Ashank Desai Centre for Policy Studies
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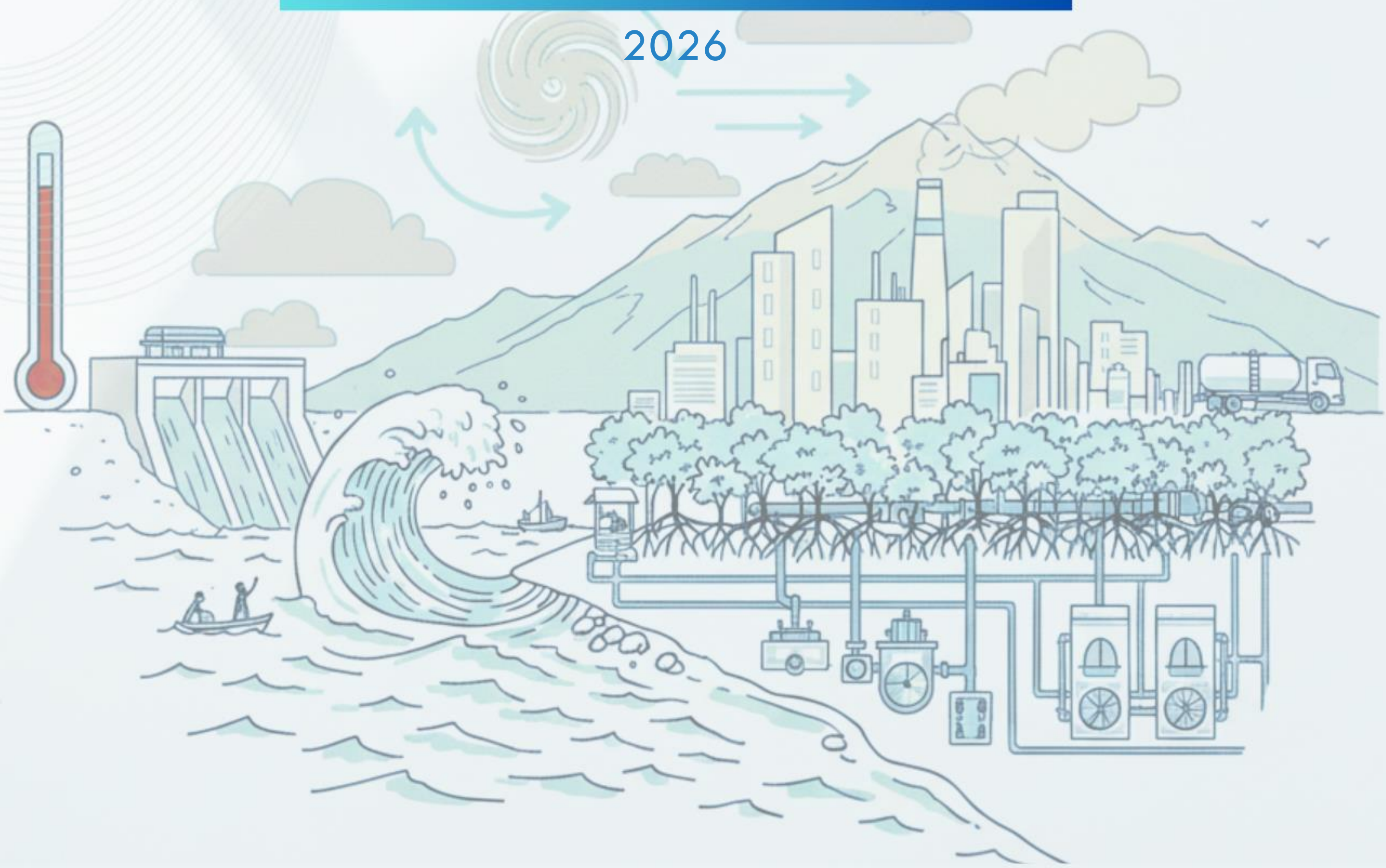
(Report No. CRCC-KA-03-2026)

Towards Climate-Resilient Urban Water & Sanitation Systems

Situational Assessment Report

KARWAR, KARNATAKA

2026



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TITLE

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EXECUTIVE SUMMARY

Climate change is fundamentally reshaping global water systems through more frequent extremes and growing hydrological uncertainty. The resulting impacts threaten water security while escalating risks to lives, critical infrastructure, and ecosystems, with coastal cities at the forefront. Against this backdrop, the 'Climate Resilient Coastal Cities' initiative was initiated by Ashank Desai Centre for Policy Studies (ADCPS), IIT Bombay in collaboration with India Sanitation Coalition (ISC) and CDD India with financial support from HSBC India. Under the initiative, ADCPS, IIT Bombay led the scientific research component and conducted comprehensive situational assessments of the Water and Sanitation Systems in 12 coastal towns across Gujarat, Maharashtra, Karnataka and Karnataka. The primary objective of our assessment is to evaluate the operational and institutional readiness of water and sanitation systems to adapt to an increasingly volatile hydro-climatic regime in these coastal towns. To achieve this, we map the physical water and sanitation infrastructure within the biophysical environment of the city, and evaluate specific risks and challenges to service delivery against local and felt climate realities. Through a comprehensive analysis of greenhouse gas (GHG) emissions, energy footprints, institutional and policy landscape, and municipal finances, the report identifies critical gaps and opportunities for adaptation and mitigation. Rather than prescribing final solutions, this situational assessment provides the crucial evidence base needed to lay the foundation for climate-resilient WaSH futures and to inform future research on actionable, context-specific resilience strategies.

Coastal towns on India's west coast represent extreme cases for analysing the implications of increasing climate variability for urban water security. Unlike the acute disaster risks of the east coast, these towns face chronic, persistent stress: an observed 52% increase in Arabian Sea cyclones since 2001, rapid degradation of protective mangroves, and a reliance on short, seasonal rivers. These towns oscillate between monsoon flash floods and acute summer water scarcity, worsened by saline intrusion into local aquifers. Studying these locations offers critical insights into the long-term resilience challenges that many Indian cities will confront in the coming decades. Our case studies across 12 coastal towns not only highlight the increasing vulnerabilities of existing infrastructure-heavy approaches but also illuminate the pathways forward (figure 1).

The future of urban water security will depend not on a single intervention, but on whether cities can build coherent, adaptive, and low-carbon water systems that align engineering solutions with ecological processes, financial innovation with equitable service provision, and climate foresight with institutional reform.

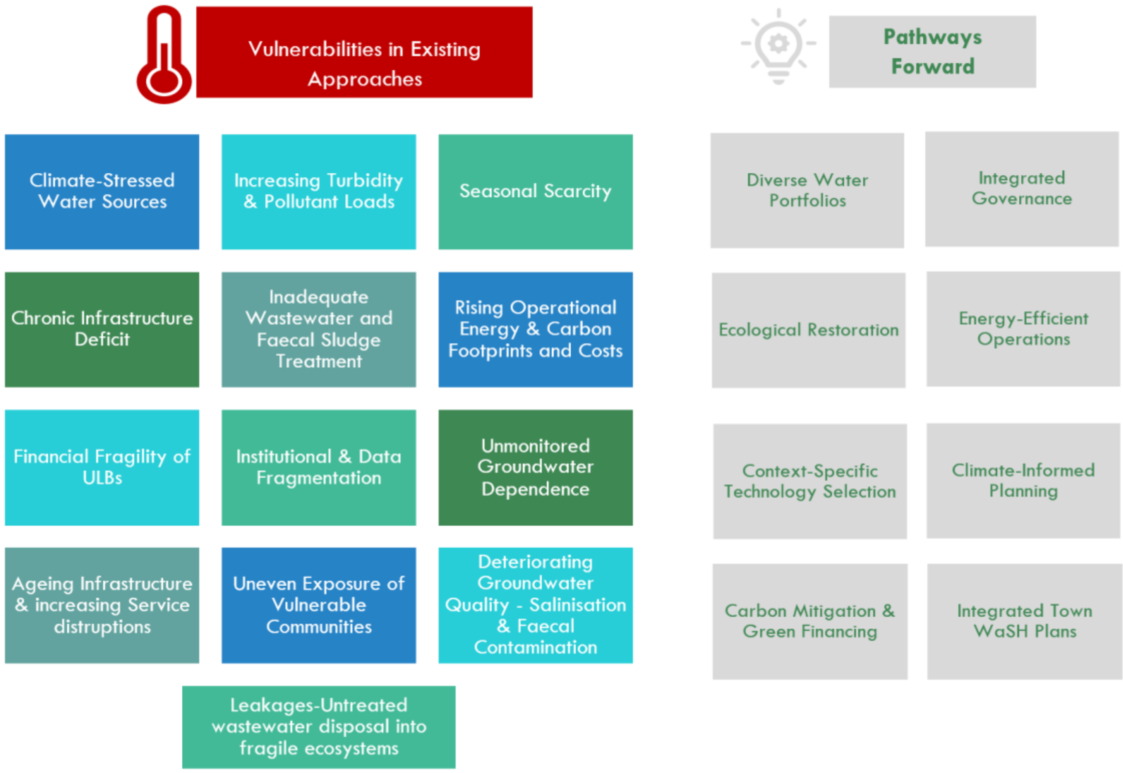

Figure: Systemic Vulnerabilities in existing approaches to WaSH and Pathways forward.

The report presents the study findings for **Karwar**, a Class-II town, in the Uttar Kannada district. Our situational assessment of Karwar's WaSH infrastructure & services from a climate lense, revealed some key challenges:

WATER SUPPLY:

Seasonal Surface Water Volatility and Infrastructure Trade-offs: Municipal reliance on the Gangavali River faces climate-driven seasonal shortages. To secure summer storage, a proposed vented barrage presents significant ecological trade-offs, including land submergence and altered flow dynamics, which are advancing without a comprehensive Environmental Impact Assessment (EIA).

Upstream Fragmentation and Salinity Intrusion: River flow is actively fragmented by upstream agricultural and industrial diversions outside municipal jurisdiction. The consequent reduction in freshwater base flows exacerbates the vulnerability of estuarine aquifers to saltwater intrusion, threatening both groundwater quality and local coastal ecosystems.

Groundwater Overexploitation and Contamination: Despite existing surface water infrastructure, there is a heavy reliance on shallow aquifers, particularly in high-density and low-income wards. These aquifers face pronounced seasonal depletion and widespread faecal contamination, while a low rate of active piped connections masks severe supply vulnerabilities.

Coastal Hydrometeorological Vulnerabilities: As a low-elevation coastal town, Karwar is highly exposed to sea-level rise, storm surges, and extreme rainfall. These hydrometeorological extremes threaten shoreline water infrastructure, overwhelm existing drainage systems, and elevate public health risks through the contamination of household wells during flood events.

Network Misalignments and Capacity Constraints: Although the municipal water network was designed for a 10 MLD capacity, current active connections remain notably low. Uncalibrated urbanisation and the scaling up of tap connections risk exposing older network infrastructure to severe pressure fluctuations, leakages, and inequitable distribution across growing wards.

SANITATION:

Affordability Barriers and Low Network Connectivity: High user charges for desludging and steep upfront costs for underground drainage (UGD) connections actively deter household adoption. This financial barrier contributes to a markedly low sewerage connection rate (currently 13%) and drives residents towards unsafe onsite containment methods, such as unlined pit latrines, which elevate the risk of groundwater contamination.

Operational Failures in Centralised Infrastructure: The existing sewage treatment plant (STP) and its associated network suffer from critical maintenance and operational deficiencies. Field observations highlight non-functional wet wells and improperly sited treated-water storage structures that allow sludge accumulation, frequently resulting in the direct discharge of untreated blackwater into coastal stormwater drains.

Inadequate Septage and Onsite Management: Given the low sewerage network coverage, the absence of a dedicated Faecal Sludge and Septage Treatment Plant (FSSTP) represents a critical structural gap. The widespread reliance on unscientific household pits and poorly managed public toilets, particularly in high-water-table areas, exacerbates local contamination risks and underscores the need for formalised septage management.

Climate Vulnerability of Sanitation Assets: Sanitation infrastructure exhibits high vulnerability to coastal and hydrometeorological extremes. Prolonged high tides frequently flood and disrupt STP operations, while elevated coastal salinity accelerates the corrosion of critical metal components. Furthermore, monsoon inundation severely overwhelms the network, contrasting sharply with acute operational challenges during summer water scarcity.

Financial Constraints and Capital Dependency: The Urban Local Body (ULB) operates under a heavily grant-dependent financial model, maintaining a critically low cost-recovery rate (25%) for sanitation services despite high collection efficiencies. This structural fiscal deficit restricts long-term operation and maintenance capabilities, a strain further compounded by mandates requiring high local financial contributions for national initiatives such as the Swachh Bharat Mission (SBM 2.0).

ENERGY USE & GHG EMISSIONS:

Carbon Intensity of Surface Water Conveyance: The bulk of municipal water relies on a highly energy-intensive supply chain, primarily driven by the long-distance lifting of water to elevated storage (the Mother Tank). This conveyance stage alone consumes over 3,000 MWh annually, generating more than 2,100 tonnes of CO_2. Without integrating renewable energy or gravity-fed efficiencies, this infrastructure locks the town into a high-emission trajectory.

Low-Emission Potential of Groundwater: In sharp contrast to surface water operations, local groundwater extraction presents a markedly lower carbon footprint. Drawing from shallow aquifers (averaging a depth of 5 metres) requires just 106 MWh per year, resulting in only 76 tonnes of CO_2 emissions. This disparity highlights the strategic value of incorporating sustainable groundwater management into a hybrid municipal supply matrix.

Methane Dominance from Onsite Containment: The sanitation sector's greenhouse gas profile is heavily dominated by methane emissions from anaerobic onsite systems. Lined and unlined soak pits generate an estimated 4,602 tCO_2e annually, while septic tanks contribute 3,114 tCO_2e. Additionally, the disposal of sludge in drying beds at the central treatment facility generates 470 tCO_2e, identifying faecal sludge management as a critical emissions hotspot requiring urgent intervention.

Hidden Climate Impacts of Greywater Discharge: Nitrous oxide (N_2O) emissions from untreated greywater represent a significant, yet frequently overlooked, climate risk. The unchecked discharge of nitrogen-rich greywater into municipal stormwater drains and estuarine environments generates over 1,100 tCO_2e annually (combined from both onsite and network-connected households), highlighting a critical gap in integrated wastewater planning.

FINANCIAL HEALTH:

Revenue Instability and Collection Deficiencies: The municipality exhibits a highly volatile cost recovery rate, which plummeted to 45% during the 2020-21 period. Revenue generation is actively undermined by inconsistent collection efficiencies—dropping to 35% in 2017-18 with projected declines to 49% by 2024-25—driven by outdated billing systems, public resistance to tariff adjustments, and weak enforcement of payment compliance.

Escalating Operational Pressures: Financial strain is exacerbated by compounded operational inefficiencies, notably high volumes of non-revenue water, escalating energy tariffs, and fluctuating bulk water purchase costs. These mounting day-to-day expenses continually outpace internal revenue generation, driving sustained operating and fiscal deficits across the utility.

Structural Grant Dependency: Both the water and sanitation sectors demonstrate an unsustainable reliance on external central and state government grants, which have become increasingly erratic post-2020. Internal revenue generation remains heavily reliant on one-time underground drainage (UGD) connection fees—yielding an exceptionally low own-revenue-to-grant ratio of just 0.03—leaving the municipality highly vulnerable to unpredictable funding cycles.

Capital and Operational Expenditure Imbalance: While municipal spending structurally prioritises new capital infrastructure development, fluctuating per capita capital expenditure is accompanied by a severe underfunding of routine operational and maintenance requirements. This systemic failure to balance capital investment with day-to-day operational spending directly jeopardises the long-term functionality and sustainability of municipal services.

Conclusion: Strategic Outlook and Gap Identification

The situational assessment of Karwar highlights the severe vulnerabilities of a low-elevation coastal municipality locked into an energy-intensive, centralised utility model while facing acute hydrometeorological extremes. The town's heavy reliance on distant surface water conveyance and grant-dependent sanitation infrastructure is increasingly misaligned with its fragile estuarine geography and severely constrained fiscal capacity. This structural mismatch not only exacerbates the municipal carbon footprint—driven by long-distance pumping and pervasive methane emissions from inadequate onsite containment—but also deepens financial deficits through escalating operational costs and consistently poor cost recovery. Moving forward, navigating these compounding climate and economic risks requires a strategic shift towards integrated, climate-resilient stewardship. The municipality must pivot away from a singular dependence on vulnerable surface water and erratic external funding, focusing instead on a hybrid supply model that safely integrates local groundwater alongside the formalisation of decentralised faecal sludge management. By prioritising billing reforms to stabilise internal revenue and adapting existing infrastructure to withstand coastal flooding, Karwar can bridge its operational financing gap and secure a sustainable, low-carbon pathway for urban service delivery.

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1. URBAN WATER & SANITATION SYSTEMS IN A CHANGING CLIMATE

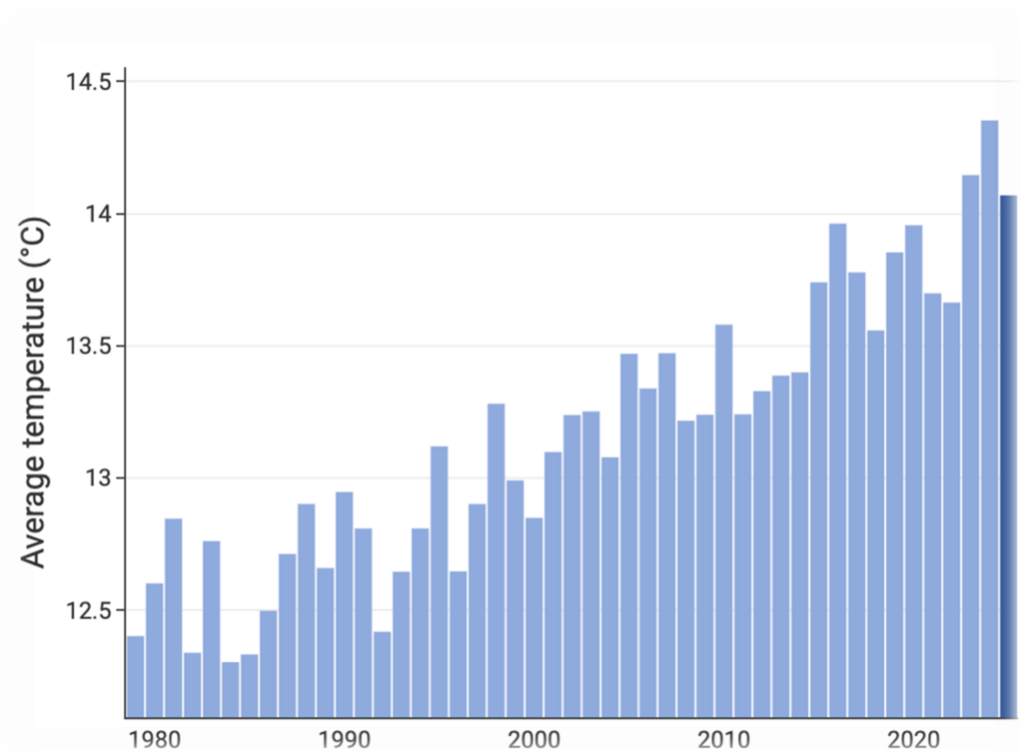
ASHISH DANGI, NEELAM RANA, N.C. NARAYANAN AND PRIYAKSHI GOGOI

This chapter establishes the universal climate-WaSH context and methodology utilised for our study of 12 coastal towns in India. It examines the impact of an intensifying global water cycle on urban water security, focusing on the emerging climate risks along India's West Coast. It is a shared chapter across all reports in this series. Town-specific findings begin in Chapter 2.

1.1 BACKGROUND

The global average air temperature over land shows a significant rising trend over the past decades with 2025 recorded as the third hottest year[1] (*Figure 1*). The persistent warming of the atmosphere effectively turns it into a larger sponge that can hold more water.

Figure 1:Global annual average land temperature (1979-2025).



Data Source: Global Water Monitor[1]

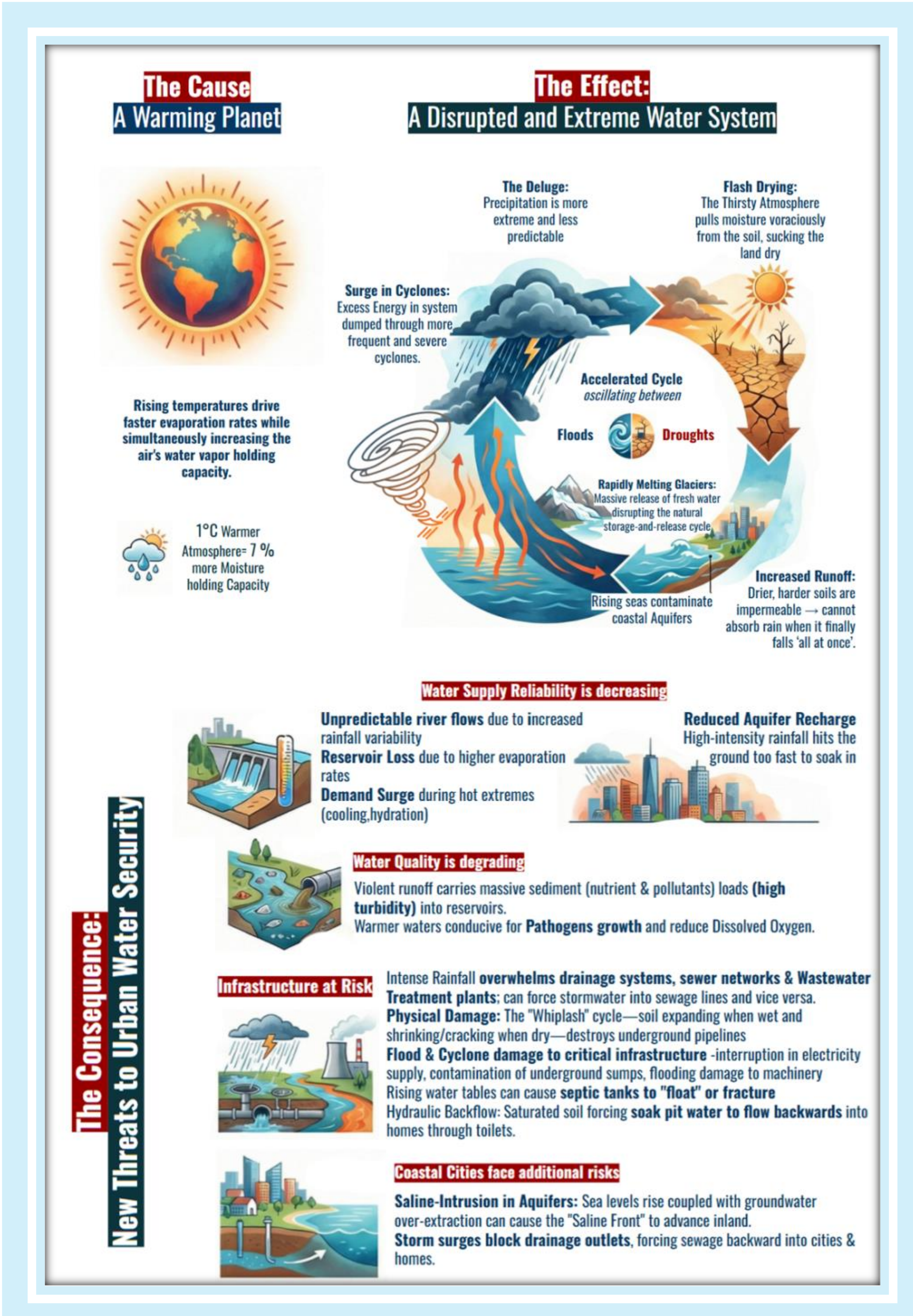
This leads to a volatile cycle: during dry periods, the 'thirstier' atmosphere aggressively evaporates moisture from soil and reservoirs, deepening drought conditions. However, once this moisture-laden air is triggered to release by a cyclone or orographic lift, it discharges with explosive intensity. Thus, cities are confronted with a dual reality referred to as the *climate whiplash*: longer, more intense dry spells that threaten source sustainability, interspersed with violent, short-duration rainfall events that overwhelm drainage infrastructure. These hydro-climatic shifts due to intensification of the hydrological cycle, destabilise water availability while escalating the threat of water-related disasters to human lives, critical infrastructure, and natural ecosystems. In fact, these hydrological extremes now constitute some of the most tangible and widespread impacts of climate change.

Between 2001 and 2018, over 74% of global natural disasters were water-related, causing over 300,000 fatalities and ~ 1.7 trillion USD in economic damages worldwide causing immense human and economic losses[2,3]. Global Climate Risk Index 2021 ranks India as the seventh-most exposed and vulnerable country to climate extremes[4]. With high risk of concurrent flood incidents, the country is among the most vulnerable countries to climate change as per Intergovernmental Panel on Climate Change (IPCC) sixth assessment report. More than 300 extreme events have hit the country in recent decades, causing losses of more than INR 5,600 billion[5]. A recent evaluation indicates that more than 75% of districts in India, including 95% of coastal districts, are hotspots for extreme events.[6]

However, focusing solely on these acute disasters obscures the more insidious, *long-term erosion of water security* that cities now face. The fundamental shift in the hydrological baseline is creating a crisis of chronic unreliability. The rising temperatures on one hand result in a surge in water demand and volatility in water availability on the other. Furthermore, warmer temperatures actively degrade water quality by promoting algal blooms and reducing dissolved oxygen levels, meaning that even when water is physically available, it is increasingly difficult and energy-intensive to treat. Ultimately, these shifts threaten to render conventional infrastructure obsolete, transforming water security from a manageable operational challenge into a persistent existential risk for growing urban populations.

Figure 2 illustrates the intensification of the water cycle driven by global warming and its cascading consequences for urban water security. A disrupted natural system reduces reliability of water supply, degrades water quality and places infrastructure at risk. Coastal cities are particularly vulnerable in this changing regime, facing compounding threats from surging cyclones, sea-level rise, and storm surges that overwhelm drainage networks and force saline intrusion into freshwater aquifers.

Figure 2:Intensification of the water cycle due to global warming and its impact on urban water security.



Source: Author's Illustration

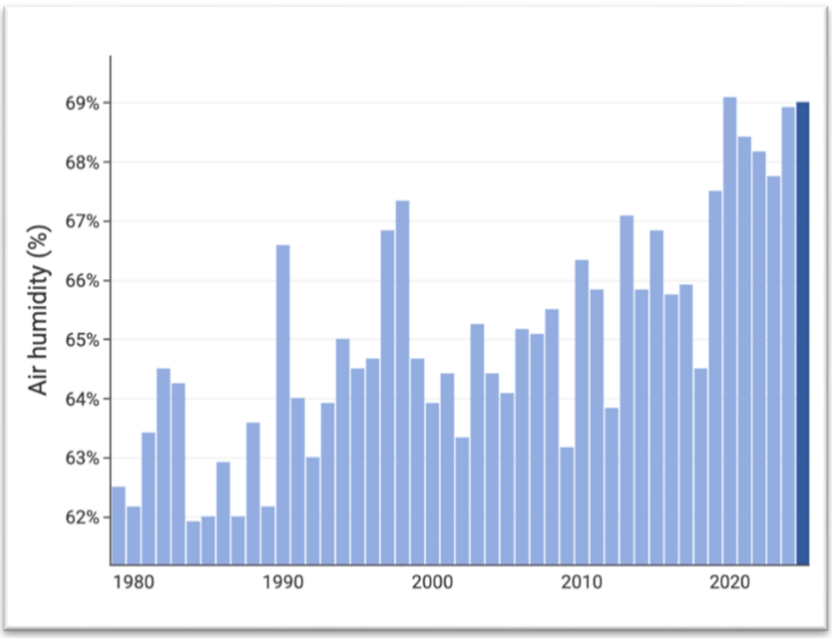
Nowhere are these hydro-meteorological shifts more immediately felt than in coastal cities, where land, ocean, and atmospheric systems intersect. The rapid retreat of glaciers and ice cover is causing sea levels to rise at unprecedented rates, further compromising the water availability and quality in coastal areas[7]. More intense rainfall combined with rising sea levels amplify storm surges, salinity intrusions and surface run-off placing coastal settlements at heightened risk. These shifts not only impact freshwater resources but also exacerbate existing vulnerabilities to flooding and inundation. A warmer atmosphere and ocean provide additional energy for storm intensification, leading to a greater number of extreme weather events. Cyclones, in particular, pose catastrophic threats not just to lives and infrastructure, but to the very backbone of urban resilience: access to WaSH. By damaging water supply and wastewater infrastructure, such events jeopardise public health and disrupt the essential services that coastal cities rely on, placing them at even greater risk. These hazards compound the existing pressures of urbanisation, placing critical water infrastructure under significant stress and exposing vulnerabilities in already stretched systems. These new risks are especially critical in India, where approximately 18% of its population resides in 72 coastal districts[8].

