TOWARDS CLIMATE-RESILIENT SANITATION FUTURES

Towards **Climate-Resilient Sanitation Futures**

The sanitation sector faces increasing pressures from climate change. Growing evidence shows that **extreme weather patterns and events** (such as cyclones, floods, droughts, and heatwaves) threaten sanitation infrastructure and disproportionately affect vulnerable populations. Understanding the **interlinkages between climate and sanitation** is key to building effective adaptation and mitigation strategies.

These climate risks disproportionately impact vulnerable communities, exacerbating pre-existing inequalities and limiting their ability to respond and recover. At the same time, fragile infrastructure and institutions collapse under extreme events, worsening these challenges. Strengthening both social and physical systems is essential for a just and resilient future. This document highlights these interlinkages and the urgency of building equitable climate-resilient sanitation systems.

This document aims to:

- **Explore the interlinkage** between sanitation and climate change through research & case studies
- **Simplifies climate concepts** for practitioners, policymakers, and funders.
- **Lays the foundation** for informed decisions on adaptation and mitigation to build resilient sanitation systems.

As this sector continues to evolve, this document will be updated with new information and data accordingly. Keep an eye out on the NFSSM Alliance website for updated versions.[1]

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Decoding Climate & Sanitation: Simplifying Key Terms

Given that climate discussions often become entangled in jargon, this section explains key terms which will enable further discussion. The **core concepts** below provide a foundation for this document, while **ancillary ones** are in the annexure 1 to build an extended understanding.

Core Concepts

- **Adaptation:** In human systems, the process of adjustment to actual or expected climate and its effects, in order 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 and its effects.

- **Carbon Footprint:** The total Green House Gas (GHG) emissions (expressed as CO_2-equivalent) generated by an individual, organisation, product, or event.

- **Carbon Neutral:** A carbon-neutral footprint is one where the sum of GHG emissions produced is offset by natural carbon sinks and/or carbon credits. The rules around carbon neutrality are less strict than for Net Zero Carbon as they allow claims of neutrality in ways such as buying offsets for avoided emissions, rather than eliminating their own emissions.

- **Circularity:** Designing systems so that the majority of outputs (including waste) are reused or recycled back into the system, minimising any end products that cannot be further utilised. In the sanitation context, this could include converting faecal sludge into compost for agriculture, thereby reintegrating nutrients into the soil and reducing overall waste.

- **Climate Action Plans:** Comprehensive strategies at national or sub-national levels outlining how to reduce emissions and enhance resilience.

- **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. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic (human-made) changes in the composition of the atmosphere or in land use.

- **Decarbonisation:** The process of reducing or eliminating GHG emissions by replacing carbon-intensive energy sources (e.g., coal, diesel) with low or zero-carbon alternatives (e.g., solar, wind). In the sanitation sector, this can include solar-powered pumping systems, energy-efficient treatment facilities, and electric or biofuel-powered waste collection vehicles.

- **Disaster Risk Reduction (DRR):** Strategies and measures to prevent, mitigate, and prepare for potential hazards so that both damage and recovery times are minimised. Although DRR covers all types of disasters, this document focuses on climate-related hazards and how sanitation systems can be better planned or retrofitted to cope with, adapt to, and recover from these events. For example, relocating critical used-water infrastructure away from disaster-prone areas, building toilets resilient against floods, etc.

- **Emission Reduction Targets:** Quantitative goals (e.g., India's Nationally Dertermined Contributions - NDC) to lower GHG emissions by a certain percentage within a specified timeframe.

- **Mitigation:** Addresses the root causes of climate change (accumulation of GHG in the atmosphere). It involves reducing emission sources or enhancing sinks of GHG and is considered a way to keep climate change moderate rather than extreme.

- **Nature-Based Solutions:** Leveraging ecological processes that help manage water, purify waste, used water treatment and store carbon.

- **Net-Zero:** At the global level, achieving a balance where the total GHG emissions from a process, facility, or system are zero or fully offset. At the micro level (e.g., a single plant, building, or local service), this often means drastically reducing emissions and then using measures like carbon sequestration or renewable energy to neutralise any remaining emissions.

- **Sanitation Value Chain:** The complete sequence of activities in sanitation service delivery to safely manage human waste, including:

    - **Containment:** Human waste is contained in an on-site system, possibly together with greywater. Waste is partially treated due to the time it is contained, and is known as faecal sludge or septage depending on the system used.

    - **Emptying:** The process of emptying the system, typically by a desludging truck with a vacuum mechanism.

    - **Conveyance/Transport:** The safe transport of faecal sludge or septage in a closed truck or through sewers.

    - **Treatment:** Faecal sludge or septage can be treated either at a Faecal Sludge Treatment Plant (FSTP), or co-treated with sewage at a Sewage Treatment Plant (STP).

    - **Reuse:** Direct use of treated waste, used-water, biosolids, nutrients, etc. for various purposes such as fertilisers, industrial cooling, or irrigation, thereby reducing demand for freshwater and other sources.

- **Waste-to-Energy:** Converting waste (solid or liquid) into usable energy (e.g., biogas from used-water treatment) to reduce emissions and reliance on fossil fuels.


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01 Sanitation in a Changing Climate: Risks and Realities

Climate change is **intensifying extreme weather events**, pushing sanitation systems to the brink. At the same time, India's urban population is projected to exceed 600 million by 2036, drastically **increasing demand** on already strained infrastructure.[2] In 2023, floods in Delhi severely damaged key used-water treatment plants, mixing sewage with floodwater and endangering public health.[3] Droughts further disrupt sanitation, as seen in Kutch, Gujarat, where severe water shortages force reliance on distant sources like the Narmada River, leaving residents with intermittent supply and 'non-water days.'[4]

Ageing infrastructure in cities and towns is ill-equipped for today's climate extremes, while budget constraints and lack of granular data limit upgrades. Meanwhile, sanitation systems themselves contribute to climate change. GHG emissions from septic tanks, sewers, and used-water treatment account for an estimated 4% of India's total waste sector emissions.[5] With municipalities spending 40–60% of their electricity on water and sanitation, often sourced from fossil fuels, decarbonising these systems is crucial for building systems for the future.[6] At the same time, **rapid urbanisation** and **intensifying climate pressures** demand urgent investments in resilient, adaptive sanitation infrastructure.

As part of the Paris Agreement, India's NDCs include cutting the country's GHG emissions per unit of gross domestic product by 45% compared to 2005 levels by 2030.[7] Further, India pledged to achieve net-zero emissions by 2070 at the 26th Conference of the Parties (COP 26) in 2021.[8] As a testament to India's commitment to a sustainable, climate-resilient future, India's 4th Biennial Update Report (BUR-4) highlighted a 7.93% reduction in GHG emissions in 2020 compared to 2019.[9]

While the country's NDC commitments primarily focus on energy transitions and afforestation, the sanitation sector plays a complementary role as a powerful lever for both adaptation and mitigation. Linking sanitation efforts with India's broader NDC targets can yield co-benefits: reducing climate risks while improving public health, equity, and resource efficiency. By integrating climate-responsive solutions into sanitation systems, we can build resilience, cut emissions, enhance equity, and secure water resources for the future.

1.1 Adaptation and Mitigation

Adaptation

Adaptation involves modifying systems, practices, and infrastructure to reduce climate risks and seize new opportunities. Key measures include expanding access to resilient and reliable sanitation facilities; implementing rainwater harvesting and groundwater recharge; and empowering vulnerable groups. Strengthening sanitation systems not only improves health and diversifies household incomes but also enables investments in education and infrastructure, ultimately enhancing a community's ability to cope with and recover from climate impacts.

Examples of adaptive strategies:

Individual Household Toilets: Access to household toilets for all (as outlined in SBM-U, leading to the construction of 1.37 lakh additional household toilets as of October 2020).[10]

Flood-resistant toilets: Raised platform toilets preventing inundation during floods (implemented in Bihar).[11]

