Discussion paper:

Climate, Sanitation and Health

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Lead Authors: Jeremy Kohlitz, Juliet Willetts and Anna Gero (University of Technology Sydney, Australia), Stephanie Lyons (WaterAid, United Kingdom), Sophie Boisson and Kate Medlicott (WHO, Switzerland)

External reviewers: Guy Howard (University of Bristol, United Kingdom), Kristie Ebi (University of Washington), Katrina Charles (University of Oxford), Pierre Mukheibir (University of Technology Sydney, Australia), Rory McKeown, Jennifer De France, and Elena Villalobos Prats (WHO, Switzerland).

Contributors at expert meetings: Eyob Abebe (Ministry of Water, Irrigation and Energy, Ethiopia), Wondowossen Anteneh (DFID, Ethiopia), Zewdu Assefa (Ethiopian Public Health Institute, Ethiopia), Hamed Bakir (WHO Eastern Mediterranean Regional Office), Hakima Bendriouich (Direction Assainissement et Environnement à l'ONEE-BO, Morocco), Diarmid Campbell-Lendrum (WHO, Switzerland), Sonia Casmiro-Trigo (WHO Mozambique), Edward Chado (Ministry of Health, Malawi), Zufan Abera Damtew (Health Extension & Primary Health Service Directorate, Ethiopia), Shewanesh Demeke (Ministry of Water, Irrigation and Energy, Ethiopia), Ramakanta Duwadi (Department of Water Supply and Sewerage Management, Nepal), Mohamed Hammam El-Sakka (WHO Bangladesh), Patrick England (Water Supply and Sanitation Collaborative Council), Jonathan Farr (WaterAid), Meerjady Sabrina Flora (Ministry of Health, Bangladesh), David Fuente (University of South Carolina), Abiy Girma (Ministry of Water, Irrigation and Energy, Ethiopia), Zerihun Getu (Ministry of Finance, Ethiopia), Bruce Gordon (WHO, Switzerland), Annika Green (WHO, Switzerland), Maha Halalsheh (University of Jordan), Rachidul Huque (Ministry of Local Government, Bangladesh), Américo Feriano José (National Institute of Health, Mozambique), Antoinette Kome (SNV), Waltaji Terfa Kutane (WHO, Ethiopia), Stephen Lindley-Jones (DFID, United Kingdom), Qi, Yong Liu (ICDC, China CDC), Tiwonge Manda (University of Malawi), Humphreys Masuku (WHO Malawi), Genito Maure (WHO Mozambique), Hendricks Mgodie (Ministry of Health and Population, Malawi), Yeshitila Mogese (WHO Ethiopia), Américo Ângelo Paulo (Ministry of Health, Mozambique), Payden (WHO Southeast Asia Regional Office), Mohammad Saifur Rahman (Ministry of Local Government, Bangladesh), Feyisa Regasa (Ethiopian Public Health Institute, Ethiopia), Manjeet Saluja (WHO India), Prakash Shah (Department of Health Services, Nepal), Raja Ram Pote Shrestha, (WHO Nepal), Carolien Van der Voorden (Water Supply and Sanitation Collaborative Council), Yael Velleman (Imperial College, London), Ton Vlugman (Office of Caribbean Program Coordination, PAHO/WHO), Osman Yiha (WHO Ethiopia), Ashrafedin Youya (Ministry of Health, Ethiopia)

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1. Introduction

An estimated 4.5 billion people worldwide live without access to safely managed sanitation (WHO and UNICEF, 2017) which puts them at risk of infectious diseases. Climate variability and change exacerbate these risks by placing strain on sanitation systems, and therefore must be considered to ensure sanitation technologies and services are designed, operated and managed in a way that minimises public health risks.

Climate change projections indicate changes to the timing, intensity and spatial distribution of weather- and climate-related events. Increasing global and regional temperatures have the potential to increase the frequency, intensity and duration some severe extreme weather events; increase variable and unpredictable precipitation; and increase mean sea-levels (IPCC, 2014a). These changes affect sanitation systems and the infrastructure, water resources, water services, and other social and governance systems on which sanitation depends. Many of the direct and indirect effects on sanitation pose a danger to human health and development.

Greater attention to understanding the links between climate change and sanitation is needed to fill gaps in knowledge and improve practice (Howard et al., 2016). World Health Organisation (WHO) recently developed guidelines on sanitation and health (WHO, 2018), aiming to support countries to meet development commitments under the 2030 Sustainable Development Goal agenda. These guidelines provide recommendations and guidance for effective consideration of public health in sanitation policies and actions. This discussion paper further expands on the critical links between climate change, sanitation and human health.

1.1. Aims and scope

This paper provides an overview of the impacts of climate variability and change on sanitation and the implications for health. It outlines potential adaptation options for strengthening climate resilience of sanitation governance, policies, systems and services, and highlights further research needs and imperatives for policy and programming. It has a global focus, noting that the specific issues may differ across countries with varying levels of onsite and sewerage sanitation systems.

This paper is not a comprehensive review but is designed to serve as a starting point to identify challenges, needs and future actions. It builds on input provided by countries and development partners at a meeting on climate resilience and sanitation hosted by WHO in March 2018, as well as on recent research.

This paper includes consideration of sanitation at national and local levels. The scope includes all aspects of excreta management, including wastewater. The paper provides input on national vulnerability assessments as well as local level risk assessment and management approaches, building on Sanitation Safety Planning (SSP) (WHO, 2016). The focus of the paper is dominantly on climate adaptation rather than mitigation.

1.2. Background

While many communities have long dealt with climate variability, climate change is imposing increasingly intense and unpredictable risks. Even if global average temperature rise is successfully limited to less than 2°C above pre-industrial levels, major changes are projected in global precipitation patterns and extreme events, with significant impacts on hydrology and groundwater (WHO, 2009; Jiménez Cisneros et al., 2014; Howard et al., 2016), including direct and indirect effects on sanitation systems.

The purpose of sanitation interventions is to protect public health. Sanitation and health are interlinked through multiple possible hazardous events that can occur along the sanitation service chain (see Figure 2).