This escalating hydro-climatic volatility inevitably converges on Water management, particularly in cities, where dense populations, concentrated infrastructure, and increasingly fragile ecosystems intersect. Urban water systems spanning water supply, wastewater management, drainage, and groundwater regulation, were designed for a different climatic reality and are now struggling to cope. For instance, the January 2025 wildfires in Los Angeles exposed critical vulnerabilities in urban water systems. Firefighting efforts were crippled when water storage tanks ran dry; officials acknowledged the system was "designed to put out house fires, not multiple neighbourhoods on fire"[9]. Traditional management focused solely on balancing supply and demand becomes obsolete. Instead, WaSH systems must evolve into adaptive instruments for disaster preparedness and public health. In an era of uncertainty, safeguarding urban liveability requires transforming these interdependent systems to withstand the dual threats of chronic scarcity and acute extremes, *making resilient WaSH infrastructure the cornerstone of sustainable cities.*

1.2 THE RISING CLIMATE THREAT TO INDIA'S WEST COAST

The West Coast of India is rapidly emerging as a new frontier of climate risk, driven by a dangerous synergy between the warming Arabian Sea and the region's unique topography. While the Bay of Bengal has historically been the more active basin, recent data reveals a paradigm shift: the Arabian Sea has witnessed a 52% increase in the frequency of cyclonic storms and a threefold rise in very severe cyclonic storms during the recent epoch (2001–2019).[10] This intensification is fuelled by rising Sea Surface Temperatures and Ocean Heat Content, which act as a massive "moisture pump" ensuring a constant supply of water vapour to the warming air with a greater water holding capacity[11]. This is corroborated by long-term atmospheric data showing a sharp surge in India's average annual air humidity, particularly in the 2020s where levels have consistently exceeded 68% (*Figure 3*). When this moisture-laden air intercepts the steep barrier of the Western Ghats, the resulting orographic lift triggers explosive, high-intensity rainfall events.

Figure 3: Annual time series of air humidity over Indian landmass.



Data Source: Global Water Monitor Data Explorer[12]

Along India's west coast, the coastal districts of Gujarat specifically have become increasingly vulnerable to tropical cyclones in recent years[13]. Further, west coast states are more exposed to sea level rise; every one-metre rise in sea level can inundate almost 5,763 km^2 of land[14]. Making the west coast more susceptible to coastal flooding and cyclones is the significant loss of the complex mangrove ecosystem, which will continue to increase beyond 2100 as per IPCC 2023 report[15].

Furthermore, historically established as fishing villages and trading posts near river mouths or perched along the slopes of the Konkan and Sahyadri mountains, the coastal settlements have evolved into thriving industrial hubs, port cities, and tourist centres. The region's undulating terrain, fragile slopes, rising sea levels, erratic weather patterns, and increasing cyclonic activity exacerbate its vulnerability. Challenges such as land submergence, wave shoaling, shoreline erosion, salt intrusion, groundwater flooding, and coastal inundation are increasingly evident. These threats contribute to environmental degradation, contamination of land and water, disruptions in essential services, and potential infrastructure failures.

1.3 SYSTEMIC VULNERABILITIES AND THE CLIMATE MULTIPLIER EFFECT

Densely populated coastal cities have long grappled with rising demand amid diminishing water availability. Over the years, infrastructure expansion, intensified water pumping, and landscape modification became embedded in policy and practice as conventional approaches to water management. Yet these approaches often degrade natural environments both within and beyond city boundaries. Water flows are altered through water extraction, river diversions, reservoir construction, and flood control measures. Impermeable built surfaces reduce rainwater infiltration and groundwater recharge, while the loss of vegetation disrupts processes like transpiration that help sustain the natural water cycle. At the same time, cities generate massive amounts of wastewater that flows back into the natural cycle, often untreated and poorly managed. In their determined efforts to cope up, cities have often compromised the very ecosystems they depend upon. In the water-stressed context of India, short-term needs are often understandably prioritised over long-term sustainability particularly for a need as vital as water: the lifeblood of urban life. However, this trade-off may no longer be tenable.

Even without climate pressures, water management in Indian cities faces deep structural challenges: widening demand–supply gaps, shrinking freshwater sources, falling groundwater tables, and the degradation of rivers, wetlands, and aquifers. Conventional approaches such as large dams, long-distance water transfers, deeper extraction, and engineered flood-control measures, have historically prioritised short-term supply augmentation at the expense of ecological stability.

The consequences are far-reaching:

- *Altered river flows and disrupted drainage systems* due to unplanned urban development
- *Low groundwater recharge* caused by impermeable surfaces
- High dependence on *energy-intensive pumping*, increasing carbon emissions
- *Large volumes of untreated wastewater* discharged into rivers, seas, and aquifers
- *Increased vulnerability to floods and salinity intrusion* as coastal ecosystems such as mangroves and estuaries decline

As a result, urban water systems across India operate under chronic stress, with climate change amplifying existing weaknesses and introducing new, compounding risks.

Further exacerbating the risks posed by climate change is the inadequate infrastructure and services in critical areas such as housing, sanitation, water, and public health, particularly for socio-economically disadvantaged groups[16,17,18,19] and are now exposed to climate change-related risks.

Governance and Policy Gaps: A Structural Barrier to Resilience

Despite clear evidence of climate impacts, policy responses across water, energy, and urban development remain fragmented. Governance arrangements continue to operate in sectoral silos:

- *Water policies* focus on augmenting supply rather than reducing demand or building resilience.
- *Energy policies* rarely account for the energy footprint of WaSH services and the water footprint of energy generation and distribution.
- *Climate strategies* frequently overlook the carbon footprint and vulnerabilities of water and wastewater infrastructure.

Urban Local Bodies (ULBs) face chronic financial and technical capacity constraints. Many rely on ad-hoc, project-driven solutions that respond to immediate complaints but do little to address systemic vulnerabilities. Institutional inertia, overlapping jurisdictions, and limited accountability impede long-term planning. Meanwhile, the most severe impacts are disproportionately borne by marginalised communities, deepening socio-spatial inequities.

Without integrated governance mechanisms, cities remain locked into cycles of over-extraction, infrastructure stress, ecological decline, and rising climate vulnerability. For comprehensive insights on policy landscape refer to our policy analysis reports.

1.4 REIMAGINING URBAN WATER RESILIENCE IN THE FACE OF CLIMATE CHANGE

Climate change on one hand, underscores the urgent need for effective urban water management to enhance the health resilience of populations and mitigate its impacts on cities. On the other, it intensifies existing water-related challenges brought by urbanisation, threatening the sustainability of urban water systems. As temperatures continue to rise, conventional water management approaches focused on large-scale infrastructure, and reactive coping strategies may prove insufficient under these compounded pressures. In fact, such strategies could worsen long-term vulnerabilities by disrupting the natural water cycle, especially in fragile coastal ecosystems.

Climate change thus acts as a wake-up call, urging policymakers to reassess the fragile relationship between urban water systems and the natural water cycle. Ensuring long-term water security and resilience demands a new paradigm that not only addresses the immediate impacts of climate change but also strives to harmonise existing water systems with natural cycles.

With this understanding, a study titled *"Landscape analysis for four coastal states on climate resilient water and sanitation infrastructure"* was initiated under the Climate Resilient Coastal Cities (CRCC) initiative financially support by HSBC India. The study focuses on evaluating the existing water and sanitation systems in the backdrop of emerging climate realities in12 coastal towns across Maharashtra, Gujarat, Karnataka, and Karnataka (*Figure 4*).

Figure 4: Case study towns across 4 west coastal states of India

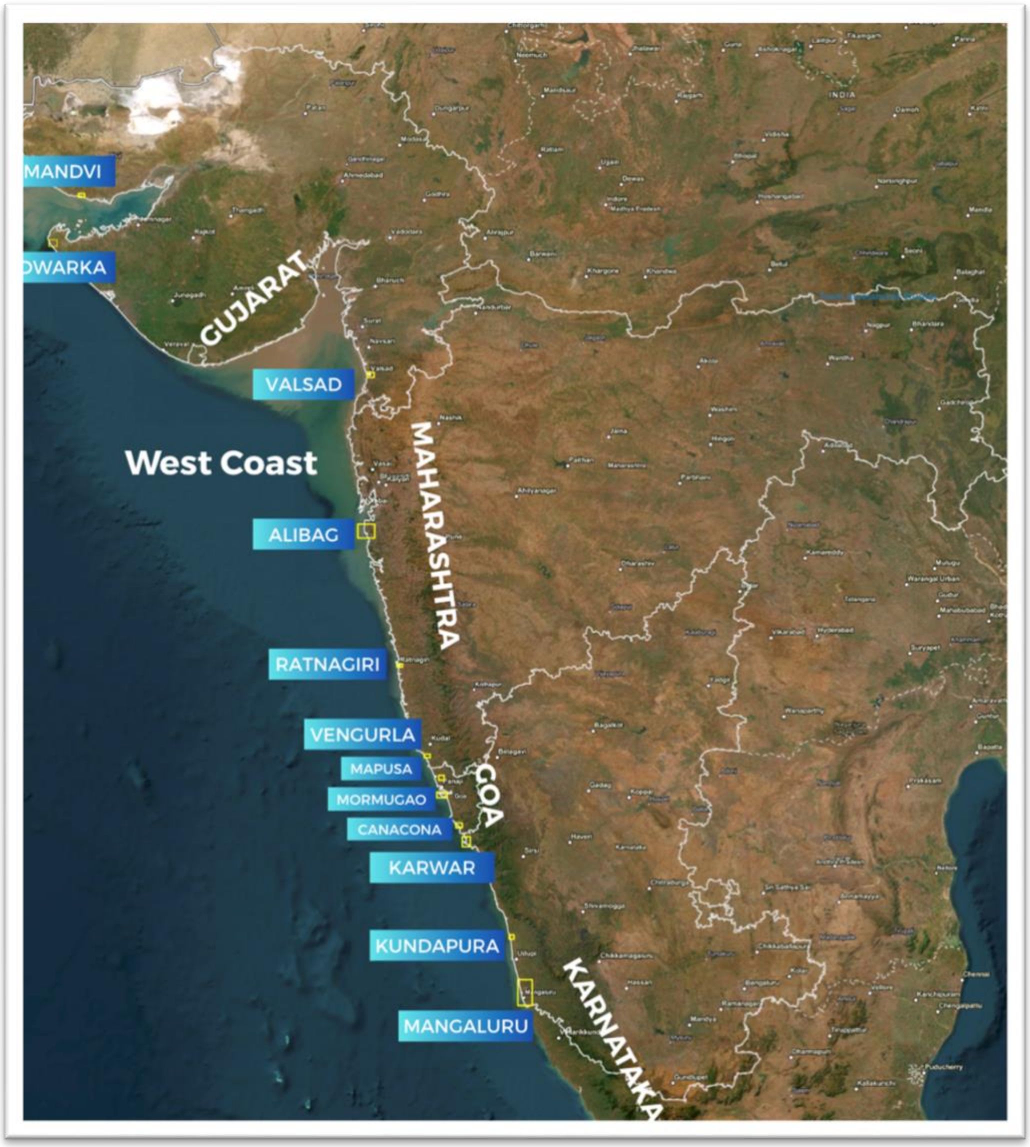


Image Source: Author's Illustration

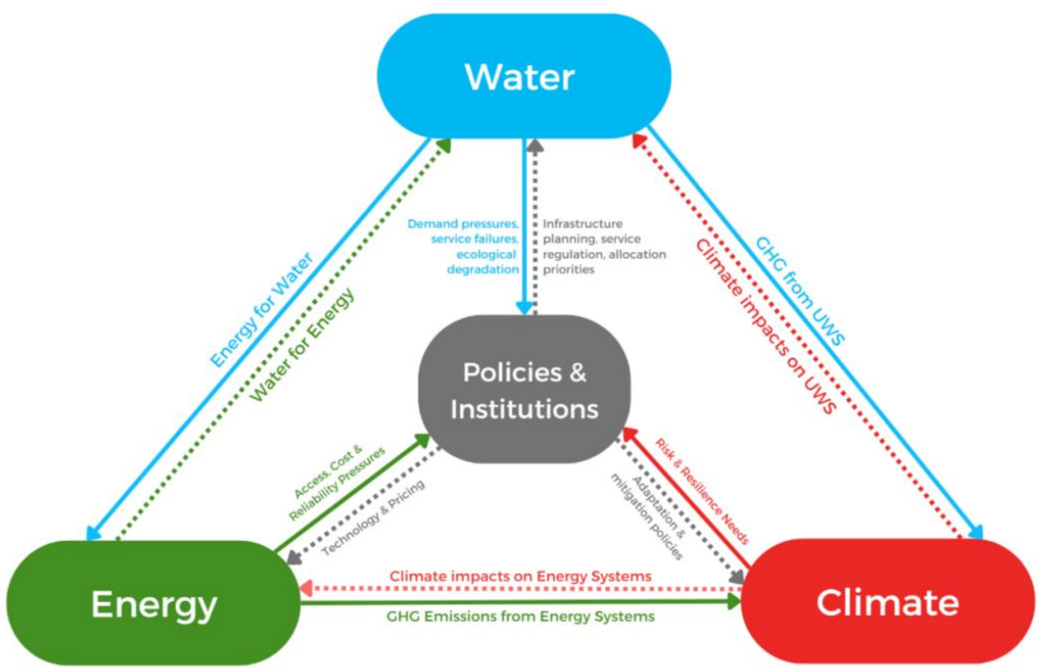
1.5 METHODOLOGY

The *primary objective* of our study is *to assess the operational and institutional readiness of the Urban Water & Sanitation sector to adapt to a changing hydro-climatic regime*, while identifying pathways for low-carbon and sustainable service delivery. The methodology is structured to build a cumulative evidence base, moving from baseline profiling to detailed diagnostics and resilience evaluation.

1.5.1 ANALYTICAL FRAMEWORK

The process begins with a systematic literature review to establish the analytical framework governing the interaction between climate impacts and water and sanitation (WaSH) infrastructure.

Figure 5: The Water-Energy-Climate Nexus in urban water systems.



Source: Author's Illustration

Our methodological approach is grounded in a systems-thinking framework that conceptualises urban water and sanitation (WaSH) not as an isolated sector, but as a dynamic component of the Water-Energy-Climate nexus. As illustrated in *Figure 5*, this approach evaluates the bi-directional interactions between these three critical domains, all of which are mediated by central governance structures.

The framework is structured around four primary nodes and their interacting flows:

1. ***The Water-Climate Interaction:*** The framework assesses the dual relationship between WaSH infrastructure and climate change. It evaluates the physical climate impacts on Urban Water Systems (UWS) such as extreme weather events, altered hydrological cycles, and coastal hazards while simultaneously quantifying the GHG emissions from UWS, establishing the carbon footprint of current water management practices.

2. ***The Water-Energy Interdependency:*** It maps the resource interdependencies, specifically focusing on the Energy for Water requirement. This involves auditing the energy intensity of extracting, treating, and distributing water, as well as conveying and treating wastewater.

3. ***The Energy-Climate Linkage:*** The framework acknowledges that the energy systems powering WaSH are themselves vulnerable to climate impacts, while their baseline GHG emissions dictate the overall carbon intensity of the urban water cycle.

4. ***Policies & Institutions:*** Placed at the core of the framework, institutional governance acts as the primary mediating force. The framework analyzes how governing bodies respond to systemic stressors such as demand pressures, ecological degradation, and risk/resilience needs and how they shape the physical systems through infrastructure planning, resource allocation, technology pricing, and the implementation of adaptation and mitigation policies.

By applying this holistic framework, the situational assessment moves beyond simple infrastructure mapping. It allows us to systematically identify operational vulnerabilities, calculate environmental footprints, and evaluate the institutional readiness required to build climate-resilient WaSH systems.

1.5.2 TOWN SELECTION CRITERIA

The town selection followed a two-step process. First, a set of criteria was developed through a comprehensive literature review (*outlined in Table 1*). These criteria were designed to ensure diversity among the case study towns in terms of WaSH infrastructure and services, geography, demographics, and climate vulnerability, administrative status, thus enabling a more representative and contextually grounded analysis.

- **Current understanding of climate risks:** The selection process considered the known climate risks each town faces, as these are critical for assessing the vulnerability of WaSH infrastructure to climate-related hazards.

- **Variation in infrastructure and urban characteristics:** Towns were selected to reflect diversity in water and sanitation infrastructure and service levels, population size, climatic conditions, and economic activities—factors that influence exposure and adaptive capacity and GHG emissions.

- **Socio-economic profile:** Differences in socio-economic conditions lead to varied water consumption and sanitation practices. These factors are crucial for understanding a town's climate resilience and estimating GHG emissions in the WaSH sector.

- **Administrative status:** The administrative status of a town significantly influences its capacity for climate change planning and response, especially in critical sectors like water and sanitation. Towns with higher administrative status—such as municipal corporations or class-I and beyond—tend to have greater autonomy, better institutional structures, and access to financial and technical resources. They are more likely to have dedicated departments, skilled personnel, and the ability to integrate climate considerations into urban development plans. These towns also benefit from larger budgets, greater revenue-generating powers, and enhanced eligibility for national and international funding schemes focused on climate adaptation and mitigation. In contrast, smaller towns or panchayats often rely heavily on state or district-level agencies, leading to delays in planning and implementation. Moreover, higher status towns typically have better data systems and monitoring capabilities, which are essential for assessing climate risks and emissions. Their greater political visibility further enhances their chances of being included in pilot projects or targeted policy interventions. Thus, a town's administrative status directly shapes its ability to design and implement effective, context-specific climate-resilient infrastructure and services.

The above process generated a preliminary list of towns, from which the final selection was made in consultation with the state Directorates of Swachh Bharat Mission Urban (SBM-U).

Table 1:Town Selection Criteria

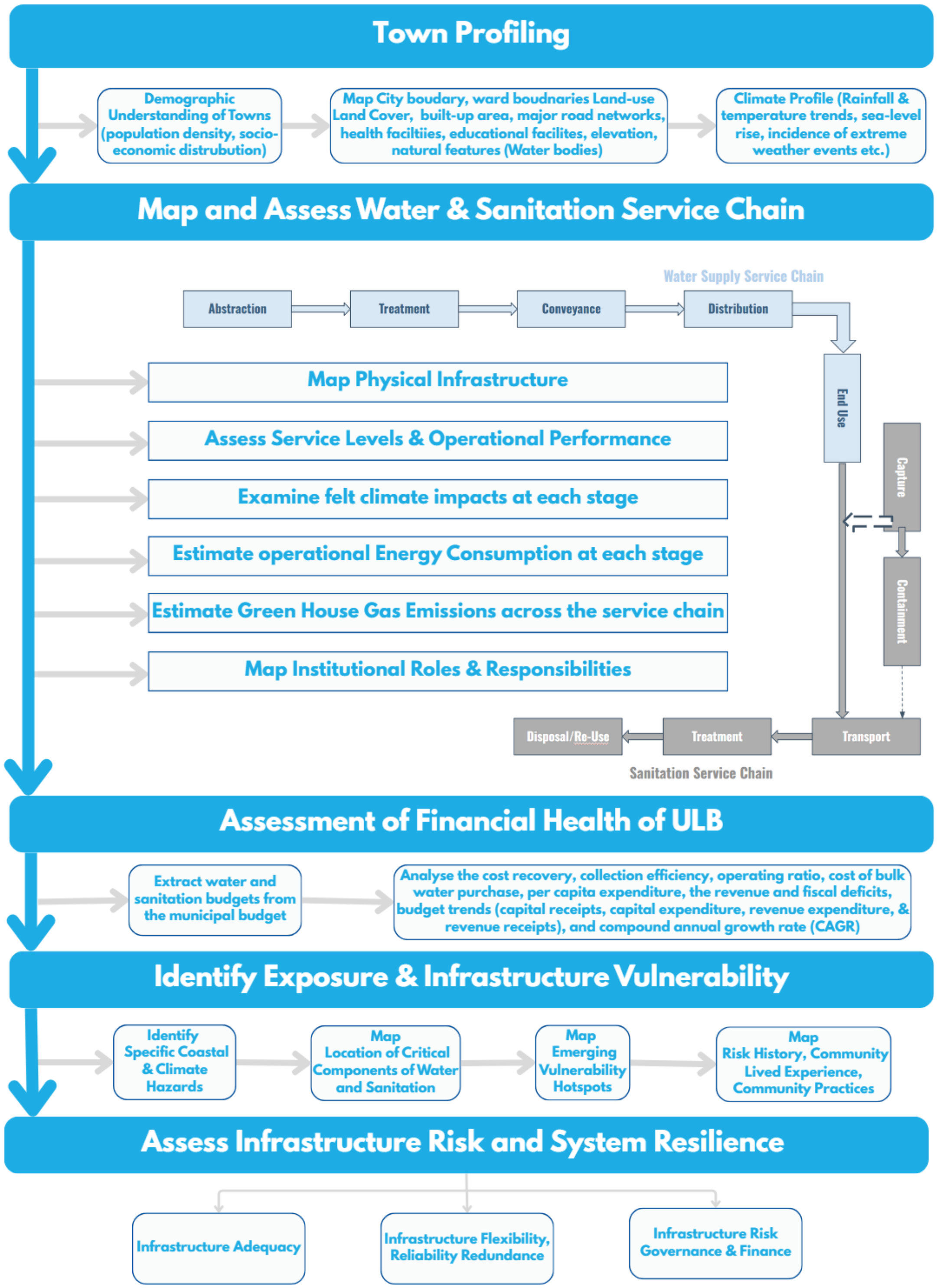
Key Parameters	Selection criteria		
Administrative status	Municipal Corporation	Municipal Council (A and B)	Nagar Panchayat (C and D)
City Size based on population	Class-I to Class IV		
Socio-economic profile	Capturing variability in socio-economic profile of the town population		
Climate Change Exposure and vulnerability	Low Risk/vulnerable	Medium Risk/vulnerable	High Risk/vulnerable
Sanitation Infrastructure Services Status	Only On-site Sanitation	OSS + % networked system	OSS+ % networked + Non-networked (NBS/ Conventional/ FSSTP)
Economic Contributions /Profile	Industrial, agricultural, tourism, service sectors		
State government and ULB support	Past and current partnerships, collaborations		

Table 2 : Selected Towns

State	Town	Population (2011)	Class
Maharashtra	**Alibag**	20,743	Class-III
	Ratnagiri	76,229	Class-II
	Vengurla	12,392	Class-IV
Karnataka	**Mangaluru**	4,99,487	Class-I
	Kundapura	30,444	Class-III
	Karwar	77,139	Class-II
Goa	**Canacona**	12,434	Class-IV
	Mormugao	94,393	Class-II
	Mapusa	39,989	Class-III
Gujarat	**Dwaraka**	38,873	Class-III
	Mandvi	51,376	Class-II
	Valsad	1,70,060	Class-I

1.5.3 STEP-BY-STEP APPROACH TO SITUATIONAL ASSESSMENT

Figure 6: Methodological framework for the situational assessment and resilience evaluation of urban WaSH systems.



As illustrated in *Figure 6*, our town-level situational assessment follows a logical, multi-step progression that begins with town profiling to establish demographic, spatial, and climatic baselines. We then map the entire water and sanitation service chain to evaluate physical infrastructure, operational performance, environmental footprints, and institutional responsibilities. This is followed by a financial health assessment of the Urban Local Body to analyse municipal budgets and expenditure trends. Next, we identify specific vulnerabilities by mapping coastal hazards against critical infrastructure locations and emerging risk hotspots. These steps finally culminate in a comprehensive resilience assessment that evaluates the overall adequacy, flexibility, reliability, and financial risk governance of the system.

1.5.4 DATA COLLECTION

To assess the resilience of water and sanitation infrastructure, the study employed a mixed-method approach combining extensive desk-based research with targeted fieldwork. Initial reviews of national and municipal datasets (e.g., Census, SBM-U) established the analytical framework and identified critical data gaps, which were subsequently addressed through stakeholder consultations with ULB and state-level officials. This was complemented by on-ground validation, including technical site visits to key infrastructure assets (WTPs, reservoirs) and rapid assessments of vulnerability hotspots, where semi-structured interviews with residents provided critical insights into service delivery challenges and local climate impacts. Detailed data collection steps and questionnaire for ground truthing (resident interviews) are provided in Annexure-I of the report.

The study also identified several critical data gaps that limit comprehensive assessment and effective decision-making. These gaps, detailed in Annexure-II, highlight the need for improved data collection, systematic reporting, and stronger integration of information across institutions to better inform future planning and resilience-building efforts.

This situation assessment report presents the study findings for ***Karwar,*** **a Class-II coastal town in Karnataka's Uttara Kannada district with a population of approximately 63,755 (Census 2011), situated in one of the four most climate-vulnerable states in India**[20]**.** The report primarily examines the town's adaptive capacity in the water and sanitation sector amid climate change and assesses the sector's GHG emissions to inform the risk assessment of climate change impacts on its infrastructure and services.

Karwar lies between the Arabian Sea and the Western Ghats. The coastal plains of Karwar are relatively narrow, quickly transitioning into hilly and forested terrain as they extend inland. These plains, in which the city is located, support both agriculture and urban settlements and is adjacent to the Kali River estuary. *Karwar faces significant challenges due to its tropical monsoon climate, increasing intensity of precipitation and rising sea levels driven by climate* *change. Further, while coastal districts in Karnataka excel in Human Development Index (HDI), Multi-dimensional Poverty Index (MPI), and poverty levels, they face increasing vulnerability due to direct threats from cyclones in the Arabian Sea and indirect impacts from eastern coastline cyclones.* The city is exposed to high risks from increasing cyclones, storm surges, and heavy precipitation, leading to flooding, inundation, landslides and saltwater intrusion. These risks are exacerbated by the city's low elevation, nearly 50 % of the administrative land at an elevation less than 10 meters above mean sea level (MSL).

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2. TOWN PROFILE

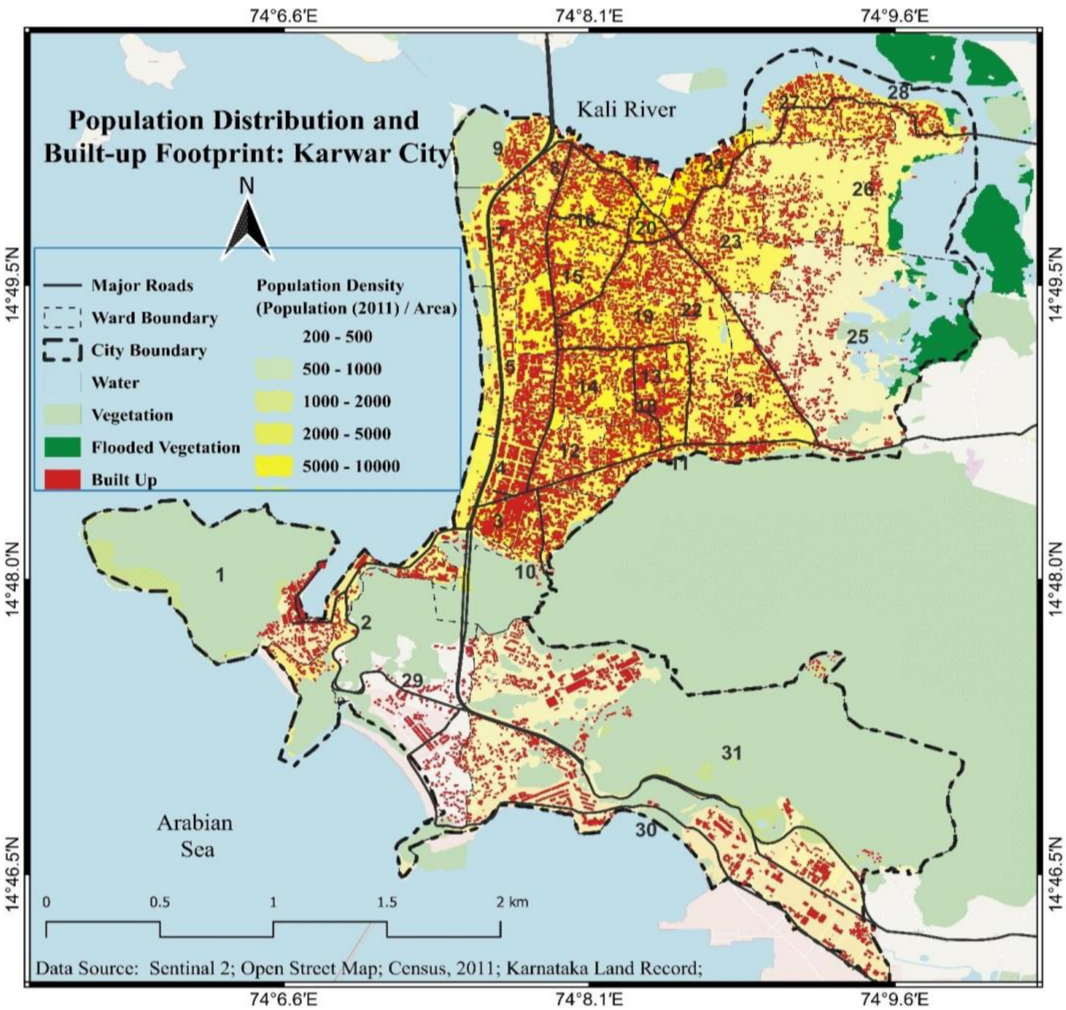
NEELAM RANA, PRIYAKSHI GOGOI, SUCHARITA ROY, TEJASH ANAND & N.C. NARAYANAN

This chapter presents a detailed town profile, covering demography, climate, topography, land use and land cover, as well as key climate risks highlighted in literature.