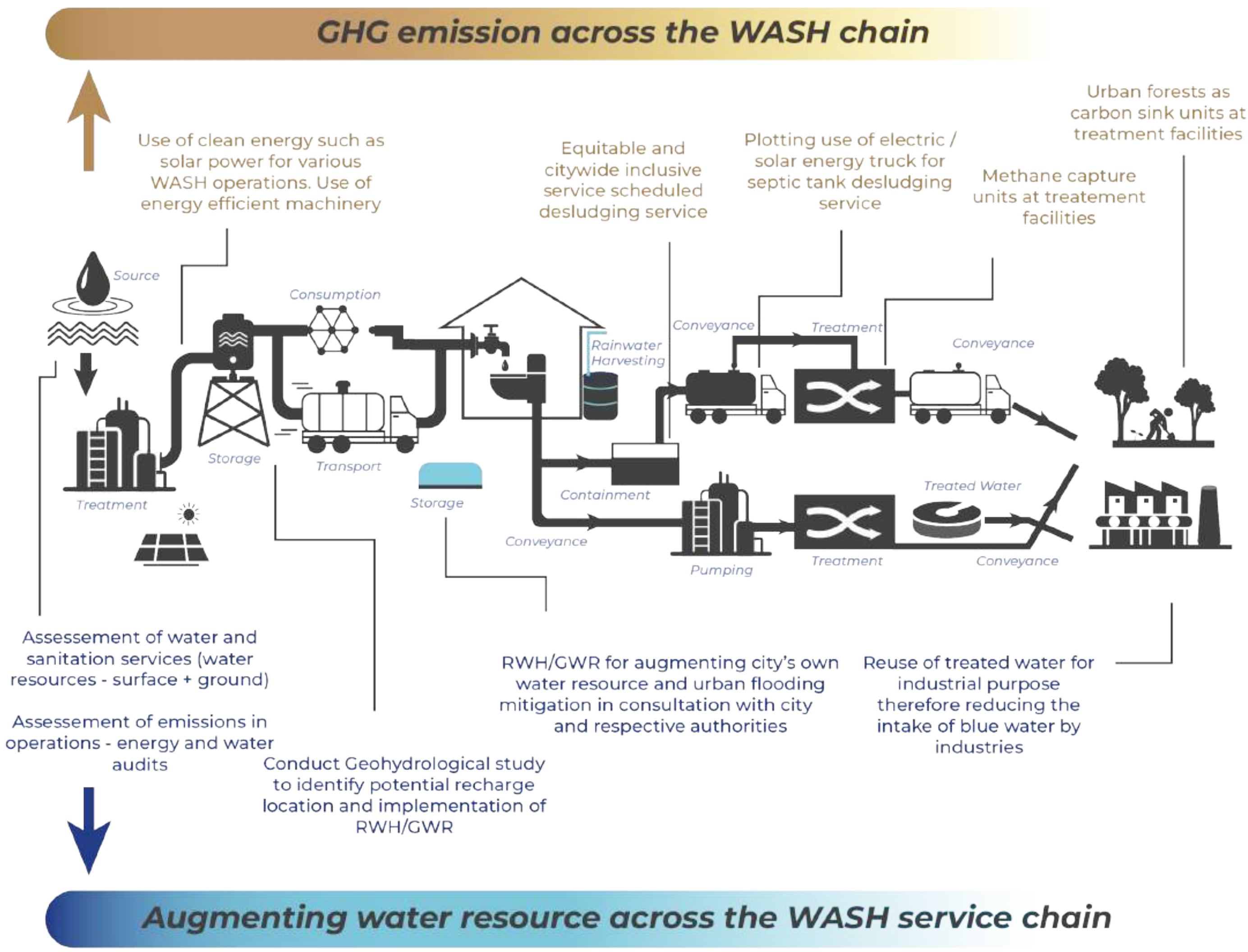
Water security in droughts: Mandated rainwater harvesting helps ensure water availability by increasing availability of ground water during lean water periods (implemented in Chennai).[12]

Dynamic pumping and rapid response: Scaling up sewage pumping stations and sewage treatment plants (STPs) to handle stormwater surges (implemented by the Delhi Jal Board.[13]

Mitigation

Mitigation involves cutting GHG emissions or enhancing carbon absorption to limit climate change. The sanitation sector could contribute to India's NDC targets through focused actions such as:

- **Scheduled desludging of septic tanks:** Regular emptying of septic tanks prevents methane buildup, contamination and improves overall efficacy of waste treatment. Wai, Maharashtra, became the first Indian city to implement this system, ensuring all septic tanks are emptied every three years on a fixed schedule.



- **Solar-powered sanitation operations (Sewage pumping stations, treatment plants, etc):** Using renewable energy for sewage, faecal sludge, and water treatment reduces dependence on fossil fuels. In Maharashtra, solar-powered STPs, FSTPs, and WTPs are expected to cut 7,011 tons of CO_2e emissions over 25 years.

Adaptation and mitigation efforts in the sanitation sector address climate impacts through sustainable sanitation systems that ensure that infrastructure and services remain functional despite climate stresses and extreme weather events. Together, these strategies enhance the ability of communities to anticipate, absorb, and recover from climate-induced disruptions.

1.2 The Dual Imperative of Climate Justice and Systems Preparedness

Climate change and sanitation disruptions disproportionately affect marginalised communities, exposing and deepening vulnerabilities in both systems and people. Vulnerable communities, including low-income groups, marginalised populations, and those in climate vulnerable regions, bear the heaviest burden. Pre-existing inequalities in access to resources, social protections, and decision-making power exacerbate their exposure, leaving them with fewer means to prepare for, respond to, and recover from climate shocks.

Low-income households, women, and those in informal settlements face compounded risks, from disease to lost livelihoods – when infrastructure and access to efficient services fail, women, children, and people with disabilities struggle more during crises due to limited mobility and resources. In many cases, climate extreme events render sanitation facilities inaccessible for persons with disabilities, underscoring the need for public and community toilets to be mandatorily designed with disability- and elderly-friendly features. In Nellore city, Andhra Pradesh, for example, traditional toilets have been retrofitted with such features to improve accessibility.[14] Women in flood-affected areas report high rates of urinary tract infection (UTI) due to unsafe sanitation, yet 43% of state climate plans overlook gender-specific sanitation needs.[15] An **equity-driven approach** must recognise and prioritise these groups to ensure climate resilience efforts do not deepen existing disparities.

At the same time, **systemic vulnerability** – the fragility of infrastructure and institutions in the face of climate risks – further amplifies these challenges. Many current systems, from drainage networks to energy grids and healthcare facilities, are not built to withstand extreme weather events, leading to failure when they are needed most. Without proactive investment in climate-resilient infrastructure, these breakdowns will continue to disproportionately harm those already at risk. Strengthening both social and physical systems is essential to building a future that is not only sustainable but also just.

Although this document focuses on urban sanitation, climate shocks severely impact rural and peri-urban areas as well. In many rural communities, inconsistent desludging services and outdated infrastructure often lead to untreated sludge overflow during heavy rains. Similarly, peri-urban regions face emerging vulnerabilities, with unregulated septic tanks and untreated faecal waste discharges posing growing threats. Addressing these challenges is essential for a comprehensive, climate-resilient sanitation strategy that protects all communities.

Despite these challenges, the sanitation sector offers a critical opportunity for both adaptation and mitigation. Integrating climate-responsive solutions into sanitation systems can enhance resilience, reduce emissions, and address the vulnerabilities of marginalised communities. Strengthening both infrastructure and social systems mitigates climate risks while ensuring equitable access to safe sanitation and safeguarding water resources for the future. Building resilient sanitation systems also requires gender-responsive design, inclusive policies, and community-driven solutions to ensure that no one is left behind.

The full potential in building resilient sanitation systems can only be realised when adequate financing, strong policies, and inclusive governance strategies are aligned to drive technological innovations and community-driven solutions. A holistic, inclusive approach to sanitation is essential for building a climate-resilient future that protects all communities, especially those most at risk.

02

Urban Sanitation and Climate Interlinkages

Urban sanitation systems both impact and are impacted by climate stressors such as flooding, heat, and water scarcity. This section explores these interlinkages across the sanitation value chain to inform climate-resilient solutions and decisions.

2.1 How Does Climate Change Affect Sanitation?

Climate change intensifies extreme weather events, which directly impact the functionality and long-term sustainability of sanitation systems. Stressors like flooding, water scarcity, heat waves, storms, and cyclones can disrupt services and damage infrastructure, especially in fast-growing cities. For example, cyclones, with their destructive winds, heavy rainfall, and storm surges, cause major damage to infrastructure and disrupt drinking water and sanitation services, often leading to flooding. Vulnerable urban populations, in densely populated urban poor regions, are most at risk due to inefficient service delivery. Climate change and extreme weather events also correlate with a higher incidence of water-related diseases[16]. Below, we examine how these stressors can affect the sanitation value chain and disrupt overall service delivery.

Approximately 90% of extreme weather events are water-related, affecting water cycles, degrading water quality, and compromising overall availability of clean water.[17]

Flooding

Flooding is a major climate stressor that disrupts urban sanitation, especially in informal settlements which often lack proper infrastructure. In India, rapid urbanisation and changing climate patterns have made urban flooding a persistent challenge, across different topographies and the kind of flood it is impacted by:

Coastal Flooding: Driven by storm surges, tidal fluctuations, and rising sea levels, coastal flooding can lead to saltwater intrusion, contaminating freshwater sources leading to sanitation systems being overwhelmed.

Inland Flooding:
Caused by heavy rainfall, river overflows, and poor drainage, inland flooding can result in prolonged waterlogging, infrastructure damage, and the spread of waterborne diseases.

Flash Floods: These sudden and severe floods, often resulting from intense rainfall over a short period, can overwhelm urban drainage systems, leading to rapid inundation and contamination of water supplies.

Sea-Level Rise: Gradual sea-level rise exacerbates coastal flooding, leading to more frequent and severe inundation events, which compromise sanitation infrastructure and increase the risk of disease outbreaks.

India is the second worst flood-affected country in the world after Bangladesh, with 40 million hectares of its land prone to flooding.[18]

Some key impact areas:

Infrastructure Damage, Contamination and System Malfunction:

Containment of Waste:

- Pit latrines, septic tanks, and leach pits can be submerged by rising groundwater and floodwaters, causing untreated sewage to overflow, contaminating safe water sources and surrounding environments. This contamination undermines safe sanitation efforts, worsening water pollution and increasing the spread of waterborne diseases.

- Flooding can render toilets unusable (particularly when waste backflows into them) and restrict mobility, forcing many people to resort to open defecation. While this affects all users, those relying on shared or community facilities face the greatest challenges in maintaining safe, dignified sanitation.

- Storms can damage or destroy latrine superstructures and conveyance pipes, potentially resulting in increased slippage to open defecation and disruptions to pumping and treatment facilities.

