include regular cleaning of water storage tank, gutters and filters. Climate change, causing shifts in rainfall patterns, may impact the functioning of rainwater harvesting systems.

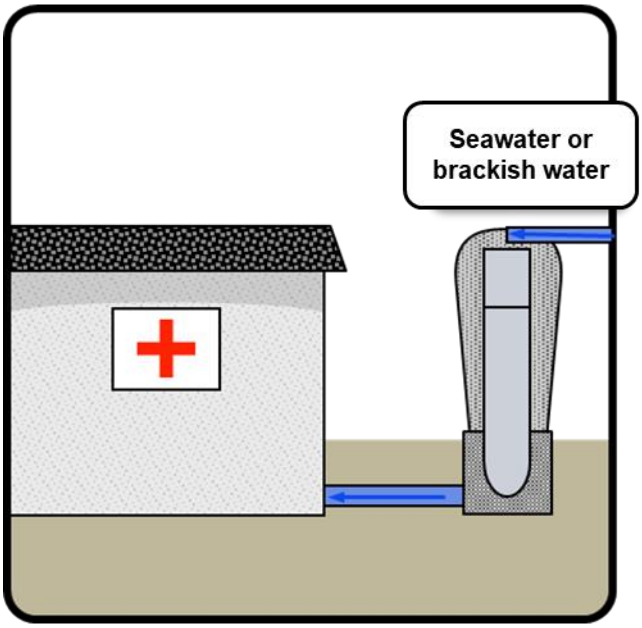
Expected associated costs

Anticipate relatively modest expenses, primarily allocated to storage tanks, pipes and pumps if needed. Depending on the end-use and disinfection requirements, additional costs may arise based on the chosen disinfection approach.

Current status of the technology

Rainwater harvesting demands minimal expertise, although careful design, particularly regarding tank sizing and water quality control mechanisms, is essential to ensure the system's reliability.

Clean water source if well-maintained	**Cheap water source**	**May require large storage tanks**	**Seasonal variability and susceptible to climate change**	**Mature technology**	**Requires regular maintenance**



WATER SUPPLY

Desalination

Desalination allows seawater and brackish water to be transformed into drinking-water supply. The most common technology types to achieve desalination are reverse osmosis, electrodialysis, multi-effect distillation, solar distillation, multi-stage flash and nanofiltration. This technology is increasingly deployed in small-island settings with scarce water resources; however, it is a high-cost option with extensive O&M requirements.

Expected performance and outcomes

Reverse osmosis is commonly used to turn seawater or brackish water into freshwater. Desalination technologies produce high-quality drinking-water with low levels of impurities and pathogens.

Technology scalability

Desalination plants typically have a relatively small physical footprint and can serve small or larger water supply requirements. Modular designs are increasingly available. Solar distillation is possible for small-scale applications

Energy requirements

Energy-intensive and generally requires economies of scale. More recently, solar-powered systems are being used to address high energy demands. Dilution of seawater with other water sources is another technique used to reduce energy requirements.

Operation and maintenance

Requires high-level technical expertise for O&M, making sustainable implementation in low-resource settings challenging.

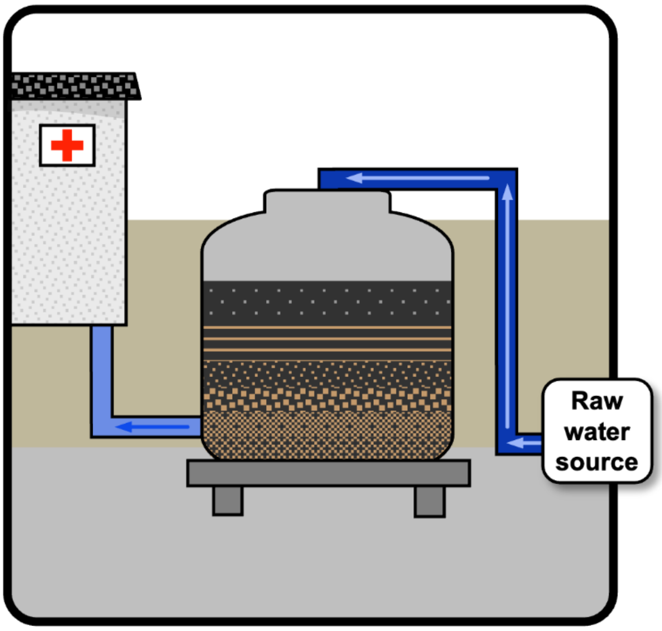
Expected associated costs

Anticipate high capital and ongoing O&M costs. It is unlikely to be financially affordable unless there are major grants or subsidies available, which should cover not only capital costs but also O&M.

Current status of the technology

Desalination is a mature technology with continuous new advances that increase efficiencies, and over time may reduce costs.

High-quality water supply	**Provides supply in water-scarce areas**	**High energy requirements**	**High capital and operational costs**	**Modular designs**	**Mature but complex technology**



WATER SUPPLY

Granular media filters

Where available water sources are of poor quality, granular media filters can remove suspended and dissolved materials with or without coagulation via adsorption and biofilms. Granular media filters can consist of multiple design and filtering media materials (most commonly sand), require ongoing maintenance and usually require disinfection follow-up steps. Construction, maintenance and operation usually require economies of scale, but may support use of surface water if no other source is available.

Expected performance and outcomes

Granular media filters are a primary technology in numerous municipal water treatment plants, yielding high-quality water. Operation substantially influences outcomes, impacting both quality and quantity, potentially requiring additional processes such as coagulation, flocculation and disinfection.

Technology scalability

Granular media filters can produce large volumes of water, and due to the associated capital cost are generally recommended for medium- to large-sized applications. Their construction requires relatively ample space.

Energy requirements

Energy needs for granular media filters can fluctuate based on their set-up and treatment process. Generally, they have moderate energy requirements since the filtration process is not pressurized, although substantial pumping may be involved.

Operation and maintenance

O&M require experts to achieve optimal operation and ensure system effectiveness. Routine tasks encompass regular cleaning, including backwashing, pump management and potential chemical dosing.

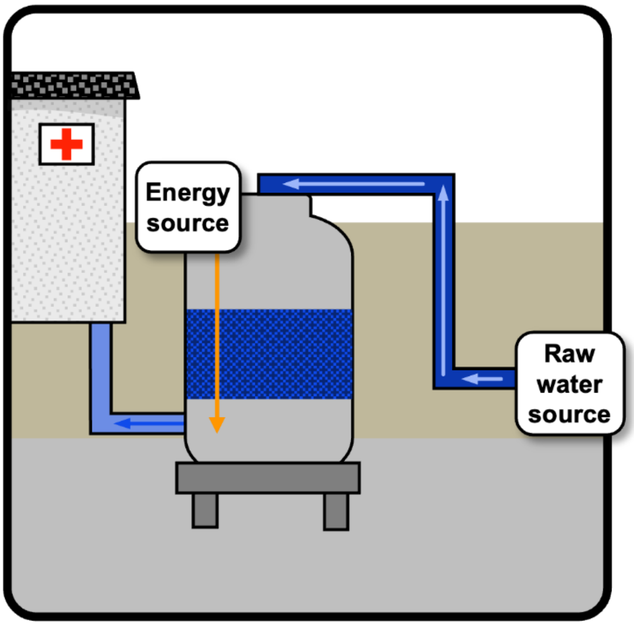
Expected associated costs

While initial capital and ongoing operational costs may be relatively high, the potential for economies of scale can lead to cost-effective water production.

Current status of the technology

Sand filters are extensively employed in municipal water treatment plants and have also found application as on-site treatments to enhance hospital water quality, being acknowledged as a well-established and mature technology.

High treatment performance	Suitable for poor water quality	Expensive, and requires ample space	Complex operation	Mature technology	Non-drinking- and drinking-water



WATER SUPPLY

Membrane systems

Compact on-site water treatment can be achieved using membrane technologies, yielding high-quality water with modular stages and reduced infrastructure. Membrane processes employ semipermeable films and driving forces (pressure, temperature, electric potential) for water treatment. While most are pressure-driven (membrane filtration), electric and thermal methods like electrodialysis are viable. Membrane pore size influences removal efficacy and operation.

Expected performance and outcomes

Membrane systems produce high-quality water, streamlining treatment stages and infrastructure. Ultrafiltration membranes effectively eliminate most microbiological pathogens and viruses.

Technology scalability

Membrane systems can produce large volumes of water, and due to the associated capital cost are generally recommended for medium- to large-sized applications. Their modular nature permits gradual capacity expansion.

Energy requirements

Membrane systems demand significant electricity due to pressurized filtration in contrast to other water treatment methods.

Operation and maintenance

Continuous monitoring and technical proficiency are necessary for optimal operation. Maintenance and repairs involve materials and expertise that might not be widely accessible, posing challenges in the event of supply-chain disruptions.

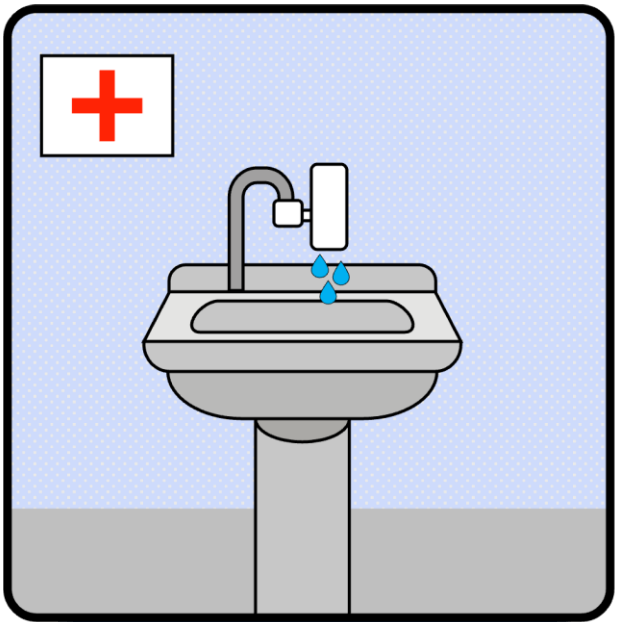
Expected associated costs

Both initial capital and ongoing operational costs are anticipated to be relatively high, primarily due to limited availability of services and materials. Moreover, energy demands for system operation contribute to the overall expenses.