Karwar, a coastal town in the Uttara Kannada district of Karnataka, is situated along a 30-kilometer stretch of coastline on the west coast of India. It lies between Latitude 14° 45' N and 14° 55' N, and Longitude 74° E to 74° 07' 30" E (National Centre for Coastal Research). The City Municipal Council of Karwar was formed on June 30, 1864, and later upgraded to a City Municipal Council on January 1, 1986. Covering an area of 27.15 square kilometers, it includes 31 council wards and has approximately 210 kilometers of roads. Serving as the administrative headquarters of Uttara Kannada, Karwar is located along the Kali River. The town is uniquely positioned between the Arabian Sea and the Western Ghats. The coastal plains of Karwar are relatively narrow, quickly transitioning into hilly and forested terrain as they extend inland. These plains support both agriculture and urban settlements, but their proximity to the sea makes them susceptible to storm surges and saline intrusion. Karwar is flanked by the Western Ghats, a UNESCO World Heritage Site renowned for its biodiversity and ecological significance. The steep slopes of these hills influence local weather patterns, causing orographic rainfall during the southwest monsoon. Their elevation accelerates runoff, limiting groundwater recharge and increasing the risk of flash floods. The Kali River, a key water body in the region, flows into the Arabian Sea near Karwar, creating estuarine ecosystems vital for biodiversity and fisheries. However, increased runoff during heavy rainfall can lead to flooding, affecting both natural and built environments.

Demographic Profile: The city has 16,369 households according to the 2011 census in 31 wards. As per the 2011 census, Karwar city has a total population of 63,755, including 32,207 males and 31,548 females. The average sex ratio is 979 females per 1,000 males. The child population aged 0-6 years is 5,753, which is 9% of the total population. Karwar boasts a literacy rate of 93%, surpassing the district's average of 84.8%. A total of 22,872 individuals in KMC area were engaged in work activities. Of these workers, 85.2% were employed in main work (defined as employment lasting more than six months), while 14.8% were involved in marginal work, earning a livelihood for less than six months. Among the 27,708 main workers, only 111 were cultivators (either owners or co-owners), and 153 were agricultural labourers[21].

Figure 7: : Municipal Council Map with Population Density and Built-Up Area



Source: Author's Illustration

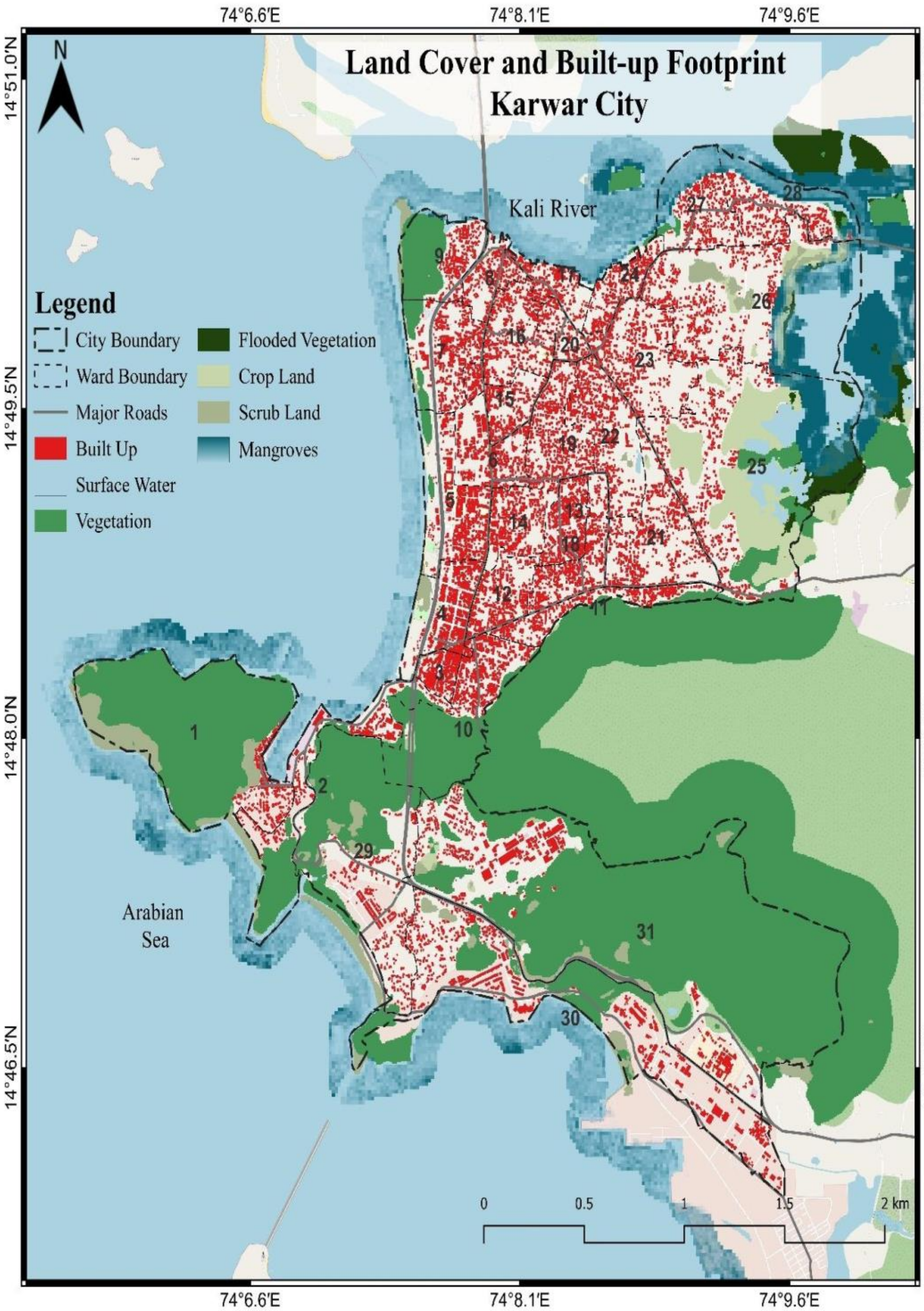
Land-use Land Cover: Karwar city is the administrative centre of Karwar taluks. The taluk region has a significant forest cover, plantations and croplands and has seen a significant increase in built up over the last couple of decades. The major landcover classifications for Karwar city are built up, vegetation and water (figure 8, table 3). The Kali River estuary has one of the highest numbers of mangrove species present in the Karnataka coast.[22] The ward level built up footprint reveals that wards 1, 25, 29 and 31 are the least built up. These wards together form a ridge which is a continuation of the ghats in the east, densely vegetated, and sloping down both in the north towards the Kali estuary and towards the south with low lying wards habited by fishing communities.

Table 3: Ward-wise Population Distribution and Built-up Footprint

Ward	Population Census 2011	Estimated Population Density	Estimated Area (sq. km)	Built Area %	Ward	Population Census 2011	Estimated Population Density	Estimated Area (sq. km)	Built Area %
1	1441	669	2.2	5.6%	17	2185	9603	0.2	42.2%
2	1553	1934	0.8	15.6%	18	1929	5034	0.4	46.5%
3	1102	7972	0.1	68.9%	19	3703	7718	0.5	46.4%
4	1677	3514	0.5	43.2%	20	2560	16458	0.2	40.8%
5	2568	3998	0.6	32.9%	21	1955	2631	0.7	30.6%
6	3377	8339	0.4	39.8%	22	1236	2082	0.6	35.6%
7	2582	4372	0.6	30.3%	23	1853	2698	0.7	30.2%
8	1157	4854	0.2	40.0%	24	2652	10412	0.3	45.6%
9	1611	3157	0.5	17.6%	25	2555	904	2.8	8.9%
10	2359	2488	0.9	19.4%	26	2684	1336	2.0	13.3%
11	1118	3320	0.3	39.4%	27	1266	2306	0.5	23.0%
12	1037	3244	0.3	45.1%	28	2312	3670	0.6	22.5%
13	2115	7800	0.3	60.7%	29	814	455	1.8	8.1%
14	2494	7384	0.3	45.3%	30	1447	686	2.1	15.7%
15	1666	5763	0.3	47.5%	31	2751	506	5.4	5.6%
16	3990	8826	0.5	41.4%					

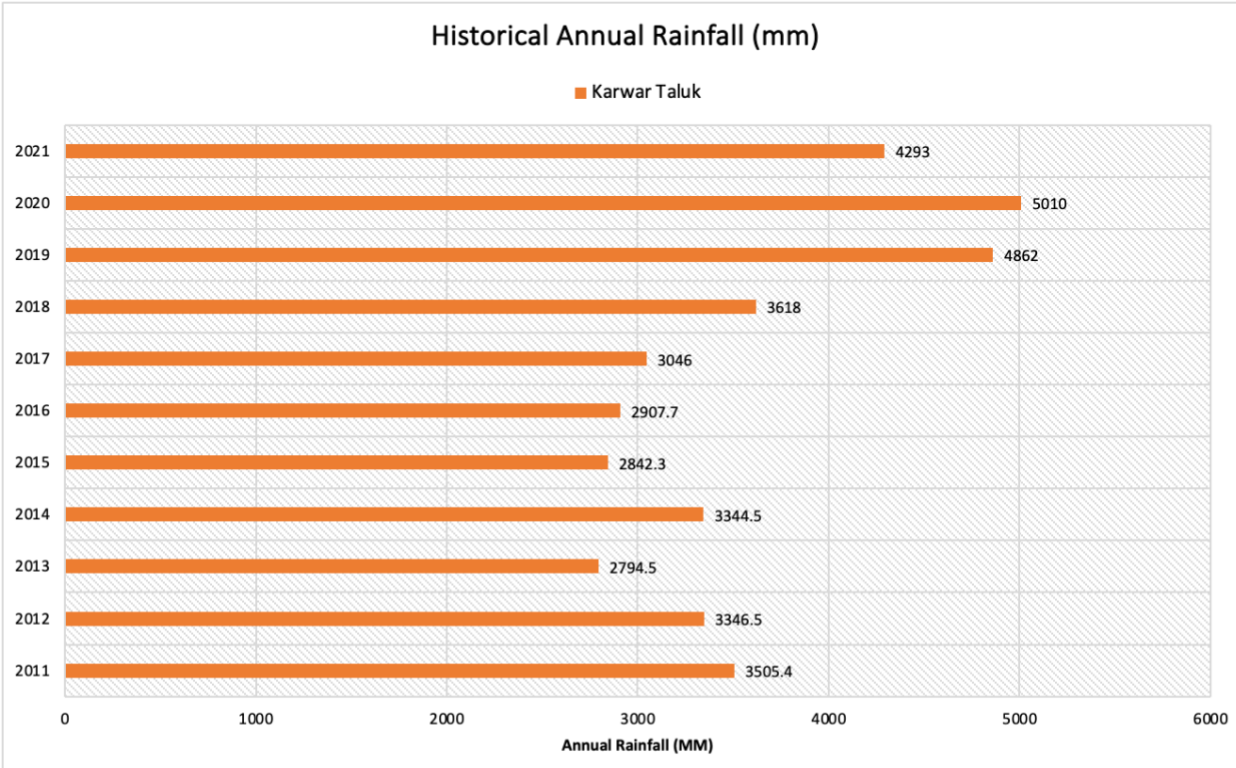
Climate: The data at town level is lacking. Uttara Kannada district has a tropical monsoon climate, with hot and humid conditions along the coast year-round. Temperatures rise from January, peaking around 30°C in May, occasionally reaching 38°C. The district receives an average of 2,750 mm of rainfall annually over 103 rainy days, **with Karwar taluk ranking among the top five for rainfall** (Ref. Figure 9).

Figure 8: Land cover and built-up footprint of Karwar



Source: Author's Illustration based on Sentinal 2 10 m (LULC), 2024 and Open Street Maps

Figure 9: Historical Annual Rainfall in Karwar Taluka



Source: (Uttara Kannada District Disaster Management Authority, 2023)

Disasters: Town level data on disasters is lacking. Hence, we relied upon district and taluk level secondary data on disasters. Cyclones in the district are low frequency and high impact hazards (Ref. Table 4). Historically, the worst cyclone to hit the district was during the year 1979. No major damage was reported during that period. On the other hand, floods in Uttara Kannada are a high frequency and high impact phenomenon. Draughts in Uttara Kannada district are high frequency and high impact hazards as compared to floods. The district faced many drought conditions earlier due to deficit rainfall and overexploitation of groundwater resource[23].

Karwar taluk, which experiences higher-than-average annual rainfall compared to the district, saw approximately 7,000 people affected during the 2019 floods. As per the table 5, Karwar Municipal Council seems to be also impacted by the floods (Uttara Kannada District Disaster Management Authority, 2023). In August 2019, heavy monsoon rains led to widespread flooding in Karwar city, causing significant transportation disruptions and property damage[24]. Intense rainfall, combined with dam releases, led to severe waterlogging and inundation, submerging parts of National Highway 66 and temporarily disconnecting

Karwar from Goa. While no lives were lost, the event exposed Karwar's vulnerability to urban flooding during extreme rainfall, highlighting deficiencies in drainage infrastructure.

Table 4: Impact vs Frequency Mapping of Hazards in Uttara Kannada District

Events	High impact low frequency	High impact High frequency
Cyclones/Heavy Rains		
Floods		
Draughts		
Sea Erosion		

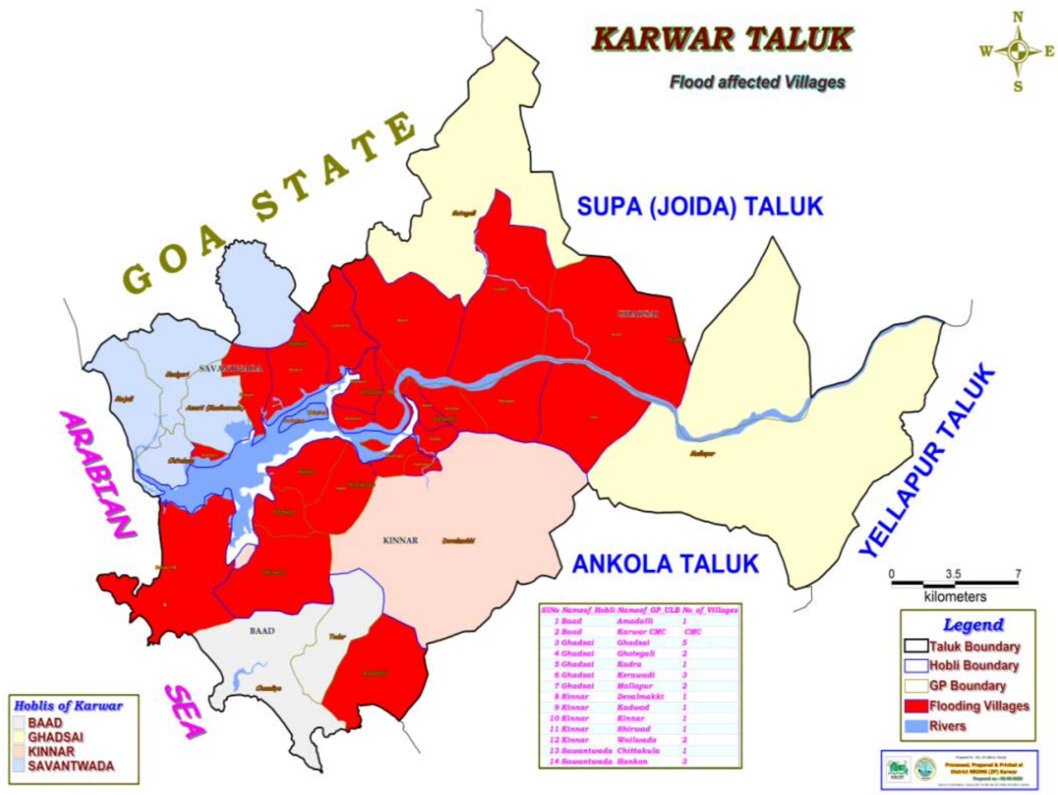
Source: (Uttara Kannada District Disaster Management Authority, 2023)

Table 5: History of Disasters in Uttara Kannada District, Karnataka

Events	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Cyclones/ Heavy Rains													
Floods													
Draughts													
Sea Erosion													

Source: (Uttara Kannada District Disaster Management Authority, 2023)

Figure 10: Flood Impacted Areas in Karwar Taluk



Source: Uttar Kannada Disaster Management Plan 2022-23

As per climate change projections, the drought' years are projected to decline, in the range of 1 to 3 years under RCP 4.5 scenario, and 1 to 4 years under RCP 8.5 scenario for Short-term (2030s), for Uttara Kannada. However, about 15 districts in Karnataka, excluding Uttara Kannada, are particularly vulnerable to heat waves (Government of Karnataka, 2023)[25]. The increased heat wave incidences will lead to increase in water demand for both potable and non-potable purposes[26]. In Karnataka, an increase in the number of rainy days is projected for most of the districts of Karnataka, under both RCP 4.5 and 8.5 scenarios.

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[26] Heat wave is considered if the maximum temperature of a station reaches at least 40°C or more for plains, 37°C or more for coastal stations and at least 30°C or more for hilly regions. Specific criteria is: heat wave = departure from the normal is 4.5°C to 6.4°C; Sever heat wave = departure from the normal is > 6.4°C. For plains only, heat wave = when the actual maximum temperature ³ 45°C ; Sever hear wave = when the actual maximum temperature ³ 47°C

3. STATUS OF WATER INFRASTRUCTURE AND SERVICES

ASHISH DANGI[27] AND NC NARAYANAN

This chapter provides a situational assessment of water infrastructure and services in Karwar, Karnataka, through a climate lens. It examines how the town is responding to increasing water demand amid growing constraints on availability and quality, as well as pre-existing systemic challenges. The analysis highlights critical gaps, vulnerabilities, and potential opportunities for transitioning toward more climate-resilient urban water systems.

The port city of Karwar is uniquely positioned, bordered by the Kali River to the north, the Arabian Sea to the west and south, and the Kali River estuary to the east (Ref. Figure 5). This distinct geography, with its combination of hills and water bodies, influences local hydrology, groundwater recharge, and urban expansion. While the proximity to water sources provides opportunities for water supply, it also poses challenges such as saltwater intrusion, flood risks, and limited space for infrastructure expansion.

Figure 11: Geographical features of Karwar

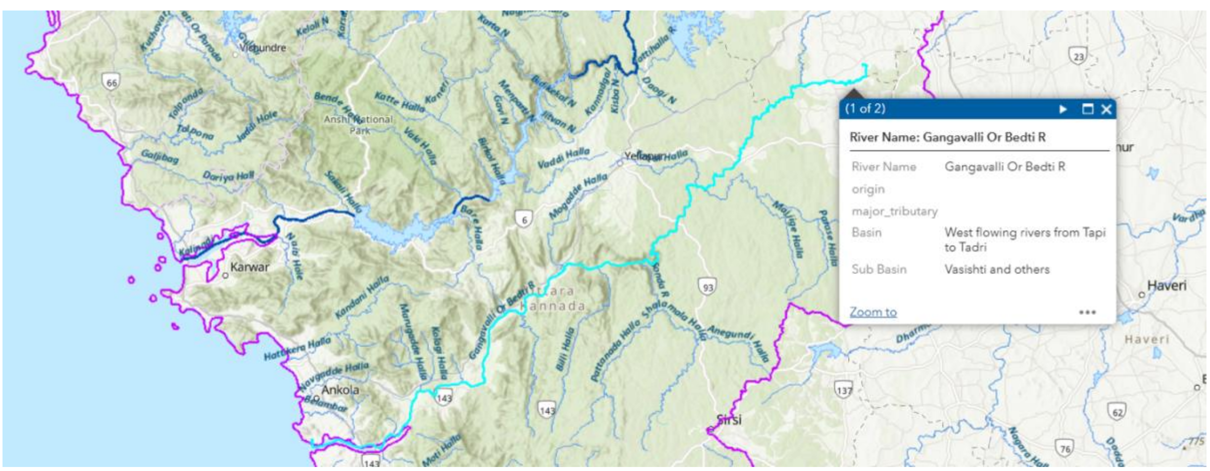
Source: Author's illustration using Google Earth satellite imagery

3.1 SURFACE WATER SOURCES

Gangavali River

The Gangavali River, also known as Bedthi or Gangavalli, is a crucial water source for Karwar and surrounding areas. Originating in Dharwad district, it flows for approximately 161 km through Uttara Kannada, Dharwad, and Haveri before draining into the Arabian Sea at Manjguni-Ankola (refer figure 12). The river has a catchment area of 3,935 sq. km, encompassing key towns such as Sirsi, Mundgod, Ankola, Hubli, Dharwad, and Shiggaon. Its major tributaries include Bedthi, Vibuthi Holé, Huli Devara Kodlu, Yenne Hole, Shalmala, and Sonda. Rainfall in the catchment varies significantly due to orographic influences, ranging from 1,000 mm in the plains of Hubli to over 4,500 mm in the Ghats of Yellapura, contributing to an estimated water yield of 45 to 70 TMC. The catchment's population has grown steadily, increasing from 879,809 in 2001 to 1,014,711 in 2011. This growing demand, coupled with numerous small-scale diversions such as check dams and bunds, highlights the need for sustainable water management to balance ecological and human water needs in the region.

Figure 12: Gangavalli or Bedthi River in the West flowing rivers from Tadri to Kanyakumari Basin



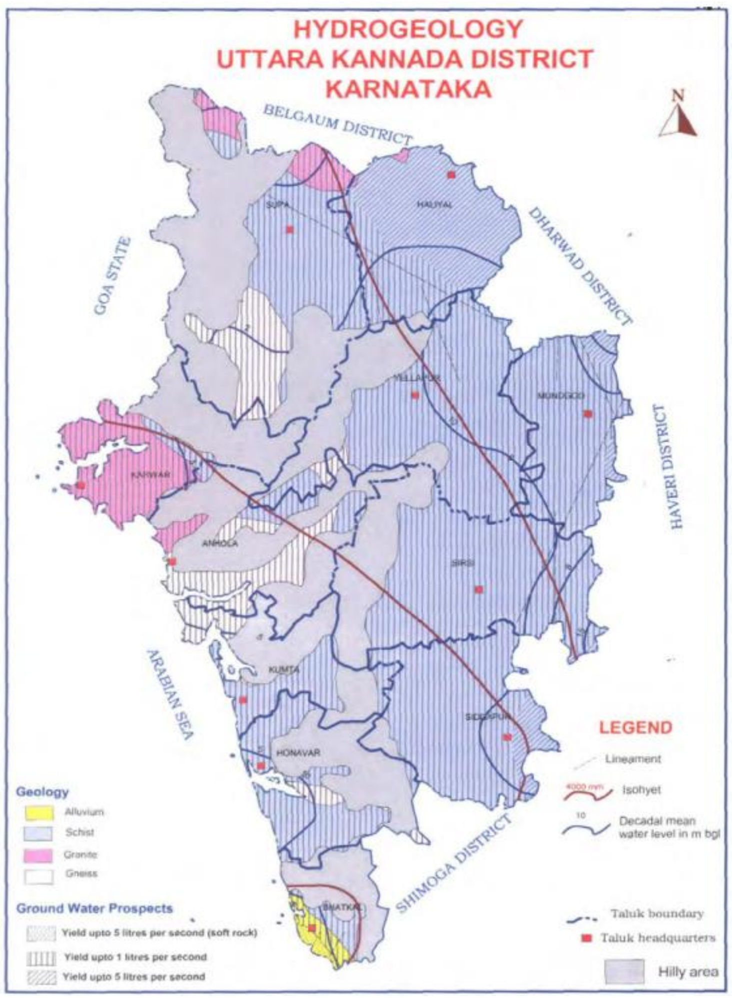
Source: India-Water Resources Information System (WRIS)

In this context, the Haladi River is more than just a natural resource; it is a shared and contested system shaped by both natural forces and human interventions. Ensuring its long-term sustainability will require integrated watershed management that accounts for climatic variability, upstream-downstream equity, and the cumulative impact of human activities across the basin.

3.2 GROUNDWATER

Laterite rocks are prominent in the area forming potential phreatic aquifers. These are highly porous and permeable and get fully recharged after monsoon. The aquifer drains out due to subsurface out flow in the post monsoon period. The dug wells tapping these aquifers located in sloping grounds get dried up during summer months, even if the groundwater extraction in the area is low.

Figure 13: Hydrogeology Uttara Kannada district Kanyakumari Basin



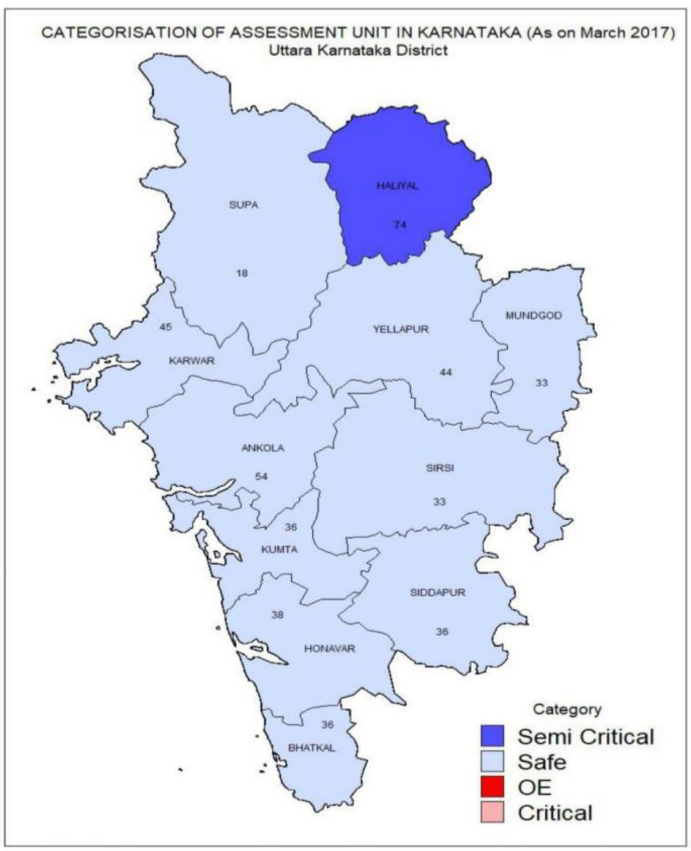
Source: Central Ground Water Board (CGWB), 2012 [28]

Granite Aquifers: The inland areas surrounding Karwar are underlain by granite rocks (Figure 13). These hard rock formations typically have limited primary porosity but can store and transmit groundwater through secondary porosity features such as fractures and weathered zones. Alluvial Aquifers: Along river valleys and floodplains near Karwar, alluvial deposits composed of sand, silt, and clay can form aquifers. These alluvial aquifers are often unconfined and can be significant sources of groundwater. However, due to their unconfined nature they are highly susceptible to contamination.

Estuarine Aquifers: The Kali River to the north of Karwar estuary plays a significant role in shaping estuarine aquifers by mixing freshwater from rivers and saline water from the sea. The interaction between river discharge and tidal movement directly affects the salinity gradient within such aquifers. Karwar lies at the far end of Kali River and therefore highly vulnerable to interruptions in river discharge due to human interventions upstream. These aquifers highly sensitive to climate change due to their connection with both freshwater and seawater systems. Climate change alters hydrological balances, increasing the risk of **salinity ingress, reduced freshwater recharge, and ecosystem degradation**. These aquifers sustain mangrove ecosystems, which are crucial for biodiversity and coastal protection.

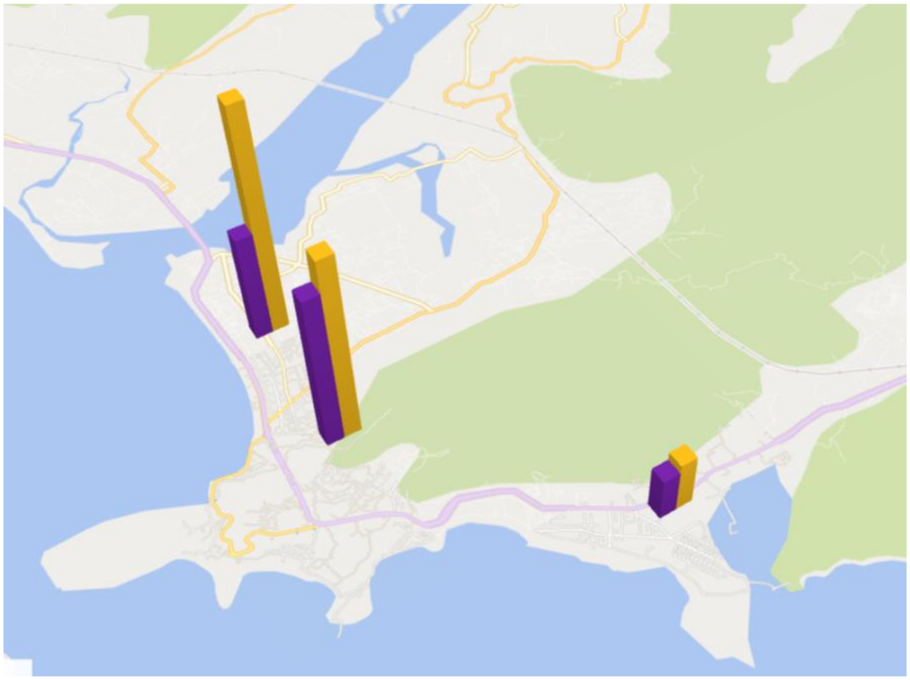
According to a report by groundwater directorate Karnataka and the Central Ground Water Board published in 2020[29], Karwar Block is classified as 'Safe' for groundwater use, with around 45% of resources utilized as of March 2017 (Figure 14).

