GREEN CLIMATE FUND | Sectoral Guides

Annex III | Water Security Sectoral Guide

GCF Water Project Design Guidelines

Part 3: Practical guidelines for designing climate-resilient sanitation projects

Acknowledgements
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Contents

Abbreviations

AE	Accredited Entity
CRS	Climate-resilient Sanitation
CSO	Civil Society Organisation
DAE	Direct Access Entity
GCF	Green Climate Fund
GEDSI	Gender Equality, Disability and Social Inclusion
GHG	Greenhouse Gas
IAE	International Access Entity
ILK	Indigenous and Local Knowledge
IWRM	Integrated Water Resource Management
NAP	National Adaptation Plan
NDA	National Designated Authority
NDC	National Determined Contribution
SDG	Sustainable Development Goal
WASH	Water, Sanitation and Hygiene

Glossary

Term	Description
Adaptation	Adaptation is any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities.
Climate-resilient sanitation	Refers to sanitation systems (both non-sewered and sewered), services and behaviours which can survive, function or quickly recover in the face of a range of climate-related shocks, chronic stresses and seasonal variabilities, ensuring that faecal matter is safely contained throughout the sanitation service chain and does not contaminate the environment, emit excessive greenhouse gases or cause risk to public health. Ideally, climate-resilient sanitation both adapts to climate change and mitigates contributions to climate change simultaneously.
Container-based sanitation	A sanitation service in which excreta is captured in sealable containers that are then transported to treatment facilities.
Containment	Describes the ways of collecting, storing, and sometimes treating the products generated at the toilet (or user interface).
Conveyance	The transport of products from either the toilet or containment step to the treatment step of the sanitation service chain. For example, where sewer-based technologies transport wastewater from toilets to wastewater treatment plants.
End use / disposal	The methods by which products are ultimately returned to the environment as reduced-risk materials and/or used in resource recovery.
Exposure	The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.
Faecal sludge	Solid and liquid wastes removed from on-site storage containers, also called septage when removed from septic tanks.
Greywater	The total volume of water generated from the household, but not from toilets.
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.
Mitigation	Reducing the flow of heat-trapping greenhouse gases into the atmosphere, either by reducing sources of these gases or enhancing the “sinks” that accumulate and store these gases.

On-site sanitation	A sanitation technology or system in which excreta (referred to as faecal sludge) is collected and stored and emptied from or treated on the plot where they are generated.
Resilience	The capacity for a socio-ecological system to: (1) absorb stresses and maintain function in the face of external stresses imposed upon it (e.g., by climate change), and (2) adapt, reorganise, and evolve into more desirable configurations that improve the sustainability of the system, leaving it better prepared for future (climate change) stresses.
Risk	The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change.
Sanitation service chain	All components and processes comprising a sanitation system, from toilet capture and containment through emptying, transport, treatment (in-situ or off-site) and final disposal or end use.
Sanitation system	A context specific series of sanitation technologies (and services) for the management of faecal sludge and/or wastewater through the stages of containment, emptying, transport, treatment and end use/disposal.
Sanitation worker	All people (employed or otherwise) responsible for cleaning, maintaining, operating or emptying a sanitation technology at any step of the sanitation chain.
Sewer	An underground pipe that transports blackwater, greywater and, in some cases, stormwater (combined sewer) from individual households and other users to treatment plants, using gravity or pumps when necessary.
Sewage	Wastewater that is transported through the sewer.
Sewerage	The physical sewer infrastructure for conveyance and treatment of sewage.
Stormwater	The general term for the rainfall runoff collected from roofs, roads and other surfaces before flowing towards low-lying land. It is the portion of rainfall that does not infiltrate into the soil.
Toilet	The user interface with the sanitation system, where excreta is captured; can incorporate any type of toilet seat or latrine slab, pedestal, pan or urinal. There are several types of toilet, for example pour- and cisternflush toilets, dry toilets and urine-diverting toilets.
Treatment	Process/es that changes the physical, chemical and biological characteristic or composition of faecal sludge or wastewater so that it is converted into a product that is safe for end use or disposal.

Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
Wastewater	Used water from any combination of domestic (households and services) industrial, stormwater and any sewer inflow/infiltration.

Executive summary

Purpose of this document

The Green Climate Fund (GCF) is the world's largest dedicated fund helping developing countries respond to climate change. GCF have developed a series of Sectoral Guides to provide evidence-based information for impactful projects in priority investment areas and to support the efficient and effective delivery of GCF projects and operations.

This Annex provides practical guidelines for developing projects and programmes that address the climate crisis through **climate-resilient sanitation (CRS)** solutions, in line with GCF's strategy and mandate. The Annex complements the **GCF Water Security Sectoral Guide** that describes the position and ambitions of GCF's investment in the water sector, as well as the financial mechanisms and implementation arrangements that GCF is willing to support. The GCF Water Security Sectoral Guide consist of three parts:

- **Annex 1** - ***Practical guidelines for designing water-climate-resilient projects***[1] provides generic practical guidelines and a step wise approach for project design that meets GCF requirements.
- **Annex 2** - ***Applications of the Practical guidelines for designing water-climate-resilient projects in IWRM, CR-WASH, and Drought and Flood management***[2] provides context and guidance for when applying the guidelines to specific Integrated Water Resource Management (IWRM) projects and water sub-sectors as identified by GCF Climate-resilient (CR) WASH, Drought Management and Flood Management.
- **Annex 3** - ***Practical guidelines for designing climate-resilient sanitation projects*** (the current document) provides additional, specific, context and guidance for applying the guidelines to CRS, which is inclusive of both adaptation and mitigation components.

Why this Annex is needed

The world is off track towards achieving the sanitation and wastewater SDG targets by 2030. About 43% of the global population are without access to a safely managed sanitation service (Target 6.2)[3], while only 56% of household wastewater flows are safely treated (Target 6.3).[4] The sanitation crisis has a profound impact on public health, human rights, economic productivity, and environmental integrity. This crisis is now being exacerbated by the impact of climate change on sanitation infrastructure and services.

The linkages between climate change and sanitation are increasingly being recognized. Climate change is damaging sanitation systems, disrupting services and contaminating the environment through floods, sea-level rise, drought, intense storms and extreme temperatures. The impact is greatest on the poorest and most marginalized communities, who often reside in disaster-prone areas, heightening the inequalities in access to safely managed sanitation services. Additionally, poorly managed sanitation is a significant greenhouse gas (GHG) emitter. Emissions from sanitation systems are often underestimated,

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[1] https://www.greenclimate.fund/sites/default/files/document/gcf-water-sector-project-design-guidelines-part-1-feb-20_0.pdf

[2] https://www.greenclimate.fund/sites/default/files/document/gcf-water-sector-project-design-guidelines-part-2-feb-20_0.pdf

[3] Progress on household drinking water, sanitation and hygiene 2000–2022: special focus on gender. New York: United Nations Children's Fund (UNICEF) and World Health Organization (WHO), 2023. https://washdata.org/reports/jmp-2023-wash-households

[4] https://www.unwater.org/publications/progress-wastewater-treatment-2021-update

and global estimates do not always consider the non-sewered sanitation systems which are prevalent in rapidly growing cities in low-and middle-income countries.[5]

Delivered effectively, climate-resilient sanitation helps to build resilience - of the sanitation systems themselves and of communities more broadly. In addition to significant opportunities for climate mitigation and adaptation within the sanitation sector, sanitation offers unique co-benefits with other sectors, including water supply (wastewater re-use, for example, has potential to help alleviate water scarcity)[6], agriculture and safe food production[7] (through water and nutrient re-use), marine and freshwater environment protection, and energy production.

However, these opportunities are not yet properly understood or adequately represented in national policy and strategy documents for climate change, such as Nationally Determined Contributions (NDCs), National Adaptation Plans (NAPs), Climate Action Plans, Nationally Appropriate Mitigation Actions and Methane Action Plans.[8] This contributes towards, and is compounded by, the underfunding of sanitation at all levels: for example, of US$ 5 billion invested by the GCF as of 2020, only $1.24 million was directed towards sanitation.

The neglect of sanitation represents a missed opportunity. The co-benefits of adaptation and mitigation of sanitation systems, which this Annex aims to support, are much needed to achieve the kind of transformative adaptation demanded by the IPCC 6th Assessment report on impacts, adaptation and vulnerability.[9]

The target audience for this Annex

The Annex is designed to be useful to any organisation interested in accessing GCF funding for climate-resilient sanitation projects. This includes Direct Access Entities (DAE) at the national levels, who co-originate projects with the National Designated Authorities (NDA); International Access Entities (IAE); Accredited Entities (AE), who work alongside countries to develop project ideas and submit funding proposals to GCF; and other entities interested to access climate finance for sanitation.[10]

GCF's approach towards and ambitions for climate-resilient sanitation

GCF considers that a sanitation system protects and promotes human health by providing a clean environment and breaking the cycle of disease. The sanitation system encompasses relevant institutional actors such as ministries, regulators and service authorities; the users; and the infrastructure and service providers required for the collection, transport, treatment and management of end products of human excreta, wastewater, solid waste and stormwater. Sanitation systems should be resilient to the impacts of climate change, such as increased rainfall, flooding, or droughts. This means systems should be designed to function effectively under varying climatic conditions and be adaptable to future changes.

[5] Lambiasi, L., Ddiba, D., Andersson, K., Parvage, M., & Dickin, S. (2024). Greenhouse gas emissions from sanitation and wastewater management systems: a review. Journal of Water and Climate Change. https://doi.org/10.2166/wcc.2024.603.

[6] Rodriguez, D.J., Serrano, H.A., Delgado, A., Nolasco, D. and Saltiel, G. 2020. From Waste to Resource: Shifting paradigms for smarter wastewater interventions in Latin America and the Caribbean. Washington, DC.: The World Bank.

[7] ACS EST Water 2024, 4, 4, 1166–1176 https://doi.org/10.1021/acsestwater.3c00803

[8] Dickin, S., Bayoumi, M., Giné, R., Andersson, K. and Jiménez, A. (2020). Sustainable sanitation and gaps in global climate policy and financing. Npj Clean Water, 3(1). 1–7. DOI: 10.1038/s41545-020-0072-8

[9] https://unfccc.int/sites/default/files/resource/FINAL_IPCCContribution_GGA_5thWorkshop_IPCC.pdf

[10] Accredited Entities can be private or public, non-governmental, sub-national, national, regional or international, as long as they meet the standards of the Fund.

GCF's envisioned paradigm shift for climate-resilient sanitation (CRS) is that: *Transformative sanitation planning and programming for climate-resilient sanitation is applied in national and regional adaptation and mitigation planning and programming.* The Annex will support the realisation of this paradigm shift, alongside the overall vision of GCF to promote transformational planning and programming; catalyse climate innovation; mobilize financing at scale; and promote coalitions and knowledge to scale up success.

In line with IPCC approach to climate-resilient development, CRS includes integrated consideration of:

- **Adaptation**: *reducing the impacts of climate change on sanitation service delivery and leveraging opportunities*. Sanitation systems are at risk of destruction or disruption from a range of climate hazards. The Annex provides guidance on conducting risk assessments, grounded in the risk approach advocated in the GWP/UNICEF strategic framework – described in the Water Sector Guidelines Annex 1 – and in the WHO Sanitation Safety Planning Manual (2022); and provides guidance on operational responses and systems strengthening interventions that can support effective adaptation.

- **Mitigation**: *reducing the contribution of sanitation to climate change.* The Annex summarises the climate science and provides guidance on reducing emissions which arise within sanitation infrastructure and services when they are operated as designed; reducing emissions which are associated with sanitation failures and with discharge of incompletely stabilised faecal waste into the environment; reducing emissions from appropriately designed and operated wastewater treatment plants; and leveraging the substitution potential of products from sanitation systems to reduce emissions.

Five specific strategies have been identified as key to the realisation of GCF's vision for climate-resilient sanitation. The Strategies broadly align with the Sanitation and Water for All building blocks, while also building on the two paradigm-shifting pathways in the GCF Water Security Guidelines[11], and the interlinkages between sanitation, wastewater treatment and other sectors. Strategies 1 and 2 should be conceived of as the key outcomes of climate-resilient sanitation activities. Strategies 3-5 are conceived of as key enablers required to delivered these outcomes.

Outcomes

1. **Climate-resilient infrastructure and services**: invest in building new and upgrading existing sanitation infrastructure, to achieve synergies between adaptation and mitigation, and to withstand climate-related impacts along the whole sanitation chain — including (but not limited to) flood-resistant sanitation systems, decentralized climate-resilient sanitation (including wastewater treatment), and the adoption of sustainable sanitation technologies.
2. **Circular economy and integrated management**: promote projects that integrate sanitation with broader water, food and energy security, ensuring ecosystem protection. This includes practices like water recycling and the safe reuse of wastewater and faecal sludge for agriculture. In urban contexts, infrastructure and services should be integrated with water supply and stormwater management, including greywater management.

[11] **Pathway 1:** enhance water conservation, water efficiency and water re-use; **Pathway 2:** Strengthen integrated water resources management – protection from water-related disasters, preserve water resources and enhanced resilient water supply and sanitation service

Enablers

3. **Community engagement and capacity building**: alongside capacity development support to service providers, empower local communities through understanding of climate risks, and training and involvement in the planning, maintenance and accountability of resilient sanitation systems. This ensures the sustainability and resilience of projects by leveraging local knowledge and fostering ownership.
4. **Policy, regulatory and governance support**: assist governments in developing and implementing policies that promote climate-resilient sanitation services and practices. This includes creating regulatory frameworks that encourage private sector investment and public-private partnerships.
5. **Monitoring and evaluation**: Implement robust systems for: operational monitoring of climate-resilient sanitation; evaluating the impacts of climate change on sanitation; and evaluating the impacts of climate-resilient sanitation projects on community resilience and the resilience of the environment. Use data to continually improve and adapt strategies.

Developing a sanitation proposal for GCF

The document provides specific step-by-step basis for the development of sanitation proposals to GCF (**Figure E1**), which will additionally be assessed taking into account articulation of the climate science basis and rationale for the project; and alignment with the overall GCF investment criteria:

- Impact potential
- Paradigm shift potential
- Sustainable development potential
- Needs of the recipient
- Country ownership
- Efficiency and effectiveness

Box E1: Summary of key points for developing a successful sanitation proposal to GCF.

To be successful, sanitation proposals to GCF must have a clear climate rationale and must display a level of ambition consistent with GCF's envisioned paradigm shift for climate-resilient sanitation. Successful proposals must achieve the following:

- Effective articulation of the climate science basis and rationale for the project
- Alignment with overall GCF investment criteria
- Alignment with GCF key strategies for climate-resilient sanitation

Structure of this document

The document is structured to provide overarching guidance to inform the content of CRS proposals to GCF, in line with the key points summarised in **Box E1.**

- **Section 1** provides introductory context on the sanitation crisis and GCF's approach to climate-resilient sanitation;

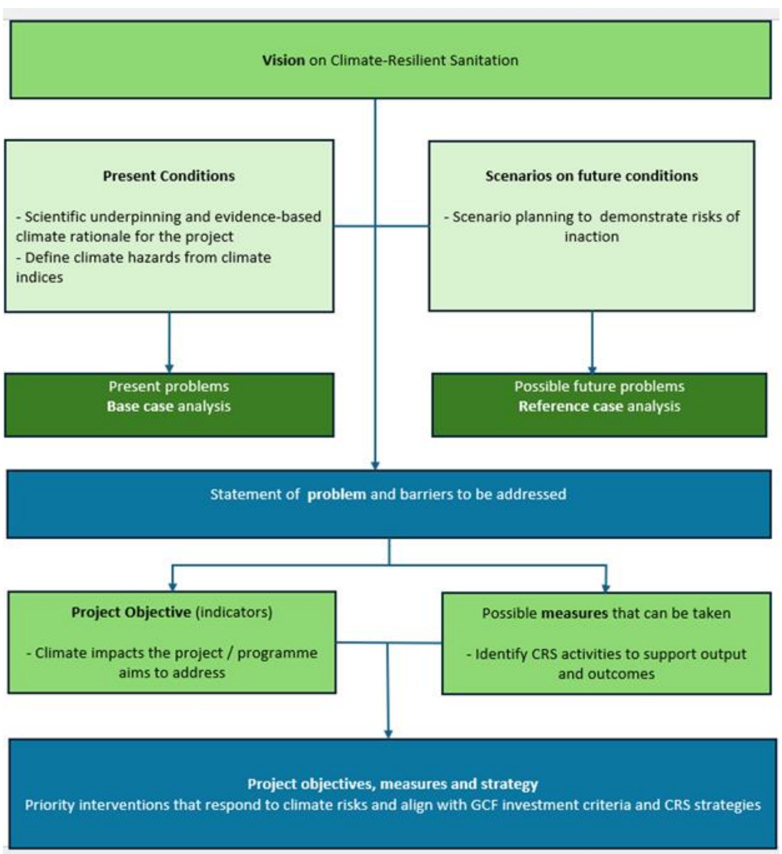
- **Section 2** provides the climate science basis and rationale for the adaptation component of climate-resilient sanitation projects and programmes. It sets out the known risks posed by climate change to sanitation systems; and provides guidance for assessing climate risks to sanitation, looking at hazards, exposure and vulnerability.

- **Section 3** provides the climate science basis and rationale for the mitigation component of climate-resilient sanitation projects and programmes. It sets out the known linkages between sanitation and greenhouse gas emissions, and provides guidance on how these can be assessed.

- **Section 4** provides guidance on the specific interventions that can be included within climate-resilient sanitation projects and programmes to support A) adaptation, relating both to infrastructure adaptations and how these can be enabled; and B) mitigation.

- **Section 5** summarises the content-related and procedural guidance for developing a GCF proposal on climate-resilient sanitation and the specific requirements that need to be met.

Figure E1: Steps in the development of sanitation project proposals to GCF.



1. Introduction

This introductory Section:
- Explains how this Annex relates to the GCF Water Security Sectoral Guide, and who the Annex is aimed at;
- Provides important context on the status of sanitation globally, the impacts of the sanitation deficit, including on human health, and how the crisis is being exacerbated by climate change;
- Introduces the concept of climate-resilient sanitation and outlines GCF's approach and ambitions in this area;
- Introduces overall GCF investment criteria;
- Introduces key strategies for inclusion in climate-resilient sanitation proposals to GCF; and
- Outlines the structure of this document.

This document provides practical guidelines for developing projects and programmes that address the climate crisis through climate-resilient sanitation (CRS) solutions, in line with GCF's strategy and mandate. This approach falls within GCF's goal statement for water security: "GCF promotes a paradigm shift in water security that is low-carbon, resilient to climate change, and meets the goals of the UNFCCC and Paris Agreement," which is inclusive of sanitation.

This Annex complements the Water Security Sectoral Guide that describes the position and ambitions of GCF's investment in the water sector, as well as the financial mechanisms and implementation arrangements that GCF is willing to support.

1.1 How this Annex relates to the GCF Water Security Sectoral Guide

The GCF Water Security Sectoral Guide consist of three parts:

- **Annex 1** - ***Practical guidelines for designing water-climate-resilient projects*** provides generic practical guidelines and a step wise approach for project design that meets GCF requirements.[12]
- **Annex 2** - ***Applications of the Practical guidelines for designing water-climate-resilient projects in IWRM, CR-WASH, and Drought and Flood management***[13] provides context and guidance for when applying the guidelines to specific Integrated Water Resource Management (IWRM) projects and water sub-sectors as identified by GCF Climate-resilient (CR) WASH, Drought Management and Flood Management.
- **Annex 3** - ***Practical guidelines for designing climate-resilient sanitation projects*** (the current document) provides additional, specific, context and guidance for applying the guidelines to CRS, which is inclusive of both adaptation and mitigation components.

[12] https://www.greenclimate.fund/sites/default/files/document/gcf-water-sector-project-design-guidelines-part-1-feb-20_0.pdf

[13] https://www.greenclimate.fund/sites/default/files/document/gcf-water-sector-project-design-guidelines-part-2-feb-20_0.pdf

Annex 3 aligns with and expands upon the Water Security Sectoral Guide's two major pathways for paradigm shifts:

- **Pathway 1: Enhance water conservation, water efficiency and water reuse** — including through (for example) demand management, resilient digital water management, decentralized operation models and resource recovery.
- **Pathway 2: Strengthen integrated water resources management** – including protection from water-related disasters, preservation of water resources, and provision of resilient water supply and sanitation services, through (for example) ecosystem-based management, alternative water sources and IWRM.

While the Water Security Sectoral Guide describes **what** is to be achieved, this Annex translates the sanitation component of the Guide into **how** projects can be designed to be suitable for GCF finance, because they meet GCF's investment criteria and deliver results in GCF's result areas.

1.2 The target audience for this Annex

The Annex is designed to be useful to any organisation interested in accessing GCF funding for climate-resilient sanitation projects. This includes Direct Access Entities (DAE) at the national levels, who co-originate projects with the National Designated Authorities (NDA); International Access Entities (IAE); and Accredited Entities (AE), who work alongside countries to develop project ideas and submit funding proposals to GCF.[14]

1.3 Introduction: the status of sanitation globally

The sanitation crisis is widespread and the world is off-track to achieve the sanitation and wastewater SDG targets. The most recent reports note as much as 43% of the global population is without access to a safely managed sanitation service (Target 6.2)[15], and only 56% of household wastewater flows are safely treated (Target 6.3).[16] This creates critical environmental and human health threats, particularly in low- and middle-income country contexts, and denies the many opportunities for sanitation-related value generation.

Sanitation services are not just about infrastructure, particularly when it comes to onsite sanitation services, which have become the most prevalent service model globally - between 2000 and 2022 six times as many households gained access to a septic tank compared to households gaining a new sewer connection.[17] Rather, sanitation services entail prevention of human contact with faecal waste the whole way along the sanitation chain, from the user interface (the toilet), to the containment system, conveyance by road or pipes and treatment, and re-use or disposal; and include a range of service providers including households themselves, masons, emptiers, and treatment plant operators.

If the sanitation chain is poorly managed, the result is health risks including water- and excreta-related diseases, spread of antimicrobial resistance, lost dignity and privacy, environmental pollution, greenhouse gas emissions and reduced overall societal resilience to climate change. These impacts are

[14] Accredited Entities can be private or public, non-governmental, sub-national, national, regional or international, as long as they meet the standards of the Fund.

[15] Progress on household drinking water, sanitation and hygiene 2000–2022: special focus on gender. New York: United Nations Children's Fund (UNICEF) and World Health Organization (WHO), 2023. https://washdata.org/reports/jmp-2023-wash-households

[16] https://www.unwater.org/publications/progress-wastewater-treatment-2021-update

[17] UNICEF and WHO. Progress on Household Drinking Water, Sanitation and Hygiene 2000 - 2022. United Nations Children's Fund (UNICEF) and World Health Organization (WHO); 2023.

explored further in **Section 1.4** below. Inadequate sanitation also results in missed opportunities for co-benefits in water scarcity (renewal of a scarce resource), agriculture and safe food production (water and nutrient re-use), marine and freshwater environment protection, energy production and other areas.

These co-benefits of proactive management of sanitation and wastewater mean that sanitation should be included within climate financing investments in areas such as water supply, health, agriculture, and coastal protection, as well as stand-alone investments with sanitation and wastewater at their core.

1.4 Sanitation, the climate crisis, and health

The global sanitation deficit exerts a huge negative impact on human health, wellbeing and economic progress and resilience. Sanitation is both a human right and a public good for which cost-effective benefits of investment accrue across a variety of health, environment and economic outcomes[18]. The lack of safely managed sanitation undermines progress on a range of health targets under SDG 3, in particular SDG 3.9 on substantially reducing the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.

Globally, 560,000 deaths annually are attributable to poor sanitation services, largely from diarrheal disease, and 1.7 billion people have faecally contaminated drinking-water.[19] However, these figures underestimate the full health impact of poor sanitation, because methods don't capture the health impacts of untreated wastewater on communities downstream using water sources for drinking, food production or recreation; do not estimate the burden of other diseases and risks such as vector-borne diseases, antimicrobial resistance and chemical pollution; and do not account for impacts on mental health, safety, wellbeing and access to education and economic opportunity, particularly for adolescent girls and women (**Figure 1.1**).

The additional burden of disease associated with climate change is uncertain, due to the variability of climate scenarios and the mediating effect of societal responses[20]. However, unless systems are made climate-resilient, climate change is likely to slow, undermine or reverse progress on access. By extension, progress on the elimination and control of water- and sanitation-related disease will also be slowed or undermined by climate change. Past estimates of changes in disease due to climate change by 2030, compared to 2000 levels, point to a 10% higher risk of diarrhoea in some regions[21]. More recently, cholera has increased dramatically – in 2023 double the number of countries are reporting larger, longer and more deadly outbreaks driven by dual pressures of climate change and conflict[22] — and there has also been a surge in the geographic breadth and incidence of dengue fever linked to poor sanitation.