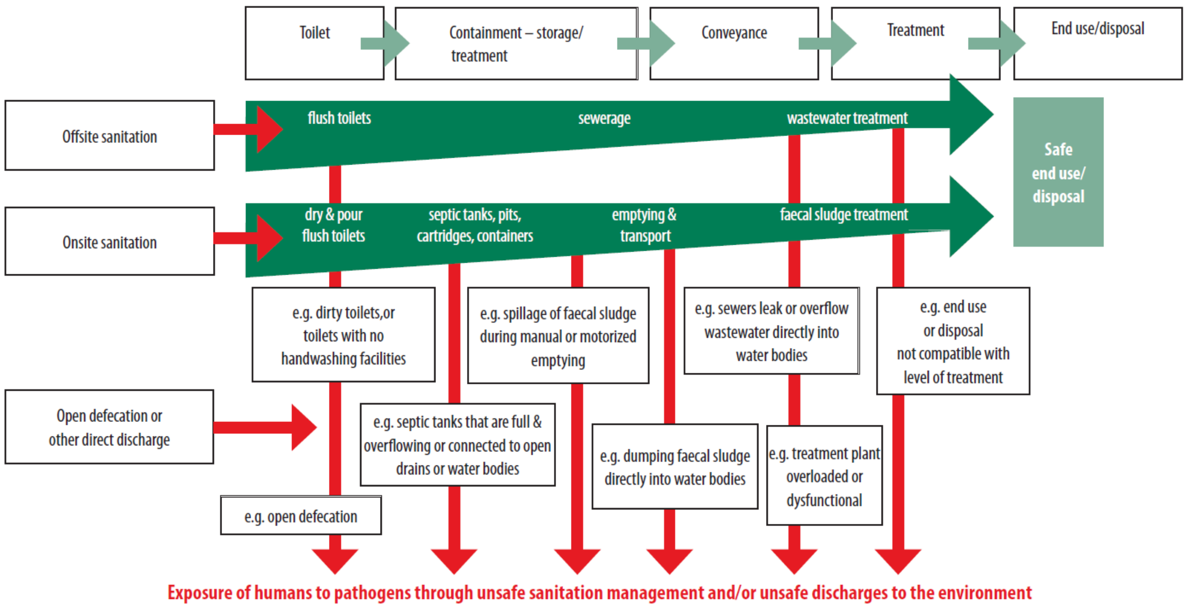

Figure 2: Excreta flow diagram showing examples of hazardous events at each step of the sanitation service chain (adapted from Peal et al., 2014)

As recommended in recent guidelines (WHO, 2018), universal access to toilets that safely contain excreta, and their sustained use in homes and institutions, and safe management through conveyance, treatment and end use and disposal, should be a key priority for all governments, and a core part of locally delivered services. Health authorities have an integral role to play in coordination, setting norms and standards, and in including sanitation in health policies and surveillance systems, all of which are increasingly critical in the face of a changing climate.

This paper draws on concepts discussed in the literature and practice in climate change, sanitation and health. Key definitions of terms are shown in Box 1.

Box 1. Definitions of key terms used in this paper

Adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects. (IPCC, 2014b)

Climate variability: Climate variability describes the way climate elements such as temperature and rainfall depart from the average value in given months, seasons, years, decades or centuries. This variability is the result of natural, large-scale features of the climate, which can occur at the same time as climate change (Climate Change Australia 2016).

Climate change: Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. (IPCC, 2014b)

Climate resilient health system: A climate resilient health system is one that is capable to anticipate, respond to, cope with, recover from and adapt to climate-related shocks and stress, so as to bring sustained improvements in population health, despite an unstable climate. (WHO, 2015)

Health: A state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity. (WHO, 1948)

Mitigation of climate change: A human intervention to reduce the sources or enhance the sinks of greenhouse gases. (IPCC, 2014b)

Resilience: The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation. (IPCC, 2014b)

Risk assessment and management for sanitation: The process of systematically identifying, prioritising and managing health risk along the sanitation chain from waste generation to final disposal or reuse (WHO, 2016).

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. (IPCC, 2014b)

This paper does not deal in detail with climate change mitigation, however there are three key areas concerning emissions potential and renewable energy that warrant mention.

- First, human excreta is a globally significant source of greenhouse gas (GHG) emissions. Pit latrines are estimated to account for approximately 1% of global anthropogenic methane emissions (Reid et al., 2014). GHG emissions from biological processes in wastewater treatment plants are poorly understood, but there is evidence they are major GHG contributors in some countries (Mannina et al., 2016). Promotion of composting toilets (Reid et al, 2014), regular emptying of septic tanks (IPCC, 2006) and good wastewater management (Howard et al., 2016) can reduce GHG emissions resulting from the breakdown of excreta.
- Second, there is a potential to reduce energy use in sewerage conveyance through gravity-based systems and increased use of distributed or decentralised systems that reduce pumping distances (Carrard and Willetts, 2017).
- Third, there is considerable potential to recover energy from faecal waste and wastewater, and hence the increasing relevance of combined mitigation-adaptation interventions.

2. Impacts of climate variability and change

Climate change exacerbates the risks that the current climate, including variability, poses for sanitation, and creates new risks, heightens uncertainties, and can increase inequality in sanitation access (Kohlitz et al., 2017). These three dimensions are informed by three key perspectives in the climate change literature, namely **risk-hazard, resilience** and **vulnerability.** Further, the potential consequences of climate change for the sustainability of water and sanitation services intersect with other causes of failures such as mechanical failure, poor siting or construction, and underlying institutional, financial and social factors. The implications for sanitation policy and programming responses of increased risks, uncertainties, and potential inequalities are outlined below, followed by discussion of the climate variability and change risks for sanitation.

Increasing risk to sanitation systems (risk-hazard perspective): The effects of climate variability and change are often framed in terms of the physical risks that climate hazards pose (Eakin and Luers, 2006). Many risks for sanitation come through extreme events and gradual changes to the hydrological cycle with corresponding changes to water resources (WHO, 2017a). There are other ways in which climate hazards can create risks for sanitation service delivery:

- **More intense or prolonged precipitation:** E.g. Greater rainfall in an event potentially creates more frequent or more intense flooding that can disrupt faecal sludge management (FSM) services if roads and access to containment and/or treatment plants are blocked, result in sewage overflows, and exceed the intake capacity of wastewater treatment plants.
- **More variable or declining rainfall or run-off:** E.g. Longer dry periods can lead to a decline in water supply that impedes the functioning of water-reliant sanitation systems, for instance concerning flushing toilets or blockages due to low sewer flows. High variation in rainfall can cause ground movement in soils with high clay content, resulting in pipe damage for sewer conveyance. Drier conditions can also have a beneficial effect of attenuating the flow of pathogens into water sources.
- **More frequent or more intense storms or cyclones:** E.g. Storms can damage or destroy latrine superstructures, conveyance pipes, power supplies etc, potentially resulting in increased slippage to open defecation and disruptions to pumping and treatment facilities.
- **Sea-level rise:** E.g. Rising sea-levels and consequent salinization can expose coastal wastewater treatment plants and other sanitation infrastructure to inundation and corrosive saltwater.
- **More variable and increasing temperatures:** E.g. Higher water temperatures can be conducive to the proliferation of algal blooms and compound the effects of sanitation pollution in freshwater. Higher temperatures can also have a beneficial effect of increasing the efficiency of biological processes in wastewater treatment.

More detailed examples of specific risks and benefits that climate change creates for sanitation are shown in Table 4. This material is not exhaustive – the cascade of risks for sanitation infrastructure, especially in urban settings, can be complicated and extensive when one considers the full sanitation service chain and associated systems.

Table 4: Examples of climate variability and change effects on sanitation systems

