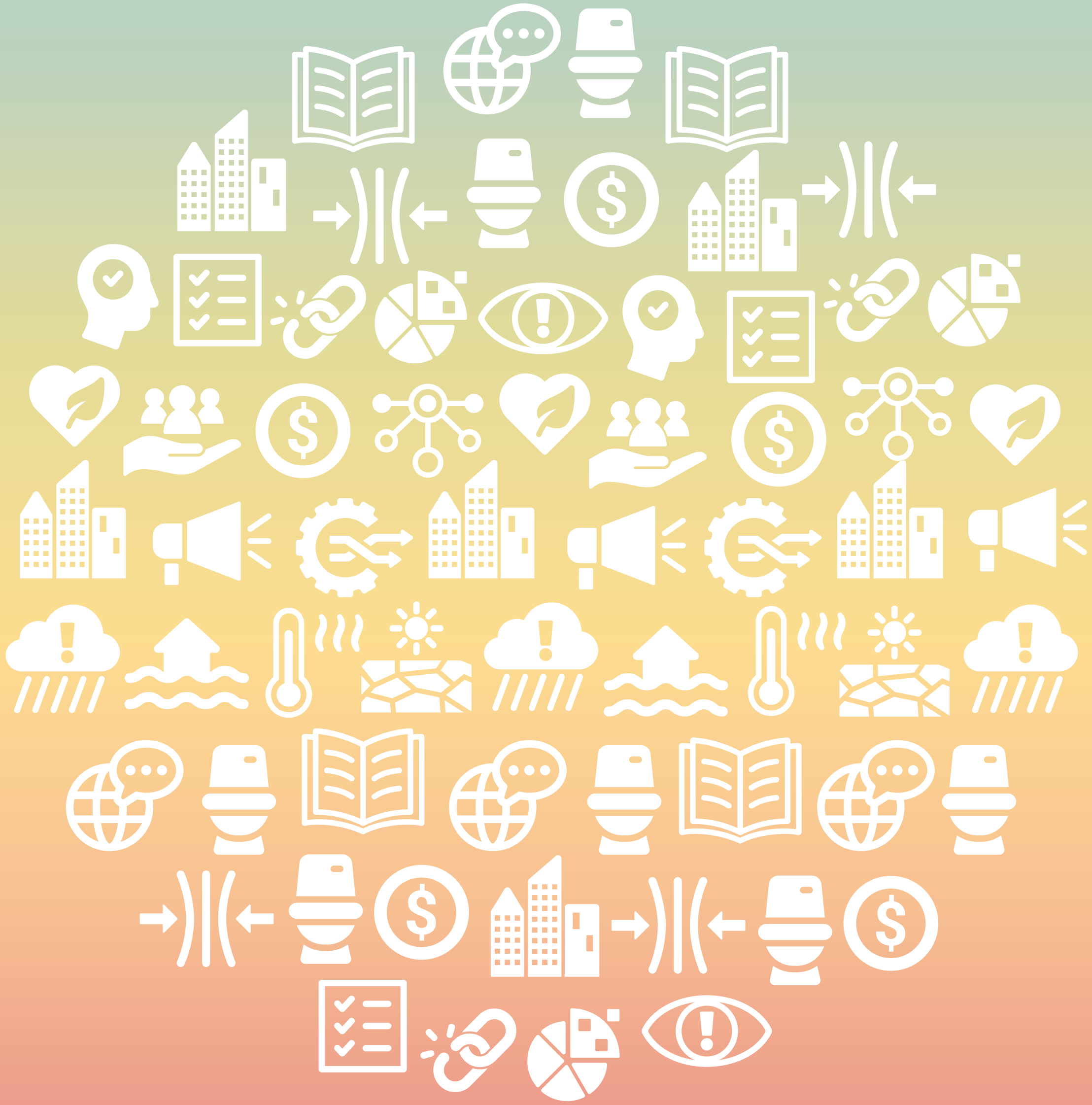
Climate Resilient Urban Sanitation

Accelerating the Convergence of Sanitation and Climate Action



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CLIMATE RESILIENT URBAN SANITATION

Accelerating the Convergence of Sanitation and Climate Action

FOREWORD

Cities are incredibly vulnerable to climate change. Although sanitation is a critical urban system and service, it is not widely considered a climate change issue. While water has long been recognized as a central component of climate change adaptation, there is only sparse research and evidence on the impacts of climate change on sanitation infrastructure and services, and therefore limited discussion of effective approaches for adaptation.

However, **we believe sanitation can be a crucial driver for climate change adaptation and mitigation. Through investments in resilient sanitation systems, we can safeguard public health and further, create a sustainable economy around sanitation services, as well as foster innovation as a pivotal component of combating climate change at the global scale.** We also believe that a shift to sustainable sanitation will require a coordinated effort with other urban services, a better understanding what resilient sanitation systems are and how they can contribute to a city's overall resilience. We can continue to try to solve urban sanitation with single, targeted interventions. But at the pace of growth, and the pace of in particular climate-related challenges, we will fail to provide adequate infrastructure and services. Without a doubt we must focus on developing responses and solutions that have multiple benefits. Building holistic urban resilience requires that cities gain a better understanding of all their challenges including sanitation and seek to solve them holistically in partnership with people outside of government including technical experts, community leaders, and businesses.

The Sector Programme *Sustainable Sanitation* at the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the Resilient Cities Network (R-Cities) – partnered to conduct this study to improve our understanding of the impacts of climate change on urban sanitation and the role and potential of sanitation in the context of urban and climate resilience. We are hoping to contribute to the wider understanding of these issues, as well as provide a first set of guiding principles that can support practitioners and policymakers to achieve better outcomes. Being resilient is about identifying the most important priorities for a city faced with multiple challenges, recognizing that shocks and stresses are interconnected, and solutions must be as well.

In undertaking this assignment, we reached out to our partners in four cities. We would like to extend our heartfelt thanks to them for providing us with deep insights into the current climate-related challenges of urban sanitation in their cities, as well as the opportunities for urban resilience which may arise through sanitation. For Cape Town: we would like to thank Amy Davison, Claire Pengelly, Gareth Morgan, and Mogamat Armeen Mallick; for Chennai: Abishek S. Narayan, Ashok Natarajan, Krishna Mohan Ramachandran, M R Jaishankar, Phillip Ligy, Santhosh Raghavan, and Sheela Nair; for Lusaka: Amanda Mallaghan, Bwalya Funga, Chola Mbilima, and Mwansa Nachula Mukuka; and for Santa Cruz de la Sierra: Carina Castro, Carlos Gongora, Cinthia Asin, Erica Plata, Humberto Cáceres Magnus, Ivy Beltran, Jose Daniel Medrano, Marco S. Salinas, and Ronald Pasig.

We would also like to share a special thanks to our reviewers who gave us constructive and thoughtful feedback, inputs and points for discussion. This includes Kim Andersson, Akshaya Ayyangar, Stefan Gramel, Christoph Lüthi, John Matthews, Elke Peetz, Thorsten Reckerzügl, Parama Roy, Stephanie Wear and Juliet Willetts. Furthermore, we would also like to thank our colleagues Anna Berg, Jens Götzenberger, Anna Kristina Kanathigoda, Robert Kranefeld, Helmut Lang, Brenda Mwalukanga, David Nonde Mwamba, Sandra Schuster and Marcel Servos for their contributions to this study.

We hope that reading this publication will be as insightful and joyful as this collaboration and study has been for us.

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EXECUTIVE SUMMARY

Our climate is rapidly changing, with impacts acutely observed in urban areas where 55 per cent of the world's population lives. Impacts are most prominently felt on the water cycle; however, drought, flooding and other extreme weather events are also impacting sanitation systems. This report has been commissioned by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, in collaboration with Resilient Cities Network (R-Cities) to better understand how climate change impacts will affect urban sanitation systems, and what needs to be done to address this.

An 'urban sanitation system' refers to the combination of the sanitation service chain (i.e., infrastructure and services for containment, transport, treatment, and disposal or reuse of faecal waste) **and the enabling environment within which it operates** (e.g., institutional arrangements, monitoring, planning). This system is susceptible to four direct climate change shocks and stresses: (i) extreme heat, (ii) water scarcity and droughts, (iii) increased precipitation, flooding, and extreme weather, and (iv) rising sea levels. The penultimate impact is reported to be the most significant for urban sanitation systems. Flooded onsite (i.e., pit latrines or septic tanks) and offsite (i.e., sewer networks) sanitation facilities are damaged – leading to a loss of access to sanitation – and / or are no longer able to contain the waste, leading to the contamination of the environment and the outbreak of diseases such as cholera. Lower-income communities, typically in flood-prone areas, are most likely to endure the impacts of the failure of urban sanitation systems.

> Lower-income communities, typically in flood-prone areas, are most likely to endure [climate-related] impacts of the failure of urban sanitation systems.

The adaptation response to this threat of climate change on sanitation systems was considered in four cities: Cape Town (South Africa), Chennai (India), Lusaka (Zambia) and Santa Cruz de la Sierra (Bolivia). To date, the increased climate resilience of sanitation services has been an indirect benefit rather than the primary driver of action. Adaptation responses to water scarcity and droughts primarily focus on ensuring reliable water supply services through diversifying and enhancing water sources. As part of these efforts, cities such as Santa Cruz introduced regulatory mechanisms to ensure the regular emptying of pit latrines. In Chennai, wastewater recycling became a legal requirement for new developments.

> To date, the increased climate resilience of sanitation services has been an indirect benefit rather than the primary driver of action.

Adaptation to flooding on the other hand involved the construction of lined and elevated containment systems in cities such as Lusaka. In Cape Town, so-called 'container-based' sanitation services were delivered to 20,000 residents of informal settlements. Vulnerability mapping was also implemented in Cape Town and Lusaka to avoid construction of sanitation facilities in flood prone areas or to avoid contamination of groundwater.

Evidently, significant gaps remain in the global effort to create climate resilient urban sanitation systems. One of these gaps is the lack of metrics. To address this, the authors present a strawman proposal for a City Sanitation Resilience Approach (CSRA), an adaptation of the City Water Resilience Approach. To avoid 'reinventing the wheel', the CSRA incorporates existing tools from the sanitation sector such as the excreta flow diagram (SFD) and the City Service Deliver Assessment (CSDA). These tools would contribute to the development of City Sanitation Characterisation Reports and City Sanitation Resilience Profiles; however, they would need to be strengthened to better consider resilience.

One of the other key gaps identified is the need to strengthen the integration and coordination within and outside of sanitation systems. This includes the political and institutional bottlenecks, which act as a serious brake on service delivery and sustainability, particularly for vulnerable communities. The final critical gap identified is the need to develop a better understanding of the cost of resilience and financing that gap. No data is available on the global cost of achieving climate resilient urban sanitation, nor the cost of a 'do-nothing' scenario.

> Existing political and institutional bottlenecks act as a serious break on service delivery and sustainability, particularly for vulnerable communities.

However, there are also opportunities. The sanitation sector has developed numerous urban strategies, targets, and plans. There is potential to incorporate resilience into these, particularly at city-level. Furthermore, the globally recognised set of principles, Citywide Inclusive Sanitation (CWIS), could be further revised to drive resilience rather than simply acknowledge it.

To finance these urban sanitation strategies and plans, the opportunity exists to better capitalise on climate finance. SDG 13.a pledges to jointly mobilise USD 100 billion annually to strengthen climate resilience in development countries. Similarly, the Paris Agreement has led to major funds being made available through mechanisms such as the Green Climate Fund and the Global Environmental Facility. Ultimately, dodging the bill for climate resilient sanitation systems is not a sustainable option.

Another opportunity and co-benefit of climate resilient urban sanitation is the mitigation of greenhouse gas emissions. The sanitation sector is estimated to contribute between 2 and 6 per cent of the global methane emissions, and between 1 and 3 per cent of nitrous oxide emissions. Much of these emissions are generated from wastewater disposal directly into the environment without reuse. As such, the global expansion of treatment not only increases the resilience of sanitation

Above: Furious Cyclone 'Nilam' Chennai

systems but could also play an important role in mitigating climate change.

The global expansion of treatment not only increases the resilience of sanitation systems but could also play an important role in mitigating climate change.

To systematically plan for and develop climate resilient urban sanitation systems, the start of a conceptual framework is proposed by the authors based on the City Water Resilience Framework (CWRF). The proposed framework needs to be further developed via a thorough consultation process with stakeholders; however, alignment with CWRF would be a good starting point. Adoption of the four dimensions of CWRF is proposed, which are (i) leadership and strategy, (ii) planning and finance, (iii) infrastructure and service delivery, and (iv) health and environment. Overarching goals cities should strive for are also proposed for each dimension. For instance, under the leadership and strategy, cities should aim to: create empowered communities, achieve a consistent strategic vision, and coordinate governance to avoid the current fragmentation and silos.

There is no blueprint for achieving climate resilience for urban sanitation systems. Climate change manifests itself differently around the globe and even within individual cities. Cities start from different levels of preparedness and capacities when facing these challenges. It is not just sanitation infrastructure that must be resilient to everchanging shocks and stresses, but also the interconnected social, institutional, and physical systems. As the old adage goes, 'resilience is not an end state; it's a journey'.

'Resilience is not an end state; it's a journey.'

Furthermore, the current and future needs of urban populations are at the centre of a vulnerability-led perspective to resilience. This is critical because climate change is likely to exacerbate the current inequalities of urban sanitation provision. To address this, urban sanitation systems need to look beyond 'infrastructure' and 'coverage'; they need to provide suitable platforms for inclusive feedback and consultation from urban residents, as well as adequate monitoring, warning, and response mechanisms.

To achieve climate resilient urban sanitation, resilience needs to become one of the foundations of sanitation planning. Furthermore, resilience could become an opportunity for silos between urban systems to be finally broken, allowing for effective integration between sanitation and for instance drainage, solid waste, energy, and transport. This integration should be a continually evolving process and must be adaptable to the changing risks, vulnerabilities, and capacities of urban populations.

Above: Wastewater in street – informal settlement near Cape Town, South Africa

CONTENTS

1 INTRODUCTION

1.1 PROJECT BACKGROUND AND OBJECTIVES

This report has been commissioned by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, in collaboration with Resilient Cities Network (R-Cities) to better understand how climate change impacts will affect urban sanitation systems, and what needs to be done to address this. It does so by collating and reflecting on existing knowledge and highlighting how some cities have approached adaptation. It intends to engage with and propose to a diverse set of sector leaders an outline of the next steps needed to support cities in building the climate resilience of their sanitation services and infrastructure.

The report was prepared at a time when, according to the directors of UNICEF and the WHO "progress against sanitation targets in the Sustainable Development Goal 6 has been too slow... And this challenge comes amid the trials of a global [COVID-19] pandemic, an economic recession, and an on-going climate crisis"[1]. While the world is evidently facing multiple global challenges negatively impacting local communities, this can also present us with an opportunity to 'build back better', more efficiently and effectively.

A vast array of stakeholders across sanitation systems are likely to be able to capitalise on this report, including:

1. local government and local structures;
2. utility and sanitation engineers responsible for designing, operating and maintaining systems;
3. city planners and decision-makers (e.g., councillors);
4. national government and their often-fragmented sanitation ministries;
5. policy makers and regulators influencing sanitation systems; and
6. development partners and international financing institutions keen to support and accelerate change, including but not limited to Germany's Federal Ministry for Economic Cooperation and Development (BMZ) and its implementing organisations GIZ, Kreditanstalt für Wiederaufbau (KfW), Physikalisch-Technische Bundesanstalt (PTB), and Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).

Above: Informal settlement, Cape Town

In line with the detailed objectives of this study, the report is divided into the following seven chapters:

Chapter 1: This introduction, which outlines the project background, introducing urban sanitation in a changing climate, framing the international climate change discourse, and introducing key definitions.

Chapter 2: An overview of the impacts of climate change on urban sanitation, considering the following climate change impacts: extreme heat, water scarcity and drought, increased precipitation, flooding and extreme weather, and rising sea levels.

Chapter 3: A selection of case studies from four cities presenting their sanitation-related climate change adaptation responses: Cape Town, Chennai, Lusaka, and Santa Cruz de la Sierra (hereafter referred to as Santa Cruz).

Chapter 4: An overview of the key gaps and opportunities for climate resilient urban sanitation.

Chapter 5: The proposal of a framework for climate resilient urban sanitation.

Chapter 6: A strawman proposal for the future development of a tool to assess the resilience of urban sanitation systems.

Chapter 7: The conclusion, providing a summary of key takeaways from the report.

1.2 URBAN SANITATION IN A CHANGING CLIMATE

1.2.1 CITIES AND CLIMATE CHANGE

Our climate is rapidly changing. Today, the frequency of flooding, drought, and other extreme weather events are having a devastating impact on communities, a trend that is set to continue unless urgent action is taken by the global community[2]. Of the 1,000 most severe disasters[a] that have occurred since 1990, water-related disasters accounted for 90 per cent of these.[3]

Increasing temperatures, as a result of global warming, has already been experienced across most regions of the world[4]. An estimated 20 to 40 per cent of the global population live in regions that, by 2015, had already experienced warming of more than 1.5°C above pre-industrial levels[5]. This trend is set to continue, with global temperatures being estimated to increase by at least 2°C by 2100, leading to more extreme and unpredictable weather events such as heavy precipitation and drought.[6]

Box 1

CLIMATE CHANGE IN 100 CITIES

A 2015 assessment[7] of climate change in 100 cities had the following key findings:

- Mean annual temperatures in 39 cities have increased at a rate of 0.12 to 0.45°C per decade between 1961 and 2010.
- Mean annual temperatures for the 100 selected cities are projected to increase by 1.3 to 3.0°C by the 2050s, and 1.7 to 4.9°C by the 2080s.
- Mean annual precipitation for the 100 cities is projected to change by -9 to +15 per cent by the 2050s, and -11 to +21 per cent by the 2080s.
- Sea levels in 52 coastal cities are projected to rise 15-60 cm by the 2050s, and 22-124 cm by the 2080s.

a The Centre for Research on the Epidemiology of Disasters classifies natural disasters according to the type of hazards that provoke. The classifications are geophysical (e.g., earthquake, volcanic activity), meteorological (e.g., extreme temperature, storm), hydrological (e.g., flood, landslide), climatological (e.g., drought, wildfire), biological (e.g., epidemic, insect infestation) and extraterrestrial (e.g., impact, space weather). Retrieved from EM-DAT: https://www.emdat.be/classification.

While projections for future climate change are most often defined globally and nationally, the risks are not the same everywhere. Extreme weather events have differing impacts on both urban and rural communities within the same region. The sheer size and density of populations in urban areas leaves residents particularly vulnerable to climate change[8]. For example, an increased demand for water, particularly during warmer temperatures, can leave residents more vulnerable to water scarcity. At the same time, the prevalence of concrete and tarmac surfaces in urban areas reduces infiltration, leading to rapid surface run-off, which in turn can lead to more flash flooding and landslides[9]. These events can destroy urban infrastructure, undermine access to basic services and decimate livelihoods. These issues combined with the well documented impacts of the Urban Heat Island Effect, means global warming is magnified in urban areas.[10]

At the same time, cities are also a key contributor to climate change, as urban activities are major sources of greenhouse gas (GHG) emissions. Estimates suggest that cities are responsible for around 70 per cent of global CO_2 emissions, with transport and buildings being among the largest contributors.[11]

Today, around 55 per cent of the world's population lives in urban areas, a proportion that is expected to increase to 68 per cent by 2050[12]. Projections show that urbanisation, combined with the overall growth of the world's population could add another 2.5 billion people to urban areas by 2050, with close to 90 per cent of this increase taking place in Asia and Africa[13]. It is therefore vital that city authorities, urban citizens, and businesses take important steps now, to plan and respond to climate change.

Most recently, COVID-19 has drastically changed the world we live in. The pandemic has affected urban populations the most, endangering not only public health, but also disrupting the economy and the fabric of society. At the same time, the pandemic has helped highlight the importance of a functioning and resilient urban water, sanitation, and hygiene (WASH) system, and will be an important theme during post-COVID recovery in urban areas.

1.2.2 THE IMPACT OF CLIMATE CHANGE ON URBAN SANITATION

The impacts of climate change are felt first through the impacts on the water cycle[14]. This in turn leads to major secondary impacts for the sanitation chain, especially in the case of sewers which rely heavily on water for transport, treatment, and disposal. Drought, flooding, and other extreme weather events can all undermine the provision of basic sanitation services, with disastrous health impacts for urban populations.[15]

During extreme climate-related events, non-resilient urban sanitation systems will often:

1. **Lose their ability to deliver essential services** due to direct infrastructure damage (from floods, windstorms, and tide surges) or lack of water (e.g., during a drought or when extreme cold weather turns water into ice).
2. **Become a significant source of chemical and biological contamination** of ecosystems, water bodies and soil by means of their discharges and pollution overload in the case of flooding and overflows, leading to major public health impacts and increased water scarcity.