Current status of the technology

Membrane systems are currently employed in many water treatment plants globally, yet expertise for their design and operation remains relatively limited. Ongoing research aims to enhance process optimization.

High treatment performance	**Compact systems**	**Energy-intensive**	**Materials may not be locally available**	**Emerging technology**	**Drinking-water**



WATER SUPPLY

Point-of-use (sterilization)

Three main point-of-use treatments are employed to make small water quantities sterile for specific uses: **tap filtration** prevents bacterial passage and controls outbreaks; **boiling** at >77 °C kills pathogens, removing microorganisms and pathogens, although it is impractical for large volumes due to energy and time constraints. **Solar water disinfection** (SODIS) disinfects through sunlight exposure but may be unreliable.

Expected performance and outcomes

Microbe-free water for specific medical and clinical uses can be achieved with the three treatment methods. The cost-benefit in terms of time, energy, convenience and materials varies. Tap filtration and boiling are preferred over SODIS in terms of reliability.

Technology scalability

The quantity of sterile water generated varies considerably among methods, typically remaining limited and suited for on-demand use in specific applications.

Energy requirements

Energy demands exhibit significant variation, with SODIS and on-tap filtration requiring minimal energy, while boiling requiring considerably higher energy consumption.

Operation and maintenance

O&M are generally straightforward but differ depending on the method. On-tap filtration necessitates frequent filter replacements; SODIS and boiling involve regular batch monitoring and control. Boiling entails risk management.

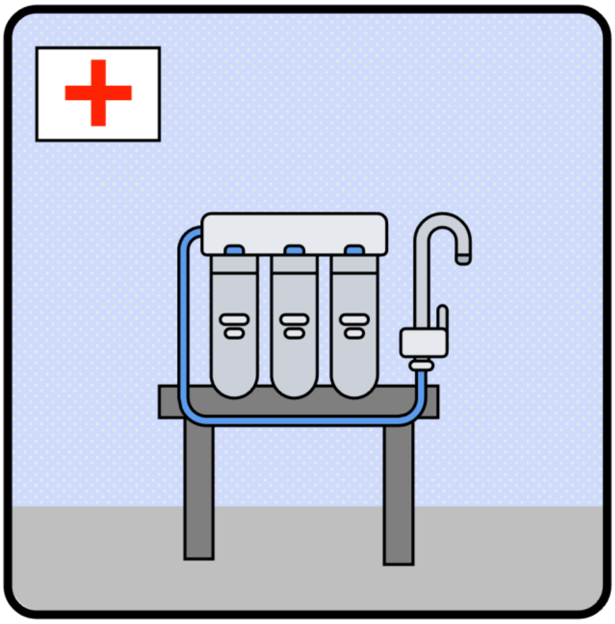
Expected associated costs

Costs also significantly vary with the method. SODIS is cost-effective but lacks scalability. On-tap filtration offers greater scalability but comes with filter replacement costs. Boiling is cost-intensive, but potential economies of scale arise depending on the energy source.

Current status of the technology

All these methods are firmly established. Boiling and SODIS are straightforward to implement, not demanding extensive infrastructure, while on-tap filters are commercially accessible from multiple manufacturers.

On-demand use	**Enable specialized activities**	**Can be energy-intensive**	**Materials may not be locally available**	**Mostly mature technologies**	**Advanced treatment**



WATER SUPPLY

Point-of-use

(high purity)

In medical labs, ultra-pure water is vital for activities like diagnostics, chemistry and cultures. Point-of-use treatment offers cost-effective high purity in smaller quantities. **Distillation** heats, condenses to eliminate impurities, but is time- and energy-intensive. **Reverse osmosis** forces water through a membrane; it is costly but highly effective. **Deionization** uses resins for ion removal, while carbon filters enhance taste and purity.

Expected performance and outcomes

All the methods can produce water with minimal dissolved compounds. Distillation, reverse osmosis and deionization cater to laboratory needs, while carbon filtration/adsorption enhances taste and odour.

Technology scalability

While these technologies can be applied on a larger scale, their cost-effectiveness is most favourable for small-scale, on-demand utilization.

Energy requirements

Energy demand varies; distillation and reverse osmosis are energy-intensive, while deionization via resins and on-tap carbon filters are less so.

Operation and maintenance

Distillation is operationally simple yet time-consuming. Reverse osmosis requires expertise for O&M. Deionization and carbon filtration are simpler to operate. Deionization resins may not be locally available, while carbon filters require frequent replacement.

Expected associated costs

Costs vary based on material, equipment and energy availability. Distillation and reverse osmosis expenses are primarily operational, while deionization and carbon filters are largely influenced by material acquisition.

Current status of the technology

Many technologies are now established, with commercial products available for strategic placement in HCFs. Active research focuses on optimizing reverse osmosis operations.

On-demand use	**Enable specialized activities**	**Can be energy-intensive**	**Materials may not be locally available**	**Mostly mature technologies**	**Advanced treatment**

3.2 Sanitation

The wastewater produced by HCFs − and particularly, hospitals − carries a greater risk compared to domestic and municipal wastewater due to higher concentrations of pathogens and emerging pollutants, including ARB and pharmaceuticals (Verlicchi et al., 2010; Rodriguez-Mozaz et al., 2015). Consequently, whenever possible, the adoption of advanced wastewater treatment technologies capable of reducing the concentration of these pollutants is essential to protect public health and the environment in HCFs. In facilities where medical activities lead to elevated pathogen and pollutant concentrations, this becomes particularly vital.

However, in many LMICs where HCFs lack basic sanitation systems and directly release effluents into the environment, implementing and maintaining advanced wastewater treatment technologies may not be feasible due to limited resources, or may not be warranted in HCFs providing limited services, such as small health clinics. In such scenarios, simplified systems can still contribute to mitigating public health risks compared to direct disposal, and should be adopted as improvement steps.

Wastewater treatment is commonly classified into three levels:

- *primary treatment:* This initial stage involves the physical removal of large solids and floating debris, resulting in a reduction of the organic load and suspended solids concentration.
- *secondary treatment*: Building on primary treatment, the secondary stage aims to further decrease the organic and biological content of the wastewater. This is typically achieved through biological processes that are carefully regulated and controlled hydraulically.
- *tertiary/advanced treatment:* Tertiary treatment focuses on the removal of specific contaminants beyond what is achieved in primary and secondary treatment. It targets nutrients such as nitrogen and phosphorus, pathogens and other emerging contaminants (e.g. antibiotics, endocrine-disrupting compounds and personal care products).

These three treatment levels work in conjunction to progressively improve the quality of the wastewater, addressing different types of pollutants and achieving specific treatment objectives. Within this context, a set of 12 technologies and practices was identified, spanning from well-established to emerging options. These encompass widely adopted practices, incremental improvements over inadequate sanitation and on-site wastewater treatment technologies. The specific technologies in the summary presented in Table 7 and covered in the following pages include the following:

- direct conveyance to sewer or co-treatment (pre-treatment followed by sewer disposal);
- pit latrine (primary treatment);
- dry composting toilet (primary treatment);
- septic tank (primary treatment);
- anaerobic baffled reactor (primary treatment);
- constructed wetlands (primary-secondary treatment);
- activated sludge (secondary-tertiary treatment);
- membrane bioreactor (secondary-tertiary treatment);
- chemical flocculation and disinfection (tertiary treatment);
- activated carbon adsorption (tertiary treatment);
- zeolite adsorption (tertiary treatment); and
- advanced oxidation processes (tertiary treatment):

These technologies can be organized into different treatment sequences, allowing for diverse combinations in various situations. Moreover, considering the contextual variations, technologies of varying treatment levels and scales can be categorized as improvement steps, simplified treatments, advanced treatments or add-on treatments. Sequencing of treatment units must be carefully designed, since, for example, disinfection of water that is high in organic matter can lead to harmful mutagenic and carcinogenic disinfection by-products.

This resource does not aim to provide comprehensive details about sanitation technology design, operation and maintenance. Supplementary resources, though not health care-specific, offer insights into water supply technologies. The comprehensive guide *Compendium of Sanitation Systems and Technologies* (EAWAG, 2014) provides in-depth information on certain sanitation technologies covered in this report. In addition, WHO guidelines on sanitation and health are an important and useful resource (WHO, 2018).

In addition, this resource does not include **faecal sludge treatment technologies**, as it is unlikely that an HCF would take sole responsibility for such a technology. Where they are in use, an HCF instead ensures regular desludging of relevant sanitation systems and transportation of sludge to relevant faecal sludge treatment facilities. As noted for wastewater, however, the sludge generated from HCFs, particularly hospitals, may include a wider range of contaminants than normal faecal sludge, and available faecal sludge treatment processes should be checked accordingly for their ability to cope with these additional contaminants.

Table 7. Summary of key wastewater treatment technologies relevant to health-care facilities

Level of treat-ment	Wastewater and sludge treatment technologies	PhCs removal	ARB removal	Cost*	Area	Scale	O&M	Energy use	Considerations
None	Direct discharge to sewer	–	–	$	–	All	–	–	Where wastewater composition permits, wastewater from an HCF may be directly directed to the municipal wastewater treatment.
P	Co-treatment (also known as "pre-treatment")	L-M	L-M	$-$$	S-M	S-La	L	L	In some HCFs, particularly hospitals, effluents require appropriate treatment prior to disposal in sewers to avoid cost and risk externalization.
P	Chemical flocculation	L-M	L-M	$$	S-M	S-La	M-H	M	Must be used with subsequent secondary and tertiary treatments. Requires specialized staff for operation and materials may not be locally available.
P	Pit latrine**	L	L	$	S	S	S	L	Very limited treatment performance, perceived as an improvement step.
P-Se	Dry composting toilets**	L	L	$	S	S	S	L	Potential alternative for water-scarce locations. Composted solid waste requires safe removal, treatment and disposal.