Figure 14: Categorization of assessment units in Uttar Kannada district based on Groundwater Estimation Methodology (GEC-2015), as on March 2017 (CGWB)



Source: Central Ground Water Board

Figure 15: Observed Range of water level (mbgl) between May 2023 to May 2024



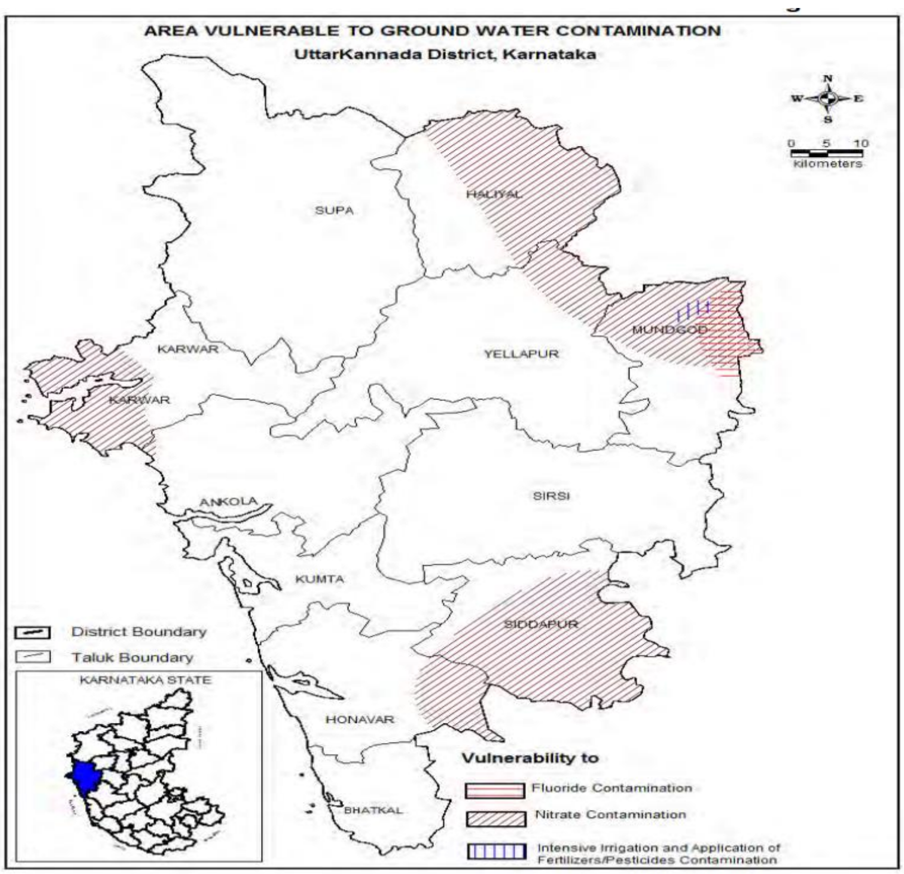
Source: Author's own illustration based on data source from India Water Resources Information System[30]

Figure 15 illustrates the observed range of groundwater levels (meters below ground level, mbgl) from May 2023 to May 2024 across different telemetry stations in the Karwar region. The Karwar city center exhibits significant seasonal fluctuations, with higher recharge during monsoon months and notable depletion in dry periods. This variation suggests intensive groundwater extraction, particularly in high-population-density areas, indicating a strong reliance on groundwater to meet the city's water demand. The other two stations to the south of the city exhibit relatively lower variations, suggesting more stable aquifer conditions or lower dependence on groundwater extraction.

Ground Water Quality

As per the ground water year book of Karnataka (2021)[31] , fluoride concentration of 1.67 mg/L was observed which is more than permissible limit of 1.5 mg/L. Further, the CGWB identifies Karwar's groundwater as being vulnerable to nitrate contamination (Figure 16).

Figure 16: Areas vulnerable to Ground Water Contamination

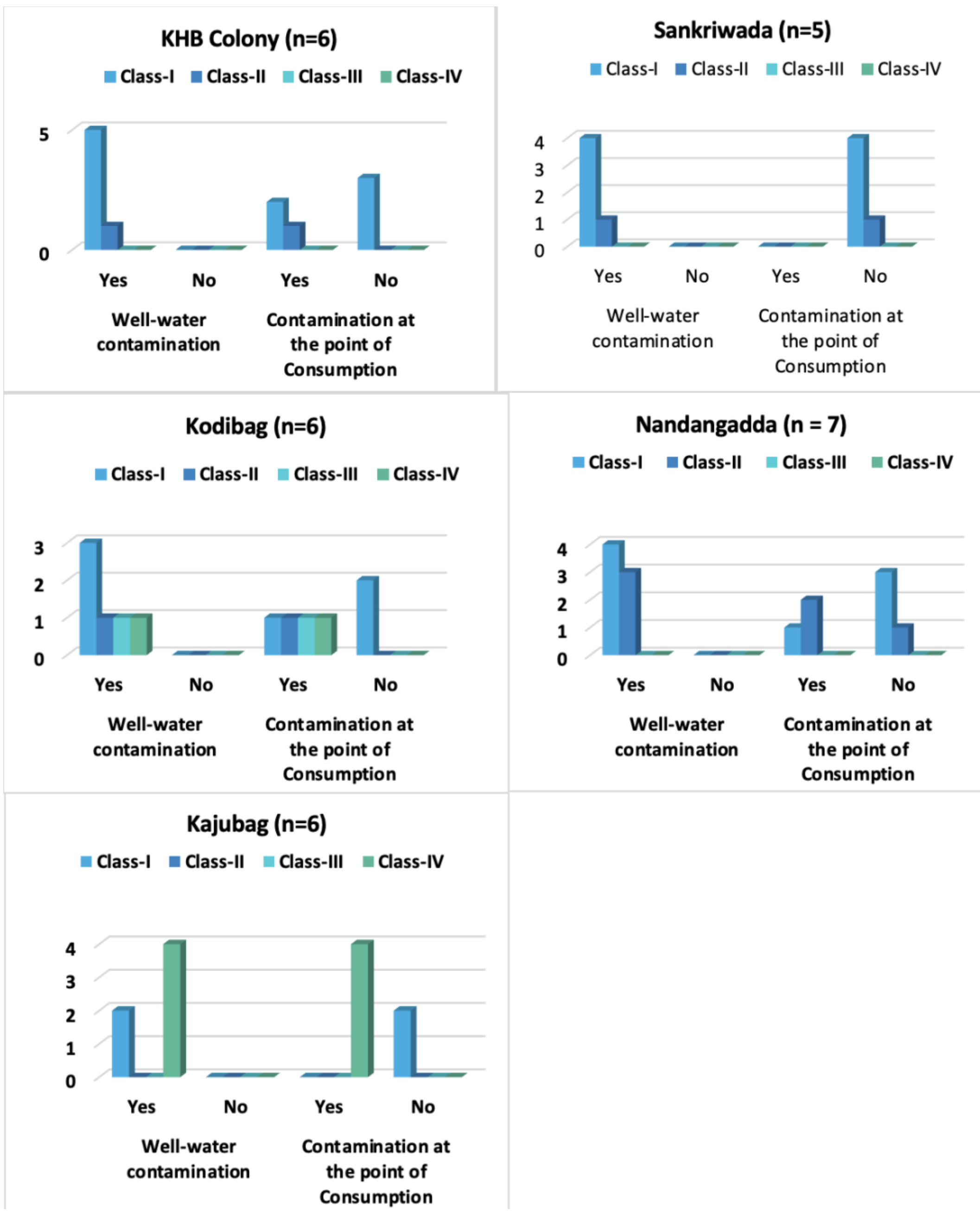


Source: Central Ground Water Board (CGWB), 2012

Kukanur et. Al (2021)[32] conducted a study (refer figure 17) in Karwar to assess the bacteriological quality of household well water at both the source and point of consumption. The study involved 30 households selected through simple random sampling. These households were classified into four groups based on their socioeconomic status based on the B. G. Prasad SES scale 2021 which takes into account per capita income of a family. The findings revealed that **all well water samples were contaminated with *Escherichia coli* (E. coli),** indicating fecal contamination. Furthermore, 80% of the samples collected **at the point of consumption** also showed coliform presence, with **47% confirming E. coli contamination**.

These results highlight significant health risks associated with consuming untreated well water in the region. The study also noted that water handling practices at the point of consumption played a critical role in water quality, suggesting that post-collection contamination is a major concern **particularly in low-income households**. To mitigate these risks, it is essential to implement regular water quality monitoring, improve sanitation infrastructure to prevent faecal contamination, and promote effective household water treatment and safe storage practices.

Figure 17: Contamination of water samples taken at source and point of consumption among different communities belonging to various SES



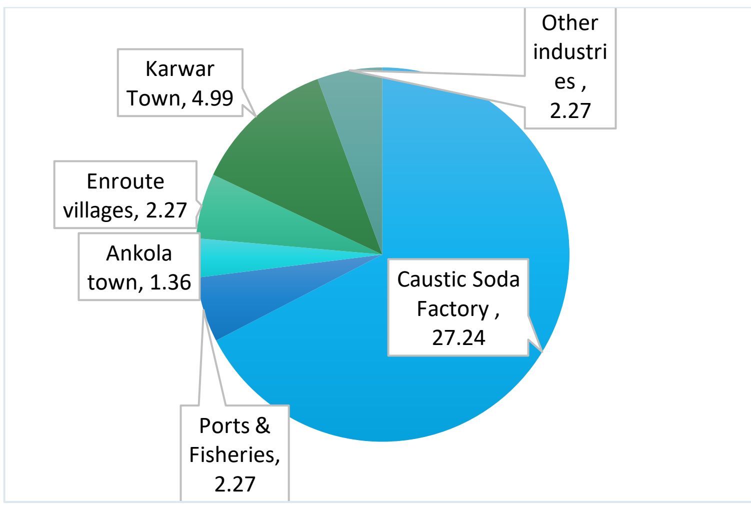
Source: Own illustration based on Kukanur et. Al (2021)

3.3 WATER INFRASTRUCTURE

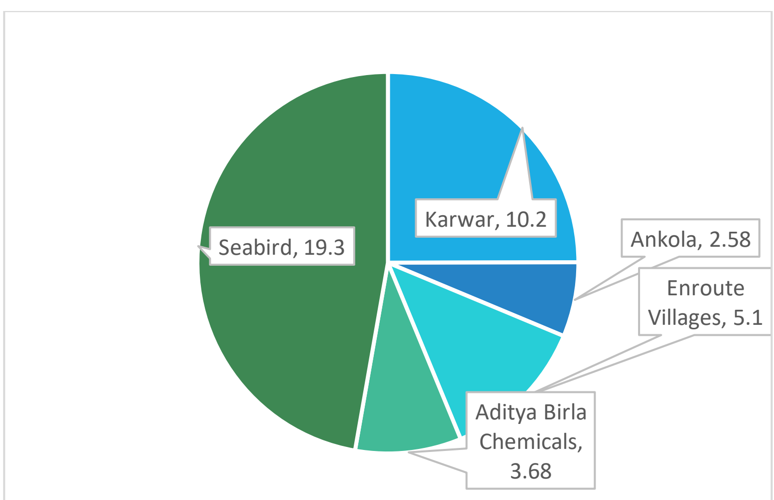
The water supply scheme for Karwar, Ankola, enroute villages, and Aditya Birla Chemicals (formerly Caustic Soda Factory) was commissioned in May 1975 (Ref. Figure 18), with an installed capacity of 40.86 MLD. The scheme sources water from the west-flowing Gangavali River, located approximately 40 km from the supply area. Over the years, water allocation was revised as Aditya Birla Chemicals could not utilise the allocated quantity and also to accommodate urban expansion, particularly during improvements executed between 2009 and 2011.

Figure 18: Allocations (1975) and re-allocations (2011) under the Karwar Ankola Water supply scheme

Allocations 1975 (40.86 MLD)



Re-allocations 2011 (40.86 MLD)



Source: Authors' illustration

Figure 19: Schematic of the water supply scheme and description of key components

Source: Author's illustration using Google Earth satellite imagery

Table 6: Details of Water Supply Infrastructure

Abstraction	Conveyance	Treatment & Distribution
Intake works at Honnalli - *Jackwell & Low lift pump house (3 x 125 HP DWT Pumps)* - *Flash mixer* - *2 x Clarifoculator* - *2 LL cap. Sump and high lift pumphouse (3 x 550 HP centrifugal pumps)* *Total capacity 40.86 MLD*	- *8 km MS rising mains (700 mm)* - *50 LL cap. GLSR (Mother tank)* - *31 km MS gravity mains (711 mm)* - *4.54 LL cap. Sump & Pumphouse (2 x 150 HP centrifugal pumps)* - *5 LL cap. GLSR at Binaga bifurcation point* - *2.1 km MS rising mains (508 mm)*	***13.2 MLD WTP at High church*** *- Aerator* *- Gravity sand filter unit for 13.2 MLD* *- 40 LL GLSR* *- 2.5 LL backwash tank (9 m staging)* ***5 MLD WTP at Baithkol*** - *9 LL & 12 LL GLSR* - *Gravity sand filter unit (5 MLD)*

Source: Author's illustration

As shown in figure 19 and table 6, the scheme consists of three main components: abstraction, conveyance, and treatment & distribution.

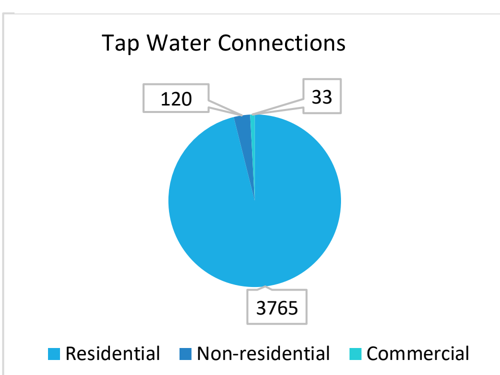
- **Abstraction:**
    - Water is lifted 25 m from the Gangavali River at Honnalli using three 125 HP deep well turbine (DWT) pumps.
    - Suspended solids are removed via clariflocculators before further conveyance.

- **Conveyance & Storage:**
    - The raw water is pumped 80 m uphill to a 50 lakh litre (LL) Mother Tank at NavaGadde via an 8 km rising main (700 mm MS pipe).
    - Water then flows 31 km by gravity (711 mm MS pipe) to Binaga, where it is stored in a 4.4 LL sump.
    - From Binaga, water is lifted 70 m using 150 HP centrifugal pumps and sent to two treatment plants – Baithkol (5 MLD) and High Church (13.2 MLD).
- **Treatment & Distribution:**
    - High Church WTP (13.2 MLD):
        - Filtration through gravity sand filters.
        - Stored in a 40 LL GLSR before distribution by gravity.
    - Baithkol WTP (5 MLD):
        - Treats 1.5–2 MLD.
        - Water is stored in 9 LL & 12 LL GLSRs before distribution by gravity.

HOUSEHOLD LEVEL WATER INFRASTRUCTURE

Rooted in a deep history of water access through dug wells, majority of the population in this coastal town still relies on well water for their domestic needs. Only 23% of the households have water access through tap water connections although the entire area of KMC, Karwar is covered by piped water distribution network (Ref. Figure 20).

Figure 20: Water access infrastructure in KMC area as on 01-04-2024



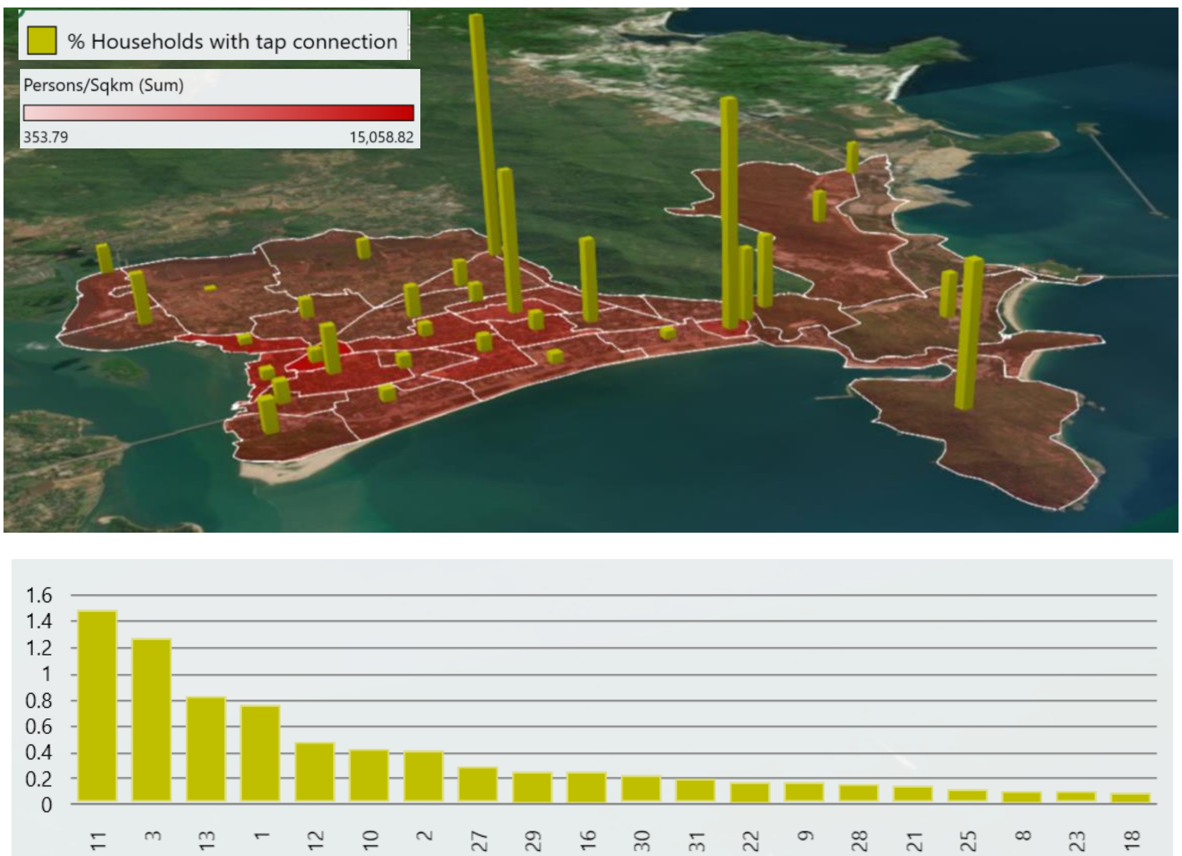
Households	16369
Number of open wells	3895
Number of Public Wells	3708
Number of Public tap Connections	10
Number of tap connections	3918

Data Source: Karwar City Municipal Council

Analysis of Tap Water Dependency and Urban Density

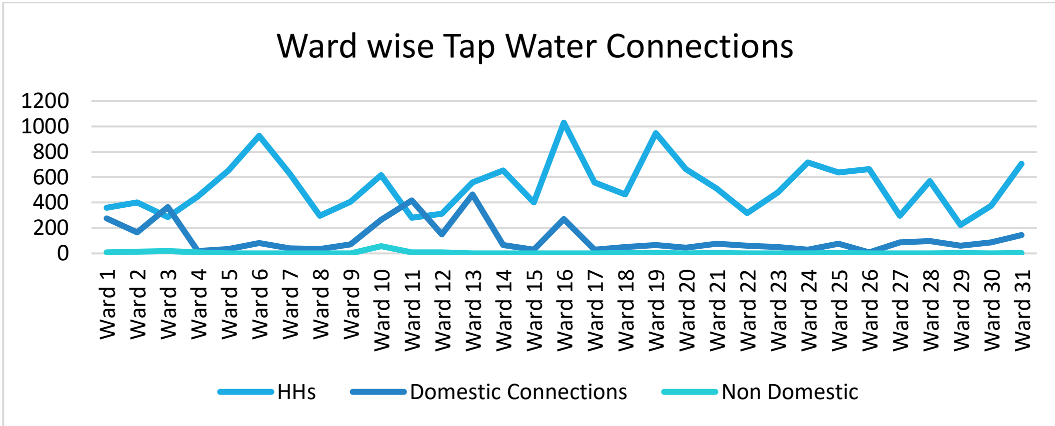
The distribution of tap water connections within the municipality demonstrates a clear shift in household water dependency, particularly in densely populated urban centers. As illustrated in the spatial distribution map (Figure 21 & 22), the highest percentage of households with tap connections (represented by the prominent yellow vertical bars in figure 22) strongly correlates with areas of high population density, denoted by the dark red zones. In these specific wards, land availability constraints and diminishing groundwater yields have necessitated a transition from traditional groundwater extraction to municipal piped supplies. While some households retain existing dug wells within their premises as a secondary source for non-potable activities like gardening and washing, most traditional wells have been neglected or the land reclaimed. This trend underscores how urbanization and spatial constraints directly drive the demand for formalized water infrastructure.

Figure 21: Spatial distribution of tap water coverage in KMC



Source: Author's illustration based on data provided by KMC

Figure 22: Ward-wise distribution of households and tap water connections in KMC area



Data Source: Karwar City Municipal Council

Figure 23: Wards with highest tap water coverage located along the Konenala drain (marked with yellow line) and STP

Source: Author's illustration using Google Earth satellite imagery

Impact of Groundwater Quality and Drainage Infrastructure

Further examination of the ward-wise data reveals that the highest tap water coverage is concentrated in Wards 1, 2, 3, 10, 11, 12, and 13. Both the line graph and the supplementary bar chart confirm that domestic connections in these specific wards represent the highest proportion relative to total households. Geographically, these wards are situated along the Konenala (Figure 23), the city's largest open drainage channel that discharges into the sea. As highlighted in the accompanying satellite map showing the location of the 1.5 MLD Sewage Treatment Plant (STP) along the drainage corridor, this area is highly susceptible to sewage contamination. Site visits confirming the pollution of the Konenala suggest that the shallow aquifer in its vicinity is highly compromised. Consequently, the exceptionally high reliance on municipal tap water in these specific wards is largely driven by necessity; the severe degradation of local groundwater quality renders it non-potable, making the piped water network critical for domestic consumption and public health.

3.4 WATER DEMAND & SUPPLY

As per the 2011 Census, Karwar has a population of 63,755, distributed across 16,369 households. The total water demand is estimated at 10.3 Million Litres per Day (MLD), based on a domestic per capita consumption of 135 liters per capita per day (lpcd), with an additional 20% allocation for commercial and institutional demand.[i] For meeting this demand Karwar primarily relies on groundwater withdrawals as well as around 3.6 MLD[ii] of imported water from the Gangavalli river supplied by the Karnataka Urban Water Supply and Drainage Board (KUWSDB). Assuming 20% distribution losses in the ageing piped water distribution network of Karwar, approximately 2.9 MLD demand is met from imported waters (surface water) and the remaining 7.4 MLD is presumed to be met through groundwater withdrawals (Figure 24)[iii].

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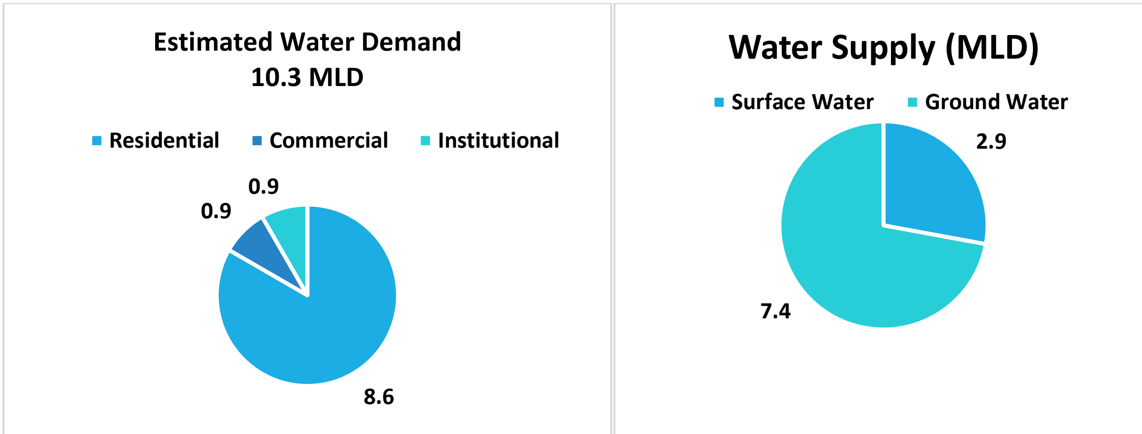
[i] Floating population demand is presumed to be accounted for in the commercial (10%) demand.

[ii] Average billed bulk water consumption for CMC, Karwar for Sep-Dec 2024 by KUWS&DB.

[iii] Note: Population projections for current year through standard population projection methods may be unreliable for a small coastal town like Karwar due to limited land availability within municipal limits. Additionally, new population growth is largely concentrated in outgrowth areas beyond the municipal boundary, and out-migration is not accounted for in standard projection methods. Consequently, 2011 Census figures are used for demand estimation, though accurate and updated population data is essential for more precise assessments of water demand and resource sustainability.

Figure 24: Water demand estimated on the basis of census 2011 and water supplied



Source: Authors' Illustration

3.5 CLIMATE RISKS AND CHALLENGES

Karwar, a coastal town at the confluence of the Western Ghats, the Arabian Sea, and the Kali River estuary, lies at the frontline of compounding climate and water-related vulnerabilities. The city's unique geography provides both abundant water sources and heightened exposure to climate-induced disruptions. As climate change accelerates, altering the water cycle, Karwar's reliance on seasonal surface flows, fragile groundwater aquifers, and energy-intensive infrastructure poses significant risks to water security and urban resilience.

FRAGILE SOURCE SUSTAINABILITY AND CLIMATE-DRIVEN VARIABILITY

Karwar depends primarily on surface water drawn from the Gangavali River, a west-flowing river with a high monsoonal yield but notable seasonal variation. While monsoons guarantee sufficient flow, the summer months are increasingly dry exacerbated by climate change-induced shifts in rainfall timing, intensity, and duration. Prolonged dry spells, sudden intense rainfall events, and erratic monsoon behaviour have made the system more volatile.

The town draws only 3.8–4 MLD out of its 10 MLD allocated quota from the Gangavali River, yet rising demand from surrounding urban, agricultural, and industrial areas continues to place stress on the source. Without adaptive management and watershed protection, long-term water security is at risk.

To address seasonal shortages, a proposal has been made for constructing a vented barrage across the Gangavali River, with a storage capacity of 0.383 TMC to provide 120 days of summer water storage. While this intervention aims to enhance water security and reduce dependence on groundwater, it comes with notable environmental and land-use trade-offs:

- Submergence of 34.98 Ha of forest land and 17.90 Ha of non-forest land, impacting local ecosystems and potentially displacing flora and fauna.
- Modification of river flow dynamics, which could affect downstream water availability and aquatic ecosystems.
- Exemption from Environmental Impact Assessment (EIA) requirements, as drinking water projects are not mandated to undergo this process. This raises concerns about the lack of comprehensive assessment of long-term ecological and socio-economic impacts.

While the barrage is a strategic solution for improving seasonal water storage, ensuring sustainable water management will require additional measures.

VULNERABILITY TO UPSTREAM INTERVENTIONS

The Gangavali River flows over 150 km before reaching Karwar's intake point at Honnalli. Along its course, upstream agricultural diversions, industrial withdrawals, check dams, and bunds are already fragmenting flow patterns. Climate change further reduces base flows and intensifies the unreliability of runoff. These upstream alterations, largely beyond Karwar's jurisdiction, directly impact downstream water availability, especially during lean periods.

The estuarine aquifers that border Karwar are also highly sensitive to such upstream changes. Reduced freshwater flows accelerate **saltwater intrusion**, posing long-term risks to both aquifer health and coastal ecosystems like mangroves that are critical for biodiversity and coastal protection.

OVERRELIANCE ON GROUNDWATER AND THE ILLUSION OF ABUNDANCE

Despite the presence of surface water infrastructure, Karwar continues to rely heavily on groundwater—particularly in high-density and low-income neighbourhoods. The relatively shallow lateritic and alluvial aquifers recharge quickly during the monsoon but are also prone to drying in summer. Groundwater levels exhibit significant seasonal fluctuation in telemetry data, particularly around the urban core, indicating over-extraction.

Moreover, the city's piped water coverage although widespread is limited in terms of actual active household connections, creating an illusion of secure supply. During recent crises, such as the severe shortage at the Indian Navy base (Figure 25), emergency supplies had to be brought in from Mumbai, revealing deep system vulnerabilities. This perceived reliability of groundwater masks mounting risks: contamination, aquifer depletion, and increased dependence on an invisible, poorly monitored source.

Figure 25: News report on water crisis at Karwar naval base in 2019


Karnataka

Karwar: Water crisis may force INS officials to shift warships to Mumbai

The base requires six million litres per day (MLD), but it is receiving less than 1 MLD water.