   This contamination may sometimes be irreversible and may also affect areas beyond local and national borders. For example, in Europe, there are over 150 transboundary rivers whose combined watersheds cover more than 40 per cent of the land surface area of the region, leading to widespread contamination of water sources, if sanitation systems are inundated.[16]

More gradual climatic changes such as rising sea levels will also have an impact on urban sanitation systems. Some coastal communities and infrastructure will experience gradual flooding, making them uninhabitable, damaging infrastructure, and reducing access to sanitation.[17]

Box 2

SANITATION ALSO CONTRIBUTES TO CLIMATE CHANGE

According to[18], faeces and the overall sanitation chain contribute to climate change through the emission of 3 main gasses: **carbon dioxide** (CO_2), **methane** (CH_4) and **nitrous oxide** (N_2O), with the latter two having the most significant impact. Methane alone accounts for more than 20 per cent of current climate warming.[19]

Some CO_2 is emitted from biological processes during the containment (e.g., in a pit latrine or septic tank) and treatment of the faeces, however the majority is emitted from the energy consumed to manage the waste across the chain, mainly powering treatment plants[20]. CH_4 and N_2O are emitted from the natural biological decomposition of faeces (mainly anerobic processes, whether at containment or treatment stages), with the former contributing between 2 and 6 per cent of global CH_4 emissions, and the latter contributing between 1 and 3 per cent of N_2O emissions.[21]

Untreated wastewater released into the environment generates a greenhouse gas footprint roughly three times greater than when the same wastewater is treated in a traditional wastewater treatment plant[22,23]. As only 20 per cent of wastewater produced globally is treated, this represents a significant opportunity for GHG mitigation.[24]

1.2.3 THE SANITATION CRISIS: INCREASING VULNERABILITY TO CLIMATE CHANGE

Over the last few decades, a truly global effort has been made to improve water, sanitation, and hygiene conditions for millions of people worldwide. Since 1990, 6 billion people gained access to improved water and 2.1 billion people have gained access to improved sanitation.[25]

Despite this progress, the world remains in the midst of a sanitation crisis. Around 2 billion people globally still lack access to basic sanitation of whom 30 percent lives in urban areas (see Box 3), whilst around 670 million people still practice open defecation of whom 9 percent lives in urban areas.[26]

There are wide disparities between countries in terms of access to basic sanitation services in urban areas. For example, in North America and Western Europe close to 100 per cent of urban households have access to at least basic sanitation services, whereas in Central Africa in many cities, this remains less than 40 per cent[27]. At the same time, climate change threatens to undermine the positive progress made over the past decade as climate resilience has not been considered in the provision of the new, basic sanitation systems installed.

Globally, sanitation planning and associated infrastructure development has not kept pace

Box 3

KEY FACTS - THE URBAN SANITATION CRISIS[28]

Basic sanitation refers to facilities not shared with other households and are designed to hygienically separate excreta from human contact, including a handwashing facility with soap and water.

Safely managed sanitation refers to basic sanitation facilities where excreta are safely disposed of in situ or transported and treated offsite. Around 53 per cent (or 2.2 billion people) of the world's urban population do not yet have access to safely managed sanitation services.

Over 600 million people also do not have access to safely managed water supply; something which is imperative for functioning sanitation and hygiene systems, particularly during a climate-related crisis.

with rapid population growth and urbanisation, creating a sanitation crisis in urban areas[29]. The urban poor, particularly those without access to basic water and sanitation services are the most vulnerable to the impacts of climate change[30]. They are the least likely to be able to access safe water during a drought and are also most likely to have their homes flooded as a result of flash-flooding and sea-level rise.[31]

Where sanitation systems do exist, adaptation to climate change, learning and reflection has been slow or completely missing. Deficiencies here are a particular weakness of today's urban sanitation systems globally, and the sector is chronically under-managed[32]. This leaves communities, systems, and infrastructure susceptible or vulnerable to climate change.

1.3 THE INTERNATIONAL DISCOURSE OF CLIMATE CHANGE AND SANITATION

1.3.1 THE SUSTAINABLE DEVELOPMENT GOALS

In 2015, 193 countries adopted a set of goals, known as the Sustainable Development Goals (SDGs) which aim to end poverty and protect the natural environment as part of a new Sustainable Development Agenda[33]. Each goal sets specific targets to be achieved to help guide progress to 2030. Three of the SDGs are most relevant to Climate Resilient Urban Sanitation (CRUS):

SDG6: Ensure availability and sustainable management of water and sanitation for all

SDG11: Make cities and human settlements inclusive, safe, resilient, and sustainable

SDG13: Take urgent action to combat climate change and its impacts.

The targets for each of these SDGs is provided in Annex B.

As seen in Figure 1, sanitation has strong links with nearly all goals, including SDG11 and SDG13[35]. The former has a relatively high direct call for action[b] on sanitation, as well as synergies[c] with its respective targets, while SDG13 has a moderate level of call for action and synergies with its targets[d]. For instance, water and sanitation systems must be resilient to climate change; but they also play a vital role in supporting broader climate resilience efforts, particularly in urban areas[36]. Research suggests very few trade-offs between these two SDGs and sanitation, but rather demonstrates a strong need for integrated interventions[37], and an opportunity for CRUS to be recognised as a major priority for urban development.

1.3.2 THE PARIS AGREEMENT

In December 2015, 195 nations adopted the Paris Agreement which aims to strengthen the global response to the threat of climate change by "limiting the temperature increase to 1.5°C above pre-industrial levels"[38]. This will be achieved through a series of global, regional, and country-level efforts. The Paris Agreement works on a 5-cycle of climate action. Each nation is required to develop their successive Nationally Determined Contributions (NDCs). Through their NDCs countries primarily outline and communicate actions they plan to take to reduce GHG emissions to reach the goals of the Paris Agreement. Planned adaptation and resilience building measures at the country-level are also communicated in the NDCs[39]. The NDCs are non-binding. However, they provide an indication of national policy priorities and interests. A recent analysis showed that within all submitted NDCs only few concrete actions have been proposed with regard to sanitation.[40]

The Paris Agreement re-emphasises the role of National Adaptation Plans (NAPs) which were established under the Cancun Adaptation

b 'Call for action' refers to a connection where an SDG target requires action on sanitation to support the achievement of such target.
c 'Synergies' refers to two-way positive connections with sanitation for each SDG target, whether an action in sanitation could support the achievement of a target, and if achievement towards the target could support sanitation objectives (Diep, et al., 2020).
d 'Trade offs', seen in Figure 1, refers to a 'negative' link between an SDG target and sanitation, whereby the achievement of a target might not be supportive of the sanitation target.

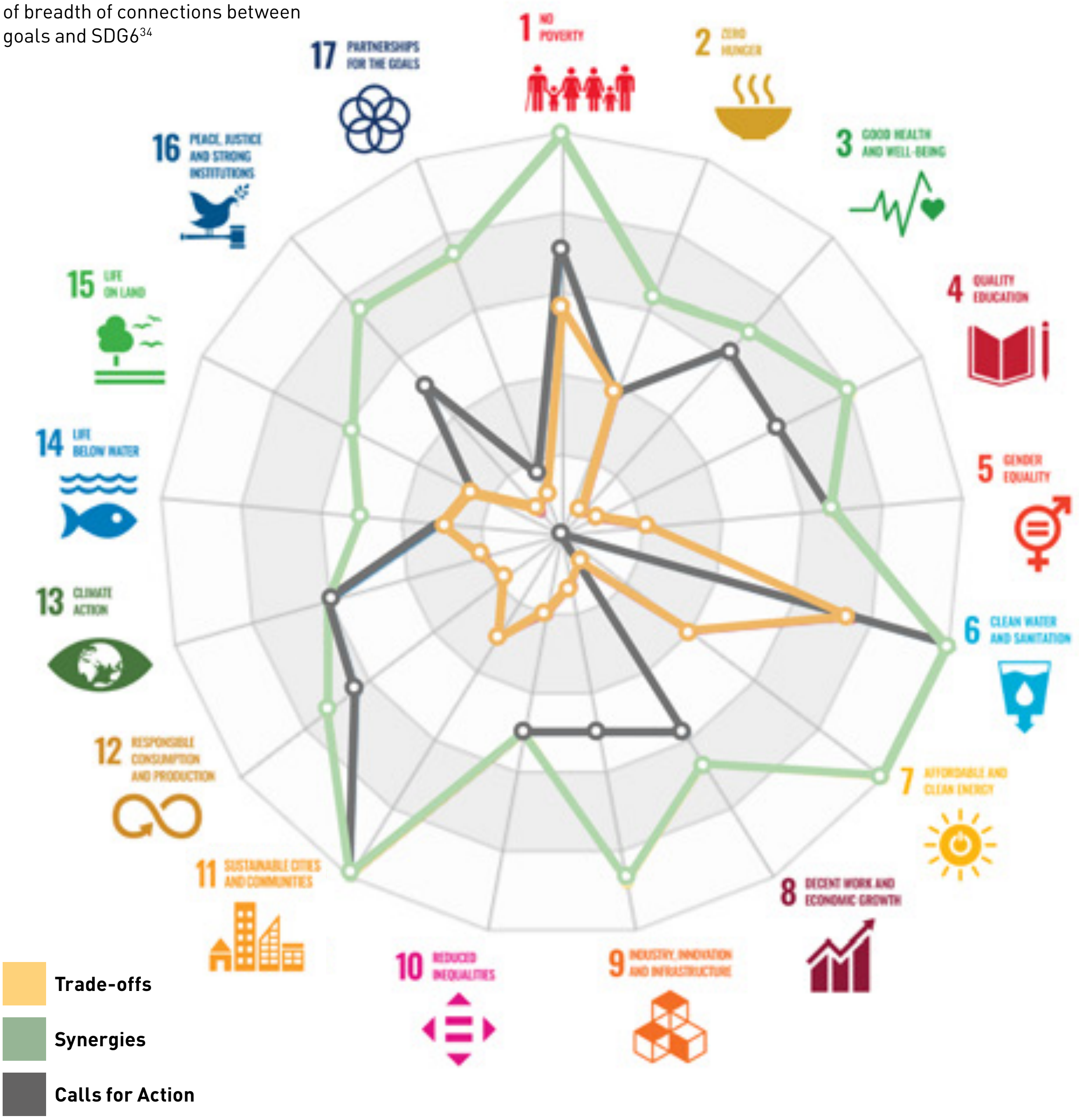

Figure 1. Spider-web representation of breadth of connections between goals and SDG6[34]

framework. NAPs were created to enable least developed and other developing countries to identify medium- and long-term adaptation needs and develop implementing strategies and programmes to address them[41]. The NAP process would build on existing activities, providing a platform for coordination of adaptation efforts and national level. For example, Saint Lucia developed a water sector NAP (Sectoral Adaptation Plan for Water), which includes the guiding wastewater and faecal sludge interventions under a changing climate through the development of a wastewater master plan and guidelines[42]. Thus far only 22 developing countries have submitted NAPs, none of which include the case study cities considered in this report.

1.3.3 THE SENDAI FRAMEWORK FOR DISASTER RISK REDUCTION

The Sendai Framework for Disaster Risk Reduction (2015 - 2030) was adopted in 2015 as an outcome of the Third United Nations World Conference on Disaster Risk Reduction in Sendai, Japan.

The framework identifies four priority areas for action, namely:

- **Priority 1:** Understanding disaster risk.
- **Priority 2:** Strengthening disaster risk governance to manage disaster risk.
- **Priority 3:** Investing in disaster risk reduction for resilience.
- **Priority 4:** Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation, and reconstruction.

Sanitation is not explicitly mentioned in the framework. However, under Priority 4 the framework emphasises as one of the targets "To promote the resilience of new and existing critical infrastructure, including water, transportation and telecommunications infrastructure, educational facilities, hospitals and other health facilities, to ensure that they remain safe, effective and operational during and after disasters in order to provide live-saving and essential services".[43]

1.4 DEFINITIONS

This section introduces some of the key definitions and concepts used in the report. A comprehensive glossary of the terms used is provided in Annex A.

1.4.1 URBAN CLIMATE RESILIENCE

According to the IPCC, the term resilience refers to "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"[44]. Urban resilience can therefore be defined as the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience.[45, 46]

1.4.2 QUALITIES OF A RESILIENT SYSTEM

The City Resilience Framework suggests that resilient systems have seven main qualities which allow to maintain functionality in the face of climate-related shocks and stresses: reflective, robust, redundant, flexible, resourceful, inclusive, and integrated[47]. Referred to throughout this report, and provided in Annex A, these qualities are defined by the City Resilience Framework as such:

1. **Reflective:** Reflective systems are accepting of the inherent and ever-increasing uncertainty and change in today's world. They have mechanisms to continuously evolve and will modify standards or norms based on emerging evidence, rather than seeking permanent solutions based on the status quo. As a result, people and institutions examine and systematically learn from their past experiences and leverage this learning to inform future decision-making.

2. **Robust:** Robust systems (similar to resistance[48]) include well-conceived, constructed, and managed physical assets, so that they can withstand the impacts of hazard events without significant damage or loss of function. Robust design anticipates potential failures in systems, making provision to ensure failure is predictable, safe, and not disproportionate to the cause. Over-reliance on a single asset, cascading failure and design thresholds that might lead to catastrophic collapse if exceeded are actively avoided.
3. **Redundant:** Redundancy refers to spare capacity purposely created within systems so that they can accommodate disruption, extreme pressures, or surges in demand. It includes diversity: the presence of multiple ways to achieve a given need or fulfil a particular function. Examples include distributed infrastructure networks and resource reserves. Redundancies should be intentional, cost-effective, and prioritised at a city-wide scale, and should not be an externality of inefficient design.
4. **Flexible:** Flexibility implies that systems can change, evolve, and adapt in response to changing circumstances. This may favour decentralised and modular approaches to infrastructure or ecosystem management. Flexibility can be achieved through the introduction of new knowledge and technologies, as needed. It also means considering and incorporating indigenous or traditional knowledge and practices in new ways.
5. **Resourceful:** Resourcefulness (similar to response / recovery[49]) implies that people and institutions can rapidly find different ways to achieve their goals or meet their needs during a shock or when under stress. This may include investing in capacity to anticipate future conditions, set priorities, and respond, for example, by mobilising and coordinating wider human, financial, and physical resources. Resourcefulness is instrumental to a city's ability to restore functionality of critical systems, potentially under severely constrained conditions.
6. **Inclusive:** Inclusion emphasises the need for broad consultation and engagement of communities, including the most vulnerable groups. Addressing the shocks or stresses faced by one sector, location, or community in isolation of others is an anathema to the notion of resilience. An inclusive approach contributes to a sense of shared ownership or a joint vision to build city resilience.
7. **Integrated:** Integration and alignment between city systems promotes consistency in decision-making and ensures that all investments are mutually supportive to a common outcome. Integration is evident within and between resilient systems, and across different scales of their operation. Exchange of information between systems enables them to function collectively and respond rapidly through shorter feedback loops throughout the city.

1.4.3 THE SANITATION SERVICE STRUCTURES

The **sanitation service chain** (see Figure 2), also referred to as the **sanitation chain**, is a context-specific series of technologies, infrastructure and services utilised for the management of human excreta (urine and faeces), faecal sludge[e], and wastewater, for their collection (or capture), containment, transport (or conveyance), transformation (or treatment), utilisation (or reuse) or disposal (adapted from Tilley, et al., 2014).

There are two main types of sanitation chains: onsite and offsite. **Onsite**[f] or non-sewered sanitation chains refer to the technologies, infrastructure and services required to safely operate and maintain toilets which hold waste onsite for a certain period (e.g., containers, pits, or septic tanks). Depending on the design of the containment structure and number of users, emptying of faecal sludge is undertaken on a scheduled or on-demand basis, and transported by vehicles via road networks to centralised or decentralised treatment facilities.

Offsite or sewered sanitation chains refer to technologies, infrastructure and services required to safely operate and maintain toilets connected to a piped network. The piped network could be a conventional or a non-conventional (e.g.,

Figure 2. The sanitation service chain for both onsite and offsite sanitation

simplified, small-bore) sewer, with centralised or decentralised treatment facilities. Offsite sanitation is heavily reliant on large quantities of water to transport the waste (or wastewater) through gravity fed sewers; in many cases the topography of the city also necessitates the use of energy intensive pumping / lift stations to transport the wastewater to treatment facilities.

Conventional, nature-based and innovative solutions exist for treating faecal waste, from both onsite (faecal sludge) and offsite (wastewater) systems and transforming it into useful by-products. **Conventional solutions** are typically focused on centralised treatment and disposal, with transformation (e.g., water recycling, biogas-to-energy, etc.) considered an add-on to treatment rather than a driver for the design of the rest of the sanitation chain. Conventional centralised treatment systems with a relatively small footprint are energy reliant and intensive, while those with a larger footprint require less (or no) energy. Few incentives are found for the integration of conventional treatment and transformation systems with other urban systems; in some cases, regulation even disincentivises integration (e.g., use of treated sludge in agriculture is heavily regulated).

Nature-based solutions for treatment of faecal waste are increasingly being implemented. They often require much less energy than conventional solutions, and can be heavily integrated into urban ecosystems, flood protection, and wellbeing. However, in some cases they may contribute to increased GHG emissions (e.g., wetlands).

Innovative waste-to-resource solutions focus on transformation of the faecal waste into useful by-products, including but not limited to:

1. recycled water (e.g., for agricultural, (re) forestation, urban parks, or industrial use),
2. distilled water,
3. soil conditioners and fertilizers from each the urine and faeces,
4. carbonised and non-carbonised solid fuel,
5. biogas-to-energy, and
6. insect production (used as protein for animal feed or other insect by-products).

As with the recycling of domestic solid waste, when the focus of the faecal waste system is on transformation, the following becomes critical: **segregation** at source (i.e., separate collection of urine, faeces and water at the toilet), **avoiding contamination** (i.e., no heavy metals), and **avoiding dilution** (i.e., no addition of water for flushing). Evidently, innovative waste-to-resource solutions favour onsite sanitation systems with urine-diverting toilets (i.e., separation of urine and faeces). It also incentivises integration, not only

e Faecal sludge refers to waste found in onsite facilities, such as septic tanks and pit latrines. The waste is made from partially digested human excreta and other materials disposed of into containment structures, such as flush water, cover material, anal cleansing materials, and in many cases inappropriately disposed of solid waste (e.g., plastic bottles).

f Onsite systems are part of a category of non-networked decentralised systems, as per BMZ guidelines. These include household level (e.g., pit latrines or toilets with septic tanks), and treatment level (e.g., sludge treatment) facilities for a limited number of users, such as a neighbourhood. Networked, decentralised sanitation systems include smaller sewer systems with up to a few thousand people connected.

into the different by-product markets, but also other waste systems (e.g., biowaste, agricultural waste, etc.).

At a global level, UN member states set Target 6.2 of SDG6 as follows: "By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations"[50]. To monitor this, the Joint Monitoring Program (JMP) has proposed an update of the Millennium Development Goal (MDG) sanitation ladder to the **sanitation service ladder** as defined in Table 1. The global indicator used for Target 6.2 is the 'proportion of population using safely managed sanitation services including a handwashing facility with soap and water'[51]. Safely managed sanitation applies to both onsite and offsite sanitation, ensuring that toilets are safe (including appropriate hygiene facilities) as well as the associated services across the sanitation chain.

Table 1. The JMP sanitation ladder service levels and definitions[52]

Service Level	Definition
Safely Managed	Use of improved facilities that are not shared with other households and where excreta are safely disposed of in situ or transported and treated offsite
Basic	Use of improved facilities that are not shared with other households
Limited	Use of improved facilities shared between two or more households
Unimproved	Use of pit latrines without a slab or platform, hanging latrines or bucket latrines
Open Defecation	Disposal of human faeces in fields, forests, bushes, open bodies of water, beaches or other open spaces, or with solid waste

1.4.4 SANITATION SYSTEM

The 'sanitation system' describes the combination of the sanitation service chain and its so-called enabling environment within which it operates. This includes for instance institutional arrangements and coordination, monitoring, planning, financing, regulation and accountability, environment, learning and adaptation, as well as the capacity of actors and their inter-relationships.

1.4.5 SUSTAINABLE SANITATION

The Sustainable Sanitation Alliance (SuSanA) defines sustainable sanitation as a system designed to meet certain criteria and to work well over the long-term[53]. It considers the entire sanitation chain and includes five features or criteria in its definition; systems need to be economically and socially acceptable, technically and institutionally appropriate, and protect the environment and natural resources[54]. While the last criterion includes elements of climate resilience, its focus is on the preservation or recycling of resources consumed (e.g., energy, water), rather than resilience to climate change.