Failures in sanitation systems also lead to downstream health risks to (for example) farmers and recreational users of contaminated drinking water supply from surface or groundwater (**Figure 1.2**). And evidence clearly shows that, like herd immunity for vaccines for example, high levels of community sanitation coverage are needed to prevent transmission at the population level[23]. This means that even a relatively small reduction in sanitation coverage at the community level due to climate change is likely

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[18] World Health Organization, 2020. State of the world's sanitation: an urgent call to transform sanitation for better health, environments, economies and societies. https://www.who.int/publications/i/item/9789240014473

[19] Reference to be added

[20] http://www.who.int/globalchange/publications/COP24-report-health-climate-change/en/

[21] http://apps.who.int/iris/bitstream/handle/10665/42792/9241580348_eng_Volume1.pdf

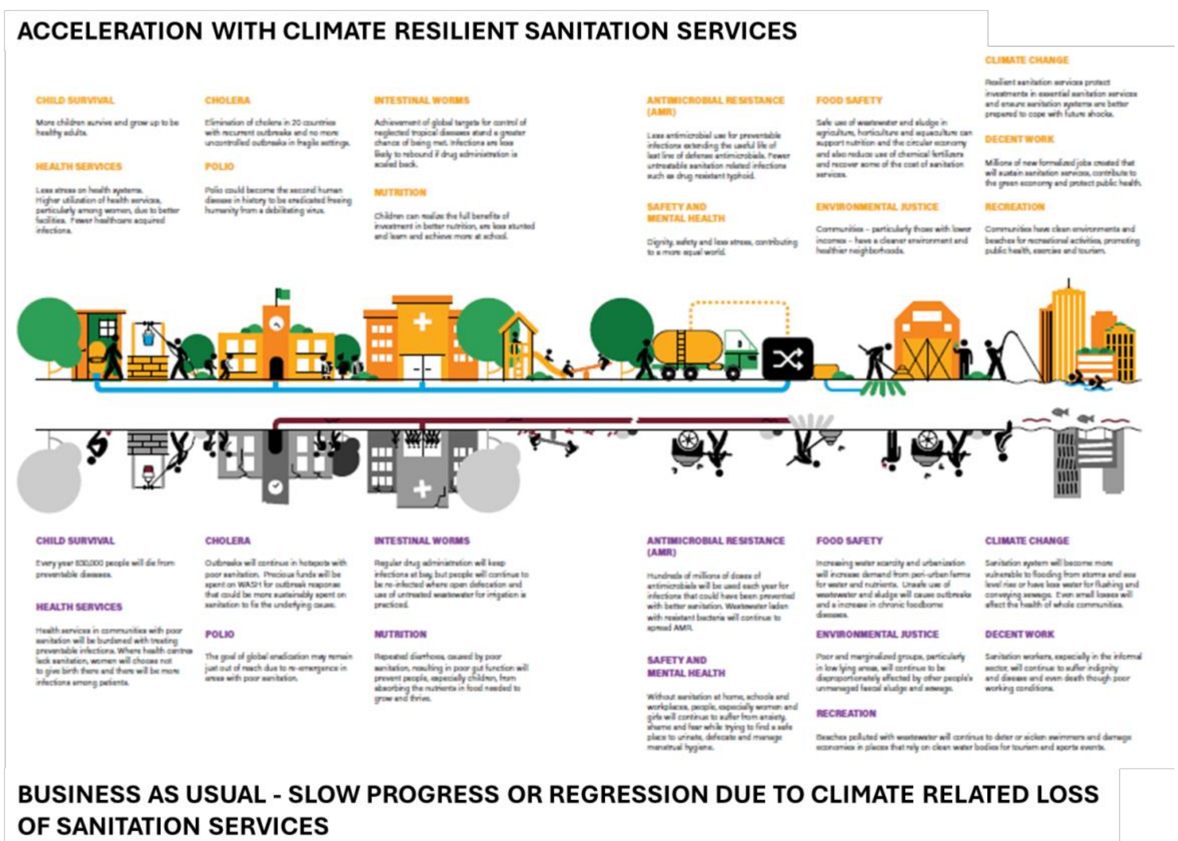
[22] https://www.gtfcc.org/

[23] https://www.who.int/publications/i/item/9789241514705

to have a disproportionate effect on human health. To protect health, climate-resilient sanitation services are required at whole community scale, deploying a mix of service types, and with health risk-informed design.

Finally, safe sanitation systems support community resilience in general, and quite specifically in the areas of food security and safety. Globally, 2.4 billion people suffer from moderate or severe food insecurity[24] and unsafe food causes 600 million cases of foodborne diseases annually[25] – food borne infections (e.g. helminths) and their impact on nutritional status are high but not well quantified. Untreated wastewater and sludge is currently widely used for irrigation and fertiliser for food crops. Demand is likely to increase in response to water scarcity and climate change. Safe use of wastewater is an increasingly attractive strategy to address food insecurity, especially in peri-urban areas, where wastewater is a reliable nutrient-rich source of irrigation water in the circular economy (SDG12). However, safety is key to ensure beneficial use for food security without increasing negative consequences for food borne disease[26].

Figure 1.1: Climate-related health risks and potential impact of resilient sanitation services.

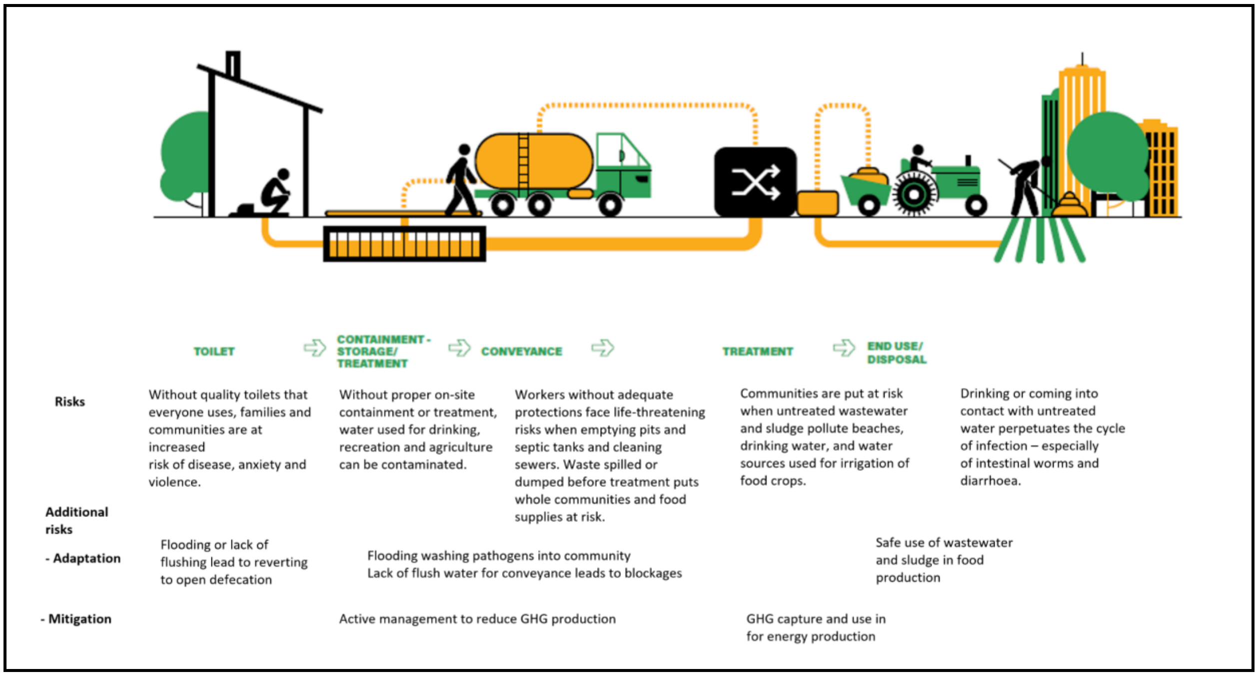


24 FAO (2023) The state of food security and nutrition in the world 2023.

25 https://www.who.int/activities/estimating-the-burden-of-foodborne-diseases#:~:text=Each%20year%20worldwide%2C%20unsafe%20food,diseases%20and%20420%20000%20deaths

26 https://www.who.int/teams/environment-climate-change-and-health/water-sanitation-and-health/sanitation-safety/guidelines-for-safe-use-of-wastewater-greywater-and-excreta

Figure 1.2: Sanitation systems can pose risks to health at all steps of the sanitation service chain presenting addition risks and also potential for GHG reduction and resilience in other sectors.



1.5 Why discrete GCF guidance is needed for climate-resilient sanitation

The climate sector has brought significant attention to water as perhaps the most visible manifestation of the climate crisis. This is demonstrated in floods, sea level rise, and droughts. Sanitation is often bundled with water and hygiene as WASH, and this is reflected in Part 2 of the GCF Guidelines. However, sanitation has a distinct role from water and hygiene, one that warrants its own discrete guidance.

What is Climate-Resilient Sanitation (CRS)?

In line with IPCC approach to climate-resilient development, CRS includes *integrated* consideration of:

> **Adaptation**: reducing the impacts of climate change on sanitation service delivery and addressing opportunities; and
> **Mitigation**: reducing the contribution of sanitation to climate change.

Sanitation, with a strong infrastructure-based component, is vulnerable to climate events that damage and destroy facilities from flooding, storms, and sea level rise (SLR). Elevated temperatures challenge waste treatment plants' ability to process sludge and sewage. Additionally, when climate events displace populations, they frequently lose access to safely managed sanitation, and may overwhelm the sanitation systems in the locales where they relocate. Finally, in addition to infrastructure damage, sanitation is fundamentally a service and a behaviour, and climate events disrupt the ability to practice safe sanitation behaviours, as well as the ability of service providers to provide essential services. All of these factors require strong **adaptation** programs.

Sanitation is also understood as a significant greenhouse gas (GHG) emitter. The anaerobic processes of stagnant, poorly-managed sanitation, results in large emissions of the powerful GHG methane (CH_4) as well as carbon dioxide (CO_2). Sanitation also emits CO_2 throughout the service chain due to energy use, from pumping, transportation, treatment, and final disposal, and sunk carbon in the cement and steel production required for sanitation systems. Wastewater and faecal sludge treatment plants can also release nitrous oxide (N_2O), an important GHG, as can onsite sanitation systems. A 2022 study in Kampala estimated that almost 50% of the city's GHG emissions are from sanitation[27]. A USAID-funded study estimated that sewered and unsewered sanitation systems in urban sub-Saharan Africa contributed between 3% and 5% to the region's total annual anthropogenic methane emissions in 2020 – and this is projected to grow to 8% by 2030[28].

Finally, damage or disruption to sanitation by climate events has profound negative impacts on human and environmental health. Damaging storms spread faecal matter already in the environment from open defecation, and can break sewage pipes and flood wastewater treatment plants, distributing pathogens into communities and pollutants into the environment. Toilets impacted by floods or water shortages cannot be used, which can lead to return to open defecation. These lead to increases in diarrheal diseases including cholera. Additionally, untreated waste released into the environment damages freshwater and marine ecosystems. This can lead to fisheries collapse, as well as converting carbon sinks to carbon emitters. For example, seagrass beds sequester carbon at 35 times faster than terrestrial forests, and 88% of seagrass ecosystems are exposed to wastewater[29]. All these factors require strong **mitigation** programs.

Climate-resilient sanitation (CRS) strengthens other sectors covered in the GCF guidelines, notably Cities, buildings, and urban systems; Energy access and power generation; Health and well-being; Forest and land use; Agriculture and food security; Ecosystems and ecosystem services; and Energy efficiency (see **Section 4.1**). Without a strong climate-resilient sanitation program, those sectors will struggle to meet their targets.

Despite the strong interconnection of sanitation and other sectors, sanitation only receives limited mention in the GCF Water Security Sectoral Guide, primarily contained within Annex II (*Applications of the Practical guidelines for designing water-climate-resilient projects in IWRM, CR-WASH, and Drought and Flood management*), and with a focus on adaptation and no discussion of mitigation.

1. 6 GCF's approach towards climate-resilient sanitation

GCF's envisioned paradigm shift for CRS is that: *Transformative sanitation planning and programming for climate-resilient sanitation is applied in national and regional adaptation and mitigation planning and programming.* This Annex supports the realisation of this paradigm shift, alongside the overall vision of GCF to promote transformational planning and programming; catalyse climate innovation; mobilize financing at scale; and promote coalitions and knowledge to scale up success.

In line with the understanding of sanitation and its impacts presented in **Section 1.4** and **Section 1.5**, GCF considers that **a sanitation system protects and promotes human health by providing a clean environment and breaking the cycle of disease**. The sanitation system encompasses the institutions

[27] Johnson, J., Zakaria, F., Nkurunziza, A. G., Way, C., Camargo-Valero, M. A., & Evans, B. (2022). Whole-system analysis reveals high greenhouse gas emissions from citywide sanitation in Kampala, Uganda. Communications Earth & Environment, 3. doi:10.1038/s43247-022-00413-w

[28] USAID Urban Resilience by Building and Applying New Evidence in Water, Sanitation, and Hygiene (URBAN WASH). 2023. Managing the climate impact of human waste. Washington, D.C. USAID URBAN WASH Project.

[29] Mapping global inputs and impacts from of human sewage in coastal ecosystems. C. Tuholske; B. Halpern; et al. November 10, 2021. https://doi.org/10.1371/journal.pone.0258898

regulating the system, the organizations and management, the users, the entire technical infrastructure, as well as all the services required for the collection, transport, treatment and management of end products of human excreta, wastewater, solid waste and stormwater. Sanitation systems should be resilient to the impacts of climate change, such as increased rainfall, flooding, or droughts. This means systems should be designed to function effectively under varying climatic conditions and be adaptable to future changes.

Sanitation projects have traditionally been driven by several key objectives aimed at **improving public health, protecting the environment, and ensuring equitable access to essential services**. At their core, these projects seek to prevent the spread of water- and excreta-related diseases by promoting hygiene and providing proper waste management facilities. This involves constructing and maintaining toilets, latrines, and wastewater treatment plants to ensure that waste is treated and disposed of in a way that does not contaminate water sources or harm local ecosystems.

Ensuring universal access to sanitation services is a fundamental goal, with programmatic emphasis on reaching the underserved and marginalized communities. These projects strive to make sanitation facilities affordable and accessible to all socio-economic groups, thereby addressing inequalities and improving overall community health. Moreover, traditional sanitation initiatives emphasize the importance of behavioural change through education and awareness campaigns. These efforts aim to capacitate communities about the significance of proper sanitation practices and encourage the consistent use of facilities to maintain public health standards.

Sanitation climate adaptation and resilience objectives expand this scope to include:

- *Anticipating and preparing for climate impacts,* ensuring systems and services are not just functional but robust against future climate scenarios.
- *Encouraging the use of innovative technologies, service models and community involvement to* create adaptive, resilient, and sustainable sanitation systems and to contribute to build community and ecosystems resilience.
- *Integrating sanitation within the wider context of climate goals,* promoting sustainable practices, and reducing the carbon footprint.

These new objectives refer to elements of sanitation that are sensitive to climate change and trigger both climate adaptation and mitigation efforts. Through these, GCF aims to create an enabling credit enhancement and blended financing environment, through alternative funding solutions and the establishment of water reuse/sanitation infrastructure as a new water asset, by defining the investment value of the asset and creating the enabling financial and institutional environment to take the asset to private market and investors.[30]

Overall GCF investment criteria

In designing a sanitation project proposal to GCF, it is important to keep the core GCF investment criteria front of mind. The GCF investment criteria provide a framework to evaluate and prioritize projects that seek funding for climate adaptation and mitigation. When contextualized for sanitation and wastewater projects, these criteria ensure that such initiatives contribute to broader climate goals while addressing immediate needs. Within this context, the six GCF investment criteria are summarised below:

1. **Impact potential:** this criterion assesses the extent to which the project can achieve significant climate adaptation and mitigation benefits. For sanitation and wastewater

[30] Water Asset Transition through Treating Water as a New Asset Class for Paradigm Shift for Climate–Water Resilience (Elmahdi et. Al., 2022)

projects, this means reducing greenhouse gas emissions through energy-efficient waste treatment processes, the application of appropriately treated wastewater and faecal by-products to soil and agricultural lands, enhancing water conservation, or improving the resilience of sanitation infrastructure to climate impacts like floods and droughts.

2. **Paradigm shift potential:** Projects are evaluated on their ability to catalyze systemic change and drive long-term sustainable development. Sanitation and wastewater projects should demonstrate innovative approaches, such as circular economy principles where waste is treated and repurposed as a resource (e.g., biogas production, water reuse and/or nutrient recovery), and scalable solutions that can be replicated or expanded to other regions.
3. **Sustainable development potential:** This criterion looks at the co-benefits of the project, including environmental, social, and economic impacts. For sanitation projects, this includes (but is not limited to) improving public health outcomes by reducing disease prevalence; creating jobs through the construction and maintenance of sanitation facilities and the provision of sanitation services; economic benefits such as tourism from cleaner environments; educational gains from reduced absenteeism; gender equity; and enhanced water quality in local ecosystems.
4. **Needs of the recipient:** The focus here is on addressing the specific vulnerabilities and needs of the communities involved, particularly those most affected by climate change. Sanitation projects should target underserved populations, ensuring access to resilient and sustainable sanitation services that protect them from climate-related hazards like flooding or water scarcity.
5. **Country ownership:** Projects are evaluated on the degree of alignment with national climate strategies (e.g. Nationally Determined Contributions and National Adaptation Plans) and the involvement of local stakeholders. Effective sanitation and wastewater projects should be integrated into national and local development plans, involve community participation, and build local capacity to manage and sustain the infrastructure over the long term.
6. **Efficiency and effectiveness:** This criterion assesses the project's cost-effectiveness and the adequacy of its financial structure to achieve the intended results. Sanitation projects need to demonstrate efficient use of resources, leveraging co-financing and ensuring that the financial models are sustainable, enabling long-term operation and maintenance of the facilities.

Key strategies for inclusion in climate-resilient sanitation proposals to GCF

In addition to the GCF investment criteria and envisioned paradigm shift, five specific strategies have been identified as key to the realisation of GCF's vision for climate-resilient sanitation. The Strategies broadly align with the Sanitation and Water for All building blocks, while also building on the two paradigm-shifting pathways in the GCF Water Security Guidelines[31], and the interlinkages between sanitation, wastewater treatment and other sectors.

The strategies are summarised below. Strategies 1 and 2 should be conceived of as the key outcomes of climate-resilient sanitation activities. Strategies 3-5 are conceived of as key enablers required to deliver these outcomes.

[31] **Pathway 1:** enhance water conservation, water efficiency and water re-use; **Pathway 2:** Strengthen integrated water resources management – protection from water-related disasters, preserve water resources and enhanced resilient water supply and sanitation service

More information on potential activities to include in GCF proposals in each of these strategic areas is provided in **Section 4**.

Outcomes

1. **Climate-resilient infrastructure and services**: invest in building new and upgrading existing sanitation infrastructure, to achieve synergies between adaptation and mitigation, and to withstand climate-related impacts along the whole sanitation chain — including (but not limited to) flood-resistant sanitation systems, decentralized climate-resilient sanitation and wastewater treatment, and the adoption of sustainable sanitation technologies. For more detail on potential interventions in this area to include in GCF proposals, see **Section 4.2** and **Section 4.3**.
2. **Circular economy and integrated management**: promote projects that integrate sanitation with broader water, food and energy security, ensuring ecosystem protection. This includes practices like wastewater recycling and safe wastewater reuse for potable, industrial and agricultural uses. In urban contexts, infrastructure and services should be integrated with water supply and stormwater management, including greywater management in urban contexts — see **Section 4.1.**

Enablers

3. **Community engagement and capacity building**: alongside capacity development support to service providers, empower local communities through understanding of climate risks, and training and involvement in the planning and maintenance of resilient sanitation systems. This ensures the sustainability and resilience of projects by leveraging local knowledge and fostering ownership. For more detail on interventions in this area, see **Section 4.2.**
4. **Policy, regulatory and governance support**: assist governments in developing and implementing policies that promote climate-resilient sanitation services and practices. This includes creating regulatory frameworks that encourage private sector investment and public-private partnerships. For more detail on interventions in this area, see **Section 4.4.**
5. **Monitoring and evaluation**: Implement robust systems for: operational monitoring of climate-resilient sanitation; evaluating the impacts of climate change on sanitation; and evaluating the impacts of climate-resilient sanitation projects on community resilience and the resilience of the environment. Use data to continually improve and adapt strategies.

By focusing on these areas, GCF investments can help create resilient, sustainable, and inclusive sanitation systems that effectively address the impacts of climate change across a range of closely related sectors.

These considerations should be seen in conjunction with the full analysis framework of the Water Sector Design Guidelines (Annex 1 to the GCF Water Security Guide) and the broader WASH guidelines (pages 16-24) of existing Annex 2.

Box 1.2: Key points for developing a successful sanitation proposal to GCF.

To be successful, sanitation proposals to GCF must have a clear climate rationale and must display a level of ambition consistent with GCF's envisioned paradigm shift for climate-resilient sanitation. Successful proposals must achieve the following:

- Effective articulation of the climate science basis and rationale for the project (see **Sections 2 - 3**)
- Alignment with overall GCF investment criteria
- Alignment with GCF key strategies for climate-resilient sanitation

Further guidance on GCF proposal development is provided in **Section 5**.

1.7 Structure of this document

In line with the aims of this document to provide guidance for developing CRS proposals to GCF, the document is structured to address the key questions presented in Box 1. Each of these Sections is intended to provide overarching guidance to inform the content of CRS proposals to GCF.

- **Section 2** provides the climate science basis and rationale for the **adaptation** component of climate-resilient sanitation projects and programmes. It sets out the known risks posed by climate change to sanitation systems; and provides guidance for assessing climate risks to sanitation, looking at hazards, exposure and vulnerability.
- **Section 3** provides the climate science basis and rationale for the **mitigation** component of climate-resilient sanitation projects and programmes. It sets out the known linkages between sanitation and greenhouse gas emissions, and provides guidance on how these can be assessed.
- **Section 4** provides guidance on the specific interventions that can be included within climate-resilient sanitation projects and programmes to support A) adaptation, relating both to infrastructure adaptations and how these can be enabled; and B) mitigation.
- **Section 5** summarises the content-related and procedural guidance for developing a GCF proposal on climate-resilient sanitation and the specific requirements that need to be met.

2. Building the Climate Rationale for Sanitation Projects: Adaptation

Section 2 provides the climate science basis and rationale for the inclusion of adaptation activities in GCF sanitation projects. The Section:
- Introduces climate risk assessment as a critical step in developing the climate rationale for any GCF project;
- Provides guidance for conducting sanitation-focused climate risk assessments; and within this
- Sets out the known risks posed by climate change to sanitation systems, requiring the development of adaptation solutions. These solutions are explored in Section 4.

2.1. Introduction to climate risk assessments

This section explores the complex factors at play when assessing the risks that climate events pose to sanitation systems. These risks provide the rationale for the adaptive strategies detailed in **Section 4.**

Climate risk assessments are one of the initial steps in crafting a sanitation-specific adaptation plan, and are an essential step in the development of any proposal to GCF (see also **Section 5**). A climate risk assessment is a systematic process used to identify, evaluate, and prioritise risks posed by climate change to natural and human systems. This type of assessment helps policymakers, organisations, and communities understand the potential impacts of climate change and develop strategies to mitigate and adapt to these risks.

The structure of this section reflects four of the common steps involved in undertaking a risk assessment (**Figure 2.1**):

1. **Hazards:** a first step when developing a risk assessment is to identify potential climate hazards and the potential impacts they could have on the area or system under consideration.
2. **Exposure:** once the hazards have been identified, the systems and populations that are most likely to come into contact with climate hazards should be mapped.
3. **Vulnerability**: once exposure is understood, how likely systems and populations will suffer adverse effects when exposed should be evaluated.
4. **Responses**: a recent addition to risk assessment, this step involves analysing how responses to climate events, and the dynamic interactions between responses, can generate additional risks.

As defined by IPCC, it is important to recognise the dynamic nature of risk: each of the three elements (hazard, vulnerability and exposure) is subject to change over time due to climatic changes or socio-economic change.[32] The relationship between risk, hazards, exposure and vulnerability is summarised in **Figure 2.1** below.

[32] https://www.ipcc.ch/site/assets/uploads/2021/02/Risk-guidance-FINAL_15Feb2021.pdf

Box 2.1: Introduction to the risk approach advocated in Annex 1 of the GCF Water Security Sectoral Guide and implications for CRS project proposals.

Proposals to GCF must incorporate a climate risk assessment of the project. This assessment should follow the structure of the risk approach advocated in the GWP/UNICEF strategic and the WHO Sanitation Safety Planning Manual (2022) and described in section 2.2.3 of the Water Sector Guidelines Annex 1: **Risk = Hazard X Exposure X Vulnerability**.

To compile the evidence that the project addresses climate-induced risks, typical questions to be answered are:

- ***What hazards must be accounted for***? How is the project vulnerable to climate change through sanitation-related hazards, taking into account both the WASH cycle and the local basin context? (issues like drought, floods, saltwater intrusion, water stress and other issues like agriculture, environment, etc.). What are the objectives and performance indicators reflecting the ambition for CRS, especially the climate adaptation and mitigation building component? [For guidance on this aspect, see **Sections 2 and 3]**
- ***What are the risks****?* What are the impacts of the current and future climate on the CRS sector system for the timeframe under consideration? What is the likelihood of unacceptable performance of the CRS system due to these impacts based on formulated objectives and indicators for CRS? [For guidance on this aspect, see **Sections 2 and 3]**
- ***How to contribute to mitigation efforts****?* How can the CRS sector contribute to reducing CO_2, CH_4 and N_2O emissions? (by e.g., volume of biogas and biomass that can be recovered from wastewater and used as energy sources, reduction in methane emissions, etc.) [For guidance on this aspect, see **Section 5]**
- ***How to adapt****?* How can the sanitation sector improve the performance of CRS under climate induced hazards? How can the CRS sector contribute to building community resilience to the impacts of the climate crisis? [For guidance on this aspect, see **Section 5]**

This section examines the risks posed to both core and support infrastructure across various sanitation options, including sewered systems and non-sewered systems. However, it is crucial to extend focus beyond infrastructure when undertaking a risk assessment, particularly because much of non-sewered sanitation is still largely considered the domain of households and is managed by them;[33] and because all sanitation systems depend on workforces. Assessing the exposure of these communities and workers to climate hazards, the impacts of these hazards, and their vulnerability to these impacts are all vital elements of a comprehensive risk assessment for developing an adaptation plan for sanitation.

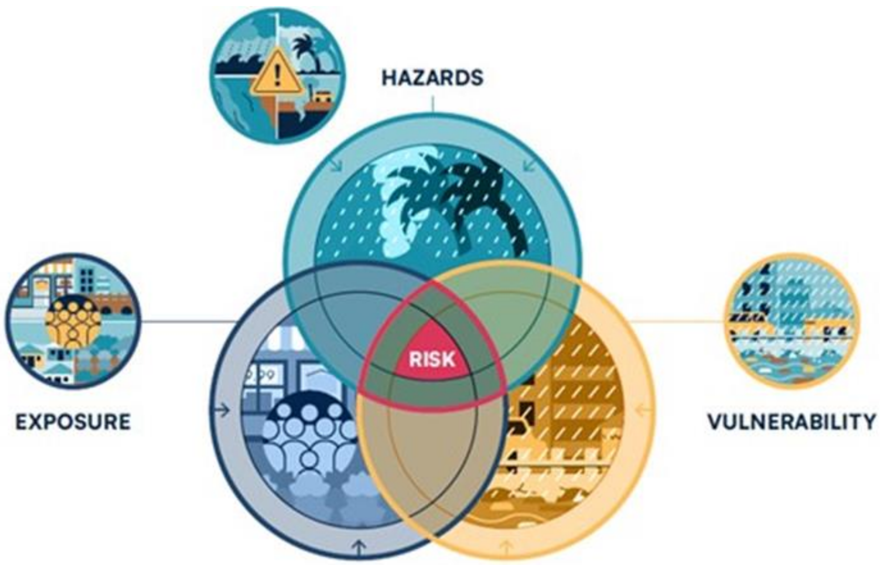
If the starting point is a geographical area rather than a sanitation system, a climate risk assessment will need to assess risks to communities themselves, in addition to impacts on sanitation systems. As climate risk assessments of communities encompass broader considerations, and are well-documented in other guidance,[34] this resource focuses primarily on sanitation-specific infrastructure considerations.