Climate change effect	Potential hazards and changes	Examples of risks (and benefits) for sanitation systems
More intense or prolonged precipitation	• Increased flooding • Increased erosion, landslides • Contamination of and damage to surface water and groundwater supplies • Changes to groundwater recharge and groundwater levels	• Destruction and damage to sanitation infrastructure • Damage to other infrastructure/systems on which sanitation systems rely (e.g. electricity networks for pumping; road networks used by FSM vehicles) • Flooding of on-site systems causing spillage and contamination • Flooding and collapse of pit latrines, including via groundwater • Overflow and/or obstruction of sewerage and septic systems • Floating of septic systems due to groundwater levels • Treatment plants receive flows that exceed their design capacities, resulting in flows bypassing the treatment processes
More variable or declining rainfall or run-off	• Longer dry seasons/periods • Droughts (both seasonal and longer-term) • Reduced surface water flows • Reduced groundwater levels/resources	• Declining water supply impeding function of water-reliant sanitation systems (e.g. flush toilets, sewerage, treatment) • Greater distance between pit latrine pollutants and groundwater levels, beneficially allowing for pathogen attenuation [benefit] • Obstruction creating reduced capacity in rivers or ponds that receive wastewater • Increased reliance on wastewater for irrigation which, if not adequately managed, can increase health risks • Increased corrosion of piped sewers • Higher pollution concentration in wastewater and reduced capacity of receiving water bodies to dilute wastewater • Ground movement in soils with high clay content leading to broken pipes and joints
Sea-level rise	• Saline intrusion in coastal/low-lying zones • Rising groundwater levels in coastal/low-lying zones • Higher risk of inundation, especially from extreme weather events (potentially contributing to flooding, erosion, landslides)	• *See impacts from flooding above* • Damage to underground infrastructure from rising groundwater levels • Damage to wastewater treatment works (which are often low-lying/coastal) from exposure to saltwater • Reduced effectiveness of biological treatment processes due to saltwater exposure from saline intrusion into wastewater influent
More variable or increasing temperatures	• Higher ambient air temperatures in homes or facilities • Higher freshwater temperatures • Hot and cold temperature extremes	• Water temperatures beneficially increase efficiency of biological wastewater treatment (if temperature stays within operational limits) [benefit] • Reduced efficiency of biological wastewater treatments (if temperature exceeds or falls below operational limits) • Proliferation of algal blooms or microbes carried by vectors in water • Increased corrosion of sewers • Quicker drying of faecal sludge in waterless latrines if increasing temperature is matched with drying conditions
More frequent or intense storms or cyclones	• Increased flooding • More extreme winds	• *See impacts from flooding above* • Damage to latrine superstructures and other infrastructure • Damage to other infrastructure/systems on which sanitation systems rely (e.g. electricity networks for pumping; road networks used by FSM vehicles)

Note: This table was developed with reference to Howard and Bartram, 2010; Howard et al., 2016; Oates et al., 2014.; Sherpa et al., 2014; ISF-UTS & SNV, 2019. Elaborated based on input from participants at WHO meeting on sanitation and climate change, March 2018. Examples provided depend on context, and those provided here are illustrative and not exhaustive.

Management of the physical risks created by existing climate hazards can be an effective first-step in an adaptation strategy. Climate risk management for sanitation can be achieved through making modifications to sanitation infrastructure that make them more resistant to climate hazards or through improving their operational management. Section 5.1 explains how SSP, a risk-based management tool, can be extended to incorporate climate considerations.

Heightened uncertainties surrounding sanitation planning and management (resilience perspective): There is significant uncertainty associated with how the climate in specific locations will change and when consequences will be felt (Deser et al., 2012). There are perhaps even greater uncertainties associated with how climate-related risks will interact with other factors (e.g. urbanisation, population growth, land-use change, etc.) and how society at local and national levels will respond (Dessai and Hulme, 2004). Predicting and resisting climate risks should be done where this is possible. However, it is impossible to predict, and precisely plan for, all of the direct and indirect ways in which climate change will affect sanitation.

These uncertainties create multiple challenges for sanitation, including:

- **Inadequate preparation for unexpected events:** Risk management strategies for sanitation may fail to account for events that are emergent or unexpected (e.g. sudden spike in rural-urban migration driven by climate stress on food security in rural areas). Failing to account for unexpected risks or events can lead to inadequacies in available sanitation services and inefficient ad-hoc solutions.
- **“Paralysis” about what to do next:** Uncertainty can be paralysing to climate adaptation action if stakeholders perpetually wait for more clarity on the problem (Nerlich, 2010). By adopting a “wait and see” attitude to climate change, WASH professionals may fail to recognise the imperative to take immediate action (Batchelor et al., 2011).

Developing sanitation services to be *flexible and adaptable* can help address challenges of uncertainties (Kohlitz et al., 2019a). Being able to readily change the management and operation of sanitation services, continual learning, and good understanding of sanitation system components can help to develop sanitation services that adapt to changing conditions (Box 2). To operationalise this, indicators of change can be developed to provide the necessary lead times for triggering appropriate responses based on the available information (e.g. see United Utilities, 2018 on developing redundancy and quick response and recovery in water utilities). “Low regrets” approaches to sanitation development – approaches that are beneficial regardless of the climate scenario – should also be pursued (Oates et al., 2014). For example, scheduled emptying of latrines in advance of flood seasons.

Box 2. Adaptable urban sanitation

“Being adaptable to uncertain conditions is the key to resilience. It requires continual learning and corresponding adjustments to changing conditions, which is far from the reality of management of urban sanitation services in many cities today. Poor understanding of a city’s sanitation system, along with a lack of monitoring and warning or response mechanisms, limits the ability of service providers and the public to prepare for or adapt to change. Flow monitoring, for example, could trigger an alert to fix pumps or warn the public of sewer overflows. Many cities lack up-to-date plans, asset registers of sanitation infrastructure and services, and learning processes to adapt management to changes in system performance.”

Source: ISF-SNV, 2019

Deepening inequalities in sanitation access (vulnerability perspective): The risks of climate variability and change affect sanitation users unequally, and the capacity to prepare for climate-related risks to health and sanitation effectively varies greatly across individuals and social groups (OHCHR, n.d.). Poverty and marginalization are primary determinants of increased vulnerability, and climate change can exacerbate poverty resulting in people becoming increasingly trapped in a position of disadvantage (Leichenko and Silva, 2014).

Implications of the unequal risks of climate change for sanitation access include:

1. **Structural deficits** (e.g. lack of income, education, health, political power) must be addressed to enable disadvantaged households to effectively adapt to climate risks (Eakin et al., 2014; Lemos et al., 2016). For example, disadvantaged households may need to be supported with financial or hardware subsidies for climate-resilient facilities, and given access to land, to construct latrines that are suitable for changing environmental conditions (e.g. rising groundwater table).
2. Development activities to alleviate poverty or address inequalities can **inadvertently put groups at increased risk of future climate change** (Agrawal and Lemos, 2015). For example, installation or expansion of sewerage services to a low-income slum area may provide near-term benefits, but create longer-term harm to those populations if a future decrease in water availability causes the sewerage network to fail and no alternative sanitation facilities are available, and if they are limited in their own resources to adapt.

Addressing climate change risks to the sanitation sector, therefore, should pay careful attention to the needs of vulnerable groups (ISF-SNV, 2019) and the reality that the capacity to respond to climate change effectively is differentiated within communities and households (Kohlitz et al., 2019b). In particular, low-income populations living along waterways or in flood prone areas require additional attention. Mitigation of the underlying drivers of marginalisation and vulnerability can itself be an effective response to climate change and enhance the effectiveness of risk-management and resilience-building activities. Approaches that link vulnerability to both socioeconomic stresses and climate change can help identify hotspots in which to focus specific adaptation efforts (see for example, Mukheibir and Ziervogel 2007).

Impacts on health through sanitation systems

Climate change impacts on health can result from sustained high temperatures which can be mediated through either environmental or social/human systems (IPCC, 2014c). Sanitation, along with water, food systems and disaster risk reduction, are 'health determining' sectors (WHO 2018). Climate change is expected to exacerbate existing health problems including those related to poor sanitation (IPCC, 2014c). Given that only 0.5% of multilateral climate finance has funded health projects (WHO 2018), greater attention and resourcing is required to protect communities from the health implications of climate change, including those relating to sanitation.