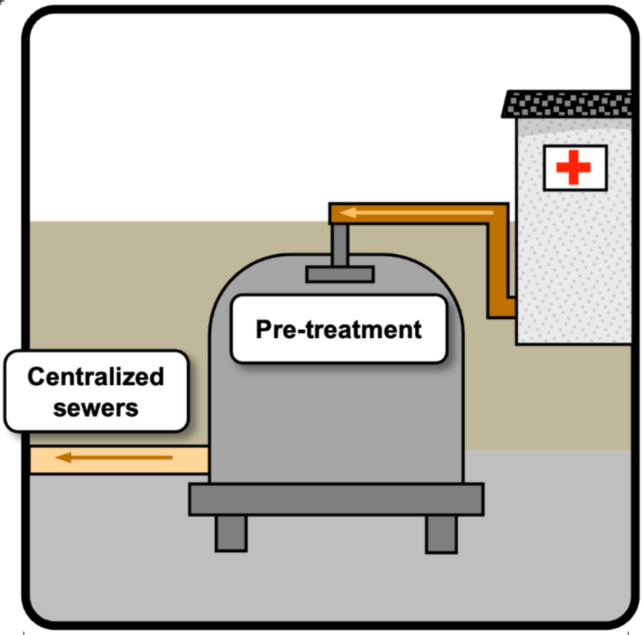
P	Septic tanks**	L	L	$-$$	S	S-M	S	L	Limited treatment performance, requiring additional treatment for HCFs pollutants and ARB. Requires sludge removal and treatment.
P	Anaerobic baffled reactors**	L	L	$-$$	S	S-M	S	L	Limited treatment performance, requiring additional treatment for HCFs pollutants and ARB. Requires sludge removal and treatment.
P-T	Constructed wetlands	L-M	L-M	$-$$	M-La	S-La	L	L-M	Requires tertiary disinfection for ARB. Requires relatively large area.
Se-T	Activated sludge	L-M	L-M	$$	S-M	M-La	M-H	M-H	Requires tertiary disinfection for ARB. Requires specialized staff for operation, is energy-intensive and parts may not be locally available.
Se-T	Membrane bioreactor	L-M	L-M	$$	S	S-La	M-H	M-H	Requires tertiary disinfection for ARB. Requires specialized staff for operation, is energy-intensive and parts may not be locally available.
T	Chemical disinfection	L-H	L-H	$$	S-M	S-La	M-H	M	Requires primary and secondary treatment for solids, organic matter and nutrients. Requires specialized staff for operation, is energy-intensive and parts may not be locally available.
T	Activated carbon adsorption	H	H	$$-$$$	S-M	S-La	M-H	L	Requires primary and secondary treatment for solids, organic matter and nutrients. Requires specialized staff for operation, is energy-intensive and parts may not be locally available.
T	Zeolite adsorption	M-H	M-H	$$-$$	S	S-M	H	M-H	Requires primary and secondary treatment for solids, organic matter and nutrients.

									Requires specialized staff for operation, is energy-intensive and parts may not be locally available. It is an emerging technology with a limited number of suppliers and experts on design and operation.
T	Advanced oxidation processes	H	H	$$$	S	S-M	H	H	Requires primary and secondary treatment for solids, organic matter and nutrients. It is an emerging technology with limited number of suppliers and experts on design and operation.

ARB: antibiotic-resistant bacteria; H: high; HCF: health-care facility; L: low; La: large; M: medium; O&M: operation and maintenance requirements; P: primary; PhCs: pharmaceuticals; S: small; Se: secondary; T: tertiary.

* Life-cycle costs are denoted from relatively low to relatively high ($, $$, $$$).

** These simplified biological treatment processes have been included due to their extensive use in LMICs; however it should be noted that on their own they do not provide sufficient treatment for the wastewater produced by HCFs, particularly larger HCFs and hospitals.



SANITATION

Direct conveyance to sewer or co-treatment

In some cases, HCF wastewater may be directly conveyed to centralized wastewater treatment plants. However, for hospitals and larger HCFs, co-treatment (also known as pre-treatment) of HCF effluents may be needed because municipal wastewater treatment plants are not designed to remove emerging contaminants like pharmaceuticals or ARB, found at higher levels in HCF effluents than in municipal wastewater.

Expected performance and outcomes

Municipal treatment may be feasible for some HCF wastewater depending on its composition. Co-treatment substantially reduces potential risks. Performance and outcomes hinge on pre-treatment type and the municipal plant's treatment sequence.

Technology scalability

Centralized treatment may be able to accommodate relevant HCF wastewater volumes. Co-treatment is more applicable to larger HCFs with more complex effluents containing diverse chemical and biological hazards.

Energy requirements

Disposal to sewers has limited or no energy requirement. Energy demands for co-treatment vary. Small facilities with municipal effluent compositions have lower energy needs, while larger ones using advanced oxidation may have higher energy demands.

Operation and maintenance

No O&M required for disposal to sewers. Co-treatment protocols require skilled personnel to ensure safe removal of emerging compounds while minimizing production of hazardous by-products.

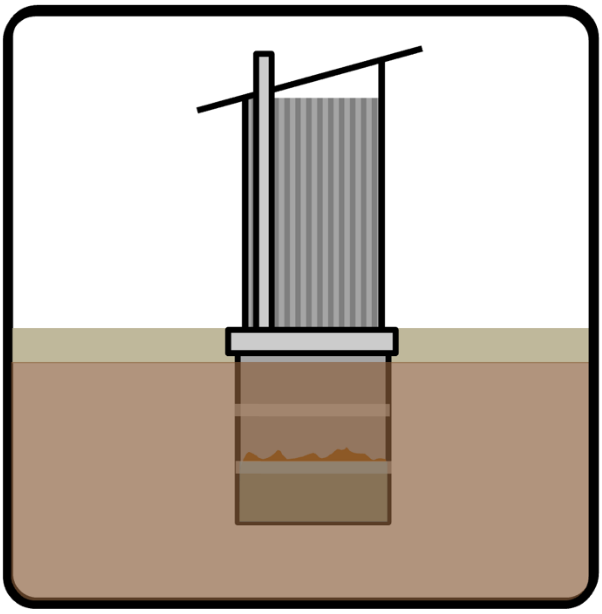
Expected associated costs

Sewer disposal costs are likely to be affordable for an HCF. Costs of co-treatment are significant, although absence of pre-treatment for effluents containing pharmaceuticals or hazardous compounds may lead to cost externalization.

Current status of the technology

Centralized municipal treatment processes are used worldwide, and co-treatment is a widespread practice.

Simplified operation	Safeguard local public health	Cost and risk externalization	Low removal of emerging pollutants	Widespread practice	Improvement step



SANITATION

Pit latrine

Pit latrines have a lined chamber holding excreta and anal-cleaning materials. Pits optimize waste by leaching water into soil while some compounds undergo biological breakdown. The remaining material requires emptying, treatment and safe disposal. Pit treatment is not effective at removing emerging pollutants, which accrue in HCFs without sanitation services. Pits vary as single, double or ventilated designs; double reduces emptying frequency and ventilated minimizes odour and vector risks.

Expected performance and outcomes

Pit latrines aim to isolate waste from people and vectors, reducing disease transmission. Minimal treatment is required, although proper containment, transportation and treatment are necessary when the holding chamber is full.

Technology scalability

Pit latrines are suitable for small-scale HCFs lacking water and surrounding infrastructure access. Climate risks are notable due to potential for contamination in areas with a higher groundwater table or prone to flooding.

Energy requirements

Regular operation does not demand energy, although construction or emptying of the chamber might require an energy input if machinery is used.

Operation and maintenance

O&M are simple and well-suited for resource-limited locations, such as remote areas. However, pit emptying is a necessity and contents must be disposed safely. Double-pit latrines involve alternating usage for longevity. Infrastructure upkeep and vector control remain vital.

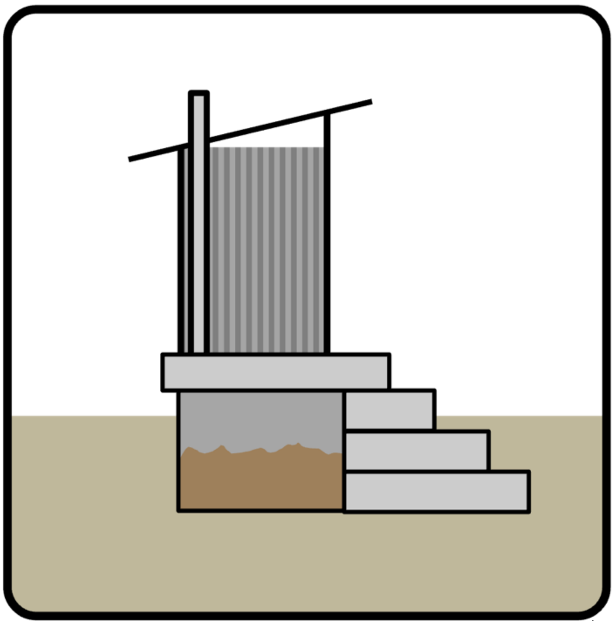
Expected associated costs

Capital and operational costs are expected to be relatively low. It is a suitable solution for remote areas or locations with limited resources. Safe disposal of accumulated sludge may require payment to emptying services.

Current status of the technology

Pit latrines are globally used, with widespread familiarity in design, operation and maintenance.

Waste isolation	**Initial step to safeguard public health**	**Environmental risk**	**Low removal of emerging pollutants**	**Widespread practice in low-resource settings**	**Sensitive to climate risks such as flooding**



SANITATION

Dry composting toilet

A dry toilet operates without flush water, with options such as a raised pedestal or squat pan. Excreta fall through a drop hole, decomposing into compost and needing proper emptying, treatment and disposal. These toilets are water-saving options for areas with water scarcity. Odour concerns arise if they are not properly maintained and can be avoided through newer designs and ventilation. Isolation and sealing of the chamber are vital to prevent pollution and health risks. Urine diversion options are also possible.

Expected performance and outcomes

Dry composting toilets create compost from toilet waste, but caution is needed when using compost from individuals with high pharmaceutical intake and potential ARB. Thermophilic co-composting may also be an option.