[33] Hyde-Smith, L., Zhan, Z., Roelich, K., Mdee, A. and Evans, B. (2022). Climate Change Impacts on Urban Sanitation: A Systematic Review and Failure Mode Analysis. Environmental Science & Technology, 56(9). 5306–21. DOI: 10.1021/acs.est.1c07424

[34] Eg 2018 Climate Risk and Vulnerability Assessment Tool: Communities and Water Infrastructure Projects

For further detail on undertaking a risk assessment for WASH, see GWP and UNICEF's 2017 WASH Climate-resilient Development Risk assessments for WASH guidance note; and WHO's Sanitation Safety Planning Manual (2022), which provides guidance for step-by-step risk management of safely managed sanitation systems.[35]

Figure 2.1: Risk is the combination of hazards, exposure and vulnerability.



2.2 Climate hazards and their impacts

Climate-related hazards include extreme weather events (e.g., hurricanes, floods, heatwaves), long-term changes (e.g., rising temperatures, sea-level rise), and secondary impacts (e.g., drought leading to food insecurity). Impacts can be direct (e.g. physical damage to infrastructure) and indirect (e.g. economic losses, health effects). In describing hazards, it is recommended to use the definitions provided by the United Nations Office for Disaster Risk Reduction (UNDRR) - *Hazard definition and classification review: Technical report* (2020).[36]

Hazards can significantly impact sanitation systems, people and businesses, causing interrupted service provision and infrastructure damage. These impacts affect the full spectrum of service providers, from utilities to small-scale emptiers, precipitating major health risks, environmental deterioration, and contamination, and threatening businesses and livelihoods.

Both sewered and non-sewered sanitation systems bear the brunt of these repercussions, which can affect every stage of the service chain and are felt differently in urban and rural areas, due to the different nature of sanitation systems used. Where sanitation systems become completely unusable, there is a risk of communities resorting to open defection.

[35] Available at: https://www.who.int/publications/i/item/9789240062887

[36] Available at: https://www.undrr.org/media/47681/download?startDownload=20240829

Climate hazards can also damage critical support infrastructure such as roads, power lines, and telecommunications, which can be beyond the control of sanitation providers to readily adapt or rehabilitate, making disaster preparedness and response more challenging.

Below we set out the known climate hazards to sanitation infrastructure — including floods, windstorms, droughts, water scarcity, sea level rise, and temperature fluctuations — and the respective impacts of these hazards. For each hazard, we include a table showing the available evidence for climate impacts on sanitation infrastructure, derived and adapted from Hyde-Smith et al (2022): *Climate Change Impacts on Urban Sanitation: A Systematic Review and Failure Mode Analysis* and WHO (2022) *Sanitation Safety Planning: Step-by-step risk management for safely managed sanitation systems*. For guidance on assessing the impact of climate hazards on households, communities and workforces, see also CRIDF (2018) *Climate Risk and Vulnerability Assessment Tool: Communities and Water Infrastructure Projects*.

2.2.1 Floods

From 2000 to 2019, 72% of disaster events were caused by meteorological and hydrological disasters, with floods having the most significant impact on people. Floods occur when excessive water on land overwhelms natural or controlled drainage systems[37] which can cause severe damage (figure 3) to sanitation services, including their complete failure.

Floods can submerge non-sewered sanitation systems and cause backflows in sewer systems, preventing them from discharging and draining properly and leading to contaminated water supplies and ecosystems through the release of faecal pathogens in the surrounding environment.[38] Floods can also cause direct physical damage to non-sewered and sewered sanitation infrastructure (including treatment plants, sewer pipes, pumps, pits, septic tanks, toilets and superstructures), with pipes and treatment facilities most affected;[39] and cause damage to equipment used by pit emptiers. Increased levels of stagnant water and groundwater levels mean that containment structures fill quickly while also preventing people from being able to bury their waste onsite, creating a greater need for emptying services and alternative sanitation options. At the same time, there is an increased likelihood of sludge being dumped into the environment and waterways where faecal sludge collection, transportation and services and facilities fail. In regions where open defecation is widespread, particularly in rural areas, flooding can result in exceedingly high levels of faecal matter in floodwaters.[40]

High-magnitude flooding, or flash floods, bring sudden high levels of water ingress into sewers and are more likely to cause burst pipes and sewage overflow, particularly where sewers are not designed to carry rain and increasingly even when they are combined wastewater and stormwater sewers. Flash floods can also increase the volume of sediment and solid waste entering sewers, another cause of disruption, backflow and overflow in sanitation system.

[37] Rudari et al., 2017; Flood | UN-SPIDER Knowledge Portal, 2017; https://www.preventionweb.net/knowledge-base/hazards/flood

[38] Smith et al., 2022

[39] Shresta et al., 2023

[40] Bundis Entwicklung Hilft, 2023)(Okaali et al., 2022)

Floods can also damage key support infrastructure, including roads, energy grids, and telecommunications systems, thereby disrupting the associated sanitation services.[41] When damaged roads hinder or compromise the removal of faecal sludge from non-sewered sanitation, the contaminants present in the sludge may cause health issues or contribute to surface water and soil contamination.[42] Damage to infrastructure can also create knock-on effects of increased competition for infrastructure investment.

As well as the general impacts of flooding, coastal flooding brings additional challenges of saline intrusion, as explored in more detail in the following Sections on storms and sea level rise.

[41] Leonie Hyde-Smith, Zhe Zhan, Katy Roelich, Anna Mdee, and Barbara Evans. Climate Change Impacts on Urban Sanitation: A Systematic Review and Failure Mode Analysis. Environmental Science & Technology 2022 56 (9), 5306-5321

[42] Baloch et al., 2023

Table 2.1: Climate change impacts on urban sanitation systems – flooding. Sources: Hyde-Smith et al, 2022; WHO, 2022.

Evidence of Climate Change Impacts on Urban Sanitation System (relevant to flooding and storms) (Hyde-Smith et al, 2022)					
Hazard	**Impacts** (using Peal et al, 2020 failure mode classification)				
	Fecal sludge not contained, not	**Fecal sludge and supernatant not delivered**	**Fecal sludge and supernatant not treated**	**Wastewater not delivered to treatment**	**Wastewater not treated**
High-intensity rainfall, increased flooding, erosion and landslides	Damage to pits or superstructures making latrines unusable	People 'drain' toilets into the environment using floodwater during flood	Flooding and damage to wetland flora	Increased frequency or spill volume of combined sewer overflows	Flooding and damage to wastewater treatment plant structure and equipment
	Pits overflow/collapse leading to fecal contamination	Structural damage to pavements		Increased risk of urban flooding (overflow of inspection chambers, flooding of basements)	Flooding of wastewater treatment plant leading to temporary system failure and discharge of raw sewage
	Toilets become inundated/inaccessbile (causing people to abandon toilets and revert to open defecation)	Road collapse or development of sinkholes due to destabilization of soil caused by damages sewers		Increase risk of pipe damage due to changed soil moisture and subsidence	Electricity failure leading to failure of pumps and aeration
				Changes to inflow and infiltration rates into the sewer system	Road interruptions leading to disruption of site access for wastewater treatment plant staff and supplies
	Electricity failure resulting in lack of water supply and non-functioning of toilets	Damage to roads infastructure elements other than pavements (eg bridges)		Sewer blockages after an event because of sand, debris or solid waste entering sewers and pump stations	Pollutant load exceeding biological treatment capacity of wastewater treatment plants
	Inundation of drainfields	Road capacity decreases/increases in congestions/travel time increases		Electricity failure leading to failure of pumps	Discharge of untreated/partially treated effluent due to overloading or bypassing of treatment
	Backflow/overflow of sewage from septic tanks	Roads become inaccessible		Damage to sewer pumps and mains	Increased dilution of influent
	Damage to pits, septic, tanks and absorption fields	Electricity failure leading to traffic light failure		Overload of sewer system resulting in overflow to the drainage system	Reduced nutrient removal cpacity during high-intensity rainfall events (eg due to reduced retention time and high
Contamination of and damage to surface water and groundwater supplies				Higher pollutant concentration in receiving waters due to increase in combined sewer overflow spill volumes/frequency	Contamination of receiving water bodies due to wastewater treatment plant failure
Changes to groundwater recharge and groundwater levels	Floatation and damage of septic tanks due to high groundwater levels	Structural damage to pavement (destabilisation of the substrate)			Inflow and infiltration into seprate systems causes higher inflow into wastewater treatment plants that stretch their design capacity
	Flodding and famage of septic tanks due to high groundwater levels				
	Higher groundwater pollution				
More extreme winds				Uprooting of trees and replacement of dmaged electricity poles leading to damage of sewer pipes	Damage to wastewater treatment plant infrastructure/buildings

2.2.2 Extreme storms

Storm surge relates specifically to excess wave height in coastal waters and often occurs when storms coincide with high tides. Storm surges can be very destructive and may overwhelm existing sea defences (sea walls etc) and cause widespread flooding of sanitation infrastructure.[43] This may include damage and inundation of sewers and on-site containment structures. In addition to immediate effects, inundation by saltwater may lead to corrosion problems in the longer term. Storm surges may also overwhelm coastal wastewater treatment plants, causing damage to infrastructure and equipment.[44] Inundation by saltwater is more damaging to equipment than inundation by freshwater, substantially increasing the risk of failure.[45] Where saltwater from a surge swamps treatment plants, there may also be interference with biological processes requiring the plant to put operations on hold for rehabilitation.[46] The loss of coastal ecosystems, which is itself being accelerated by sanitation failures (see **Section 3.3**) exacerbates the impacts from extreme storms.

Windstorms are commonly associated with flash floods, which carry the risks outlined in Section 2.2.1. They are also commonly associated with debris flows (landslides and landslips), which are of particular concern in areas with steeper slopes and thin soil cover, especially where there is little or no vegetation. Debris flows pose a specific risk to sanitation systems as they may destroy sanitation facilities (both sewered and on-site containments) and cause damage to roads, power lines and telecommunications that can impair the functioning of sanitation systems.

One of the major consequences of windstorms is that there is a high risk that they disrupt critical ancillary services, particularly power lines and telecommunications.[47] This may result in pumps becoming non-functional, leading to sewer overflows, and interrupting the performance of wastewater treatment plants. The loss of telecommunications will inhibit timely response in the case of automated systems that rely on telemetry and remote monitoring. Loss of telecommunications also inhibits the response between operators at affected plans and support systems. The loss of ancillary services from the impact of windstorms may be more important than direct damage to infrastructure and systems and may lead to prolonged system failure and increased risk of environmental contamination.

2.2.3 Sea level rise

Sea level rise is the increase in the height of global and local sea levels, driven by changes in the ocean volume due to the melt of glaciers and ice sheets, the thermal expansion of ocean water, and the local subsidence of land.[48] Sea level rise has already measurably worsened the flooding impacts of tropical cyclones, and further rises will encroach on coastal infrastructure and compound flood risks globally.[49]

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[43] Howard et al 2016

[44] Andy Richards

[45] Danilenko et al 2010

[46] Takamatsu et al 2014

[47] O'Neill et al 2022

[48] IPCC, 2022a

[49] IPCC, 2022: Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001.

Sea level rise can increase the magnitude and frequency of storm surges and high tides inundating or infiltrating coastal sanitation infrastructure.[50] These may reach previously unrecorded levels and affect much wider areas, particularly because coastal areas tend to be low-lying. As discussed, this can cause backflow through discharge channels and pipes,[51] corrosion of pipes, pumps and valves being exposed to saltwater, wastewater overflows, and reduced treatment efficiency due to exposure of microorganisms to saltwater, all entailing higher operation and maintenance costs.[52] Sea level rise will also significantly increase coastal flooding frequency, particularly in the tropics,[53] which carries the risks associated with flooding and saline intrusion.

Sea level rise can cause groundwater rise,[54] which can exacerbate the risks of leaking sewers contaminating groundwater and buoyancy forces damaging substructures when they come into contact with high groundwater.[55] For on-site sanitation, groundwater rise can reduce the vertical separation between containment units and the saturated zone and heighten the risk of groundwater pollution.[56]

Finally, sea level rise contributes to shoreline erosion, which can damage coastal infrastructure,[57] particularly for wastewater treatment facilities which are often located on the coast, to take advantage of low elevations and proximity to water bodies for discharge.

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[50] Cahoon LB, Hanke MH. Inflow and infiltration in coastal wastewater collection systems: Effects of rainfall, temperature, and sea level. Water Environment Research. 2019 Apr;91(4):322-31.

[51] Cao A, Esteban M, Mino T. Adapting wastewater treatment plants to sea level rise: learning from land subsidence in Tohoku, Japan. Natural Hazards. 2020 Aug;103:885-90

[52] Flood JF, Cahoon LB. Risks to coastal wastewater collection systems from sea-level rise and climate change. Journal of Coastal Research. 2011 Jul 1;27(4):652-60.

[53] Vitousek et al., 2017

[54] Bosserelle AL, Morgan LK, Hughes MW. Groundwater rise and associated flooding in coastal settlements due to sea-level rise: a review of processes and methods. Earth's Future. 2022 Jul;10(7):e2021EF002580.

[55] Cao et al., 2020

[56] Graham JP, Polizzotto ML. Pit latrines and their impacts on groundwater quality: a systematic review. Environmental health perspectives. 2013 May;121(5):521-30.

[57] Griggs G, Reguero BG. Coastal adaptation to climate change and sea-level rise. Water. 2021 Aug 5;13(16):2151.

Table 2.2: Climate change impacts on urban sanitation systems – sea-level rise. Source: Hyde-Smith et al, 2022; WHO, 2022.

Evidence of Climate Change Impacts on Urban Sanitation System (relevant to sea-level rise) (Hyde-Smith et al, 2022)					
	Impacts (using Peal et al, 2020 failure mode classification)				
Hazard	**Fecal sludge not contained, not emptied**	**Fecal sludge and supernatant not delivered to treatment plant**	**Fecal sludge and supernatant not treated**	**Wastewater not delivered to treatment**	**Wastewater not treated**
Rising groundwater levels in coastal / low lying zones	Higher groundwater / surface water pollution risk caused by increased mobility of pollutants from septic tank drainfields			Higher groundwater pollution risk	Buoyant forces in areas that were not designed for high groundwater levels migt cause damage to pipes
				Increased dry weather flow in sewer pipe due to infiltration	
					Inflow and infiltration into separate systems causes higher inflow into wastewater treatment plant that stretch their design capacity
Saline intrusion in coastal/low-lying zones				Damage to pipes through saltwater infiltration	Saltwater intrusion/inundation affects biological treatment processes
High water levels (potentially contributing to flooding, erosion, landslides)		Road capacity decreases/increase in congestion/ Travel time increase		Wastewater back-up and flooding through inspection chambers and toilets	Reduced capacity to discharge treated wastewater by gravity/risk of backflow during high tides
		Roads become inaccessible			Damages to wastewater treatment plant equiopment throughexposure to saltwater

2.2.4 Droughts and water scarcity

Climate change is exacerbating both water scarcity and droughts as rising temperatures disrupt precipitation patterns and the entire water cycle. Water scarcity places additional stress on sanitation infrastructure, particularly in urban areas where high water demand for sanitation competes with other uses. Reduced water availability can lead to the malfunctioning of flush toilets and sewage systems, contributing to blockages, overflows, and increased maintenance requirements. Water scarcity can prompt temporary changes in behaviour, such as abandoning flush toilets in favour of unsafe practices such as open defecation or the use of makeshift sanitation methods that pose environmental and health risks, including water- and excreta-related diseases.

Droughts can have significant impacts on sanitation systems, exacerbating existing challenges and creating new ones. Inadequate sanitation practices during droughts can lead to faecal-oral transmission of pathogens, contributing to diarrheal diseases and other public health concerns.[58] During droughts, reduced flow rates and higher concentrations of wastewater were found to cause a buildup of solids and

[58] Grimason, A.M., Smith, H.V., & Thangata, N. (2014). Public Health Implications of Rural Water Supply and Sanitation Projects in Malawi and Knowledge, Attitudes and Practices: A Critical Review of the Literature. Water, 6(5), 1342–1352.

Sharma, A., Bhatt, M.R., & Chiranjivi, S. (2018). Impact of Water Scarcity on Sanitation and Health Situation in Western Nepal. Environmental Health Insights, 12, 117863021878944.

Srinivasan, S., O'Shaughnessy, S.A., & Horney, J.A. (2019). Effects of Water Scarcity on Rural and Remote Communities: A Case Study from Rural Louisiana. International Journal of Environmental Research and Public Health, 16(10), 1746.

Xu, Y., Furey, S., & Mekonnen, M.M. (2019). Urbanization and Water Scarcity in Africa: Thirsty Cities in the Sahel. Earth's Future, 7(12), 1451–1463.

Halbe, J., Akashi, H., & Kumar, S. (2020). The Relationship between Water Scarcity and Open Defecation in the Ganges Basin, India: A Statistical Analysis. International Journal of Environmental Research and Public Health, 17(3), 1041.

subsequently blockages in sewage systems, contributing to corrosion and odours.[59][60] Changes in moisture cause soils to shift, especially in those with high clay content, and increase the risk of sewer pipe and onsite containment structure breakages.[61]

Droughts also affect how sanitation system failures impact water bodies. On the one hand, lower groundwater levels are thought to reduce the risk of groundwater contamination from pathogens,[62] in particular from unlined pit latrines. On the other hand, combined sewer overflows during periods of less intensive rainfall are found to cause higher pollutant concentrations due to reduced dilution in receiving water bodies.[63]

With droughts posing multifaceted challenges to sanitation systems, integrated water and sanitation management strategies are needed to ensure the continued provision of safe and sustainable sanitation services. As outlined in **Section 4.2**, sanitation can also contribute to water security and food security through the safe reuse of wastewater and faecal sludge, strengthening the climate resilience of other sectors.

[59] Howard, G.; Bartram, J. *Vision 2030: The Resilience of Water Supply and Sanitation in the Face of Climate Change. Technical Report*; World Health Organization: Geneva, Switzerland, 2010.

[60] Langeveld, J. G.; Schilperoort, R. P. S.; Weijers, S. R. Climate change and urban wastewater infrastructure: There is more to explore. *Journal of Hydrology* 2013, *476*, 112– 119, DOI: 10.1016/j.jhydrol.2012.10.021

[61] Howard, G.; Bartram, J. *Vision 2030: The Resilience of Water Supply and Sanitation in the Face of Climate Change. Technical Report*; World Health Organization: Geneva, Switzerland, 2010.There is no corresponding record for this reference

[62] Howard, G.; Bartram, J. *Vision 2030: The Resilience of Water Supply and Sanitation in the Face of Climate Change. Technical Report*; World Health Organization: Geneva, Switzerland, 2010.

[63] Abdellatif, M.; Atherton, W.; Alkhaddar, R. Assessing combined sewer overflows with long lead time for better surface water management. *Environmental Technology (United Kingdom)* **2014**, *35* (5), 568– 580, DOI: 10.1080/09593330.2013.837938 There is no corresponding record for this reference

Table 2.3: Climate change impacts on urban sanitation systems – declining rainfall or run-off. Sources: Hyde-Smith et al, 2022; WHO, 2022.

Evidence of Climate Change Impacts on Urban Sanitation System (relevant to more variable or declining rainfall or run-off) (Hyde-Smith et al, 2022)					
	Impacts (using Peal et al, 2020 failure mode classification)				
Hazard	**Fecal sludge not contained, not emptied**	**Fecal sludge and supernatant not delivered to treatment plant**	**Fecal sludge and supernatant not treated**	**Wastewater not delivered to treatment**	**Wastewater not treated**
More extended dry periods, increased frequency of occurance of drought (seasonal and longterm)	Pit latrines were used as a coping mechanism due to water restrictions resulting in fecal contamination of groundwater	Reduced slow pavement deterioration		Higher risk of blockages in the sewer systsm and discharge pipes	Higher concentration of wastewater leading to less effective treatment
				Higher risk of corrosion of sewers	Corrosive influent damages equipment in treatment plants
	Low moisture content of soil leading to erosion and damage of subsurface structures			Pipe and joint breakages through ground settlement after prolonged droughts	Excess deposition due to low flo
				Decreased risk of urban flooding (overflow of inspection chambers, floodig of basements	
				Decrease in combined sewer overflow spills	
Reduce surface water flows	Decreasing levels of hydro-electric productivity resulting in failure of mechanical groundwater pumps providing water for pour-flush toilets			Combined sewer overflow spills causing higher pollutant concentrations from receiving waters due to reduced dilution	Less dilution in receiving waters
Reduced groundwater levels/resources	Lower groundwater pollution risk from pit latrines				

2.2.5 Extreme temperatures

Increased global temperature caused by climate change is leading to higher ambient temperatures and more frequent temperature extremes. This has both a direct and indirect impact on sanitation services. Indirectly, rising and extreme temperatures cause or exacerbate hazards such as storms, sea level rise, changes in groundwater levels, and other stressors that impact sanitation systems as discussed in previous sections.

Directly, temperature variations can positively or negatively impact the efficacy of wastewater and faecal sludge treatment processes. Moderate increases in temperature have been associated with increased biological treatment efficiency in septic tank systems and wastewater treatment plants. However, more extreme temperatures were found to reduce the efficiency of biological treatment.[64] Temperature fluctuations also affect infrastructure. Common materials used in sanitation core and

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[64] Leonie Hyde-Smith, Zhe Zhan, Katy Roelich, Anna Mdee, and Barbara Evans. Climate Change Impacts on Urban Sanitation: A Systematic Review and Failure Mode Analysis. Environmental Science & Technology 2022 56 (9), 5306-5321
DOI: 10.1021/acs.est.1c07424; Cooper, J. A.; Loomis, G. W.; Amador, J. A. Hell and high water: Diminished septic system performance in coastal regions due to climate change. PLoS One 2016, 11 (9), e0162104, DOI: 10.1371/journal.pone.0162104 37
Morales, I.; Amador, J. A.; Boving, T. Bacteria transport in a soil-based wastewater treatment system under simulated operational and climate change conditions. J. Environ. Qual. 2015, 44 (5), 1459, DOI: 10.2134/jeq2014.12.0547 38
Abdulla, F.; Farahat, S. Impact of Climate Change on the Performance of Wastewater Treatment Plant: Case study Central Irbid WWTP (Jordan). Procedia Manufacturing 2020, 44, 205– 212, DOI: 10.1016/j.promfg.2020.02.223
Adin, A.; Baumann, E. R.; Warner, F. D. EVALUATION OF TEMPERATURE EFFECTS ON TRICKLING FILTER PLANT PERFORMANCE. Water Sci. Technol. 1985, 17 (2–3), 53– 67, DOI: 10.2166/wst.1985.0119 135

supporting infrastructure such as concrete are subject to thermal deformation with temperature rises as well as rapid cooling rates, causing cracks and compromising the integrity of structures.[65]

Extreme temperatures can also make the work of service providers very difficult and hazardous, reducing the use of PPE, and in some cases leading to heat stress and even death. Small-scale pit emptiers, who often work outside without shade or access to water, are particularly vulnerable to these effects.

Table 2.4: Climate change impacts on urban sanitation systems – increasing temperature. Sources: Hyde-Smith et al, 2022; WHO, 2022.

Evidence of Climate Change Impacts on Urban Sanitation System (relevant to more variable or increasing temperatures) (Hyde-Smith et al,

Hazard	**Impacts** (using Peal et al, 2020 failure mode classification)				
	Fecal sludge not contained, not emptied	**Fecal sludge and supernatant not delivered to treatment plant**	**Fecal sludge and supernatant not treated**	**Wastewater not delivered to treatment**	**Wastewater not treated**
Higher ambient air temperatures		Damage to road pavements because of degradation of permafrost or other freeze and thaw effects	Increased temperature might increase the efficiency of fecal sludge treatment in septic tank systsms		Moderate increases in temperature might increase efficiency of biological wastewater treatment
		Increasing winter temperature reduces pavement damage caused by frost			Variability in winter temperature might lead to deterioration of efficiency of wastewater treatment
		More variable winter temperature leading to increase of freeze and thaw events and increasing damage of pavement			
Hot and cold temperature extremes		Roads become inaccessible because of wildfires			Reduced efficiency of biological treatment if temperatures exceed or fall below operational limits
		Heat and damage of (access) roads			

2.3 Exposure

Exposure assessments are essential to properly identify the different elements at risk and calculate loss estimates.[66] This involves identifying which systems and populations are present in an area where hazard events may occur.[67] While exposure and vulnerability are often conflated, they are distinct. An entity can be exposed without being vulnerable (e.g. living in a floodplain but having sufficient means to adapt the building structure and behaviour to mitigate potential loss).[68] Conversely, vulnerability to an extreme event only comes into play following exposure to a hazard.

[65] Xiaoda Li, Zhipeng Yu, Kexin Chen, Chunlin Deng, Fang Yu, Investigation of temperature development and cracking control strategies of mass concrete: A field monitoring case study,
Case Studies in Construction Materials, Volume 18, 2023, e02144, ISSN 2214-5095, https://doi.org/10.1016/j.cscm.2023.e02144.