Climate change-related health consequences from sanitation systems generally fit within two overarching categories: (i) increased risk of disease or illness from exposure to pathogens and hazardous substances through increased environmental contamination, and/or (ii) increased risk of disease or illness resulting from a lack of access to adequate sanitation when systems are destroyed or damaged. In addition, sanitation workers may experience additional risks depending on their work context and level of occupational health and safety.

Poor and vulnerable groups face the most immediate and severe consequences from climate change, and health is no exception. People without access to good quality health care and basic services experience overlapping forms of disadvantage and are likely to face the worst effects. Further, rigid sanitation services that are unable to accommodate more variable and extreme climate conditions are more likely to fail, and expose populations to health risks, than flexible services, which can be achieved either through infrastructure and technology choice or through relevant management arrangements. Tools such as impact mapping can be useful for identifying causal links relating to health and climate change and identifying specific intervention points (Mukheibir et al. 2017).

Health risks from faecal contamination result from the combination of hazard (a contaminant that can cause harm to human health, e.g. pathogens), the level of exposure to the hazard (the frequency that a hazardous event occurs) and the susceptibility (which may depend on age, and level of immunity). Examples of the types of health effects that can result from climate impacts on sanitation systems are shown in Table 5.

Table 5: Examples of health effects resulting from climate change risks for rural and urban sanitation systems

Climate change effect	Example impact on sanitation	Examples of associated health effects
More intense precipitation (leading to extreme rainfall events, floods, landslides, etc.) or inundation caused by mean sea-level rise	Flooding of on-site systems causing destruction of facilities, spillage, overflow and environmental contamination (e.g. in water supplies, floodwaters, surface water, soil)	• Increased stress, fear, potential exposure to violence and anxiety from lack of access to toilet facilities and reliance on open defecation • Increased risks of water- and vector-borne diseases through reduced functioning • Increased exposure to faecal contamination resulting in environmental enteric dysfunction
Long-term declines in rainfall and run-off (leading to e.g. long-term drought etc.)	Declining water supply impeding function of water-reliant sanitation systems (e.g. flush toilets, sewerage); Increased demand for use of wastewater – especially in agriculture; shifting ground due to drying soils cracks or damages infrastructure	• Increased risks of water- and vector-borne diseases (e.g. due to lack of water for flushing and cleaning resulting in poor sanitary conditions and poor hygiene, and changes in mosquito breeding between dry and wet) • Increased open defecation and associated health risks • Increase risk of water- and vector- borne diseases linked to untreated wastewater reuse for food production
Higher temperatures (leading to e.g. warmer surface water and soil temperatures, heatwaves)	Malfunction, breakdown or inaccessibility of sanitation systems deterring safe sanitation behaviours (e.g. strong odours during heatwaves deterring use of latrines)	• Health impacts resulting from unsafe use or non-use of sanitation systems (e.g. physical or mental health conditions)

Note: This table was developed with reference to WHO, 2017a, and the sources informing Table 1. Examples provided depend on context; they are illustrative and not exhaustive

3. National level responses

This section describes processes for national level risk assessments (Section 4.1), as well as key national level mechanisms to support climate resilient sanitation (Section 4.2).

3.1 National level assessments

Many countries have completed national assessments of climate change risk and adaptation options through a variety of processes, often driven by global agreements such as the United Nations Framework Convention on Climate Change (UNFCCC), and particularly for low- and middle-income countries. These assessments generally consider climate change vulnerability in relation to a range of sectors, and often include proposed adaptation options (for example Fiji (Government of Fiji 2017) (see Box 3), Ethiopia (IWHO, 2018 (in press)) and European countries (see European Environment Agency 2018). Examples are provided below in **Error! Reference source not found.**.

Table 6: National assessments of climate change risk and adaptation

National Assessment	Focus and aims
National Adaptation Plans (NAPs)	NAPs were established under the UNFCCC's Cancun Adaptation Framework and encourage all developing countries to identify medium- and long-term adaptation needs and develop plans to address them for the purposes of domestic decision making.
Health National Adaptation Process (HNAPs)	Led by WHO, health adaptation planning within the NAP process (HNAP) aims integrate health adaptation to climate change into national health planning strategies, processes, and monitoring systems (WHO 2014).
National Adaptation Programmes of Action (NAPAs)	Least developed countries communicate their urgent and immediate needs regarding adaptation to the UNFCCC through the NAPA process, which was established in 2001 and draws on an eight-step process resulting in a list of discrete projects. Completing NAPAs enabled countries to be eligible for Least Developed Countries Fund.
Nationally Determined Contributions (NDCs)	As part of the Paris Agreement, developed and developing countries have goals to reduce their emissions and adapt to the impacts of climate change. These details form the core of NDCs.
Climate Vulnerability Assessments (CVAs)	Climate vulnerability assessments (CVA – also called National Climate Assessments, Resilience Assessments) are an approach to understanding the risks and impacts of climate change at the national level, often taking a sectoral approach. CVAs can support the development of adaptation plans, with human health often being identified through the CVA process as a sector with specific vulnerability to climate change. The Bangladesh CVA includes a chapter on health vulnerability to climate change, with particular attention paid to heat stress (Goosen et al. 2018).

Box 3: Climate vulnerability assessment: Making Fiji climate resilient

Fiji's climate vulnerability assessment aims to improve the understanding of how climate change will impact upon the country's development priorities. The report quantifies climate change impacts by analysing human settlement patterns and the expected changes to severe weather. The report also explores socio-economic resilience as a measure of adaptive capacity. Given Fiji's development priorities which include coastal development agriculture, health and tourism, the report outlines how these sectors are likely to be impacted by climate change. It also provides five major areas for intervention to adapt to climate change, through reducing risks and managing residual risk. Amongst priorities for the next 10 years is investment of FJ$1.1 billion to strengthen resilience in the water and sanitation sector to mitigate risks of damage to infrastructure, service disruption, and environmental or health hazards during extreme climate events.

Source: Government of Fiji 2017

National level assessments primarily inform national level policy, strategy and planning processes. They can also be used to inform local level assessment (Section 4) however greater resolution and specificity may be necessary to usefully inform management and adaptation at local level.

At the national level, consideration of climate change in relation to sanitation and health remains limited, and needs to be better situated in wider national level processes to address climate change, such as the assessments outlined above in **Error! Reference source not found.**.

National level assessments provide nationally compiled information on climate-related hazards, human and natural system exposure to those hazards, and the vulnerability or resilience of these systems. They project changes in weather and climate patterns, and their possible consequences for sectors such as WASH, health, infrastructure, energy, agriculture, education and environment. Sanitation may often be missed or excluded from detailed consideration. For example, Ethiopia's Country Climate Risk Assessment Report describes climate change vulnerability in sectors including health, environment and water, as well as poverty and gender equality (Irish Aid 2018), but not sanitation specifically. National assessments often draw on standardised methods to assess risk and adaptation options. These methods include Vulnerability and Adaptation (V&A) assessments, climate risk assessment and mapping, social vulnerability indexes, and adaptation readiness. Ways in which these assessments can inform climate resilience in national level mechanisms for sanitation include (Section 5.2)**:**