Technology scalability

Dry composting toilets are well-suited for small-scale HCFs due to the extended composting duration and operational challenges that arise when managing larger volumes of waste and compost. Composting toilets are suitable for water-scarce regions.

Energy requirements

Routine operation does not require energy; however, energy may be needed for construction or chamber emptying, especially if machinery is utilized, and small amounts of energy may be needed for fans and ventilation.

Operation and maintenance

Operation requires consistent monitoring and compost management but does not require specialized equipment or expertise.

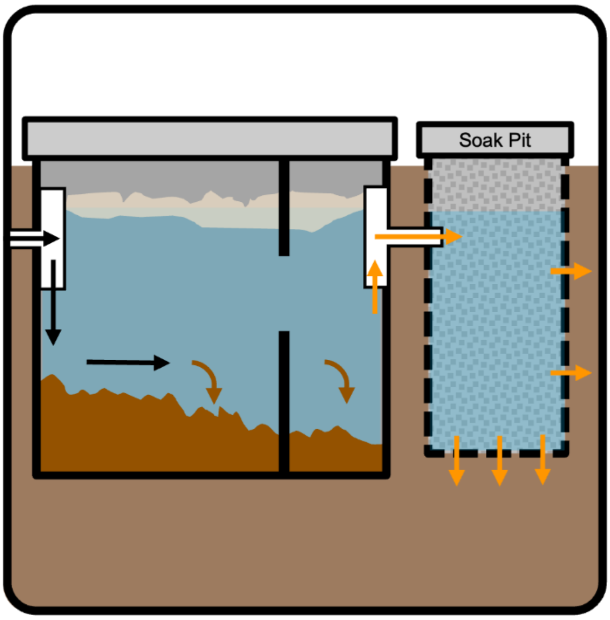
Expected associated costs

Costs are expected to be relatively low and there is potential to reuse compost, which can result in savings in another area.

Current status of the technology

Dry composting toilets are widespread globally and considered a mature technology. Emerging designs contain smells and provide a modern look and experience.

Waste isolation and produces compost	**Waterless**	**Suitable for small scales**	**Low removal of emerging pollutants**	**Mature technology**	**Simplified treatment**



SANITATION

Water-based toilet with septic tank

A septic tank, including an infiltration pit called a soak pit, provides initial treatment. Solid particles settle at the bottom, fats float, and microorganisms degrade sludge. Inlets and outlets have T-shaped pipes for flow direction, sedimentation and biological processes. Septic tanks are mostly anaerobic, limiting removal of pathogen and emerging compounds. Larger HCFs may need extra treatment for specific pollutant removal. Septic tanks represent a step forward in areas lacking proper sanitation services.

Expected performance and outcomes

Septic tanks greatly reduce organic matter and solids in wastewater but have limited efficacy against emerging compounds in HCF effluents; they are therefore best suited for HCFs where the composition of the wastewater stream resembles municipal wastewater.

Technology scalability

Septic tanks are suitable for low- to medium-scale HCFs, and larger volumes of wastewater, particularly more complex wastewater, may be optimally treated using advanced technologies.

Energy requirements

Operational energy needs are minimal, relying on gravity for flow and naturally occurring microorganisms for wastewater treatment, with energy use limited to sludge emptying.

Operation and maintenance

Operation is straightforward but entails occasional monitoring and sludge emptying. There is risk of clogging if improper materials are flushed down the toilet. External service providers are necessary for sludge removal, treatment and proper disposal.

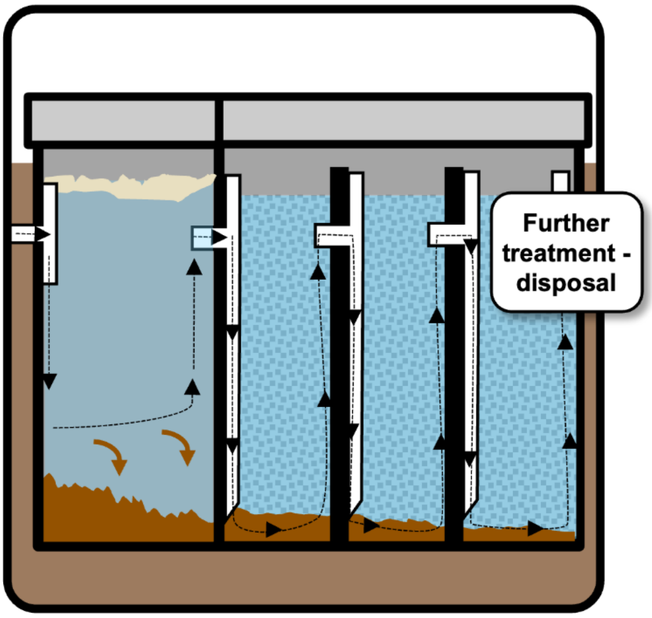
Expected associated costs

Costs are projected to range from low to moderate, subject to variations based on size, soil type and waterproofing approach. Operational expenses for emptying can escalate if the septic tank is undersized, but are generally low.

Current status of the technology

Septic tanks are an established wastewater treatment technology for primary treatment. Although not effective at removing concentrated emerging pollutants from effluents, they still represent an advancement over situations with no wastewater treatment.

Satisfactory removal of pollutants	**Low cost and simple operation**	**Requires sludge removal and treatment**	**Low removal of emerging pollutants**	**Mature technology**	**Primary and secondary treatment**



SANITATION

Anaerobic baffled reactors

Anaerobic baffled reactors operate on similar principles to septic tanks but with compartments separated by baffles, directing flow downward through multiple chambers. This boosts removal of suspended solids and organic matter contact with bottom sludge. However, anaerobic baffled reactors exhibit low removal for emerging pollutants found in health-care effluents. Nevertheless, they represent a significant step forward in areas lacking proper sanitation services.

Expected performance and outcomes

A**naerobic baffled reactors** follow septic tank principles with optimized design for better removal of organic matter and suspended solids. However, they still lack efficacy against emerging pollutants, especially in high concentrations.

Technology scalability

Anaerobic baffled reactors are appropriate for small- to medium-sized HCFs, while larger and more complex wastewater volumes are better treated with alternative technologies. They do provide significantly larger capacity than septic tanks.

Energy requirements

Operational energy requirements are minimal, utilizing gravity for flow and natural microorganism processes for wastewater treatment, with energy required only for sludge emptying.

Operation and maintenance

Operation is medium and involves intermittent monitoring and sludge emptying. There is a risk of clogging if inappropriate materials are flushed. External service providers are needed for sludge removal, treatment and appropriate disposal.

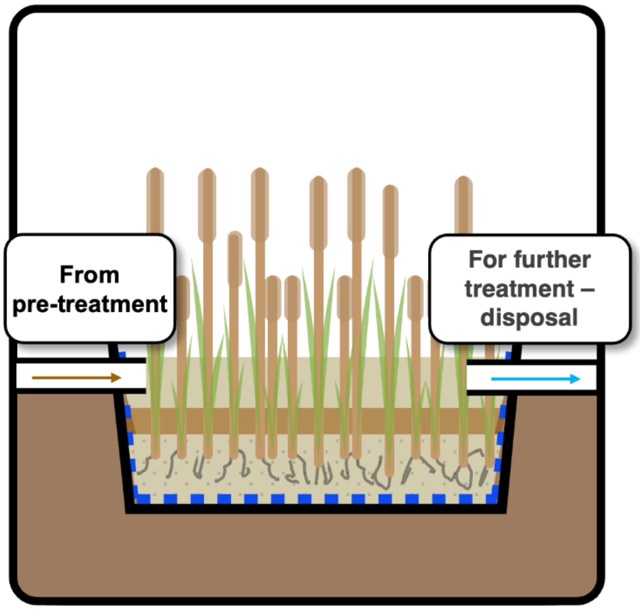
Expected associated costs

Projected costs span from low to moderate, contingent on factors like size, soil type and waterproofing. If the an**aerobic baffled reactor** is undersized, operational costs for emptying may rise.

Current status of the technology

Anaerobic baffled reactors are an established wastewater treatment technology. Despite their limited ability to remove concentrated emerging pollutants from effluents, they represent an advancement over situations lacking wastewater treatment.

Satisfactory removal of pollutants	**Low cost and simple operation**	**Requires sludge removal and treatment**	**Low removal of emerging pollutants**	**Mature technology**	**Primary and secondary treatment**



SANITATION

Constructed wetlands

Constructed wetlands (CWs) use plants and microorganisms to break down contaminants and can be used with septic tanks or anaerobic baffled reactors. Subsurface CWs filter the wastewater through a medium; plants supply oxygen, creating zones for pollutant removal that are optimized through hydraulic design. CWs are more effective than other nature-based solutions for removal of emerging pollutants, although additional treatment is recommended for fine pathogens and effluent polishing for pharmaceuticals.

Expected performance and outcomes

CWs can achieve significant removal of organic matter, solids and nutrients. While their removal of emerging compounds is considerable, more advanced technologies can yield better results. To enhance performance, CWs can be employed in conjunction with septic tanks or anaerobic baffled reactors.

Technology scalability

CWs are applicable for wastewater treatment across a range of scales from small to large and have been installed in municipal wastewater treatment plants. Nevertheless, their construction requires a substantial area.

Energy requirements

Energy demands for CWs differ based on design, varying from gravity-fed systems to those involving pumps. Typically, energy needs are minimal to low.

Operation and maintenance

Operating the system is simple, involving occasional plant pruning and zone alternation based on the CW design. CWs themselves do not generate sludge, but if used in conjunction with septic tanks or anaerobic baffled reactors, the latter will require emptying. CWs are a resilient nature-based technology.