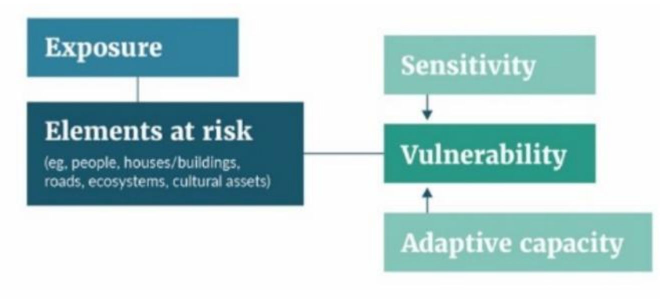
[66] Keping, Chen, John McAneney, Rusell Blong, Roy Leigh, Laraine Hunter, and Christina Magill. 2004. "Defining area at risk and its effect in catastrophe loss estimation: a dasymetric mapping approach." Applied Geography 24, no. 2 (April): 97-117; Cardona, OD, MK van Aalst, J. Birkmann, M. Fordham,, G. McGregor, R. Perez, RS Pulwarty, ELF Schipper, and BT Sinh. 2012. "Determinants of Risk: Exposure and Vulnerability." In A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC), 65-108. Cambridge, UK: Cambridge University Press.

[67] Cardona, 1990; UNISDR, 2004, 2009b

[68] Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh, 2012: Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

The distinct characteristics of exposure and vulnerability are summarised in **Figure 2.2 below**. Exposure is an expression of elements at risk; the level of vulnerability of these elements is then influenced by sensitivity and adaptive capacity.

Figure 2.2: Key characteristics of Exposure and Vulnerability.



Identifying which assets, areas, and components are most likely to be exposed is essential for crafting targeted solutions and enhancing the resilience of sanitation systems against diverse climate hazards. The exposure of every aspect of the sanitation service chain should be considered — from containment structures and their superstructures to supporting infrastructure such as transport and electricity, sewer networks, wastewater and faecal sludge treatment plants, the workforce, and households managing their own sanitation systems.

Geographical areas prone to exposure include, but are not limited to: small islands, coastal regions, floodplains, river basins and arid/semi-arid zones. Low-income communities frequently reside in areas more prone to natural hazards, making them more likely to be exposed while also having fewer resources to adapt and invest in resilient infrastructure. Wastewater treatment facilities are particularly exposed to sea level rise and increasing windstorm intensity as they are often located on coasts to benefit from low elevations and proximity to water bodies for discharge.[69]

2.4 Vulnerability

Vulnerability assessments are essential for understanding the susceptibilities and weaknesses of systems and populations when exposed to climate hazards. While exposure indicates the presence of systems and populations in hazard-prone areas, vulnerability refers to their propensity to suffer adverse effects due to various predispositions, susceptibilities, and lack of capacities.

Key elements to consider when conducting a vulnerability assessment include the physical robustness of sanitation infrastructure, the socio-economic conditions of affected communities, and the institutional capacity to support adaptive measures. By thoroughly evaluating these factors, targeted strategies can be developed to enhance the resilience of sanitation systems against climate hazards. When assessing the vulnerability of sanitation infrastructure, design, age, and maintenance are critical factors. The design should incorporate resilience to extreme weather events, while aging infrastructure may be more susceptible to damage. Regular maintenance is crucial to ensure that sanitation systems remain functional and effective under stress. For non-sewered sanitation systems, robustness of

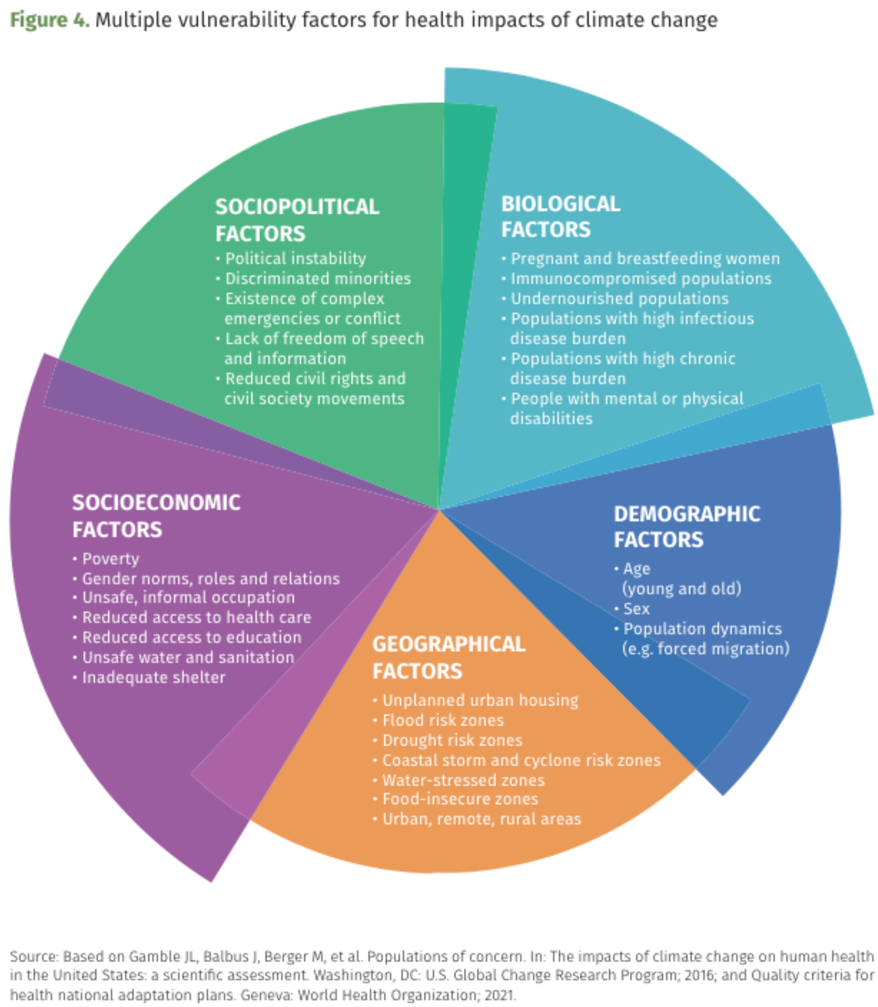
[69] IPCC, 2021

superstructures and adequacy of waste containment are key considerations. Additionally, supporting infrastucture such as transport and electricity that aid in the operation of these systems should be assessed for vulnerabilities.

As sanitation systems rely on a workforce, and non-sewered sanitation, in particular, is often managed by households and informal sanitation providers, considering the vulnerability of communities is essential for determining the overall vulnerability of a sanitation system. The susceptibility of people to suffer adverse consequences, thus impacting their ability to manage their sanitation solutions following exposure to hazards, is determined by many complex socio-economic factors. These include income levels, education, access to resources, and social networks. The livelihoods of sanitation workers, for example, are highly vulnerable to climate hazards. Intervention will be particularly urgent in areas where low levels of sanitation access and high levels of vulnerability to climate hazards converge. An example assessment of community vulnerability is presented in **Figure 2.2.**

By integrating these various dimensions into the vulnerability assessment, more comprehensive and effective adaptation strategies can be developed, ensuring that sanitation systems are resilient and capable of withstanding climate-related challenges.

Figure 2.2: An example assessment of community vulnerability. Source: 2021 WHO climate change and health vulnerability and adaptation assessment.



2.5 Climate Response

Risks relating to sanitation can also arise from human responses to climate change. These risks come about when the human responses do not achieve their intended outcomes or have trade-offs or negative side-effects on nature or society.[70] Responses that create risks may be considered "maladaptations" which include, for example, actions that unnecessarily increase greenhouse gas emissions, cause people to become exposed to other hazards, shift the burden of climate impacts onto other groups, or result in environmental degradation.[71]

Although sanitation risks relating to responses are relatively less studied in literature, some examples can be found. Households in urban areas of Indonesia reported deliberately opening pits or tanks during

70 Reisinger, A., Howden, M., Vera, C., et al. (2020) The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions. Intergovernmental Panel on Climate Change, Geneva, Switzerland. pp15

71 Juhola, S., Glaas, E., Linnér, B.O. and Neset, T.S., 2016. Redefining maladaptation. Environmental Science & Policy, 55, pp.135-140.

flooding events to allow floodwater to wash out the contents.[72] Raising latrines as an adaptation to flooding may create accessibility issues for people with physical limitation or be unacceptable to community members who do not wish to be seen entering a latrine.[73] Finally, climate-resilient toilets and the increased cost of emergency emptying services can be unaffordable for low-income households.[74] On a larger scale, climate change may lead to changes in human migration[75] which can affect sanitation access in the origin communities, for people in transit, for host communities, and for people settled in new areas, such as migrants who make homes in informal settlements that are not reached by sanitation services.[76]

[72] UTS-ISF, UI and UNICEF (2021). Climate-resilient urban sanitation in Indonesia: Hazards, impacts and responses in four cities. Institute for Sustainable Futures, University of Technology Sydney: Sydney. Authors: Freya Mills, Jeremy Kohlitz, Osha Ombasta, Dwica Wulandari, Ni Nyoman Sri Natih S., Inas Imtiyaz, Cindy Priadi and Juliet Willetts. Page 32.

[73] Kohlitz, J. and Iyer, R. (2021) 'Rural Sanitation and Climate Change: Putting Ideas into Practice' Frontiers of Sanitation: Innovations and Insights 17, Brighton IDS.

[74] ISF-UTS and SNV, 2019. Considering climate change in urban sanitation: conceptual approaches and practical implications. The Hague: SNV.

[75] Kaczan, D.J. and Orgill-Meyer, J., 2020. The impact of climate change on migration: a synthesis of recent empirical insights. Climatic Change, 158(3), pp.281-300.

[76] Jobbins, G., Landown, I. and Bernard, G. 2018. 'Water and sanitation, migration and the 2030 agenda for sustainable development. London: ODI.

3. Building the Climate Rationale for Sanitation Projects: Mitigation

Section 3 provides the climate science basis and rationale for the inclusion of mitigation activities in GCF sanitation projects. The Section sets out the nature (scope, type and relative importance) of emissions associated with sanitation systems and services across the entire sanitation value chain. The discussion considers three broad cases where emissions arise and maps these to the Scope 1/2/3 framework of the Greenhouse Gas Protocol:

- Emissions which arise within sanitation infrastructure and services when they are operated as designed;
- Emissions which are associated with sanitation failures and with discharge of incompletely stabilised faecal waste into the aquatic environment; and
- Emissions which arise from the use of products which could be appropriately substituted by products from sanitation systems applied on land or used for energy production.

3.1 Mapping emissions from sanitation

In an effort to standardise reporting of emissions from industrial and commercial entities, The World Business Council for Sustainable Development and World Resources Institute developed an approach to GHG accounting and reporting which uses three 'scopes'[77].

- **Scope 1: GHG emissions associated with normal operation of a system**, including energy generation, chemical processing, transportation of waste, materials and employees, and fugitive emissions;
- **Scope 2: GHG emissions from imports of electricity, heat, or steam**; and
- **Scope 3: other indirect emissions including employee travel, disposal or reuse of end products etc.**

The mapping of emissions from sanitation onto these accounting categories in its infancy. Sanitation systems are complex, diverse, often failing to take advantage of opportunities for circularity and characterised by significant failure; potential interventions are similarly diverse and may be designed to mitigate emissions from fully functional or from failed systems. It is therefore important from a *sanitation policy* point of view to make a distinction between three cases giving rise to sanitation emissions:

- emissions arising from the **as-designed operation of sanitation infrastructure and services;**
- emissions arising because of **disposal of unstable feacal matter into the aquatic environment or on to land;** and
- emissions arising from **the use of products including fertilisers and energy sources which could be substituted by well managed use of by-products from sanitation systems.**

[77] The World Business Council for Sustainable Development and World Resources Institute, September 2001: *The Greenhouse Gas Protocol a corporate accounting and reporting standard*. ISBN 2-940240-18-3

The relative size of these categories of emissions varies along the sanitation service chain and with the type of sanitation systems used. For simplicity, sanitation systems can be divided into two broad classes:

(a) Systems which store human excreta at the point of production, and from which in some cases part of the excreta may be taken away by road for disposal or treatment and disposal elsewhere; and
(b) Systems which move human excreta immediately away from the point of production by means of various types of water-borne sewers.

A significant majority of sanitation systems worldwide fall into the first class and this is also the fastest growing class of sanitation systems. Although there are many examples of sewered systems that are not adequately managed and which are prone to failure, onsite systems are particularly variable, and rarely operated as part of a well-planned system of waste collection and treatment at present[78].

The principal mechanisms and categories of emissions in these broad scopes, categories and classes are summarised in Tables 3.1 and 3.2.

Table 3.1. Principal sources of greenhouse gas emissions from whole-chain sanitation systems which store waste onsite before using road-based transport to move to treatment (pit latrines, septic tanks and container-based sanitation) [79]

	Containment	**Emptying and transport**	**Treatment**	**Managed or unmanaged disposal in aquatic environments or on land**	**Substitution of sanitation by-products for other products**
Scope 1					
Direct and fugitive emissions	CO_2, CH_4 and N_2O from pits, tanks and containers	n/a	CO_2, CH_4 and N_2O from treatment plants	CO_2, CH_4 and N_2O from land and water bodies	n/a
Transport	n/a	CO_2 from truck fuel combustion	n/a	CO_2 from truck fuel combustion removing sludge for land disposal	n/a
Scope 2					
Imported energy use	n/a	n/a	CO_2 from imported energy used in treatment processes	n/a	n/a
Scope 3					
Embedded carbon	Materials in construction of pits, tanks and containers	n/a	Materials in construction treatment plants	n/a	n/a
Other indirect emissions	n/a	n/a	n/a	n/a	Reduction in manufacturing and transportation

[78] Strande, L., Evans, B., von Sperling, M., Bartram, J., Harada, H., Nakagiri, A., & Nguyen, V. -A. (2023). Urban Sanitation: New Terminology for Globally Relevant Solutions?. *Environmental Science & Technology*. doi:10.1021/acs.est.3c04431

[79] Modified from Johnson, J., Zakaria, F., Nkurunziza, A. G., Way, C., Camargo-Valero, M. A., & Evans, B. (2022). Whole-system analysis reveals high greenhouse gas emissions from citywide sanitation in Kampala, Uganda. *Communications Earth & Environment*, *3*. doi:10.1038/s43247-022-00413-w

					emissions associated with chemical fertilisers, energy generation and pumping of water which are substituted

Table 3.2. Principal sources of greenhouse gas emissions from whole-chain sanitation systems which use systems connected to sewers[79]

	Containment	Emptying and transport	Treatment	Managed or unmanaged disposal in aquatic environments or on land	Substitution of sanitation by-products for other products
Scope 1					
Direct and fugitive emissions	n/a	CO_2, CH_4 and N_2O from in-sewer wastewater	CO_2, CH_4 and N_2O from treatment plants	CO_2, CH_4 and N_2O from land and water bodies	n/a
Transport	n/a	n/a	n/a	CO_2 from truck fuel combustion removing sludge for land disposal	n/a
Scope 2					
Imported energy use	n/a	CO_2 from imported energy used in pumping wastewater	CO_2 from imported energy used in treatment processes	n/a	n/a
Scope 3					
Emedded carbon	n/a	Materials in construction of sewerage	Materials in construction of treatment plants	n/a	n/a
Other indirect emissions	n/a	n/a	n/a	n/a	Reduction in manufacturing and transportation emissions associated with chemical fertilisers, energy generation and pumping of water which are substituted

The rate and scale of emissions from any particular sanitation system is highly dependent on the technology deployed, the manner of its operation and local contextual factors, including ambient temperatures and rainfall. To date, only limited empirical data exist with which to estimate emissions from complete sanitation systems. Although further research is needed in this area, it is possible from the available literature to draw several broad conclusions:

Firstly, the primary source of emissions in most sanitation system are direct emissions (part of Scope 1) caused by the stabilisation of faecal sludges in storage pits and tanks or at treatment plants[80]. These

[80] Cheng, S., Long, J., Evans, B., Zhan, Z., Li, T., Chen, C., . . . Li, Z. (2022). Non-negligible greenhouse gas emissions from non-sewered sanitation systems: A meta-analysis. *Environmental Research*, *212*(Part D). doi:10.1016/j.envres.2022.113468
Johnson, J., Zakaria, F., Nkurunziza, A. G., Way, C., Camargo-Valero, M. A., & Evans, B. (2022). Whole-system analysis reveals high greenhouse gas emissions from citywide sanitation in Kampala, Uganda. *Communications Earth & Environment*, *3*. doi:10.1038/s43247-022-00413-w

emissions are significant and are likely to have been systematically underestimated historically. Linked to this, it seems likely that in a large number of situations, operational emissions (from trucks and from pumping) may not be the main concern, although they do tend to attract the attention of policymakers and operators.

Secondly, the focus of many mitigation interventions is on the modification of wastewater treatment processes (usually seeking to reduce Scope 2 emissions from use of electricity), failing to address the primary issue that in many contexts, most faecal waste never reaches treatment. This emphasis may be because the limited empirical evidence that does exist about the rate of emissions from sanitation arises from studies of these wastewater treatment processes.

Finally, there is currently limited evidence that either of the classes of sanitation systems — those which use storage, and those which use sewers — are categorically ‘better’ than the other in terms of emissions. In many cases, the main sources of emissions are direct emissions which arise in poorly managed storage or treatment and from discharges of untreated faecal waste into the aquatic environment from leaking sewers and illegal dumping of the contents of pits and tanks. These are often significant and are further expanded below.

3.2 Direct emissions from excreta decomposition (Scope 1)

Direct emissions from the sanitation service chain (SSC) are caused by the microbiological processes taking place within the SSC elements. Processes that take place within initial containment, transport, treatment, and final release of treated or untreated effluent will all create pathways for direct GHG emissions. As explained in the table above, operational emissions will also exist from the SSC due to the release of fossil-based CO_2 into the atmosphere during production of energy for effluent transport and treatment systems.

The choice of process used to treat wastewater and faecal sludge will greatly impact the types and quantities of GHG emissions from individual sites. Anaerobic treatment systems or anaerobic conditions within containment and transportation will be a key pathway for CH4 emissions from the natural breakdown of organic matter. In comparison, aerobic treatment systems will be prone to producing higher amounts of N2O, although this is still possible within primarily anaerobic systems. CO2 will be released in both examples; however, these are largely treated as modern biogenic-based CO2 emissions. Therefore, unless there is a fossil-derived pollution element of wastewater or faecal sludge the direct CO2 emissions are not included in the IPCC national emissions accounting methodology[81]. It is important to properly differentiate between biogenic and non-biogenic CO2 emissions during plant operation, otherwise there is a risk of underestimating fossil-based CO2 emitted from direct and operational processes within treatment systems[82].

There are important differences in the type of waste produced by sewered systems and sanitation infrastructure which stores human excreta at the point of production. Systems which utilise sewers for transportation can be seen as conveying wastewater. This is because the system must have a relatively

[81] IPCC. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

[82] Wang, D., Ye, W., Wu, G. et al. Greenhouse gas emissions from municipal wastewater treatment facilities in China from 2006 to 2019. Sci Data 9, 317 (2022). https://doi.org/10.1038/s41597-022-01439-7

high water content for a sewer system to properly operate[83]. Alternatively, human waste stored at the point of production can be either wet or dry (e.g. flushed with or not flushed water, groundwater intrusion, or external drainage). This waste will typically have a higher organic content than wastewater found in sewered systems, since this will become diluted from domestic greywater, stormwater, groundwater, or other run-off water during transportation[84]. Human waste from systems that store in-situ is classified as faecal sludge. Treatment processes designed specifically for the treatment of wastewater will not be able to tolerate the much higher organic content of faecal sludge nor the often much thicker consistency.

Faecal sludge can be mixed into aerobic wastewater treatment plants at low quantities, however alternative processes specifically designed for faecal sludge are preferred. Anaerobic digestion, waste stabilisation ponds, drying beds, and planted wetlands are utilised globally for the treatment of faecal sludge. These will have a mix of anaerobic and aerobic conditions within them, with primarily anaerobic conditions existing. The treatment processes within wastewater treatment plants are currently far better understood than the complex processes which take place in systems which do not rely on sewers for immediate transportation of human waste.

The breakdown of organic matter in wastewater and faecal sludge during anaerobic conditions is the primary route for CH4 emissions within pits, tanks, sewers, treatment, and release. Sanitation infrastructure designed to store human waste on-site before emptying (pits and tanks) will inevitably operate under anaerobic conditions below the surface of the sludge. Some aerobic process may exist on the top layer of the scum or sludge. CH4 production will be driven by the lack of oxygen available in the anaerobic system and the amount of organic matter available for digestion and degradation. The decomposition of organic matter in wastewater and faecal sludge involves a series of three steps in which microorganisms change organic material eventually into acids, which methanogenic archaea can use to form bio-methane, carbon dioxide and sludge. Methanogenic archaea populations are key to CH4 emissions[85]. Numerous factors such as temperature, pH, oxygen levels, and other competing processes can affect the amount of CH4 produced from wastewater and faecal sludge[86]. CH4 can also be produced within wastewater treatment plants due to the stripping of methane partially dissolved within wastewater having formed in sewers and other pre-processes[87].

Nitrous oxide on the other hand is primarily produced during nitrification and de-nitrification processes or incomplete versions of these, especially in wastewater treatment plants. This is carried out by specific groups of bacteria in wastewater and faecal sludge treatment systems. Nitrification is known to take place at the liquid surface of pits and tanks where oxygen is available, but may not be limited to this location. During denitrification, N2O produced in anaerobic areas may dissolve into a liquid phase or be transformed into N2 before it can be released as a gas. Passing aerobic and anaerobic conditions have

[83] Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., Schertenleib, R. and Zurbrügg, C. 2014. Compendium of Sanitation Systems and Technologies. 2nd Revised Edition. [Online]. Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag). Available from: https://www.eawag.ch/en/department/sandec/publications/compendium/.

[84] Zewde, A.A., Li, Z. and Xiaoqin, Z. 2021. Improved and promising faecal sludge sanitizing methods: treatment of faecal sludge using resource recovery technologies. Journal of Water, Sanitation and Hygiene for Development. 11(3), pp.335–349.

[85] Meisam Tabatabaei, Raha Abdul Rahim, et al. … : Importance of the methanogenic archaea populations in anaerobic wastewater treatments, Process Biochemistry, Volume 45, Issue 8, 2010, Pages 1214-1225, https://doi.org/10.1016/j.procbio.2010.05.017

[86] Cioabla, A.E., Ionel, I., Dumitrel, GA. et al. Comparative study on factors affecting anaerobic digestion of agricultural vegetal residues. Biotechnol Biofuels 5, 39 (2012). https://doi.org/10.1186/1754-6834-5-39

[87] Matthijs R.J. Daelman, Ellen M. van Voorthuizen, Udo G.J.M. van Dongen, Eveline I.P. Volcke, Mark C.M. van Loosdrecht. Methane emission during municipal wastewater treatment. Water Research, Volume 46, Issue 11, 2012, Pages 3657-3670, ISSN 0043-1354, https://doi.org/10.1016/j.watres.2012.04.024

been shown to increase N2O emissions from heterotrophic denitrification, which could be important at the liquid surface of pits and tanks. Other factors including stripping of N2O due to aeration, pH, nitrite, and the existence of free nitrous acid[88]. These processes are relatively well understood in wastewater treatment plant design, however much less knowledge exists surrounding the processes for N2O emissions in pits, tanks, sewers and faecal sludge treatment plants. It has been shown that septic tanks can emit N2O, but there is a general absence of information for N2O emissions from pits and tanks, and other in-situ storage systems[89].

3.3 Emissions from transport of sludges (Scope 1)

In both sewered and road-based sanitation systems there may be transport of feacal sludges. In the former case this is usually associated with wastewater treatment processes, and partially stabilised sludges may be moved between treatment steps or taken away from the site of treatment for disposal on land, in the aquatic environment or for incineration or reuse in another industry. These 'operational' emissions fall with Scope 1 and are directly within the control of the operator of the sanitation service. The scale of such emissions will vary with the scale of the sanitation operation.

3.4 Emissions in the aquatic environment usually arising from sanitation failures (Scope 1)

Failure modes identified from sanitation systems include[90]:

- Open defecation into water bodies and surface run-off from open defecation zones[91];
- Overflowing pits and tanks, pits and tanks piped directly to water bodies, leaching from pit latrines, leach pits, and over-full septic tanks, plus injection wells for wastewater disposal that reaches groundwater without appropriate treatment in the soil matrix[92] [93];
- Direct dumping of the contents of pits and/or connection of septic tanks into the drainage system or other water bodies;
- Direct discharge of raw wastewater from wastewater treatment plants during bypass events (e.g., after heavy rainfall treatment plants do not have the capacity to treat all the incoming wastewater[94]);
- Sewer overflows (the discharge of wastewater before it reaches the treatment plant); and

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[88] Law Yingyu, Ye Liu, Pan Yuting and Yuan Zhiguo 2012Nitrous oxide emissions from wastewater treatment processesPhil. Trans. R. Soc. B3671265–1277. http://doi.org/10.1098/rstb.2011.0317

[89] Methane, Carbon Dioxide, and Nitrous Oxide Emissions from Septic Tank Systems Libia R. Diaz-Valbuena, Harold L. Leverenz, Christopher D. Cappa, George Tchobanoglous, William R. Horwath, and Jeannie L. Darby. Environmental Science & Technology 2011 45 (7), 2741-2747. DOI: 10.1021/es1036095

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[93] Orner, K.D., Naughton, C. and Stenstrom, T.A. (2018). Pit Toilets (Latrines). In: J.B. Rose and B. Jiménez-Cisneros (Eds), Water and Sanitation for the 21st Century: Health and Microbiological Aspects of Excreta and Wastewater Management (Global Water Pathogen Project). UNESCO. https://doi.org/10.14321/waterpathogens.56

[94] Xie, Y., Liu, X., Wei, H., Chen, X., Gong, N., Ahmad, S., Lee, T., Ismail, S., & Ni, S.-Q. (2022). Insight into impact of sewage discharge on microbial dynamics and pathogenicity in river ecosystem. Scientific Reports, 12(1), 6894–6894. https://doi.org/10.1038/s41598-022-09579-x

- Discharge of treated or partially treated waste from wastewater treatment plants[95].

As a result of these failures, there are large volumes of treated and untreated wastewater entering coastal environments globally.

- An estimated 4.3-7.1 million tonnes of nitrogen from wastewater enter coastal environments every year, from both unsafely and safely-managed sanitation[96].
- An estimated 1.5 million tonnes of phosphorus from wastewater enter surface waters every year[97].