1.4.6 CLIMATE RESILIENT URBAN SANITATION

This report proposes the use of CRUS as a description of sanitation systems that can survive, adapt, and function in the face of climate-related chronic stresses and acute shocks. In turn, CRUS also strengthens the overall resilience of towns and cities – allowing them to continue providing essential sanitation services and protect public health in the face of climate-related crises.

From a technical standpoint, CRUS means that all the links in the sanitation chain continue to operate as intended despite climate-related shocks and stresses. The strength, or resilience of this chain ultimately allows the safe management of human waste, from collection all the way through to safe disposal or reuse.

Acute shocks can be classed as sudden, intense events that threaten an urban community and their sanitation systems[55],[56]. Examples include rapid onset flooding, hurricanes, landslides, fires, disease outbreaks and infrastructure failures. The impact of these acute shocks is exacerbated by **chronic stresses** that may weaken the fabric of an urban community over time.[57]

Above: Trials for the design of faecal sludge treatment facilities in Lusaka

2 THE IMPACT OF CLIMATE CHANGE ON URBAN SANITATION

Climate change has varied effects in different parts of the world. Some areas will warm substantially more than others. Some will receive more rainfall, while others will be subjected to more frequent droughts. People, ecosystems and infrastructures are being impacted by regional temperature and precipitation variations. **Many urban sanitation systems are not adequately equipped to cope with the effects of current climate variability[58,59].** This chapter details the impact of climate change on sanitation systems. It is divided into four sections, representing direct shocks and stresses caused or exacerbated by climate change: extreme heat; water scarcity and droughts; increased precipitation, flooding, and extreme weather; and rising sea levels. In practice, one region can be prone to several and cascading risks, and thus deal with multiple uncertainties concurrently. Where possible, impacts are considered on infrastructure and service provision, finance, the water cycle, environment, and public health.

2.1 EXTREME HEAT

Rising temperatures are one of the most prominent consequences of climate change. There is substantial evidence of climatic warming over the last century, with 2015 to 2019 being the warmest five years on record[60]. Climate models also indicate an increase in the occurrence, length, and severity of heat-related events in most countries[61]. Urban areas are particularly vulnerable due to the *Urban Heat Island Effect*, whereby cities (roads, buildings, etc.) absorb and re-emit the sun's heat more than natural landscapes, resulting in higher temperatures.

Extreme heat can increase the risk of public health for the over 700 million users of unimproved sanitation facilities globally, over half in urban areas[62]. The poor design and construction of these facilities can increase the existing risk of infection and diseases such as diarrhoea and Hepatitis A[63]. Increased odours caused by extreme heat can also, in turn, disincentivise and limit toilet usage.[64]

Depending on the process by which onsite treatment is expected, increased temperatures can have either a positive or negative impact on waterless toilets. Waterless sanitation facilities can either treat biosolids through dehydration (e.g., urine diverting toilet) or biodegradation (e.g., composting toilet). Both do not require sewage infrastructure and minimise environmental and groundwater pollution when being safely managed. However, temperature and humidity play an essential role in their operation. Increased temperatures and low humidity compromise biodegradability in composting toilets due to the lack of sufficient moisture in the biosolids to support microbial growth[65]. Similarly, worms used in vermicomposting may struggle to survive at extreme temperatures, even the most tolerant compost worms can die off as the temperature of the tank approaches and surpasses 35°C.[66]

Extreme heat can positively impact the functioning of septic tanks by increasing the temperature of wastewater, thus improving anaerobic digestion and pathogen inactivation. This also results in reduced sludge accumulation, reducing the emptying frequency and cost to consumers[67]. However, a septic tank's soakaway[g], which relies on aerobic digestion, is likely to be negatively impacted by high temperatures due to greater oxygen demand by biochemical treatment processes in the soil.[68]

Sewer networks are likely to be negatively impacted by higher temperatures. Wastewater fermentation increases with higher temperatures, thus producing more hydrogen sulphide, and increasing a network's susceptibility to corrosion[69]. This in turn increases the cost of maintaining a sewer network, requiring more frequent maintenance to avoid collapse of piping and supply disruptions.

Increased temperatures have an impact on natural and non-mechanised treatment processes, less so on mechanised ones. Studies have shown that natural treatment processes are subjected to decreased performance during colder seasons, with warmer seasons creating more favourable treatment conditions due to increased bacterial removal efficiencies[70]. However, a temperature above the optimal range of a biological treatment process will negatively impact it; the maximum threshold depends on the type of process. The main treatment processes impacted by temperature changes are sedimentation, biological aeration, waste sludge processing, stabilisation ponds, and chlorination[71]. Processes such as activated sludge and aerobic film reactors are less impacted by such changes due to a high level of technological input and mechanisation.[72]

Water bodies receiving treated wastewater effluent are likely to be negatively impacted by increase in temperature. Increasing temperatures alter the properties of water bodies, lowering the levels of dissolved oxygen, increasing the concentration of nutrients and pollutants as well as the rate of evapotranspiration, and reducing their ability to host organisms[73]. Climatic changes can also alter water bodies' physical, chemical, and biological properties, affecting natural processes such as pollutant transportation and biochemical transformations[74]. As most wastewater treatment effluents are discharged in surface water bodies, the associated impacts such as pollutant and nutrient discharge may aggravate the anticipated changes in water temperature. Therefore, sewage treatment effluents associated with higher temperatures constitute a significant threat to aquatic ecosystems in the receiving waters and may increase algae bloom proliferation.[75]

For users of sanitation facilities and sanitation service providers, intense heat waves can trigger various heat stress conditions such as cardiovascular and respiratory disorders[76]. In additional to the occupational health risks of sanitation workers, physical functions, capacity, and productivity may become restricted.

2.2 WATER SCARCITY AND DROUGHT

Anthropogenic activities have significantly increased the number of drought years, a trend which is expected to continue due to climate change. Climate model projections highlight the Mediterranean region (including southern Europe, northern Africa, and West Asia) as future hydro-climatic change hot spots[77]. Irregularities in dry weather due to extreme drought can cause a severe imbalance in water cycles, resulting in low surface water volumes and groundwater recharge, thus affecting the hydrological systems on which some sanitation systems rely on.

At the user-interface level, in conditions of drought and reduced water availability, securing sufficient volumes of water for the normal operation of flush toilets may be challenging. Water scarcity can impact the frequency of flushing, the functionality of the handwashing stations, and the overall cleanliness of the toilet, potentially reducing the level of hygiene by exposing

g A soakaway (or soak pit) is a covered, porous-walled chamber that allows effluent from a septic tank to slowly soak into the ground. Small particles are filtered as the effluent percolates through the soil, and organics are digested by microorganisms (adapted from (Tilley, et al., 2014)).

users to faeces, odours, and vectors[78]. Poor cleanliness of toilets discourages their consistent use; users often prefer investing considerable time and energy in avoiding a toilet rather than suffering the indignity of using a dirty one.[79]

The emptying and transport, or conveyance of faecal waste from sanitation facilities can become restricted because of water shortages. Sludge from onsite sanitation facilities may be more challenging to pump and thus require more power due to lower moisture content[80]. Sewers are also expected to experience decreased functionality due to extended dry-weather periods. These are typically designed for a certain quantity of wastewater flow to regularly 'flush' the pipes, which if significantly decreased, could increase clogging[81]. Lower quantities of water in sewers also results in higher concentration of contaminants and increased production of hydrogen sulphide, which consequently contributes to pipes corrosion[82]. Piping buried in shallow soils in an extensive drought zone may be exposed to significant stresses by shrinking soils and ground movement, which could result in cracks, leaks, and potential damage to nearby structures.[83]

Water scarcity and drought have a multitude of direct and indirect impacts on treatment infrastructure. Higher concentration of contaminants, as previously highlighted, increase the burden on treatment systems. Reduction in the quality of effluents would be expected, with increased potential of eutrophication of receiving water bodies which are already under stress and with limited dilution capacity due to reduced precipitation and increased evaporation[84]. Maintaining adequate clean water supplies to communities will become more challenging, requiring additional treatment units and potentially higher energy input. In cases where water and wastewater treatment facilities are highly dependent on hydropower for their energy supply, droughts can have a significant negative impact on their operations[85]. Water-stressed areas may also increase their reliance on wastewater for crop irrigation, consequently increasing the risk of polluting soils with pathogens, heavy metals, and excess salts, and thus increasing the risk to public health and the environment.[86]

Service providers delivering sanitation services are expected to be financially impacted by water scarcity and drought. Lower water availability and delivery would be expected to reduce revenues, especially for utilities with combined water and sanitation services where sanitation tariffs are pegged to water tariffs.

A potential increase in insecurity is expected during droughts due to the increased competition for water resources. For instance, in Mexico, water trucks were reportedly hijacked and threatened by underserved communities[87]. Employees of service providers with combined services (e.g., vacuum trucks operated by water utilities) may be exposed to such insecurity, although no reports have been found to corroborate this.

However, drought conditions and reduced water usage may not represent a direct risk to containment structures of onsite sanitation facilities and may in fact be beneficial. For example, drier environments with lower surface water infiltration, less groundwater flooding, and lower groundwater levels may positively impact groundwater quality by protecting it from the risk of contamination from what may otherwise have been saturated containment facilities.[88]

Another positive impact of water scarcity and droughts on treatment, particularly on non-mechanised dewatering processes (e.g., drying beds), is the potential improvement in efficiency, and increased capacity of the existing infrastructure.

Above: Sludge from a pit latrine with relatively low moisture content being disposed of at a treatment facility in Lusaka

2.3 INCREASED PRECIPITATION, FLOODING AND EXTREME WEATHER

There is substantial evidence that continued anthropogenic warming has led to an increase in the occurrence, magnitude, and volume of heavy precipitation events globally[89]. Changes in precipitation will alter surface water flows, groundwater levels, and storm events leading to floods, which are among the most damaging and costly natural disasters[90]. The increase in flood events and intensity means that new areas with no recent flooding history will become severely affected.

Onsite sanitation facilities are vulnerable to flooding and consequently increase the risk to public health and the environment[91]**.** The typically limited oversight on the design, construction and emptying of decentralised onsite sanitation facilities allows for several points of failure in flood-prone areas. When flooded, the contents of containment systems (e.g., pit latrines, septic tanks) enter the environment, polluting flood waters, groundwater and / or surface water with contaminants and pathogens, leading to infectious waterborne diseases such as cholera, typhoid fever, and Hepatitis A[92]. This in turn increases morbidity and mortality rates of populations within these flood prone areas.[93]

Flooding of onsite sanitation facilities limits households' ability to access a safe toilet, increases its emptying frequency, and may lead to its damage or destruction. This is particularly a challenge in coastal areas or areas affected by river floods[94]. In cities with high groundwater levels that are directly impacted by rain (e.g., Dakar, Senegal and Dar es Salaam, Tanzania), the ingress of rain and groundwater - combined with poor drainage – into containment systems requires more frequent emptying, thus increasing the economic burden on households[95]. This has created an opportunity for the emptying services market to grow considerably compared to other cities with a different climate and hydrogeology.[96]

Increased precipitation, flooding, and extreme weather impact two critical and interdependent infrastructures on which onsite sanitation facilities depend on to properly function: drainage and transport systems. Many drainage systems – often linked to road networks – are unable to cope with increased rains, leading to the above-mentioned negative impacts on the environment and public health. They often fail during extreme weather events, preventing service vehicles from accessing onsite sanitation systems to empty their contents.

Sewer networks are also highly vulnerable to heavy rainfall events and flooding as they are exposed to multiple threats from the source through disposal. Intensified rainfall may increase sewage flow in networks due to water infiltration into aging infrastructure, or direct inflow into combined sewer networks. This excess flow is likely to lead to sanitation sewer overflows (i.e., raw sewage) into the environment. Furthermore, the risk of damage to sewers during flood events is substantial, and highly dependent on their size and depth underground[97]. Treatment facilities are equally vulnerable to damage from flooding, particularly as they are typically locating in lower-lying areas of gravity-fed systems, near to surface water bodies (rivers, oceans, seas, etc.).

Increased precipitation associated with climate change may in some cases increase inflows of wastewater into treatment facilities. This increases the risk of inundating and damaging treatment infrastructure, and introducing chemicals into the process from a variety of potentially toxic sources[98]. A clear relation has been established between water-borne diseases, heavy precipitation, and sewerage outfalls when treatment facilities are overwhelmed, and sewerage is discharged into the natural environment[99]. Where treatment systems are bypassed to minimise the potential damage from a surge of incoming wastewater, there is an increased risk of contaminating receiving water bodies due to raw dumping of wastewater. This is particularly an issue for combined sewerage systems (i.e., receiving both wastewater and rainfall from drainage).

Treatment facilities for faecal waste from onsite facilities are not by design located in low-lying and flood prone areas (unless combined with sewered systems), and as such are less likely to be damaged by heavy rains. However, what is more commonly observed is the damage caused by rains on poorly designed, constructed and maintained drainage and transport infrastructure at such treatment facilities, severely restricting access to them by vehicles transporting faecal sludge. Such service providers often report increased damage to their vehicles due to poor roads and increased travel time, which often incentivises illegal and unsafe disposal into the environment.

2.4 RISING SEA LEVELS

Sea levels are expected to rise worldwide as a result of climate change, especially in tropical and subtropical regions (see Figure 3)[100]. Coastal zones are at a high level of risk, expected to experience inundation, flooding, and coastal erosion. Coastal areas experiencing sea-level rise may become uninhabitable and may face water scarcity due to saline intrusion.

As sea levels rise, coastal communities will experience flooding. Sanitation infrastructure in these areas is at risk of damage and inundation, potentially reducing access to sanitation and increasing exposure to public health hazards[102]. Sewers in coastal cities may experience backflows of wastewater into homes and the rest of the sewerage network and infrastructure[103]. This is particularly a risk for wastewater treatment infrastructure, which are often at the 'bottom' of gravitational sewerage networks and located in low-lying areas close to rivers or coastal zones to minimize the cost of collecting influent and discharging it into water bodies. Biological processes at treatment facilities are also likely to be impacted due to saltwater intrusion.[104]

Onsite sanitation containment systems can also be impacted by saltwater intrusion into groundwater. The efficiency of the biological processes taking place in a septic tank are negatively impacted due to saline exposure[105], thus reducing the removal efficiency of organics and sludge settleability. However, it is important to note that unlike sewerage infrastructure with centralised treatment facilities, the severity of 'failure' of decentralised onsite systems and their associated services (emptying, transport, treatment) from saltwater intrusion are likely to be lower.

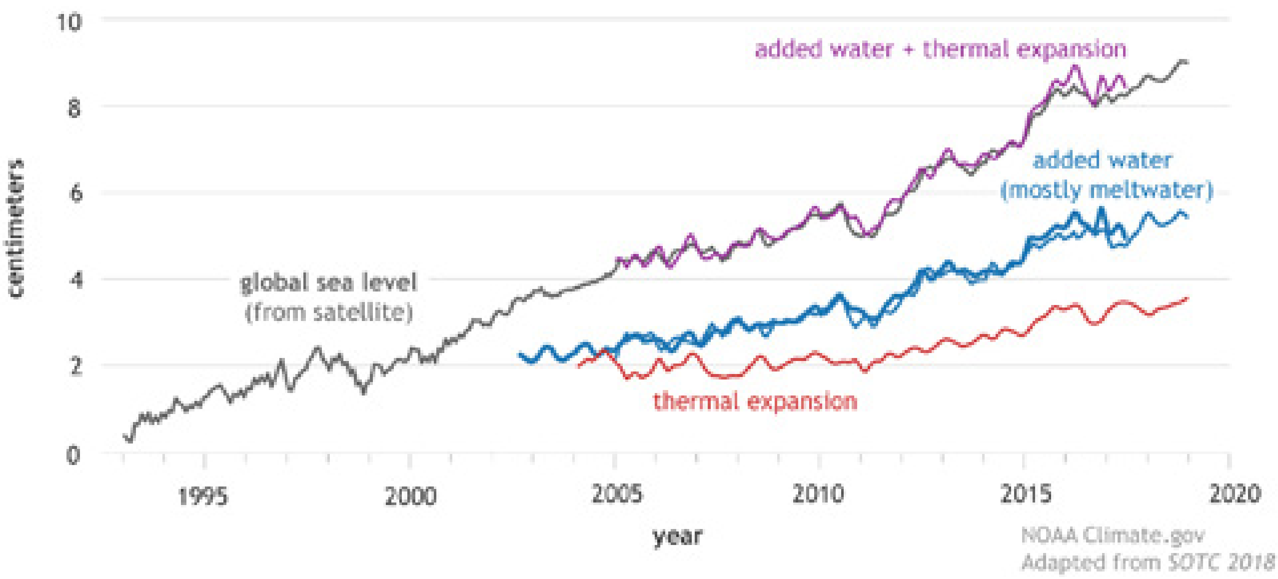

Figure 3. Observed sea level and different contributions to sea level rise since 1993[101]

3 ADAPTION RESPONSES TO URBAN SANITATION – CASE STUDIES

This chapter highlights climate change adaptation responses for urban sanitation in four case study cities. It is divided into three sections: the background for each of the selected cities as it relates to demographics, sanitation and climate change, followed by a section describing the demand and willingness of cities to invest in climate resilient sanitation, and finally a section outlining the adaptation responses to the two main climate-related shocks and stresses reported in these cities: water scarcity[h] and droughts, and flooding.

As shown in Figure 4, the selected cities are: Cape Town (South Africa), Chennai (India), Lusaka (Zambia), and Santa Cruz (Bolivia). To an extent, the selection process for the cities considered the following criteria:

1. allow for a variation of climate change impacts, both in terms of types of impact (i.e., flooding, water scarcity, sea level rise, extreme weather events) and intensity,
2. allow for a variation in geographic locations (Africa, Asia, Latin America),
3. allow for a variation in population sizes,
4. allow for a variation in level of economic development,
5. each city has a variation of sanitation systems and services (offsite and onsite, gray and green infrastructure, etc.),
6. allow for a variation in adaptation responses for urban sanitation (technology vs management solutions), and
7. each have established relationships and supportive relationships with GIZ and / or R-Cities.

Table 2 presents a snapshot of each city, including their main acute shocks and chronic stresses, as well as climatic conditions and forecast climatic changes.

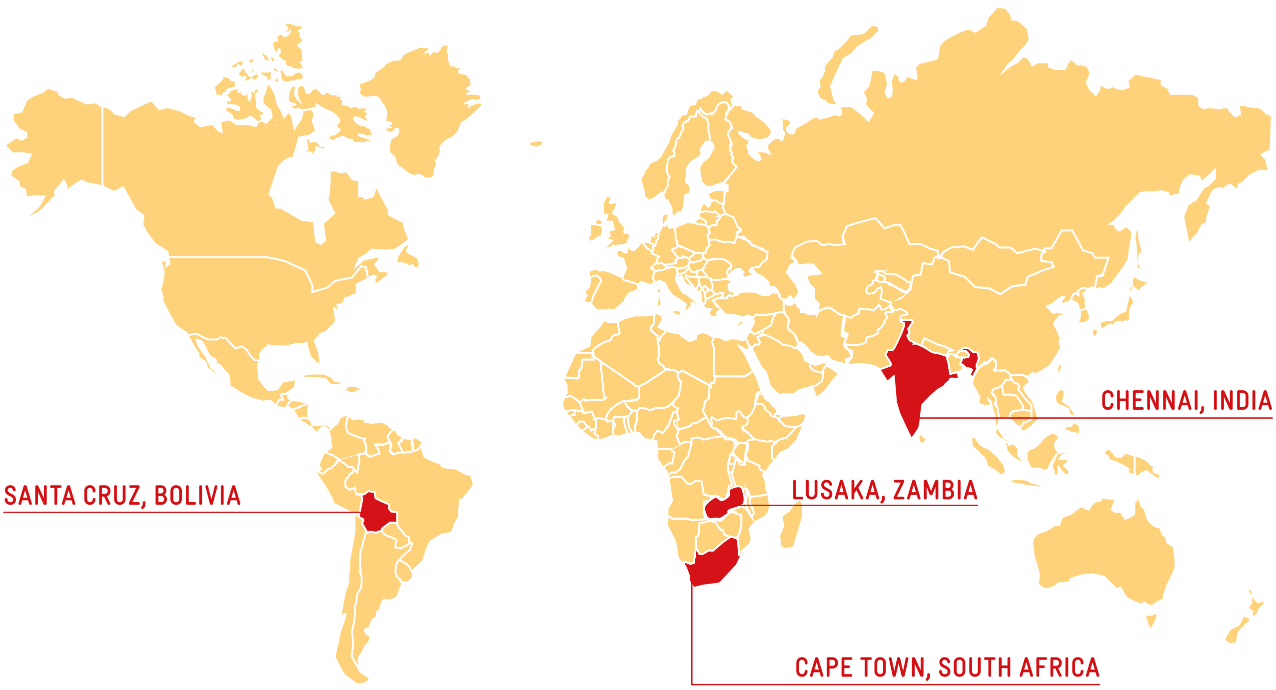

Figure 4. Map of case study cities

h Water scarcity is defined as the lack of access to adequate quantities of water for human and environmental uses due to the failure of appropriate management (e.g., significant losses, contamination, etc.) and / or adequate infrastructure (retrieved from https://www.unwater.org/water-facts/scarcity/ and https://www.worldwildlife.org/threats/water-scarcity).