- **Vulnerability and adaptation (V&A) assessments** form part of the preparation of National Communications to the UNFCCC. V&A assessments draw upon specific methods, tools and data to enable assessment of sectoral vulnerability and adaptation options. Most countries have already undertaken some assessments of vulnerability to climate change and adaptation options, and new V&A assessments related to sanitation should aim to build on this knowledge base.
- **Climate risk assessment and mapping** are conducted to identify geographic areas that are most likely to be exposed to and severely affected by climate-related hazards (e.g. flood prone areas or areas exposed to landslides) (EC, 2010). For sanitation, climate risk assessment of this type could involve mapping sanitation infrastructure and overlaying hazard maps indicating where floods, water scarcity, landslides, salinization, etc. are most likely to occur to identify areas where sanitation services could be disrupted. Visual risk maps can be created by combining data on the physical location of sanitation infrastructure with existing data and maps on climate-related risk factors compiled through national level assessments. A feasible approach would involve working with national climate change teams to build on existing mapping and models and integrate sanitation into these. Where data exist, maps of relevant biophysical features important for sanitation (e.g. groundwater table or soil types) should also be included.
- **Social vulnerability indexes** aim to measure vulnerability of populations using indicators (e.g. related to economic welfare, social well-being, access to technology, etc.) that are then weighted and combined into an index that ranks the vulnerability of population in different areas (Smit and Wandel, 2006), and where they exist, could support strengthened integration of socio-economic dimensions to planning for adaptations related to sanitation. A vulnerability index that includes sanitation could combine nationally aggregated data on water and sanitation access, exposure to climate hazards (as per Amarnath et. al, 2017), and relevant socioeconomic factors. However, some experts warn that these types of indexes oversimplify the complex nature of vulnerability and should not be used alone for comparing regions or allocating resources (Barnett et al., 2008; Hinkel, 2011). National level assessments may already have developed such indices, based on Demographic and Health Surveys (DHS) and Multiple Indicator Cluster Surveys (MICS) and other sources to then develop standardised units and overall vulnerability scores (Luh et al., 2015, Barnett et al., 2008).
- **"Adaptation readiness"** refers to the strength and existence of government and other structures and policy processes for implementing climate change adaptations (Ford and King, 2015). Assessment of adaptation readiness often focuses on factors such as available funding, institutional organization, usable science, decision-making and stakeholder engagement processes, public support for adaptation, and leadership from local to national government levels (Ford and King, 2015). This type of assessment can shed light on the strengths and gaps in the enabling environment needed to effectively implement climate adaptations in the sanitation sector. Adaptation readiness with respect to sanitation can be assessed

qualitatively through an examination of national documents and processes (Ford and King, 2015). This could include assessing:

(i) the extent to which climate policies, NAPs, or other climate strategies address sanitation (and equally, whether sanitation plans and strategies address climate change)
(ii) the presence of embedded climate change expertise within sanitation-related government departments including health and public works, or the existence of networks and cooperation with stand-alone agencies focused on climate change
(iii) availability of nationally relevant peer-reviewed and grey literature on climate and sanitation
(iv) statements and engagement from political leaders on issues of climate change and sanitation
(v) the amount of climate financing focused on the sanitation sector
(vi) the level of demand from the public or media for action on climate change and sanitation

3.2 Strengthening climate resilience in national level mechanisms for sanitation

The promotion of climate resilient sanitation at the national level can occur through a number of mechanisms. In this section, national level mechanisms in alignment with the six "building blocks" of climate resilient health systems (WHO, 2015) are described. The six building blocks are leadership and governance, health workforce, health information systems, technologies,[1] service delivery and financing. Examples of mechanisms are described below with their corresponding building block(s) in parentheses.

- **Mainstreaming climate change into sanitation policies and governance** (Leadership and governance): Incorporation of climate change adaptation objectives into sectoral development planning – known as mainstreaming – can build resilience to climate change and lead to improved development outcomes (UNDP-UNEP, 2011). Mainstreaming requires policy and planning frameworks, risk assessments and management approaches to build preparation for climate change risks into sanitation development. In particular, it will be important to ensure an enabling environment for local level risk assessment such as sanitation safety plans (SSPs) (see section 5.1), for example through ensuring inclusion of risk assessment and management approaches and their monitoring in the national sanitation policy framework (WHO, 2016).

- **Supporting improved cross-sectoral coordination** (Leadership and governance): Preparing for climate change requires a whole of government response, and sanitation itself is a cross-sectoral issue that spans multiple line ministries or agencies (WHO, 2017b). In the case of sanitation, coherent mainstreaming of climate change is required across several relevant ministries, including infrastructure or public works, health and environment ministries, as well as linkages to ministries focused on water resource management and agriculture. Dedicated climate change ministries or departments, where they exist, can help to facilitate cross-sectoral coordination to ensure the entire sanitation service chain is addressed and align sanitation interventions with national adaptation plans. National mechanisms facilitating disaster risk management are also another entry point. Lastly, coordination with other actors, including civil society and the private sector, can further enabling the integration of climate change considerations across sectors.

[1] Please note that in the WHO framework this category is described as 'essential medical products and technologies', however only 'technologies' is relevant in the context of sanitation.

- **Addressing national health workforce engagement and capacity** (Health workforce): While sanitation is often implemented through multiple ministries and utilities, health authorities hold significant responsibility for ensuring that sanitation investments improve public health (WHO, 2018). This includes sanitation investment pertaining to climate change. The health sector should develop contingency plans for deployment of health personnel during climate-related disasters, national strategies for addressing climate change risks to health, including via sanitation, and communicate and raise awareness of the links between climate, sanitation and health (WHO, 2015).

- **Strengthening climate, sanitation and health information systems** (Health information systems): Any sanitation or health intervention aiming to tackle the risks of climate variability and change should be informed by national assessments (including of health risks via sanitation, e.g. HNAP or V&A assessments) of individuals and groups, as well as of the vulnerability of specific infrastructure and systems, regions and climatic zones. Section 4.1 above describes broad approaches to assessing this information at a national level.

- **Developing a coherent national approach to infrastructure technology and service delivery choices** (Technologies; Service delivery): Sanitation infrastructure choices at the national level need to be consider climate change risks. This is particularly important because national policy shapes sector development and larger-scale sanitation investments (particularly for urban areas) are often made by national governments (either directly or indirectly through specialised funding or other transfers). Country-level trends in terms of water scarcity, drought, flooding and extreme weather events described in national vulnerability assessments, as described above, should shape national level discussion about technology choices. In addition, because win-win solutions may exist, consideration of climate mitigation together with adaptation needs is important.

  In particular, for urban areas, decision-making about the appropriate balance in offsite (e.g. city-scale sewerage treatment and sludge treatment), distributed (e.g. local or decentralised wastewater and/or sludge treatment) and onsite (e.g. household level septic tanks, pit latrines etc.) should take into account changing climate-related hazards, in terms of expected technology performance and management arrangements. Feasibility studies for new infrastructure should include consideration of a range of climate and development scenarios. Further, consideration of energy requirements, links to the broader water cycle and to water and nutrient re-use are critical. Equally, chosen institutional arrangements for service delivery (e.g. leadership on service delivery by utilities or by city governments) need to take into account capacity of institutions to be responsive to climate change-related risks for sanitation.

- **Mobilising national financing mechanisms** (Financing): Adequate financing to address the impacts of climate change on sanitation and health is needed in developed and developing contexts. Climate financing flows from high to low- and middle-income countries has been increasing, for example through the Green Climate Fund, Global Environment Facility Funds and Adaptation Fund (OECD, 2018). Mechanisms exist to access funds, with national authorities delegated with authority to apply. However, whilst UNDP and UNEP may support, access to such funds can be difficult with strict requirements (e.g. the accreditation process and financial management systems) posing a barrier to access in some countries (Resch et al. 2017). National sanitation and health stakeholders in low- and middle-income countries will require support to successfully access adaptation funds, including demonstrating the links between climate and sanitation to donors, plan who will manage climate funds, plan how funds will be targeted, think of ways in which to align investments with national climate policies, and identify gaps and needs (WaterAid, 2016).