When wastewater pollution enters aquatic environments, it can lead to nutrient over-enrichment and subsequent eutrophication. The evidence that eutrophication leads to an increase in greenhouse gas emissions along the freshwater to marine continuum is strong, with several documented examples from different systems demonstrating this ([98], [99], [100], [101]; [102]). The primary greenhouse gasses emitted are CO2, CH4, and N2O and the drivers for their release are complex. However, in broad terms, CO2 and CH4 are produced primarily via degradation of organic matter through aerobic and anaerobic processes, respectively. N2O is primarily produced through microbially mediated nitrification and denitrification [14], [15]). Organic matter is both directly discharged with wastewater and formed indirectly via nutrient-driven algal production.

Wastewater pollution not only leads to an increase in greenhouse gas emissions through changes in the biogeochemistry of the water column and sediment, it also directly impacts freshwater, coastal, and marine ecosystems. The degradation of these ecosystems also leads to an increase in greenhouse gas emissions. In freshwater systems, submerged plants are the most common primary producer. These plants deliver oxygen to sediment and promote CH_4 oxidation, both of which reduce the amount of CH_4 that is produced and reaches the atmosphere[14]. When freshwater systems receive too much nutrient loading, they shift to a phytoplankton dominated state, which can trigger low oxygen states that promote CH_4 production. Phytoplankton also produce N_2O, and the contribution of eutrophic lakes to

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[95] Hamdhani, H., Eppehimer, D. E., & Bogan, M. T. (2020). Release of treated effluent into streams: A global review of ecological impacts with a consideration of its potential use for environmental flows. Freshwater Biology, 65(9), 1657–1670. https://doi.org/10.1111/fwb.13519

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[101] Nguyen, An Truong, Julien Némery, Nicolas Gratiot, Thanh-Son Dao, Tam Thi Minh Le, Christine Baduel, and Josette Garnier. "Does Eutrophication Enhance Greenhouse Gas Emissions in Urbanized Tropical Estuaries?" *Environmental Pollution* 303 (June 15, 2022): 119105. https://doi.org/10.1016/j.envpol.2022.119105.

[102] Trevathan-Tackett, Stacey M., Alexandra C.G. Thomson, Peter J. Ralph, and Peter I. Macreadie. "Fresh Carbon Inputs to Seagrass Sediments Induce Variable Microbial Priming Responses." *Science of The Total Environment* 621 (April 15, 2018): 663–69. https://doi.org/10.1016/j.scitotenv.2017.11.193.

N_2O emissions has been estimated to be 18% of the N_2O currently accounted for from all rivers, estuaries, and coastal zones[103] [104].

Domestic wastewater pollution in coastal environments has well-documented impacts on coastal ecosystems like tidal marshes, mangrove forests, and seagrass meadows. These ecosystems provide a wide range of provisioning, regulating, habitat, and cultural services, and their total estimated economic values (US$/ha/yr, converted to 2023 values) are $284,478 for wetlands (i.e., tidal marshes, mangroves and salt water wetlands) and $42,437 for coastal systems (i.e., estuaries, continental shelf area, and seagrass) [105]. In recent years, these ecosystems have also become increasingly recognised for their carbon sequestration abilities. Globally, it has been estimated that seagrass meadows, mangrove forests, and tidal marshes hold 1.7-21 billion, 3-12 billion, and 0.86-1.35 billion tonnes of carbon, respectively[106]. The wide ranges in estimates are based on uncertainties around ecosystem extents, natural variability in carbon stocks, and differences in methodologies used to calculate carbon stocks. The degradation and loss of these ecosystems leads to both lost sequestration potential and loss of existing carbon stocks.

Nutrient over-enrichment and subsequent eutrophication of coastal areas has been identified as one of the main drivers of seagrass meadow loss [107] [108]. The main mechanism leading to this decline is light reduction through stimulation of high-biomass algal overgrowth as epiphytes and macroalgae in shallow coastal areas and as phytoplankton in deeper coastal waters. Once seagrass meadows begin to degrade, there are a variety of feedback loops that exacerbate their decline.

Nutrient over-enrichment acts in more insidious but also significant ways to destabilize tidal marshes and mangrove ecosystems[109] [110]. One of the main ways that mangroves respond to nutrient over-enrichment is to increase aboveground growth and biomass, and reduce allocation of resources to belowground biomass, which is where long-term carbon storage primarily occurs[23]. This shifting allocation of resources interacts with climate change in two ways: 1) it means that mangroves reduce

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[103] Burlacot, A., Richaud, P., Gosset, A., Li-Beisson, Y., & Peltier, G. (2020). Algal photosynthesis converts nitric oxide into nitrous oxide. *Proceedings of the National Academy of Sciences*, *117*(5), 2704-2709

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[109] Mack, M. R., J. Adam Langley, I. C. Feller, and S. K. Chapman. "The Ecological Consequences of Nutrient Enrichment in Mangroves." *Estuarine, Coastal and Shelf Science* 300 (May 1, 2024): 108690. https://doi.org/10.1016/j.ecss.2024.108690.

[110] Mozdzer, Thomas J., Elizabeth Burke Watson, William H. Orem, Christopher M. Swarzenski, and R. Eugene Turner. "Unraveling the Gordian Knot: Eight Testable Hypotheses on the Effects of Nutrient Enrichment on Tidal Wetland Sustainability." *Science of The Total Environment* 743 (November 15, 2020): 140420. https://doi.org/10.1016/j.scitotenv.2020.140420.

the amount of carbon they sequester[23], [111]; 2) it makes them more vulnerable to degradation from extreme weather events and erosion, which are amplified by climate change ([112], [113], [114], [23], [115]).

Once coastal ecosystems begin to degrade, the sediment underneath the living biomass is exposed to wave energy and water movement, destabilizing it and exposing it to oxygen. This exposure leads to increased microbial activity, which releases large amounts of CO2 emissions to the atmosphere or water column ([116], [22], [25], [117]).

The global average amount of carbon stored in living seagrass biomass and the top one meter of sediment has been estimated to be ~168 Tonnes C ha−1.[118] Recent estimates of global seagrass cover are between 300,000 and 600,000 km^2 and 88% of seagrass meadows are exposed to some level of domestic wastewater pollution.[119] Based on these values, conservatively, 4.4 billion Tonnes of Carbon are vulnerable to wastewater pollution, equating to nearly half of the worldwide emissions of CO_2 from burning fossil fuels. Mangrove forests store ~250 Tonnes C ha−1 in their soil[30 25]. Although there are no estimates of the prevalence of mangrove ecosystem exposure to wastewater pollution, given where they are found, they are likely exposed to high rates of treated and untreated domestic wastewater. In many places, mangroves are specifically used as wastewater treatment options, given their ability to seemingly absorb high levels of pollution[120].

3.5 Emissions on land resulting from managed disposal or systems failures (Scope 1)

Apart from emissions in the aquatic environment, sanitation systems can also contribute to GHG emissions when sanitation products or byproducts are disposed of on land*. When effluent is disposed of in soak pits, the presence of anaerobic conditions as it percolates through the soil can generate significant amounts of CH_4 emissions. N_2O emissions can also be significant when effluent is disposed of in leach fields where nitrification and denitrification processes occur as effluent is dispersed into the soil.

Sludge disposed of in landfills or other surface disposal sites, even temporarily, can generate significant CH_4 emissions due to the anaerobic conditions typically present in these environments. This is especially

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[111] Santos-Andrade, Mauricio, Vanessa Hatje, Ariane Arias-Ortiz, Vinicius F. Patire, and Luciana A. da Silva. "Human Disturbance Drives Loss of Soil Organic Matter and Changes Its Stability and Sources in Mangroves." *Environmental Research* 202 (November 1, 2021): 111663. https://doi.org/10.1016/j.envres.2021.111663.

[112] "Coastal Eutrophication as a Driver of Salt Marsh Loss | Nature." Accessed May 23, 2024. https://www.nature.com/articles/nature11533.

[113] Feller, Ilka C., Emily M. Dangremond, Donna J. Devlin, Catherine E. Lovelock, C. Edward Proffitt, and Wilfrid Rodriguez. "Nutrient Enrichment Intensifies Hurricane Impact in Scrub Mangrove Ecosystems in the Indian River Lagoon, Florida, USA." *Ecology* 96, no. 11 (November 1, 2015): 2960–72. https://doi.org/10.1890/14-1853.1.

[114] Lovelock, Catherine E., Marilyn C. Ball, Katherine C. Martin, and Ilka C. Feller. "Nutrient Enrichment Increases Mortality of Mangroves." *PLOS ONE* 4, no. 5 (May 19, 2009): e5600. https://doi.org/10.1371/journal.pone.0005600.

[115] Turner, R. Eugene. "Beneath the Salt Marsh Canopy: Loss of Soil Strength with Increasing Nutrient Loads." *Estuaries and Coasts* 34, no. 5 (September 1, 2011): 1084–93. https://doi.org/10.1007/s12237-010-9341-y.

[116] Atwood, Trisha B., Rod M. Connolly, Hanan Almahasheer, Paul E. Carnell, Carlos M. Duarte, Carolyn J. Ewers Lewis, Xabier Irigoien, et al. "Global Patterns in Mangrove Soil Carbon Stocks and Losses." *Nature Climate Change* 7, no. 7 (July 1, 2017): 523–28. https://doi.org/10.1038/nclimate3326.

[117] Trevathan-Tackett, Stacey M., Alexandra C.G. Thomson, Peter J. Ralph, and Peter I. Macreadie. "Fresh Carbon Inputs to Seagrass Sediments Induce Variable Microbial Priming Responses." *Science of The Total Environment* 621 (April 15, 2018): 663–69. https://doi.org/10.1016/j.scitotenv.2017.11.193.

[118] Fourqurean et al., 2012.

[119] Tuholske et al., 2021

[120] Ouyang, Xiaoguang, and Fen Guo. "Paradigms of Mangroves in Treatment of Anthropogenic Wastewater Pollution." *Science of The Total Environment* 544 (February 15, 2016): 971–79. https://doi.org/10.1016/j.scitotenv.2015.12.013.

so if the sludge has not undergone adequate stabilization. In some contexts, sludge is disposed of via incineration to generate energy and this contributes to N_2O emissions and, to a lesser extent, CH_4, depending on the combustion efficiency. When sludge and sludge-derived products such as compost or pellets are applied to agricultural land, CH_4 emissions are negligible, especially if well-stabilized products are used. However, the N_2O emissions can be significant, particularly in warmer conditions and poorly drained soils where denitrification is more active. When applying sludge and sludge-derived products to agricultural land, it is essential to consider their full substitution effect which can significantly influence the overall emissions accounting across the entire sanitation chain (see 4.3.5).[121]

3.6 Emissions from use of imported energy for operations (Scope 2)

In both sewered and road-based sanitation systems energy may be imported for pumping wastewater in sewered systems and at both wastewater and faecal sludge treatment plants. Electricity may also be used to run administrative offices, call centres and other indirect service elements of the sanitation system. Unlike the energy used to physically move sludges around, these 'operational' emissions fall within Scope 2. The scale of such emissions will vary with the scale of the sanitation operation.

3.7 Unrealised potential emissions reductions from substituting sanitation products in place of higher-cost, higher-impact inputs (Scope 3)

Sanitation produces several categories of by-products (or products) including water, nutrients, energy and other high value materials. Each of these has potential to be used under some circumstances, in the downstream economy, and can substitute for other higher-cost higher-impact inputs[122].

- **Water:** Over 360 billion m^3 of municipal wastewater is generated globally every year, but less than 30 billion m^3 of treated wastewater ends up in planned reuse[123]. The reuse of treated wastewater at the point of production (for example as flushing water), or at larger scale for agricultural irrigation, industrial processes, replenishing aquifers or even direct potable reuse, can enhance water availability especially in water scarce regions and reduce freshwater extraction, reducing the need for pumping freshwater from long distances, and efficiently delivering water to the point of need.
- **Nutrients:** Up to a quarter of the global demand for nitrogen and phosphorus fertilizers in agriculture could theoretically be met through nutrient recovery from excreta-derived waste streams like urine and wastewater[124] thereby offsetting the need for synthetic fertilizers with their high carbon footprint.
- **Energy:** The energy embedded in the amount of wastewater generated globally is sufficient to power 158 million households[125], based on the calorific value of excreta and other excreta derived waste streams.

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[121] Lambiasi, L., Ddiba, D., Andersson, K., Parvage, M., & Dickin, S. (2024). Greenhouse gas emissions from sanitation and wastewater management systems: a review. *Journal of Water and Climate Change*.https://doi.org/10.2166/wcc.2024.603.

[122] UNEP and GRID-Arendal, "Wastewater – Turning Problem to Solution. A UNEP Rapid Response Assessment," September 8, 2023, 26–45, https://doi.org/10.59117/20.500.11822/43142.

[123] UNEP and GRID-Arendal, 26–45.

[124] UNEP and GRID-Arendal, 26–45.

[125] UNEP and GRID-Arendal, 26–45.

- **Other materials:** It is possible to recover other types of materials such as cellulose, volatile fatty acids, extracellular polymeric substances and polyhydroxyalkanoates, all of which have various industrial applications[126].

3.8 Introductory guidance for measuring and monitoring emissions from sanitation systems

As the evidence for emissions from in situ real-life sanitation systems is currently in a state of rapid development, it is not appropriate to provide rigid guidance on methods of measurement or estimation. Both measurement and estimation are highly context-specific and specialised. In the case of measurement in particular, the recommendation is to work with qualified scientists with a track record in measuring emissions across the entire sanitation value chain.

In terms of estimation, the Intergovernmental Panel on Climate Change (IPCC) provides comprehensive guidelines and methodologies for estimating greenhouse gas (GHG) emissions across five sectors: i) Energy; ii) Industrial processes and product use; iii) Agriculture, forestry, and other land use; iv) Waste; and v) Other. These methodologies are presented in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) and the more recent refinements (IPCC, 2019). Each sector contains standardised methodologies for calculating GHG emissions measured as carbon equivalent (CO2e) to support the preparation of national GHG inventories and to monitor progress towards the achievement of Nationally Determined Contribution (NDC) targets.

The estimation of Scope 1 emissions from sanitation systems is covered in Volume 5, Chapter 6 of the 2019 refinement of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019). Other potential sources of GHG emissions, such as those related to the use of manure for fertiliser, are also included in IPCC guidance. In addition, there are indirect emissions that are outside the IPCC Waste Volume 5 (IPCC, 2019c), which include:

i) Emissions associated with operational emissions (Scope 2) that are covered in Volume 2 of the Guidelines (IPCC, 2019a); and

ii) Emissions related to embedded carbon (Scope 3) that are covered in Volume 3 of the Guidelines, 'Industrial Processes and Product Use' (IPCC, 2019b).[127]

Over the coming years there will be significant additional data which can be used to prepare estimates with increasing levels of confidence as the empirical evidence base grows.

[126] UNEP and GRID-Arendal, "Wastewater – Turning Problem to Solution. A UNEP Rapid Response Assessment," September 8, 2023, 26–45, https://doi.org/10.59117/20.500.11822/43142.

[127] Adapted from UNICEF (forthcoming) *Estimating Greenhouse Gas Emissions from Sanitation Systems: Methodologies and Guidance for Application at National and City Levels*. Draft report prepared by ECOPSIS and University of Bristol.

4. Responses and Interventions

Section 4 provides guidance on the specific interventions that can be included within climate-resilient sanitation projects and programmes. The Section begins by outlining the potential for sanitation to act as an entry point for wider systems change across sectors and to contribute to transformative adaptation to climate change. The Section then introduces:

- Potential sanitation interventions to support climate change adaptation across the sanitation service chain. These interventions respond to the risks posed by climate change to sanitation outlined in Section 2;
- Potential sanitation interventions to support climate change mitigation through reduced greenhouse gas emissions, building on the linkages set out in Section 3; and
- Potential policy, institutional, regulatory and financing (PIRF) interventions to strengthen sanitation systems and enable climate-resilient sanitation.

4.1 Adaptation

4.1.1 Introduction to transformative adaptation

In addressing adaptation needs, there are three types of capacity important to support preparedness and dealing with disrupted sanitation services: coping capacity, adaptive capacity and transformative capacity.[128] Interventions to address climate impacts on sanitation systems can focus on any of these three, based on the specific contextual risks and the available resources to support adaptation. In some contexts, support to users to cope with disrupted services and reduce health risks may be valuable. In other contexts, either building adaptive capacity to modify technologies or practices, or transformative capacity to engage in wider systems change may be possible.

Incremental adaptation focuses on modifications to existing sanitation systems to improve their ability to withstand or quickly recover from climate hazards. Many of these modifications are explored in **Section 4.2** below. By contrast, transformative adaptation involves wider systems change, and in the case of sanitation, there are opportunities to reconfigure sanitation systems within the wider water cycle, particularly in urban contexts. The IPCC Sixth Assessment Report asserts with high confidence that most adaptation efforts are fragmented and sector-specific and that greater attention is needed towards processes of transformative adaptation.

Transformative adaptation to climate change follows six key characteristics: restructuring, path-shifting, innovation, multi-scale change, systemwide change and persistence.[129] For sanitation systems, there are many opportunities to use sanitation as an entry point for wider systems change that works across

[128] Christophe Béné, Rachel Godfrey Wood, Andrew Newsham and Mark Davies. September 2012 Resilience: New Utopia or New Tyranny? Reflection about the Potentials and Limits of the Concept of Resilience in Relation to Vulnerability Reduction Programmes, IDS WORKING PAPER Volume 2012 Number 405

[129] Fedele et al., 2019, Transformative adaptation to climate change for sustainable socialecological systems https://doi.org/10.1016/j.envsci.2019.07.001

sectors, to promote climate resilience not only of sanitation systems but more broadly. Integrated management and fostering the interlinkages between sectors are important considerations for GCF when assessing project proposals. These interlinkages between sanitation and other sectors are summarised in **Box 4.1** below.

Box 4.1: The importance of integrated management approaches in CRS proposals to GCF.

For GCF it is important that sanitation project proposals elaborate on the interlinkages that foster the integrated nature of sanitation and wastewater management with broader environmental and socio-economic systems, highlighting the importance of comprehensive and coordinated management approaches. In the context of a changing climate, such interlinkages between sanitation and wastewater treatment and other sectors include (but may not be limited to):

1. **Water supply:** efficient wastewater treatment ensures safe reuse of treated water, augmenting water supply especially in water-scarce regions.
2. **Water resource management:** proper management of wastewater reduces pollution in water bodies, aiding in drought and flood management by maintaining the quality of available water resources.
3. **Health:** effective sanitation and wastewater management prevent water- and excreta-related diseases, improving public health outcomes.
4. **Food security:** treated wastewater can be used for agricultural irrigation, enhancing safe food production and security; [130] nutrients from human waste can be reused in agriculture.
5. **Ecosystem protection**: reducing pollutants through wastewater and faecal sludge treatment protects aquatic ecosystems and biodiversity.
6. **Energy:** adequate sanitation systems and wastewater treatment plants can generate biogas from organic waste, contributing to renewable energy supplies and reducing greenhouse gas emissions.
7. **Economy and livelihoods:** where the proper safeguards are in place, sanitation provides a wide range of economic benefits, including decent work for sanitation workers.

In urban contexts, it is emphasised that **sanitation should be considered alongside wider urban services and development processes**. Climate-resilient urban sanitation requires integrated planning processes that recognise interdependencies between water supply, sanitation (sewered and non-sewered), greywater management, stormwater management, solid waste management and other basic services, including (but not limited to) transport and road access, electricity, housing and land tenure.

4.2 Potential interventions to support climate change adaptation across the sanitation service chain

The adaptation responses discussed in this section and summarised in Table 4.1 are presented according to their position in the sanitation chain for both sewered and non-sewered sanitation services. Examples for each type of adaptation response have been included, referencing both LMIC and HIC contexts.

[130] For guidance on optimising the health and food security benefits of safely managed sanitation, see WHO *(2022) Sanitation Safety Planning: Step-by-step risk management for safely managed sanitation systems.*

Climate-resilient sanitation responses can be grouped into three main categories:

- ***Technical modifications to new or existing infrastructure:*** specific modifications to the design of new or existing sanitation infrastructure to adapt them to new climate change conditions.
- ***Active management:*** proactive approaches to the management of sanitation services, anticipating extreme weather events, instead of reacting to issues as they arise.
- ***Preparing sanitation systems for cascading impacts of failures in other systems:*** providing redundancy/flexibility in sanitation systems to allow them to continue operating without disruption when other systems which they rely on are impacted by climate change.

Table 4.1: Sanitation Adaptation Responses.

Type of Response	**Containment**	**Emptying and Conveyance**	**Treatment, Reuse and Disposal**
Technical modifications to new or existing infrastructure	Raised latrines/ containment **CRIS** Robust and resilient latrines/ containment **CRIS** Low or no water latrines **CRIS** Sealable and removable containment CRIS	Simplified sewers **CRIS** Vacuum sewer systems **CRIS** Treatment of sewer overflows **CRIS/IM** Sustainable Drainage Systems **CRIS/IM**	Site selection and flood prevention **CRIS** Corrosion resistant design **CRIS** Modular FSTP/WWTP design **CRIS** Decentralised/ distributed FSTP/WWTPs **CRIS**
Active management of the infrastructure or service		Scheduled or more frequent emptying for OSS **CRIS** Preventative O&M of sewer systems **CRIS**	Application of treated wastewater and faecal sludge **CRIS/IM**
Preparing sanitation systems for cascading impacts of failures in other systems	Alternative water sources for flush toilets **CRIS/IM**	Alternative emptying vehicles and equipment for OSS **CRIS**	Alternative power sources for FSTPs and WWTPs **CRIS**

Elements of GCF projects: CRIS – Climate Resistant Infrastructure and Services, IM – Integrated Management

4.2.1 Containment

Responses to avoid containment failure which either address failures caused by intense and prolonged precipitation, storms, cyclones or water scarcity as a result of variable or declining rainfall.

Technical modifications to containment infrastructure

Below we summarise modifications that can support the climate resilience of containment infrastructure. This may involve incorporating these design features as part of: the provision of new sanitation infrastructure, for households or communities who currently use an unimproved facility or practice open defecation; replacement infrastructure (for example, the bulk of rural sanitation infrastructure is already beyond its expected lifespan and in need of replacement)[131]; or modifications to existing sanitation facilities.

Raised latrines to avoid pit and tank overflow, and flotation of underground tanks. Raised latrines are a commonly proposed alternative to pit-based latrines in flood-prone areas. These '*above-ground-level'* latrines may sometimes reduce the risk of flood water entering the tanks or pits that would otherwise cause them to overflow. The application of raised latrines in urban contexts can be found in Lusaka[132] and Madagascar[133]; they have also been used in villages in Bangladesh, Burkina Faso and India[134]. The design of the raised toilet should consider increased exposure to wind hazards[135] and the risk of catastrophic failure in flooding situations. It is essential that any modified toilet design maintains full accessibility for those with different physical abilities.

Construction of more robust latrines that resist extreme weather. Several responses focus on building more resilient latrines and containment structures that can resist extreme weather events. Anti-cyclone standards have been incorporated into latrine design in Madagascar[136]and Bangladesh[137]. Some communities in the Lake Victoria Basin[138] [139] are using heavier construction materials and improved construction practices to preserve the structural integrity of latrines. Examples of this include the use of concrete rings to reinforce pits, the sealing of joints to resist groundwater ingress and the use of geodesic shapes to better withstand the force of flooding. Containment that can be sealed and removed has proven effective for ensuring no waste is released into the environment during flooding[140] and holds potential for providing safe and rapidly deployable emergency and transitional sanitation.

By selecting to build robust toilets it is implicit that households can afford to pay or will be subsidised to pay for a robust toilet, that the builder of the toilet is sufficiently trained, and that there is all-year access to the materials required to build and repair the toilets. The decision on the type of toilet to be used should be taken in discussion with the community, since in some cases (for example, where there is only seasonal access to materials markets) it might be preferable to build quickly reparable toilets from local materials rather than robust toilets.[141]

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131 SNV – Climate-resilient rural WASH services.

132 Jeremy Kohlitz, Ian Cunningham, Juliet Willetts. ClimateFIRST: Climate Framework: How to Guide, Sydney: UTS-ISF, 2023

133 Integrating sanitation and climate change adaptation: lessons learned from case studies of WaterAid's work in four countries, Gordon Tallulah and Hueso, Andres, 2021 Waterlines Vol 40. pp107-114

134 Integrating sanitation and climate change adaptation: lessons learned from case studies of WaterAid's work in four countries, Gordon Tallulah and Hueso, Andres, 2021 Waterlines Vol 40. pp107-114

135 Jeremy Kohlitz, Ian Cunningham, Juliet Willetts. ClimateFIRST: Climate Framework: How to Guide, Sydney: UTS-ISF, 2023

136 Integrating sanitation and climate change adaptation: lessons learned from case studies of WaterAid's work in four countries, Gordon Tallulah and Hueso, Andres, 2021 Waterlines Vol 40. pp107-114

137 Jeremy Kohlitz, Ian Cunningham, Juliet Willetts. ClimateFIRST: Climate Framework: How to Guide, Sydney: UTS-ISF, 2023

138 Stephen, Marcus Hannah, Muga Raphine. Hodgkins. Climate adaptation and WASH behaviour change in Lake Victoria Basin s.l Journal of Water, Sanitation and Hygiene for Development, 2023

139 Climate adaptation and WASH behaviour change in the Lake Victoria Basin. Marcus, Hannah, Muga, Raphine and Hodgkins, Stephen, 3, 2023 Journal of Water, Sanitation and Hygiene for Development Vol 13 pp 174-186

140 World Bank. 2019. "Evaluating the Potential of Container-Based Sanitation." World Bank, Washington, DC.

141 Jeremy Kohlitz, Ruhil Iyer, Frontiers of Sanitation: Innovations and Insights: 17 Rural Sanitation and Climate Change: Putting Ideas into Practice, 2021

Latrines with low or no water requirements to reduce water consumption. Dry or waterless toilets are commonly used to combat water scarcity caused by the decline in rainfall whilst also providing the opportunity for the safe reuse of excreta. The ecosan and fossa alterna toilets require significant space to build the containment tanks used to store faeces until it is safe to reuse.[142] In dense urban settings, container-based sanitation provides a viable option for toilets that can be installed inside dwellings. Container-based sanitation is a sustained sanitation service, featuring toilets that use little or no water and include containers that are frequently sealed and collected, and their contents are often used to generate reuse products (biomas, biogas, soil conditioner, animal feed, fertiliser (urine derived)). For communities more familiar with flush toilets, effective communication and socialisation is required to overcome any opposition to changing to dry toilets[143].