Table 2. Overview of case study cities

	Cape Town	Chennai	Lusaka	Santa Cruz
Population (million)	4.3	7.5	2.5	1.9
Access to safely managed sanitation (%)	**71%** [106]	**62%** [107]	**17%** [108]	**70%** [109]
Area (km2)	2,456	426	418	325
Population density (population/km²)	1,530	26,553	8,863	4,464
Country per capita GNI (PPP) USD / year	12,630	3,580	6,960	8,910
Acute Shocks	**Direct: droughts and water scarcity, rapid onset flooding, gale force winds.** Indirect: spread of water-borne diseases, financial shocks, and reduced livelihoods.	**Direct: rapid onset flooding, droughts.** Indirect: spread of waterborne diseases, loss of life, population displacement, financial shocks, and reduced livelihoods.	**Direct: rapid onset flooding, cyclones, droughts.** Indirect: spread of water-borne diseases, population displacements, financial shocks.	**Direct: rapid onset flooding (The Niño and Niña).** Indirect: spread of water-borne diseases.
Chronic Stresses	**Direct: Recurrent flooding; water scarcity; informal settlements.** Indirect: rapid urbanisation; informal settlements; poverty and inequality; insecure municipal finance.	**Direct: Recurrent flooding, water scarcity through mismanagement.** Indirect: Reduced water quality; changing distribution of vector-borne diseases, high-prevalence of diarrheal disease and high stunting rates; rapid urbanisation; poverty and uneven economic growth.	**Direct: Recurrent flooding, water scarcity.** Indirect: Reduced water quality and over extraction of groundwater; prevalence of water-related diseases and high stunting rates; rapid urbanisation; poverty and uneven economic growth; high slum population.	**Direct: Recurrent flooding.** Indirect: water scarcity through deteriorating water quality.
Average Temperature (°C)	July (min. 7.9°C to max. 17.7°C). February (min. 15.6°C to max. 26.3°C).	January (min. 21°C to max. 29°C). October (min. 28°C to max. 37°C)	July (min. 8°C to max. 25°C). October (min. 17°C to max. 32°C).	24.8°C
Average Precipitation (mm / year)	**505 mm per year**	**1,400 mm per year**	**802 mm per year**	**1,300 mm per year**
Projected Climate Change Impacts [110]	**1. Temperature increases** of 3°C to 4°C by 2100 **2. Decline in precipitation** (-44.37 mm per year by 204-2059) causing increased intensity and frequency of droughts.	**1. Temperature increases** of 4°C by 2080. **2. Decline in precipitation** causing increased intensity and frequency of droughts. **3.** Increase in **extreme precipitation** events. **4. Sea-level rise** of between 0.19 and 1.2 metres by 2050	**1. Temperature increases** of 1.2°C to 3.4°C by 2060. **2. Moderate** decrease in rainfall.[111] **3.** More **extreme weather** events, with increased frequency and intensity of heavy rainfall events, floods, and droughts.	**1. Temperature increases** of 2.19°C by 2040. **2. Decline in precipitation** by 11 mm by 2040 **3. Extreme precipitation** events, with annual maximum 5-day rainfall rise by 10.39 mm by 2040

3.1 CITIES BACKGROUND

This first section introduces each of the case study cities, detailing the current demographic, sanitation and institutional context, the impacts of climate change on sanitation, and the projected future impacts of climate change.

Above: Cape Town from the air

3.1.1 CAPE TOWN

Cape Town is South Africa's second most populous city and legislative capital. In South Africa, devolved Local Authorities are mandated to ensure sanitation services within their jurisdiction. The City of Cape Town (CCT) is the local authority for Cape Town and serves as both the service authority and service provider for water supply and sanitation. Accordingly, it performs wide-ranging responsibilities pertaining to sanitation, including expanding onsite and offsite sanitation services, wastewater treatment at 17 wastewater treatment works as well as six smaller facilities, maintaining a 9,000 km sewer network, and stormwater management.

The city's provision of sanitation services is comparatively high relative to other case-study cities; however, there is a critical disparity in services and segments of the population remain without access to basic sanitation. 89 per cent Cape Town's population utilise a flush toilet connected to the sewerage system, and only 2 per cent a flush toilet with a septic tank. Nearly 20 per cent of the city's inhabitants reside in informal areas, the highest of any of South Africa's metropolitan areas[112]. The city has over 200 informal settlements, where around 0.5 million people reside. Sanitation services are substantially lower in these areas. Overall, 4.5 per cent of Cape Town's inhabitants are reliant on a bucket toilet, 1.2 per cent on a chemical toilet, 0.4 per cent on a pit toilet and 2.5 per cent have no access to a sanitation facility[113], nearly all of which reside in informal settlements.

Extreme water scarcity is the most impactful consequence of climatic change on sanitation services in Cape Town. The city is heavily reliant on surface water from rainfall stored at a nearby dam catchment area. From 2015 to 2018, the city endured a 'one-in-590-year' drought[114]. This resulted in Cape Town progressively moving closer towards 'day zero', when the total water supply in the dam would be below 13.5 per cent of total storage capacity. 'Day zero' was ultimately avoided; however, the prolonged water scarcity challenges were reported to have a range of impacts on sanitation services:

1. Communal toilets in informal settlements not operating properly due to decreased water pressure resulting in vandalism and blockages and the overflow of toilets and nearby sewerage systems.
2. Spread of water-borne diseases (i.e., gastroenteritis) because of the increased handling of greywater because of the push for increased greywater recycling to reduce water usage.
3. Higher than normal degradation and sometimes even collapse of parts of the sewer network due to significantly reduced flows (ranging from 17 per cent to 52 per cent reductions). [115]
4. Wastewater treatment plants – especially smaller plants and plants using biofilter technology – failing to treat wastewater to acceptable levels because of higher pollution concentrations.[116]

Above: Aerial photograph of Cape Town's Thewaterskloof reservoir – 2018

Rapid onset and recurrent flooding also significantly impact sanitation services. Heavy downpours in the winter months (May-August) cause flooding in informal settlements located in low-lying or flood-prone areas (i.e., wetlands and retention and detention ponds). Flooding has several sanitation-related impacts, including stormwater flooding sewers, dispersal of liquid and solid waste that has not been properly disposed of into the wider environment, and wastewater treatment plants receiving flows exceeding their capacity thus requiring the raw discharge of sewage directly into the environment. Wealthier populations that benefit from sophisticated and well-planned services and infrastructure – and typically reside in higher areas – are generally spared the impacts of rapid onset and recurrent flooding.

Climate change is projected to increase the frequency and intensity of several of the acute shocks and chronic stresses impacting sanitation services in Cape Town. Temperature increases of up to 3ºC by the 2040s, an increased number of very hot days and reduced overall rainfall will all contribute to reductions in the availability of water from existing water resources – this is projected to decline from 300 million kilolitres in 2020, to 275 million kilolitres by 2040[17]. Despite reductions in the overall amount of rainfall, more intense rainfall events are predicted, thereby increasing the likelihood and impacts of floods.[118]

3.1.2 CHENNAI

Chennai is the capital of India's Tamil Nadu State. It is governed by the Greater Chennai Corporation (GCC), which holds several responsibilities for sanitation as well as solid waste and stormwater management. The Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) holds key responsibilities for offsite sanitation, including operation and management of sewerage facilities and extending sewerage services. The role of private operators encompasses emptying and transport of faecal sludge as well as operating sewage treatment plants and pumping stations.

Forty-two per cent of Chennai's population access offsite sanitation services - these consist of a 5,200 km sewer network with 265 stations and 13 wastewater treatment plants[119]. The remaining 58 per cent utilise onsite sanitation, nearly 80 per cent of which are sealed, fully lined tanks and 15 per cent are lined tanks with impermeable walls and open bottoms[120]. In 2017, GCC declared Chennai open defecation free; however, it is still being practiced. 62 per cent of the excreta produced in Chennai is safely managed[121]. Nevertheless, effectively enforcing faecal sludge management guidelines represents a key challenge, with rivers, canals, lakes, empty plots, and stormwater drains being common receptors.

Climatic changes are profoundly impacting the performance of Chennai's sanitation services. Droughts and prolonged instances of water scarcity have recently become critical challenges; in 2019, piped water supplies and many of Chennai's reservoirs ran dry. Droughts and water scarcity events have increased in frequency and intensity because of changing rainfall patterns that led to monsoon deficits in 2016 and 2018 as well as several chronic stresses: increased groundwater extraction, unsustainable agriculture practices, rapid urbanisation, seawater intrusion and the mismanagement of water resources. There is a lack of data on the specific impacts of water scarcity and droughts on sanitation services. However, consulted stakeholders noted several effects:

1. higher concertation of pollutants in wastewater because of reduced water consumption, thus creating challenges for wastewater treatment plants.
2. reduced functionality of water-reliant sanitation systems (i.e., flush toilets, sewerage networks), and
3. compromised sanitation and hygiene behaviours and practices.

Chennai has a long history of floods and cyclones, which have recently increased in frequency due to climatic changes and rapid unplanned urbanisation. In 2015, unprecedented rainfall caused devastating flooding that claimed 470 lives, caused huge economic shocks and severely impacted sanitation services. There was widespread spillage and contamination through the flooding of onsite facilities, the collapse of pit latrines and the overflow of sewerage systems that are often connected to the city's network of stormwater drains. Moreover, treatment plants received flows far exceeding their design capacities and were forced to discharge raw sewage with storm overflows directly into the environment. Other infrastructure and systems that sanitation services are reliant on were also damaged, including electricity and road networks.

Chennai also experiences droughts, which have historically interspersed flooding events. Climate change forecasts predict a decline in precipitation across South Asia that will increase the intensity and impact of droughts and water scarcity challenges. Moreover, the frequency of heavy rainfall events is projected to increase, thereby increasing the risk of flooding. Sea-level rise of between 0.19-1.2 metres over the next few decades has also been forecast[122], which would severely impact sanitation services in low-lying and coastal Chennai.[i]

3.1.3 LUSAKA

Lusaka is Zambia's capital and largest city with a rapidly growing population of 2.5 million, 70 per cent of which reside in informal settlements. Lusaka City Council (LCC) is one of Zambia's 107 devolved Local Authorities responsible for ensuring sanitation services. It delegates the responsibility for providing offsite and onsite sanitation services across the sanitation service chain to the commercial utility, Lusaka Water Supply and Sanitation Company (LWSC). However, LWSC only directly manages a fraction of sanitation services – households with sewer connections as well as seven wastewater treatment plants. This leaves a substantive gap that has been filled by private sector operators (i.e., formal and informal emptying and transport service providers). Community-based 'water trusts' with delegated management contracts with LWSC also provide water and sanitation services to low-income communities in peri-urban areas, some of which deliver safe pit emptying and faecal waste treatment services.

Sanitation coverage rates have stagnated over the last 15 years, with LWSC struggling to keep up with rapid urbanisation. The percentage of households accessing sewer services has declined considerably from 2006 to 2015 (22 per cent to 9 per cent), while – driven by economic development – the percentage using pour-flush latrines and septic tanks has risen (14 per cent to 32 per cent). Notable disparities exist in sanitation services. In Lusaka's densely populated and low-income communities, there are very few offsite or higher quality onsite sanitation services, with 95 per cent of the population using pit latrines[123]. Only 17 per cent of faecal sludge and wastewater are safely managed, and substantial challenges exist in ensuring the safe management of effluent across the sanitation service chain.[124]

In Lusaka, floods have increased in frequency and intensity over the last two decades[125] – they are the most visible effect of climate change on sanitation services in the city. There is a lack of specific data detailing the impacts of flooding on sanitation services. Consulted stakeholders noted that flooding has caused the collapse of pit latrines, overflow of faecal sludge and septage from pits and septic tanks respectively causing environmental contamination, as well as wastewater treatment plants receiving flows exceeding their capacities resulting in direct discharge of raw sewage directly into the environment. This has had profound public health and economic impacts – including the spread of cholera – most acutely felt by low-income communities in flood-prone areas. Climate projections suggest heavy rains will occur more frequently, further exacerbating the threat posed by floods.[126]

While flooding is largely viewed as the primary impact of climate change on sanitation in Lusaka, droughts and instances of water scarcity also have considerable impacts. These include:

1. Reduced functionality of water-reliant sanitation technologies (i.e., flush toilets and sewerage networks).
2. Households compromising on key sanitation and hygiene practices when water sources run dry.
3. Further disposal of non-compliant effluent from Lusaka's wastewater treatment plants due to the higher concentration of pollutants in the influent wastewater further straining the already under performing treatment facilities.

i These include increased vulnerability to water scarcity through damage to desalination plants and degradation of underground infrastructure (i.e., pipes, sewers, septic tanks, soakaways) and reduced groundwater quality because of increased saltwater intrusion.

4. Increased incidents of shut down of treatment facilities and compromised treatment processes due to the loss of power caused by national electricity shortages and load shedding; hydroelectricity constitutes 85 per cent of Zambia's electricity generation pool, thus making it highly vulnerable to water scarcity.[127]

3.1.4 SANTA CRUZ

Santa Cruz is Bolivia's largest city with 1.9 million inhabitants. The Autonomous Municipal Government of Santa Cruz is the sanitation authority in charge of sanitation services. Drinking water is provided by more than 25 semi-private operators referred to as cooperatives, only eight of which also provide sanitation services. Cooperativa de Servicios Públicos de Santa Cruz Ltda (SAGUAPAC) is the largest service provider covering 64 per cent of all customers. It has seven wastewater treatment plants, including the only plant in Santa Cruz that receives faecal sludge. In 2019, there were 37 registered private emptying and transport service providers; however, only 22 of which deposited faecal sludge at the SAGUAPAC treatment plant.

Around 94 per cent of Santa Cruz's inhabitants access at least a basic sanitation service, and 53 per cent have a sewer connection[128]. However, the challenge of delivering universal sanitation services is intensified by significant population growth – Santa Cruz has a six per cent annual population growth rate[129], causing a high-level of informal settlements. Septic tanks and lined pits are the main sanitation facilities utilised in informal settlements. Overall, 21 per cent of Santa Cruz's inhabitants utilise toilets connected to a septic tank, 23 per cent a lined pit and three per cent practice open defecation[130]. The Metropolitan Master Plan sets the goal of universal sewer access by 2026; however, the challenge of reaching this target is recognised, with intermediary solutions provided.

Pollution of Santa Cruz's aquifer, the city's only water source, is a major environmental challenge – 30 per cent of generated wastewater and faecal sludge are not effectively treated before entering the environment[131]. Water scarcity due to pollution is expected to be the

main challenge related to sanitation that Santa Cruz faces. Hydrogeologic studies[j] suggest clean water availability, especially from groundwater sources, will become more challenging to access in the future due to:

1. Reduced percolation for recharging aquifers because of (i) high-intensity rainfall with limited infiltration capacity of the soils; (ii) intense deforestation of the catchment despite much of it being designated a protected area; and (iii) reduction in permeable surfaces due to rapid urbanisation.

2. Pollution due to poor management of onsite sanitation, and faecal sludge and wastewater not being treated.

Flooding and high-intensity rainfall are the main climate change shocks impacting Santa Cruz. Santa Cruz is built along the Piraí River, which has tremendous discharge variability. Flash floods caused by intense rainfall are relatively common, the greatest of which were in 1983, 1992, 2006 and 2007, 2011, 2018, and 2021[132]. Moreover, the Niño and Niña phenomenon have major effects on extreme rainfall events[133], leading to two to three significant flood events each year. These floods have had several impacts on sanitation services – for example, wastewater treatment lagoons recently collapsed because of intense rainfall. Moreover, 53 per cent of the city's households do not reside in areas with effective drainage systems, resulting in these areas being flooded for at least three days after each event. When these areas include flood prone onsite sanitation facilities, this leads to major environmental hazards.

j PERIAGUA phase III, a GIZ programme that commenced in April 2021, is implementing protection measures and interventions to ensure the sustainable management of groundwater resources.

Above: Sampling water in Santa Cruz – 2018

3.2 DEMAND AND WILLINGNESS FOR CLIMATE RESILIENT URBAN SANITATION

This section presents the drivers that influenced key stakeholders and decision-makers to strengthen the climate resilience of sanitation services in their respective cities.

Tangible impacts from chronic stresses and acute shocks such as severe water scarcity challenges as well as recurrent or rapid onset flooding and the subsequent spread of water-borne diseases played a key role in influencing stakeholders to invest in increasing the resilience of services. In Cape Town and Chennai, forecasts and assessments highlighted the vulnerability of the cities to droughts and water scarcity challenges; however, it was only after acute shocks that resulted in the loss of life, severe economic challenges or forced substantial changes in day-to-day behaviours that stakeholders took substantial and concerted action. The importance of this driver for action partially explains why significant measures have been implemented in Chennai and Cape Town – both of which have been severely impacted by water scarcity challenges – while smaller investments have been made in resilience in Lusaka and Santa Cruz.

Investments that are directly or indirectly strengthening the climate resilience of sanitation services are generally not been driven by an intentional desire to increase the climate resilience of said services. Across the four cities, a wide range of measures are being implemented that are enhancing the climate resilience of sanitation services. These are, however, typically driven by the desire to strengthen the resilience of water supply services in the face of rising water scarcity challenges or the broader objective of improving service delivery. To date, in the case study cities, the increased climate resilience of sanitation services has been an indirect benefit rather than the primary driver of action.

To date, in the case study cities, the increased climate resilience of sanitation services has been an indirect benefit rather than the primary driver of action.

A wide range of stakeholders have played a critical role in strengthening the resilience of sanitation services. Local governments and utilities have often led efforts to strengthen the resilience of services. However, in all four cities, other actors have played a key role. For example, in Lusaka, the National Water Supply and Sanitation Council (NWASCO, Zambia's water supply and sanitation regulator) is taking measures to ensure climate resilience is considered by utilities. In Cape Town and Chennai, households and industries have rapidly transformed their behaviours, while civil society and media outlets have placed pressure on government and service providers. Given the resource constraints in some of the case study cities, donor and development partner funding continues to play a critical role in enabling action in this area.

3.2.1 CAPE TOWN

In Cape Town, the acute shock of the substantial water scarcity challenges that occurred from 2015-2018 highlighted the importance of resilient services and served as a wake-up call to the city. The severity of this drought galvanised stakeholders around the need to first avoid 'day zero' when Cape Town's conventional water supply system would have stopped working and then take concerted action to reduce the likelihood that such an event could happen in the future. As the service authority and primary sanitation service provider, CCT played a key role in driving action on resilience and has taken several vital steps to mainstream a focus on resilience into planning and decision-making. Households and industries also played an important role by rapidly transforming their behaviours as it relates to water consumption, and civil society and media outlets placed considerable pressure on CCT, households and industries to address this challenge.

Several interventions are being implemented – often at a considerable scale – that are coincidentally rather than intentionally strengthening the climate resilience of sanitation services. The two factors primarily and intentionally driving investments in these interventions are:

1. The desire to increase the city's overall resilience to water scarcity challenges and droughts, which are projected to become more severe because of reduced rainfall and rapid urbanisation, through limiting consumption and diversifying water supply sources.
2. The aim to generally improve sanitation service provision in Cape Town's many informal settlements where inhabitants are often unserved or utilise bucket and chemical toilets or pit latrines.

3.2.2 CHENNAI

In Chennai, demand for climate resilient services was ignited by the acute shocks of the 2015 'once in 100 years' flood and, even more so, following incredibly severe water scarcity challenges from 2018-2019. These events, along with the media and subsequent public pressure, united key stakeholders behind the need to take concerted action and, in both cases, a series of programmes and interventions were implemented following the acute shocks. No one governmental or non-governmental stakeholder has pushed forward efforts to strengthen climate resilience – it has been a combined effort involving GCC, CMWSSB, national- and state-level governmental actors, civil society, households, the private sector, research institutions, donors, and development partners.