Emptying and Transportation:

- Sewer networks lack sufficient capacity to handle extreme rainfall and flash floods, leading to overflow, pipe bursts, and backflow into residential areas.
- Flooding also leads to silt accumulation, solid waste in drains and sewer lines, which affect flow of used-water once the floods recede.
- For non-sewered systems (e.g., pit latrine or septic tanks), flooded roads impede access for desludging vehicles. Desludging operations may be delayed or halted, causing overflows and unsanitary accumulation of faecal sludge in affected communities. In areas with improper drainage, flooding leads to water stagnation, which may lead to vector borne diseases.
- Brackish or flooded low-lying areas

complicate access for desludging vehicles, heightening overflow risks in coastal zones.

Treatment & Disposal:

- Treatment facilities are often built at lower elevations to reduce pumping costs, but this design choice leaves them highly susceptible to flooding. Untreated biosolids, mixes with water, becoming a breeding ground and causing the spread of pathogens.
- Flooding poses a serious threat to sludge treatment facilities, jeopardising long-term service reliability. Faecal Sludge Treatment Plants (FSTPs) risk structural damage, treatment disruptions, and sludge overflow into surrounding areas. Large, centralised Used-Water Management Plants (UWMPs), often near water bodies, can be inundated during major floods, forcing shutdowns and the direct discharge of untreated sewage into rivers, lakes, and storm drains. Gokul Nagar, Anjar, Gujarat, is a notable case where the sewage pumping station is situated in a low-lying area near a box canal.[19] During the monsoon, floodwaters rise to ~4–5 feet, mixing with the sewer line and creating unhygienic conditions for the local population.
- Increased salinity of water resources can corrode or damage septic tanks and treatment plants, leading to frequent breakdowns, higher maintenance costs, and an overall decline in sanitation service quality.

Water Scarcity

Globally, over four billion people experience severe water scarcity for at least one month each year. Water scarcity is an escalating climate stressor, particularly in urban India, driven by surging demand for water due to rapid urbanisation and population growth.[20] By 2050, at least 30 Indian cities will face a grave water risk.[21] Droughts and reduced freshwater availability weaken urban sanitation systems, especially flush-based toilets and treatment plants, reducing their efficiency.

By 2050, the average per capita water availability in India is expected to decrease by over 26% from 2011 levels, close to the official water scarcity threshold.[22]

Here are some key ways in which water scarcity affects sanitation systems:

Containment of Waste:

- Water-dependent sanitation systems, including pour-flush latrines, septic tanks, and sewered toilets, become inoperable in periods of extreme water scarcity.

Emptying and Transportation:

- Water scarcity reduces flow rates in sewer networks, leading to sludge accumulation,

Simultaneous Floods and Water Scarcity in Mumbai

Cities often plan for floods and water shortages separately, assuming these hazards occur at different times or seasons. In reality, urban areas can – and increasingly do – face both extremes in quick succession, compounding disruptions to sanitation services. When heavy rainfall floods treatment plants and sewer systems, it can contaminate local water sources and cause waste backflows. At the same time, water scarcity limits the flushing and operational capacity of toilets, sewers, and treatment facilities.

In July 2021, Mumbai experienced a severe water crisis as torrential rains inundated the city. The Indian Meteorological Department (IMD) placed the city under a red alert. Within a 24-hour period, rainfall of above 100 mm was recorded at various locations. The Bhandup Water Purification Complex, one of Asia's largest water treatment plants, was severely flooded, disrupting water supply to nearly 65% of the city. The flooding triggered a mechanical failure at the plant, forcing authorities to temporarily shut down operations and advise residents across the city to consume water only after boiling it.

This incident highlights the critical need for resilient urban infrastructure and climate-adaptive planning to safeguard essential services against extreme weather events.

pipe blockages, and solid waste build-up in conveyance infrastructure. This diminishes system efficiency and increases maintenance and desludging costs.
- Reduced water availability and droughts can delay or complicate desludging processes.

Treatment & Disposal:
- Increased concentration of used-water in sewer lines and accumulation leads to more sewer gas production.
- The quantity of faecal sludge arriving at treatment units reduces considerably, affecting the chemical composition and overall performance of treatment plants, leading to slow and inefficient treatment processes.
- Large treatment plants need enough water to dilute and process waste. Low water flow during droughts leads to high concentration of pollutants in water, more than what the treatment plants are designed to handle, impacting performance and output.

Heat Stress

Unlike flooding or drought, heat stress does not cause immediate system failure, but its cumulative effects gradually degrade infrastructure and disrupt treatment processes, creating long-term challenges to sanitation systems.

Containment of Waste: Heat speeds up the decomposition of waste, heightening odors and leakage risks, particularly in poorly maintained latrines and septic tanks.

Emptying and Transportation:
- Pipes and pumping stations experience overheating, leading to energy inefficiencies and increased maintenance costs.
- Extreme heat can also lead to vehicle overheating and mechanical failures, disrupting desludging services.
- Heat waves put sanitation workers at risk of heat stress, often forcing desludging schedules to shift or reduce, further disrupting services.

Treatment & Disposal: High temperatures can enhance microbial activity, speeding up the breakdown of organic material in oxidation ponds and sludge treatment systems. However, excessive heat also reduces dissolved oxygen (DO) levels, which can hinder microbial efficiency and require more energy to maintain adequate oxygen levels. Additionally, cooling demands at large treatment plants rise in heat-prone urban areas, leading to increased energy consumption and operational costs. Thus, while moderate temperatures benefit microbial activity, extreme heat presents challenges in both treatment efficiency and energy requirements.

Storms and Cyclones

Cyclones are caused by atmospheric disturbances around a low-pressure area distinguished by swift and often destructive air circulation. They are usually accompanied by violent storms (a storm is characterised by strong winds, rain, thunder, lightning, or even snow, depending on the type) and bad weather. These events can cause widespread flooding, particularly in coastal urban areas, leading to the contamination of water sources and damage to sanitation facilities. The combined effect of flooding and storm surges during cyclones pose a severe threat to urban sanitation systems. For instance, the May 2024 severe cyclonic storm 'Remal'[15] in West Bengal resulted in extensive damage to sanitation infrastructure, leading to increased open defecation and disrupted waste disposal services.[23]

Containment of Waste: Intense rainfall and storm surges can lead to the overflow of latrines, septic tanks, and sewer systems, causing the spread of untreated waste into communities.

Emptying and Transportation: Flooded roads and infrastructure damage hinder the access of desludging vehicles, delaying the removal of waste and increasing health risk (see Floods, under 2.1).

Treatment and Disposal: Treatment facilities may be inundated, leading to operational failures and the release of untreated sewage into the environment.

Landslides

A landslide is the mass movement of rock, debris, earth or mud down a slope. It can be caused by rainfall, earthquakes, droughts, volcanic eruptions or erosion. In urban areas, especially in mountainous terrain with unplanned construction and deforestation, landslides can destroy sanitation infrastructure, block access to clean water, and contaminate existing water supplies with debris.

Containment of Waste: Landslides can damage or bury sanitation facilities, leading to the rupture of containment units and the release of waste into the soil and water sources.

Emptying and Transportation: Blocked or destroyed access routes impede waste collection and transportation services, resulting in the accumulation of waste at source. Similarly, broken sewage pipes impede the flow of used-water, leading to slow or blocked drains.

Treatment and Disposal: Damage to treatment plants from landslide debris can halt operations, causing untreated waste to accumulate or be improperly disposed of.

Earthquakes

Earthquakes can cause significant structural damage to urban sanitation systems, including the rupture of sewage lines, destruction of treatment facilities, and contamination of potable water sources. The disruption of sanitation services post-earthquake increases the risk of disease outbreak.

Containment of Waste: Seismic activity can cause structural damage to latrines, septic tanks, and sewer lines, leading to leaks and contamination of surrounding areas.

Emptying and Transportation: Earthquake induced infrastructure damage, such as collapsed roads and bridges, disrupts waste collection and transportation networks.

Treatment and Disposal: Treatment facilities may suffer structural impairments, leading to operational disruptions and the potential release of untreated sewage.

Addressing these challenges requires a multifaceted approach, including the development of resilient infrastructure, implementation of early warning systems, and community engagement in disaster preparedness and response.

After examining how climate change affects sanitation, we now explore how sanitation itself can contribute to climate change.

2.2 How Does Sanitation Affect the Climate?

Sanitation primarily protects public health and the environment, but it also contributes to GHG emissions, including carbon dioxide (CO_2), methane (CH4), and nitrous oxide (N2O). Additionally, water and sewage pumping account for 40% to 60% of a municipal corporation's electricity use.

While the sanitation sector already contributes 1.3% of global GHG emissions, recent estimates suggest underreporting, particularly for CH4 emissions, which has over 80 times the warming power of CO2 over the first 20 years after reaching the atmosphere.[24, 25]

Non-sewered systems alone account for up to 4.7% of global anthropogenic methane emissions.[26] Used-water and sludge management together produce 257 million tonnes of CO_2 equivalents (CO_2-eq), with an additional 267 million tonnes attributed to non-sewered sanitation.[27] In Ichalkaranji, Maharashtra, a study found that water and sanitation systems generate about 31,088t CO_2-eq annually from direct and indirect emissions.[28]

Examining the entire sanitation value chain helps identify and address emission hotspots holistically. Here are key ways sanitation contributes to climate change:

Containment of Waste: These include non-sewered systems such as pit latrines, septic tanks, and leach pits and contribute to methane emissions through the anaerobic decomposition of organic waste. Poorly designed or overfilled containment systems leak methane directly into the atmosphere, especially in high-density urban areas where desludging is infrequent.