Active management of containment

***Frequent* emptying and emptying pits and tanks before large rain events.** As outlined in Section 3, the frequency and intensity of rainfall events is increasing in many parts of the world. Where sanitation containment is poorly designed and irregularly emptied, rainfall event modelling reveals the extensive travel of pollution plumes and pathogens from the overflow of containment units into local drainage systems. In parallel to improving latrine construction as discussed above, the frequent emptying of facilities and scheduled emptying that considers seasonal rainfall patterns, are active management methods which increase the resilience of sanitation systems at city level. Active management also requires that households and service providers are reached by early warning systems and know what actions to take. Active management is discussed in more detail in the section on faecal sludge/septage emptying and transportation.

Preparing for cascading impacts of failures in systems related to containment

Use of alternative water sources for flushing toilets to reduce water consumption. Water scarcity is increasingly leading to the use of alternative water sources to flush toilets. In Hong Kong for example, seawater is used for flushing[144] ; and in Jordan, San Francisco and Cape Town there are examples of reusing greywater for this purpose. In Jordan, UNICEF has used solar-powered, decentralised greywater treatment in schools. Greywater from school handwashing basins is collected and treated to provide water for flushing and irrigation[145]. Cape Town has developed guidelines to promote safe reuse of greywater by its citizens at household level. Further detail of how wastewater reuse is being applied by several cities worldwide is provided in **Section 4.2.4**.

4.2.2 Emptying and Transportation of Faecal Sludge/Septage

Responses to address disruption to faecal sludge/septage management services due to climate change, including preventative emptying and research into alternative emptying mechanisms.

Active management of faecal sludge/septage emptying and transportation

Active management of faecal sludge (FS)/septage emptying and transportation is predominantly about regular/preventative emptying of pits and tanks and the delivery of collected waste for effective treatment. In India for example, CEPT University is working with city governments in the provision of scheduled desludging services [146]. In Cox's Bazar, Oxfam Bangladesh uses the '*PIT Intelligent Tracker'* app

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142 Jeremy Kohlitz, Ian Cunningham, Juliet Willetts. ClimateFIRST: Climate Framework: How to Guide, Sydney: UTS-ISF, 2023
143 Jeremy Kohlitz, Ian Cunningham, Juliet Willetts. ClimateFIRST: Climate Framework: How to Guide, Sydney: UTS-ISF, 2023
144 GIZ, Climate-resilient Urban Sanitation: Accelerating the Convergence of Sanitation and Climate Action, 2021
145 UNICEF, WASH Climate-Resilient Development Technical Brief Climate-resilient Sanitation in Practice s.l. UNICEF, 2022
146 Willets, Juliet, Kumar, Avni and Mills, Freya. Urban Sanitation and Climate Change: A public service at risk, 2022

to predict the extent to which a containment unit is filling up, allowing operators to proactively schedule desludging activities. Finally, in Santa Cruz, Bolivia, regulatory mechanisms have been introduced to promote timely emptying of pit latrines[147]. As a sustained sanitation service, featuring toilets with containers that are sealed and frequently collected (1-3 times a week), container-based sanitation, whether on a temporary or longer-term basis, delivers an effective active management solution.[148] When promoting more regular emptying of latrines, consideration should be given to the capacity of users to pay for a more frequent service and to the health, safety and capacity of pit emptiers. The use of targeted subsidies should be considered for households that could not otherwise afford this service. To be most effective the time of regular/scheduled emptying should take into account seasonal rainfall patterns. Early warning systems should be designed to reach pit emptiers, who should also be aware of what actions to take. It should be noted that in order to strengthen resilience, active management will require the fundamentals of sustainable sanitation services to be in place, such as accessible roads, sufficient occupational and health and safety measures, and discharging of sludge into a FSTP and not drains or the local environment.

Preparing for cascading impacts of failures in systems related to faecal sludge emptying and transportation

Damage to roads or flooding can cause disruption to faecal sludge/septage emptying services where there is a reliance on motorised emptying vehicles such as vacuum tankers. Alternative emptying and transportation systems need to be used when motorised emptying vehicles are unable to access the household containment structure.

In Uganda, the Brilliant Sanitation Limited enterprise offers two types of emptying service to customers: cesspool/vacuum tankers for lined pits and septic tanks; and a 'gulper' technology (a direct lift pump that can enter a pit larine up to three meters for unlined toilets and pits located in areas that are difficult to access with the vacuum vehicles[149]. In Kisumu, Kenya, Opero Services and Practica Foundation are rolling out a mobile pit emptying unit powered by a portable compressor that can be used in areas with low accessibility, while providing a safe emptying method to workers and a pump mechanism and valve system which minimises blockages from large solids[150]. As container-based sanitation services are well-suited to the most densely populated areas, they usually use a mix of vehicle types to transport waste and reach last mile customers, including hand carts, increasing the likelihood that customers can still be reached at times when motorised emptying vehicles can't.

4.2.3 Wastewater Conveyance

Climate-induced failures in sewer systems are mostly due to A) a reduction in sewer flow due to water scarcity, responses to which include the construction of simplified sewers; or B) significant increases in flow due to more frequent intense rainfall events, responses to which include upsizing, pre-treatment of overflows and Sustainable Drainage Systems (SuDs).

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[147] Mikhael Georges et al, Climate-resilient Urban Sanitation: Accelerating the Convergence of Sanitation and Climate Action. Bonn: Deutsche Gesellschaft fur Internationale Zusammenarbeit, 2021

[148] World Bank. 2019. "Evaluating the Potential of Container-Based Sanitation." World Bank, Washington, DC.

[149] Brilliant Sanitation (Online) [Cited: 15 April 2024] https://www.brilliantsanitation.com/services

[150] Opero Services. (Online) 2023, The PuPu Pump

Technical modifications to wastewater conveyance infrastructure

Use of sewer systems that require less water to operate in water-scarce areas

Simplified or condominial sewers are a climate-resilient response for wastewater conveyance in water-scarce areas, as they require less water to operate than conventional sewers. They usually employ small-diameter pipes laid at a relatively shallow gradient within the property boundary or under sidewalks in front of the house. A simplified sewer network functions by gravity. This removes (or reduces) the need for pumping stations, which provides the overall system with additional resilience as pumping station operations can be vulnerable to climate effects such as power outages[151].

Simplified sewers are used in multiple cities, often in densely populated, informally laid out areas with difficult access and limited space for implementing conventional sewers. Examples of simplified sewers can be found in Nairobi, Kenya;[152] and in Fortaleza, Brasilia, Salvador and Recife in Brazil[153] [154]. Active operation and maintenance is as crucial for the sustainability of these types of sewers as it is for conventional sewers. In Brasilia, the water and sanitation company CAESB's approach to simplified sewerage also recognised the importance of undertaking community and household outreach and involving the community at each stage from system design to construction, leading to high levels of ownership, connection rates in excess of 98% and high willingness to pay the connection costs and subsequent monthly tariffs.

Vacuum sewer systems also require less water to operate. Their use has been seen in systems that separate blackwater from greywater, such as in Helsingborg, Sweden, where the vacuum system allows for low-flush toilets to be used. The city's 'Tre-Rör-Ut' ('Three-Pipes-Out') initiative is an innovative source-separation and resource-recovery system for blackwater, greywater and food waste that currently serves 900 people in a new area of urban redevelopment. The system has separate pipes that collect and transport blackwater, greywater and food waste for their respective treatment and reuse.[155]

Adapting to more frequent extreme weather events and intense rainfall

Increases in the volume and frequency of overflows from sewer systems, due to increased precipitation, is a common issue in cities with combined sewer systems, adversely impacting the quality of water bodies that receive the overflow. Responses to these scenarios include:

Upsizing - Current UK government plans call for an overall reduction in storm overflow discharges[156]. In London, the 'Thames Tideway', a 25km tunnel is being built to intercept, store and transfer 1.6 million m^3

[151] Simplified sewer. Sustainable Sanitation and Water Management Toolbox (Online) [Cited 15 April 2024] https://sswm.info/taxonomy/term3792/simplified-sewer

[152] WSUP (2022) A Guide to Simplified Sewer Systems in Kenya.

[153] Urban Water Atlas. Finding a Two-Prong Solution to Fortaleza's Water Scarcity and Sanitation Issues. (Online) 2020 [Cited 21032023] https://www.urbanwateratlas.com/2020/12/08/fortaleza/

[154] Sustainable Sanitation and Water Management Tool Box Simplified Sewerage (Online) [Cited: 24 April 2024] https://sswm.info/sites/default/files/reference_attachments/SANICON%20ny%20Simplified%20Sewerqage.pdf

[155] Schelbert, V., et al. "Tre-Rör-Ut" in Helsingborg, Sweden. Lighthouse Synthesis Report. s.l. : Eawag.

[156] DEFRA, 2022, Storm Overflows Discharge Reduction Plan and Report on Feasibility of Elimination of Discharges from Storm Overflows, Department for Environmental Food and Rural Affairs, 26 August 2022

of wastewater from combined sewers to treatment which would otherwise discharge directly to the River Thames[157].

Pre-treatment - The town of Carimate in Italy has introduced constructed wetlands to pre-treat sewer overflows before they are discharged into the environment [158]. This approach has also been adopted by Dwr Cymru (Welsh Water), where in addition to removing pollutants from the sewer overflows, the wetland provides local amenity and biodiversity benefits and resulted in an 80% cost saving and a significant carbon saving as compared to the traditional approach of providing increased stormwater storage.[159]

Reduced stormwater flows in combined sewers - Limiting the amount of stormwater entering a combined sewer system can prevent failure due to overload. Cities such as New York and Washington DC are responding to overload failures in their sewer systems by improving stormwater management and expanding infiltration, buffering and stormwater storage capacity.

Sustainable Drainage systems (SuDs) are increasingly being used in cities to improve drainage and reduce climate change impacts on the sanitation system. For example, in San Francisco, a Stormwater Management Ordinance has been put in place to capture runoff from impervious surfaces by using green infrastructure. Such infrastructure includes permeable pavements, green roofs, vegetated swales, rainwater harvesting, stream buffers and disconnection of rooftop and impervious areas.

Other notable examples of SuDs include the 'Sponge City' programme across 30 cities in China, to design low-impact development principles and nature-based solutions which improve drainage and filter out pollutants in a way that absorbs 70% of rainfall through low-intervention infrastructure, such as permeating pavements and rooftop gardens[160]; and Hanoi, which is focusing on the separation of sewerage and drainage systems for new urban areas, alongside rainwater harvesting, to better manage flood mitigation.[161]

The use of SuDs can mitigate the need for grey interventions whilst providing additional biodiversity benefits. For example, in Mansfield UK, the application of biodiversity interventions instead of traditional drainage systems will provide up to 60% of the additional water capacity needed by 2050 for potable uses. The biodiversity interventions will mitigate the need for installing buried tanks or new sewers[162] .

Corrosion Prevention – The useful life of sewers can be extended by using corrosion resistant materials such as polyvinyl chloride (PVC), high-density polyethylene (HDPE), and fiberglass reinforced plastic (FRP)[163]. Existing sewers can be made resistant to corrosion through the replacement of existing pipes

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157 The Tunnel. Tideway London. [Online] [Cited 10 May 2024] https://www.tideway.london/the-tunnel/

158 Constructed wetlands for the treatment of combined sewer overflow upstream of centralized wastewater treatment plants, Masi F et al 2023. Ecological Engineering Vol.193

159 Pont-y-felin Lane, Torfaen. A nature-based approach to combined overflows. Arup [Online] [Cited 7th May 2024] https://www.arup.com/projects/pont-y-felin-lane

160 Circle Economy Foundation. China's Sponge Cities Programme. Knowledge Hug: Circle Economy Foundation [Online} Circle Economy, 14042023 https://knowledge-hub.circle-economy.com/article/5040?n=China%27s-Sponge-Cities-program.

161 UN Habitat (2023) Global Report on Sanitation and Wastewater Management in Cities and Human Settlements.

162 Mansfield. SuDs how can nature increase flood resilience while supporting biodiversity and wellbeing? Arup [online] [Cited 8 May 2024] https://www.arup.com/projects/mansfield-suds

163 Controlling Hydrogen Sulfine Corrosion in Sewer Pipelines. Trenchless. [Online] [Cited 10 May 2024] https://trenchlesspedia.com/controlling-hydrogen-sulfidecorrosion-in-sewer-pipelines/2/4599#:~:text=The%20best%20way%20to%20prevent%20corrosion%20is%20 to%20use%20pipe,when%20exposed%20to%20sulfuric%20 acid

with corrosion resistant materials, or where this is not possible, by lining sewer lines and chambers with a corrosion resistant epoxy and polymer coating.

Active management of wastewater conveyance infrastructure/services

Proactive maintenance and cleaning of sewers can enhance their resilience to blockages caused by significant flow variations and by the illegal/uncontrolled discharge of solid waste to the sewers. In Cape Town for example, the Water and Sanitation Department performs preventative maintenance by cleaning sediment from the sewer system; they have also developed an incident response protocol for rapid response to failures. These responses are usually combined with educational/awareness campaigns to encourage citizens to only dispose of suitable materials into the sanitation systems.

Survey and monitor existing networks to identify groundwater infiltration. Survey and monitoring networks are commonly used by the water companies in the UK to identify groundwater entering sewers and drains. Wessex Water, invests over GBP 1 million per year in implementing infiltration reduction programmes in 30 catchments assessed as vulnerable to groundwater inundation. Sewer lines are monitored and inspected and any infiltration defects are fixed by installing watertight liners. Wessex Water also collaborates with the UK Environment Agency, with local authorities and with clients to minimize infiltration and inflow throughout the broader drainage system, including from private sewerage systems and highway drains [164].

4.2.4 Faecal Sludge/Septage Treatment and Wastewater Treatment

Responses to prevent the failure of wastewater treatment plants (WWTPs), faecal sludge/septage treatment plants (FSTPs), and combined wastewater/FS/septage treatment plants, relate to minimising the risk of flooding, failure due to power cuts, and the use of more flexible plants or treatment system arrangements that better cope with flow variations.

Technical modifications to FSTP/WWTP infrastructure

Flood Prevention Measures - Site vulnerability to climate induced risks needs to be a key consideration in site selection process for new treatment infrastructure For existing facilities, the incorporation of flood defences or anti-flooding measures, such as gates or barriers that prevent flood inundation[165] should be considered. In Cox's Bazar, Bangladesh, FS/septage treatment plant infrastructure was raised to avoid flooding in the rainy season[166]. The implementation of effective surface water management around the treatment facilities can prevent equipment being damaged or affected by runoff and can reduce waterlogging and erosion.[167] Specific protection can also be provided to components that are key for the operation of the plants, such as raising, sealing and/or waterproofing electrical equipment and pumps[168].

Corrosion Prevention Measures - The Bremen Overseas Research and Development Association (BORDA) in Zambia is exploring lining treatment facilities with sulphur-resistant cement to protect them against corrosion[169]. In HICs, concrete and steel elements of wastewater treatment systems are commonly

[164] Infiltration Reduction Plans Wessex Water [Online] [Cited 7 May 2024] https://corporate.wessexwater. co.uk/our-future/our-plans/infiltration-reductionplans#:~:text=About%20groundwater%20infiltration,to%20 identify%20and%20reduce%20infiltration.

[165] Jeremy Kohlitz, Ian Cunningham, Juliet Willetts. ClimateFIRST: Climate Framework: How-to Guide. Sydney : UTS-ISF, 2023

[166] Arup Oxfam. Technical assessment of faecal sludge management in the Rohingya response (Phase 2), 2022

[167] Jeremy Kohlitz, Ian Cunningham, Juliet Willetts. ClimateFIRST: Climate Framework: How-to Guide. Sydney : UTS-ISF, 2023

[168] Jeremy Kohlitz, Ian Cunningham, Juliet Willetts. ClimateFIRST: Climate Framework: How-to Guide. Sydney : UTS-ISF, 2023

[169] Willetts, Juliet, Kumar, Avni and Mills, Freya. Urban sanitation and climate change: A public service at risk. 2022

protected by applying anti-corrosion coatings that form a protective layer against hydrogen sulphide, sulphuric acid, seawater or other strong chemicals that may be found in wastewater.

Modular Treatment Plants - The performance and effectiveness of treatment plants can be negatively affected by significant variations in flow. In Cape Town, which is increasingly affected by extended periods of drought, a study concluded that modular plants, able to disconnect/bypass settling tanks and biological nutrient removal systems during periods of low flow, were able to perform more effectively than traditional treatment plants [170]. Implementing real time monitoring of treatment inflows and quality can facilitate the timely adjustment of pumps, treatment processes and/or dosing to suit new flow conditions [171].

Extensive wastewater treatment systems (those that are nature-based such as waste stabilization ponds and constructed wetlands) are more robust to influent variations of both flow and organic loading than intensive systems (primarily mechanically driven treatment processes, such as activated sludge. Extensive systems require a larger land footprint due to their extended retention times[172] ; however, they don't require electricity inputs to function, making them considerably more resilient to power outages than intensive systems and reducing their carbon emissions when compared to intensive systems.

Decentralised/Distributed Treatment Systems – Complementing or replacing a centralised treatment system with decentralised/distributed treatment facilities increases resilience by reducing dependence on a single central plant, which if it fails leads to the failure of the whole system. By contrast, if a decentralised sewer network, pumping station or treatment plant fails the impact is localised and easier to tackle[173]. Examples of decentralised/distributed treatment systems can be found in Hamburg, Helsingborg, San Francisco, Cape Town, Bangalore, Brasilia and Chennai.

Preparing for cascading impacts of failures in systems related to FSTPs/WWTPs

Alternative power sources — Having an independent power supply for a treatment plant provides resilience to failures in the city electricity system. Treatment plants can have back-up power sources that can be used to operate the plant when the city power system fails, or their own power source to fully remove reliance on the city grid. UNICEF is implementing decentralised wastewater systems for schools in Jordan with their own solar power system making them energy self-sufficient [174].

The adoption of local energy efficient and renewable energy sources (such as biogas, solar, wind power, thermal power and hydropower), can also decrease operational costs and GHG emissions. Sanepar, the utility of Paraná State in Brazil, undertook a GHG assessment which revealed that the biogas generated in their sewage treatment plants was responsible for over 90% of their emissions. This prompted changes to the design of their WWTPs and the capture of biogas to generate electricity contributing to the reduction of GHG emissions.

[170] Mikhael, Georges, et al. Climate-resilient Urban Sanitation: Accelerating the Convergence of Sanitation and Climate Action. Bonn : Deutsche Gesellschaft fur Internationale Zusammenarbeit, 2021

[171] The World Bank. Resilient Water Infrastructure Design Brief. 2020.

[172] JM. Brault, K. Buchauer and M. Gambrill. Wastewater Treatment and Reuse: A Guide to Help Small Towns Select Appropriate Options. s.l. : The World Bank, 2022.

[173] Mikhael, Georges, et al. Climate-resilient Urban Sanitation: Accelerating the Convergence of Sanitation and Climate Action. Bonn : Deutsche Gesellschaft fur Internationale Zusammenarbeit, 2021

[174] UNICEF. WASH Climate-Resilient Development Technical Brief Climate-Resilient Sanitation in Practice. s.l. : UNICEF, 2022.

In Cape Town, a study showed that Solar PV systems were able to power the energy intensive processes of the wastewater treatment facility, effectively reducing the utility's energy consumption requirements and reducing the municipality's energy bill. Nevertheless, without the capacity to store energy (e.g. in a battery), or to replace energy from the grid with energy from a diesel generator, the plant was not protected against power outages[175]. In deploying such solutions, all alternative power suppliers, generators, batteries and related elements need to be positioned above floodwater levels.

Contributions to water security – In water-scarce regions, WWTPs are increasingly being adapted to provide treated water for agricultural, industrial and domestic purposes. For example, in Chennai, WWTPs provide treated water for industry. This reduces reliance on freshwater sources for water supply and contributes to circularity.

Contributions to food and energy security – Sludge derived from WWTPs and FSTPs has traditionally been sent to landfill or used informally in local agriculture. However, resource recovery and recycling processes are now increasingly included in WWTP/FSTP designs. Excreta derived products such as biomass, soil conditioners and biochar can enhance soil health and fertility, increasing crop yields and resulting in greater food security in areas where traditional agriculture is disrupted by climate-induced impacts. Biogas or solid fuels can also be derived from WWTP/FSTPs, providing an alternative energy source in areas where there are disruptions to conventional energy sources. A further emerging reuse approach includes the production of Black Soldier Fly. The larvae consume organic waste and convert it into a valuable biomass rich in proteins and fats. This biomass can be processed and used as a protein source in animal feed, reducing the need for traditional feed ingredients like soy and fishmeal. This not only conserves resources but also promotes sustainable and responsible animal agriculture.[176]

4.2.5 Engaging communities in climate-resilient sanitation planning and implementation

The voice and participation of communities in planning and provision of safe sanitation services along the service chain is often lacking. This has negative impacts on sustainability and maximizing public health and environmental outcomes of sanitation interventions in most low- and medium-income countries.

Communities should be placed at the centre of climate-resilient sanitation programming with mechanisms put in place to enhance their capacities to actively engage with service providers and policy makers, and to create and maintain social norms. This will involve awareness creation, motivation and increased knowledge to help communities make informed decisions about key behaviours and practices that will promote climate-resilient sanitation and broader community resilience to climate-related shocks and stresses.

Communities should be closely involved in the development of adaptation responses. Examples from both rural and urban contexts confirm the importance of involving communities at each stage of the planning and implementation of climate-resilient sanitation. Residents' and informal sanitation workers' knowledge of the settlement in which they live and work is vital in identifying climate change hotspots e.g. flood prone areas; and in identifying the impact of climate effects on different members of the community[177]. This knowledge can then be used to reflect on the local context and determine how

[175] . GreenCape. Factsheet 10/10: Energy storage systems at wastewater treatment works. Cape Town : s.

[176] https://www.sciencedirect.com/science/article/pii/S0959652622042998

[177] Jeremy Kohlitz, Ruhil Iyer, Frontiers of Sanitation: Innovations and Insight: 17 Rural Sanitation and Climate Change: Putting Ideas into Practice, 2021

sanitation facilities and services need to be organised and sited to ensure uninterrupted access. This will include agreement on the siting of facilities as well as the selection on the type of facilities that are appropriate for the users and their context.

To address this issue, context-specific climate resilience messages should be incorporated in the community engagement and empowerment interventions from the planning stage. This should aim at addressing knowledge gaps, raising awareness of risks, changing perceptions of community members and sanitation workers, dispelling myths and misconceptions, and tackling imbalanced gender roles and social stigma – all of which can hamper efforts to promote climate-resilient sanitation.

As part of wider community engagement strategies for effective and sustainable delivery of climate-resilient sanitation, children and young people should also be acknowledged and supported so that they can lead and encourage positive social and behaviour change for themselves, amongst their peers, and within their communities – and ultimately influence the decisions of policy makers.

An example of mainstreaming gender inclusion into climate-resilient sanitation planning can be seen in Lao PDR and Nepal, where SNV and ISF-UTS are developing practical guidance for local government to assess how the changing climate impacts affect women and men differently, and how their existing district level sanitation plans can be modified. SNV activities to promote climate-resilient WASH services in Lao PDR have included specific focus on gender equality, disability and social inclusion (GEDSI) in the WASH sector, including increased female leadership among local WASH provisioners, civil society organisations (CSOs), communities and households.[178]

It is also important to support countries in including Indigenous and local knowledge (ILK) into climate-resilient sanitation planning. Methodologies like the ones applied by UNESCO LINKS programme, including trialogues to enhance scientific and policy understanding of ILK's role in water management and resource conservation for climate resilience, provide actionable insights for countries developing climate-adapted sanitation systems through community-driven solutions. For instance, in Timor-Leste, Indigenous communities employ Tara Bandu, a traditional system of resource management and conflict resolution, to protect water sources and maintain ecosystem balance. This practice involves setting customary rules that regulate water use, forest conservation, and social behaviors around water bodies. Specialized UN agencies such as UNESCO, through methodologies that support community-led research, emphasize the role of ILK in water resource management and its potential for strengthening climate resilience and sanitation infrastructure in rural areas.

4.2.6 Creating user demand for climate-resilient sanitation products

In rural areas, sanitation is generally on-site (mostly latrines), though in some rare cases of more dense settlements there could be a decentralised wastewater treatment (DEWATS). Domestic latrines are a consumer product, and investment is generally done by the household. Local governments have a key role in promoting demand creation as well as sanitation market development.

Dedicated demand creation activities for climate-resilient sanitation products are particularly important in rural areas, where people may have practiced open defecation all their lives and not see the benefit of toilets, or even feel uncomfortable in using toilets.[179] Approaches for sanitation demand creation must be

[178] SNV – Climate-resilient rural WASH services.

[179] For wider guidance on key principles for rural sanitation programming, see https://washmatters.wateraid.org/publications/rethinking-rural-sanitation

tailored to the needs to a specific area, but may include community-led total sanitation (CLTS).[180] Quality of sanitation demand creation processes — particularly ensuring do-no-harm — is essential.

Demand creation for climate-resilient sanitation will need to be accompanied by activities to strengthen consumer supply chains and finance (see also **Section 4.4**). Supply chains for affordable, appropriate and desirable WASH products in rural areas are generally deficient or non-existent. Building viable consumer markets for all segments is a challenge in rural areas and requires a dedicated effort in close collaboration with the private sector. This is likely to involve analysis of supply chains; consumer preferences, within the options available to ensure climate resilience; and finance options. Market development for sanitation usually requires various iterations to come to the right products, price, business models, and marketing and sales strategies.

Involving sanitation businesses in the planning process and supporting the development of efficient and effective service chains — as seen in the the IDE/UNICEF project SanMarkS in Bangladesh, for example[181] — is another important element for building sustainable climate-resilient sanitation systems.

4.3 Mitigation

4.3.1 Greenhouse gas emissions and their reduction

As outlined in **Section 3**, quantifying the climate impacts of full-cycle sanitation services can reveal significant mitigation potential, particularly for reducing direct methane emissions from human waste. Sanitation proposals to GCF should include estimates for GHG emissions under different scenarios, and clearly outline any interventions that are being proposed to reduce emissions (see also **Section 5**).