As in the other cities, adaptions implemented in Chennai have not been driven by an intentional desire to strengthen the climate resilience of urban sanitation services. Instead, most interventions have been motivated by a broader wish to strengthen the climate resilience of wider elements of service delivery (i.e., water supply). Except for interventions focused on wastewater recycling and decentralised wastewater treatment systems (DEWATS), none of the 86 activities detailed in the Resilient Chennai Strategy seek to directly strengthen the resilience of sanitation services.[134]

Above: Floating reed bed, Asyar river, Chennai

3.2.3 LUSAKA

In Lusaka, ongoing chronic stresses – which are correlated with climatic changes – have been the key driver for action and pushed stakeholders to begin focusing on climate resilience. These chronic stresses include recurrent flooding – and consequently near-annual cholera outbreaks – that frequently affect many of Lusaka's low-income communities, as well as ongoing water scarcity challenges that are becoming increasingly problematic. Key governmental stakeholders including local government, the water and sanitation utility, and the national water and sanitation regulator have been drivers of change. Several development partners and donors have also played a critical role in funding and facilitating interventions on climate resilient urban sanitation as well as broader programmes that are increasing the climate resilience of sanitation services. Despite this, it is important to recognise that while the strengthening of the climate resilience of sanitation services is rising up the agenda and more action is expected to be taken in the future, it is not currently a core priority. In a context where basic sanitation service delivery is still lacking, evident in some parts of the city with over 95 per cent of inhabitants utilising poorly constructed pit latrines, key stakeholders find it challenging to integrate and prioritise climate resilience.

3.2.4 SANTA CRUZ

In Santa Cruz, demand for adaptation responses is mainly related to the chronic stress of limited availability of affordable and safe water, the lack of which negatively impacts the functionality of sewered sanitation systems. Demand for investment in climate resilient sanitation stems from the need to reduce groundwater contamination from onsite facilities, which is seen as the main source of water scarcity in the city. While utilities have been acutely aware of the need for additional sources of affordable, safe water due to increased demand and limited resources, the approach did not appear to be driven by a holistic climate change adaptation strategy. Demand for adaptation of water resources in Santa Cruz came from local government and the public, which increased during extreme droughts in La Paz, most recently in 2016. However, this level of demand was temporary, gradually losing momentum to the next major human or natural event.

Above: Assessing demand for services in Lusaka

3.3 ADAPTATION RESPONSES TO SPECIFIC SHOCKS AND STRESSES

This section presents the key adaption responses in each of the four case studies. The focus is mainly on adaptations related to the acute shocks and chronic stresses of water scarcity and droughts, as well as recurrent and rapid onset flooding, as these are the main areas where noteworthy adaptions have been taken (or are planned) across all cities. Cape Town and Chennai feature heavily in this section, as these cities have been most adversely impacted by climatic events and have implemented the most significant adaption measures to date. Table 3 provides a summary of the main adaptation responses for water scarcity and droughts as well as recurrent and rapid onset flooding from across the four case-study cities.

Water Scarcity and Droughts	Recurrent and Rapid Onset Flooding
– Diversification and enhancement of existing water supply sources, including nature-based solutions. – Addressing water quality challenges. – Overall reduction in water usage, including modifications to sanitation facilities to reduce their water usage. – Wastewater recycling. – Construction of wastewater treatment plants with greater technical robustness.	– Construction Modifications to onsite sanitation facilities to reduce vulnerabilities to floods. – Utilisation of container-based sanitation services. – Utilisation of decentralised wastewater treatment systems. – Improved stormwater management infrastructure. – GIS-based vulnerability mapping and flood monitoring and forecasting tools.

Table 3. Overview of Adaptation Responses

3.3.1 WATER SCARCITY AND DROUGHTS

Adaption responses to water scarcity and droughts primarily focus on ensuring reliable water supply services through diversifying and enhancing water sources. Significant investments and at scale interventions are made in this area to reduce vulnerabilities, indirectly increasing the climate resilience of sanitation services, primarily offsite services. In Cape Town, measures are reducing reliance on surface water through increased utilisation of groundwater sources and desalinated solutions, as well as the development of several new aquifers.[k] In Santa Cruz, measures to limit water scarcity caused by poor water quality have centred on improving the monitoring and regulation of sanitation services, ensuring timely emptying of pit latrines, and the drilling of deeper wells.

Steps have been taken to reduce vulnerabilities to water scarcity through resourcefulness and nature-based solutions. In Chennai, GCC recently began restoring 210 water bodies to be used for water storage and eventually drinking water supply[l, 135]. In Cape Town,

k Cumulatively, these measures are expected to increase the availability of water from 350 million kilolitres per year in 2015, to just under 500 million kilolitres per year by 2037. These measures are reported to have reduced the yearly risk of Cape Town not having sufficient water to meet demand from 2 per cent to 0.5 per cent (CCT, 2018).

l GCC has already constructed tertiary treated ultra-filtration plants, which are supplying 34 million litres per day (MLD) of water, with several further 10 MLD tertiary treated ultra-filtration plants planned.

nature-based solutions are protecting the long-term health of surface water sources through: (i) managed aquifer recharge with wastewater and stormwater; (ii) maintenance of aquifers' infiltration capacity; and (iii) increased regulation[136]. There is also a substantial focus on removing non-native and invasive vegetation from the city's large dam system to augment water supply by 55 billion litres[137].

Cities are reducing overall water usage to reduce vulnerabilities and increase redundancies. As 'day zero' approached Cape Town in 2018, the city's inhabitants rallied together to reduce water consumption by 40 per cent, and it is now known as the 'number one water saving city in the world'[138]. A myriad of measures achieved this: (i) water restrictions; (ii) sensitisation campaigns; (iii) increased tariffs; (iv) reducing the pressure in the network; and (iv) household-level adaptions such as low-flow taps and water-efficient shower heads[139]. While per capita water consumption has now increased, it remains below pre-drought level, suggesting lasting changes in behaviour. In Chennai, several bottom-up solutions (i.e., low usage taps and shower heads and placing bricks in toilet water tanks) driven by the private sector and households reduced water consumption.

Resourceful approaches to wastewater recycling are increasing robustness and water availability. These adaptions are increasing resilience through saving freshwater and securing access to water in times of scarcity. In Chennai, wastewater recycling has been made mandatory, with GCC only issuing permits for new developments if wastewater recycling is integrated into the design[140]. A few DEWATS have been implemented at a modest scale,[m] and CMWSSB has set the objective of constructing 24 DEWATS with tertiary technologies for a total of 360 MLD by 2030[141]. The use of recycled wastewater for industrial purposes is a further significant strengthening of integration in Chennai and Cape Town. In Chennai, CMWSSB sells treated wastewater to large industries, and industries are required to achieve zero liquid discharge in their operations – no wastewater is to be discharged into the environment; it must all be treated and re-used[142]. In Cape Town, some large industries have developed wastewater treatment facilities to reduce (or eliminate) their dependency on the City of Cape Town's drinking water network. Treated effluent reticulation networks were also extensively used during the drought.

Designing wastewater treatment plants that can cope with higher concentrations of pollutants (primarily chemical oxygen demand and suspended solids) and low flow conditions builds their robustness and flexibility. Research studies conducted following the drought experienced in Cape Town found that "plants with inherent flexibility, such as the ability to take settling tanks and biological nutrient removal systems offline during low flow conditions and allow for the recycling of effluent within the plant to maintain hydraulic load were able to withstand low flow conditions better than inflexible systems."[143]

Household sanitation facilities have been adapted to be less water reliant. In Cape Town, modifications have been made to communal sanitation facilities in informal settlements to increase their robustness by reducing water usage when flushing to just two litres per flush by adjusting the design of the U-bend. This adaption has only been piloted – the technology costs 30 per cent more than the existing fixtures, which could present a barrier to scaling.

Ongoing messaging and sensitisation are critical for inclusion, by ensuring the adoption and sustenance of changes in behaviours by households and institutions (i.e., using recycled wastewater, investing in water saving sanitation technologies). It is not realistic to expect the rapid uptake of new technologies without ongoing substantive behaviour change activities. In Chennai, 900,000 rainwater harvesting structures have been constructed because of legislation mandating water supply and sanitation services include rainwater harvesting systems, and yearly campaigns since 2002 for the regular maintenance of these systems[144]. However, many of these facilities are non-functional due to a lack of proper maintenance.

More can be done to ensure household-level adaption technologies are inclusive of low-income households. In Chennai, the campaigns to increase households' utilisation of rainwater harvesting systems are targeted to over-exploited, critical, and semi-critical aquifer regions using data from the Central Ground Water Board of the Ministry of Water Resources. While this has led to

m The Solar Active Island Reactor and BioGill Wastewater Treatment System are two particularly interesting DEWATS variants focused on directing sewerage into in-situ treatment systems before it enters water bodies (GCC, 2019).

a sizeable increase in rainwater harvesting, these solutions have overwhelmingly benefitted middle- and high-income households that can afford them. Similarly, in Cape Town, it is primarily better off households that have benefited from adaptions such as drilling boreholes.

A collaborative approach to developing large, city-wide assessments is critical for achieving inclusion, flexibility, consensus and buy-in for climate resilience. In Cape Town, a large CCT-led climate change assessment provided an important overview of the probable impacts of climate change and included exposure, vulnerability, and resilience assessments. Critically, it brought together many key stakeholders to focus on the issue. In many ways, this participatory process was seen to be more impactful than the assessment's findings as it helped ensure the buy-in of key stakeholders and developed a consensus of the probable impacts of climate change. In the other case study cities, comprehensive assessments have been conducted; however, the process has been more ad-hoc and often failed to bring together key stakeholders in a truly collaborative manner.

Regardless of the importance of assessments, it is important to acknowledge that there is a high degree of uncertainty regarding the extent of climatic changes. Data and assessments are important in gauging, as much as possible, the extent of the challenge, identifying key vulnerabilities and forming a consensus on the need for improvements. However, stakeholders found that defining thresholds and tipping points is challenging, and that reflectiveness is necessary. There is an acceptance that interventions strengthening the resilience of sanitation services cannot always be made with a high degree of certainty. This makes embracing adaptivity vital and a focus on the need to implement approaches with at least some element of 'learning-by-doing'. In Cape Town, several large infrastructural adaptions were implemented to diversify water supply during the drought (i.e., desalination plants); however, surface water levels were restored to normal before these solutions could be deployed. The adaptations are however relevant for increased resilience of services in the future, as well as for providing vital learnings on the suitability of different technologies.

Successfully mainstreaming and integrating resilience and climate change into planning and decision-making is challenging but very impactful. In Cape Town, several plans and strategies have been developed and are being implemented that take a resilience or climate change lens[145,146], and a new climate change strategy and action plan is currently being developed. Moreover, one of the five pillars of the Cape Town Resilience Strategy focuses on a "collectively, shock-ready city", and includes a variety of activities grouped under four goals: (i) future-proofing urban systems; (ii) strengthening individual, family, and community resilience;

Above: Theewaterskloof reservoir providing over 40% of the water storage capacity available to Cape Town

(iii) encouraging investments in household and business resilience; and (iv) exploring new funding mechanisms[147]. Some of the key factors reportedly enabling the mainstreaming of resilience and climate change are the creation of a cross-departmental working group on climate change, the establishment of a Resilience Department at CCT, utilisation of specialised programme managers mandated to take a resilience lens, a dedicated policy and strategy unit that help the developers of CCT's various policies and strategies to take a resilience and climate change focus. More needs to be done by key stakeholders in Lusaka, Santa Cruz and (to a slightly lesser extent) Chennai to mainstream and integrate resilience and climate change across different systems to overcome some of the barriers to implementing and scaling proposed adaptions.

Regardless of the varying levels of development and extent of action taken to date, in all four case study cities, additional resourcefulness is needed to address capacity gaps. For example, in Lusaka, LWSC has identified a broad range of capacity gaps relating to climate resilient urban sanitation and outlines a series of steps required at the management and operational levels to address them. Paramount among these steps are greater leadership and institutional responsiveness to climate change (i.e., policy development, planning, budgeting, strategy development, resource mobilisation, knowledge management), increased capacity to conduct climate modelling and incorporate the projected impacts of climate change into core activities, improved coordination with other stakeholders, and learning and adaption.[148]

3.3.2 FLOODING

Onsite sanitation technologies can be designed and constructed to increase their resilience to floods. In Lusaka, the focus of climate resilient onsite sanitation as it relates to floods has centred on the design and construction of containment structures, with the objective of preventing faecal waste from contaminating the surrounding environment during floods. This was achieved by raising the height of the containment structure above the surrounding ground level, ensuring it is fully lined, and utilising non-permeable blocks in its construction. 2,500 of a planned 5,500 facilities have been constructed thus far. In Cape Town, CCT facilitates the delivery of container-based sanitation (CBS) services to about 20,000 residents of informal settlements. The implementation of these container-based sanitation services is driven by the desire to improve access to safe sanitation services more broadly, rather than ensuring climate resilient sanitation. However, due to their above-ground nature, small, sealable, and regularly emptied containers, these toilets are considered less vulnerable to excreta entering the environment during flooding compared to other solutions such as pit latrines[149]. For both these sets of interventions, concerted messaging and sensitisation have been key to ensuring community acceptance.

The use of DEWATS increases flexibility by reducing dependencies on large, centralised wastewater treatment plants impacted by flooding. In Chennai, DEWATS have so far only been used on a modest scale as part of several pilots. Nevertheless, the use of many comparatively small facilities rather than a few centralised wastewater treatment plants has the potential to provide greater flexibility and in-built resilience to floods through spreading the risk of failure – damage to one or even several facilities during a flood should not catastrophically impact other systems. Their shorter piped networks compared to longer centralised networks also reduces the possibilities of overloading sewers and failures in the system[150]. Furthermore, most of the DEWATS and wastewater recycling facilities in Chennai are not dependent on electricity, thereby helping to ensure their continued operation during power failures common during floods[151]. However, it is important to note that recent legislation from India's central government has made wastewater standards more stringent, making it more challenging to implement certain DEWATS designs.

Increasing treatment capacity can create redundancies and mitigate the impacts of flooding. Due to illegal sewage connections to stormwater drains, a key challenge Chennai faces during floods is faecal waste entering stormwater drains and contaminating water bodies. To address this, sewage treatment plants have been installed to intercept and treat the contaminated stormwater; the wastewater is treated to such high

levels so as to allow for certain categories of reuse (e.g., irrigation). In Chennai, Lusaka and Santa Cruz, there have also been concerted efforts to improve onsite sanitation services, with the goal of reducing the proportion of faecal sludge entering the environment, particularly during floods.

A range of broader activities – not driven by a core desire for climate resilient sanitation – are also reducing the vulnerability of sanitation services to flooding. In Chennai, large stormwater management programmes have – and continue to be – implemented that reduce sanitation services' vulnerabilities to floods by increasing the city's capacity to handle heavy rainfall events. Also, in Chennai, investments are being made in GIS-based flood monitoring and forecasting tools to observe long-term trends and help government, communities and emergency teams respond more quickly and reduce the impact of floods.[152]

Vulnerability mapping has played an important role in prioritising and targeting onsite sanitation interventions. In Cape Town, GIS mapping is used to determine the risk that informal settlement face to different categories of flood events (i.e., a 1-in10, 1-in-50 or 1-in-100-year flood event) and prioritising the construction of onsite sanitation facilities in areas determined to be of high vulnerability. Ultimately, this approach is intended to be reflective, and limit the amount of excreta entering the environment. In Lusaka, groundwater vulnerability maps and data on past cholera hotspots were used to prioritise interventions for onsite sanitation facilities. Lined sanitation containment systems were targeted to typically low-income households that are in areas at high risk of flooding and cholera outbreaks, and with highly vulnerable groundwater.

Inclusive multi-stakeholder collaboration and nature-based solutions are used to address flood control. In Chennai, GCC is restoring 210 degraded water bodies, including the 100-acre Sembakkem lake that flows into the Pallikarani wetland[153], and the Buckingham Canal[154], thus re-enabling them to function as flood sinks. It benefited from an online platform and initiative called Chennai City Connect, which helped strengthen coordination between stakeholders, fostering long-term and integrated planning, empowering and range of stakeholders, and promoting cohesive and engaged communities.[155]

Development partners have been playing a key role in financing interventions in cities with limited public investment in climate resilience to flooding. In Lusaka, interventions to increase resilience to flooding have been heavily reliant on donor funding from organisations including the African Development Bank, the Bill and Melinda Gates Foundation, GIZ, KfW, and the World Bank. This is, in part, a reflection of limited government budget allocations for sanitation and climate resilient sanitation, and the resourcefulness of relevant authorities in addressing the gap. In Santa Cruz, there has historically there has been limited investment in reducing vulnerabilities to flooding. However, in February 2020, the World Bank approved a USD 50 million loan aimed at strengthening the city's resilience and increase its capacity to reduce and prevent climate risks, including flooding[156]. While there has been public investment in climate resilience in Chennai, some development partners such as the World Bank and KfW increased their investment in preventing or mitigating the impacts of floods following the 2015 so-called 'once in a 100-year flood'.

Above left: Flooding in Santa Cruz – 2019
Above right: Floods in peri-urban areas of Santa Cruz – 2018

4 SANITATION AND URBAN RESILIENCE: GAPS AND OPPORTUNITIES

Moving resilience forward in urban sanitation requires a better understanding of the gaps and opportunities which exist. This chapter highlights some of those elements.

4.1 KEY GAPS

There are numerous gaps in the sector's ability to build the resilience of sanitation systems to climate change. The three key ones expanded on hereafter are integration and coordination within and outside sanitation systems, global metrics for measuring climate resilient urban sanitation, and understanding the cost of resilience and the associated financing gap.

Other gaps do exist, such as researching the potential transferrable lessons from the still unfolding global and prolonged shock of the COVID-19 pandemic. Its novelty has required rapid learning, adaptive responses, and cooperation on a global level. Research would be helpful to uncover its impact on urban sanitation systems (potentially identifying unforeseen weaknesses), co-benefits that sanitation could offer (e.g., early warning systems for disease presence or prevalence), and the potential change in demand for improved resilience.

4.1.1 INTEGRATION AND COORDINATION WITHIN AND OUTSIDE SANITATION SYSTEMS

Urban sanitation resilience depends on complex relationships and interdependencies of mandates, interests and power dynamics between different stakeholders, services, and infrastructure. The current discourse around sanitation resilience and adaptation is yet focused on technology, with a prevalence of silo thinking and fragmentation of institutions and service chains[157]. Silos often represent a gap in leadership, where a vision and common goals are not clearly defined, and competition between different sectors limits knowledge sharing and progress.

A gap in investments, knowledge, and capacity in the sanitation sector hinder progress towards establishing effective and evolving integration and coordination with within and outside sanitation systems. Financers and planners need to be able to better understand and engage with systems outside of WASH. There is a clear gap in research and capacity building that investigates the climate resilience of complex urban sanitation systems in an integrated manner and that takes into account the complexity of service and policy arrangements, interdependencies with other sectors, and how these change over time. Where integration does take place, it is essential that sanitation be continually advocated for, placed front and centre, highlighting its potential to trigger transformative change.[158]

Existing political and institutional bottlenecks act as a serious break on service delivery and sustainability, particularly for vulnerable communities[159]. In many cities the sanitation sector is fragmented and relies on weak institutions and complex service chains that often heavily rely on private, informal, and poorly regulated service providers. Formal service providers such as utilities often serve only a small portion of a city's population, and often - deliberately or not - neglect parts of the community that are most in need of better sanitation planning and vulnerable to climate change effects. Planning approaches for managing uncertainty and improving resilience for urban water and sanitation utilities, such as the World Bank Utility Road Map[160], often do not reach critical parts of the population.

4.1.2 GLOBAL METRICS FOR CLIMATE RESILIENT URBAN SANITATION

As of yet, there are no globally accepted definitions or metrics (e.g., measurable outcomes or indicators) that allow for the monitoring of climate resilient urban sanitation. This has been an issue in general when it comes to tracking adaptation to climate change, further complicated by the limited evidence available on the impact of climate change on sanitation systems and the effectiveness of adaptation measures.[161]

It is still easier to measure the adaptation of toilets to climate change than it is measure the resilience of institutions and service providers[162]. It is also easier to measure climate through the reduction of GHG emissions, with considerably more research to support it. Without a framework to monitor climate resilient urban sanitation, it is challenging to set targets or generate the necessary evidence to inform decision-making.

Various authors have recommended overcoming the artificial separation between adaptation and development and are proposing the adoption of concepts such as 'adaptive' or 'resilient development'[163]. The SDG Target 6.2 offers a global framework to measure efforts to improve global access to sanitation. In 2015, the JMP went further than the previous Millennium Development Goals by introducing 'safely managed sanitation' to Goal 6.2, thus ensuring the entire sanitation chain is considered, and not only the toilet itself (i.e., 'basic sanitation'). Consideration may need to be given as to whether resilience could be considered for integration into SDG 6.2, and the ability of countries and cities to respond to such a change.

4.1.3 UNDERSTANDING THE COST OF RESILIENCE AND FINANCING THE GAP

According to World Bank estimates, the global levels of WASH financing are only adequate to cover the capital costs of achieving basic access by 2030[164]. Meeting the SDG target 6.1 and 6.2 would require tripling of capital investments per year[165]. Considering the pressure on governments to achieve the SDGs and the often-challenging budget constraints, investing in climate resilient urban sanitation has inevitably become a secondary priority and a significant gap for governments.