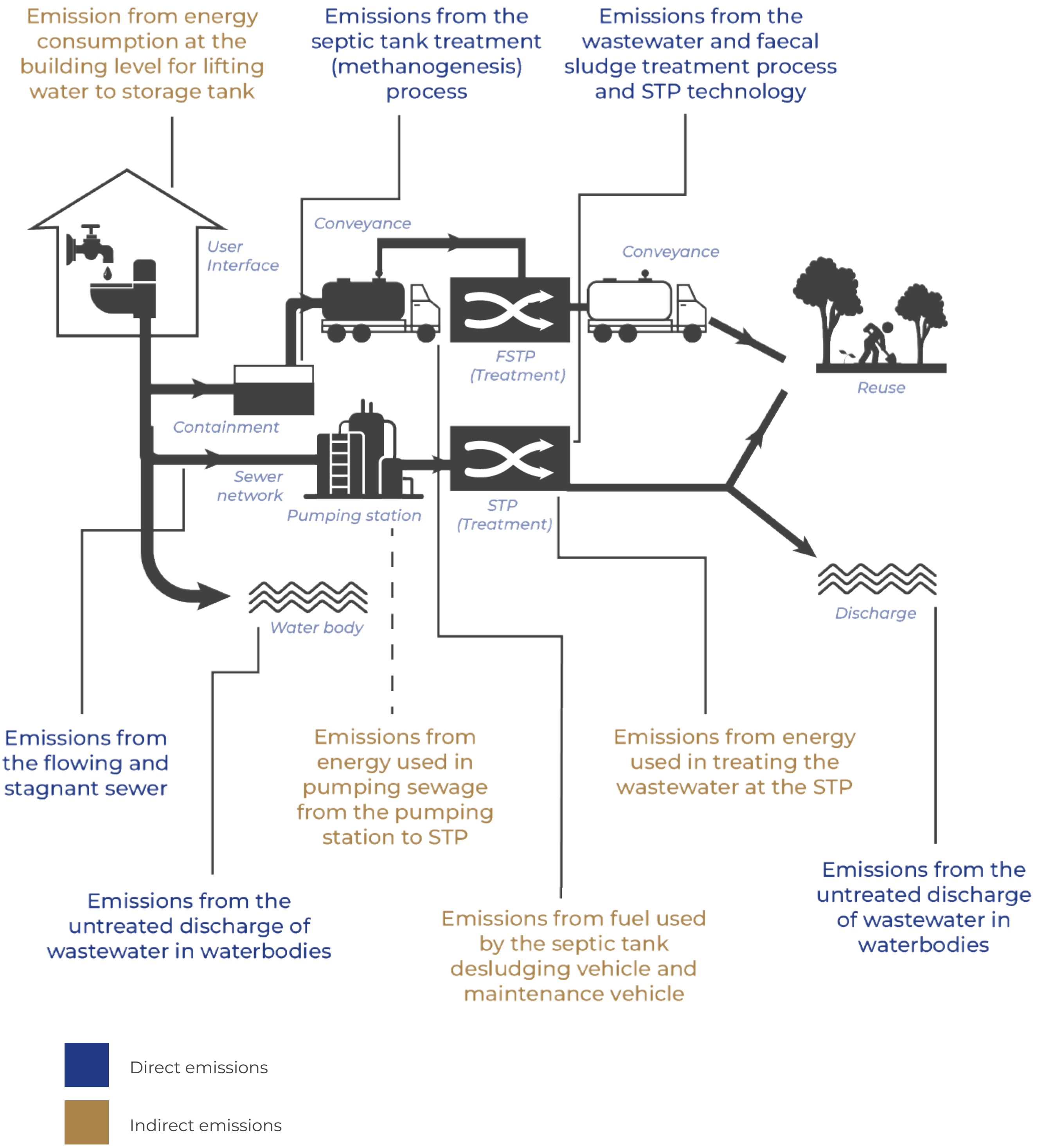
Emptying and Transportaion: Vacuum trucks and motorised desludging vehicles used in transporting sludge to treatment sites emit CO_2 and particulate matter from fuel combustion.

Open drains and combined sewer overflows not only pollute water bodies but also release methane due to the breakdown of organic waste in stagnant water.

Treatment and Disposal:
Large scale centralised treatment plants are major energy consumers, with aeration, pumping, and sludge digestion being highly energy intensive

Inefficient treatment processes produce high methane and nitrous oxide emissions, especially in systems that rely on anaerobic digestion without methane capture.

In decentralised treatment models, where faecal sludge is managed offsite, methane leaks from uncovered drying beds or unregulated disposal sites can be substantial.



Some sources of GHG across the value chain are :

Gas	Production
CO_2	• During sludge transport (empyting trucks) in the case of non-sewered sanitation • During used water treatment, mainly due to organic matter degradation • Linked to the production of electricity to supply the plant • During sludge treatment: combustion or flaring of biogas, on-site sludge incineration • Direct discharges into water sourses without treatment
CH_4	• Networked sewage emissions in the case of stagnant, open and hot sewers • At the WWTP production by decomposition of organic matter under anaerobic conditions (COD treatment) • Potential CH_4 leakage during biogas production • Emissions when discharging to sea, river or lake
N_2O	• On the WWTP, linked to the treatment of nitrogen present in used water • Urea, ammonium, proteins (NTK reduction) • During discharge of treated water into the natural environment during composting or sludge spreading • During sludge incineration. It should be noted that N_2O emission occurs naturally in natural aquatic environments. (rivers, estuaries, lakes)

Table : GHG Production Sources[29]

03

Approaches to Climate-Resilient Sanitation

By 2036, over 600 million people, more than 40% of India's population, will live in urban areas, putting immense strain on sanitation systems already struggling with ageing infrastructure. Climate change intensifies this pressure, causing service disruptions and infrastructure damage due to flooding, water scarcity, and extreme heat. A 2021 study by CEEW finds that a staggering 75% of Indian districts are hotspots for such climatic extremes, and that 80% of the population reside in vulnerable regions[31]. By 2050, the average per capita water availability in India is expected to decrease by over 26% from 2011 levels (1,545 m^3 to 1,140 m^3), exacerbating the challenges in the sanitation sector.[32]

This section examines climate-resilient sanitation through adaptation, mitigation, and building resilience, emphasizing the urgent shift from conventional 'collect-and-dispose' models to integrated, sustainable solutions, especially for growing cities and smaller towns.

3.1 Adaptation Approaches for Climate-Resilient Sanitation

Adaptation requires rethinking the entire sanitation value chain—from sourcing water to reuse. Each component can experience failure during a climate crisis if not made resilient. Adaptation is inherently context-dependent: local geographies, governance, and communities shape which strategies are most feasible. Several frameworks and tools exist to assess climate risks and design resilient sanitation solutions (see Annexure 2). Below we explore adaptive measures to fortify against climate crises. While there are no universal solutions, each hazard-specific subsection illustrates a few ways to minimise disruptions in service delivery and protect public health under changing environmental conditions.

Building Protective Infrastructure

Flood-Proofing:

- Elevated Infrastructure: Building toilets, treatment units, electrical controls, and storage above known flood levels.
- **Levees, Berms, or Retaining Walls:** Defensive structures around key assets like pumping stations, critical sewers, or drying beds can keep floodwaters at bay.

Design for Heat Resilience:

- **Shading and Enclosure:** Enclosing critical treatment units or vegetative buffers, green roofs, and reflective coverings can reduce interior temperatures.
- **Elevated/Protected Equipment:** Where feasible, elevating sensitive electrical components and keeping them ventilated can mitigate temperature spikes.
- **Re-locating or Co-locating:** In extreme climates, situating treatment facilities

near energy sources (solar farms, backup generators) can prevent outages. Co-ordinating with local energy suppliers and sub-stations can also help modulate load shedding if needed.

- **Efficient Pumps and Motors:** Retrofitting older equipment with high-efficiency versions reduces energy consumption (and costs), while helping systems cope with temperature extremes.

Decentralised and Modular Systems

Modular or Decentralised Treatment: Smaller, distributed treatment units reduce the risk that a single failure will collapse the entire system. They are easier to repair, relocate, or scale up when conditions change. Cities with decentralised used-water treatment plants recover faster from floods because their sanitation systems are not fully dependent on large, centralised infrastructure.

Mobile or Containerised Units: Temporary units can be rapidly deployed if a main plant is inundated or damaged.

Stormwater Management

Separate Sewers: Where feasible, separate stormwater from sewage to avoid combined system overflows.

Nature-Based Solutions: Enhance infiltration with wetlands, bioswales, or permeable pavements to slow runoff before it enters sewers, thus lowering flood peaks.

Hybrid Solutions: Integrating wetlands, green buffers, or permeable surfaces around sanitation infrastructure can absorb shock from floods or heatwaves and act as "living sponges". When combined with engineered systems, these hybrid models often recover faster from extreme events.

Integrated Urban Infrastructure

Zoning: Identifying high-risk zones, such as flood-prone areas, to guide where new sanitation infrastructure should be placed, or how it should be protected, so that facilities in vulnerable areas can be built to withstand extreme weather events.

Integrated Urban Planning: Coordinating sanitation with housing, roads, and disaster management ensures that climate measures are built into city expansion plans rather than added retroactively. For example, by ensuring that used-water treatment plants are located outside flood zones and incorporating rainwater harvesting in city designs, sanitation services can remain functional during extreme weather events.