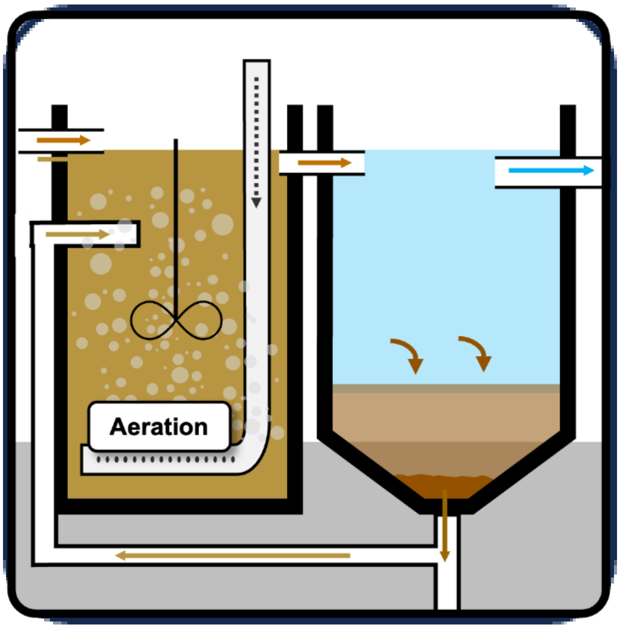
Expected associated costs

Capital costs are more significant, while operational costs remain relatively low. Capital costs vary considerably based on land cost, soil type, and availability and cost of bed media and plants.

Current status of the technology

CWs are an established global technology for wastewater treatment, including HCF effluent. They require a substantial land area and can achieve better treatment results than other nature-based solutions. However, they do not remove all emerging compounds, and effluent polishing is recommended.

Good removal of pollutants	Simple O&M, cheap and resilient	Requires large areas	Low removal of emerging pollutants	Mature technology	Advanced treatment



SANITATION

Activated sludge

Activated sludge (AS) is widely used for wastewater treatment. AS handles health-care emerging pollutants through sludge sorption or biodegradation. Pollutants in sludge need subsequent treatment. Complete removal is challenging due to its complexity. Adjusting sludge, retention times and redox potential enhances treatment performance. AS requires skilled operators and benefits from steps involving combined physicochemical or advanced oxidation processes.

Expected performance and outcomes

AS yields purified effluent with low organic matter, nutrients and solids. AS is good at removal of emerging pollutants, but other technologies offer higher performance. AS produces extensive volumes of sludge, requiring additional treatment.

Technology scalability

AS is versatile in the treatment of various wastewater volumes, but its construction and equipment capital costs make it more feasible for moderate- to large-scale treatment.

Energy requirements

Energy demands are substantial due to water and sludge pumping, as well as aeration. However, this leads to a notable reduction in the required treatment unit area compared to nature-based technologies.

Operation and maintenance

O&M are intricate, necessitating expertise and access to materials and parts that may not be locally accessible, especially in rural or remote areas or during supply chain disruptions.

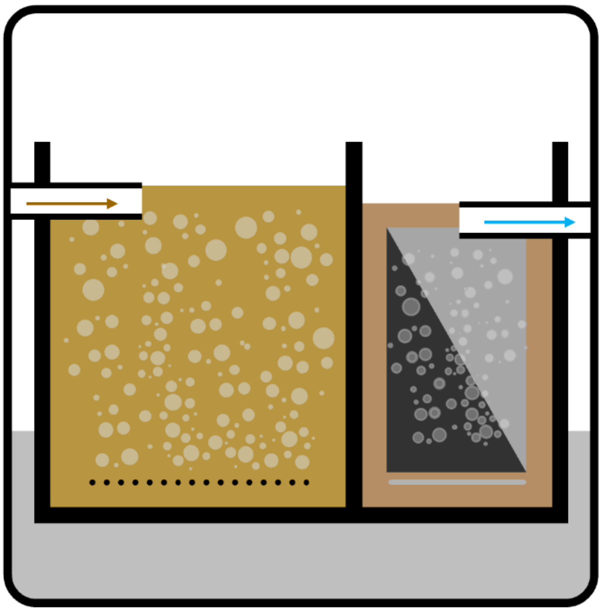
Expected associated costs

Costs range from moderate to high for both construction and operation. However, in urban settings with limited space and substantial wastewater volumes, economies of scale can lead to favourable cost-benefit outcomes.

Current status of the technology

AS is a globally used, advanced wastewater treatment technology, with established O&M needs that require expertise and specific parts. While its removal of emerging compounds is significant, supplementary polishing is recommended.

High removal of pollutants	**Flexible and tailored operation**	**High operational costs**	**Specialized skills required**	**Mature technology**	**Advanced treatment**



SANITATION

Membrane bioreactor

Membrane bioreactors (MBRs) are an emerging technology merging biological and membrane filtration processes for wastewater treatment. They have high treatment performance with a smaller footprint than AS technology. MBRs effectively remove pathogens. Despite higher removal of emerging compounds, subsequent effluent polishing is still recommended. Operation of MBRs requires skilled personnel, and operational optimization is still under active research.

Expected performance and outcomes

MBRs yield purified effluent with low organic matter, nutrient, solids and pathogens. MBRs are very good at removal of emerging pollutants, but other technologies offer higher performance.

Technology scalability

MBRs are adaptable for diverse wastewater volumes, but their construction and equipment costs make them better suited for moderate- to large-scale treatment.

Energy requirements

Energy requirements are relatively high due to water pumping, filtration and aeration. It has significantly smaller treatment unit footprint than AS technology.

Operation and maintenance

MBRs demand expert O&M, with potential challenges in sourcing construction and maintenance components such as membranes. While they produce less biomass than activated sludge, external providers are still needed for treatment.

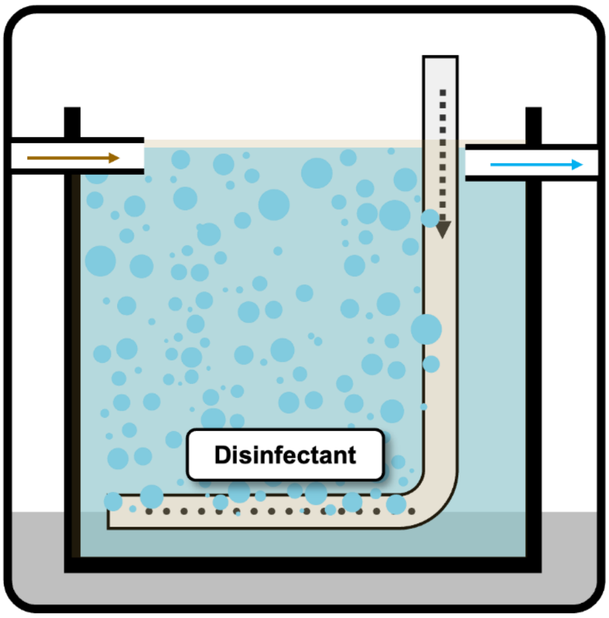
Expected associated costs

Costs reach moderate to high levels for construction and operation. However, in densely populated urban areas with constrained space and considerable wastewater volumes, economies of scale can result in advantageous cost-benefit scenarios.

Current status of the technology

MBRs represent an emerging technology that, despite being extensively researched and employed in diverse contexts, is still undergoing active research for operational optimization.

High removal of pollutants	**Compact system**	**Costs and availability of materials**	**Specialized skills required**	**Emerging technology**	**Advanced treatment**



SANITATION

Chemical flocculation and disinfection

Chemical flocculation before biological treatment enhances removal of some pharmaceuticals in subsequent stages. Chemical disinfection may not be effective for removing ARB, sometimes even increasing their concentration or generating harmful disinfection by-products if organics are present. Chemical disinfection is widely used.

Expected performance and outcomes

Chemical flocculation and disinfection serve as complementary treatment technologies that can effectively improve wastewater treatment performance when strategically applied, either as pre-treatment or polishing stages.

Technology scalability

Chemical flocculation and disinfection exhibit versatility in treating a wide range of wastewater volumes, from small to large.

Energy requirements

Energy demands are typically low to moderate, contingent upon the extent of energy-intensive mixing needed. The requirement can be minimal when hydraulic mixing is feasible.

Operation and maintenance

O&M demands are relatively high, involving frequent monitoring to ensure proper dosage and mixing. Effective management of chemical stock and supply is crucial, and the local availability of chemicals may pose a challenge. Inappropriate addition of chemicals can produce harmful by-products.

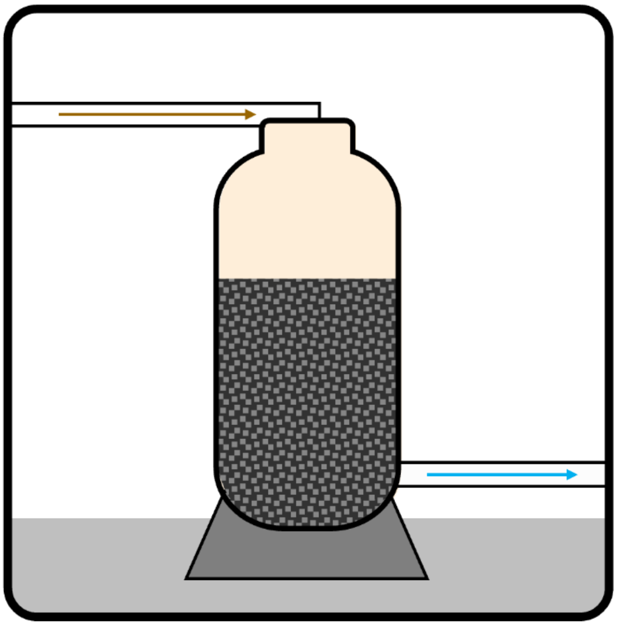
Expected associated costs

Costs can be relatively high, primarily in terms of operational expenses due to continuous reagent acquisition, which may involve costly imports. Despite this, favourable cost-benefit outcomes can be achieved by optimizing other treatment stages, thereby reducing the overall cost.

Current status of the technology

Chemical flocculation and disinfection are established techniques in water and wastewater treatment, necessitating expertise and specific reagents, not only for their operation but to integrate them appropriately with other treatment units.

Optimized treatment performance	**Flexible and tailored operation**	**Cost and availability of materials**	**Specialized skills required**	**Mature technology**	**Disinfection by-products possible**



SANITATION

Activated carbon adsorption

Activated carbon adsorption, using powder-activated carbon (PAC) or granular-activated carbon (GAC), effectively tackles a range of emerging contaminants. PAC is utilized as a pre-treatment or polishing treatment, GAC as a dedicated or tertiary treatment. Adsorption is a powerful complementary treatment for health-care effluents. PAC and GAC can achieve high removal of pharmaceuticals after conventional treatment. Material costs, maintenance and operation affect feasibility.