There are two broad classes of intervention that can reduce the overall greenhouse gas (GHG) footprint of the sanitation system:

- Interventions **outside the sanitation system,** which may involve the reuse of end products in secondary or adjacent sectors such as food or energy production.
- Interventions **directly related to the sanitation system**, which involve modification of systems and process to reduce direct or operational emissions. Interventions to reduce Scope 1 (direct) emissions are likely to fall within this category.

As outlined in **Section 1**, circular economy approaches are considered as a crucial component to both climate mitigation and adaptation strategies in the context of GCF. Circular economy approaches are included in both the GCF *Water Security*[182] and the *Cities, buildings, and urban systems*[183] sectoral guides. This points to a more holistic approach to identifying interventions than might be suggested by a more linear understanding of the sanitation system.

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[180] See for example https://sanitationlearninghub.org/practical-support/the-community-led-total-sanitation-approach/

[181] Jeremy Kohlitz, Ruhil Iyer, Frontiers of Sanitation: Innovations and Insight: 17 Rural Sanitation and Climate Change: Putting Ideas into Practice, 2021

[182] GCF, "Water Security Sectoral Guide," Sectoral Guide Series (Yeonsu: Green Climate Fund (GCF), 2022), https://www.greenclimate.fund/sites/default/files/document/gcf-water-security-sectoral-guide-consultation-version-1.pdf.

[183] GCF, "Cities, Building and Urban System (Urban) Sectoral Guide," Sectoral Guide Series (Yeonsu: Green Climate Fund (GCF), 2021), https://www.greenclimate.fund/sites/default/files/document/gcf-water-security-sectoral-guide-consultation-version-1.pdf.

Circular economy literature often uses the "waste hierarchy" concept[184] to identify interventions at various levels and scales from fundamental shifts in the conception or organisation of the system, through internal modifications of existing arrangements, and through efficiency gains. However, the very use of the term 'waste' in the sanitation context may limit the potential to understand opportunities for improvements. To ensure the circular economy potential of sanitation is fully realised, a radical shift is required from 'waste' to 'resource'. This Section argues the first step to reduced emissions and greater resilience in sanitation is to refocus design and management solutions on the resources within the sanitation system. Once that is done, process modifications and efficiency gains can follow.

Section 4.3.2 below summarises potential interventions to reduce GHG emissions from sanitation systems. In the sections that follow, we explore in more detail opportunities for recovery of energy, nutrients and water from the sanitation system and their impact on emissions; the importance of capturing nutrients before they enter the aquatic environment; and finally operational and design gains which could be achieved within the sanitation system itself.

4.3.2 Summary of strategies to reduce emissions from sanitation systems and services

Table 4.2 summarises some examples of interventions that have been proposed that may have the potential to reduce emissions. The table identifies routes by which these may result in the reduction of emissions. It is important to stress that the evidence base for mitigation across the sanitation value chain is limited, albeit growing rapidly. Table 4.3 maps these interventions against the GCF key strategies for climate-resilient sanitation presented in Section 1.

Table 4.2: Example interventions which may have the potential to reduce overall emissions profile (in all cases careful monitoring and active management is recommended to ensure expected benefits are realised).

	Effect category	*Reuse of end products*		*Reducing failures*	*Sanitation system modifications*		
Intervention type		*Capture and productive use of emissions*	*Substitution of products*	*Reduction of emissions in the environment*	*Optimising sanitation system design for low emissions*	*Ensuring efficiency of scale of operations*	*Gaining operational efficiency*
Infrastructure modifications	*Anaerobic digestion at treatment (with or without co-treatment of MSW)*	⤊ H			⤊ H		
	Addition of methane/biogas capture on aerobic treatment plants	⤊ H			⤊ H		
	Enhanced composting	⤊ H	⤊ H		⤊ H		

[184] Fedra Vanhuyse et al., "The Lack of Social Impact Considerations in Transitioning towards Urban Circular Economies: A Scoping Review," *Sustainable Cities and Society*, September 24, 2021, 103394, https://doi.org/10.1016/j.scs.2021.103394.

	of fecal wastes to produce agricultural products (including black soldier-fly lava)						
	Water recovery from wastewater or fecal sludge treatment for use in agriculture		⤊ H				
	Additional tertiary treatment and enhanced nutrient removal			⤊ H			
	Regular emptying of household pits and tanks particularly prior to rainfall			⤊ M		⤊ H	⤊ H ⇔ H
Scale and management operations	*Optimisation of scale and design of sewerage*					⤊ L ⥁ L	⤊ H ⇔ H
	Optimisation of scale of operations for onsite / road-based sanitation					⤊ L ⥁ L	⇔ H
Governance and regulatory modifications	*Improved regulation of emptying including incentives for planned emptying and disposal at treatment*			⤊ H	⤊ H	⤊ L ⇔ L ⥁ L	⇔ H
	Results-based contracts for treatment operators			⤊ H	⤊ H		⇔ M

H=high impact; M=medium impact; L=low or no impact; N=negative impact (high risk of increased emissions)/ ⤊ Direct emissions; ⇔ Operational emissions; ⥁ Embedded carbon

Table 4.3: Interventions mapped against GCF key strategies for climate-resilient sanitation.

Intervention type	Effect category	Category
Infrastructure modifications	*Anaerobic digestion at treatment (with or without co-treatment of MSW)*	*CRIS/IM*
	Addition of methane/biogas capture on aerobic treatment plants	*CRIS/IM*
	Enhanced composting of faecal wastes to produce agricultural products (including black soldier-fly lava)	*CRIS/ IM*
	Water recovery from wastewater or faecal sludge treatment for use in agriculture	*CRIS/IM*
	Additional tertiary treatment and enhanced nutrient removal	*CRIS/IM*
Scale and management operations	*Regular emptying of household pits and tanks particularly prior to rainfall*	*CRIS*
	Optimisation of scale and design of sewerage	*CRIS*
	Optimisation of scale of operations for road-based sanitation	*CRIS*
Governance and regulatory modifications	*Improved regulation of emptying including incentives for planned emptying and disposal at treatment*	*CRIS*
	Results-based contracts for treatment operators	*CRIS*

Elements of GCF projects: CRIS – Climate Resistant Infrastructure and Services, IM – Integrated Management

4.3.3 Reuse of end products

Resource recovery from sanitation systems can contribute to climate mitigation through two main avenues:

- **Capture and productive use of emissions:** Biogas capture at wastewater or sludge treatment facilities transforms greenhouse gases into renewable energy sources, contributing to a reduction in the emissions that would have otherwise occurred from decomposition of excreta-derived sludge. Human excreta or sludge can also be transformed into biochar, whose application to soil not only sequesters carbon but also revitalizes soil health, turning it from an emissions source to a carbon sink[185]. Healthy soils, rich in organic matter, absorb atmospheric carbon, whereas degraded soils contribute to greenhouse gas emissions.
- **Substitution of sanitation-derived products for other products:** The use of resource recovery products often substitutes for other products which would have generated direct or indirect GHG emissions. For example, the use of nutrients recovered from sanitation systems via excreta-derived fertilizers, compost or soil conditioner, can reduce the need for artificial fertilizers whose production is energy intensive and contributes to significant GHG emissions.[186] The use of treated wastewater reduces the need for freshwater extraction and treatment and the indirect emissions

[185] R. P. Premalatha et al., "A Review on Biochar's Effect on Soil Properties and Crop Growth," *Frontiers in Energy Research* 11 (June 30, 2023), https://doi.org/10.3389/fenrg.2023.1092637.

[186] UNEP and GRID-Arendal, "Wastewater – Turning Problem to Solution. A UNEP Rapid Response Assessment," September 8, 2023, 26–45, https://doi.org/10.59117/20.500.11822/43142.

associated with it. Similarly, recovering energy through biogas production and use or recovering heat from wastewater management systems can replace or reduce the need for more carbon-intensive energy sources.

4.3.4 Reducing sanitation's negative impact on the aquatic environment and its carbon stock capacity

Poorly managed sanitation is known to have negative impacts on the aquatic environment and its capacity to store carbon. Although there are a wide range of pollutants within wastewater that impact aquatic ecosystems,[187] the most well-studied constituents of wastewater pollution are organic matter and nutrients. The World Health Organization considers sewer connections that are not shared and deliver the wastewater to treatment plants where they receive treatment (at least secondary treatment, or primary treatment with a long ocean outfall[1]) as "safely managed sanitation". Although secondary treatment does lead to some reduction in nutrients, separating nitrogen from the wastewater requires more advanced treatment processes.[188] These nitrification and denitrification processes can, however, lead to the emission of increased amounts of N_2O to the atmosphere if they are not properly designed and carefully operated. One key measure that can be implemented to reduce damage to coastal ecosystems and their carbon stock is to limit the amount of nutrients that enter the environment. There are multiple studies that show that when advanced wastewater treatment is implemented, seagrass meadows can recover, although it is harder to recover the sediment carbon stocks lost, given the long timescales over which sediment carbon accumulates. Alternative approaches, such as source separation sewer systems as used in Helsingborg, Sweden, and elsewhere, can maximize the capture and treatment of nitrogen and phosphorous for reuse, avoiding their discharge into the environment and avoiding the emission of nitrous oxide.

The ratio between nitrogen (N) and phosphorus (P) is also important to consider, as wastewater treatment can have higher removal efficiency of phosphorus than nitrogen.[189] In some circumstances, a larger N:P ratio can lead to greater ecological impacts, and in other contexts, a lower N:P ratio can lead to proliferation of cyanobacteria, which produces CH_4.[190]

Another primary route for nutrients to enter the aquatic environment is through sanitation systems failure. Thus improved management and operation of all sanitation systems may have significant impacts on reduced ecosystem degradation and GHG emissions from the environment. Eliminating combined wastewater and stormwater sewers as far as possible and their replacement with separate sewers or alternative road-based systems can also reduce the amount of nutrients discharged into the environment.

Finally optimising and modifying the treatment and downstream use of wastewater sludges and faecal sludge / septage will have an important impact on potential spills into the environment. The unregulated disposal of sludges onto agricultural or other land or dumping into water bodies may all have significant negative impacts on the environment and result in increased emissions.

4.3.5 Process modifications and efficiency gains in sanitation infrastructure and services

[187] Wenger et al., 2023; Wear et al., 2024.

[188] Tilley et al., 2014.

[189] Tong et al., 2020

[190] Ford et al., 2018; Li et al., 2021; Tong et al., 2020

In light of the main causes of emissions in sanitation infrastructure and services, the objectives of systems modifications is to maintain or improve public health protection while:

1. Optimising treatment for low emissions with high production of products;
2. Ensuring appropriate levels of scale for efficient collection and use of the products; and
3. Gaining operational efficiency in the rest of the system.

Optimising sanitation system design for low emissions with high production of products

Optimising for low emissions requires that treatment processes are closely matched to local operational conditions. For example, where opportunities exist to co-process human excreta with an additional stream of carbon-rich substrate (for example organic municipal waste), anaerobic digestion can offer opportunities for efficient treatment with low energy requirements and potential to recover biogas for productive use. Alternatively, where space allows, low energy aerobic treatment systems such as waste stabilisation ponds or oxidation ditches offer high levels of treatment efficiency and can be modified to include methane capture. Other approaches to treatment of human waste such as the use of black soldier-fly larvae may also offer opportunities for reducing emissions when compared to simple composting.

Ensuring appropriate levels of scale for efficient collection and use of the products

Scale efficiency of operations may offer some potential for saving of operational emissions. For example, organising collection and transport in road-based sanitation systems at a larger scale may allow for significantly lower per capita use of truck-miles when compared to poorly regulated disaggregated systems. Similarly for sewered sanitation systems, scale optimisation can reduce pumping in the network, as can the use of small-bore or simplified sewerage, particularly for upstream zones of the network. Furthermore, depending on the context, either road-based or sewered sanitation may have significant operational efficiency advantages in different locations. A move towards more systematic planning and assessment of scale of operations and mode of delivery can significantly enhance performance of core functions of sanitation systems while exerting a positive downward pressure on emissions.

Gaining operational efficiency in the rest of the system

Operational efficiency in the rest of the system can also significantly improve operational performance of sanitation systems. For example, effective regulation, monitoring and pricing signals can create positive incentives for road-based emptying and transport service providers to deliver waste quickly and efficiently to treatment. Results-based contracts for operators of treatment services can create positive incentives for more waste to be appropriately collected, moved to treatment and properly treated rather than being dumped (see also **Section 4.4**)); similarly, results-based contracts for getting households to connect to existing sewer networks have successfully been used by Sabesp in Brazil to maximize the connection of low-income households to sewers. There is also a requirement for better monitoring, incentives and accountability mechanisms to ensure effective management and maintenance of faecal sludge and wastewater treatment plants.

4.4 Strengthening systems to enable climate-resilient sanitation

Following the same criteria provided by GCF guidelines across sectors, sanitation project proposals to GCF should be investment-oriented — enabling environment components of project proposals can only be included when combined with associated investments (co-financing). However, it is recognised that infrastructure solutions alone will not address the challenges in promoting climate-resilient sanitation, which should be conceived as the combination of:

- Specific operational responses across the sanitation service chain (as outlined in Sections 4.2 and 4.3); and
- The enabling environment within which the service chain operates.

To deliver sustainable, climate-resilient sanitation at scale, operational responses and the enabling environment should be aligned. Priority policy, institutional, regulatory and financing (PIRF) mechanisms should be identified, and governments supported in enacting them. Below we summarise some of the key PIRF mechanisms specific to enabling climate-resilient sanitation which can be considered when developing proposals to GCF.

4.4.1 Policy

Ensuring projects align with and strengthen relevant climate policies and plans, particularly NDCs and NAPs

There is currently limited integration of sanitation and climate change in strategic policy documents at the international, national and subnational levels[191].For example, a recent analysis of sanitation-related national policy documents from five countries in Eastern Africa revealed that none of them addresses climate mitigation opportunities in the sanitation sector[192], while less than half of countries that responded to the UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) 2021/2022 survey address risks of climate change impacts in their urban and/or rural sanitation policies and plans[193]. At the same time, opportunities for climate mitigation and adaptation within the sanitation sector are not adequately represented in the range of types of policy and strategy documents for climate change such as Nationally Determined Contributions (NCDs), National Adaptation Plans (NAPs), Climate Action Plans, Nationally Appropriate Mitigation Actions and Methane Action Plans.

These limitations in integrated approaches to sanitation and climate policy and action results from barriers such as limited knowledge and awareness of linkages between climate and sanitation among some stakeholders, inadequate coordination between stakeholders working on sanitation and climate issues at the national level, absence of funding and incentives for integrated approaches and overall limited capacity for to address the linkages in policy interventions at national and subnational levels[194]. There is therefore a need to address these barriers so as to have more coherent and integrated approaches to climate and sanitation policy which takes into account the latest scientific knowledge

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[191] Dickin, S., Bayoumi, M., Giné, R., Andersson, K. and Jiménez, A. (2020). Sustainable sanitation and gaps in global climate policy and financing. Npj Clean Water, 3(1). 1–7. DOI: 10.1038/s41545-020-0072-8

[192] Ddiba, D. Macura, B., Dickin, S. (2023). Integrating Sanitation And Climate Change Policy And Action: Insights From Five Countries In Eastern And Southern Africa, IWA Water and Development Conference in Kigali, December 2023.

[193] WHO (2022). Strong Systems and Sound Investments: Evidence on and Key Insights into Accelerating Progress on Sanitation, Drinking-Water and Hygiene. The UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) 2022 Report. World Health Organization (WHO), Geneva. https://www.who.int/publications-detail-redirect/9789240065031

[194] Ddiba, D. et al (2023).

about the opportunities for both mitigation and adaptation. Integrated approaches in climate and sanitation policies are especially important since they can signal the prioritisation of sanitation within a country's climate action agenda.

In order to properly align with GCF investment criteria, **proposed sanitation projects need to have strong linkages with the relevant climate policies and plans, particularly NDCs and NAPs where relevant**, since this demonstrates ownership at the country level as well as the interest of local stakeholders in the outcomes of the proposed project. For countries where sanitation actions have been adequately described in the climate policy documents, the proposed projects can be those concrete actions. However, proposed projects can also contribute towards making NDCs and NAPS more concrete, especially in cases where the description of sanitation-related targets are on a more general level in the policy documents.

Projects can also support the coherent translation of national plans to the local level, including city-level and service provider investment plans, enabling cities and districts to develop detailed activities and programmes that are adapted to their context and which support national aspirations; support consistency of national and local legislation; and support the development of local and city action plans to underpin and drive innovation at the national level. This work must be supported by the development of metrics and indicators to assess progress in the sector.

Ensuring policy frameworks promote safe circular economy approaches

As outlined in **Section 1**, circular economy approaches are viewed by GCF as central to climate-resilient sanitation. To unlock the full potential of climate-resilient sanitation, the linkages should be emphasised between safe wastewater and faecal sludge reuse, and wider climate resilience, particularly in water-scarce contexts.

In many countries, an urgent priority is the revision of policy frameworks to support safe wastewater and sludge reuse and wider circular economy approaches. Demonstration projects to achieve proof of concept may be required to facilitate widespread implementation of circular economy approaches and the associated supporting policy revisions.

It is emphasised that the safe adoption of circular economy approaches can only be achieved when all parts of the sanitation service chain – containment, conveyance and treatment – are functioning properly. Safe wastewater and faecal sludge reuse should therefore be conceived as dependent on, and a potential outcome of, safely managed sanitation. It is critically important that wastewater and faecal sludge reuse complies with safety standards – unsafe reuse is maladaptive and recycles pathogens and disease.

Specific policy revisions that may be considered include:

- Requirement that re-use does not undermine human health and ecosystems. This can be supported by the requirement to conduct risk management processes such as Sanitation Safety Planning;
- Explicit recognition of container-based sanitation as a viable option, within a wider menu of services, with particular relevance to densely populated urban areas and water-scarce contexts (see **Section 4.2);**
- Policies to certify waste products and by-products;
- Policies to promote separate blackwater and greywater systems and re-use of these waste streams;
- Policies to promote urine diversion;

- Policies to promote nutrient recovery and to strengthen nutrient limits on wastewater treated effluent discharge to receiving water bodies;
- Policies that incentivize the reuse of waste products and remove unfair competition from the products they can substitute (for example, competition of waste-based fertilizer with heavily subsidised chemical fertilizers);
- Policies that recognise the relationship between rainwater, stormwater runoff and their negative impacts on sanitation systems, and which support rainwater harvesting and rainwater gardens/buffer zones.[195]

4.4.2 Institutions

Ensuring service providers are equipped with climate-specific knowledge and skills and prepared for a future of multiple revenue streams

To support the adoption of climate-resilience approaches, knowledge, capacities and skills must be developed at all levels of the sanitation sector — including ministries, regulators and service providers. Specific project activities that may be valuable in this area include the development of comprehensive capacity building programmes to retool the sanitation sector, ideally led by the relevant line ministry (for example, improving the climate-specific knowledge and skills of sanitation service authorities, and the capacity of institutions responsible for monitoring and risk assessment); support to peer-to-peer learning networks, as natural forums for the exchange of good practice in climate-resilient sanitation; partnerships between service authorities and research institutions, to support cutting-edge research and the development of specialist technical expertise in climate-resilient sanitation; the provision of improved climate services for use by the sanitation sector, such as flood risk and climate risk analysis; and targeted data collection, research and evidence generation to sensitize and influence decision makers to the importance of climate-resilient sanitation.[196]

As part of these efforts, and to capitalise fully on the opportunities afforded by the circular economy, water and sanitation utilities in particular must be supported in preparing for a future where sales of by-products for uses in water supply, energy and agriculture are a crucial part of their revenue streams.

In rural areas, where sanitation services are generally onsite, the capacity to ensure quality of construction and rehabilitation of latrines is a key driver for sustainability. In both rural and urban contexts, this must be incorporated in targeted capacity development programmes. This is closely interlinked with quality of procurement, contracting and oversight of works, as well as social embedding.

4.4.3 Regulation

Mainstreaming climate-resilient sanitation into regulations, guidelines, standards, and codes of practice at every step of the sanitation service chain

In many countries, the urgent need for climate-resilient sanitation necessitates a review of existing regulatory frameworks and connected regulations, guidelines, and standards. Regulatory frameworks should be assessed to assess if climate resilience is integrated across all levels of guidance for

[195] Arup, WSUP (2024) Urban Sanitation in Times of Climate Change. Report prepared for World Bank.

[196] Arup, WSUP (2024) Urban Sanitation in Times of Climate Change. Report prepared for World Bank.

sanitation service providers. Building on Sections 4.2 and 4.3, regulatory frameworks and associated regulations and standards should be developed or reviewed to :

- Protect serviceability of onsite and networked systems in flood-prone and/or water scarce areas;
- Reduce contamination risk from onsite systems to groundwater or surface in flood-prone areas, or with raised groundwater levels;
- Ensure continued safe faecal sludge transportation, through extreme temperatures and high precipitation;
- Incentivise the connection of unconnected households to existing or planned sewer networks;
- Protect serviceability of networked systems in flood-prone and/or water scarce areas;
- Protect collection, transport and treatment infrastructure;
- Ensure sufficient financial allocations for equitable provision of climate-resilient sanitation infrastructure and / or service delivery models; and
- Support the progressive formalisation of pit and tank emptying services, to facilitate frequent emptying and active management of onsite systems.
- Protect and improve the working conditions of sanitation workers.
- Promote stormwater/rainwater separation for wastewater/sanitation systems and promote buffer/garden/storage/harvesting systems.

Within the review of regulatory frameworks, regulatory obstacles to innovative technology and service approaches should be systematically identified and addressed; and key performance indicators (KPIs) reviewed to ensure environmental and climate change considerations are reflected in performance assessments of sanitation service providers.

The development of regulatory frameworks and standards to support climate-resilience is only a first step. Projects should consider how they can support regulators in translating standards into action, which will involve appropriate resourcing and capacity; an understanding of target groups and how to build compliance; and the ability to monitor and resort to sanctions where required. Further guidance in this area is provided in WHO (forthcoming).[197]

4.4.4 Financing

Leveraging a menu of financing options to support the sustainability and scalability of project interventions

Achieving the sustainable development goal targets for universal sanitation coverage (SDG 6.2) and increasing wastewater treatment and reuse (SDG 6.3) necessitates substantial global investment. Estimates of the global investment needs for SDG6 suggest a staggering annual requirement of 30 billion to 1.1 trillion USD,[198] with sanitation specifically demanding at least 105 billion USD annually to cover both capital and operational costs.[199]

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[197] WHO (forthcoming) A Roadmap for Advancing Sanitation Regulation.

[198] Kulkarni, S., Hof, A., Ambrósio, G., Edelenbosch, O., Köberle, A. C., Rijn, J. van and Vuuren, D. van (2022). Investment needs to achieve SDGs: An overview. *PLOS Sustainability and Transformation*, 1(7). e0000020. DOI: 10.1371/journal.pstr.0000020

[199] Hutton, G. (2022). Chapter 7 - SDG 6 global financing needs and capacities to ensure access to water and sanitation for all. In Financing Investment in Water Security. Leflaive, X., Dominique, K., and Alaerts, G. J. (eds). Elsevier. 151–75. DOI: 10.1016/B978-0-12-822847-0.00001-6

The sanitation sector is traditionally reliant on public funding but faces chronic underinvestment in many nations. The UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) 2021/2022 survey[200] underscores this, revealing that over 75% of participating countries report insufficient funds to meet their sanitation strategies and plans. This financial shortfall encompasses both the capital required to develop new infrastructure and the ongoing costs necessary for maintaining existing services. While large capital expenditure for sanitation infrastructure is often financed by public or donor funds, households tend to cover the majority of recurrent costs[201] and in some contexts, households bear the biggest portion of the total annualised costs for sanitation services altogether which further exacerbates inequalities.[202]

International climate finance, such as that provided by the GCF, can play a pivotal role in complementing other funding sources. Through mechanisms like co-financing and blended finance, climate finance can amplify the impact of investments in sanitation, facilitating the implementation of comprehensive projects that address both climate action and sanitation needs effectively. Moreover, given the strong linkages between adaptation and mitigation opportunities in sanitation and other sectors such as agriculture, energy and marine conservation, sanitation-related actions can be implemented as integrated components within broader GCF projects focused on agriculture, energy, marine conservation etc, not only as distinct projects. Sanitation proposals to GCF should therefore clearly set out if they are seeking co-financing and how this will be leveraged (see **Section 5**).

Project proposals to GCF should be based on **context-specific analysis of the true costs of climate-resilient sanitation in the local context**, including operation and maintenance (O&M) costs. The specific costs of climate-resilient sanitation is a priority evidence gap to be addressed; however, initial estimates suggest climate change impacts and adaptive management will increase the O&M costs of sanitation assets.

Once cost estimates are established, proposals should consider how domestic resource mobilisation and wider financing and funding mechanisms will be leveraged to ensure the sustainability and scalability of interventions. This may involve revisions to tariff models, supported by cross-subsidies and public subsidies and potentially by external financing, to balance financial viability of the service provider with affordability and equity of services for low-income customers. Wider finance mechanisms which may be considered include (but are not limited to) green municipal bonds, carbon credits and other forms of innovative green funding mechanisms; concessional financing; commercial loans; public-private partnerships, microfinance and microinsurance.

Creating targeted financial incentives to support private sector engagement and resource recovery

In alignment with the GCF focus on the circular economy and private sector involvement, projects may consider the strengthening of incentives for private sector engagement in climate-resilient sanitation service delivery and resource recovery across the sanitation service chain. This could include results-based financing and targeted subsidies to support climate-resilient infrastructure improvements at the household level; stimulating private sector provision of formalised pit emptying services, including to the most vulnerable, to support active management; the creation of tax-based incentives for capital

[200] WHO (2022). Strong Systems and Sound Investments: Evidence on and Key Insights into Accelerating Progress on Sanitation, Drinking-Water and Hygiene. The UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) 2022 Report. World Health Organization (WHO), Geneva. https://www.who.int/publications-detail-redirect/9789240065031

[201] Hutton (2022)

[202] Dodane, P. H., Mbéguéré, M., Sow, O. and Strande, L. (2012). Capital and operating costs of full-scale faecal sludge management and wastewater treatment systems in Dakar, Senegal. Environmental Science and Technology, 46(7). 3705–11. DOI: 10.1021/es2045234

investment in sanitation; consideration of economic policy incentives (EPIs) and emission trading schemes to promote climate change adaptation and mitigation policies; and providing wider financial incentives to promote wastewater and faecal sludge reuse.