4. Local level responses

This section describes ways in which climate resilience can be built into local level risk assessments (Section 6.1) which represents a key approach to incorporating climate considerations to sanitation at local level, as well as broader local level responses in relation to the building blocks of climate resilient health systems (WHO, 2015) (Section 6.2).

4.1 Building climate resilience into local level risk assessment

Sanitation Safety Planning (SSP) is a risk-based management tool for sanitation systems (WHO, 2016). SSP provides a structure to bring together actors from different sectors to identify health risks in the sanitation system and agree on improvements and regular monitoring, ideally under the leadership of the agency responsible for sanitation service delivery. The approach encompasses a systematic assessment to identify and prioritize key risks at each stage of the entire sanitation chain, ensuring that control measures *target the greatest health risks* and emphasises incremental improvement over time. It can be used at the planning stage for new schemes, and to improve the performance of existing systems. SSP underscores the leadership role of the health sector in managing wastewater, excreta and greywater, and helps to bring a human health perspective to traditional non-health sectors like sanitation engineering and the agricultural sector. SSPs can be extended to incorporate climate variability and change considerations (see Table 7 below). It should be noted that climate change is a significant driver of interactions between SSP and Water Safety Planning (WSP), in that climate resilient WSP (CR-WSP) is inherently linked to climate resilient sanitation, particularly at the catchment level. For further information on CR-WSP see WHO (2018).

Table 7: Climate considerations in sanitation safety planning processes

Sanitation safety planning steps (WHO, 2016)	Climate considerations
Module 1: Prepare for SSP Modules: 1.1 Establish priority areas or activities 1.2 Set objectives 1.3 Define the system boundary and lead organization 1.4 Assemble the team Outputs: • Agreed priority areas, purpose, scope, boundaries and leadership for SSP • A multidisciplinary team representing the sanitation chain for development and implementation of SSP	• Engage ad hoc support from climate-related experts[2] as needed during key stages of SSP development and review • When establishing priority areas and SSP objectives: ○ Identify geographic areas or activities where climate is known to currently or historically affect sanitation infrastructure or performance (e.g. wastewater treatment plants that are frequently flooded; coastal communities affected by storm surges) ○ Identify geographic areas or activities that are highly exposed to climate-related hazardous events (communities located in floodplains; sanitation infrastructure located near the ocean) ○ Identify current or historical climate-related hazardous events that are known to pose significant health risks to the collection, treatment, reuse and/or disposal of human wastes (e.g. overflowing of pit latrines contaminating drinking water sources)
Module 2: Describe the sanitation system Modules: 2.1 Map the system 2.2 Characterize the waste fractions 2.3 Identify potential exposure groups	• Collect more detailed information on how climate-related events and variability have affected system performance and infrastructure in the past (e.g. wastewater flowrates across seasons; impacts of past extreme events on sanitation infrastructure and services), including all steps in the sanitation

[2] Examples include, meteorologists, climatologists, hydro(geo)logists, adaption/disaster/emergency management specialists, strategic planners, civil contingency planners, climate change and public health specialists, risk management specialists, economists, climate resilient water safety planners, natural resource managers, integrated water resource managers.

Sanitation safety planning steps (WHO, 2016)	Climate considerations
2.4 Gather compliance and contextual information 2.5 Validate the system description Outputs: • A validated map and description of the system • Potential exposure groups • An understanding of the waste stream constituents and waste related health hazards • An understanding of the factors affecting the performance and vulnerability of the system • A compilation of all other relevant technical, legal and regulatory information	service chain and considering all waste fractions (e.g. domestic wastewater, faecal sludge, urine, stormwater overflows) • Collect information on how climate-related events and variability have affected waste fractions in the past (e.g. proportions of liquid and solid waste during a drought) • Collect existing information on climate change projections and future impacts in the region (e.g. from national level assessments listed in section 4.1) • Include a focus on current and past climate-related events and variability when validating the system description through interviews, focus group discussions, or surveillance • Assess the extent to which relevant quality standards, certification and auditing requirements and/or system performance monitoring accounts for climate-related events and variability • Check whether national guidelines for climate change preparedness or disaster planning and local disaster management plans have relevant content for sanitation that could inform the SSP process

Module 3: Identify hazards, assess existing controls and assess exposure risk
Modules:
3.1 Identify hazards and hazardous events
3.2 Refine exposure groups and exposure routes
3.3 Identify and assess existing control measures
3.4 Assess and prioritize the exposure risk
Outputs:
• A risk assessment table which includes a comprehensive list of hazards, and summarizes hazardous events, exposure groups and routes, existing control measures and their effectiveness
• A prioritized list of hazardous events to guide system improvements
	• Identify climate-related hazardous events that expose people to a hazard from the sanitation system, considering the full sanitation chain (see Annex 1 and
	• Table 4 for examples) as well as via changes in sanitation demand and use (e.g. people reverting to open defecation due to repeated storm damage to latrines; increased wastewater flow resulting from rural-urban migration driven by climate impacts; increased demand for sludge or wastewater as a crop fertiliser)
	• Consider how climate change may:
	  o Increase or decrease the likelihood of the identified climate-related hazardous events occurring
	  o Increase or decrease the severity of the identified climate-related hazardous events
	  o Create new or unprecedented hazardous events
	• Consider how climate change can influence all exposure and transmission routes of excreta-related disease
	• Identify any expected changes in health risks associated with waste fractions under climate change (e.g. domestic wastewater, faecal sludge, urine, stormwater overflows etc.)
	• When considering how climate change may influence existing hazardous events or create new ones, analyse how the risks are differentiated across the potential exposure groups (particularly integrating considerations of equity and vulnerable groups)
	• Where the future effects of climate change are not known, consider different climate scenarios (e.g. drought, flooding/prolonged rainfall, cyclone/storm, and sea-level rise scenarios) when identifying hazards and assessing risk (whether using descriptive, semi-quantitative or quantitative assessment methods)
	• Consult local sanitation users and service providers to obtain local knowledge, experiences and insights on how climate affects sanitation
	• Analyse whether the effectiveness of existing control measures for hazardous events are likely to be reduced under particular climate scenarios, or analyse the effectiveness of existing control measures as “low-regrets” measures (i.e. measures beneficial under any climate scenario).