Expected performance and outcomes

Activated carbon is the principal adsorbent for eliminating emerging pollutants, employed either as a pre-treatment or polishing step. As a complementary treatment, it operates alongside other units and is effective in removing various emerging pollutants.

Technology scalability

Activated carbon can be employed across a spectrum of scales, featuring dedicated GAC units for larger operations and PAC for smaller units or on-demand uses.

Energy requirements

Energy requirements for activated carbon adsorption are generally not expected to be significant. However, since it operates as a complementary treatment, the overall energy demand may be higher depending on the combination of other technologies used.

Operation and maintenance

Operation is relatively straightforward, involving routine monitoring for GAC regeneration or replacement, or PAC dosing. Challenges can arise due to the non-availability of materials locally. It is a relatively compact treatment unit.

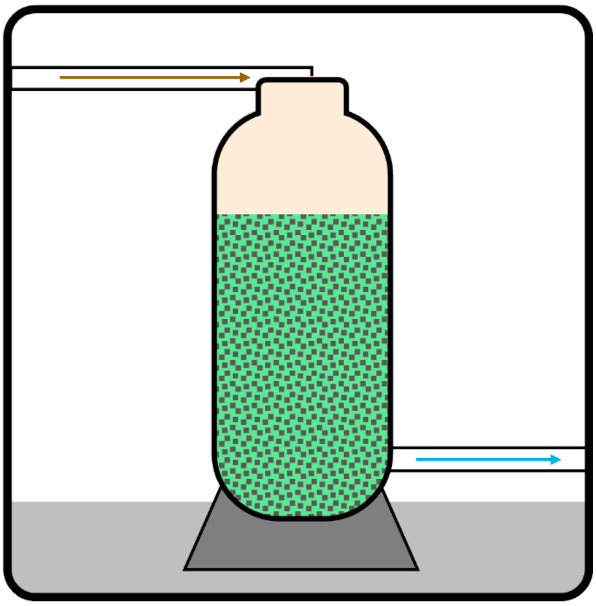
Expected associated costs

Costs may be relatively high, influenced by the local availability of materials. Due to its ability to enhance treatment performance, activated carbon utilization can lead to cost savings in the design and operation of other treatment units.

Current status of the technology

Activated carbon adsorption is a widely utilized treatment technique, with a broad array of global product suppliers offering various dosages and sizes.

Removal of persistent pollutants	**Compact or add-on system**	**Availability of materials**	**Operational costs**	**Well-established technology**	**Add-on treatment**



SANITATION

Zeolite adsorption

Metal-exchanged natural zeolites have emerged as a promising approach for removing recalcitrant compounds such as ARB, heavy metals and pharmaceuticals. Operations and design are still under active research. Zeolite adsorption is an advanced treatment that should be performed with other treatment units, requiring a depurated effluent for viable and economic operation.

Expected performance and outcomes

Zeolites are a promising technology for removal of ARB, heavy metals and pharmaceuticals, being used as a polishing treatment unit after a comprehensive treatment train.

Technology scalability

Zeolite adsorption is currently well suited for small- to medium-scale applications, with ongoing research focused on optimizing processes and enhancing scalability.

Energy requirements

Energy demands for zeolite adsorption are not anticipated to be high. However, as a highly purified effluent is necessary, preceding treatment units are expected to consume moderate to high energy.

Operation and maintenance

Optimal O&M, including zeolite regeneration, are still subjects of active research but are expected to be demanding, requiring expertise and possibly relying on reagents not readily available locally. It is a relatively compact treatment unit.

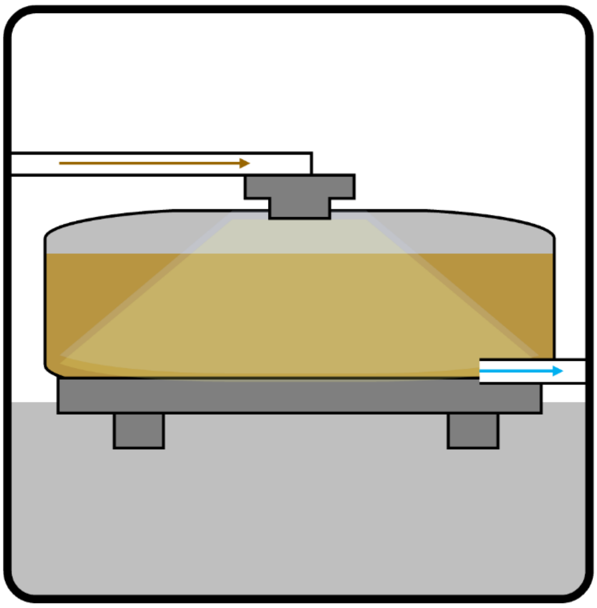
Expected associated costs

As an emerging technology, it is expected that costs will be high, especially for materials and expertise needed for system design, operation and maintenance.

Current status of the technology

Zeolite adsorption is an emerging technology in advanced wastewater treatment, currently undergoing active research. Expertise in designing, operating and maintaining such systems is still specialized.

High removal of persistent pollutants	**Compact system**	**Specific materials requirements**	**Highly specialized skills required**	**Emerging technology**	**Add-on treatment**



SANITATION

Advanced oxidation processes

Advanced oxidation processes (AOPs) are emerging tertiary wastewater treatments, including **ozonization**, **fenton**, **photo-fenton**, **photocatalysis** and **electrochemical** methods. AOPs generate powerful hydroxyl radicals, significantly removing emerging pollutants. AOPs have compact designs and minimal chemical dosing. AOPs are still under active research development, requiring skilled personnel and equipment.

Expected performance and outcomes

The effectiveness of AOPs varies based on wastewater and process type, but they excel in removing persistent compounds. Compact and complementary, they serve as pre-treatment or polishing units.

Technology scalability

AOPs are currently well-suited for small- to medium-scale applications, with ongoing research focused on optimizing processes and enhancing scalability.

Energy requirements

Energy demands for advanced oxidation processes are typically high, leading to a compact treatment unit footprint.

Operation and maintenance

O&M of advanced oxidation processes are intricate and currently under research, demanding highly specialized personnel. Parts and reagents for different AOPs remain niche and may not be accessible locally.

Expected associated costs

As an emerging technology, costs are anticipated to be high, particularly in terms of materials and expertise required for system design, operation and maintenance.

Current status of the technology

This emerging technology has been consistently recognized as the most promising for eliminating complex and persistent pollutants from water. Expertise in designing, building, operating and maintaining these systems remains highly specialized.

High removal of persistent pollutants	**Compact system**	**High energy and resources requirements**	**Highly specialized skills required**	**Emerging technology**	**Add-on treatment**

4 Management practices

Management practices can substantially improve water and sanitation services and decrease infrastructure requirements for safe water and sanitation in HCFs. In the context of water and sanitation technologies in HCFs, management practices include the ways in which systems are configured as well as the actions and behaviours of the people that use, manage and operate them.

WASH FIT (Water and Sanitation for Health Facility Improvement Tool), co-published by WHO and UNICEF (WHO and UNICEF, 2022), offers a practical framework to enhance WASH in HCFs, with emphasis on key management practices. This resource includes technical fact sheets to support activities that facility staff can undertake to improve the functioning of water and sanitation systems.

When selecting suitable technologies, besides the technology operation and maintenance requirements (previously covered in the decision-support framework on technology factors under “Operation and maintenance requirements”), there are three additional, specific and interrelated management practices that impact technology selection, since they influence technology requirements:

- wastewater source control, segregation and tailored treatment;
- wastewater reuse; and
- adequate maintenance and operation of water plumbing systems.

4.1 Wastewater source control, segregation and tailored treatment

Source control and separation can be an effective measure to significantly reduce the volume of wastewater generated in an HCF and mitigate the need to upgrade its on-site wastewater treatment plant.

Not all liquids should go down the drain together, and their segregation can facilitate their treatment. For instance, laboratory chemicals such as strong acids and bases can significantly alter the pH of wastewater, compromising biological processes downstream.

WHO has published a handbook for the safe management of wastes, including liquid wastes, from health-care activities, which sets out management strategies for minimization, reuse and recycling, and for segregation, storage and transport of wastes requiring specialized treatment (Chartier, 2014).

Another example is the segregation of urine from patients subjected to radioactive treatments, which is likely to have higher concentrations of radioactive compounds. The International Commission on Radiological Protection recommends its separation in several published guidelines on how to manage this type of wastewater. Implementation of urine-diverting toilets for those patients followed by appropriate storage, treatment and disposal is a valid alternative to minimize the impact of this source of pollution (Lecomte et al., 2019).

Wastewater segregation may allow tailored treatment for different wastewater effluent streams of different compositions. Blackwater, which refers to wastewater containing human waste from toilets, can be segregated and treated independently, reducing complexities in treatment. For instance, blackwater can be subjected to simplified preliminary and secondary treatment using a septic tank followed by a CW and thus be used for sub-superficial irrigation of gardens within the HCF perimeter.

In general, achieving source control and segregation of different streams requires early consideration in a technology selection process, since it impacts the choice of treatment technologies and design of plumbing systems within an HCF. In addition, once technologies are installed, it is critical to ensure that the appropriate IPC protocols are correctly applied during operation. For instance, if an unsuitable type of waste enters the incorrect stream, this may compromise system performance and potentially lead to its failure.

4.2 Wastewater reuse

Wastewater reuse can reduce pressure on water supplies, especially for non-potable applications like irrigation and flushing. Source segregation is essential to avoid health risks from reused water containing harmful compounds. Well-designed plumbing systems in HCFs can enable selective reuse with minimal treatment for less stringent purposes.

Greywater, originating from sinks, showers and laundry, may be able to undergo simplified treatment for non-drinking use within certain HCFs where potential risks are low. For instance, kitchen greywater can be treated via primary separation of fats before being used for garden irrigation. Another approach involves diverting sink water to toilets to reduce potable water demand for toilet flushing. However, if sink water is likely to contain infectious agents or other contaminants, this approach should be avoided, particularly if there is a risk of human contact with the water stream.