No data is available on the global cost of achieving climate resilient urban sanitation, nor the cost of a 'do-nothing' scenario. In 2011, Fankhauser and Schmidt-Traub assessed the costs of climate-proofing the MDGs in Africa. Whilst the actual numbers as well as the proportional increase of costs might be very different for the SDGs, their conclusion that adaptation measures concerning water and sanitation infrastructure were amongst the costliest climate-proofing measures is likely to remain valid[166]. It is thus safe to assume that climate resilience will increase investment needs compared to the already challenging SDG target of 100 per cent 'safely managed sanitation', particularly for lower-income countries. Since resilience is related to risk, 'total' resilience is not achievable. Negotiating 'appropriate' resilience will always involve trade-offs between acceptable levels of residual risks and the costs improving resilience.

> No data is available on the global cost of achieving 100 per cent climate resilient urban sanitation, nor the cost of a 'do-nothing' scenario.

The importance of quantifying the cost of 'do-nothing' cannot be understated. The evidence generated by the World Bank's Economics of Sanitation Initiative (ESI) has been repeatedly used for and by politicians to change the dialogue from sanitation being too financially expensive to invest in, to too economically expensive to do nothing about[167]. Such an approach could address the limited awareness of the linkages between sanitation and climate change, as well as the adaptation and mitigation opportunities.[168]

Financing sanitation, particularly onsite sanitation, has been heavily reliant on household investments. The TrackFin Initiative estimated household contributions to sanitation to be between 60 and 70 per cent in Ghana, Mali, and Burkina Faso[169]. Incentivising household investments into climate resilient sanitation – as an integrated part of a wider climate resilience effort – is thus critical, particularly for lower-income urban households who are often the most vulnerable to the impacts of climate change.

4.2 KEY OPPORTUNITIES

4.2.1 CLIMATE RESILIENT AND SANITATION IN URBAN STRATEGIES, TARGETS, AND PLANS

Integrating climate resilience and sanitation into new and existing sanitation strategies, targets and plans is a much-needed starting point for governments, financing institutions and sanitation authorities. Opportunities for integration could start at national level with increased consideration and inclusion of adaptation for sanitation in the Paris Agreement NDCs. Thus far, only 2 per cent of NDCs deal with sanitation access, and 3 per cent with wastewater management, indicating the limited awareness of the linkages between sanitation and climate change among stakeholders[170]. Inclusion of climate resilience in national WASH strategies could and should also be sought.

At city level, investment in and inclusion of sanitation in city resilience strategies and plans are opportunities to be sought. Opportunities also exist to mainstream climate resilience in sanitation planning, such as in the preparation of CWIS strategies. While CWIS does highlight the fact that climate change has had an impact on sanitation, it does not detail what that impact is, and how to systematically address it. Many of the CWIS principles are aligned with the CRUS framework proposed in Chapter 5, however, without considering sanitation systems from a resilience lens, critical gaps remain in the planning process. Further research into the extent to which climate resilience is already considered in the implementation of CWIS might provide valuable insights in the potential for strengthening it. More on CWIS and climate resilience is detailed in Box 4 (overleaf).

Above: Stakeholder meeting at one of Lusaka's faecal sludge treatment facilities

Box 4

CWIS AND CLIMATE RESILIENCE

Defining CWIS: "Everyone benefits from adequate sanitation service delivery outcomes; human waste is safely managed along the whole sanitation service chain; effective resource recovery and re-use are considered; a diversity of technical solutions is embraced for adaptive, mixed and incremental approaches; and onsite and sewerage solutions are combined, in either centralized or decentralized systems, to better respond to the realities found in developing country cities."[171]

The Citywide Inclusive Sanitation (CWIS) was conceptualised as a set of principles for planning and implementation of sanitation systems that has a focus on outcomes instead of specific technology recommendation. Climate resilience of sanitation systems is not prominently emphasised in the CWIS principles. However, the general conceptualisation of the CWIS framework with its focus on sustainable service outcomes, governance structures and alternative ways of allocation of funding seems to offer opportunities to anchor climate resilient sanitation systems within the approach.[172,173]

In terms of infrastructure and services, CWIS principles promote efficient service provision, rather than a focus on specific technologies or infrastructure types[174]. Similar strategies of reducing the reliance of a single system through flexibility and diversification of infrastructure and services could increase the climate resilience of sanitation systems.[175]

The CWIS principles also challenges the way urban sanitation is funded. This is an opportunity to rethink the funding, financing mechanisms, allocation of costs for strengthening the climate resilience of urban sanitation systems so they are reflective of the vast public benefits for present and future generations.

4.2.2 CLIMATE FINANCE FOR RESILIENT SANITATION

Accessing major climate change funding mechanisms should be a major priority for national and local authorities moving forward. Billions of dollars in funding have recently been made available for climate risk planning and adaptation activities because of the Paris Agreement and SDGs, including the Green Climate Fund (GCF), the Global Environmental Facility (GEF), the Adaptation Fund, the Least Developed Countries Fund, and the Specialist Climate Change Fund.

SDG 13.a pledges to implement the commitment of developed nations to jointly mobilise USD 100 billion annually by 2020 to support developing countries in strengthening their climate resilience. Similarly, the Paris Agreement has led to major funds being available through mechanisms such as the GEF and GCF.[176]

The sanitation sector however has yet to leverage these funds. For example, only 7 per cent of the projects approved until 2019 by the GCF board are focused on or related to sanitation and wastewater, with the sanitation elements mainly funded by development banks or national governments rather than GCF itself[177]. Including climate resilience in national sanitation planning frameworks in the form of 'adaptive development' could mobilise currently underused climate funds.

Another opportunity is to consider including sanitation as part of the recovery from the yet ongoing global COVID-19 pandemic. Consideration needs to be given to how we can build resilient systems that are not only focused on infrastructure but also creating co-benefits like supporting economic development through creating new jobs, mitigating GHG emissions, etc. Recent research has shown that recovery packages that seek synergies between economic and climate goals have better potential for reducing climate risks, increasing national wealth, and enhancing productive human, social, physical, and natural capital.[178]

Box 5

ENERGY PERFORMANCE AND CARBON EMISSIONS ASSESSMENT AND MONITORING TOOL (ECAM)

ECAM is an open-source tool developed under the *Water and Wastewater companies for Climate Change Mitigation* (WaCCliM) joint initiative by GIZ and IWA. It is designed to quantify and evaluate GHG emissions of water and wastewater utilities at a system-wide level, allowing for an identification of opportunities for reducing energy consumption and the overall footprint of the utility.

Earlier versions of ECAM focused on conventional water and wastewater systems only, however non-sewered sanitation have been incorporated in the most recent version.

For more information visit: https://wacclim.org/ecam-tool/

4.2.3 SANITATION AND GHG MITIGATION

The sanitation sector is estimated to contribute between 2 to 6 per cent of the global methane emissions, and between 1 and 3 per cent of the nitrous oxide emissions[179]. However, a systematic assessment of global GHG emissions from different technologies across the sanitation chain has yet to been undertaken and understood. Some tools have been developed to support such efforts, such as the Energy Performance and Carbon Emissions Assessment and Monitoring Tool (ECAM) – see Box 5.

Capturing value from waste however is known not only to improve the overall ecosystem, but also contributes to mitigating climate change. It is estimated that pit latrines – often used by people living in informal urban settlements – holding faecal waste in anaerobic conditions emit approximately 112 Megatonnes[n] of CO_2-equivalents, representing 0.32 per cent of global emissions in 2014[180]. An alternative to anerobic pit latrines is urine-diverting toilets with off-site composting. Recent research has shown that such sanitation systems can reduce GHG emissions by about 126 kg of CO_2 equivalent per capita per year[181]. If scaled globally, offsite composting could mitigate approximately 336 Megatonnes of CO_2 equivalent per year, or 13 to 44 per cent of the sanitation sector's CH_4 emissions[182]. Beyond the value of compost as an agricultural fertilizer and the reduction in GHG emissions, the co-benefits of the urine-diverting and offsite composting system include increased resilience[183], the provision of safely managed sanitation, soil regeneration, reduction in diarrhoeal diseases and the creation of sustainable jobs.

Some estimate that 80 per cent of wastewater generated globally is disposed of into the environment without treatment or reuse[184,185]. SDG 6.2 aims to decrease that to 40 per cent by 2030[186]. Wastewater treated in conventional sewerage plants releases one third of the GHGs compared to untreated disposal of wastewater[187,188]. The key GHG emissions from such treatment systems are CH_4, N_2O and CO_2, the latter resulting mostly from the energy consumed during the treatment process. Mitigating emissions from untreated wastewater vastly outweigh those associated from the energy consumed from constructing and maintaining a new treatment facility.[189]

As such, the global expansion of treatment not only increases the resilience of sanitation systems, but it also plays an important role in mitigating climate change. It can address the SDGs on climate and sanitation, as well as the Paris Agreement commitments. Using renewable energy to power treatment facilities and improving energy efficiency can also help reduce emissions[190]. Reusing resources (water, nutrients, carbon, organic matter, etc.) can also play an important role, with increased direct and co-benefits when segregated at source (e.g., urine diversion, separate grey and blackwater, etc.), and where dilution is minimized.

n 1 Megatonne = 10^6 tonnes

5 FRAMEWORK FOR CLIMATE RESILIENT URBAN SANITATION

This chapter describes what climate resilience means for an urban sanitation system, and what a climate resilient urban sanitation system could look like. Its structure is based on the City Water Resilience Framework (CWRF), which is often used as a conceptual lens through which cities can assess their resilience challenges and opportunities[191]. The framework does not focus on resilience to climate change only, but general resilience to all shocks and stresses a city may face.

For the purpose of this report, the framework will be used with a focus on climate-related shocks and stresses to sanitation systems. To this purpose the dimensions and goals have been adapted, leaning on the concepts and programme actions identified in the Urban Sanitation and Hygiene for Health and Development Learning Paper on climate change in urban sanitation[192] as well as the Sanitation Cityscape Framework[193] and the principles defined in what is referred to as Citywide Inclusive Sanitation (CWIS).[194]

The definition of CRUS (Section 1.4.5) acknowledges the mutual dependencies of resilient sanitation system and resilient urban spaces. As a result, planning for resilience of urban sanitation systems

DIMENSIONS

A. Leadership & strategy

B. Planning & finance

C. Infrastructure & service provision

D. Health & environment

GOALS

A1. Create empowered communities
A2. Strategic vision
A3. Coordinated governance

B1. Effective regulation and accountability
B2. Adaptive and integrated planning
B3. Sustainable funding and finance

C1. Effective disaster response and recovery
C2. Effective asset management

D1. Healthy urban communities and protected natural Environments
D2. Equitable service provision

cannot happen in isolation[195]. Core of urban climate resilient sanitation systems are the people living in the city and depending on the sanitation systems.

Inspired by the CWRF, the - often overlapping - four dimensions of CRUS are: **leadership and strategy, planning and finance, infrastructure and service delivery, and health and environment.** The chapter is structured based on these dimensions, with respective goals for each dimension proposed (inspired from the CWRF and adapted to the sanitation context), and examples from literature drawn on to demonstrate how these goals can be achieved. Chapter 6 of this report proposes a consultative process for developing a sector-wide vision of what drives resilient sanitation systems, using this proposed framework as a starting point.

The chapter will continue to utilise the 'language' of the seven qualities of resilient systems, as defined in the Cities Resilience Framework, summarised below as:

1. **Reflective:** ability to learn
2. **Robust:** limits spread of failure
3. **Redundant:** has back up capacity
4. **Flexible:** has alternative strategies
5. **Resourceful:** can easily repurpose resources
6. **Inclusive:** broad consultation and communication
7. **Integrated:** systems work together.

5.1 LEADERSHIP AND STRATEGY

This dimension relates to the need for effective leadership and long-term strategies that drive decisions around sanitation infrastructure and services. The main goals are to (i) create empowered communities, (ii) strategic vision and (iii) coordinated governance across the sanitation chain. Because elements of the sanitation chain are frequently managed across a fragmented landscape of mandates and regulation, integrated and evidence-based decision-making is essential. Leadership around sanitation is often the domain of government (or a delegated authority) operating at the municipal, regional, or national level, with gaps in oversight and services typical in non-sewered and informal settlement areas. A human rights-based approach (HBRA) to sanitation and resilience programming is required to reveal and gradually overcome power imbalances that are the root of basic service inequalities. A HRBA values the processes as much as the outcomes. As such, the establishment of multi-stakeholder partnership of public and private sector, and civil society is necessary.

5.1.1 CREATE EMPOWERED COMMUNITIES

Climate resilient urban sanitation systems need to put people in the centre of all decision making. Empowered communities are a pre-condition to understand the sanitation specific needs and vulnerabilities of urban communities in the context of a changing climate. This goal therefore describes a need for a strong community that is empowered to participate in sanitation decision-making and implementation actively and meaningfully, with increased ability to assess decisions made and provide meaningful feedback on actions.

Promote active involvement of urban communities in risk and vulnerability assessments. The resilience of different sanitation technologies and infrastructure types to different climate hazards is relatively well understood[197, 198], however, the resilience of individuals and communities using these technologies and services cannot be easily generalised and will depend on context specific factors and is intrinsically related to power. As an example, the Vision 2030 research[199] identifies pit latrines as a technology group as resilient because there are adaptable design options such as raising or sealing toilets against flooding or protecting pits against erosion. Users of pit latrines in informal settlements, however, might not be able or motivated to invest in these adaptive design options because of land right or tenancy issues or due to lack of affordability and competing household investment interests.

Onsite sanitation systems are frequently still characterised by household management, low traceability of investments, and transactions and informality of service chains. Consequently, city and sanitation planners might not have full visibility and understanding of specific bottlenecks and vulnerabilities of the sanitation system. Including urban communities in climate vulnerability and risk mapping and assessment helps cities to identify and include differentiated needs and insights into resilience planning. They can then show sanitation resilience actions that are appropriate, acceptable, and in some cases where local knowledge and materials are used, even affordable for the local context.

→ **A tool that can be used for such a differentiated bottom-up assessment is the *Urban Community Resilience Assessment* developed by WRI and Cities Alliance[200].** ←

Box 6

PARTICIPATORY FLOOD RESILIENCE AND ADAPTATION PLANNING IN KIBERA, NAIROBI

An example for involving communities in risk assessments and adaptation planning is the work of the Kounkuey Design Initiative (KDI) in Kibera, Nairobi. Since 2017, KDI have been implementing a community-responsive flood adaptation programme that engages residents of informal settlements, local government, and university partners into a collaborative process to co-design and implement flood resilience and adaptation interventions involving hard solutions such as flood protection or drainage and soft measures such as flood preparedness and early warning systems.

The project benefits from experience gained through an urban flood resilience action-research project (2015-2026) that resulted in the inter alia in the production of a toolkit for building urban flood resilience in low-income settlements[196].

Raise awareness and build community knowledge on CRUS. Empowerment of communities to take part and be at the centre of planning and decision-making processes for CRUS starts with raising awareness and building knowledge about the local impacts of climate change in the community. This includes, facilitating a dialogue about. Considering possible ways to prepare, adapt and respond to extreme weather events and a changing climate. Information about climate risk and potential preventive actions needs to be co-produced between technocrats, specialists, and communities, and thereafter disseminated in a clear and appropriate manner and sequence to allow continuous learning for all parties. It is important to note that sometimes a 'solution' to one problem may result in another unintended 'problem' or consequence. For instance, raising pits may be effective for 'climate proofing' toilets against flooding but can result in more difficult access for some community members[201]. Giving communities the opportunity to decide on the most appropriate mechanism/ resilience action, equipping them with various types on knowledge that supports their needs as well as openness to feedback after implementation ultimately improves the efficiency of the measures implemented in the unique and local context.

5.1.2 STRATEGIC VISION

This goal refers to the need of a consistent strategic vision that guides decision making around urban sanitation system. Uncertainty around climate impacts, existing access gaps and service shortcomings, as well as complex service arrangements in urban sanitation systems should not be used as excuse to treat climate resilience of urban sanitation systems as an afterthought. The goal Strategic Vision focuses on the government's role in incorporating CRUS into citywide sanitation planning.

Facilitate long-term strategy development for sustained service delivery that is based on outcomes. To date, planning of urban sanitation provision often follows a technocratic approach that concentrates on infrastructure investments and neglects service outcomes (i.e., sustained service provision)[202]. Climate adaptation of sanitation systems is at risk to follow the same infrastructure-led paradigms[203] which might be an obstacle for inclusive planning and overcoming sector silo thinking. Therefore, actors in the sanitation governance system across disciplines and rigid sector boundaries need to come to a shared vision for long-term goals and priorities for guiding programmes and investments for CRUS.

Incorporate expert and technical knowledge into decision-making around climate resilient urban sanitation. CRUS planning does not only require intersectoral coordination (Section 5.1.3) but also the inclusion of technical experts beyond formal service providers. For instance, including representatives from manual pit emptiers and exhauster truck drivers along with disaster risk, emergency response experts, and climate and meteorological experts into technical working groups could help to better understand the challenges climate change induced hazards have on the emptying and transport part of the decentralised onsite sanitation service chain.

Acknowledge the scattered and unequal distribution of costs and benefits of climate resilient sanitation in decision making. The benefits of sanitation investments are not equally distributed and spatially spread across the household, community, and city-scale[204]. Sanitation has various non-user benefits and protects public and environmental health. The full range of sanitation benefits is notoriously difficult to measure and is often not felt by the direct beneficiary or cost bearer of a sanitation improvement[205, 206]. Climate resilient sanitation adds a temporal scale to the mix. At least part of investments in climate resilient sanitation are investments in future benefits. These facts need to be considered in decision-making on funding schemes and investments in CRUS (Section 5.2).

Box 7

SUPPORTING FAECAL SLUDGE EMPTIERS

Supporting faecal sludge emptiers to organise themselves is a first step to enable them to represent their expertise and experience in decision-making forums. In several countries (e.g., Zambia, Uganda) emptiers have formed associations that enables them to raise awareness for the decentralised onsite sanitation service gap as well as improving their working conditions and legal status.

In February 2019, 19 emptying associations from across the continent created the Pan African Association of Actors for non-sewer Sanitation (PASA).[207]

5.1.3 COORDINATED GOVERNANCE

Climate resilient urban sanitation needs to be understood as part of climate resilient city planning that values multi-stakeholder partnership of public sector, private sector and civil society as articulated in the Agenda 2030 for Sustainable Development and SDG 17. The governance of urban sanitation systems is often fragmented, and roles and responsibilities are insufficiently clearly defined between various actors. Therefore, the goal Coordinate Governance describes the enhanced need for proactive coordination and communication between decision-makers.

Facilitate inter-sectoral coordination, multi-stakeholder partnerships and a citywide approach to sanitation service provision. Climate resilient sanitation systems starts with recognising the need for integrated citywide, interdisciplinary, and inter-sectoral thinking. Urban services are interlinked and there are various interdependencies between urban sanitation systems and other urban services and infrastructures (e.g., drainage, solid waste, energy supply, health, and transport). A multi-stakeholder perspective impels the consideration of mandates, interests, levels of operation and power dynamics amongst different categories of stakeholders. Particularly, it gives momentum to private sector participation, community empowerment and collective leadership. Involving experts from different sectors including disaster and emergency response actors into climate resilient sanitation planning can be a way to identify effective measures not only in terms of prioritising specific neighbourhoods and population groups but also in terms of opening the discussion beyond 'traditional' sanitation interventions.

As an example, an increased risk of urban flooding is one of, if not the most, substantial climate change related hazard associated with the functioning of urban sanitation systems (Section 2.3). Urban flooding is not only a result of heavy rainfalls but also directly linked to urban land-use and infrastructure and people living in urban low-income areas are often especially affected by urban flooding[208]. The vulnerability of low-income communities to flooding is not only caused by low-income settlements being frequently located in areas susceptible to flooding, they also often suffer from a lack of appropriate drainage systems, waste management and other basic infrastructure and services[209]. Depending on the context, 'climate-proofing' latrines might be the obvious, 'traditional' sanitation sector approach for sanitation climate resilience whilst interventions coming from different sectors e.g., improving road drainage systems or introducing a more effective solid waste management systems preventing solid waste blocking existing drainage systems might be equally or even more effective measures

Promote clear stakeholder roles and responsibilities. Unclear service provision mandates and stakeholder roles are one of the most frequently cited 'soft' obstacles to adequate and sustainable sanitation service provision. CRUS requires clearly defined roles and responsibilities among relevant stakeholders including the private sector (see below).