Unlocking Funding Opportunties: Municipal bonds, insurance schemes, or climate funds (e.g., green bonds, results-based financing) can cover extra costs of designing and maintaining robust infrastructure. Securing funding is key to both routine O&M and rapid recovery after shocks.

Early Warning and Maintenance Protocols

Early-Warning Systems: Real-time monitoring of water levels, cyclones, storms, or heatwaves allows operators to activate emergency procedures (e.g., pre-flood desludging, shifting power loads) before disasters strike. Continuous monitoring of system performance (flow rates, energy usage, breakdown frequency) also helps justify financial investments and refine climate measures over time.

Real-Time Sensors: Installing temperature and turbidity sensors at strategic points helps utilities anticipate changes in water quality, allowing them to adjust processes pre-emptively.

Flood Forecasting: Municipalities can use rainfall data and predictive models to prepare treatment plants and inform communities in advance.

Pre-Flood Desludging: Clearing septic tanks before flood season minimises the volume of waste that could spill into floodwaters.

Adaptive Disinfection: Warmer water due to heat stress can change microbial ecology; operators may need to adjust chlorine dosing or use alternative disinfection methods (UV, ozonation).

Contingency Planning & Rapid Recovery Protocols

Standby and Backup Power: On-site solar arrays, diesel generators, or battery systems ensure critical processes (ex- pumping, disinfection) remain operational during grid strain or failures due to flooding or heat.

Water Storage: Emergency water storage tanks help maintain supply if intake sources are disrupted.

Post-Flood Recovery: Creating SOPs for disinfecting distribution lines and mobilising portable toilets in areas where on-site systems are damaged. Clear and detailed guidelines help staff respond to equipment failures, supply chain disruptions, or severe weather.

Emergency Infrastructure Kits: Portable toilets, mobile treatment units, or backup pumping stations can be deployed on short notice if primary facilities are compromised, vital in major floods or quake zones.

Service Continuity during Water Scarcity

Source Diversification and Recharge

- **Aquifer Recharge:** In suitable regions, direct infiltration basins or injection wells can replenish depleted groundwater.
- **Watershed Rehabilitation:** Reforestation or wetland restoration in upstream catchments to improve infiltration and sustain base flows.
- **Treated Used Water for Non-potable Uses:** Incentivising industries, parks, or agriculture to use reclaimed water can preserve fresh water sources.

Strengthening Treatment Technologies

- **Advanced Filtration:** Where water quality is compromised, adding membranes (e.g., microfiltration, reverse osmosis) addresses salinity or chemical contamination.
- **High-Recovery Processes:** Recycling backwash water and optimising chemical dosing minimises wastage within treatment plants.

Leak Reduction: Pipeline audits to detect and repair ongoing leaks can drastically cut non-revenue water, essential in water-scarce settings.

Demand Management & Consumer Awareness

Staggered Distribution: Supplying water during cooler periods (overnight or early morning) can limit evaporation and reduce peak strain on infrastructure.

Public Cooling Points: In public spaces, well-maintained water or cooling stations reduce the risk of dehydration and reduce ad-hoc demands on pipeline networks.

Consumption Regulation: Tiered pricing, rationing, or progressive taxes on water discourages excessive usage while ensuring basic needs are met.

Awareness Building: IEC and BCC activities targeted towards water conservation can foster a culture of frugality.

3.2 Mitigation Approaches for Climate-Resilient Sanitation

While adaptation measures help sanitation systems cope with climate extremes, mitigation focuses on reducing (GHG) emissions. In practice, this means controlling methane (CH_4) and nitrous oxide (N_2O) from treatment processes, reducing fossil-fuel-based energy consumption,

and harnessing waste as a resource. Mitigation efforts can strengthen service resilience while addressing public health and environmental imperatives. By embracing the circular economy and optimising energy use, sanitation can become more sustainable and contribute to long-term climate goals.

Reducing Direct Emissions from Used Water and Sludge

Frequent Desludging & Sealed Containment: Regular emptying of septic tanks and pit latrines prevents excessive anaerobic decomposition, thereby cutting down methane leaks. Properly sealed pits and tanks also reduce contamination risks for local groundwater and surface water.

Anaerobic Digestion with Biogas Capture: Instead of allowing sludge to degrade in open lagoons, covered digesters capture methane and convert it into biogas. This can power on-site operations or local grids, offsetting fossil-fuel consumption and curbing potent methane emissions.

Optimised Nutrient Removal: Inefficient nitrogen removal in conventional plants can release nitrous oxide (N_2O). Upgrading to advanced biological processes, for improved nitrification and denitrification, limits N_2O emissions.

Nature-Based Solutions: Afforestation, green belts, and constructed wetlands can support in reducing carbon emissions.

Energy Efficiency and Renewables

Efficient Pumping & Aeration: Water supply and used-water management are energy-intensive processes; installing high-efficiency pumps, blowers, or motors with variable frequency drives can significantly lower electricity use and carbon emissions.

On-Site Solar Power: Treatment plants can integrate rooftop or ground-mounted solar arrays to supplement grid power. This not only reduces fossil-fuel-based energy consumption but also provides backup power during blackouts—an added resilience benefit.

Low-Energy Treatment Options: Natural and decentralised systems, such as waste stabilisation ponds, constructed wetlands, or gravity-based sewers, minimise the mechanical pumping and aeration required in traditional setups, thereby reducing energy costs and emissions.

Energy Audits: Conducting energy audits can help lower energy costs through reduced utility bills from more efficient energy use, enhance performance, and reduce waste in energy systems leading to improved energy efficiency. These audits also increase awareness of energy use patterns and areas for future improvement, which reduces greenhouse gas emissions from optimised energy consumption, contributing to decreased carbon emissions.

Faecal sludge and used-water contain valuable resources that can be treated to convert into ***useful products.*** ***For example, every individual*** *excretes around 4.5 kg of nitrogen, 0.5 kg of phosphorus, and 1.2 kg of potassium annually, all of which are key nutrients for fertilising and* ***restoring agricultural soils. Additionally, faeces*** *have an energy value of about 4,115 kcal per kilogram of dry solids, which can be treated to harness as a renewable energy source.*[33]

Resource Recovery and Circular Economy

Waste-to-Energy (WtE): By converting sludge and organic waste into biogas, biodiesel, or other energy products (through processes like gasification or co-incineration), municipalities reduce landfill usage and generate new energy streams.

Composting & Fertiliser Production: Co-composting faecal sludge with biodegradable solid waste yields nutrient-rich soil conditioners. This approach cuts dependence on synthetic fertilisers (which have their own carbon footprint) and channels essential nutrients back into agriculture.

Used water as a Resource: Treating used-water to a safe standard for irrigation, industrial processes, or landscaping reduces the need for energy-intensive groundwater pumping or desalination. It also eases stress on freshwater resources during dry periods.

- **Closed-Loop Systems:** Encouraging industries or large institutions to install on-site treatment and reuse systems for cooling, flushing, or landscaping.
- **Nutrient Recovery:** Recovering phosphorus and nitrogen from sludge reduces reliance on chemical fertilisers (which require water for production).

Waste-to-Wealth (WtW): Advanced solutions like omni processors go a step further by transforming faecal sludge into electricity, drinking water, and bio-char with minimal external inputs, making sanitation systems more self-sustaining. These innovations align with the waste-to-wealth approach by turning sanitation waste into multiple valuable resources.[34]

Reinvented Toilets

In line with global efforts to develop off-grid, low-water sanitation, the Gates Foundation launched the Reinvent the Toilet Challenge, spurring innovation in toilet design.Designed for household use, this “reinvented toilet” kills pathogens through heat treatment and bioprocessing while recycling water and converting solid waste into ash, thereby eliminating the need for external sewer connections or off-site treatment.

Such next-generation toilets hold significant promise for regions lacking centralized infrastructure or where water resources are scarce. By safely managing human waste on-site with zero methane emissions, ‘reinvented toilets’ can contribute to a circular sanitation approach that reuses or transforms waste into valuable end products.

Low-Emission Transport and Logistics

Scheduled Desludging: Planned desludging can streamline operations, allowing vehicles to make fewer trips around the same areas and lowering emissions.

Route Optimisation for Collection: Sludge and waste collection fleets can significantly lower emissions by using GIS-based scheduling to minimise travel distances, idle time, and fuel use.

Transition to Clean Transportation: Switching from diesel vehicles to electric or biofuel-powered trucks cuts particulate matter and CO_2 emissions. This becomes even more impactful when coupled with renewable energy sources for vehicle charging or fuel production.

A Holistic Approach to Climate-Resilient Sanitation

Climate resilience is the sum of all the efforts made through adaptation and mitigation measures that together strengthen the ability of individuals, communities, and systems to cope with crises. It demands robust governance, inclusive community engagement, and sustainable financing to support climate action.

Adaptation and mitigation measures within sanitation systems complement (and often converge with) each other to reduce emissions, enhance equity, and build infrastructure capable of withstanding and/or recovering from climate extremes—building a resilient system. Many mitigation solutions also bolster resilience, such as biogas or solar energy integration providing on-site energy and backup capacity. Likewise, nature-based adaptive flood defences can mitigate extreme events and support biodiversity. For example, constructed wetlands absorb excess rainwater, prevent sewage overflows, and naturally filter used-water. Resilience demands robust governance, inclusive community engagement, and sustainable financing.