These solutions, among other factors, aim to reduce water demand and are commonly applied in water-scarce regions. However, incorporating this type of thinking into the technology selection and decision-making processes is not yet a common practice. Another common barrier is the lack of economic motivation for water conservation by applying these practices, particularly in areas with abundant, low-cost water. Retrofitting existing plumbing systems in HCFs can be economically impractical; introducing such practices in new facilities with a substantial non-potable water demand is likely to be more successful.

4.3 Adequate maintenance and operation of water plumbing systems

Proper maintenance and operation of plumbing systems may help minimize bacterial colonization and disease outbreaks within hospitals, and reduce wastage and inefficiencies. For instance, continuous flow within the plumbing system should be guaranteed since stagnant water in pipes fosters bacterial growth, which can turn into outbreaks in HCFs due to the higher risk of contamination and the presence of ARB (Ortolano et al., 2005; Cervia et al., 2008). Specific points in the plumbing system, such as dead-ends, heat exchangers and storage tanks, which may promote biofilm development, should receive special attention in routine maintenance regimes (Bartram et al., 2007). Legionella, in particular, is of concern in relation to improperly managed water systems, but there is guidance available to support appropriate practices (Bartram et al., 2007). Other pathogens of future importance include mycobacteria.

When microorganisms have become prevalent in the plumbing system, systematic disinfection to remove them may be required. Two common methods used are chemical disinfection and heat treatment, often in combination. Chemical disinfection, using chlorine-based compounds, effectively eliminates microbes, but can be costly and potentially corrode pipes. In hot water systems, superheating water to 71–77 degrees Celsius followed by flushing effectively eliminates most microorganisms (Le Dantec et al., 2002).

Adequate maintenance is also important to reduce water wastage and losses, not least in the context of climate change and increasing water shortages in many locations. Leaks from pipes, faucets and valves can be minimized through regular maintenance, and the use of water-efficient fixtures can also reduce water demand. HCFs should enlist the services of competent, trained plumbers to install and maintain plumbing systems and components.

5 Climate resilience

5.1 Impacts of climate change in water and sanitation systems

Climate change is leading to unpredictable weather patterns, including gradual and long-term changes and trends as well as sudden and extreme events, which can significantly affect the performance of water and sanitation systems in HCFs.

Gradual changes and trends encompass extended droughts, rising sea levels, saline intrusion in freshwater resources and increasing average temperatures, which may compromise the availability and quality of water resources.

Sudden extreme events such as storms, landslides, cyclones, heavy rainfall and flooding can damage infrastructure and compromise the operation of such systems, and lead to public health risks and environmental pollution. Furthermore, such extreme events may also compromise the supply chain of parts and services that are essential for the construction, operation and maintenance of water and sanitation systems.

Because of the increasing occurrence and magnitude of such trends and events, the capacity of technologies and surrounding management systems to cope with, adapt to and recover from hazards driven by climate change and return to normal functioning – also known as climate resilience – is a crucial factor for the long-term effectiveness of water and sanitation systems.

5.2 Assessing the climate resilience of water and sanitation technologies

Climate resilience, as previously described, refers to a system's ability to cope with, adapt to and recover from climate change-related trends and events. Since the impacts of climate change on weather patterns are uncertain (in terms of their frequency and severity) and context-specific, the technologies themselves cannot be said to possess an inherent, fixed level of climate resilience.

Instead, a thorough evaluation of a technology's suitability within a particular setting is necessary. This assessment should consider requirements for a given technology within the local context and its ability to withstand potential risks, the way in which it is constructed and housed, and changing conditions that are expected to affect the relevant water resources, supply chains and infrastructure.

A dedicated framework to assess the climate resilience and prioritization of WASH technologies in general (not specifically focused on unique HCF requirements) was proposed by Global Water Partnership (GWP) and UNICEF in the technical brief for WASH climate-resilient development, *Appraising and prioritising options for climate resilient WASH* (GWP and UNICEF, 2017). The framework encompasses eight criteria: effectiveness, efficiency, timing for implementation, uncertainty, capacity, equity, synergies and legitimacy.

The framework presented in this report incorporates climate resilience in several of the factors that are important in the technology selection process. The primary areas where climate resilience has been included are:

Site and environmental factors: All four factors referring to the natural environment include aspects related to climate change, since climate events and trends are likely to have an impact in this area:

- water resources availability and local climate (e.g. exposure and sensitivity to droughts and flooding);
- topography and soil (e.g. slope considerations and susceptibility to landslides);
- site water source characteristics (e.g. exposure and sensitivity to droughts and flooding); and
- disposal site characteristics (e.g. exposure and sensitivity to droughts and flooding).

Institutional factors: A dedicated factor focused on climate resilience has been included:

- public sector planning for climate change and disaster response (e.g. public sector systems for vulnerability and risk identification, budget allocation, and responsive protocols for climate change risks and disaster management).

Technological factors: A dedicated factor on climate resilience has been included, and aspects are considered in other factors:

- treatment performance (e.g. consideration of how relevant hazards may impact treatment performance);
- energy requirements (e.g. consideration of renewable energy sources to reduce emissions); and
- technology climate resilience (e.g. considering alterations in design and operation that can enhance resilience.

The subsections below provide further ideas on how technology design features and system management can address climate resilience.

5.2.1 Technological features

The interaction between the fundamental features and principles of a technology and the contextual factors in which it is deployed can influence its climate resilience. For instance, rainwater tanks that serve as an invaluable additional or backup water source for non-potable uses may be of low value in locations with long seasonal dry periods. Similarly, pit latrines and dry composting toilets are suitable for areas with limited water accessibility. Nonetheless, these solutions may be particularly vulnerable to flooding if safeguards are not in place.

Another example is the reliance on energy to operate the system, and the availability and robustness of renewable energy sources. Some advanced wastewater systems may rely heavily on electricity, but if robust and reliable renewable energy sources are in place, this might not be a limitation. In contrast, nature-based solutions such as CW are less reliant on external sources of energy and are therefore robust, but their performance may be affected by extreme weather events and take longer to recover.

5.2.2 Systems management and integration

Climate resilience is not determined solely by technological features; the way a technology is managed, operated and integrated plays a key role in shaping how water and sanitation systems cope with, adapt to and respond to climate events.

For instance, relying only on a centralized water supply system may entail lower operational and maintenance needs compared to on-site water supply systems, but could make an HCF vulnerable to water shortages during long droughts or if an important water pipe gets damaged. On the other hand, having a water supply system on-site means that the HCF needs to have response plans in place for critical circumstances. These include ensuring that enough spare parts and materials are readily available to fix system components if supply chains break down or parts become damaged. To do so, HCFs need trained staff who know how to design and implement these plans and to maintain the existing water and sanitation systems.

By incorporating interconnected plumbing systems that encourage the reuse of wastewater, HCFs can reduce their reliance on external water sources. This, in turn, enhances the facility’s ability to withstand water shortages. For example, repurposing greywater from handwashing sinks for toilet flushing and utilizing treated greywater from kitchens for irrigating gardens can significantly reduce the non-drinking-water demand within the HCF. This strategic management approach ensures that potable water is conserved and employed sensibly, particularly during water shortages, but also requires strong controls to ensure that any potential risks are minimized.

5.3 Strategies to increase the climate resilience of water and sanitation technologies

A technology's climate resilience can be enhanced by adjusting its design and operation to better manage, respond to and recover from climate-related risks. In practice, technological design should be risk-informed, so that a technology can continue to operate in the face of climate hazards and the impact of any damage minimized in the event of unavoidable failure. The ClimateFirst framework (UTS-ISF, 2023) outlines six types of design features aimed to increase a technology's capacity to withstand climate change hazards.

- **Avoiding exposure to hazards:** Design features such as raising, burying and ensuring portability of infrastructure may reduce the likelihood that critical components of the technology become directly exposed to a climate hazard. For instance, raised toilets can be less susceptible to flooding if the superstructure is robust.

- **Withstanding exposure to hazards:** Design features, such as armouring, oversizing and sealing, may enable the technology to resist a climate hazard and continue to operate normally (i.e. no hardware or operational change) even when exposed to climate hazards. For example, larger storage tanks may withstand extended periods of drought.

- **Enabling flexibility of operations:** Design features such as interoperable parts and modular components may enable the technology to be adapted or reconfigured to operate differently and continue providing services when exposed to climate hazards. For instance, in the event of a pump failure, being able to replace it with other compatible models instead of a specific one may allow continuous operation despite damage or supply chain shortage at the original manufacturer.

- **Containing failures:** Design features such as decentralization and frangibility may enable the technology to continue providing basic services and meet user needs despite damage to technology components caused by climate hazards. For example, multiple water sources may compensate for unavailability of the usual source during droughts or local pollution.

- **Limiting consequences of complete failure:** Design features such as reusable materials, system lockdown and safe disposal may minimize the negative health and environmental consequences of complete failure due to a climate hazard. For instance, latrines built with non-toxic materials that can be safely discarded if damaged during hazards, and containment units that lock down if the system is damaged, can protect the environment and public health during failures.

- **Facilitating fast recovery:** Design features such as repair speed and early-stage flaw detection may enable the system to be quickly rebuilt or restored if damaged, disrupted or destroyed by a climate hazard. For instance, technologies relying on locally available components and on-hand repair expertise can lead to faster recovery compared to those requiring less accessible materials and skills.

The climate resilience of water and sanitation technologies is only one of the many pillars that are required to ensure proper functioning of HCFs in the face of climate change-driven challenges. The *WHO guidance for climate-resilient and environmentally sustainable health care facilities* (WHO, 2020b) sets out a comprehensive list of interventions in four intervention categories: health workforce; water, sanitation and health-care waste; energy; and infrastructure, technology and products.

These interventions should be continuing improvement processes. They include assembling and training a multisectoral team, establishing a baseline, defining and prioritizing short- and long-term interventions, developing and implementing improvement plans, and monitoring and evaluating improvements.