INS Kadamba Naval Base in Karwar | Express

Source: New Indian Express[33]

COASTAL AND CLIMATIC HAZARDS: A DOUBLE BURDEN

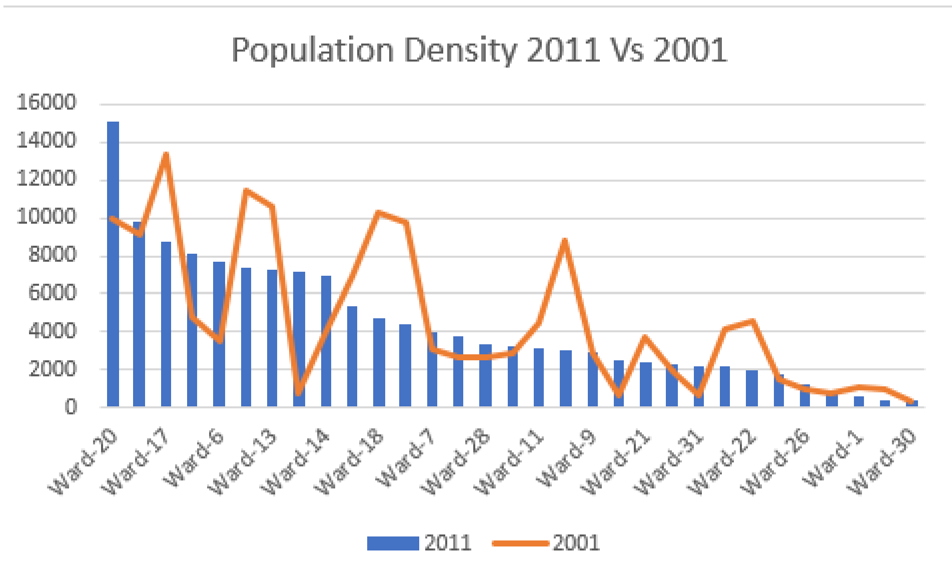
As a low-elevation coastal town, Karwar is doubly exposed to hydrometeorological extremes. Rising sea levels, coastal erosion, and storm surges intensified by warmer oceans and extreme rainfall, pose direct threats to water infrastructure located near the shore or within flood-prone zones. Sewage contamination of stormwater drains like the Konenala suggests that already, heavy rains and urban runoff are overwhelming existing drainage systems and compromising water quality.

In addition to infrastructure damage, these climate risks also raise **public health concerns**. Inadequate sanitation and poor water quality especially from untreated well water heighten the risk of disease outbreaks during floods or service disruptions. Field studies have shown widespread **faecal contamination** in household wells, particularly in low-income neighbourhoods.

URBANISATION AND CHANGING DEMAND PATTERNS

Karwar's urban growth over the past two decades has reshaped water demand across wards, revealing misalignments between population trends and infrastructure capacity (Ref. Figure 26). The town's current water supply infrastructure was designed for a projected demand of 10 MLD, yet active connections and actual consumption remain well below this mark. As new tap connections are added, especially in high-density wards, challenges such as **inequitable distribution, pressure fluctuations**, and **leakages** are expected to rise.

Figure 26: Karwar ward-wise population density 2001 Vs 2011



Data Source: Census 2011

Without up-to-date population data and network recalibration, scaling up the system to operate at full capacity may expose older parts of the network to failure. Additionally, many low-income households continue to depend on dug wells despite contamination risks, particularly in areas where piped water is either unreliable or unavailable.

NOTES & REFERENCES

[27] Author's Note: This chapter is based on ongoing doctoral research by Ashish Dangi under the supervision of Prof. N. C. Narayanan at the Ashank Desai Centre for Policy Studies (ADCPS), Indian Institute of Technology Bombay. Key findings and interpretations presented here are part of a broader analysis that is currently being prepared for publication in a peer-reviewed academic journal. Readers are requested to cite this report appropriately and direct any academic queries to the author.

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4. URBAN SANITATION SYSTEMS IN KARWAR: STATUS, INSTITUTIONS AND CHALLENGES

NEELAM RANA, PRIYAKSHI GOGOI, NC NARAYANAN

Assessing the state of sanitation services is critical for identifying infrastructure gaps, service-related vulnerabilities, and climate-related risks, and for informing adaptive, resource-efficient, and low-carbon development strategies. This assessment also involves mapping institutional arrangements to clarify the roles of Urban Local Bodies (ULBs), their interactions across governance levels, and the interdependencies among key stakeholders. This chapter addresses these objectives through a detailed case study of Karwar, drawing primarily on secondary data supplemented by semi-structured interviews with ULB officials, district disaster management officers, and residents to validate findings and address data gaps. The chapter examines the sanitation service chain and reviews the institutional framework governing sanitation services, and concludes by identifying key challenges and opportunities for strengthening sanitation infrastructure, service delivery, and governance.

4.1 BACKGROUND

Climate risks are significantly exacerbated by inadequate infrastructure in critical, interlinked sectors such as water and sanitation which disproportionately affecting socio-economically disadvantaged communities[34,35,36]. *Climate change-induced water stress and insecurity have been linked to a rise in waterborne infectious diseases, threatening to reverse progress toward the SDGs and exacerbating existing social and health inequities*[37]. WaSH services are essential for preventing disease outbreaks, particularly in the aftermath of climate hazards such as heavy rainfall and flooding[38], [39]. In this context, *ensuring access to safe, reliable water, sanitation, and hygiene services* is widely *recognized* as a *low-regret adaptation measure*—offering substantial benefits *regardless of the severity of future climate scena*[40]. The *IPCC* highlights *universal access to WaSH*—specifically the achievement of SDG targets 6.1 and 6.2—as a *high-confidence adaptation strategy*, underscoring its central role[41].

India has only one national-level policy dedicated to urban sanitation—the National Urban Sanitation Policy (NUSP), introduced in 2008. The policy defines sanitation as the 'safe management of human excreta, including its safe confinement, treatment, disposal, and associated hygiene-related practices[42]. In the context of climate change, the policy links sanitation to GHG emissions and advocates the adoption of low-energy solutions, such as decentralized or onsite wastewater treatment technologies and distributed utilities. City

Sanitation Plans (CSPs) are expected to incorporate these concerns, including the impacts of climate change, diminishing water resources, and the need for energy-efficient infrastructure (ibid).

Although sanitation is not explicitly identified as a focus area in India's *National Action Plan on Climate Change (NAPCC)*, it is closely linked to climate action through missions on water, sustainable habitats, and energy. The *National Water Mission (NWM)* emphasizes water conservation and efficiency—critical for sustainable sanitation systems, especially in water-stressed urban areas. The *National Mission on Sustainable Habitat (NMSH)* more directly addresses sanitation-related concerns, including urban waste management, wastewater recycling, and climate-resilient infrastructure, thereby contributing to both mitigation and adaptation objectives. Sanitation is also aligned with the NAPCC's broader emphasis on *energy efficiency and GHG emission reduction,* as centralized wastewater treatment plants are significant sources of methane and nitrous oxide. Innovations such as *waste-to-energy systems and resource recovery from faecal sludge* further support this agenda. Additionally, *State Action Plans on Climate Change (SAPCCs)*—developed in line with the NAPCC—are increasingly acknowledging sanitation as a key sector for climate intervention, particularly in climate-vulnerable regions. Though the NAPCC predates the *SDGs,* it has gradually evolved to align with global frameworks. National programs such as *SBM and AMRUT* have also begun integrating climate resilience and sustainability into urban sanitation planning and implementation.

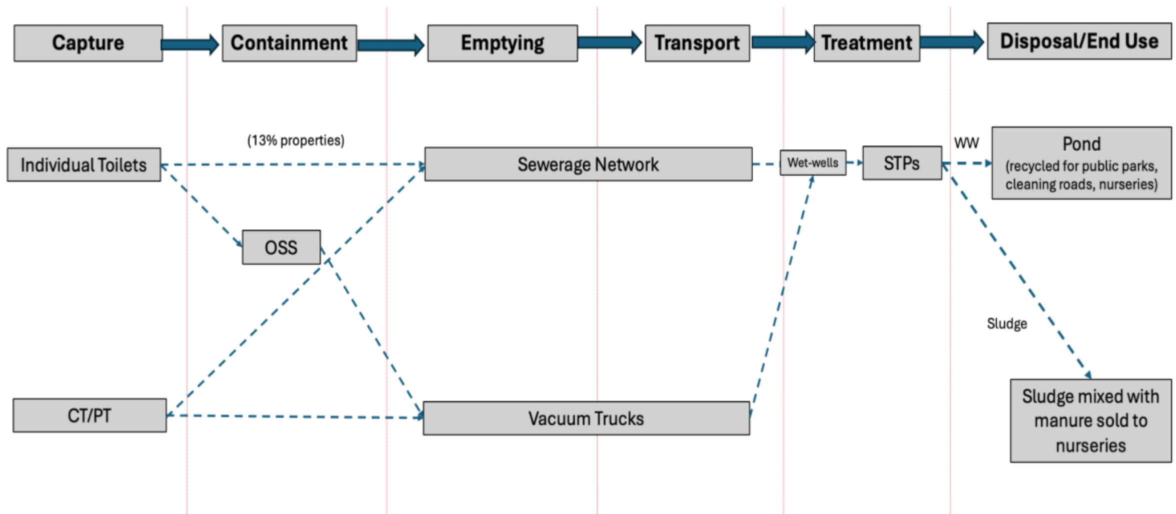
Hence, assessing the current state of sanitation services is essential for identifying infrastructure gaps, vulnerabilities, and climate-related risks. Such an assessment supports the design of proactive adaptation measures, promotes efficient resource use, and enables low-carbon development strategies. A critical component of this process is mapping existing institutional arrangements—clarifying responsibilities, particularly the role of ULB, their engagement across different governance levels, and the interdependencies among key stakeholders. This chapter seeks to address these objectives through a detailed case study of *Karwar.* Data collection was primarily conducted through secondary sources, supplemented by primary data gathered via semi-structured interviews with ULB officials, district disaster management officers, and residents. These interviews helped fill information gaps and validate secondary data.

The chapter is organized into the following sections: Section two discusses the sanitation service chain, covering all critical stages—toilet access, containment, transportation, treatment, and final disposal or end-use. *Section three* reviews the institutional framework, detailing the roles and responsibilities of various stakeholders involved in sanitation governance. *The final section* concludes the chapter by highlighting key challenges and opportunities for improving sanitation infrastructure, service delivery, and governance.

4.2 SANITATION SERVICE CHAIN

Human waste must be safely managed throughout the entire sanitation service chain, which may have different stages, including capture, containment, emptying, transport, treatment, and disposal or end use[43]. This section outlines the service chain and identifies the key gaps. The entire service chain is depicted in *Figure 27*.

Figure 27: Sanitation Service Chain in Karwar

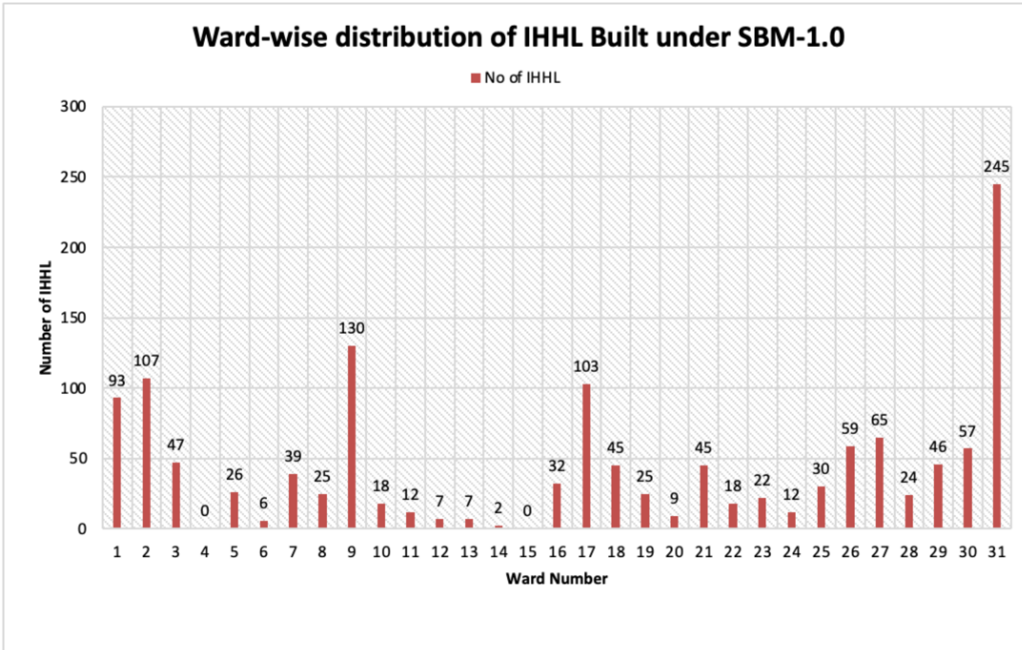


Source: Authors' Analysis and Illustration

- **Capture:** This includes toilets (individual household level , community, public) . The primary function of a toilet is to capture excreta while effectively separating people from the waste to ensure safety and hygiene.
    - **Toilets:** According to the 2011 Census, out of 19,820 (Karwar municipal council +Out growth) households in the area, 3,872 households did not have individual toilets. However, the latest data from KMC, as reported in the SLB 2022-23 report, confirms that all households now have access to individual toilets, achieving **100% coverage.** The town has been declared Open Defecation Free Plus (ODF++), aligning with the SLB set by the Government of India and SDG target 6.2. While a few households without toilets still rely on community or public toilets, significant progress has been made. The ULB provided us data on IHHL. Under the SBM, households with legal land rights but without individual toilets were provided with sanitation facilities. Currently, 1,356 households have Individual Household Latrines (IHHLs) across different wards of the city (Ref. Figure 28). Furthermore, under SBM 2.0, the city is constructing an

additional 250 Individual Household Latrines to further improve sanitation coverage.

Figure 28: Ward-wise details of Individual Household Toilets under SBM



Source: Data Obtained from KMC

- **Community Toilets and Public Toilets**[44]**:** According to the data received from the ULB, currently, the city has a total 38 functional community (30) and public toilets (8), which serve areas and habitation without access to toilets. While asking the ULB officials about the location selection, ULB officials stated that the **locations of these** public toilets were strategically chosen based on the needs of the public. However, information on **community and public toilet coverage** is unavailable, as the ULB does not maintain any registers or records tracking the number of users or whether the facilities are **able to cater the demand.**

  To assess the condition of public toilets, we spoke with ULB officials, who reported that the facilities are in good condition and well maintained. To verify these claims, our team visited two toilets (Ref. Photo). During our visits, we observed that both toilets were indeed clean, well maintained, and had access to running tap water. However, the ULB does not maintain any formal records of cleaning activities. Additionally, the ULB has recently received Rs.18

lakhs from SBM 2.0 to construct 3 PT with 12 seats in the city and Rs.18 lakhs for one aspirational toilet with 12 seats.

Photo: Community Toilet in Low-income Locality

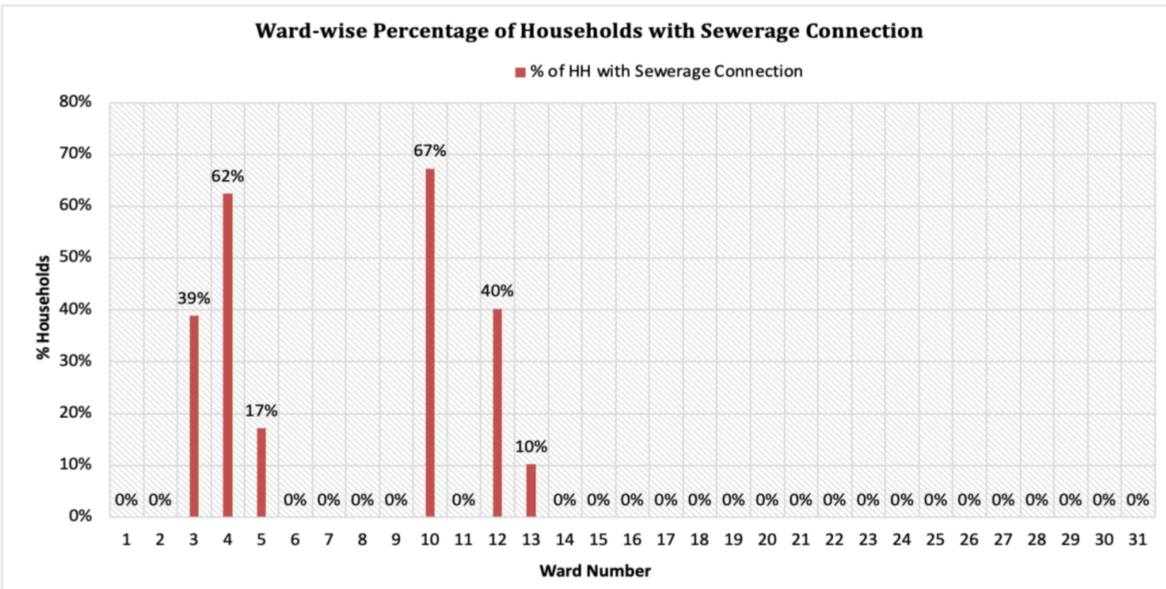
- **Containment:** According to the SLB (2022-23) data from the ULB, 13% of properties are connected to the sewerage network. And about 87% of properties rely on the OSS such as septic tanks combined with soak pits or release wastewater untreated.

  Information on the typology of toilets and OSS is crucial—not only for assessing the quality and adequacy of sanitation services, but also for estimating the GHG emissions associated with different toilet systems. However, the last comprehensive assessment was conducted as part of the 2011 Census, and no updated data has been made available, either at the national, state, or city level. Collecting such data would require a dedicated household-level survey, which falls outside the scope of routine assessments.

- **Emptying and Transport:** *As mentioned in the previous section, properties connected to* sewerage networks is only 13% as highlighted in the SLB 2022-23 report and 7% of the population (63,755 people as per Census 2011). As per the ULB, sewerage network connections are available in only 8 out of the city's 31 wards which were commissioned in 2011. The (figure 29) illustrates the ward-wise distribution of households with sewerage connections, emphasizing wards with a notably higher percentage of connections compared to others. According to the ULB, wards with a lower percentage of connections may have experienced this disparity due to residents perceiving the one-time sewage connection fee of INR 4500 as prohibitively expensive.

The remaining 87% of the properties depend on septic tanks with soak pits, which are serviced by two vacuum trucks owned by the ULB. The ULB charges INR 2300 for residential and INR 5350 for commercial properties for emptying the septic tanks. As per the ULB officials, the wastewater from CT and PT gets collected in the sewerage network. However, there is conflicting information in this matter, certain community toilets might be releasing wastewater directly into nearby open drain or open land.

Figure 29: Ward-wise Percentage of Households with Sewerage Network Connection in Karwar



Source: Data obtained from KMC

The SLB 2022-23 data reveals that 86% of the city has **stormwater drainage network coverage**. Our field observations align with this data, as we found evidence of extensive drainage infrastructure on the ground. However, apart from stormwater drainage coverage, there is a lack of secondary data regarding typology and GHG emissions. For this it needs detailed studies, which is out of our study scope.

The typology of the sewerage network and stormwater drains was beyond the scope of this study. Furthermore, the ULB does not possess any maps of the sewerage network, and relevant information regarding the type of drainage system is also unavailable in secondary sources.

Figure 30: Sanitation Infrastructure Map

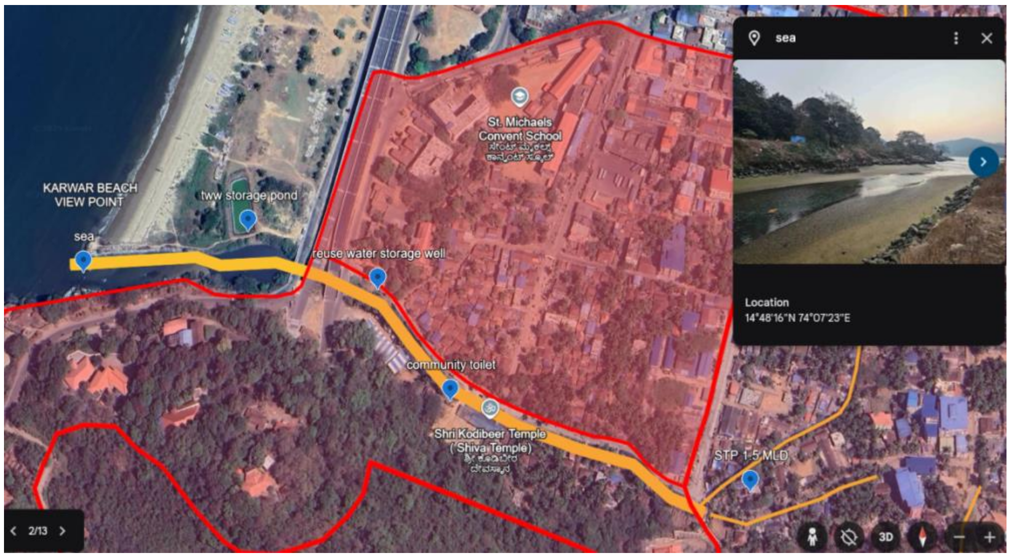
Source: Plotted on Google Earth

- **Treatment:** The city generates 5.2 MLD of wastewater[45]. The city has 1 Sewage Treatment Plant (commission year 2011) of installed capacity 1.5 MLD, hence, creating a gap of about 3.7 MLD. Therefore, the town has substantial potential to achieve the SLB norm of 100% treatment and to make further contributions to the national commitment to SDG target 6.3[46].The technology used is Membrane Bioreactor (MBR), which as per the ULB can treat wastewater up to secondary level. The team was unable to access environmental compliance records for the STP. While the SLB data provided by the ULB indicates a 100% sewage treatment quality for the year 2021-22, the team noted the presence of a foul odour and black colour wastewater near the STP outlet, shown in the figure 31. This could lead to environmental and sea pollution.

  The ULB is planning to upgrade its sewage treatment capacity through two new proposals: a 3 MLD plant under Karnataka Urban Water Supply and Drainage Board and an 8.69 MLD plant under Karnataka Urban Infrastructure Development and Finance Corporation (KUIDFC).

  In terms of **greywater management**, field visits revealed a wide variation in practices across households. Some homes direct greywater into separate soak pits, while others discharge it into nearby drains and open areas. A few households even **channel greywater directly into the sewerage network**.

Figure 31: Black Water Flowing through the drainage system and mixing with the sea water

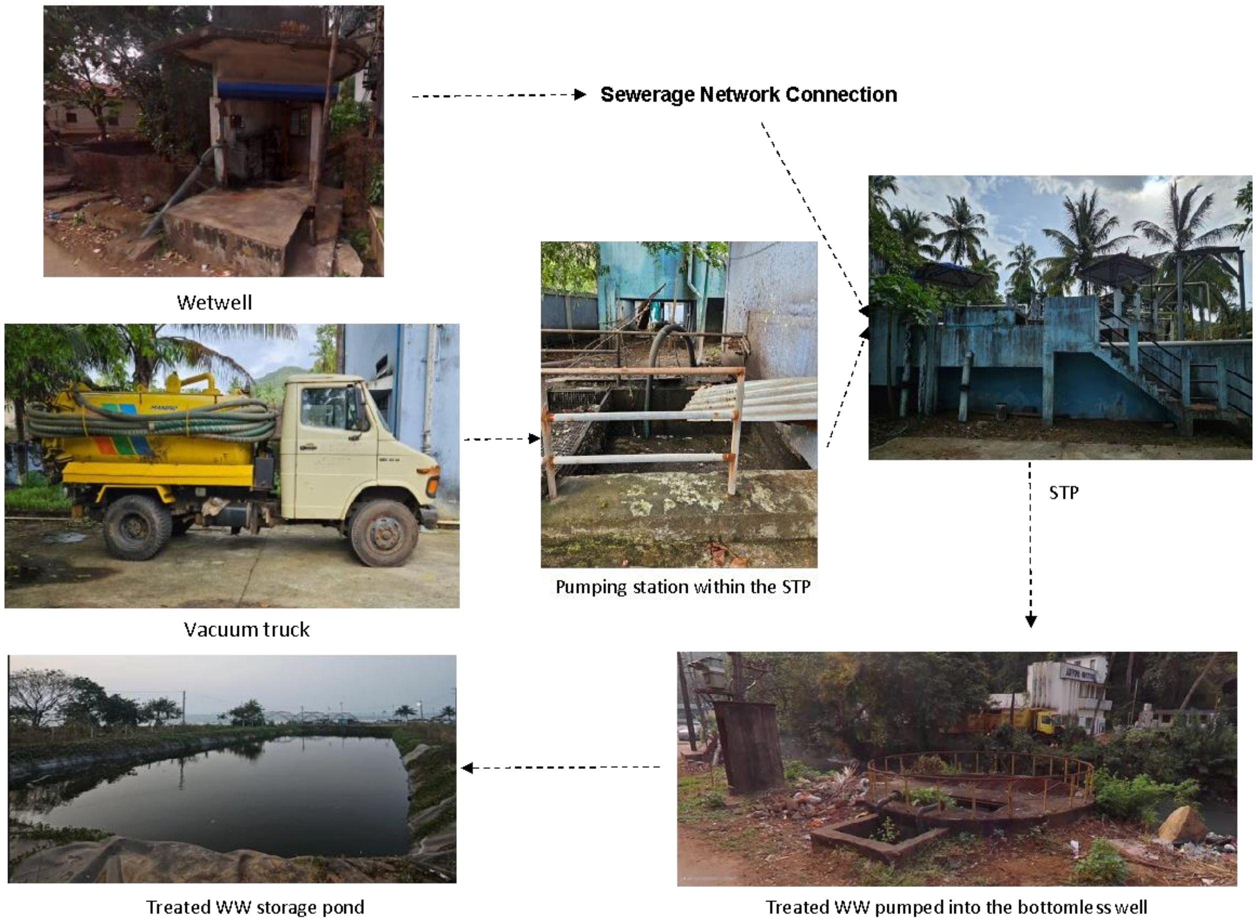


Source: Plotted on Google Earth

- **End-use Disposal (Sludge Management):** The city does not have a dedicated sludge treatment system. The septage from various properties (OSS) and CT/PT is collected by 2 jetting/suction machines (owned by ULB) in the wet well within the STP premise which is directly going to the STP for treatment. The ULB charges INR 2300 for residential and INR 5350 for commercial properties for emptying the septic tanks[47].At the STP, there are 4 drying beds constructed with sand and stone. Once the sludge has dried, it is transported to the solid waste management landfill site, located on the city outskirts. There, the dried sludge is mixed with manure to produce fertilizer, which is then sold to local residents, and local nurseries at a rate of INR 1 per kg. This is an extra source of revenue for the ULB. The treated effluent is discharged through a pipe into a holding tank, which was previously a water well, and then pumped into a pond with a mud structure and a plastic lining. From there, jetting trucks collect the water to be subsequently recycled for non-potable uses, including irrigation of public parks and green spaces, and the maintenance of public roads. The water holding tank (well) potentially leads to groundwater recharging.

- **Recycling and Reuse:** The town currently recycles and reuses only 0.2% of its wastewater, falling significantly short of the 20% SLB norm.

Figure 32: Illustration of Steps in Sewage Management – from collection to treatment to disposal



Source: Authors' Illustration

4.3 INSTITUTIONAL ARRANGEMENTS

This section examines the institutional arrangements, outlining the various departments, agencies, and organizations, along with their respective roles in delivering sanitation infrastructure and services. It also emphasizes the role of the urban local body in disaster governance.

Sanitation is a state subject, and under the 74th Constitutional Amendment Act (CAA), ULBs are primarily responsible for delivering water supply and sanitation services. However, in practice, we observed a multi-stakeholder, multi-level governance framework involved in the provision of sanitation infrastructure and services (Ref. Table 7).

Table 7: Institutional Arrangements: Sanitation Services

Intervention	Technology Selection	Land	Capital	Technology Provision	Technology implementation	O&M	O&M Funding
Toilets	HH	HH	HH	Local mesons/private vendors	Local mesons/private vendors	HH	HH
OSS	HH	HH	HH			HH septage removal by vehicles of ULB	HH
CT	ULB	ULB	ULB Centre (15th Finance Commission, Tourism department, SBM 2.0)	ULB	ULB	ULB	ULB
PT	ULB	ULB	ULB Centre (15th Finance Commission, tourism department, SBM 2.0)	ULB	ULB	ULB (3 PT) Private (5 PT)	ULB (3 PT) For remaining User charges paid to private O&M vendor
Sewerage Network	State (KUIDFC)	ULB	IFIs	State (KUIDFC)	State (KUIDFC)	ULB	ULB
STP	State (KUIDFC)	ULB	IFIs	State (KUIDFC)	State (KUIDFC)	ULB	ULB

Source: (Rana, Gogoi, & Narayanan, Forthcoming)[48]

Although ULBs serve as the nodal agency for sanitation services, the current institutional arrangement at the town level reveals their limited role, particularly in relation to larger infrastructure projects, as shown in the table below.

Capital funding for major infrastructure is primarily provided by central or state governments, or International Financial Institutions (IFIs), while the responsibility for O&M falls upon the ULBs. Given that ULBs are responsible for O&M of such large infrastructure, it is crucial to assess their financial health, as their capacity to sustain and manage these projects is directly linked to their financial stability *(discussed in section under financial health of ULBs)*.

At the household level, neither ULBs nor any other institutions are involved in the design, construction, or enforcement of standards for toilets and OSS. However, for larger establishments, a mechanism for building plan approval is in place through the town planning department to ensure compliance with relevant regulations and standards. Furthermore, interviews with the ULBs revealed that their role in disaster governance and planning is limited. They primarily focus on providing sanitation and water supply during the relief phase of a disaster.

4.4 CHALLENGES AND OPPORTUNITIES IN SANITATION INFRASTRUCTURE AND SERVICES

The town is not fully meeting several of the SLB norms set by the Government of India. The challenges outlined below are key barriers to achieving the required service levels, but they also present valuable opportunities in provision of equitable and affordable sanitation services to all.

- **Affordability Concerns:** The cost of desludging is Rs 2,300 per trip for residents, and feedback from our field interactions suggests that some residents find these charges challenging. Consequently, a few households may explore alternative options, such as pit latrines, which can pose risks to groundwater quality. Despite significant investments by the Central government in sanitation infrastructure, including STPs and sewerage networks, affordability concerns, as highlighted during the transect walk, seem to limit their widespread adoption. Residents mentioned the cost of sewerage connections (INR 4,500 one-time charge + INR 1,200 annual maintenance) as a barrier. Even in areas with existing UGD networks, many households remain unconnected.