Examples of climate-resilient sanitation include:

- **Early Warning Systems:** Tools and protocols that predict and notify communities about impending hazards, enabling them to protect critical sanitation infrastructure. For example, the iFLOWS system in Mumbai integrates rainfall and tidal data to issue flood alerts, allowing timely preventive measures.[35]

- **Emergency Training & Protocols:** Capacity-building to equip local stakeholders with crisis-response skills for sanitation management during climate extremes. For example, the CSE and WHO Training of Trainers (TOT) on Climate-Resilient Sanitation Safety Planning, which teaches frontline practitioners to manage sanitation risks during floods and other climate-related emergencies.[36]

- **Community Ownership & Governance:** Localised solutions that involve residents, such as local committees and decision-making processes that maintain and adapt systems over time and community-based hazard monitoring and action. For example, a community-based early-warning system in the Indian Himalayan Region uses a simple sensor-and-transmitter setup to detect rising river levels and alert downstream villages, saving both lives and property at scale.[37] When neighbourhoods or cooperatives help operate and maintain smaller treatment units, they can quickly mobilise local resources for repairs and adapt systems based on direct feedback. Additionally, training residents on safe hygiene practices during floods or droughts, and promoting acceptance of innovative sanitation options (e.g., container-based toilets, water reuse), strengthens community resilience.

Ultimately, a **resilient sanitation system** is one that provides uninterrupted reliable service to all segments of the population and evolves sustainably to meet future challenges.

Climate-Resilient Public Toilets in Leh, Ladakh

Leh, at 3,500 meters altitude, attracts 300,000 tourists annually but faced failing toilets, frozen pipelines, and cultural taboos around cleaning. Locals saw toilets as unusable in winter, and tourists avoided them.

Key Solutions

- **Reviving Traditional Dry Toilets:** Ladakhi Dechod compost toilets, waterless and climate-resilient, were reintroduced—eliminating reliance on frozen pipelines and complex infrastructure.

- **Weatherproof Wet Toilets:** Insulated walls, passive solar heating, and overhead water tanks in glass chambers keep facilities functional in sub-zero temperatures.

- **Sustainable O&M Through Community Engagement**
  Local NGOs and entrepreneurs manage maintenance via user fees. In Zangsti, an NGO-run café funds upkeep, normalizing sanitation work.

Impact & Scale-Up

- Cleaner, more accessible toilets with integrated livelihood opportunities.
- The Government of Ladakh is expanding these models using passive solar heating, dry-toilet systems, and revenue strategies (e.g., tourist cess, CSR funds) for long-term sustainability.

By blending traditional wisdom with modern innovations, Leh has transformed public sanitation, ensuring year-round, climate-resilient services that support public health, tourism,

From Toilet to Table: Transforming Used Water into a Resource

In peri-urban Hubli-Dharwad, Karnataka, farmers face increasing water scarcity due to erratic monsoons, declining groundwater levels, and climate-induced drought cycles. Agriculture in the region depends heavily on groundwater extraction, making it vulnerable to both seasonal shortages and long-term depletion. At the same time, urban sanitation systems generate significant volumes of used-water, which, if left untreated, pose environmental and public health risks.

Recognising the interlinkage between sanitation, climate resilience, and water security, Alliance members, Bremen Overseas Research and Development Association (BORDA) and the Consortium for DEWATS Dissemination (CDD) piloted a climate-resilient sanitation intervention that not only ensures continued sanitation service delivery during droughts but also repurposes treated used water for irrigation—a dual solution addressing both sanitation and agricultural challenges.

Measures implemented included:

Climate-Adaptive Toilets:
- Elevated and water-saving designs ensure functionality in water-scarce conditions.

Used Water Management & Safe Reuse:
- Used water undergoes UV disinfection in polishing ponds to eliminate pathogens.
- Nutrient retention in TWW reduces reliance on synthetic fertilisers, lowering agricultural costs.

Improved Agricultural Resilience:
- TWW provides a reliable, drought-resistant water source for farmers.
- Farmers report higher crop yields and nutrient-enriched produce (Vitamin C, B6, and protein).

By closing the sanitation loop, this initiative demonstrates how used-water can be leveraged as a climate-resilient resource—reducing freshwater dependency, improving agricultural resilience to drought, and cutting GHG emissions from synthetic fertilizer production. As climate variability intensifies, integrating used-water reuse within sanitation planning will be key to ensuring long-term water security, reducing environmental degradation, and

Reducing Emissions in Ichalkaranji

Ichalkaranji, a city in Maharashtra, faced a significant challenge in addressing GHG emissions from its water and sanitation systems. In 2023, the Centre for Water and Sanitation conducted a comprehensive study revealing that these services contributed approximately 31,088t CO^2 eq annually, including both direct and indirect emissions (64% and 35%, respectively). Recognising the urgent need for sustainable solutions, the city implemented targeted interventions in alignment with Indian government policies promoting low-emission technologies and energy efficiency.

- Outdated fossil fuel-powered pumps were replaced with efficient solar-powered alternatives, reducing the city's dependence on non-renewable energy sources and contributing to a measurable decrease in carbon emissions.
- Regularly scheduled desludging of onsite sanitation systems mitigated the release of methane emissions, a potent GHG.
- Methane capture units were installed at used-water management facilities to trap methane generated during the treatment process. The captured gas was converted into usable energy, reducing emissions and creating an additional energy source for the city.
- The city introduced a system for reusing treated used-water for non-potable purposes, such as industrial use and irrigation, reducing overall demand for freshwater and lowering indirect emissions associated with water extraction, treatment, and supply.

These initiatives have significantly reduced Ichalkaranji's GHG emissions while promoting sustainability in the city's water and sanitation sector.

Jalasathi: Women-Led Governance for Climate-Resilient Urban Water Management in Odisha

The Government of Odisha has prioritised universal piped water access with a focus on sustainability and climate resilience. Recognising the need for community-driven governance, the Jalasathi initiative was launched in 2019 by the Housing and Urban Development Department (H&UDD). This program integrates women Self-Help Groups (SHGs) as key stakeholders, empowering them to manage water services while promoting climate adaptation strategies.

As of March 2024, 809 Jalasathis operate across 115 Urban Local Bodies (ULBs) in Odisha. These women act as intermediaries between communities and service providers, ensuring equitable access to water and strengthening climate resilience by:

- Facilitating service delivery – assisting in new connections, regularising unauthorised connections, and identifying maintenance issues.
- Managing payments – collecting user charges and promoting digital billing to improve transparency.
- Enhancing climate awareness – advocating for reduced groundwater dependency and sustainable water usage.

Building Climate Resilience
Jalasathis are trained to incorporate climate-responsive strategies into water governance. Key climate adaptation measures include:

- Reducing reliance on groundwater by promoting universal piped water connections.
- Regular water quality monitoring to mitigate contamination risks from climate variability.
- Using digital tools (mPoS machines, a knowledge portal, and mobile apps) for efficient service delivery and data-driven decision-making.
- Raising community awareness on water conservation and sustainable usage practices.

Digital and Capacity-Building Interventions
The state-level Knowledge Portal and mobile application provide Jalasathis with training modules in Odia and English, self-paced learning, and assessment tools. These resources equip them with skills in:

- Conducting water quality tests to ensure public health safety
- Managing grievance redressal and improving service efficiency
- Using digital billing systems to enhance governance and transparency
- Implementing gender-inclusive climate adaptation strategies to ensure equitable participation

The Jalasathi model exemplifies women-led, technology-enabled, climate-resilient urban water management. The success of Jalasathi in Odisha has inspired its national replication through the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) Mission's AMRUT Mitras initiative. This adaptation leverages community-driven governance to improve urban water management across India. Continued investment in capacity building and technology will further enhance its impact, making it a replicable model for climate adaptation nationwide.

Water Planning Challenges and Solutions in Sangam Vihar, Delhi

Water planning for large, dense, unplanned urban settlements presents unique challenges, particularly in the context of climate change. Sangam Vihar, Delhi, is representative of such large, dense unplanned settlements. Spanning 5 sq. km and housing over a million residents, Sangam Vihar struggles with critical gaps in water supply, sanitation, and storm-water management, underscoring the pressing need for reimagined urban water planning. To address water-related challenges in such dense unplanned settlements, Centre for Science and Environment (CSE) conducted a study focused on the approach, methodology and analysis of urban water, used water and storm-water challenges of Sangam Vihar. The study looked at whether improving existing water, used water, and storm-water systems can work in unplanned settlements and explored new, local solutions for sanitation and storm-water management based on principles of circular economy, equity, and justice.

Challenges Identified in Water Planning for Large Settlements:

Inadequate and Inequitable Water Supply:

- **Low per capita availability:** Sangam Vihar residents receive only 45 litres per capita per day (LPCD), significantly below the minimum standard for urban settlements.
- **Heavy reliance on alternative sources:** With unreliable piped water, households depend on tankers and borewells, leading to high monthly expenses (up to INR 1,000) for water.
- **Inequity in access:** Disparities exist across Sangam Vihar's 13 blocks; economically weaker areas have lower water availability and limited capacity to purchase potable water.

Vulnerable Sanitation Infrastructure:

- **Non-sewered systems:** Approximately 60,000 properties use underground septic tanks, many of which are perforated at the base, leading to groundwater contamination.
- **Unsafe waste disposal:** Over 200 kilolitres per day (KLD) of septage is desludged, but nearly half is dumped indiscriminately, posing public health hazards.
- **Incomplete sewer network:** While efforts are underway to install sewers, the retrofitting approach risks overloading existing systems, potentially causing blockages and failures.