Further contextualization and development of local tools should be developed to enhance climate resilience in HCFs. Two examples in the Pacific are the *National WASH in health care facilities assessment tool* (WinHK) developed in Vanuatu by the Vanuatu Department of Water Resources Drinking Water Safety (see

WASHinHCF.org, n.d.), and the *Guidelines for climate-resilient and environmentally sustainable health care facilities in Fiji* (Fiji Ministry of Health and Medical Services, 2020).

6 References

Allegranzi B, Nejad SB, Combescure C, Graafmans W, Attar H, Donaldson L et al. (2011). Burden of endemic health-care-associated infection in developing countries: systematic review and meta-analysis. Lancet. 377(9761):228–41.

Bartram J, Chartier Y, Lee JV, Pond K, Surman-Lee S (2007). Legionella and the prevention of legionellosis. Geneva: WHO (https://www.who.int/publications/i/item/9241562978, accessed 21 November 2023).

Cervia JS, Ortolano GA, Canonica FP (2008). Hospital tap water as a source of Stenotrophomonas maltophilia infection. Clin Infect Dis. 46(9):1485–87.

Chaitkin M, McCormick S, Torreano JAS, Amongin I, Gaya S, Hanssen ON et al. (2022). Estimating the cost of achieving basic water, sanitation, hygiene, and waste management services in public health-care facilities in the 46 UN designated least-developed countries: a modelling study. Lancet Glob Health. 10(6):e840–9.

Chartier Y, Emmanuel J, Pieper U, Prüss A, Rushbrook P, Stringer R, William T et al., editors (2014). Safe management of wastes from health-care activities. 2nd edition. Geneva: World Health Organization.

The Council of the European Communities (1991). Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. Strasbourg: Council of the European Union (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31991L0271, accessed 7 March 2024).

D'Alessandro D, Tedesco P, Rebecchi A, Capolongo S (2016). Water use and water saving in Italian hospitals. A preliminary investigation. Ann Ist Super Sanita. 52(1):56–62.

Dolnicar S, Schäfer AI (2009). Desalinated versus recycled water: public perceptions and profiles of the accepters. J Environ Manage. 2009;90(2):888–900.

EAWAG (2014). Compendium of sanitation systems and technologies, 2nd ed. Dübendorf: Eawag Department Sandec (https://www.iwa-network.org/wp-content/uploads/2016/06/Compendium-Sanitation-Systems-and-Technologies.pdf, accessed 21 November 2023).

European Parliament, Council of the European Union (2008). Directive 2008/98/EC of the European Parliament and of the Council on 19 November 2008 on waste and repealing certain Directives. Strasbourg: European Parliament (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0098, accessed 7 March 2024).

Fiji Ministry of Health and Medical Services (2020). Guidelines for climate-resilient and environmentally sustainable health care facilities in Fiji. Suva: Fiji Ministry of Health and Medical Services (https://www.washinhcf.org/wp-content/uploads/gravity_forms/3-5eba63e8ea32857d39ea8110a786b7ee/2021/11/Guide-for-CRESHCF.pdf, accessed 21 November 2023).

Fu H, Niu J, Wu Z, Xue P, Sun M, Zhu H, et al. (2022). Influencing factors of stereotypes on wastewater treatment plants − case study of 9 wastewater treatment plants in Xi'an, China. Environ Manage. 70(3):526–35.

GWP, UNICEF (2017). Appraising and prioritising options for climate resilient WASH – technical brief. In: WASH Climate Resilient Development (https://www.gwp.org/globalassets/global/about-gwp/publications/unicef-gwp/learning-modules/session_3_identify_and_appraise_options.pdf, accessed 21 November 2023).

Kaminsky J, Kumpel E (2018). Dry pipes: associations between utility performance and intermittent piped water supply in low and middle income countries. Water. 10(8):1032.

Khan MT, Shah IA, Ihsanullah I, Naushad M, Ali S, Shah SHA et al. (2021). Hospital wastewater as a source of environmental contamination: an overview of management practices, environmental risks, and treatment processes. J Water Process Eng. 41:101990.

Kumpel E, Nelson KL (2016). Intermittent water supply: prevalence, practice, and microbial water quality. Environ Sci Technol. 50(2):542–53.

Le Dantec C, Duguet JP, Montiel A, Dumoutier N, Dubrou S, Vincent V (2002). Chlorine disinfection of atypical mycobacteria isolated from a water distribution system. Appl Environ Microbiol. 68(3):1025–32.

Lecomte JF, Shaw P, Liland M, Markkanen M, Egidi P, Andresz S et al. (2019). ICRP publication 142: radiological protection from naturally occurring radioactive material (NORM) in industrial processes. Ann ICRP. 48(4):5–67.

Republic of Italy (2006). Legislative Decree No. 152/2006 approving the Code on the Environment. Rome: Goverment of Italy.

Netherlands Water Partnership (2004). Smart water solutions: examples of innovative, low-cost technologies for wells, pumps, storage, irrigation and water treatment. The Hague: NWP (https://ec.europa.eu/echo/files/evaluation/watsan2005/annex_files/NWP/NWP1%20-%20Smart%20Water%20Solutions.pdf, accessed 21 November 2023).

Ortolano, GA, McAlister MB, Angelbeck JA, Schaffer J, Russell RL et al. (2005). Hospital water point-of-use filtration: a complementary strategy to reduce the risk of nosocomial infection. Am J Infect Control. 33(5):S1–19.

Oza S, Lawn JE, Hogan DR, Mathers C, Cousens SN (2015). Neonatal cause-of-death estimates for the early and late neonatal periods for 194 countries: 2000–2013. Bull World Health Organ. 93:19–28.

Pierce G, Gonzalez S (2017). Mistrust at the tap? Factors contributing to public drinking water (mis) perception across US households. Water Policy. 19(1):1–12.

Rodriguez-Mozaz S, Chamorro S, Marti E, Huerta B, Gros M, Sànchez-Melsió A et al. (2015). Occurrence of antibiotics and antibiotic resistance genes in hospital and urban wastewaters and their impact on the receiving river. Water Res. 69:234–42.

Socialist Republic of Viet Nam (2014). Article 72. Environmental protection in hospitals and medical facilities. In: Law on Environmental Protection No. 55/2014/QH13. Hanoi: The National Assembly.

UTS-ISF (2023). ClimateFIRST: Climate framework to improve the resilience of sanitation technologies: summary note. NSW: Institute for Sustainable Futures (https://www.uts.edu.au/isf/explore-research/projects/climate-resilient-urban-sanitation/climatefirst-outputs, accessed 21 November 2023).

Verlicchi P, Galletti A, Petrovic M, Barceló D (2010). Hospital effluents as a source of emerging pollutants: an overview of micropollutants and sustainable treatment options. J Hydrol. 389(3−4):416–428.

WASH in HCF.org (n.d.). WASH in Heltkea Fasiliti Plan. WASH in Health Care Facilities (https://www.washinhcf.org/story/integrating-disaster-risk-reduction-and-climate-change-adaptation-in-wash-in-healthcare-assessment-and-planning/, accessed 21 November 2023).

Water & Sanitation Rotarian Action Group (2012). Guidelines to planning sustainable water projects and selecting appropriate technologies. Spring Lake: WASRAG (http://transforminternational.org/wp-content/uploads/2016/11/Guidelines_Water_Sept2012sm.pdf, accessed 21 November 2023).

World Health Organization (2008). Essential environmental health standards in health care. Geneva: WHO (https://www.who.int/publications/i/item/9789241547239, accessed 12 November 2023).

World Health Organization (2018). Guidelines on sanitation and health. Geneva: WHO (https://www.who.int/publications/i/item/9789241514705, accessed 21 November 2023).

World Health Organization (2020). WHO guidance for climate-resilient and environmentally sustainable health care facilities. Geneva: WHO (https://www.who.int/publications/i/item/9789240012226, accessed 21 November 2023).

World Health Organization, UNICEF (2019). Water, sanitation and hygiene in health care facilities: practical steps to achieve universal access to quality care. Geneva: WHO (https://www.unicef.org/media/51591/file/WASH-in-health-care-facilities-practical-steps-2019%20.pdf, accessed 21 November 2023).

World Health Organization, UNICEF (2020). Global progress report on water, sanitation and hygiene in health care facilities: Fundamentals first. Geneva: WHO (https://iris.who.int/bitstream/handle/10665/337604/9789240017542-eng.pdf, accessed 26 November 2023).

World Health Organization, UNICEF (2022). WASH FIT: A practical guide for improving quality of care through water, sanitation and hygiene in health care facilities. Second edition. Geneva: WHO (https://www.who.int/publications/i/item/9789240043237, accessed 21 November 2023).

World Health Organization, UNICEF (2023). Water, sanitation, hygiene, waste and electricity services in health care facilities: progress on the fundamentals. Geneva: WHO (https://www.who.int/publications/i/item/9789240075085, accessed 21 November 2023).

Annex. Decision-support framework assessment

The table below serves to document the responses from the assessment group conducting the technology selection process. It is suggested that the assessment group include both health sector staff as well as water and sanitation experts. It is likely that a series of meetings will be required to conduct the assessment process, and that various data will be required to support the decision-making process.

Group	Factors	Assessment group responses to question prompts
Site and environmental factors **(health-care facility level)** 	Health-care facility type (e.g. size, services)	
	Health-care facility water requirements	
	Health-care facility wastewater composition and volume	
	Health-care facility plumbing design	
	Health-care facility liquid waste management	
Site and environmental factors (surrounding human environment) 	Location type (e.g. urban, rural, remote, etc.)	
	External infrastructure availability (e.g. piped water, sewer lines, faecal sludge treatment facilities)	

Site and environmental factors (surrounding natural environment) 	Water resources availability and local climate	
	Topography and soil	
	Site water source characteristics	
	Disposal site characteristics	
Institutional factors 	Standards, guidelines and regulations	
	Public sector investment capacity	
	Public sector human resources capacity and expertise	
	Public sector planning for climate change and disaster response	
	Private sector capacity and expertise	

Technology factors	Treatment performance	
	Construction requirements	
	Operation and maintenance requirements	
	Energy requirements	
	Technology climate resilience	
	Sociocultural acceptance and technology inclusivity