- **Maintenance of Critical Infrastructure:** Although the city has an STP, its operation could be improved. During our visit, we observed areas with black water, particularly in large drains leading to the sea. The centralized treatment plant's management presents opportunities for improvement to address environmental concerns. One of the wet wells, an important component of the system, was not fully functional. Additionally, the treated water storage well was in a drainage area, where black water was flowing, and the well was bottomless, resulting in floating sludge. Effective management of this infrastructure is crucial for the city's water and environmental health. If the city faces challenges in maintaining the system due to factors such as funding, skilled personnel, or land availability, exploring alternative solutions or improvements to the treatment process would be beneficial.

- **Opportunities for Improving Septage Management Solutions:** There is an opportunity to enhance septage management, particularly with the implementation of solutions like a FSSTP, especially given that only 13% of properties are connected to the sewerage network. Additionally, addressing the management of septage from certain community and public toilets can improve both environmental and public health. At the household level, transitioning from traditional pits to scientifically designed septic tanks, coupled with solutions tailored to high water table areas, can help mitigate the risk of groundwater contamination.

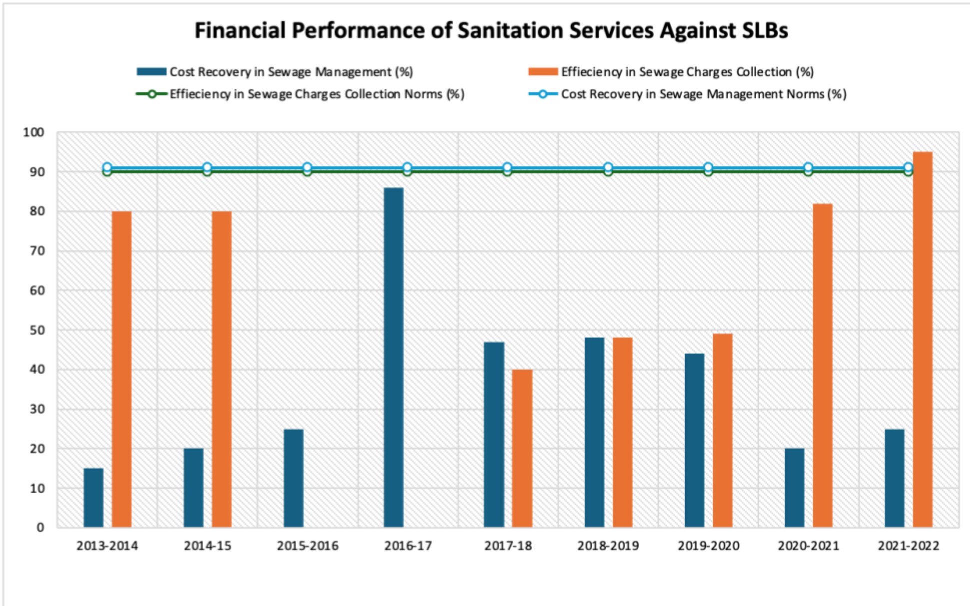
- Need of Integration of Climate Resilience in Infrastructure Planning: We were informed that the high tides lasting 6–7 hours frequently lead to flooding, which disrupts the operations of STP and accelerates corrosion of metal components due to high salinity (KMC Commissioner, 13 August 2025, Stakeholder consultation workshop, Indian Institute of Technology Bombay, Mumbai, Maharashtra, India)

  Additionally, seasonal extremes pose significant challenges—excess water during the monsoon overwhelms the system, while acute water scarcity in summer hampers its functioning. These factors highlight the urgent need to integrate climate resilience considerations into infrastructure planning and design.

- **Need of Resources:** According to our interviews, the ULB faces challenges in securing sufficient funding for essential sanitation infrastructure such as sewerage networks and sewage treatment plants. The ULB relies heavily on central and state grants for large-scale infrastructure projects due to limited revenue and a low-cost recovery rate (25%) for sanitation services[49]. However, it demonstrates a strong 95% efficiency in sewerage charge collection[50]. Furthermore, as highlighted in the below figure 33, the inconsistent performance of the ULB over the years in meeting the SLB norms for cost recovery (100%) and sewage charge collection efficiency (90%).

  Once infrastructure is developed and handed over to the ULB, ensuring its efficient operation and maintenance becomes crucial for the long-term sustainability and viability of these centralized services. Furthermore, initiatives under SBM 2.0, such as the construction of IHHLs, present a financial challenge, as local bodies are required to contribute 78% of the cost (INR 30,000 per unit), even as they work to address their existing needs.

Figure 33: Cost Recovery and Efficiency in Sewerage Fee (2013-2022)



Source: Data from KMC

- **Need of Competent and Skilled Workforce in O&M:** Field observations highlighted an opportunity to enhance the skill set of personnel for the operation and maintenance of the STP. Addressing this gap through targeted training and resource allocation could further improve treatment processes and overall wastewater management effectiveness.

- **Limited Role of ULB in Infrastructure Planning and Development:** The ULBs' reliance on state or central government capital funding can affect their decision-making authority in infrastructure development and planning, particularly for large-scale projects like sewerage networks and sewage treatment plants, especially when these funds come with conditionalities (e.g., finance commission grants). This financial dependence may result in ULBs' sanitation concerns or specific requests being less prioritized during the planning process. For instance, the ULB proposed using SBM 2.0 funds for both sewerage network development and STPs, given the city's lack of a sewerage network, which makes investing solely in STP construction less viable. However, these concerns were not fully addressed in the infrastructure planning process. This situation can impact the autonomy of ULBs regarding funds, functions, and functionality, as outlined in the 74th Constitutional Amendment Act.

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land are constraints in providing individual household toilet. These are for a more or less a fixed user group.” (CPHEEO, 2018, p. 1)

[45] According to the SLB reporting (2022-2023) by KMC, the water supplied is at 101 lpcd and wastewater generated for a population of 64,599 at 80% is 5.4 MLD.

[46] SLB 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.

[47] The city has one jetting machine with a capacity of 3,000 liters and a suction-cum-jetting machine with a capacity of 4,000 liters.

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[49] Expressed as “wastewater revenues as a percentage of wastewater expenses, for the corresponding time period” (according to SLB)

[50] Expressed as “current year revenues collected, expressed as a percentage of the total operating revenues, for the corresponding time period” (according to SLB)

5. CLIMATE IMPACTS OF WATER & SANITATION SYSTEMS

ASHISH DANGI[51] AND NC NARAYANAN

This chapter focusses on the climate impacts of the water and sanitation systems, i.e., the greenhouse gas (GHG) emissions throughout the service chain. By estimating stage-wise energy consumption and GHG emissions, our assessment provides baseline evidence for planning climate mitigation strategies in the WaSH sector.

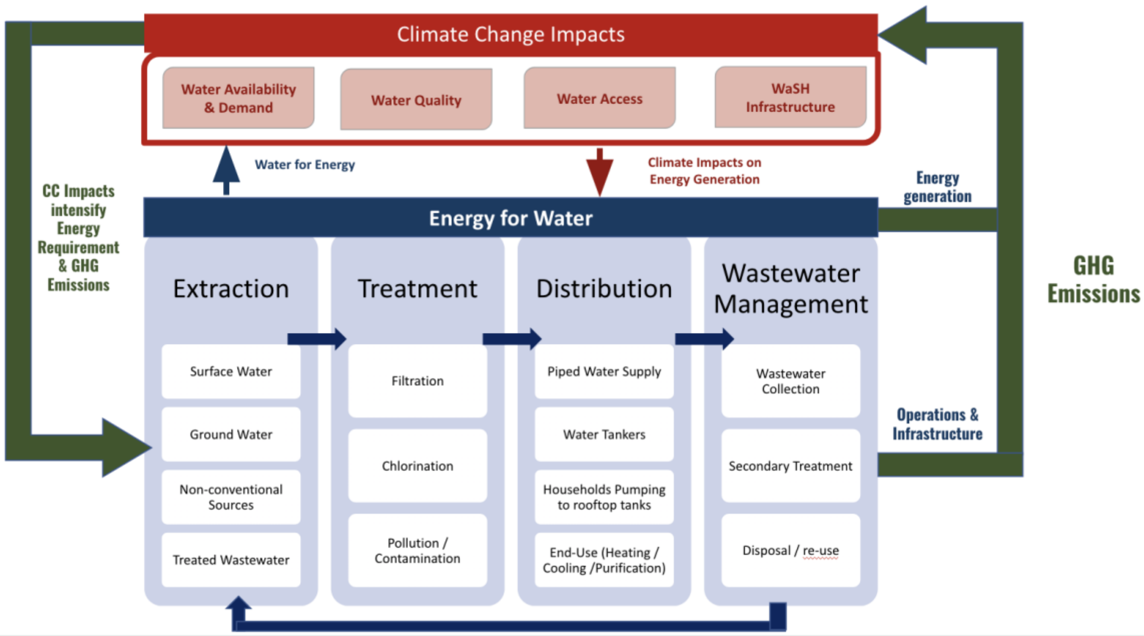
5.1 BACKGROUND

Globally, the water and sanitation systems are increasingly recognised not only as climate victims, but also significant contributors to climate change as the GHG emissions from WaSH continue to grow. Energy is the key input to every step in an urban water cycle right from water extraction to conveyance, treatment, distribution, and end-use; as well as for wastewater collection, conveyance, treatment, and re-use. This energy use further translates into GHG emissions associated with energy generation. Water sector which includes the collection and treatment of wastewater, accounts for *4% of total global electricity consumption and around 3% of global greenhouse gas emissions*[52]. According to another estimate, wastewater treatment plants alone are estimated to account for 3% global electricity consumption[53]. Additionally, biological degradation of the organic matter present in sewage and grey water across the containment, transport, treatment and discharge pathways in a sanitation service chain results in direct methane (CH4) and nitrous oxide (N2O) emissions[54]. *Direct emissions in wastewater treatment are estimated to be significant at ~1.57% of global GHG emissions*[55].

Climate change impacts on water availability, quality, and access as well as on wastewater and stormwater management, are going to *further exacerbate the scenario* by directly increasing the energy and carbon intensity of the water cycle. Additional water demand by cities is often met by higher energy use in the water cycle[56]. For instance, between 2005 and 2015, while Beijing's water supply increased by only 10%, the energy consumption associated with water supply surged by 215% [57]. In fact, *Water sector's electricity consumption is projected to significantly increase* with rising scarcity and could rise to as high as 16% of total energy consumption for countries faced with severe water scarcity such as those in Middle East[58]. With the rise in sewage generation and treatment capacity, *the energy and carbon footprint of wastewater is likely to increase dramatically in the near future* in the absence of interventions. For example, domestic wastewater emissions increased by 400% between 2000-2014 in China due to growth in WWTPs [59]. *With the increased variability posed by climate change the emission in WWTPs could further increase*[60].

Just as water systems are becoming increasingly energy-dependent, *energy generation remains heavily reliant on water*, with energy-sector's water consumption projected to rise by 60% between 2014 and 2040 and ***the future water demand for projected energy use in 2030 likely to surpass the available supply***[61]. *Clean energy transitions could exacerbate the water stress* as biofuels production, concentrating solar power, carbon capture and storage, green hydrogen and nuclear power can have more significant water demands.

Figure 34: The Water-Energy-Climate nexus in Urban Water Cycles.



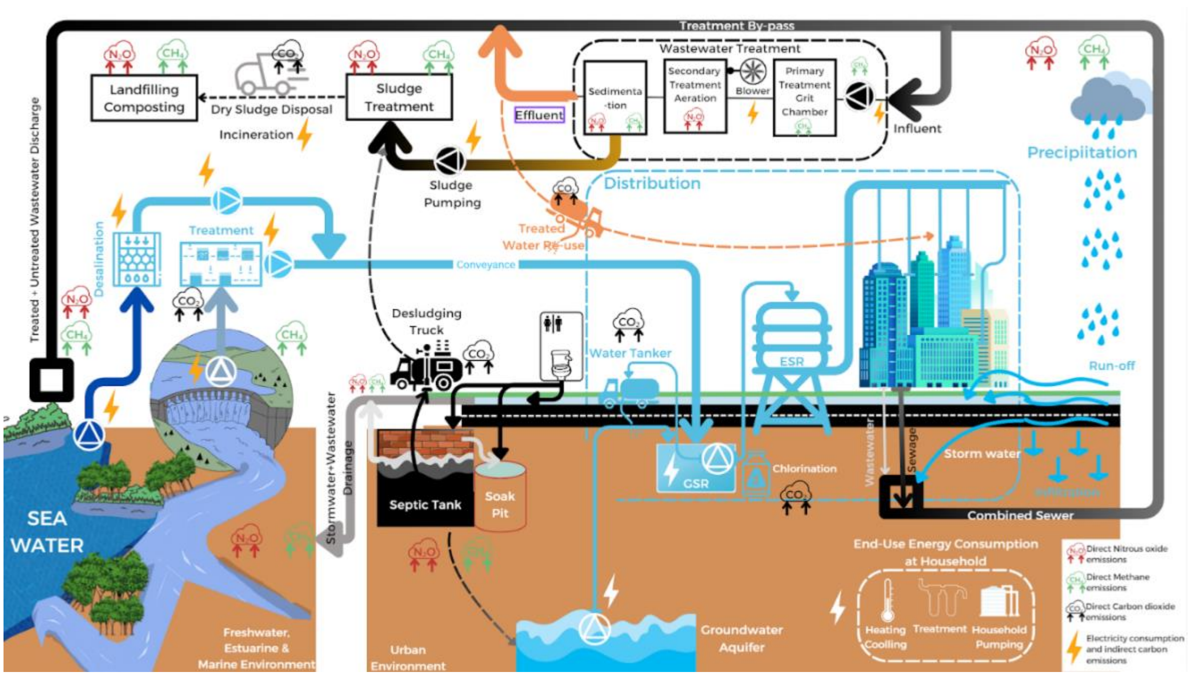
Source: Author's Illustration.

As illustrated in *figure 27*, urban water cycles relying on conventional energy-dependent approaches remain trapped in a vicious cycle where intensification of climate impacts results in increased carbon and energy footprint of urban water cycles which in turn results in worsening of climate impacts. **This escalating interdependence demonstrates exactly why designing climate-resilient urban water and sanitation systems is such an urgent priority.** The unavoidable overlap of water consumption and carbon emissions in urban environments means that achieving true resilience requires explicit coordination between water and carbon management[62]. *An assessment of the energy and carbon footprints is therefore crucial, not only for ensuring the sustainability of urban water and sanitation systems, but also for informing broader macro-policy karnatakals like energy security and greenhouse gas (GHG) mitigation.*

5.2 SOURCES OF GHG EMISSIONS IN URBAN WATER AND WASTEWATER SYTEMS

Energy is the most vital input for operating a typical urban water and wastewater system. Energy is often consumed in the form of electricity for powering pumps and machinery, resulting in indirect greenhouse gas (GHG) emissions, depending on the mode of power generation. Energy is also consumed in the form of fossils fuels in trucks that are used to transport water, sludge, material and chemicals throughout the service chain-resulting in direct GHG emissions. Direct GHG emissions can also come from large water reservoirs due to sedimentation. Further, biological degradation of the organic matter present in sewage and grey water results in direct methane (CH4) and nitrous oxide (N2O) emissions. Additionally, there is embedded energy and carbon footprint associated with the physical infrastructure and the materials and chemical used. *Figure 28* schematically illustrates the various steps in a typical urban water cycle in India as well as the electricity consumption and GHG emissions sources.

Figure 35: Graphical representation of various steps and processes in a typical urban water cycle showing sources of energy consumption and greenhouse gas emissions.



Source: Author's Illustration

5.3 SCOPE OF GREEN HOUSE GAS ESTIMATION

Assessing the carbon footprint of urban water systems requires a comprehensive approach that accounts for emissions across different stages of water abstraction, treatment, conveyance, distribution, and wastewater management. These emissions originate from various processes, including direct GHG releases, energy and chemical consumption in operations, and emissions embedded in materials that make up the physical infrastructure. In this estimation, emissions are classified into three broad categories: *Direct Emissions, Indirect Emissions, and Embedded Emissions mentioned in Table 10.* Each category captures different sources of carbon emissions within the urban water and sanitation systems.

Table 8: Scope of emissions methodology for carbon footprint assessment of the urban water cycle

Category	Possible Sources of Emissions	Methodology
Direct Emissions	- Methane (CH_4) emissions from anaerobic decomposition of organic matter in wastewater. - Nitrous Oxide (N_2O) Emissions from nitrification and denitrification of nitrogen compounds wastewater - Methane (CH_4) emissions from the decomposition of organic matter in anaerobic sediments in freshwater reservoirs*	2006 IPCC Guidelines for National Greenhouse Gas Inventories[54] (2019 Refinement[63])
Indirect Emissions	- Indirect emissions from electricity consumption - Life cycle GHG emissions associated with the chemicals used in water and wastewater treatment processes (alum, hypo, chlorine etc.)* - Emissions from diesel combustion for transportation	Electricity consumption data obtained from urban local bodies and an average grid emission factor 0.716 tCO2/MWh (*FY 2022-23*, Central Electricity Authority)[64] for Indian grid used for CO2 estimation. Diesel consumption for desludging trucks based on information obtained from interviewing truck operators.
Embedded Emissions	- Life cycle GHG emissions associated with the materials used in the physical infrastructure. *	Not estimated due to non-availability of data on material footprint.

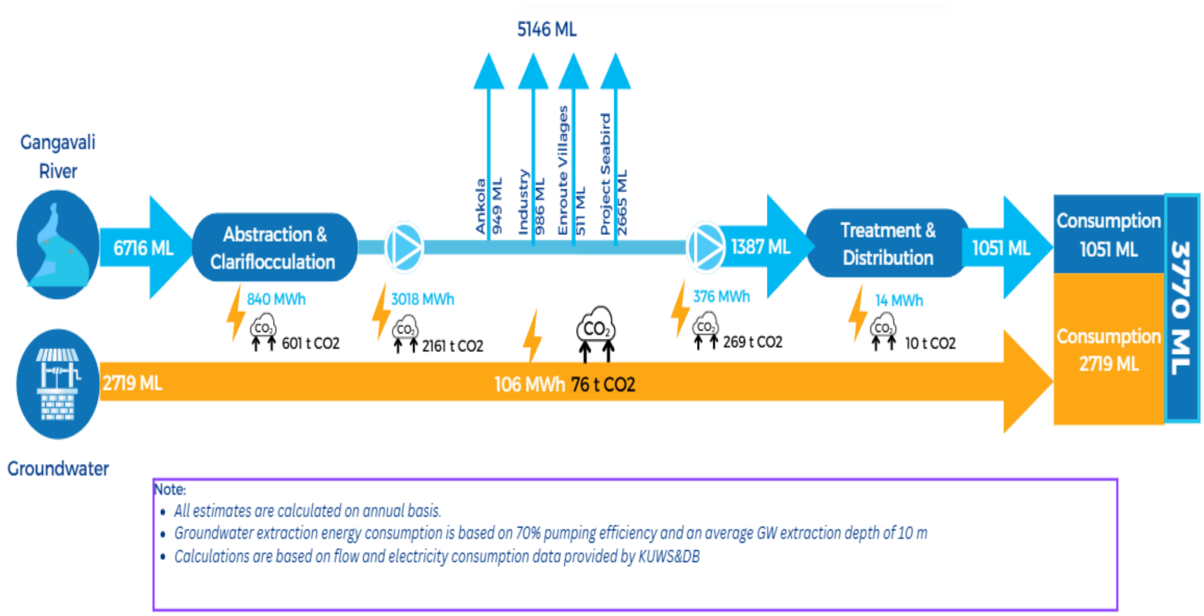
*Emissions not considered in the estimation due to non-availability of reliable activity data for the same.

5.4 GREENHOUSE GAS EMISSIONS FROM WATER SUPPLY

The energy-intensive nature of water supply spanning extraction, treatment, conveyance, and distribution results in substantial indirect GHG emissions, primarily from electricity use. Additionally, household-level pumping, purification, and heating contribute to the carbon footprint, although such household level energy use is not accounted for here. Emissions related to treatment chemicals, construction materials, and logistics also remain outside the scope of this estimation due to data constraints. Furthermore, scientific studies suggest that freshwater reservoirs may also release direct GHG emissions due to anaerobic decomposition of organic matter in sediments[65]. However, these are excluded from this analysis given methodological limitations. Hence, our assessment focuses solely on electricity-related emissions across key components of the water supply chain, as shown in *Figure 36*.

Karwar's urban water supply, though reliant primarily on surface water from the Gangavali River, is also supported by limited groundwater use. The energy-intensive nature of this system, especially due to long-distance water transfers and elevation-related pumping, contributes significantly to GHG emissions.

Figure 36: Carbon and energy footprint of Karwar's water supply.



Source: (Dangi & Narayanan, forthcoming)[66]

Surface Water: Energy-Intensive Supply Chain

The bulk of Karwar's water (approximately 6,716 million litres annually) is sourced from surface water. While 1,387 ML is treated and supplied to Karwar town, a much larger portion (over 5,100 ML) is transferred to enroute villages, the Indian Navy base, and industrial users.

- **Intake and Abstraction:** Energy use begins at the jackwell, where 840 MWh of electricity is consumed annually, resulting in 601 tonnes of CO_2 emissions.
- **Long-Distance Conveyance:** A substantial share of energy (3,018 MWh per year) is used to lift water to a hilltop Mother Tank from where it can flow under gravity. This stage alone contributes 2,161 tonnes of CO_2 annually—making it the single largest source of emissions in the water supply chain.
- **Additional Pumping (Binaga Station):** Further pumping to deliver water specifically to Karwar town (1,387 ML) consumes another 376 MWh/year, adding 269 tonnes of CO_2.
- **Treatment and Local Distribution:** At the High Church and Baithkol treatment and distribution centers, only 14 MWh is used annually, contributing a minor 10 tonnes of CO_2.

Groundwater: Lower Energy, Lower Emissions

Groundwater abstraction plays a secondary role in Karwar's water supply, contributing about 2,719 ML annually. Thanks to the relatively shallow aquifers (average depth of 5 meters) and assumed 70% pumping efficiency, the energy requirement is low at just 106 MWh/year, corresponding to 76 tonnes of CO_2. This makes groundwater significantly less carbon-intensive compared to surface water-based supply.

Key Insights

- **High Emissions from Lifting and Transfer:** The largest portion of emissions originates not from treatment or end-use, but from the energy-intensive conveyance process. Elevation-related pumping and long distances from the source make the system carbon-heavy.

- **Groundwater as a Low-Carbon Option:** Despite its limited use, groundwater abstraction exhibits a far smaller carbon footprint, suggesting opportunities for hybrid supply strategies that leverage low-emission sources where aquifers are sustainable.

- **Opportunities for Efficiency:** Upgrading pump efficiency, exploring gravity-fed systems, or integrating renewable energy into pumping operations could significantly reduce emissions in the high-energy conveyance stages.

This assessment highlights the critical link between water source choices, infrastructure design, and climate impact reinforcing the importance of integrating energy and emissions considerations into urban water planning for climate resilience.

ENERGY DEPENDENCE AND EMISSIONS LOCK-IN

Karwar's water supply is not just vulnerable to climate change it is also a contributor. The system's heavy dependence on **electricity-intensive pumping** to lift water over long distances and elevations (especially to the Mother Tank at NavaGadde) results in significant GHGemissions. Conveyance alone consumes over 3,000 MWh/year, contributing more than 2,100 tonnes of CO_2.

In contrast, groundwater abstraction, while much less energy-intensive (106 MWh/year, 76 tonnes CO_2), comes with ecological trade-offs. Without a shift toward **energy-efficient pumps**, **gravity-fed designs**, or **renewable integration**, Karwar risks getting locked into a high-emission path creating a feedback loop between climate impacts and mitigation failures.

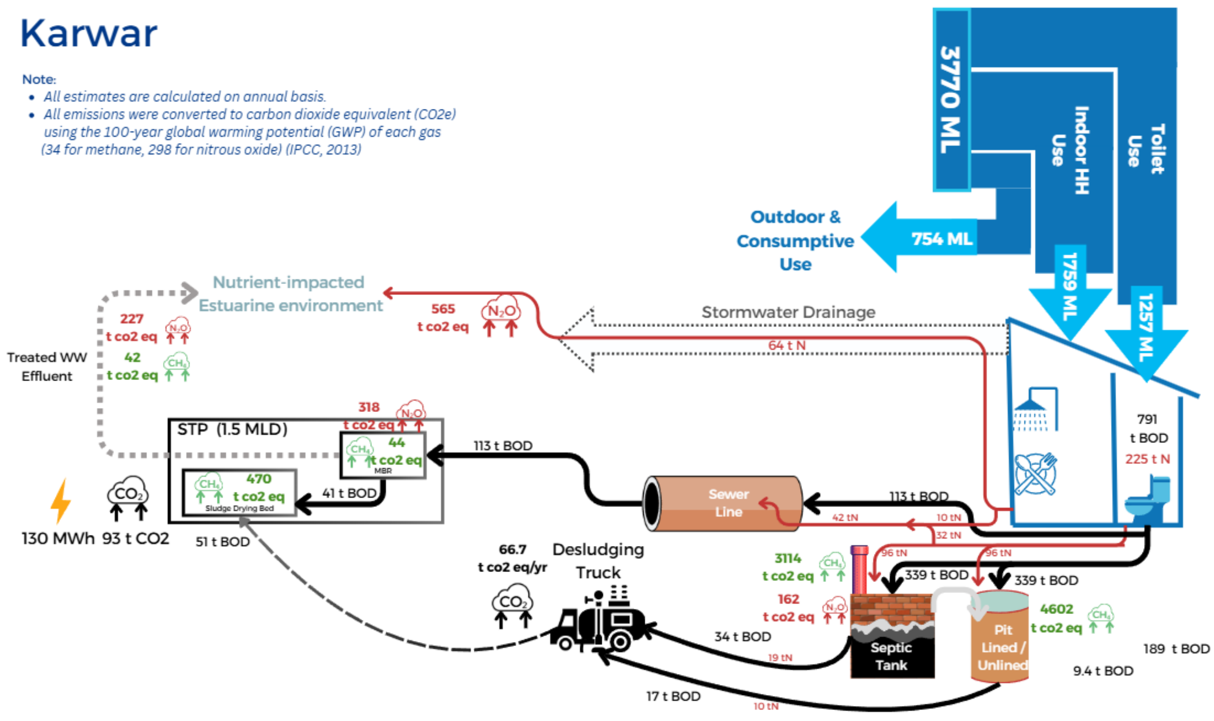
5.5 GREENHOUSE GAS EMISSIONS FROM SANITATION

The GHG emissions throughout the sanitation service chain in Karwar are illustrated in Figure 37 below.

WATER USE & WASTEWATER GENERATION

- The total annual water consumption is estimated at 3770 million liters (ML). Of this, approximately 80% (3016 ML) is used indoors and subsequently becomes wastewater, while the remaining 20% (754 ML) accounts for outdoor and consumptive uses. (Based on CPCB methodology for wastewater estimation).
- Household wastewater generation (80% of total water consumption) is further categorized as follows: Toilet use: 1257 ML and Other indoor uses: 1759 ML(As per the National Building Code, 2016, BIS).
- The total biochemical oxygen demand (BOD) load from domestic wastewater is estimated at 791 tons of BOD per year, based on an average BOD_5 generation rate of 34 g/person/day for India (IPCC 2006).

Figure 37: Carbon and energy footprint across sanitation service chain in Karwar.



Source: Dangi & Narayanan (forthcoming)[67]

WASTEWATER MANAGEMENT & GHG EMISSIONS

Direct Methane (CH4) Emissions

- Methane emissions from **on-site sanitation systems** are significant:
  - Lined/unlined pits (without a concrete bottom): 4602 t CO_2-eq/year
  - Septic tanks: 3114 t CO_2-eq/year

  (Due to the lack of reliable data on containment system types, it is assumed that 50% of on-site sanitation systems consist of septic tanks with soak pits or sand dispersal fields, while the remaining 50% are lined/unlined pits with open bottoms. This assumption also allows for a comparative analysis of the two predominant systems in the town.)

- **Desludging operations** contribute 66.7 t CO_2-eq/year, with vacuum trucks transporting 51 t BOD/year from septic tanks and pits.

(Desludging frequencies are assumed to be once every 5 years for septic tanks and once every 10 years for pits, based on field interactions with residents, municipal authorities, and desludging operators.)

- **Sludge disposal** in sludge drying beds at Sewage treatment plant results in 470 t CO_2-eq/year due to methane emissions. This includes sludge emptied from onsite systems and that generated at the STP.
- **44** t CO_2-eq/year is emitted during the biological treatment process (MBR) at the STP.
- **42** t CO_2-eq/year from treated wastewater effluent discharge from the STP into the Kone Nalla.

Direct Nitrous Dioxide (N2O) Emissions

- 160 t CO_2-eq/year from septic tanks: This results from the discharge of 192 tonnes of nitrogen originating from protein consumption into onsite containment systems. Pit latrines are not a significant N_2O source (emission factor = 0 as per IPCC 2006).
- 565 t CO_2-eq/year from greywater (OSS): This includes nitrogen contributions from household products (13%) as per IPCC, non-consumed protein in kitchen wastewater (10%) (based on significant nitrogen content in Indian kitchen wastewater, as reported by Kuntal et al.), and an additional 10 % to account for Nitrogen from commercial discharge. Field observations indicate that greywater is discharged into stormwater drains, ultimately reaching the estuarine environment, where it contributes to N_2O emissions.
- 546t CO_2-eq/year from additional nitrogen 42 t N entering the sewer system through greywater discharge from households connected to UGD.