4.4.5 Cross-cutting

Strengthening policy, institutional and regulatory frameworks to support the integration of sanitation with wider basic services and urban and rural development processes

As outlined in **Sections 1** and **4.1**, GCF considers integrated management approaches to be an important aspect of supporting climate-resilient sanitation. In urban contexts for example, sanitation should be considered alongside wider urban services and development processes, particularly water supply, solid waste management and drainage. Integration of sanitation with water resource management and environmental protection may also support a more effective policy and regulatory response to the threats posed by climate change.

In many contexts, the integration of sanitation with other basic services will involve transformational systems change and long-term processes of sector reform. This may include:

- Integration of urban sanitation policy and planning with land use and housing for aligned and sustainable urban development;
- Policy and institutional frameworks which support integration of water supply and sewered and onsite sanitation wherever feasible;
- At the regulatory level, integration of water and sanitation to support stability of financial flows, providing sanitation regulators with recourse to the water tariff and enabling cross-subsidies;
- At the national level, the involvement of Prime Ministerial offices and/or Ministries of Finance – and specifically climate finance units where these exist – to support coordinated action;
- The development of cross-ministry working groups to drive forward cross-sectoral dialogue.[203]

In rural areas, mainstreaming climate-resilient sanitation within area-wide approaches which integrate sanitation, water supply and hygiene is recommended. This may involve dedicated activities to strengthen governance and regulation for area-wide inclusive and climate-resilient services, including facilitation of government learning, budgeting and planning.[204] It is again emphasised that integrated planning approaches are required to strengthen linkages between sanitation and agriculture through the safe reuse of wastewater and faecal sludge.

Building flexibility into planning, financing, and regulatory frameworks to support service providers in adapting to emerging or unexpected conditions

Because climate change is introducing uncertainty, sanitation service providers need the freedom to adapt to emerging or unexpected conditions, such as droughts or extreme weather events. This means that flexibility must be built into the planning of services and financing frameworks,[205] and that regulation gives service providers the flexibility to adjust levels of service acceptability to ensure continuity of services in all eventualities.

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[203] Arup, WSUP (2024) Urban Sanitation in Times of Climate Change. Report prepared for World Bank.

[204] SNV – Climate-resilient rural WASH services

[205] Willetts, Juliet, Kumar, Avni and Mills, Freya. Urban sanitation and climate change: A public service at risk. 2022.

Specific project activities that may be considered in this area include support to service providers in climate risk screening and risk-based localised climate planning; supporting the collection and dissemination of accurate data on sanitation coverage and service levels, in addition to climate risks, to inform planning; and ensuring regulatory frameworks allow service providers the discretion to innovate. To safeguard continuity of service for vulnerable households, it is also critical that service tariffs are closely monitored and regulated during periods of high demand.

Box 4.1: Summary of potential PIRF interventions to enable climate-resilient sanitation.

- Ensure projects align with and strengthen relevant climate policies and plans, particularly NDCs and NAPs
- Ensure policy frameworks promote circular economy approaches
- Ensure service providers are prepared for selling by-products and equipped with climate-specific knowledge and skills
- Mainstream climate-resilient sanitation into regulations, guidelines, standards, and codes of practice at every step of the sanitation service chain
- Leverage a menu of financing options to support the sustainability and scalability of project interventions
- Create targeted financial incentives to support private sector engagement and resource recovery
- Strengthen policy, institutional and regulatory frameworks to support the integration of sanitation with wider basic services and urban development processes
- Build flexibility into planning, financing, and regulatory frameworks to support service providers in adapting to emerging or unexpected conditions

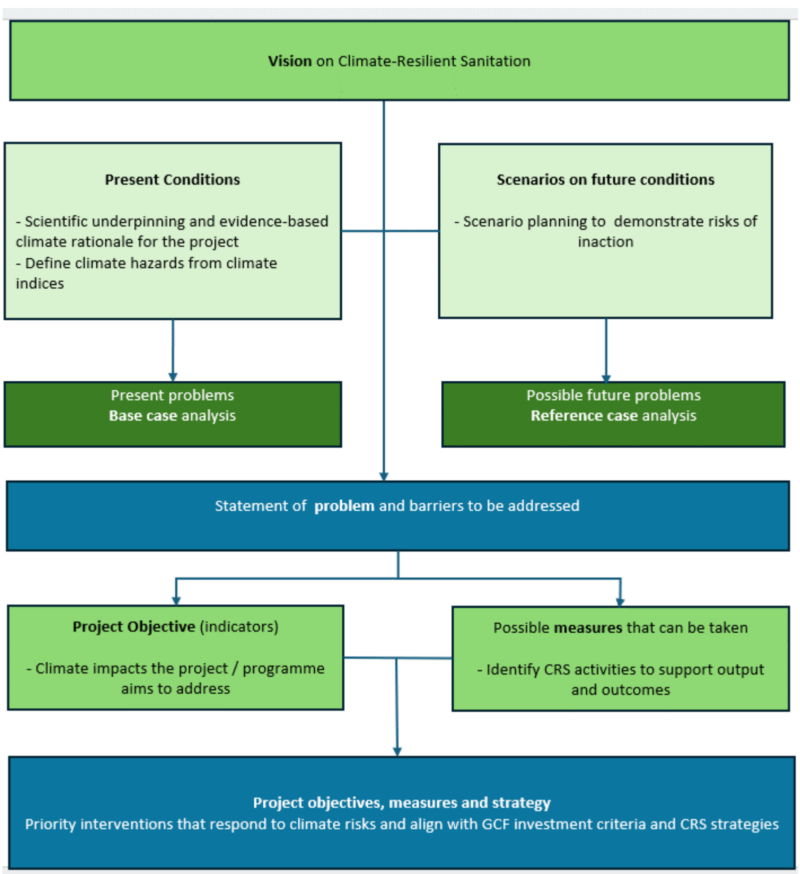
5. Developing a GCF Proposal

Section 5:
- Provides a flowchart of the key steps involved in developing a sanitation project proposal to GCF
- Provides guidance on the content that is required for a proposal to be successful, including:
  - Effective articulation of the climate science basis and rationale for the project
  - Alignment with overall GCF investment criteria
  - Alignment with GCF key strategies for climate-resilient sanitation

The Section provides the full GCF investment criteria and sub-criteria. It closes with further guiding questions to inform the selection of sanitation interventions within proposals.

To be successful, all project proposals to GCF must have a clear message; display alignment with GCF paradigm shifts, investment criteria and strategies; and should be concise and within the page limit. Figure 5.1 below presents the key steps involved in developing a sanitation proposal for GCF and the content required.

Figure 5.1: Steps in the development of sanitation project proposals to GCF.



STEP 1: Define vision on climate-resilient sanitation

As a first step in proposal development, a vision statement should be developed defining the key issue/s the project responds to. In cases where the project responds to climate challenges but also wider socio-developmental challenges, GCF may provide funding specific to the climate part of the project, either as separate funding or as GCF co-financing to the wider development project.

STEP 2: Articulate the climate science basis for the project and resulting problem statement

To be successful, GCF proposals need a strong and robust explanation of the climate impacts and risks to be addressed. The climate science articulation in a GCF proposal provides the underpinning to ensure a specific project responds directly to climate change challenges. It gives a scientific basis for climate decision making and relies on past and current data on the climate system as well as predictions and projections, grounding project interventions in the best available climate data and science. It is meant to help GCF proposals understand how the proposed activities align with the aims of the GCF. As outlined in the UNICEF-GWP climate resilience framework, understanding the problem is essential before responses can be identified, appraised, delivered and monitored.

The climate science articulation should include:

- Assessment of **present conditions,** including the climate hazards currently faced by sanitation systems, informing the *base case analysis*;

- **Scenario planning,** outlining possible future problems, informing the *reference case analysis*. This may involve determining the severity of the problem before climate was affected by increased CO2 emissions; and determining the severity of the problem at a specified point in the future (the time horizon of the project) where climate change will have altered the probabilities of the climate variability.

For proposals involving both climate-specific and wider development activities, it is essential to be clear on which parts of the project and supporting scenario planning relate specifically to climate change. This will involve the development of quantitative scenarios for climate change, which should be presented separately from other scenario components such as socio-economic developments.

Further guidance for building the climate science basis for sanitation projects is summarised below. For further guidance specific to scenario planning, see *Star et al, 2016 — Supporting adaptation decisions through scenario planning: Enabling the effective use of multiple methods.*[206]

Adaptation component

In the context of adaptation, the climate science articulation[207] aims to:

- Establish credible climate science and evidence, determining the hazards; and
- Provide a robust assessment of exposure, impacts, vulnerability and disaster risks.

As indicated in the existing GCF Water Security Guides Annex 2, it is recommended to follow the risk analysis guidance provided by the GWP-UNICEF Strategic Framework on WASH Climate Resilience. This involves the **Risk = Hazards + Exposure + Vulnerability** formulation presented in Figure 5.2.

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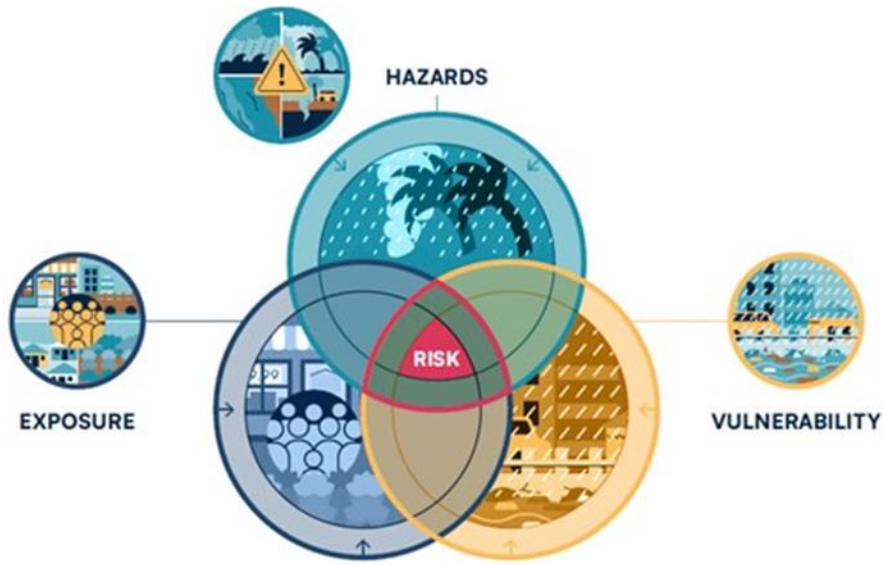
[206] Star, J., Rowland, E.L., Black, M.E., Enquist, C.A., Garfin, G., Hoffman, C.H., Hartmann, H., Jacobs, K.L., Moss, R.H. and Waple, A.M., 2016. Supporting adaptation decisions through scenario planning: Enabling the effective use of multiple methods. Climate Risk Management, 13, pp.88-94.

[207] GCF/B.21/Inf.08 : Steps to enhance the climate rationale of GCF-supported activities | Green Climate Fund

Figure 5.2: Risk is the combination of hazards, exposure and vulnerability.



Detailed guidance on the climate risks associated with sanitation is provided in **Section 2** of this document.

Mitigation component

To assess energy efficiency in sanitation and wastewater processes and understand how they can contribute to reducing greenhouse gas (GHG) emissions, a structured and methodical approach is proposed for the establishment of baseline energy consumption and emissions:

a. **Data collection:** gathering of data on direct GHG emissions across the entire value chain and for scope 1, 2 and 3 emissions. This step remains vital as there is currently insufficient empirical data available to support reliable modelled estimates of total emissions. Scope 1 emissions, including direct emissions, are known to be significant — these should be a focus of data collection, alongside more readily-available sources of information on Scope 2 emissions from imported energy use.
b. **Analysis:** analysis of the collected data to pinpoint key areas where emissions, energy efficiency and embedded carbon can be improved. Of particular importance here is to model out the entire value chain, understanding how faecal waste flows along the value chain and how much Scope 1 emissions may vary seasonally for example.
c. **System assessment and benchmarking:** evaluation of the current technology and systems in place and exploration of up to date low-emission, energy-efficient and low-embedded carbon alternatives. This can be facilitated by comparing emissions, energy usage and embedded carbon with best practices and standards to identify opportunities for reducing emissions, energy use and embedded carbon.

***Energy tariff and incentives assessment**:* energy tariffs and incentives to support investment in energy-saving technologies are often available and should be explored. Where available, rebates for solar, energy efficient appliances, and wastewater reuse can offset the cost of purchasing energy efficient solutions. Likewise, favourable feed-in tariffs for renewable energy sources can support investment. In some countries, concessional finance to invest in energy efficient technology is available for sectors that are underdeveloped or underperforming against the country's NDC targets.

Data sources to support development of the climate science basis for sanitation projects

To elaborate the climate science basis, it is advisable to use credible internationally peer reviewed climate data. The following data sources provide a starting point for analysis.

- Climate analytics includes a diverse set of interactive climate projection tools and resources for policymakers and researchers;
- World Bank – Climate Change Knowledge Portal presents Climate Risk Country Profiles - a high-level assessment of physical climate risks for countries, providing insight for decision makers into the potential for increasing, expanding, and emerging risks across space and time, and for different climate futures;
- World Resources Institute (WRI) presents the Aqueduct portal, which includes a set of tools to map water risks such as floods, droughts and stress, using open-source, peer reviewed data. The tools include a Water Risk Atlas, Country Rankings, and a specific tool to identify coastal and riverine flood risks.
- IPCC Sixth Assessment Report – Regional Fact Sheets: Working Group 1: Climate Sciences; WG2: Adaptation; WG3: Mitigation;
- Think Hazard, which gives a general view of the hazards, for a given location; and Climate Watch offers open data to help gather insights on countries' climate progress, including countries' commitments submitted by countries related to the Paris Agreement.[208]

The climate science basis provides the foundation for the problem statement, which should clearly set out the climate-specific risks and the barriers to which the project responds.

STEP 3: Identify priority measures and strategies

Following from the results of the climate risk and mitigation assessments, a robust set of measures should be proposed, that collectively and comprehensively address underlying climate risks and barriers and maximize sustainable development benefits. The proposed measures should build on stakeholder consultation and reflect the priorities of the key national stakeholders involved. The proposal should articulate how these measures will fit into the broader national and international policy and decision-making processes.

Aligning with overall GCF investment criteria

[208] In addition, Indigenous and local knowledge-focused data can provide complementary information on sustainable water management methods used historically in various environments. Local knowledge is used to predict and respond to flooding and landslides, ensuring that water sources are protected and that communities maintain safe access to clean water after hydro-meteorological events. UNESCO has documented these practices, which contribute to resilient water and sanitation systems in disaster-prone regions: https://unesdoc.unesco.org/ark:/48223/pf0000228711.

In defining interventions to be supported through the project, it is important to keep the core GCF investment criteria front of mind. The Green Climate Fund (GCF) investment criteria provide a framework to evaluate and prioritize projects that seek funding for climate adaptation and mitigation. When contextualized for sanitation and wastewater projects, these criteria ensure that such initiatives contribute to broader climate goals while addressing immediate needs. The six GCF investment criteria are detailed in **Section 1.6** and summarised below:

- Impact potential
- Paradigm shift potential
- Sustainable development potential
- Needs of the recipient
- Country ownership
- Efficiency and effectiveness

It is also emphasised that sanitation project proposals to GCF should be investment-oriented. Following the same criteria provided by GCF guidelines across sectors, enabling environment components of project proposals can only be included when combined with associated investments (co-financing).

Sub-criteria for GCF investments are presented in **Table 5.1** at the end of this section. It is essential that applicants review the GCF criteria and sub-criteria closely before formulating and finalising their proposal.

Aligning with GCF key strategies for climate-resilient sanitation

GCF's envisioned paradigm shift for CRS is that: ***Transformative sanitation planning and programming for climate-resilient sanitation is applied in national and regional adaptation and mitigation planning and programming.*** This paradigm shift complements the overall vision of GCF to promote transformational planning and programming; catalyse climate innovation; mobilize financing at scale; and promote coalitions and knowledge to scale up success.

As outlined in Section 1, five specific strategies have been identified as key to the realisation of GCF's vision for climate-resilient sanitation. The Strategies broadly align with the Sanitation and Water for All building blocks, while also building on the two paradigm-shifting pathways in the GCF Water Security Guidelines, and the interlinkages between sanitation, wastewater treatment and other sectors.

The strategies are detailed in **Section 1.6** and summarised below:

Outcomes

1. Climate-resilient infrastructure and services
2. Circular economy and integrated management

Enablers

3. Community engagement and capacity building
4. Policy, regulatory and governance support
5. Monitoring and evaluation

By focusing on these areas, GCF investments can help create resilient, sustainable, and inclusive sanitation systems that effectively address the impacts of climate change across a range of closely related sectors.

These considerations should be seen in conjunction with the full analysis framework of the Water Sector Design Guidelines (Annex 1 to the GCF Water Security Guide) and the broader WASH guidelines (pages 16-24) of existing Annex 2.

Further considerations in defining sanitation interventions

In addition to ensuring alignment with relevant GCF criteria and strategies, the following questions are provided for guidance in the selection of interventions as part of proposal and project design:

How can proposals respond to the level of ambition reflected in the GCF paradigm shift for CRS?

To be successful, sanitation project proposals to GCF will need to reflect the level of ambition reflected in the envisioned paradigm shift for CRS. This will involve *expanding the scope of sanitation programming to incorporate climate adaptation and resilience objectives*, ensuring that projects:

- *Anticipate and prepare for climate impacts,* to ensure systems and services are not just functional but robust against future climate scenarios.
- *Encourage the use of innovative technologies and community involvement* to create adaptive, resilient, and sustainable sanitation systems and build community and ecosystems resilience.
- *Integrate sanitation within the wider context of climate goals,* promoting sustainable practices, and reducing the carbon footprint.

What sanitation interventions will most effectively respond to identified climate risks in the project location/s?

Different appraisal techniques are available to help prioritize options in the water and sanitation sector. These techniques range from sensitivity testing and scenario analyses to more sophisticated approaches that can be used to account for uncertainties. A key resource is the Technical brief "Appraising and prioritizing options for climate-resilient water, sanitation and hygiene", which focuses on appraising and prioritizing options for climate resilience with a view to informing programming and project design.

Potential interventions that respond to known climate risks to sanitation, and which contribute to mitigation through reduced greenhouse gas emissions, are detailed in **Section 4** of this document. As outlined in **Table 4.1**, the full sanitation service chain should be considered when assessing risks and potential adaptation responses, including containment; emptying and conveyance; and treatment, reuse or disposal. In selecting interventions to support mitigation and reduce emissions, optimising sanitation system design for low emissions and the capture and productive use of emissions are likely to be central — see **Table 4.2**.

It is also important to acknowledge that **climate change impacts and connected responses may differ between rural and urban sanitation systems.** While in rural settings the focus is on decentralized solutions due to disperse populations, urban settings may involve the extension and upgrading of centralized sewage systems, and incorporate advanced technologies for efficiency and capacity. It is expected that proposals will reflect the unique challenges and opportunities of rural and urban settings, outlining context-specific solutions that emphasize scalable, context-appropriate practices and technologies. These should be developed through strong stakeholder engagement with the involvement of local communities, local governments, mandated service authorities and the private sector to ensure sustainability and ownership of interventions.

What supporting policy, institutional, regulatory and financing (PIRF) mechanisms will be required to support climate-resilient sanitation in the project location/s?

Alongside operational and infrastructure-focused responses, systems strengthening activities are likely to be required to ensure the scalability and sustainability of solutions. Detailed guidance on PIRF mechanisms to support climate-resilient sanitation is provided in Section 4 and summarised in **Box 4.1**.

How do the proposed interventions connect to the long-term National Adaptation Plan (NAP) of the project country?

GCF proposals should be country-specific, and it must be explicit in the proposal that the interventions are fully aligned with existing NAPs and wider climate-related policies and strategies.

What interlinkages exist between the proposed interventions and broader environmental and socio-economic systems?

As outlined in Section 4.1, **it is important for GCF that proposals explore interlinkages between sectors and support coordinated management approaches**. Because of the interlinkages between so many different sectors, interinstitutional coordination and collaboration are essential for effective sanitation and wastewater treatment in the context of climate change. Water utilities, environmental agencies, and health departments must jointly plan and invest in infrastructure for safe wastewater reuse. Water resource management authorities and disaster management agencies should integrate wastewater treatment into drought and flood mitigation strategies. Additionally, agriculture, environmental, and energy sectors need to coordinate on using treated wastewater for irrigation, protecting ecosystems, and promoting biogas from wastewater plants. Such coordinated efforts ensure comprehensive and resilient water management, enhancing public health, socio-economic development, environmental protection, and resource efficiency.

Interlinkages between sanitation and other sectors which could be explored in proposals to GCF include (but may not be limited to):

- **Water supply:** efficient wastewater treatment ensures safe reuse of treated water, augmenting water supply especially in water-scarce regions.
- **Water resource management:** proper management of wastewater reduces pollution in water bodies, aiding in drought and flood management by maintaining the quality of available water resources.
- **Health:** effective sanitation and wastewater treatment prevent waterborne diseases, improving public health outcomes.
- **Food security:** treated wastewater can be used for agricultural irrigation, enhancing safe food production and security.
- **Ecosystem protection**: reducing pollutants through wastewater treatment protects aquatic ecosystems and biodiversity.
- **Energy:** adequate sanitation systems and wastewater treatment plants can generate biogas from organic waste, contributing to renewable energy supplies and reducing greenhouse gas emissions.

Budget development

Following from the definition of sanitation interventions, the project budget can be developed. The budget and supporting narrative should:

- Demonstrate to what extent and how the proposed activities deliver value-for-money;
- Articulate the scalability of project interventions, as a key component of value-for-money; and
- Delineate between the budget for climate-focused activities and wider development activities (where both are included).

Table 5.1: Sub-criteria sanitation considerations under the GCF investment criteria.

GCF Investment Criteria	Sub criteria
Impact potential	**Mitigation impact indicator:** ● Project proposals should describe the expected reductions in emissions resulting from reducing GHGs through improved waste treatment processes **Adaptation impact indicator:** ● The expected change in loss of lives, value of physical assets, livelihoods, and/or environmental or social losses due to the impact of extreme climate-related disasters and climate change, as well quantify beneficiaries of the intervention ● Improving the resilience of sanitation infrastructure to climate impacts like floods and droughts
Paradigm shift potential	● Innovation ● Level of contributions to global low-carbon development pathways, consistent with a temperature increase of less than 2 degrees Celsius ● Potential for expanding the scale and impact of the proposed programme or project (scalability) ● Potential for exporting key structural elements of the proposed programme or project elsewhere within the same sanitation sector as well as to other sectors, regions or countries (replicability) ● Contribution to the creation or strengthening of knowledge, collective learning processes, or institutions ● Sustainability of outcomes and results beyond completion of the intervention ● Market development and transformation ● Potential for strengthened regulatory frameworks and policies to drive investment in low-emission technologies and activities, promote development of additional low-emission policies, and/or improve climate-responsive planning and development ● Identify a vision for paradigm shift and impact beyond a one-off investment; accompanied by a robust and convincing theory of change for replication and/or scaling up ● GCF paradigm shifting pathways: 1. Enhanced water conservation/efficiency/reuse and 2. Strengthened WRM ● For sanitation – circular economy principles (e.g. biogas, nutrient recovery, ww reuse) a non-sewered approach to cost efficiencies and effectiveness and using sanitation as a driver to accelerated WRM health/ecosystem/water security issues

Sustainable development potential	● Expected positive environmental impacts, including in other result areas of the Fund, and/or in line with the priorities set at the national, local or sectoral level, as appropriate ● Expected positive social and health impacts, including in other result areas of the Fund, and/or in line with the priorities set at the national, local or sectoral level, as appropriate ● Expected positive economic impacts, including in other result areas of the Fund, and/or in line with the priorities set at the national, local or sectoral level, as appropriate ● Potential for reduced gender inequalities in climate change impacts and/or equal participation by gender groups in contributing to expected outcome ● Strong climate proposals identify links to other SDGs, and positive co-benefits: (a) Economic co-benefits, e.g. creation of jobs in the sanitation sector, poverty alleviation through averted medical costs and illness related absences form work/school. (b) Social co-benefits, improvements in public health and safety, access to education, social inclusion; (c) Environmental co-benefits – e.g. water and soils quality, conservation and biodiversity; from safely managed services (d) Gender empowerment co-benefits outlining how safe sanitation reduce gender inequalities.
Needs of the recipient	● Scale and intensity of exposure of people, and/or social or economic assets or capital, to risks derived from climate change (adaptation only) ● Comparably high vulnerability of the beneficiary groups ● Level of social and economic development of the country and target population ● Opportunities for the Fund to overcome specific barriers to financing ● Opportunities to strengthen institutional and implementation capacity in relevant institutions in the context of the proposal ● Focus on addressing specific vulnerabilities and needs of underserved communities viz sanitation that are affected by climate change ● Strong Project proposals should describe the country's financial, economic, social and institutional needs and the barriers to accessing domestic (public), private and other international sources of climate related finance. ● Outlines how the proposed intervention will address the identified needs and barriers.
Country ownership	● Objectives are in line with priorities in the country's national climate strategy ● Proposed activity is designed in cognizance of other country policies ● Experience and track record of the Accredited Entity or executing entities in key elements of the proposed activity ● Stakeholder consultation and engagement ● Strong sanitation focused climate proposals should clearly alignment with the country's NDC and other relevant national plans, and/or climate change policies. ● Effective sanitation projects will be integrated into national/local development plans, help build capacity to manage and sustain services over time and will have been developed in consultation with local stakeholders.

Efficiency and effectiveness	● Financial adequacy and appropriateness of concessionally ● Cost-effectiveness (mitigation only) ● Potential to catalyze and/or leverage investment (mitigation only) ● Expected economic and financial internal rate of return ● Financial viability in the long run ● Application of best practices and degree of innovation ● Sanitation projects need to demonstrate efficient use of resources, leveraging co-financing and ensuring financial models are sustainable. ● Projects should describe how the proposal applies and builds on the best practices in the sector. ● Enable long term operation and maintenance of the facilities.

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