Inadequate Storm-Water Management:

- **Frequent flooding:** With no designated storm-water infrastructure, greywater drains double as storm drains, leading to overflow and flooding after even brief rainfall.
- **Lack of groundwater recharge:** The absence of open spaces and unpaved areas prevents natural water infiltration, worsening surface runoff and flood risks.
- **Disconnected governance:** Storm-water management responsibilities fall on agencies like the Delhi Metro Rail Corporation (DMRC), which lack the mandate or capacity for holistic water planning.

Solutions and Recommendations:

Rethinking Water Supply Strategies:

- **Decentralised water sources:** Leverage nearby water bodies, recharged with treated wastewater, to create local water reserves, reducing dependence on centralised sources.
- **Augmentation of supply:** Double the current water provision to meet minimum standards, reducing reliance on expensive private water sources.
- **Affordable access models:** Introduce tiered pricing or subsidised rates for economically weaker sections to ensure equitable access to potable water.

Integrated Sanitation Solutions:

- **Hybrid sanitation networks:** Combine centralised sewers with decentralised sewage treatment plants (STPs) to distribute load and prevent systemic failures.
- **Enhanced septage management:** Improve desludging practices, ensure regulated

disposal, and incentivise the sealing of perforated septic tanks to prevent groundwater contamination.

- **Community-led initiatives:** Engage local residents in sanitation management programs, building awareness and encouraging responsible waste disposal.

Sustainable Storm-Water Management:

- **Nature-based solutions:** Introduce permeable surfaces, bio-swales, and rain gardens to promote groundwater recharge and reduce surface runoff.
- **Decentralised drainage systems:** Establish micro-drainage networks that direct storm water to recharge points or holding ponds, minimising flood risks.
- **Policy-driven interventions:** Develop city-wide frameworks for storm-water management, integrating unplanned settlements into broader urban planning strategies.

Sangam Vihar highlights the multifaceted challenges of water-planning in large, dense, unplanned settlements. Traditional retrofitting strategies fall short in addressing the needs of such complex ecosystems. What works is a holistic approach that considers the socio-economic fabric of settlements and promotes context-specific solutions. Inclusive planning that prioritises equity and community engagement is critical to ensure that all urban residents, regardless of economic status, have access to safe water and sanitation.

04

Opportunities for Action in Building a Climate-Resilient Future

Climate change threatens the sustainability of sanitation services, requiring policies and communities to adapt. This section outlines a pathway for transformative change by addressing policy gaps, enhancing cross-sectoral coordination, scaling innovative financing, and integrating climate resilience into sanitation planning, service delivery, and infrastructure.

Policy & Regulatory Frameworks

India has made significant progress in Swachh Bharat Mission-Urban(SBM-U), with cities now advancing towards ODF++ and Water+ certifications, emphasising safe used-water. Recognising sanitation's role in climate resilience, the Government of India is addressing risks like flooding, water scarcity, and disease outbreaks. However, existing policies, such as National Urban Sanitation Policy (NUSP), lack explicit climate integration. Although several central schemes offer funds for urban infrastructure, specific climate resilience measures are not always mandatory.[38] This results in patchwork adoption of flood-proofing or water-reuse models. Some cities leverage public–private partnerships (PPPs) or innovative municipal bonds, but these primarily target coverage expansion rather than "build back better" approaches that account for future climate risks.

Aligning sanitation efforts with India's Nationally Determined Contributions (NDCs) offers a key opportunity to strengthen inter-departmental coordination, revise regulatory frameworks, and embed climate resilience into sanitation planning.

- **Strengthen Policy Alignment:** Update urban sanitation policies and schemes (e.g. Swachh Bharat Mission, Atal Mission for Rejuvenation and Urban Transformation, Jal Jeevan Mission, National Urban Sanitation Policy of India, National Action Plan on Climate Change) to integrate climate resilience, set measurable targets, and align with India's NDCs. Embed climate metrics (emissions reduction, adaptive capacity) in sanitation planning and evaluation (e.g., City Sanitation Plans).

- **Enhance Governance & Coordination:** In addition to the existing state-level climate change cells, establish an inter-departmental "Climate Convergence Cell" to improve collaboration between ULBs, state governments, and central ministries (e.g., MoHUA). Promote multi-stakeholder engagement (government, academia, private sector, civil society) for effective policy implementation.

- **Regulatory, Monitoring & Capacity Building Measures:** Building on the Environmental Information System (ENVIS) and Green Skill development programmes:
  - Mandate climate-resilient infrastructure through updated regulations, ensuring clear guidelines for energy-efficient technologies, renewable energy use, and decentralised treatment.
  - Develop centralised data-sharing platforms for real-time sanitation-climate monitoring.
  - Build capacity through targeted training for local administrators, technical staff, and community leaders.

- **Mainstream Climate Action in the Master Plan:** Integrate mandatory climate adaptation measures into statutory master plans to ensure robust, future-proof urban sanitation services.

- **Focus on Equity in Climate Resilience Policies:** Ensure that climate resilience solutions go beyond infrastructural upgrades and last-mile connectivity by incorporating measures that guarantee equitable access to sanitation services for all, especially vulnerable, marginalised, and underserved communities.

Community and Stakeholder Engagement

Climate-resilient urban sanitation requires community participation and inclusive collaboration. Top-down and one-size-fits-all approaches often fail to address local challenges, while participatory decision-making and structured community engagement strengthens ownership, governance, service delivery, leveraging community knowledge. An example of this is the sustainable Suvidha centres established in Mumbai, which operates on a community-led model and addresses the sanitation, hygiene, drinking water, and laundry needs of over 200,000 low-income urban household users annually.[39]

Community-Based Organisations (CBOs), including women-led groups bridge this gap by mobilising residents and maintaining infrastructure. Strengthening the capacity of CBOs and engaging communities in local governance can enhance accountability and drive equitable, climate-resilient sanitation.

- **Institutionalise Participatory Planning:** Ensure communities have a direct voice in sanitation infrastructure and service priorities. Enable citizen-led data collection and audits (GIS, dashboards, SMS-based tools) for transparency and evidence-based decision-making.

- **Strengthen Community-Based Organisations (CBOs):**
  - Formalise CBO roles in slums and informal settlements.
  - Provide governance and financial training.
  - Promote women's leadership and integrate Menstrual Health Management (MHM) into city policies.
  - Establish leadership rotation mechanisms to sustain participation.

- **Youth & Multi-Stakeholder Engagement:** Engage youth groups in designing and monitoring sanitation solutions, including tech-driven initiatives. Institutionalise city sanitation committees for regular community-government dialogue.

- **Accountability & Local Ownership:** Expand grievance redressal systems and citizen-driven sanitation audits (e.g., jan sunwai models). Provide municipal support for community-run projects to enhance sustainability and climate resilience.

Financial Mechanisms

In 2021-22, India invested 32% of all annual climate finance (USD 21 billion) in the sanitation sector, with 90% coming from public sources.[40] However, the current sanitation landscape is marked by underutilised adaptation funds, with heavy reliance on public-sector financing and limited participation from private investors lacking viable business models or incentives. Climate-specific financial tools, such as green bonds and targeted resilience funds, remain underdeveloped, while the absence of standardised impact measurement complicates efforts to secure and scale investments. Addressing these gaps and aligning new financing mechanisms with broader national and local climate strategies can significantly strengthen urban sanitation systems against growing climate risks.

- **Leverage Climate Financing:** Develop standard metrics for adaptation benefits in sanitation to qualify for climate finance, including carbon credits. City governments should allocate dedicated budgets for climate-resilient sanitation and establish

municipal “climate resilience funds” for more direct access to adaptation financing.

- **Expand Public & Private Investment:** Explore public financing options (e.g., NABARD) and incentivise private-sector participation through tax benefits and risk-sharing mechanisms. Adopt blended finance models that combine public, private, and climate-based resources to scale innovative sanitation solutions, such as the “SHE” toilets in Warangal, Telangana, constructed with CSR support and land from Greater Warangal Municipal Corporation (GWMC) under PPP contract to Safai Karamchari related private entities.

- **Develop Scalable Business Models:** Position sanitation as a viable investment with clear revenue streams, encouraging sustainable market-driven solutions.

- **Adopt Circular Economy Approaches:** Promote used-water reuse and resource recovery to reduce strain on natural resources while unlocking new financing opportunities. Recognise and monetise the potential of methane capture in faecal sludge and used-water treatment by generating carbon credits. This creates an additional revenue stream to offset operational costs and attract further investment.

- **Sanitation-Linked Disaster Insurance:** Develop insurance products specifically designed to protect sanitation infrastructure from floods and droughts. Such products can reduce financial risks and facilitate rapid recovery after climate-induced disasters.

- **Enhance Accountability & Investor Confidence:** Standardise impact measurement methodologies to track adaptation benefits and attract long-term investment.

Technical Innovations

Outdated, centralised infrastructure is ill-equipped to cope with intensifying floods, droughts, and growing urban populations. Limited real-time data and insufficient resilience measures compound the risk of system failures under climate stress. Embracing decentralised solutions, nature-based approaches, and emerging technologies, such as AI-driven monitoring, will not only enhance flexibility and robustness but also extend sanitation coverage more rapidly to underserved areas.

- **Climate-Responsive Infrastructure:** Integrate resilience indicators through thorough assessments and retrofitting into sanitation planning to withstand extreme weather events.