Indirect Emissions

- 130 MWh / yr is the estimated electricity consumption for treating 1.18 MLD wastewater estimated to be generated by UGD connected household. Adding up **93 t** CO_2-eq/year of indirect emissions.

  (Note: The electricity consumption data for the STP was not made available by Karwar Municipal Council and hence it was estimated using energy intensity for MBR technology as per CPCB- Performance evaluation of sewage treatment plants in India, 2013. The electricity of wetwells for pumping the wastewater to the STP could not be estimated due lack of information on the same)

KEY INSIGHTS

- Water conveyance and wastewater management are the highest energy-intensive processes, with pumping and on-site sanitation contributing significantly to emissions.
- Methane emissions from onsite sanitation are the dominant contributors to overall GHG emissions, highlighting the need for improved faecal sludge management.
- Nitrous oxide emissions from greywater discharge into stormwater drains are a hidden but significant climate impact, emphasizing the need for integrated wastewater management.
- Groundwater abstraction is significantly more energy-efficient than surface water supply, which could inform future water resource planning.

Given the high energy intensity of wastewater management processes—particularly due to pumping and on-site sanitation—there is a pressing need to explore energy-efficient sanitation alternatives. Methane emissions from on-site sanitation systems emerge as the dominant source of GHGs in the sanitation sector, underscoring the importance of strengthening faecal sludge management practices. In parallel, nitrous oxide emissions from greywater discharged into stormwater drains represent a less visible but equally significant climate risk, suggesting that more integrated and climate-informed wastewater management approaches are required.

5.6 CONCLUSION & WAY FORWARD

Karwar's municipal emissions profile reveals a structural lock-in: an energy-heavy surface water supply running parallel to a methane-intensive sanitation sector. The geographical necessity of lifting surface water over long distances dictates the bulk of the water sector's carbon footprint, creating a high-emission trajectory that contrasts sharply with the low energy demands of local aquifers. Concurrently, the widespread reliance on anaerobic onsite containment—coupled with the unregulated discharge of nitrogen-rich greywater—generates massive, often overlooked, methane and nitrous oxide hotspots across the town.

Decarbonising these essential services necessitates a targeted, hybrid approach. To mitigate the conveyance lock-in, the municipality must prioritise pump efficiency upgrades, gravity-fed network optimisations, and the sustainable integration of low-carbon groundwater into the supply matrix. Simultaneously, climate-proofing the sanitation sector demands the urgent formalisation of faecal sludge management to intercept methane emissions at the source, alongside integrated greywater treatment strategies to curb downstream nitrous oxide pollution.

NOTES & REFERENCES

[51] Author's Note: This chapter is based on ongoing doctoral research by Ashish Dangi under the supervision of Prof. N. C. Narayanan at the Ashank Desai Centre for Policy Studies (ADCPS), Indian Institute of Technology Bombay. Key findings and interpretations presented here are part of a broader analysis that is currently being prepared for publication in a peer-reviewed academic journal. Readers are requested to cite this report appropriately and direct any academic queries to the author.

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6. PERFORMANCE AND FINANCIAL ANALYSIS OF WATER SUPPLY AND SANITATION

ABHAY JUNAGHARE[68] AND NC NARAYANAN

This chapter evaluates the operational and financial health of the water supply and sanitation systems. It begins by assessing current service delivery against established performance benchmarks for both the water and sewerage networks. Next, it analyses the underlying revenue streams, focusing on retail tariffs and the sector's reliance on external grants versus internally generated revenue. Finally, the chapter provides a comprehensive financial assessment to pinpoint the primary fiscal challenges hindering sustainable service delivery in these sectors.

6.1 BACKGROUND

This chapter analyses the performance analysis against the SLBs for urban water supply and sanitation by the Ministry of Housing and Urban Affairs (MoHUA). The section also analyses the revenue streams and grants available to KCMC for water supply and sewerage & sanitation. The revenue sources include central government grants, state government grants, and their own revenue sources. Here, the ratio of grants to own revenue sources is analyzed to identify the percentage availability of each source for water supply and sewerage & sanitation. The assessment of financial health of the water utility and sewerage & sanitation is performed here by examining the capital receipts, capital expenditure, revenue expenditure, & revenue receipts from the city municipal budget statements. The water and sanitation budgets are created from the municipal budgets to analyse the cost recovery, collection efficiency, operating ratio, cost of bulk water purchase, per capita expenditure, the revenue and fiscal deficits, budget trends (capital receipts, capital expenditure, revenue expenditure, & revenue receipts), and compound annual growth rate (CAGR)[69]. The above given ratios are essential to identify the financial health of the water utility and sewerage & sanitation at council.

6.2 PERFORMANCE ANALYSIS: SERVICE LEVEL BENCHMARKS

The performance[70] of the utility for water and sanitation services can be assessed based on the performance indicators. These nine performance indicators known as the SLBs for urban water supply and sewerage and sanitation in India were proposed by the then MoUD (refer to table 7). These SLBs can ascertain the inefficiencies in the urban water supply system and sewerage & sanitation besides providing the corrective measures that are vital to achieve sustainable water supply and sewerage & sanitation. The SLBs can be distinguished into four major indicator groups, viz., access, quality of water supply and treated used water, financial viability and environmental sustainability that further fits into social, economic and environment dimensions. Increasing urbanization, unplanned floating tourist population and changing consumption patterns have stressed the existing water supply and sewerage & sanitation infrastructure of the town.

6.2.1 WATER SUPPLY

The water supply indicators for KCMC reveal significant gaps in service quality, accessibility, and financial sustainability compared to the India averages and national benchmarks (Ref. Table 9). While some aspects, such as metering and complaint redressal, show positive performance, major deficiencies exist in coverage, per capita supply, continuity, and cost recovery.

Coverage of connections is alarmingly low at 24%, far below the national average of 70% and the benchmark of 100%, leaving a 76% gap. This indicates that a substantial portion of Karwar's population lacks direct access to piped water, potentially relying on unreliable or unsafe alternatives. Expanding coverage should be a top priority to ensure universal access. Per Capita Supply of Water is 101 litres per capita per day (lpcd), which falls 34 lpcd short of the benchmark of 135 lpcd and even below the India average of 114 lpcd. This shortfall suggests that residents receive insufficient water for daily needs, which may be due to inadequate infrastructure, limited water sources, or distribution inefficiencies. Metering of Connections stands at 97%, which is significantly higher than the India average of 22% and just 3% below the 100% benchmark. This is a positive indicator, as metering helps in monitoring consumption and reducing wastage, contributing to better resource management.

Non-Revenue Water (NRW), representing water lost due to leakages, theft, or unbilled consumption, is at 20%, which is an improvement compared to the India average of 31% but still 5% above the benchmark of 15%. Further reduction of NRW through leak detection and pipeline maintenance can improve efficiency and revenue collection. Continuity of Water Supply is extremely poor, with an average supply of just 2 hours per day, significantly below the 24-hour benchmark and even lower than the India average of 2.7 hours. This 22-hour gap indicates severe limitations in infrastructure and water availability, necessitating urgent interventions to improve reliability. Water Quality and Treatment meet standards in only 80% of cases, falling 20% short of the benchmark of 100%. This suggests that some of the supplied water may not be safe for consumption, potentially leading to health risks. Strengthening treatment processes and monitoring systems is crucial to ensure potable water quality.

Table 9: Performance Indicators for Water Supply at KCMC

Sl. No.	Water Supply Indicators	Calculations	Benchmarks	India Average*	2024-25**	Gaps
1	Coverage of Connections	(Total no. of HHs with water supply connections)/ (Total no. of HHs in the City)	100%	70%	24%	-76%
2	Per capita supply (lpcd)	(Water supplied)/ (Population served)	135 lpcd	114 lpcd	101 lpcd	-34 lpcd
3	Metering of connections	(No. of metered connections + No. of metered Public Standposts)/ (Total no. of connections + Total no. of Public Standposts)	100%	22.00%	97%	-3%
4	Non-revenue water (NRW)	(Total water produced) - (Total water sold)/(Total water produced)	15%	31%	20%	5%
5	Continuity of water supply (hours)	Average hours of water supply	24 hours	2.7 hours	2 hours	-22 hours
6	Quality and treatment	(Number of samples that meet the specified potable water standards)/ (Total number of complaints received related to water supply)	100%	95%	80%	-20%
7	Redressal of customer complaints	(Total number of complaints redressed)/ (Total number of complaints received related to water supply)	80%	89%	100%	20%

*Source: * CPHEEO Guidelines for 24x7 WSS (Drink from Tap), Dec 2021; ** KCMC, 2025*

Redressal of Customer Complaints is a strong point, with 100% of complaints being addressed, surpassing the benchmark of 80% and the national average of 89%. This indicates an efficient grievance redressal system, which helps maintain consumer trust in the water supply services.

6.2.2 SEWERAGE AND SANITATION

The sewerage and sanitation SLBs indicators for KCMC present a mixed picture, with strong performance in toilet coverage and sewage treatment quality, but severe gaps in sewage network coverage, wastewater collection, recycling, and financial sustainability (refer to table 10).

Coverage of Toilets is at 100%, meeting the benchmark, indicating that all households have access to either individual or community toilets. This is a significant achievement, as it prevents open defecation and promotes hygiene. However, coverage of sewage network services is extremely poor, with only 13% of households connected to the sewage network, leaving a massive 87% gap. This suggests that a vast majority of residents rely on alternative sanitation methods such as septic tanks, open drains, or improper disposal systems, which can lead to environmental and health hazards. Collection efficiency of the sewage network is at 80%, which is 20% below the benchmark. This means that a significant portion of wastewater generated is not being collected properly, possibly leading to contamination and pollution of local water bodies.

Table 10: Performance Indicators for Sewerage & Sanitation at KCMC

Sl. No.	Sewerage and Sanitation Indicators	Calculations	Benchmarks	2020-21	2021-22 (Target)	Gaps
1.	Coverage of Toilets	(Total number of HHs with access to individual or community toilets within walking distance in the city)/ (Total number of HHs without individual or community toilets within walking distance)	100%	100%	100%	0%
2.	Coverage of Sewage Network Services	(Total number of HHs with direct connection to the sewage network)/ (Total number of HHs in the city)	100%	62%	65%	-38%
3.	Collection Efficiency of the Sewage Network	(Wastewater collected)/ (Total water supplied + Estimated water use from other sources)	100%	85%	95%	-15%
4.	Adequacy of Sewage Treatment Capacity	(Treatment plant capacity)/ (Total water consumed + Total number of HHs with direct connection to sewage network)	100%	82%	85%	-18%
5.	Quality of Sewage Treatment	(Number of samples that pass specified secondary treatment standards)/ (Total number of wastewater samples tested in a month)	100%	87%	95%	-13%
6.	Extent of Reuse and Recycling of Sewage	(Wastewater recycled or reused after appropriate treatment)/ (Wastewater received at STPs)	20%	80%	90%	60%
7.	Efficiency in Redressal of Customer Complaints	(Total number of complaints redressed within the month)/ (Total number of sewage-related complaints received per month)	80%	85%	90%	5%

*Source: * KCMC, 2025*

Adequacy of sewage treatment capacity is relatively high at 94%, just 6% below the benchmark of 100%. This indicates that the existing treatment plants are nearly sufficient to handle the current wastewater load, but further expansion might be needed if sewage network coverage improves. Quality of sewage treatment is 100%, fully meeting the benchmark. This is a strong positive indicator, showing that treated wastewater meets secondary treatment standards, reducing environmental and health risks. However, reuse and recycling of sewage is at an alarmingly low 1.3%, far below the 20% benchmark, with a

19% shortfall. This suggests that almost all treated wastewater is discharged instead of being reused for purposes like irrigation or industrial use. Increasing wastewater recycling can enhance sustainability and reduce dependence on freshwater sources. Efficiency in redressal of customer complaints is at 67%, falling 13% short of the benchmark of 80%. This indicates a delay or inefficiency in resolving sewage-related grievances, which can negatively impact public satisfaction and sanitation conditions.

6.3 REVENUE STREAMS AT KARWAR CITY MUNICIPAL COUNCIL (KCMC)

This section analyses the revenue streams and grants available to KCMC, for water supply and sewerage & sanitation. The revenue sources include central government grants, state government grants, and the own revenue sources. Here, the ratio of grants to own revenue sources is analysed to identify the percentage availability of each source for water supply and sewerage & sanitation.

6.3.1 WATER SUPPLY

Central Government Funds

KCMC received central government grants for water supply projects under the 14th and 15th Finance Commissions (FC) (Table 11). The 14th FC granted INR 3,49,38,000 in a single instalment for 2017-18, with no further allocations until 2022-23. The 15th FC grants started in 2018-19, with amounts steadily increasing from INR 2,63,20,000 to INR 4,24,99,000 in 2019-20, peaking during these years.

Table 11: Funds received by KCMC (in INR Lakhs) for Water Supply under Central Government Schemes (in INR)

Year	14th FC Grants	15th FC Grants
2015-16	0	0
2016-17	0	0
2017-18	34938000	0
2018-19	0	26320000
2019-20	0	42499000
2020-21	0	35909000
2021-22	0	21480122
2022-23	0	1422793
Total	**3,49,38,000**	**12,76,30,915**

Source: Budget Documents, KCMC

However, funding declined in subsequent years, with grants dropping to INR 14,22,793 in 2022-23. The total grants under the 15th FC were INR 12,76,30,915, significantly higher than the 14th FC's INR 3,49,38,000. This suggests a strategic focus on water supply improvements, with major investments made in the early years, followed by a tapering off likely due to project completion or changes in funding priorities.

State Government Funds

KCMC received state government grants for water supply and MLA Local Area contributions, with total funding for water supply amounting to INR 1,58,14,176 over the years (Table 12). Grants fluctuated significantly, with the highest allocation of INR 45,52,972 in 2019-20, and substantial grants in 2016-17 (INR 39,34,900) and 2017-18 (INR 34,28,000). However, the funding sharply declined in 2018-19 (INR 6,82,000) and remained low in the subsequent years, suggesting allocations were based on project needs and available state resources.

Table 12: Funds received by KCMC (in INR Lakhs) for Water Supply under State Government Schemes (in INR)

Year	Water Supply (State Government Grants)	Grants & Contributions for Specific Purposes from State Government - MLA Local Area
2015-16	0	487500
2016-17	3934900	0
2017-18	3428000	0
2018-19	682000	0
2019-20	4552972	0
2020-21	500000	0
2021-22	1580656	0
2022-23	1135648	0
Total	**1,58,14,176**	**4,87,500**

Source: Budget Documents, KCMC

A one-time MLA Local Area grant of INR 4,87,500 was received in 2015-16, but no further contributions were made thereafter, indicating irregular state-level discretionary funding. The inconsistent funding pattern suggests that while the state government supported water supply projects, the reliance on Finance Commission grants likely became more crucial for sustained infrastructure development.

Own Revenue

KCMC's water supply-related revenues and grants have shown notable fluctuations over the years, with the total revenue from water supply charges amounting to INR 3,58,14,036 (Ref. Table 13). The revenue generally increased, peaking at INR 1,11,20,264 in 2021-22, though there was a significant drop in 2019-20 and 2022-23, possibly due to billing or consumption issues. Penalty revenue was minimal, totalling just INR 2,615 in 2019-20, suggesting weak enforcement of penalties. Revenue from new tap connections totalled INR 56,26,087, with consistent demand for new connections, particularly in 2016-17 and 2018-19.

Table 13: Revenue Income from Water Supply at Karwar (in INR)

Year	Water Supply Charges	Penalties & Fines	Tap Connection Charges	Salary Grants for Water Supply
2015-16	2052474	0	193000	0
2016-17	2496863	0	761672	600000
2017-18	3200548	0	768149	486000
2018-19	5579680	0	990750	775000
2019-20	2338103	2615	424221	648000
2020-21	7877652	0	540954	660000
2021-22	11120264	0	990941	1046000
2022-23	1148452	0	956400	2500000
Total	**3,58,14,036**	**2,615**	**56,26,087**	**67,15,000**

Source: Budget Documents, KCMC

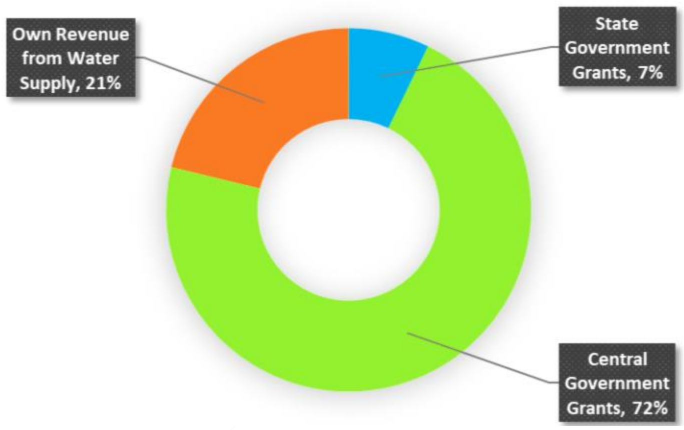
Salary grants for water supply totalled INR 67,15,000, with allocations gradually increasing from INR 6,00,000 in 2016-17 to INR 25,00,000 in 2022-23, indicating a rising dependency on external funding for workforce expenses. The fluctuations in water supply charges and the negligible penalties highlight inefficiencies in revenue collection and enforcement, which could jeopardize financial sustainability. To ensure long-term viability, the KCMC needs to improve revenue collection, strengthen penalty enforcement, and reduce reliance on salary grants and external funding.

Ratio of grants and own revenue for water supply

The financial ratio of owned revenue to grants for water supply at KCMC reveals significant fluctuations in the municipality's financial independence (Ref. Figure 38).

In 2015-16, the ratio was exceptionally high at 4.61, indicating strong self-sufficiency, but this dropped sharply in 2016-17 to 0.98, suggesting a growing reliance on grants. Between 2017-18 and 2020-21, the ratio plummeted to as low as 0.07 in 2019-20, with grants far outpacing own revenue, reflecting weak revenue generation. A notable improvement occurred in 2021-22, and by 2022-23, the ratio rebounded to 1.80, with own revenue surpassing grants, indicating better revenue collection efforts. However, over the years, the average ratio was only 0.27, meaning 73% of funding relied on external grants, raising concerns about sustainability. The positive trend in 2022-23 should be maintained through improved billing efficiency, enforcement, and diversification of revenue sources to reduce dependence on grants and ensure long-term financial health for water supply services.

Figure 38: Share of grants vs own revenue for water supply at Karwar Municipal Council



Source: Author's Analysis of Municipal Budgets from 2016-17 till 2023-24, Karwar City Municipal Council (KCMC)

6.3.2 SEWERAGE AND SANITATION

Central Government Funds

KCMC received Central Government grants for sewerage and sanitation under three key components, viz., the 14th and 15th Finance Commission (FC) Grants, and SBM Toilet-specific grants (Ref. Table 14). The 14th FC Grants totalled INR 7.08 crore, received only in 2017-18 and 2020-21, indicating inconsistent funding, possibly due to policy changes or project-specific allocations. The 15th FC Grants for Swachh Bharat Mission Detailed Project Report (SBM DPR) began in 2019-20, with a total allocation of INR 6.54 crore, peaking in 2019-20 at INR 4.24 crore, before declining in 2021-23.

The largest share of funding, INR 8.17 crore, came from SBM Toilet grants, which were highly allocated in 2015-17, but saw a drastic reduction afterward, signalling the completion of initial projects. While the shift from SBM Toilet-specific grants to broader sewerage and sanitation infrastructure under the 15th FC aligns with a focus on wastewater management, the decline in funding in recent years raises concerns about sustaining sanitation infrastructure. The municipality needs to diversify funding sources, improve sewerage charges, and create long-term financial plans to maintain the infrastructure after central grants taper off.

Table 14: Funds received by KCMC (in INR) for Sewerage & Sanitation under Central Government Schemes

Year	14th FC Grants	15th FC Grants- SBM DPR	Central Grants & Contributions for Specific Purposes - SBM Toilet
2015-16	0	0	3,11,48,934
2016-17	0	0	3,07,37,394
2017-18	3,49,38,000	0	1,07,25,144
2018-19	0	0	45,42,343
2019-20	0	4,24,99,000	5,89,914
2020-21	3,59,09,000	0	10,00,000
2021-22	0	2,14,80,122	30,00,000
2022-23	0	14,22,793	0
Total	**INR 7,08,47,000**	**INR 6,54,01,915**	**INR 8,17,43,729**

Source: Budget Documents, KCMC

State Government Funds

KCMC received a total of INR 3.74 crore in state government grants for sewerage and sanitation, with funding starting only in 2019-20 after an initial absence from 2015-18 (Ref. Table 15). The first major state grant was INR 2.89 lakh in 2019-20, followed by gradual increases in 2020-21 (INR 10.85 lakh) and a significant jump in 2021-22 (INR 2.80 crore), suggesting a greater state focus on sanitation projects. However, funding dropped to INR 80.32 lakh in 2022-23, indicating that state contributions may be project-based rather than consistent annual allocations.

Table 15: Funds received by KCMC (in INR) for Sewerage & Sanitation under State Government Schemes

Year	Grants from State Government/ SBM DPR Grants	Grants & Contributions for Specific Purposes - MLA Local Area
2015-16	0	INR 4,87,500
2016-17	0	0
2017-18	0	0
2018-19	0	0
2019-20	2,89,500	0
2020-21	10,85,000	0
2021-22	2,80,11,156	0
2022-23	80,32,400	0
Total	**INR 3,74,18,056**	**INR 4,87,500**

Source: Budget Documents, KCMC

A one-time MLA Local Area grant of INR 4.87 lakh in 2015-16 was small and no further grants were received under this scheme, highlighting that sanitation was not a major focus for MLA funding. The inconsistent nature of state funding raises concerns about long-term sustainability, suggesting the need for more stable, continuous support and a stronger focus on securing long-term state and local contributions for sewerage and sanitation infrastructure.

Own Revenue

KCMC generates revenue for its sewerage and sanitation services primarily through UGD Charges and UGD Connection Charges. Between 2015-16 and 2018-19, the UGD charges yielded INR 25.55 lakh, peaking in 2017-18, but ceased after 2018-19, suggesting either a policy change or a decline in collection efforts (Ref. Table 16).

Table 16: Revenue Income from Sewerage & Sanitation at Karwar (in INR)

Year	UGD Charges	UGD Connection Charges
2015-16	1,29,800	INR 500
2016-17	2,08,910	0
2017-18	11,96,716	0
2018-19	10,19,838	19,27,940
2019-20	0	3,16,250
2020-21	0	11,35,550
2021-22	0	14,64,400
2022-23	0	11,37,500
Total	**25,55,264**	**59,82,140**

Source: Budget Documents, KCMC

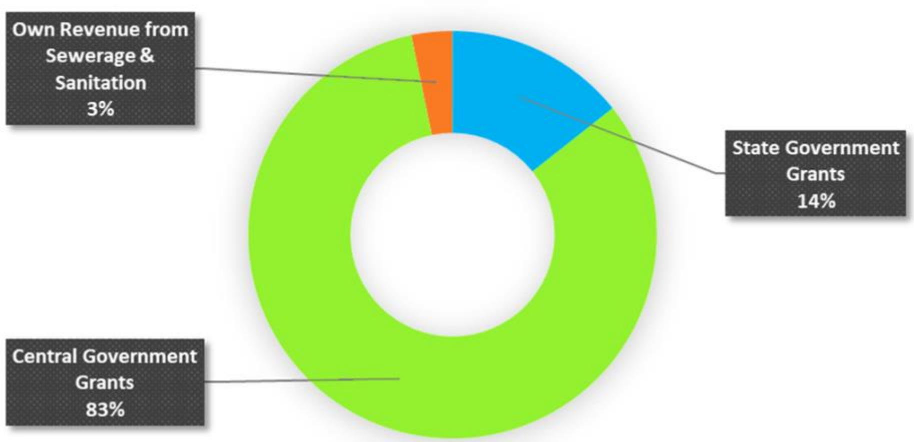
In contrast, UGD Connection Charges, which started in 2018-19, totalled INR 59.82 lakh by 2022-23, showing some fluctuation but stabilizing between INR 11.35 lakh and INR 14.64 lakh annually. The shift away from regular UGD charges to reliance on new connection fees is unsustainable long-term, as it depends on new users rather than consistent service payments. KCMC should reinstate UGD charges to ensure stable, recurring revenue and implement better billing and collection mechanisms to maintain the sewerage system's operational efficiency and financial sustainability.

Ratio of grants and own revenue

KCMC's sewerage and sanitation services are heavily reliant on external grants, with own revenue contributing only 3% of the total grants received between 2015-16 and 2022-23. The total grants amount to INR 25.59 crore, while the self-generated revenue is only INR 85.37 lakh, reflecting a significant dependence on external funding (Ref. Figure 39).

The ratio of owned revenue to grants was notably low, especially in the early years, with a slight improvement in 2018-19 (0.649) due to increased revenue from connection charges. However, this was not sustained, and the ratio dropped again in subsequent years, showing weak revenue collection mechanisms. The overall low ratio of 0.03 underscores the unsustainable nature of the current model, as reliance on grants puts the financial sustainability of sanitation services at risk. To address this, KCMC should implement regular UGD service charges, enforce user fees better, and explore new revenue sources like a sanitation cess to build a more self-reliant, sustainable revenue model.

Figure 39: Share of grants vs own revenue for Sewerage & Sanitation at Karwar Municipal Council



Source: Author's Analysis of Municipal Budgets from 2016-17 till 2023-24, Karwar City Municipal Council (KCMC)

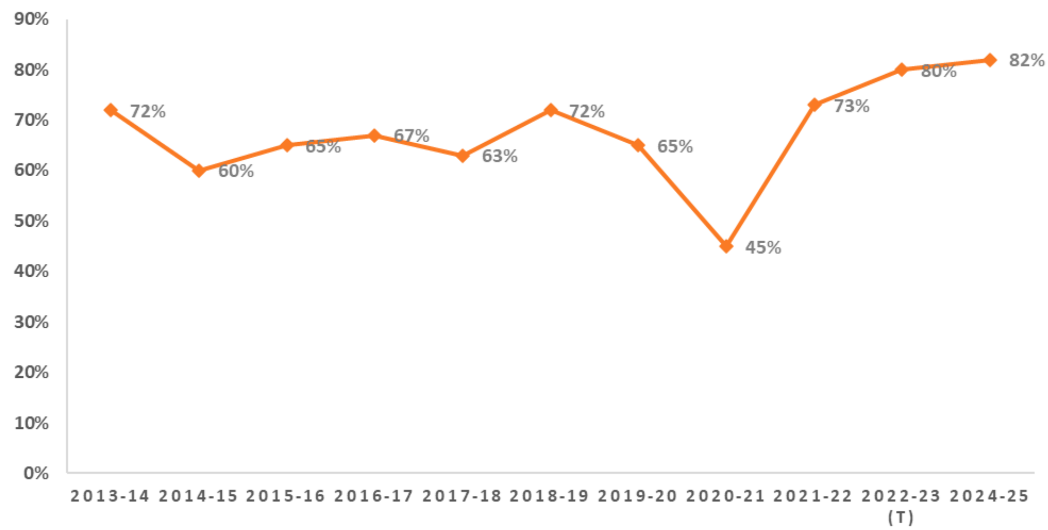
6.4 ASSESSMENT OF FINANCES

The upcoming sections analyse the trends from SLBs for water supply and sewerage & sanitation at KCMC.

6.4.1 WATER SUPPLY

Cost recovery for water supply at KCMC has experienced fluctuations, reflecting changes in revenue collection, tariff structures, and operational costs (Ref. Figure 40). While recovery rates improved in recent years, they remained inconsistent, peaking at 72% in 2013-14 before dropping to a low of 45% in 2020-21, likely due to the COVID-19 pandemic and reduced collections. However, the recovery rebounded to 73% in 2021-22 and reached 82% in 2024-25, indicating a positive trend.