Sanitation safety planning steps (WHO, 2016)	Climate considerations
Module 4: Develop and implement an incremental improvement plan Modules: 4.1 Consider options to control identified risks 4.2 Use selected options to develop an incremental improvement plan 4.3 Implement the improvement plan Outputs: • An implemented plan with incremental improvements which protects all exposure groups along the sanitation chain	• Design options to control the identified climate change risks – see Annex 2. • Consider whether existing control measures can be strengthened, or new control measures are needed, to address the most severe hazardous events under the most likely climate scenarios • Prioritise control measures that are "low regrets", especially in situations where future changes to the climate are unknown • Ensure that improvement plans for capital works, operational or behavioural measures that address non-climate related risks will still be effective under different climate scenarios • Design the improvement plan to allow for management processes and infrastructure to adapt as needed to emergent and unforeseen conditions
Module 5: Monitor control measures and verify performance Modules: 5.1 Define and implement operational monitoring 5.2 Verify system performance 5.3 Audit the system Outputs: • An operational monitoring plan • A verification monitoring plan • Independent assessment	• Check that control measures are still appropriate and effective given local trends in climate change • Monitor whether unexpected climate-related effects (e.g. rising groundwater table) are emerging and require attentions (e.g. via collection of primary data or through reporting from other institutions that track meteorological and hydrological changes) • Develop flexible monitoring programmes that reflect climate variability (e.g. developing seasonal critical limits; stipulating the need for increased frequency of monitoring post-flood event) • Ensure that information from early-warning systems (e.g. drought and cyclone warnings) is being communicated to sanitation mangers, operators, and users
Module 6: Develop supporting programmes and review plan Modules: 6.1 Identify and implement supporting programmes and management procedures 6.2 Periodically review and update the SSP outputs Outputs: • Supporting programmes and management procedures • that improve implementation of the SSP outputs • Up to date SSP outputs responding to internal and external changes	• Develop emergency response plans for the anticipated severe climate-related emergencies within the systems (e.g. flood response plan, drought response plan etc.) • Develop climate-themed supporting programmes including stakeholder engagement, awareness raising and capacity building activities that support broader climate resilient sanitation practices (e.g. training for farmers on safe biosolids application during rainy season) • Review/revise SSP following incidents/near misses related to severe climatic events • Review/revise SSP periodically to include new climate information as it becomes available • See Section 5.2 below for further potential strategies and actions

4.1 Broader local level responses

In addition to SSP, other local level responses are needed to address climate impacts on sanitation and health. As with Section 5.2 on national response mechanisms, this section describes local level mechanisms in alignment with the building blocks of on climate resilient health systems (WHO, 2015).

Providing national level support to locally-led responses (Leadership and governance): Delegating authority to subnational levels allows for local leaders to control policy direction and priorities, allocate finances and ensure local contextual issues of climate change are taken into account. This is important because climate change impacts are highly contextual. While there are benefits to decentralised governance, centralised sources of support and expertise are critical for addressing climate change impacts on sanitation that go beyond local scales (Kohlitz et al., 2019a). For example, downstream effects of sanitation pollution that are worsened due to increased surface runoff or reduced dilution capacity of water bodies may require coordination across broader scales.

Incorporating climate risks to local policy (Leadership and governance): Many subnational health sector and sanitation sector plans, targets and activities do not yet account for the additional pressures that climate change may impose. Local policy makers should consider a phased policy design to progressively addressing risks to sanitation systems as the complexity of risks increases (in line with the principles of low regrets approaches). Mainstreaming climate change-related risks into existing policies may be an efficient means to implement policy change.

Building capacity of service providers and environmental health professionals (Workforce capacity): There are opportunities to integrate climate-relevant information and guidance into existing initiatives to help service providers and communities practise safe sanitation and health behaviours in a changing climate. Healthcare and sanitation professionals are often in a strong position to raise awareness about health determinants among the groups they work with. These professionals could therefore integrate important knowledge and practical advice on how to safely manage and use sanitation systems following extreme events into existing initiatives, such as primary and community health programmes, social marketing campaigns and curricula for health workers (Rehfuess et al., 2008).

Developing effective information systems (Information systems): Local information systems can play a valuable role in ensuring that sanitation managers, operators and users can make informed decisions to ensure services are maintained. Mechanisms to improve information systems include (ISF-SNV, 2019):

- Early warning systems to alert sanitation operators to changes that should be made (e.g. turning on-off valves to divert flows and minimise system damage, ensuring back-up pumps and storage are online, protecting piles of sludge from heavy rain) and to users to take appropriate actions to protect their latrines. Early warning systems require clear and measurable indicators that are monitored and accompanying mechanisms for triggering actions when the indicator exceeds a threshold.
- Review-and-response processes to regularly collect data on how changing environmental conditions are affecting sanitation services and access, and subsequently make appropriate changes to sanitation provision and support strategies.
- Inter-sectoral monitoring and information sharing, for example, relating to meteorological, hydrological, water quality and health data so that sanitation and other stakeholders can better understand emerging challenges and react accordingly. This also includes improved monitoring and information sharing in post-disaster situations, with the context of local and national disaster risk management.

Supporting climate resilient service delivery and infrastructure (Technologies; service delivery; workforce): Changes in how sanitation services are planned and managed can make them more resilient or resistant to climate hazards. The SSP process described in Section 5.1 above provides a comprehensive approach to considering health in improving sanitation infrastructure and technologies. Additional strategies include (ISF-SNV, 2019):

- Design sanitation technologies to operate under a range of climate conditions or to be modular so that failures in one part of the service chain do not cause the entire service to fail.
- Training sanitation operators and managers to recognise changing environmental conditions and correspondingly make appropriate operational or management adaptations is an important dimension to adaptation and workforce development. This requires the availability of timely information on climate conditions and ready adaptation actions (for example pre-

decided thresholds for by-passing system components). Coordination between sanitation utilities and meteorological authorities, or co-management models whereby government and community groups agree on respective management responsibilities, can help to facilitate climate monitoring and development of mechanisms for triggering appropriate adaptations.
- Design sanitation technologies to be more resistant to specific climate hazards (see Annex 1). Alternatively, sanitation technologies could be designed to be low-cost and quickly repairable. There is tension between designing technologies to be more robust versus low-cost – the relative merits of the options, including an analysis of cost-efficiency, should be weighed in each context.
- Consideration of climate mitigation together with climate adaptation, towards win-win solutions. This includes a strengthened focus on the energy use and GHG production of sanitation technologies and systems.

Specific attention should be given to sanitation infrastructure in healthcare facilities, factoring in climate-related risks into existing risk assessment and management plans. There is also significant potential to improve sanitation in healthcare facilities through improved building codes and practice standards—an area being addressed by some countries in their adaptation plans.

Increasing engagement with users and communities (Service delivery): User engagement and awareness is important to gain the support and buy-in of the public for needed changes to sanitation. Considerations for user engagement and awareness include (ISF-SNV, 2019):

- The threat and potential consequences of climate change must be communicated to sanitation users in a way that is understandable and relevant to their lives. This involves avoiding the use confusing scientific terms and jargon, and contextualising climate impacts within users' lived experiences (McNamara, 2013; McNaught et al., 2014).
- Users, including those belonging to marginalised groups, require information and advice relating to links between climate change and sanitation, and the opportunity to meaningfully participate in sanitation decision-making. For example, special attention may need to be given to ensuring women, not just men, are beneficiaries of climate change awareness campaigns.
- Preparation for climate change requires investing for a future that may feel distant or removed from everyday challenges. Raising awareness about climate change amongst sanitation users must include messages about how it affects them directly in the foreseeable future. Conversely, users may feel overwhelmed with the magnitude and scope of climate change. Therefore, awareness-raising should include empowering messages on what users can do to help themselves and their community (McNaught et al., 2014).

There is also a major potential to combine existing knowledge on sanitation-related behavioural change with knowledge on community-based climate change adaptation behaviours (e.g. see Mortreux and Barnett, 2017 for a review of psycho-social factors of adaptation). Through this, the social and cultural barriers that impede adaptation (Adger et al., 2009) and the implementation, effectiveness and use of sanitation systems could be concurrently addressed.