Formalise service provision and include private sector informal service providers in process. Citywide sanitation systems often rely on a mixture of formal and informal service provision. Informal service providers (e.g., manual and mechanical pit and septic tank emptiers) predominantly provide services for onsite sanitation systems and operate outside of the regulatory framework that protects consumers in terms of service quality and costs, and the public health in terms of quality (Section 5.2.1). Formalising services and integrating onsite sanitation services into the service framework is needed to facilitate coordination and preparedness for and during extreme weather events.

5.2 PLANNING AND FINANCE

5.2.1 EFFECTIVE REGULATION AND ACCOUNTABILITY

Clear and enforceable rules and regulations and clearly defined accountabilities help to protect urban communities before, during and after climate related shocks to sanitation systems.

Include onsite sanitation and non-sewered services into regulatory frameworks and particularly introduce formalised tariff structures. Effective regulation protects users of urban sanitation against price curbs and unfair prioritisation of service provision during and after a disaster or shock.

In many countries, however, non-sewered sanitation is still vastly unregulated or regulation is very weak. If not regulated, costs for non-sewered sanitation services e.g., toilet emptying or deblocking can increase in times of high demand for instance during heavy rainfalls, after storm surges and in periods of raised groundwater levels rendering them unaffordable for vulnerable households[211]. ISF-UTS and SNV (2019) cite a study from Bangladesh where users were reported to pay 15 per cent more for emergency toilet emptying.

The Eastern and Southern Africa Water and Sanitation Regulator Association (ESAWAS) recently published Guidelines for Sanitation Service Tariff Setting that explicitly address

Box 8

PRICE GOUGING IN THE WAKE OF AND DURING DISASTERS

In the United States, price gouging in the wake of hurricanes is well documented. In 2004, after Hurricane Harvey killed 22 people and caused USD 11 billion in damage in Florida, there were reports of hugely inflated prices for ice for cooling to cope with power cuts, generators, roof repairs or motel rooms[210].

Particularly at the beginning of the Covid-19 pandemic, lawmakers and governments around the globe were fighting inflated prices for essential hygiene items such as hand sanitisers and personal protection equipment.

the current shortcoming with regards to tariff regulation of non-sewered sanitation and recommends a way forward to include non-sewered sanitation services into the sanitation tariff design[212]. In Zambia, the regulator NWASCO has published the Urban Onsite Sanitation and Faecal Sludge Management: Framework for Provision and Regulation[213] as a first step to develop regulatory tools that close the gap for regulation of onsite sanitation and faecal sludge management (FSM) service provision in Zambia.

Enforcement of design guidelines and construction standards for sanitation infrastructure. In densely populated urban areas, failing sanitation systems can impose environmental and public health risks on community and city scale. In many cities, climate change impacts are likely to exacerbate the risk that poorly designed and constructed urban sanitation systems already pose to the communities. Design guidelines and construction standards need to be appropriate for the local context and where feasible should be developed and implemented with participation of users and local stakeholders. It is important to note that household onsite sanitation infrastructure is mostly financed through household investments. Enforcement of construction standards therefore must not end in punishing those who cannot afford to comply but needs to be accompanied with suitable funding mechanisms (Section 5.2.3). Landlords, contractors, and service providers need to be held accountable including on upholding good practices in preventive maintenance.

Identify regulatory obstacles to innovative technology and service approaches. Cities should review the regulatory frameworks for sanitation and identify if there are any obstacles for the application of innovative sanitation technologies[214] that could be more climate resilient in a specific context such as (raised) composting toilets, CBS systems or decentralised wastewater and faecal sludge treatment.

Collect and disseminate accurate data on sanitation coverage and service levels. In many cities the understanding of the current sanitation situation is limited. Particularly, for onsite sanitation there is often limited data available and the data that is available is often focussed on coverage but not service outcomes. Poor understanding of existing bottlenecks and vulnerabilities, combined with a lack of monitoring and early warning systems makes it difficult for service providers and city-planners to adequately respond before, during and after an extreme weather event[215]. Going through the process of developing an Excreta Flow Diagram (SFD) enables stakeholders to think about the sanitation situation from a citywide and outcome focussed perspective and are useful to illustrate and communicate bottlenecks in the service chain.[216]

5.2.2 ADAPTIVE AND INTEGRATED PLANNING

The goal adaptive and integrated planning refers to strategies for citywide sanitation programme and project coordination with the aim to adapt sanitation systems to a changing climate. There are distinct overlaps with the goal Effective Asset Management (Section 5.3.2) and Coordinated Governance (Section 5.1.3).

Active monitoring and evaluation of programmes and learning from local, regional, and global experience. Understanding local climate change related hazards to sanitation systems from a citywide perspective and considering social distribution of effects[218] enables sanitation and

Box 9

LINKING TOILET MAPPING TO EMPTYING SERVICES IN LUSAKA, ZAMBIA

In Lusaka, Lusaka City Council (LCC) and Lusaka Water Supply and Sanitation Company (LWSC) with support from GIZ and Water and Sanitation for the Urban Poor (WSUP) implemented a toilet mapping of onsite facilities in the peri-urban area of Kanyama.

With the support of WSUP, the data was used to schedule pit emptying services by the Kanyama and Chazanga Water Trusts, community-based organisations providing FSM services on behalf of LWSC through a delegated management arrangement.

Government subsidised pit emptying prior to the rainy season was tried in 2017 as a way to mitigate cholera outbreaks[217]. Further research is still required to confirm if scheduled emptying is an effective measure to reduce the outbreaks of disease prior to or during a flood event.

city planners to adapt to changes. Learning from local, regional and global experiences of climate adaptability of sanitation infrastructure bears the opportunity to adopt more resilience and robust options in cities and neighbourhoods that are do not already have a high degree of infrastructure lock-in[219]. Sanitation systems in cities in Low- and middle-income countries (LMICs) often involve less fixed infrastructure and more non-fixed assets. Since retrofitting of infrastructure often comes at very high costs this more flexible set-up might come with the opportunity to implement robust strategies (e.g., separated sewer systems, nature-based solutions) that would not be feasible in areas with existing infrastructure, achieving multiple goals and consider the interconnection between sanitation and other urban sectors.[220]

Integrated planning across inter-dependent urban systems. The interdependence of urban sanitation systems with other critical infrastructure and services is emphasised throughout this proposed framework. Active cooperation and information sharing other sector agencies (e.g., water, solid waste management, transport) on infrastructure and service planning (Section 5.1.3) and land-use plans can reduce disruptions to urban sanitation systems[221]. As a rule of thumb, onsite sanitation is vulnerable to disruptions of the transport network, which is vulnerable to flooding and offsite sanitation is (mainly) vulnerable to the disruptions of the water and electricity network, which is vulnerable to drought and flooding. Both, onsite and offsite sanitation systems have considerable impacts on public health.

Promote flexible and robust solutions to deal with uncertainty. The complexity and remaining uncertainty around local climate projections threatens to paralyse planning for resilience. The complexity of climate adaptive planning processes can be reduced by using tools such as Climate Risk Narratives (CRNs) which break down complicated climate model projections into "quasi-quantitative climate scenarios"[222]. As there remains uncertainty about the actual effects of climate change on regional weather planning for varied climate scenarios (e.g., the CRNs for urban Eastern Africa includes both, wetter and drier conditions[223] prevents maladaptation).[224]

Outcome-based citywide approach to planning. No sanitation technology performs well under all potential future climate hazards[225]. The resilience of sanitation solutions to future climate changes will be context specific. Adaptive planning therefore needs to adopt an outcome-based approach adapted to the locally expected climate related hazards. Information about the resilience of various sanitation technologies under different climate change scenarios is available (see Box 10) but the differential vulnerabilities and adaption capacities amongst urban sanitation users' needs to be considered (Section 5.1.1).

5.2.3 SUSTAINABLE FUNDING AND FINANCE

Plan for adequate operation and maintenance (O&M) costs. Climate change impacts and adaptive management might increase the O&M costs of sanitation assets[226]. In LMICs water and sanitation tariffs do not cover the full costs of appropriate O&M of water and sanitation services

Box 10

SELECTION OF RESOURCES SUMMARISING THE RESILIENCE AND ADAPTABILITY OF SANITATION TECHNOLOGIES

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and therefore put the service quality and coverage levels at risk of decline even under the current climate conditions[227]. Cities and service providers need to reflect increasing costs for preventive maintenance, repairs, and replacement to adapt and cope with climate hazards to sanitation infrastructure or risk to fall behind with reaching the global sanitation access targets.

Rethink sanitation funding and subsidies. Current funding arrangements for urban sanitation are biased towards subsidising offsite sanitation. In many cities in LMIC small proportions of the population are served by sewerage at a considerable costs for the public (investment costs and often also partially subsidised O&M costs where tariffs are not fully cost-recovering) whereas the larger part of the population relies on self-funded on-site sanitation systems[228]. Public funding of climate resilient urban sanitation needs to acknowledge that there might be communities in the cities that face high climate risk exposure but have low adaptive capacity and might not be able to afford measures to improve the resilience of their sanitation. For vulnerable communities, additional support such as infrastructure and service subsidies are required[229]. Such subsidies can be financed through cross-subsidies in the tariff scheme, sanitation surcharges, general taxes, donor contribution and potentially tapping into climate finance (Section 4.2.2).

→ **In Peru, the 2016 Sanitation Sector Reform Law obliges water and wastewater utilities to earmark a proportion of their revenue from water tariffs for watershed conservation and climate change adaptation measures.[230]** ←

Address obstacles that prevent long-term planning and funding. There are structural constraints in the way government allocate funding and distribute budget to competing priorities. As a result, long-term strategic investments such as engineering for resilience of sanitation systems are often not in line with short-term budget cycles[231].

5.3 INFRASTRUCTURE AND SERVICE PROVISION

5.3.1 EFFECTIVE DISASTER RESPONSE AND RECOVERY

Climate change induced disasters and extreme weather events will affect the functioning of sanitation systems but not sanitation systems in isolation. The City Water Resilience Approach (CWRA)[232] lists under the goal Effective Disaster Response and Recovery good practices that cities should embrace to be able to respond quickly and efficiently to minimise the impact of disaster. These practices maintain their validity for the sanitation sector. To avoid repetition the below listed actions are examples for specific sanitation disaster responses and which need to be understood as specific elements of comprehensive disaster response frameworks.

Establish warning systems and build capacity amongst operators and communities how to minimise risks. Effective monitoring and early warning systems give operators and users of sanitation systems time to prepare to impending extreme weather events such as flooding, cyclones, droughts amongst others[233]. Operators and users of sanitation systems, however, do not only need warning but also the specific knowledge how to minimise risk during and after extreme climate events. Timely start of household water saving measures during dry periods and household water treatment after flooding event are examples how households can reduce the risk of infrastructure failures and health impacts. Operators of sewer and wastewater treatment facilities need to know when to open or close valves to minimise environmental contamination due to overflow and discharge of raw sewage[234]. Households and onsite sanitation service providers should also be made aware of negative actions that increase sanitation related risk for the community during extreme weather events. For instance, in Dar-es-Salaam, pit latrine users have been reported to haphazardly 'drain' their toilets into run-off water during heavy rainfall events as a cost-efficient emptying method.[235]

Coordinate monitoring, warning systems and disaster response with other sectors. Sharing information and coordination with other sectors whose operation and infrastructure affect or are affected by sanitation systems (e.g., overflowing sewers affect roads and transport systems whilst electricity failures can cause disruptions of sewer pumps and treatment processes leading to overflows – and hence again potential damages to the transport sector - and environmental pollution and potential public health risks) increases the efficiency of disaster response and recovery.[236]

Adapt disaster response to different needs of urban communities. Targeted measures to improve the understanding and monitoring of the effects of climate related events on safe sanitation for different urban communities and service delivery frameworks - e.g., through disaggregated data protocols – can improve the efficiency of the disaster response.[237]

5.3.2 EFFECTIVE ASSET MANAGEMENT

Enable active monitoring and evaluation of sanitation assets. Data on sanitation systems is often weak (Section 4.2.1). Even for offsite sanitation that is run by public utilities network plans and asset registers of sanitation systems are often out-of-date or incomplete. Introducing more active monitoring measures such as flow monitoring could enable better management of infrastructure and prevent contamination from sewer overflows.[238]

Carry out routine maintenance and upgrading of sanitation infrastructure. Regular preventive maintenance of sanitation systems such as deblocking and leakage repairs of sewers and drains or regular desludging of onsite systems can prevent systems from failure during extreme weather events and reduce public health risks through contamination of urban spaces.

Ensure adequately trained human resources for operation and (adaptive) management. A crucial aspect of operational resilience is the ability of service providers to operate and maintain their infrastructure and assets, to avoid, cope with and recover from disruptions[239]. This requires an adequate number of effectively skilled and trained staff. Sanitation operators often lack full knowledge of the system's capacity to endure shocks and stresses and how to adapt the system to changing conditions. Building knowledge of operators about appropriate operation and management under current and future climate conditions is part of the foundation for adaptive management.[240]

Ensure reliable supply chains for O&M of sanitation infrastructure. Supply chains for critical equipment, chemicals and other materials needed for preventive maintenance, operation and repairs need to be robust against shocks[241]. Reliable supply chains for personal protective equipment are crucial to protect the health of staff.

5.4 ENVIRONMENT AND HEALTH

5.4.1 HEALTHY URBAN COMMUNITIES AND PROTECTED NATURAL ENVIRONMENTS

Promote nature-based solutions and integrating green and grey infrastructure where suitable. Nature-based solutions or integrated grey-green infrastructure is suggested to be a cost-effective approach for climate resilient cities[242]. Nature-based solutions are promoted as multi-benefit infrastructure that does not only fulfil its core purpose (e.g., flood protection) but also provide multiple co-benefits such as reduction of air pollution, recreational spaces, or wildlife habitats[243]. In the context of sanitation, nature-based solutions mainly play a role as part of treatment facilities (constructed wetlands) or stormwater retention and flood protection measures.[244]

Protection of groundwater and surface water resources. Climate resilient urban sanitation systems can protect groundwater and surface water resources through adaptive management as well as through increasing the resilience of infrastructure. During droughts, the reduced runoff of rivers receiving effluent from wastewater treatment plants decreases the dilution and therefore increase the contamination load in these rivers. Changes in treatment operation and/or warnings to downstream users protect environmental and public health. Effective water resource monitoring systems are needed to enable cities to adapt appropriate strategies[245]. Extreme or prolonged rainfall can cause failures of the urban sewer and drainage networks. Stormwater, sewage and industrial rainwater overwhelm the cities drainage and treatment systems and cause sewer overflows and backups causing contamination in homes, communities and the environment. Grey (retention tanks) or green infrastructure (e.g., green roofs, permeable pavements, constructed wetlands) can contribute to mitigate urban flooding.[246]

Reduce contribution of urban sanitation to GHG emissions. Some climate resilient urban sanitation infrastructure has the potential to reduce contribution of sanitation systems to greenhouse gas emissions. For example, decentralised treatment plants that do not require electricity for aeration or pumping are more resilient against power outages and have

Box 11

POTENTIAL COST SAVINGS THROUGH NATURAL INFRASTRUCTURE

A study for a storm drainage retrofit project for the City of Los Angeles suggested that the project could potentially be between 6 and 18 times cheaper if it were to use natural infrastructure than when done with traditional grey infrastructure[247].

a lower energy consumption and thus a lower energy related carbon footprint[248]. Reducing water requirements of water-based sanitation systems increases their resilience to droughts and decreases the emissions related to water treatment[249]. Using human waste as fertiliser, processed to briquettes as charcoal replacement or for the generation of biogas for energy are other ways to reduce emissions and thus contribute to mitigation targets[250]. However, the lifecycle net GHG emissions associated with different wastewater and faecal sludge management and treatment facilities depend on multiple factors and more research is needed to understand the mitigation potential of different sanitation types.[251]

5.4.2 EQUITABLE SERVICE PROVISION

Access to sanitation is a human right. Climate resilient sanitation services need to have a strong equity focus and recognise the different capabilities of people to cope with a changed reality.

Promote equitable and inclusive climate resilient sanitation planning. Climate change related hazards are likely to exacerbate inequalities[252]. Equity and inclusion need to be actively in the centre of resilient sanitation planning to avoid exclusion of vulnerable communities. Climate resilient sanitation must go beyond 'bouncing-back' to avoid reproduction and deepening of existing inequalities.[253]

Ensure universal affordability of sanitation services. Whilst tariffs for water and sanitation services need to be cost recovering and account for potentially increasing O&M costs (Section 5.2.3) climate resilient sanitation services must be affordable for all population groups. Pro-poor tariff design and infrastructure subsidies need to be designed with participation from community and service provider representatives.

Above: Wastewater treatment facility

6 AN ASSESSMENT TOOL FOR URBAN SANITATION RESILIENCE

One of the key gaps of CRUS is the lack of metrics (Section 4.1.2). To address this, it is proposed that an approach and relevant tool(s) should be developed to support the process of assessing the resilience of and improving decision-making for sanitation systems and services. This chapter makes a strawman proposal[o] for the future development of such an approach.

Several approaches and tools have been developed for the assessment of water resilience, including the UNESCO-developed Climate Risk Informed Decision Analysis (CRIDA)[p], and the Arup-developed CWRA. Due to its focus on and relevance to cities, this report has leaned on and borrowed from the CWRA, encouraging alignment with this existing and comprehensive urban framework, allowing for improved integration, and thus avoiding 're-inventing the wheel'. The CWRA is guided by five steps, which are:

1. understanding the system,
2. assessing urban water resilience,
3. developing an action plan,
4. implementing the action plan, and
5. evaluating, learning, and adapting.

The chapter starts by proposing guidelines for adapting these first two steps, followed by the proposed approach to developing them and the respective tool(s). To differentiate it from the CWRA, it is proposed that this approach be referred to as the City Sanitation Resilience Approach (CSRA). The remaining three steps of the CWRA can be applied as is for the CSRA.

6.1 GUIDELINES

It is proposed that the same guiding qualities used in the CWRA be adapted and utilised in developing the proposed CRSA and its respective resources and tools, which are:

1. **Practical:** Any new resources should be low-cost in terms of the time and resources required of users, and the level of technological sophistication. Furthermore, tools already widely used in either sanitation planning or climate resilience should be considered. It is important to ask: how would these tools relate to the proposed approach and tools, and would it be easier to adapt an existing and widely used tool than develop a new one?
2. **Flexible:** Resources should be designed for use and input by a wide range of stakeholders[q], and should allow for flexible approaches to allow for application in diverse contexts.
3. **Consistent:** While resources and approaches should be flexible, this should be balanced with a consistent view of the goals. This is critical in supporting integration and avoiding the continued silos (Section 4.1.1).

o A strawman proposal refers to the starting point of a structured process of brainstorming and creative problem-solving to achieving a collaborative solution.
p https://agwaguide.org/about/CRIDA/
q For example, government, inter-governmental organisations, development banks, utilities, academia, NGOs, civil society, and the private sector

6.2 STEP 1: UNDERSTANDING THE SYSTEM

The objective of the first step of CSRA is to develop a common understanding of the existing infrastructure and governance processes within the sanitation system, and to map relationships between stakeholders throughout it, thereby creating a *City Sanitation Characterisation Report*.

Tools within the sanitation sector already exist to do just that, including the SFD and stakeholder mapping and analysis[254]. A mapping of other sanitation and resilience tools and resources is required to identify gaps and overlaps, and the potential need for adapting them. Potential additional tools or guidelines may be required for the following:

1. climate data at city level,
2. shocks and stresses at city level, and
3. mapping of the interdependence of urban systems with sanitation (e.g., transport, drainage, solid waste, water, etc.).

6.3 STEP 2: ASSESSING URBAN SANITATION RESILIENCE

It is proposed that the second step of the CSRA assess urban sanitation resilience by undertaking the following activities, in line with the CWRA:

1. research and data collection for the assessment process,
2. assessment process using the framework for CRUS (as proposed in Chapter 5 of this report),
3. diagnosis and sanitation resilience profile report (City Sanitation Resilience Profile),
4. visioning exercise and validation workshop.

As in Step 1, certain tools already exist and are widely applied in the sanitation and resilience[r] sectors that may support these activities. As such, an initial stocktaking exercise of existing city-level tools should be considered to identify gaps, overlaps, and potential opportunities for adaptation. One of the tools that could be considered is the City Service Delivery Assessment (CSDA), which has recently been adapted to bring it in line with CWIS principles, particularly on strengthening its ability to assess 'inclusion'[255]. Another resource is the Sanitation Safety Planning guideline developed by the WHO, which is mainly structured to consider health risks across the sanitation chain.[256]

Based on a general understanding of the existing tools, our recommendation is to consider the adaptability of the CSDA to include resilience as a cross-cutting theme (as was done for 'inclusion') and to strengthen its assessment of the integration of sanitation with other sectors (e.g., transport, drainage, solid waste, water, etc.). The key building blocks of the CSDA are summarised in Table 4.