- **Decentralised & Nature-Based Solutions:** Adopt community-level treatment plants and constructed wetlands to reduce reliance on centralised networks and enhance adaptability.

- **Smart Monitoring & Predictive Maintenance:** Leverage AI-powered predictive analytics and IoT-based monitoring systems to forecast used-water flow disruptions and optimise desludging schedules, from regular to scheduled, to mitigate the impacts of floods and droughts and ensure lesser impacts due to methane generation from contaminants.

- **Resource Recovery & Circular Economy:** Invest in technologies that convert waste into energy or reusable products, promoting sustainability and revenue generation.

- **Innovation Hubs & Open-Source Learning:** Establish hubs and training programs to accelerate the deployment of climate-smart sanitation technologies and scale successful models nationwide.

Building a Future-Focused Vision

The path to climate-resilient sanitation is not just about mitigating risks—it is an opportunity to reimagine systems that are adaptive, inclusive, future-ready, and accessible to all. By embedding climate resilience into policies, unlocking innovative financing, and strengthening community leadership, we can build sanitation systems that serve both people and the planet.

Achieving climate resilience in sanitation requires a holistic approach that addresses both the needs of vulnerable communities and the fragility of our infrastructure. As we face increasing climate risks, prioritising equity and strengthening systems is crucial for creating sustainable and inclusive solutions. By integrating climate-resilient policies, promoting nature-based solutions, and fostering community leadership, we can build sanitation systems that not only withstand future climate shocks but also contribute to the well-being of all populations. Now is the time to act, ensuring that sanitation serves as a foundation for resilience, equity, and sustainability for generations to come.

ANNEXURE 1

Additional key terms of simplifying climate and sanitation concepts.

Anthropogenic: Resulting from or produced by human activities.

Anthropogenic Emissions: Emissions of greenhouse gases (GHGs), precursors of GHGs and aerosols caused by human activities. These activities include burning fossil fuels, deforestation, land use and land-use changes, livestock production, use of fertilisers and pesticides, waste management, and industrial processes.

Carbon: Often shorthand for carbon dioxide (CO_2), which is the primary greenhouse gas (GHG) responsible for climate change. GHGs contribute to climate change by trapping heat in the earth's atmosphere, preventing it from escaping into space. This natural process keeps the planet warm enough to support life, but excessive emissions due to human-led activities intensify it, leading to global warming. In broader discussions, 'carbon emissions' can refer to the full range of GHGs.

Circular Economy: An economic model that minimises waste and maximises resource reuse and recycling of resources like water, energy, and materials. In sanitation, this includes reclaiming water, nutrients, and energy from waste streams for use in agriculture or landscaping.

Climate Extremes (Extreme Weather or Climate Event): The occurrence of a value of a weather or climate variable above or below a threshold value near the upper or lower ends of the range of observed values of the variable.

- An event in which a weather or climate variable, such as temperature or precipitation, reaches values near the upper or lower ends of its historical range. Examples include cloudbursts (intense rainfall over a short period), heat waves (sustained high temperatures), cyclones, floods, and droughts. These events, often collectively called 'climate extremes', can vary in severity from place to place and may occur in close succession (e.g., a heat wave followed by extreme rainfall). When such conditions persist over a longer period (such as a season) and produce cumulative extreme outcomes (e.g., prolonged high temperatures, recurring cyclones, heavy rainfall), they are classified as extreme climate events.

Climate Financing: While there is no agreed definition of climate finance, the term 'climate finance' is applied to the financial resources devoted to addressing climate change by all public and private actors from global to local scales, including international financial flows towards developing countries to assist them in addressing climate change.

- Climate finance aims to reduce net GHG emissions and/or to enhance adaptation and increase resilience to the impacts of current and projected climate change.
- Finance can come from private, public, or philanthropic sources, channelled by various intermediaries, and is delivered by a range of instruments, including grants, concessional and non-concessional debt, and internal budget reallocations.

Climate Proofing: Identifying potential climate impacts on infrastructure or policies and taking steps to prevent or minimise those impacts.

Climate Resilient Development: The process of implementing GHG mitigation and adaptation options to support sustainable development for all.

Climate Smart: Approaches or technologies designed to anticipate and address future climatic conditions (e.g., selecting drought-resistant crops, optimising water usage in sanitation).

Climate Vulnerability Assessment: Identifies regions, populations, or systems most at risk from climate change—informing targeted adaptation strategies, especially for essential services like sanitation.

Co-Treatment: The simultaneous treatment of faecal sludge with municipal sewage in an existing sewage treatment plant.

Desludging: The process of removing accumulated sludge from septic tanks, pits, or treatment plants to ensure efficient operation.

Disaster: A serious disruption to the functioning of a community or society, leading to widespread human, material, economic, or environmental losses. While many disasters stem from climate-related hazards (e.g., floods, hurricanes, droughts), disasters may also include events such as earthquakes, tsunamis, or industrial accidents that are not directly linked to climate change.

Energy Efficiency: The ratio of useful energy, energy services, or other useful physical outputs obtained from a system, conversion process, transmission, or storage activity to the energy input. In simpler terms, an efficient system achieves the same or better output while using less energy, reducing waste, and conserving resources.The ratio of output, useful energy, energy services, or other useful physical outputs obtained from a system, conversion process, transmission, or storage activity to the input of energy. Simply put, energy efficiency means getting the same or better output using less energy, reducing waste, and saving resources.

Environmental Impact Assessment (EIA): A process that evaluates the potential environmental (and climate) impacts of proposed projects or policies, guiding decision-making to minimize harm.

Faecal Sludge Treatment Plant (FSTP): The raw or partially digested combinations of excreta and blackwater, in a slurry or semi-solid form, with or without greywater. It is the solid or settled contents of pit latrines and septic tanks.

Green Infrastructure: A subset of nature-based solutions focusing on vegetation-based ecosystems—parks, rain gardens, urban forests—to manage stormwater, reduce heat islands, and improve water quality.

Greenhouse Gases (GHG): Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's surface, by the atmosphere itself, and by clouds. Simply put, greenhouse gases trap heat in the Earth's atmosphere, causing global warming.

Low-Carbon Economy: An economic system geared toward minimal GHG emissions, often reliant on renewable energy and efficient technologies.

On-Site Sanitation: Sanitation systems that contain and treat waste at the point of generation, such as septic tanks or pit latrines.

Recovery: Longer-term rebuilding or rehabilitation to restore and enhance systems post-disaster.

Resource Efficiency: Using water, energy, and materials optimally with minimal waste and pollution—key to both cost savings and environmental protection.

Response: Immediate actions taken during or after a climate event (e.g., emergency sanitation facilities in flood-hit regions).

Retrofitting: Upgrading existing infrastructure to meet new standards or improve efficiency (e.g., adding energy-efficient pumps to older sewage systems).

Sustainable Development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Water Security: The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development.

ANNEXURE 2

Technology Solutions Mapped to Adaptation and Mitigation Goals

Technology Solution	Adaptation Goal	Mitigation Goal
Urine-Diverting Dry Toilets (UDDTs)	Provides sanitation in water-scarce areas	Reduces methane emissions by avoiding anaerobic decomposition in pit latrines
Composting Toilets	Enhances soil fertility in degraded lands, improving food security	Reduces methane emissions from unmanaged human waste decomposition
Biogas Toilets	Provides an alternative cooking fuel in areas with limited energy access	Captures methane from human waste, reducing GHG emissions
Decentralised Wastewater Treatment Systems (DEWATS)	Reduces contamination of water sources in flood-prone areas	Low-energy treatment systems reduce emissions from conventional sewage treatment
Constructed Wetlands for Used-Water Management	Provides flood-resilient treatment options that improve water quality	Natural processes reduce the need for energy-intensive treatment
Solar-Powered Desludging Systems	Ensures sludge removal continues during extreme weather events	Replaces diesel-based desludging, lowering carbon emissions
EcoSan Systems with Nutrient Recovery	Enhances agricultural productivity in climate-stressed regions	Recycles nutrients, reducing reliance on synthetic fertilizers (which have high emissions)
Greywater Recycling Systems	Ensures water availability for non-potable uses (e.g., irrigation) in drought-prone areas	Reduces the energy demand associated with water extraction and treatment
Solar-Powered Water Treatment Systems	Enables water purification during power outages or in off-grid areas	Replaces grid electricity with renewable energy, reducing carbon emissions
Solar Toilets	Provides off-grid sanitation in remote or disaster-prone areas	Eliminates pathogens and converts waste to sterile by-products without emitting methane
Solar Septic Tanks	Improves waste treatment in water-scarce and remote regions	Solar-powered aerators reduce methane emissions from anaerobic waste processing
Low-Flush Toilets	Reduces water use, ensuring functionality during droughts	Lowers emissions by minimizing the energy required for water extraction and supply
Vacuum Toilets	Saves water by reducing the need for flushing, suitable for flood-prone areas	Reduces energy and emissions from water transport and treatment systems

ANNEXURE 3

Further Reading – Resources and References

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The NFSSM Alliance is a collaborative, multi stakeholder platform driving transformative change in India's sanitation sector. It is a national working group comprising 30+ organisations and 120+ experts across India. By harnessing collective knowledge, fostering strategic partnerships, and nurturing innovation, the Alliance works to create an enabling environment for universal, equitable, and inclusive sanitation for all.

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dasra

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National Institute of Urban Affairs

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Urban Management Centre – Making cities work for everyone

WASH Institute – Water Sanitation and Hygiene Institute

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