Securing increased local level financing for sanitation (Financing): Securing sufficient financing for sanitation services at local levels is a major long-standing challenge. At the local level, existing pricing structures for systems and services are often poorly designed, and sanitation sector struggles to compete with funding demands from other sectors (including water supply). Funding needs for both technical and human resources will only intensify with mounting risks associated with climate change, particularly with regards to poor households and marginalised and vulnerable groups. A breadth of financing mechanisms should be given consideration, including grants for rebuilding systems that are destroyed or damaged by extreme weather events, or micro-insurance and conditional cash transfer mechanisms that enable tailored, localised adaptation pilots and/or proven measures (such as household latrine adaptations). Such measures require consideration of issues of affordability and accessibility of services for poor households, and additional subsidies for the poor may be needed (ISF-SNV, 2019).

5. Further research needs

To support stronger evidence-based decision making on sanitation and health in the face of climate change, the following research areas were identified (WHO, 2009; Howard et al., 2016; Sherpa et al., 2014):

- systematic assessments of the relative sustainability and resilience of existing sanitation systems
- more precise information on the impacts of climate change specifically on sanitation systems (both technologies and management, and including in relation to health changes such as changed disease prevalence) and the according implications for human health and health systems—quantified risks, costs and benefits are critical for improving decision making
- improved decadal climate change projections at the regional (subnational) levels
- further evidence and action research on the potential climate resilience of different sanitation systems (both technologies and management, as part of a systems-based perspective) in different contexts (e.g. centralised/decentralised/mixed, community-managed, household-managed, etc.) at the city-scale and in particular for dense urban environments
- investigation into the relative cost-effectiveness of different adaptation options, including those that contribute to climate mitigation as well as adaptation, and decision-support tools.
- data on the current status and projected changes to the water resource base, including groundwater resources (given their critical role in the safe functioning of many sanitation systems)
- further scenario-based testing of different adaptation responses that capture the likely nature of changes in local contexts

6. Conclusion

This discussion paper lays out the breadth of considerations required to inform a climate resilient approach to sanitation and health. It provides a basis to consider the breadth of policy, governance, financing and workforce dimensions that need attention at both national and local levels. It also considers technical dimensions related to infrastructure and technology choice and service delivery, highlighting how existing risk management approaches at local level such as SSP can be extended to take into account climate change. Further practical information and experiences need to be shared, documented and disseminated to increase action on this critical area, as well as strengthening coordination across sectors and agencies.

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Annex 1. Examples of control measures or adaptation options for sanitation systems

The control measures described below are adapted from Howard and Bartram, 2010; Charles et al., 2010; and Sherpa et al., 2014. These were elaborated based on input from participants at WHO meeting on sanitation and climate change, March 2018 and subsequent input from ISF-UTS.

As this table shows, the health consequences arising from climate impacts on sanitation systems generally fit within two overarching categories: (i) increased risk of disease or illness from exposure to pathogens and hazardous substances via increased environmental contamination, and/or (ii) increased risk of disease or illness resulting from a lack of access to adequate sanitation where systems have been destroyed or damaged. The adaptation options included here are examples of actions that can improve sanitation systems and in turn help to protect health. They comprise 'control measures' that could be implemented as part of an SSP process.

Sanitation system	Risk	Example control measures or adaptation options
On-site systems		
Pit latrines (dry and low-flush)	• Reduced soil stability leading to lower pit stability • Environmental contamination from latrine flooding • Groundwater contamination from flooding • Risk of latrine owners using floodwaters to flush out latrine pits • Collapse of latrine due to inundation or erosion	• Lining of pits using local materials (including more permanent linings in high density areas) • Locally adapted pit latrine designs: raised latrines; smaller pits that are emptied more frequently; vault latrines; raised pit plinths; compacting soil around pits; appropriate separation distances; use of appropriate groundwater technologies; protective infrastructure around system • In highly vulnerable areas: provide low-cost temporary facilities in lieu of permanent ones • Where feasible, site systems in locations less prone to floods, erosion, etc. • Provision of regular, affordable pit emptying services • Discharge of collected waste to secure sewer discharge or transfer stations • Community education on latrine maintenance, and on hygiene and safe behaviours during/after extreme events
Septic tanks	• Increased water scarcity reducing water supplies and impeding tank function • Rising groundwater levels, extreme events and/or floods, leading to structural damage to tanks, flooding of drain fields and households, tank flotation, and environmental contamination • Increased influent pathogen load in times of outbreak	• Installation of sealed covers for septic tanks and non-return valves on pipes to prevent back flows • Ensure vents on sewers are above expected flood lines • Community education on tank maintenance, and on hygiene and safe behaviours during/after extreme events • Strong occupational health and safety practices during emptying

Off-site systems		
Conventional sewerage (e.g. combine d sewers, gravity sewers)	• Extreme rainfall events causing discharge of excess, untreated wastewater into environment • Extreme rainfall events causing back-flooding of raw sewage into buildings • Extreme events damaging sewers and causing leakage, resulting in environmental contamination • Sea-level rise raising water levels in coastal sewers, causing back-flooding in infrastructure and buildings • Increased water scarcity reducing water flows in sewers, increasing solid deposits and blockages	• Use of deep tunnel conveyance and storage systems to intercept/store combined sewer overflow • Re-engineering to separate stormwater flows from sewage • Where feasible, decentralisation of systems to localise/contain impacts • Providing additional storage for stormwater • Use of special gratings and restricted outflow pipes • Installation of non-return valves on pipes to prevent back flows • Where appropriate, installation of small-bore or other low-cost options at local level to reduce costs of separate systems • Community education on hygiene and safe behaviours during/after extreme events
Modified sewerage (e.g. small-bore and shallow sewers)	• Floods and extreme events damaging sewers, especially shallow sewers • Small-bore sewers: damage to pipework infrastructure introducing soil to system and causing solid deposits/blockage risks • Shallow sewers: increased water scarcity reducing water flows in sewers, increasing solid deposits and blockages	• Installation of non-return valves on pipes to prevent back flows • Construction of simplified sewer networks to withstand flooding and flotation, or shorter networks connected to decentralised treatment facilities to reduce sewer overload and failure • Community education on hygiene and safe behaviours during/after extreme events
Sewage treatment	• Extreme weather events or floods destroying/damaging wastewater treatment systems, causing discharge of untreated sewage and sewerage overflow, creating contamination • Extreme rainfall events damaging waste stabilisation ponds • Extreme events damaging low-lying treatment plants, causing environmental contamination • Increased water scarcity causing obstruction that reduces capacity in rivers or ponds receiving wastewater	• Install flood, inundation and run-off defences (e.g. dykes) and undertake sound catchment management • Invest in early warning systems and emergency response equipment (e.g. mobile pumps stored off-site, non-electricity based treatment systems) • Prepare a rehabilitation plan for the treatment works • Where feasible, site systems in locations less prone to floods, erosion, etc. • Safe means for manual emptying of sludge with low moisture content
Safe reuse of wastewater for food production	• Increased water scarcity leading to increased reliance on wastewater for irrigation purposes • Without adequate wastewater treatment, increased reuse can expose populations (farmers, their communities and consumers) to health hazards including pathogens, chemicals, and anti-microbial resistant bacteria	• Include climate change and variability in assessing, monitoring and establishing control measures for wastewater management • Improve enforcement of and/or incentives for regulations for wastewater reuse • Crop selection, irrigation type, withholding times, vaccination and chemotherapy • Behavioural interventions/health and hygiene promotion for safe hygiene practices, use of personal protective equipment etc.