Table 4. The building blocks of the CSDA[257]

Enabling	Delivering	Sustaining
Policy and legislation Planning and finance Inclusion	Finance Capacity and outreach Inclusion	Regulation and revenue Institutions and providers Inclusion

r For instance, (i) WRI's Urban Community Resilience Assessment, (ii) climate risk mapping, and (iii) CRNs from (Burgin, Rowell, & Marsham, 2020; Evans, Rowell, & Semazzi, 2020).

Another resource that needs to be developed is the CRUS framework; a global and coherent vision of what drives sanitation resilience needs to be agreed (i.e., the dimensions, goals and subgoals). A multi-step consultation process is proposed, whereby multiple cities and their key stakeholders (e.g., ministries, regulators, service providers, development partners, etc.) are engaged until that coherent vision is achieved. The framework proposed in Chapter 5 and summarised in Table 5 below could provide a starting point for those discussions.

Table 1. CRUS framework proposed as a starting point for discussions

Dimension	Goal
1. Leadership and Strategy	1.1 Create empowered communities 1.2 Strategic vision 1.3 Coordinated governance
2. Planning and Finance	2.1 Effective regulation and accountability 2.2 Adaptive and integrated planning 2.3 Sustainable funding and finance
3. Infrastructure and Service Provision	3.1 Effective disaster resource and recovery 3.2 Effective asset management
4. Environment and Health	4.1 Healthy urban communities and protected natural environments 4.2 Equitable service provision

7 CONCLUSION

There is no blueprint for achieving climate resilience for urban sanitation systems. Climate change manifests itself differently around the globe, and cities start from different levels of preparedness and capacities when facing related challenges. It is not just (sanitation) infrastructure that must be resilient to shocks and long-term stresses, but also the interconnected social, institutional, and physical systems.

'Resilience is not an end state; it's a journey.'

The current and future needs of urban populations are at the centre of a vulnerability-led perspective to resilience. Cities and the people living in them will start the journey to resilience at different starting points. Moving towards CRUS begins with improving sanitation systems' resilience to current climate variabilities; therefore, current bottlenecks of infrastructure, service provision and funding need to be addressed. How to ensure that everybody has access to safely managed sanitation services is one of the most pressing and urgent conversations we need to have as it is directly linked to quality of life of vulnerable communities and that of future generations.

Climate change is likely to exacerbate the current inequalities of urban sanitation provision. Resilience measures that do not adequately consider inclusiveness run the risk of reproducing or deepening inequalities. Providing suitable platforms for feedback from all urban communities, particularly those that are commonly underrepresented, is part of adaptive planning. Understanding urban sanitation systems beyond coverage aspects and establishing adequate monitoring, warning, and response mechanisms is essential.

Climate-proofing or adapting sanitation infrastructure to changing conditions is only one piece of the puzzle. Hardware is essential – failing hardware can have dramatic impacts on people's health and livelihoods. However, without ignoring the importance of well-functioning sanitation hardware, building the resilience of the entire sanitation system, including service provision and governance frameworks is critical to ensure the performance of the entire sanitation chain.

Climate change is blind to sectoral silos – resilience planning needs to take interdependencies of urban infrastructure and services into account. Taking a citywide and intersectoral approach through integration and coordination is critical – sector barriers and silos are likely to be the biggest threats to building climate resilience for sanitation. Understanding and actively cooperating with interdependent services and infrastructure sectors is crucial.

'...sector barriers and silos are likely to be the biggest threats to building climate resilience for sanitation.'

Resilience needs to become one of the foundations of sanitation planning, without allowing uncertainties around localised climate change impacts to paralyse the process. Most sanitation planning processes pay lip service to climate change, making it an afterthought for most planners. Given the uncertainties surrounding localised climate change effects and the specific impacts on sanitation systems, climate resilient sanitation planning should be 'robust to uncertainty' by being appropriate to a range of different likely climate scenarios. Multiple-barrier approaches and redundancies in the system are ways to cope with uncertainty around the hazard types and magnitudes. However, the costs, hardware, and service requirements for such approaches will not always be viable and justifiable. Decentralisation of sanitation systems is one way to create redundancy and increase resilience but might not be feasible and appropriate in every context.

Mitigation is a key and non-negotiable co-benefit of climate resilient urban sanitation systems. Although more detailed research into quantifying global contributions of both sewered and non-sewered sanitation systems is needed, there is no doubt that sanitation systems contribute considerably to global GHG emission. However, considering the more immediate threat to human health and livelihoods from sanitation failures after and during extreme weather events and the persistent sanitation crisis in many countries in the developing world, resilience should be the key driver for investments in climate resilient sanitation in countries with low levels of access to safely managed sanitation.

'...resilience should be the key driver for investments in climate resilient sanitation in countries with low levels of access to safely managed sanitation'

Integration of climate resilience into sanitation system planning should be a continually evolving process and must be adaptable to the changing risks, vulnerabilities, and capacities of the urban populations. As such, integrating climate resilience into national plans (e.g., national WASH strategies) is not an endpoint. A further challenge will be to incorporate climate resilience into subsequent government programmes and implementation actions. Funding, clear mandates and climate resilience technical capacities must also be strengthened to support this.

Dodging the bill for climate resilient sanitation systems is not a sustainable option. In the light of the funding gap for reaching the SDGs on sanitation, adding climate resilience could easily be discredited as "another costly extra". Whilst it is widely accepted that climate resilience will add costs to infrastructure planning, the importance of quantifying the cost of 'do-nothing' cannot be understated. This approach has been used effectively to drive change and investment in the sanitation sector by highlighting the annual losses from poor access to sanitation. Such an approach could also address the limited awareness of the linkages between sanitation and climate change and the adaptation and mitigation opportunities, albeit the complexity of estimating the marginal costs of and benefits of climate resilience of urban sanitation system needs to be noted. Due to the already limited financing available for the sanitation sector to achieve the SDGs, investment in climate resilience should focus on countries that are likely to face the most significant impact, and the most limited access to domestic finance.

'...the importance of quantifying the cost of 'do-nothing' cannot be understated.'

Above: Aerial view of Santa Cruz de la Sierra, Bolivia

ACRONYMS

BMZ	Germany's Federal Ministry for Economic Cooperation and Development
CBS	Container-Based Sanitation
CCT	City of Cape Town
CH_4	Methane
CMWSSB	Chennai Metropolitan Water Supply and Sewerage Board
CO_2	Carbon Dioxide
CRIDA	Climate Risk Information Decision Analysis
CRNs	Climate Risk Narratives
CRUS	Climate Resilient Urban Sanitation
CSDA	City Service Delivery Assessment
CSRA	Climate Sanitation Resilience Approach
CWIS	Citywide Inclusive Sanitation
CWRA	City Water Resilience Approach
CWRF	City Water Resilience Framework
DEWATS	Decentralised Wastewater Treatment Systems
ECAM	Energy Performance and Carbon Emissions Assessment and Monitoring Tool
ESI	Economics of Sanitation Initiative
FSM	Faecal Sludge Management
GCC	Greater Chennai Corporation
GCF	Green Climate Fund
GEF	Global Environmental Facility
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
HBRA	Human Rights-Based Approach
IWRM	Integrated Water Resource Management
JMP	Joint Monitoring Program
LCC	Lusaka City Council
LMIC	Low- and Middle-Income Country
LWSC	Lusaka Water Supply and Sanitation Company
MDG	Millennium Development Goal
N_2O	Nitrogen Oxide
NAP	National Adaptation Plan
NAPA	National Adaptation Programme of Action
NCs	National Communications
NDCs	Nationally Determined Contributions
NWASCO	National Water and Sanitation Council of Zambia
PPP	Public Private Partnership
R-Cities	Resilient Cities Network
SAGUAPAC	Cooperative de Servicios Públicos de Santa Cruz Ltda
SDG	Sustainable Development Goal
SFD	Excreta Flow Diagram
SuSanA	Sustainable Sanitation Alliance
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollars
WASH	Water, sanitation, and hygiene

ANNEXES

ANNEX A: GLOSSARY

Acute shock	Sudden, intense events that threaten a community, such as earthquakes, hurricanes, fires, floods, disease outbreaks, infrastructure failure, and landslides.[258, 259]
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.[260]
Basic sanitation	'Improved sanitation' facilities that are not shared with other households, i.e., are private[261]
Capacity	A combination of all the strengths and resources available within a community, society or organization that can reduce the level of risk, or the effects of a disaster[262]. It may include physical, institutional, social, or economic means as well as skilled personal or collective attributes such as leadership and management. Capacity may also be described as capability.[263]
Chronic stress	Chronic events that weaken the fabric of a community on a day-to-day or cyclical basis over time, such as water scarcity, recurrent flooding, high unemployment, inadequate public transport systems, endemic violence, food insecurity, substance abuse, and limited social safety nets.[264,265]
Climate Adaptation	Adjustments in ecological, social, or economic systems to reduce their vulnerability to climate change. In the case of sanitation, this could include constructing flood-proof latrines.[266]
Climate change	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.[267]
Climate mitigation	Efforts to reduce future climate changes, for example, reducing emissions and expanding carbon sinks, such as forests.[268]
Climate resilience	The capacity of social, economic, and environmental systems to cope with an acute shock or chronic stress, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning and transformation.[269]
Climate Resilient Urban Sanitation	The capacity of the sanitation system to survive, adapt, and function in the face of climate-related chronic stresses and acute shocks.
Exposure	The state of people, property or systems having no or limited protection from hazards, potentially resulting in adverse effects or potential losses.[270]

Flexible	**One of the 7 qualities of resilient systems**. Flexibility implies that systems can change, evolve, and adapt in response to changing circumstances. This may favour decentralised and modular approaches to infrastructure or ecosystem management. Flexibility can be achieved through the introduction of new knowledge and technologies, as needed. It also means considering and incorporating indigenous or traditional knowledge and practices in new ways.[271]
Global warming	An increase in combined surface air and sea surface temperatures averaged over the globe and over a 30-year period.[272]
Green Infrastructure	The interconnected set of natural and constructed ecological systems, green spaces, and other landscape features. It includes planted and indigenous trees, wetlands, parks, green open spaces and original grassland and woodlands, as well as possible building and street-level design interventions that incorporate vegetation. Green infrastructure provides services and functions in the same way as conventional infrastructure.[273]
Grey Infrastructure	Conventional engineering structures such as dams, seawalls, roads, pipes, or water treatment plants.[274]
Hazard	A dangerous phenomenon, substance, human activity, or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.[275]
Improved Sanitation	Facilities which are designed to hygienically separate excreta from human contact, including a handwashing facility with soap and water.[276]
Inclusive	**One of the 7 qualities of resilient systems.** Inclusion emphasises the need for broad consultation and engagement of communities, including the most vulnerable groups. An inclusive approach contributes to a sense of shared ownership or a joint vision to build city resilience.[277]
Integration	**One of the 7 qualities of resilient systems.** Integration and alignment between city systems promotes consistency in decision-making and ensures that all investments are mutually supportive to a common outcome. Exchange of information between systems enables them to function collectively and respond rapidly through shorter feedback loops throughout the city.[278]
Limited Sanitation	'Improved sanitation' facilities shared between two or more households.[279]
Nationally Determined Contributions	National climate plans highlighting climate actions, including climate related targets, policies and measures governments aims to implement in response to climate change and as a contribution to global climate action.[280]
Nature-based Solutions	Actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.[281]
Offsite Sanitation	A sanitation system in which excreta and wastewater are collected and conveyed away from the plot where they are generated. An offsite sanitation system relies on a sewer technology for conveyance.[282]

Onsite Sanitation	A sanitation system in which excreta and wastewater are collected and stored or treated on the plot where they are generated.[283]
Open Defecation	Disposal of human faeces in fields, forests, bushes, open bodies of water, beaches, or other open spaces, or with solid waste.[284]
Reflective	**One of the 7 qualities of resilient systems.** Reflective systems are accepting of the inherent and ever-increasing uncertainty and change in today's world. They have mechanisms to continuously evolve and will modify standards or norms based on emerging evidence, rather than seeking permanent solutions based on the status quo. As a result, people and institutions examine and systematically learn from their past experiences and leverage this learning to inform future decision-making.[285]
Redundant	**One of the 7 qualities of resilient systems.** Redundancy refers to spare capacity purposely created within systems so that they can accommodate disruption, extreme pressures, or surges in demand. It includes diversity: the presence of multiple ways to achieve a given need or fulfil a particular function. Redundancies should be intentional, cost-effective, and prioritised at a city-wide scale, and should not be an externality of inefficient design.[286]
Resilience	The ability of a system and its component parts to **anticipate, absorb, accommodate**, or **recover** from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.[287] The ability of a system, community or society exposed to hazards to **resist, absorb, accommodate, adapt to, transform**, and **recover** from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.[288]
Resourceful	**One of the 7 qualities of resilient systems.** Resourcefulness implies that people and institutions can rapidly find different ways to achieve their goals or meet their needs during a shock or when under stress. This may include investing in capacity to anticipate future conditions, set priorities, and respond.[289]
Robust	**One of the 7 qualities of resilient systems.** Robust systems include well-conceived, constructed, and managed physical assets, so that they can withstand the impacts of hazard events without significant damage or loss of function. Robust design anticipates potential failures in systems, making provision to ensure failure is predictable, safe, and not disproportionate to the cause.[290]
Safely Managed Sanitation	'Improved sanitation' facilities that are not shared with other households and where excreta are safely disposed of in situ or transported and treated offsite.[291]
Sanitation	Safe disposal of human excreta. The phrase "safe disposal" implies not only that people must excrete hygienically but also that their excreta must be contained or treated to avoid adversely affecting their health or that of other people.[292]

Sanitation Service Chain or Sanitation Chain	A context-specific series of technologies (or hardware), infrastructure and services for the management of human excreta and wastewater, for their collection, containment, transport (also referred to as conveyance), transformation (also referred to as treatment), utilisation (also referred to as reuse) or disposal (adapted from (Tilley, et al., 2014)).
Sanitation System	Includes the sanitation service chain, the 'enabling environment' within which the sanitation chain operates (i.e., institutional arrangements and coordination, monitoring, planning, financing, regulation and accountability, environment, learning and adaptation), and the capacity of actors and their inter-relationships.
Systems Strengthening	Part of taking a 'systems approach' and is a means to an end. It involves taking actions and supporting interventions that are considered likely to strengthen one or more elements of a system including both the factors (institutional arrangements and coordination, service delivery infrastructure, monitoring, planning, financing, regulation and accountability, water resources and environment, learning and adaptation), as well as capacity of actors and their inter-relationships (i.e. political economy of decision-making, incentives and dynamics) to improve quality and sustainability of WASH services and ensure that all populations are served. Many organisations engaged in systems strengthening have developed their own framework of factors or system building blocks to guide their work. It is important to note that there is no globally agreed list of sector building blocks.[293]
Unimproved Sanitation	Use of pit latrines without a slab or platform, hanging latrines or bucket latrines.[294]
Urban Heat Island Effect	Urbanized areas that experience higher temperatures than outlying areas due to concentrated urban structures such as buildings, roads, and other infrastructure that absorb and re-emit the sun's heat more than natural landscapes such as forests and water bodies.[295]
Urban Resilience	The capacity of individuals, communities, institutions, businesses, and systems within a city to **survive, adapt**, and **grow** no matter what kinds of chronic stresses and acute shocks they experience.[296]
Vulnerability	The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors.[297]
Water Scarcity	Lack of access to adequate quantities of water for human and environmental uses due to the failure of appropriate management (e.g., significant losses, contamination, etc.) and / or adequate infrastructure.[298,299]

ANNEX B: THE SUSTAINABLE DEVELOPMENT GOALS

This annex provides an extract of the SDGs and their respective targets, specifically those which relate to this study.[300]

SDG6	**ENSURE AVAILABILITY AND SUSTAINABLE MANAGEMENT OF WATER AND SANITATION FOR ALL**
Target 6.1	By 2030, achieve universal and equitable access to safe and affordable **drinking water** for all.
Target 6.2	By 2030, achieve access to adequate and equitable **sanitation** and **hygiene** for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.
Target 6.3	By 2030, improve **water quality** by reducing pollution, eliminating dumping, and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally.
Target 6.4	By 2030, substantially increase **water-use efficiency** across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.
Target 6.5	By 2030, implement **integrated water resources management** at all levels, including through transboundary cooperation as appropriate.
Target 6.6	By 2020, protect and restore **water-related ecosystems**, including mountains, forests, wetlands, rivers, aquifers, and lakes.
Target 6.a	By 2030, expand **international cooperation** and **capacity-building support** to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
Target 6.b	Support and strengthen the **participation of local communities** in improving water and sanitation management.
SDG11	**MAKE CITIES AND HUMAN SETTLEMENTS INCLUSIVE, SAFE, RESILIENT, AND SUSTAINABLE**
Target 11.1	**By 2030, ensure access for all to adequate, safe, and affordable housing and basic services and upgrade slums**
Target 11.2	By 2030, provide access to safe, affordable, accessible, and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons
Target 11.3	**By 2030, enhance inclusive and sustainable urbanisation and capacity for participatory, integrated, and sustainable human settlement planning and management in all countries**

Target 11.4	Strengthen efforts to protect and safeguard the world's cultural and natural heritage
Target 11.5	**By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations**
Target 11.6	**By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management**
Target 11.7	By 2030, provide universal access to safe, inclusive, and accessible, green, and public spaces, in particular for women and children, older persons and persons with disabilities
Target 11.a	Support positive economic, social, and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning
Target 11.b	**By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels**
Target 11.c	Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials
SDG13	**TAKE URGENT ACTION TO COMBAT CLIMATE CHANGE AND ITS IMPACTS**
Target 13.1	**Strengthen resilience and adaptive capacity** to climate-related hazards and natural disasters in all countries
Target 13.2	Integrate climate change measures into national **policies, strategies, and planning**
Target 13.3	Improve **education, awareness-raising and human and institutional capacity** on climate change mitigation, adaptation, impact reduction and early warning
Target 13.a	Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of **mobilizing jointly $100 billion annually** by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible
Target 13.b	Promote **mechanisms for raising capacity** for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth, and local and marginalized communities

ANNEX C: CASE STUDY INTERVIEWEES

City	Organisation	Interviewee	Position
Cape Town	City of Cape Town (CCT)	Amy Davidson	Head: Climate Change
Cape Town	City of Cape Town (CCT)	Gareth Morgan	Director: Resilience
Cape Town	City of Cape Town (CCT)	Mogamat Armeen Mallick	Water and Sanitation Department, Operations and Maintenance
Cape Town	Green Cape	Claire Pengelly	Water and Agriculture Programme Manager
Chennai	Chennai Metro Water (CMWSSB)	M R Jaishankar	
Chennai	ETH Zurich	Abishek S. Narayan	Water and Sanitation for Development and Humanitarian Aid Researcher
Chennai	Greater Chennai Corporation (GCC)	Ashok Natarajan	Founder Stead-Taps Consulting Private Ltd.
Chennai	Indian Institute of Human Settlement (IIHS)	Santhosh Raghavan	Senior Specialist – Engineering, Planning and Implementation Support
Chennai	Indian Institute of Technology (IIT) Madras	Phillip Ligy	Professor
Chennai	Resilient Chennai	Krishna Mohan Ramachandran	Chief Resilience Officer
Chennai	Tamil Nadu State Planning Commission	Sheela Nair	Former Vice President
Lusaka	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH	Amanda Mallaghan	Advisor
Lusaka	Lusaka City Council (LCC)	Bwalya Funga	Senior Settlement Officer
Lusaka	Lusaka Water Supply and Sanitation Company (LWSC)	Mwansa Nachula Mukuka	Sanitation Specialist
Lusaka	National Water Supply and Sanitation Council (NWASCO)	Chola Mbilima	Commercial and Financial Inspector
Santa Cruz	Asociacion de empresas de Limpieza y tratamiento de aguas residuals y lodoa (ADELTAR)	Marco S. Salinas	President
Santa Cruz	Departmental Government of Santa Cruz	Carina Castro	Climate Change Coordinator
Santa Cruz	Departmental Government of Santa Cruz	Erica Plata	Head of the Secretariat for Sustainable Development and Environment
Santa Cruz	Integration	Carlos Gongora	Water Resource Coordinator
Santa Cruz	Integration	Humberto Cáceres Magnus	Sanitation Coordinator
Santa Cruz	Integration	Ronald Pasig	Team Leader
Santa Cruz	SAGUAPAC Water Cooperative of Santa Cruz	Jose Daniel Medrano	Planning Coordinator
Santa Cruz	Santa Cruz Regional Government	Cinthia Asin	Secretary of Sustainable Development and Environment
Santa Cruz	Independent	Ivy Beltran	Climate Change Expert

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