Figure 40: Trend analysis of cost recovery in water supply charges at Karwar Municipal Council

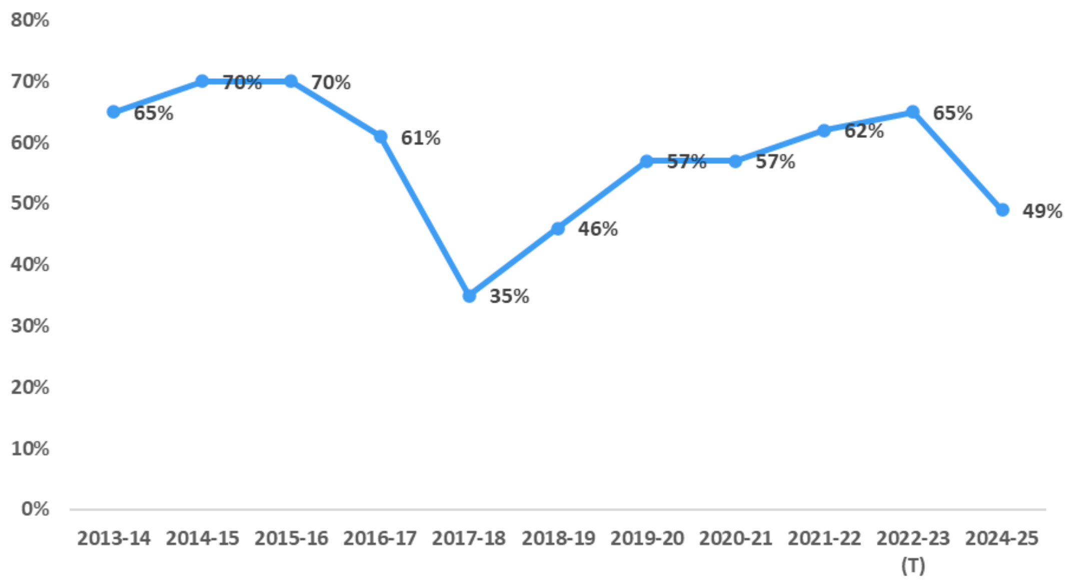


Source: KCMC, 2024

Despite these improvements, the municipality has not achieved full cost recovery, with an 18% gap remaining, which raises concerns about financial sustainability and service quality. Factors like non-revenue water, rising operational costs, and inefficiencies in billing contribute to the shortfall. To reach 100% recovery, KCMC should focus on leakage detection, automated billing, penalty enforcement, and adjusting tariffs to reflect operational costs while maintaining affordability, all while ensuring water supply remains financially self-sufficient without depending on external grants.

The collection efficiency for water supply charges at KCMC has fluctuated significantly, indicating challenges in recovering revenue from users. Between 2013-14 and 2015-16, efficiency was relatively high at 65%-70%, but it began to decline, dropping sharply to 35% in 2017-18 due to factors like administrative inefficiencies, billing issues, and potential resistance from consumers (Ref. Figure 41).

Figure 41: Trend analysis of collection efficiency in water supply charges at KCMC



Source: KCMC, 2024

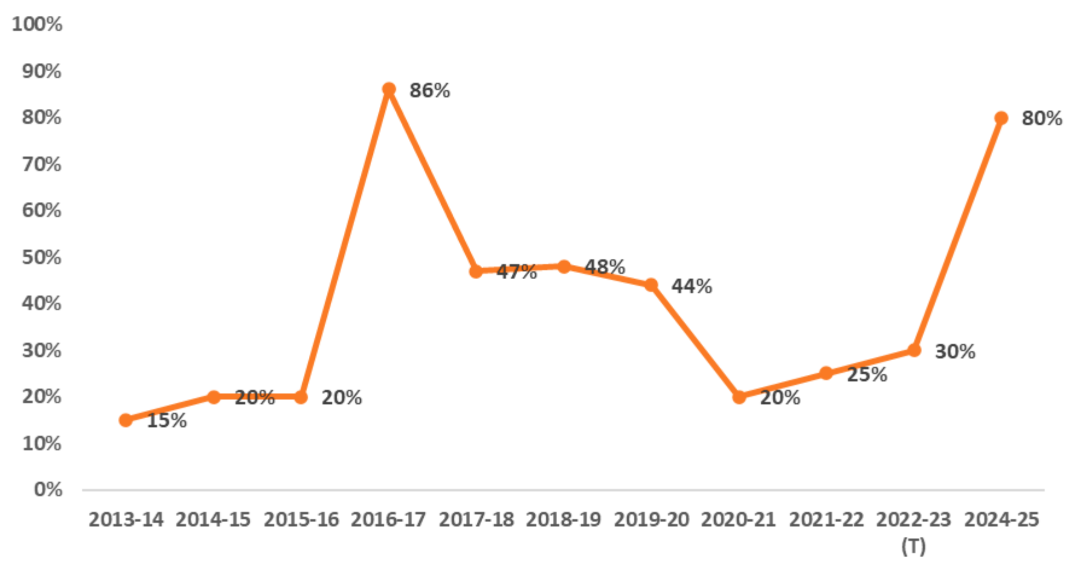
After 2017-18, there was a slow recovery, reaching 62% in 2021-22, but the projected drop to 49% in 2024-25 raises concerns about long-term sustainability. The fluctuations in collection efficiency point to structural weaknesses, including poor billing systems, high non-revenue water (NRW), and ineffective enforcement of payment rules. To improve, KCMC should implement automated billing, digital payments, reduce water losses, enforce stricter payment policies, and conduct public awareness campaigns to stabilize collection efficiency and ensure financial sustainability.

6.4.2 SEWERAGE AND SANITATION

The cost recovery for sewage management at KCMC has fluctuated significantly, reflecting both challenges and improvements in the municipality's sewerage services. Between 2013-14 and 2015-16, recovery remained low, ranging from 15% to 20%, indicating heavy subsidies for sewage management (Ref. Figure 42).

A major spike in 2016-17 saw recovery rise to 86%, but this was not sustained, with subsequent declines to 47% in 2017-18 and 44% in 2019-20, partly due to rising operational costs and inefficiencies in revenue collection. The pandemic further impacted collections, with recovery dropping to 20% in 2020-21, but post-pandemic efforts resulted in gradual improvements, reaching 30% by 2022-23. The ambitious target of 80% recovery in 2024-25 suggests a planned overhaul involving tariff increases, better collection measures, improved operational efficiencies, and public awareness campaigns. While KCMC is making strides, sustaining high-cost recovery remains a challenge, but the 80% target indicates progress toward financial sustainability.

Figure 42: Trend analysis of cost recovery in sewerage & sanitation charges at KCMC

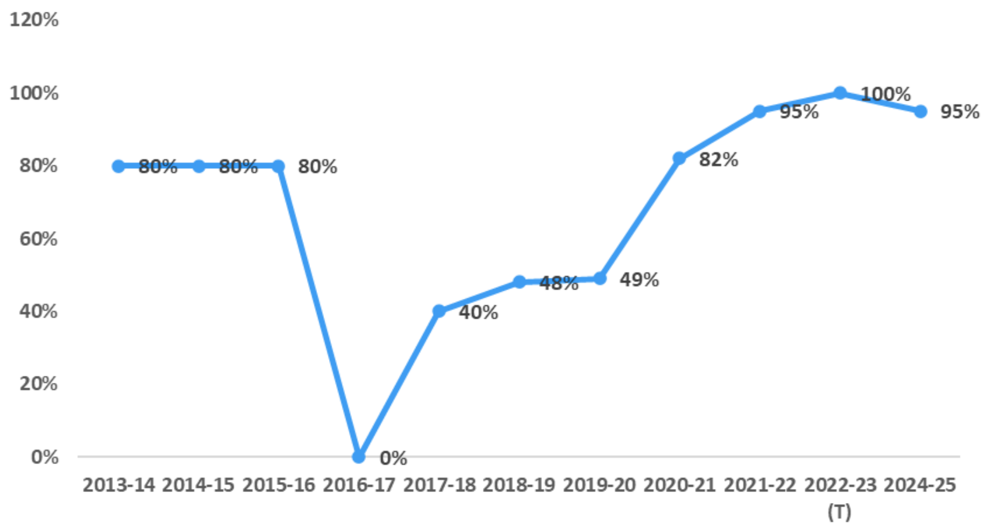


Source: KCMC, 2024

KCMC's sewage charge collection efficiency has experienced significant fluctuations, reflecting changes in revenue collection policies, enforcement, and external factors (Fig. 43). From 2013-16, efficiency was stable at 80%, but it dropped to 0% in 2016-17, indicating a breakdown in collection mechanisms.

The efficiency gradually recovered, reaching 49% by 2019-20, and then saw a sharp rise to 82% in 2020-21, followed by a further improvement to 95% in 2021-22. By 2022-23, the municipality achieved 100% collection efficiency, marking a major milestone. However, the projected slight decline to 95% in 2024-25 suggests a focus on maintaining high standards with some flexibility. The key to sustaining this efficiency lies in consistent enforcement, improved billing systems, and continued public awareness efforts.

Figure 43: Trend analysis of collection efficiency in sewerage & sanitation charges at KCMC



Source: Karwar City Municipal Council, 2024

6.5 KEY FINANCIAL CHALLENGES

KCMC faces significant challenges in ensuring the long-term sustainability of its water supply services due to its heavy reliance on government grants, which have fluctuated over the years. This reliance, coupled with inconsistent revenue generation from water supply charges, has created financial instability. Cost recovery and collection efficiency have been volatile, with severe declines such as the 35% collection efficiency in 2017-18 and the projected drop to 49% by 2024-25. Operational inefficiencies, such as non-revenue water, high operational costs, and poor billing systems, further exacerbate the issue. Additionally, the municipality's fiscal health is strained by fluctuating bulk water purchase costs and varying per capita expenditure, alongside ongoing revenue and fiscal deficits. To address these challenges, KCMC must focus on strengthening revenue collection mechanisms, reducing wastage, improving financial management, and exploring alternative funding sources to achieve financial self-sufficiency and ensure the continuity of reliable water supply services.

KCMC's sewerage and sanitation sector faces several key financial challenges, primarily stemming from inconsistent and fluctuating funding sources. Reliance on central and state government grants, which have been subject to significant fluctuations, leaves the municipality vulnerable to unpredictable financial support. The decline in central funding post-2020 and the project-based nature of state contributions create uncertainty for long-term sustainability. The municipality's own revenue, derived mainly from one-time connection fees, remains unsustainable for ongoing infrastructure maintenance, as evidenced by the extremely low ratio of own revenue to grants (0.03). Despite some improvements in cost recovery and collection efficiency, challenges such as fiscal deficits, underutilized revenue income, and a focus on capital expenditures over operational maintenance further strain the financial health of the sector. To address these, KCMC needs to diversify its funding sources, enhance revenue collection mechanisms, and find a balance between capital investment and operational expenditure to ensure the sustainability of sanitation services.

NOTES & REFERENCES

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[68]Author's Note: This chapter is based on ongoing doctoral research by Abhay Junaghare under the supervision of Prof. N. C. Narayanan at the Ashank Desai Centre for Policy Studies (ADCPS), Indian Institute of Technology Bombay. Key findings and interpretations presented here are part of a broader analysis that is currently being prepared for publication in a peer-reviewed academic journal. Readers are requested to cite this report appropriately and direct any academic queries to the author.

[69] Capital receipts are comprised of reception of grants from central and state government through its schemes.Capital expenditures are the funds used to acquire or upgrade the infrastructure that are typically large purchases. Revenue expenditures are the recurring operating expenditure that are short term and essential to run daily operations. Revenue receipts are the recurring receipts of income generated from the daily service provisions. Cost recovery is the ratio of the total annual operating revenues to the total annual operating expenses. Collection efficiency is the ratio of current revenues collected in the given year to the total operating revenues billed during the given year. The operating ratio is the ratio of revenue expenditure to revenue income, which helps assess the financial sustainability. A value greater than 1.0 indicates that revenue income exceeds operating expenses, ensuring financial stability. The revenue deficit is calculated as the difference between the revenue expenditure and revenue income. The fiscal deficit is calculated as the difference between the total expenditure and total revenue income's is annual growth rate over a specific period.

[70]Source: Mangaluru City Corporation, 2025, Government of Karnataka, 2021

7. RESILIENCE ASSESSMENT OF WASH INFRASTRUCTURE

SUCHARITA ROY, TEJASH ANAND, AND N.C. NARAYANAN

Urban infrastructure faces mounting pressure from rapid urbanization and intensifying climate-related extreme events. Inadequate infrastructure amplifies losses and increases disaster risks, underscoring the need for resilient systems that can absorb shocks, maintain essential services during crises, and recover while reducing future risks. This chapter examines the exposure and vulnerability of water, and sanitation infrastructure in the town. The assessment draws on detailed sectoral analyses presented in previous chapters. By synthesising these findings, the section identifies contextual risks, systemic gaps, and vulnerabilities affecting the resilience of town's WaSH infrastructure.

7.1 BACKGROUND

Urban infrastructure today faces dual pressures: rapid urbanization and extreme natural events driven by climate change. The World Risk Report 2016 highlights that inadequate infrastructure amplifies losses to life and property while increasing the likelihood of disasters arising from extreme natural events. Resilient infrastructure, by definition, refers to systems capable of absorbing, rebounding, and adapting to hazards and shocks to ensure continuity and safety.

Urban infrastructure in coastal cities like Karwar is increasingly pressured by rapid urbanization, rising service expectations, and extreme natural events spurred by climate change. Inadequate infrastructure not only heightens the risk of loss of life and property; it also increases the likelihood that a natural hazard will escalate into a disaster. Accordingly, resilient infrastructure is defined as systems and networks that can absorb shocks, maintain essential services during crises, and swiftly recover while simultaneously reducing future risks.

This section captures the exposure and vulnerability of the WaSH infrastructure of Karwar, a class III town and an important regional settlement in North Karnataka district of Karnataka. The situational analysis has been based on the detailed sectoral analysis undertaken by sectoral teams and captured in the previous chapters of this report. The resilience assessment of the WaSH infrastructure captures the contextual risks and gaps in the systems.

7.2 METHODOLOGY FOR RESILIENCE ASSESSMENT

Adopting resilient infrastructure not only helps reduce the intensity of adverse consequences from disasters but also provides an opportunity to shift to lower carbon pathways. The risk of infrastructure failure during disruptive events depends on several factors, including exposure to hazards, locational limitations, technology, sensitivity of the infrastructure, its governance, access to funding, and systemic agility. The Sendai Framework for Disaster Risk Reduction identifies the resilience of critical infrastructure as key for risk reduction.

An assessment of the resilience of the WaSH infrastructure, the town has been undertaken in the context of climate change to inform future planning and build climate-resilient WaSH infrastructure and services in the town. Guided by the Global Methodology for Infrastructure Resilience -UNDRR (2023)[71], *a three-step, contextualised methodology has been developed.* This methodology analyses the adequacy, reliability, and flexibility of WaSH infrastructure in the face of climate change and the robustness of governance and finance to handle future risks. This framework enables a comparative understanding of system resilience for WaSH infrastructure across towns and cities, irrespective of the level of urbanization, population size, and local body capacity. It helps identify trends and patterns across various classes of cities and develop a structured approach towards building resilience of WaSH infrastructure in coastal cities.

1. *Mapping the Existing Infrastructure and Services:* The existing infrastructure and services have been mapped and analysed based on data gathered from various sources on performance, coverage, socio-spatial variability, technology, governance, key stakeholders, existing policies, climate change initiatives, financial health of the ULB, budgets, and future projects

2. *Identifying the Infrastructure Exposure and Vulnerability:* The climate hazards faced by the settlement have been identified based on literature review. Three critical coastal risks—flooding and inundation, storm surges and coastal erosion, and saltwater intrusion—have been considered. Satellite data has been utilized to assess land use and land cover (LULC), elevation, built-up footprints, road networks, shoreline change detection, mangrove and water bodies, storm surge locations, and flood risk zones. This data has been overlaid with information from municipal bodies on administrative boundaries, flood hotspots, population distribution, critical utility locations to identify the exposure. Primary data on water usage, sanitation practices, water quality, access disparities, socioeconomic vulnerability, behavioural practices, and exposure history collected through discussions, interviews, household surveys, and ground-truthing via transect walks and visual surveys were further collated and overlayed to identify ward level exposure and infrastructure vulnerability.

3. *Assessing the resilience:* The adequacy, flexibility and reliability of the infrastructure, its governance and financial sustainability and systemic gaps have been identified and assessed along with the exposure and vulnerability. The summary of risks to WaSH infrastructure provide insights into the resilience measures needed for the coastal town.

7.3 EXPOSURE TO CLIMATE RISK

Karwar experiences a tropical monsoon climate, with heavy rainfall during the southwest monsoon season from June to September. Rising sea levels, driven by climate change, pose long-term threats to the city's low-lying coastal areas, impacting freshwater availability through saline intrusion into coastal aquifers. The Arabian Sea's increasing cyclone intensity, influenced by warmer ocean temperatures, further exacerbate risks related to storm surges and coastal flooding. Karwar, located at the mouth of Kali River, on the west coast of India, is at moderate risk from cyclones and is in seismic zone III (MSK intensity VII) i.e., exposed to moderate seismic activity and is more prone to minor to medium intensity earthquakes.

Karwar city is exposed to high risks of increasing cyclones, storm surges and heavy precipitation. Since 2018, the city has faced the impact of cyclones every year. As a result, the city is exposed to flooding and inundation and saltwater intrusion. Overall, an average of 1.1 m/yr accretion and about 1.0 m/yr erosion was noticed along the Karnataka coast. The highest accretion rate of 15.5 m per year was noticed in Karwar. [72] However, Karwar city and Taluka have been identified as at elevated risk from flooding and inundation with severe flooding reported in the month of July (monsoons) for the past 2 years (2023 and '24).

In Karwar, around 17 % of the administrative area lies less than 5 meters above MSL and up to 49% land lies at an elevation less than 10m above MSL (table17) . While storm surges in the region are generally moderate, rising high tide levels, intense rainfall events, tropical cyclones, and stronger winds originating from the Arabian Sea have heightened the city's vulnerability to flooding and inundation. In August 2019, heavy monsoon rains led to widespread flooding in Karwar city, causing significant transportation disruptions and property damage. Intense rainfall, combined with dam releases, led to severe waterlogging and inundation, submerging parts of National Highway 66 and temporarily disconnecting Karwar from Goa. While no lives were lost, the event exposed Karwar's vulnerability to urban flooding during extreme rainfall, highlighting deficiencies in drainage infrastructure.

In low elevation coastal zones and floodplains, severe flooding occurs when the soil is saturated and infiltration is minimum, water levels in creeks and rivers are elevated after a prolonged spell of monsoon rains and ground water levels rise - the flood water is unable to recede. These flood-like situations result in inundations which can continue from several hours to many days as seen in many low-lying coastal cities and towns. In a dense built-up area, an intense rainfall burst within a brief period can also result in flash flooding. Zoning control includes designating, by the responsible authority, the type of activity that can be undertaken within the flood-prone area. Most of the physical, social and economic problems associated with flooding, soil erosion and water pollution stormwater are attributable to inappropriate urbanization of the floodplain, unwise land use within the city, insufficient attention to drainage in urban planning, ineffective updating of existing stormwater control facilities and lack of enforcement of zoning ordinances.[73]

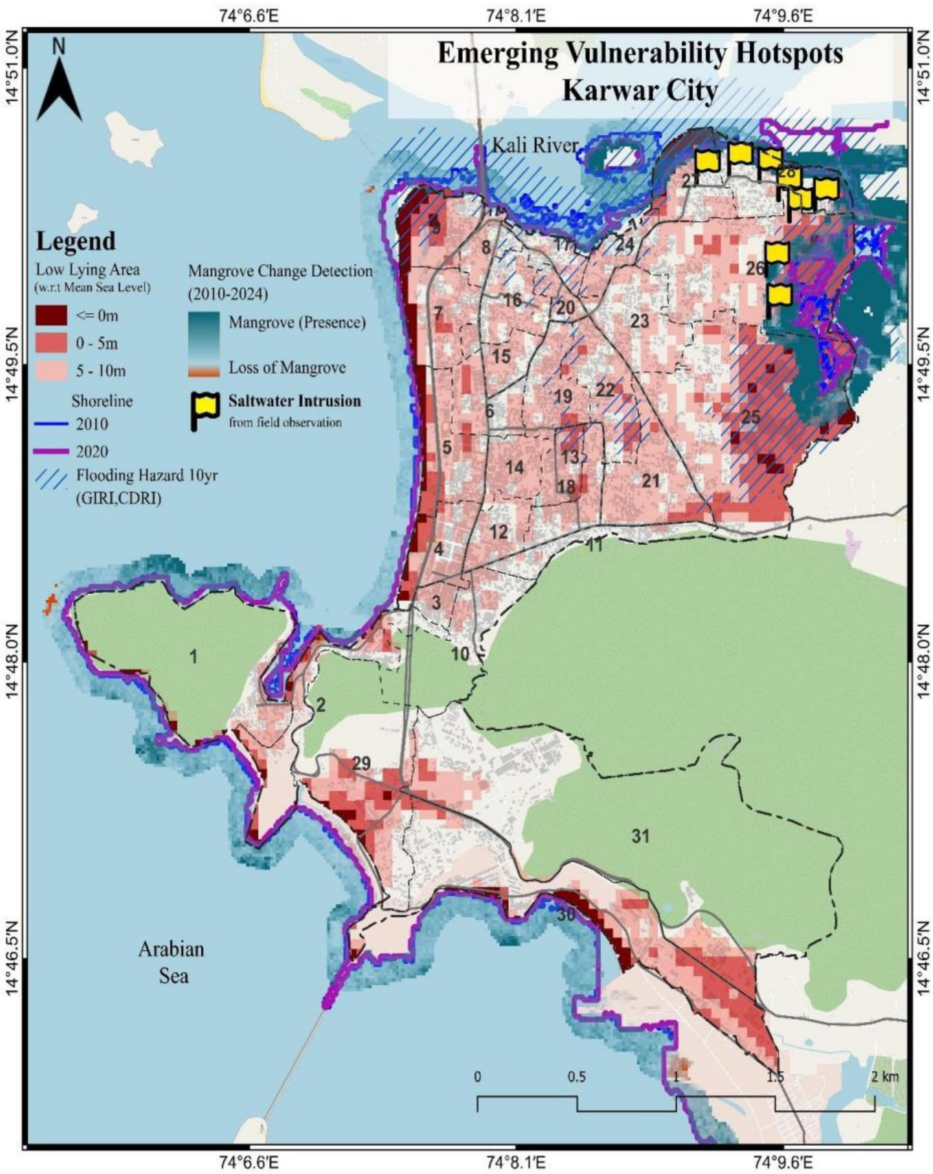
Table 17: Vulnerability to Flooding based on Elevation above MSL

Ward No	Population (Census 2011)	Very high vulnerability, Elevation <0m amsl	High vulnerability, Elevation <10 m amsl	Low vulnerability, Elevation >10m amsl	Ward No	Population (Census 2011)	Very high vulnerability, Elevation <0m amsl	High vulnerabilit y, Elevation <10 m amsl	Low vulnerabilit y, Elevation >10m amsl
1	1441	1.2%	9.8%	90.2%	**17**	**2185**	**0.0%**	**42.8%**	57.2%
2	1553	6.7%	40.7%	59.3%	**18**	**1929**	**0.0%**	**68.9%**	31.1%
3	**1102**	**0.0%**	**65.8%**	34.2%	**19**	**3703**	**0.0%**	**81.4%**	18.6%
4	**1677**	**9.2%**	**81.8%**	18.2%	**20**	**2560**	**0.0%**	**78.7%**	21.3%
5	**2568**	**11.7%**	**86.2%**	13.8%	**21**	**1955**	**0.0%**	**85.3%**	14.7%
6	**3377**	**0.0%**	**68.9%**	31.1%	**22**	**1236**	**0.0%**	**74.2%**	25.8%
7	**2582**	**12.4%**	**80.3%**	19.7%	**23**	**1853**	**0.0%**	**47.6%**	52.4%
8	**1157**	**0.0%**	**61.2%**	38.8%	**24**	**2652**	**0.0%**	**66.2%**	33.8%
9	**1611**	**24.8%**	**91.5%**	8.5%	**25**	**2555**	**4.5%**	**81.5%**	18.5%
10	2359	0.0%	15.0%	85.0%	**26**	**2684**	**2.0%**	**76.2%**	23.8%
11	1118	0.0%	9.1%	90.9%	**27**	**1266**	**26.5%**	**66.1%**	**33.9%**
12	**1037**	**0.0%**	**65.0%**	35.0%	**28**	**2312**	**3.7%**	**41.1%**	58.9%
13	**2115**	**0.0%**	**93.4%**	6.6%	29	814	2.4%	36.3%	63.7%
14	**2494**	**0.0%**	**90.1%**	9.9%	30	1447	6.9%	52.0%	48.0%
15	**1666**	**0.0%**	**66.4%**	33.6%	31	2751	0.0%	10.1%	89.9%
16	**3990**	**0.0%**	**50.6%**	49.4%					

Source: GIS analysis

Flood hazard mapping over the past 10 years[74], aligned with current climate scenarios, reveals that: flooding from runoff and river overflow, though these risks can be mitigated using nature-based flood management solutions. Flooding at the mouth of river Kali, especially due to intense precipitation, a weather event of increasing frequency in the region is a significant risk for Karwar which can see increasing devastation faced by the city. Up to 12 of the 31 wards are flood prone and these include Wards 7,8,9, 15, 16, 17, 19, 20, 22, 23, 24 and 27 which can be identified as prone to flooding based on data from last 10 years.[75] Media reports from June 2025 reconfirm the vulnerability of Karwar to flooding.*Key urban and rural areas of Karwar bore the brunt, with streets turning into streams and stormwater drains overflowing.*[76] Due to very heavy precipitation landslides were reported and Karwar has been identified by Geological Survey of India as a landslide prone zone.

Figure 44: Emerging Vulnerability Hotspots and Exposure of Karwar City



Source: Author's GIS Anlysis using Sentinel 2 & Open Street Maps Data

A storm surge refers to the abnormal rise in water levels caused by a storm, surpassing the predicted astronomical tide. Storm tide, a combination of storm surge and astronomical tide, can lead to extreme coastal flooding, especially when it coincides with high tide. Wave action on top of a surge can further elevate water levels, compounding flooding risks. Disruptions in vertical ocean circulation during these events often push seawater inland, contaminating freshwater resources. Additionally, heavy rainfall and sediment accumulation at river mouths increase the likelihood of flooding in low-lying areas—a risk observed increasingly in the eastern Arabian Ocean. The city's administrative Wards 1, 2, 29, 30, and 9 are particularly vulnerable to storm surges. These surges can lead to the contamination of surface and groundwater with saltwater, as well as the overflow of on-site sanitation pits or poorly constructed septic tanks. These wards lack off-site conveyance or underground sewerage networks. While Wards 1 and 2 have access to piped water supply (60-70% coverage), Ward 29, primarily a residential area, has only 12% coverage and relies on groundwater sources.

The flooding and inundation due to intense precipitation and storm surges and the resulting saltwater intrusion exposes the population to health and disease burden due to contamination of ground water from higher TDS and blackwater contamination in areas with inadequate water supply and underground sewerage conveyance and due to unregulated and improper containment of sewage at household levels.Change detection based on Sentinel data spanning 10 years (2010 – 2010) reveals significant changes in status of status of mangroves and the coastal shoreline. These changes increase risks such as saltwater intrusion into groundwater and contamination of open dug wells and other surface water sources, particularly near river mouths.

Coastal erosion, inundation, and loss of mangroves have exposed the city wards along the coast of Karwar, making the city's groundwater reserves more susceptible to saltwater intrusion. Primarily residential zones, Wards 4, 5, 7, 8, and 9, lack access to piped water services and thus rely on groundwater sources. Wards 1, 2, 7, 8, and 9 are entirely dependent on on-site sanitation systems. Wards 7, 8, and 9 are the most vulnerable due to their significant population and the absence of both piped water services and underground drainage systems.

Saltwater intrusion can present a critical challenge for Karwar in two primary ways. For areas without piped water, it compromises access to safe, fresh water. Additionally, the increased conductivity of groundwater caused by saltwater accelerates the corrosion of underground water and wastewater collection pipes. Research indicates that changes in soil and groundwater chemistry due to saltwater intrusion and rising sea levels can significantly shorten the service life of infrastructure like ductile iron pipes, which are expected to last between 80 and 100 years under ideal conditions. [77]

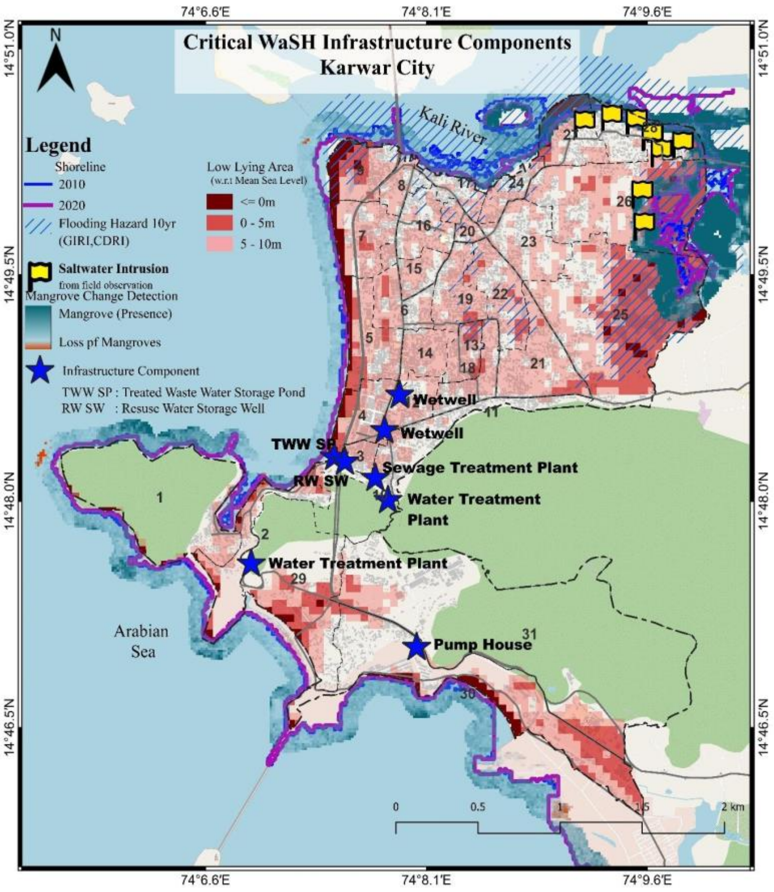
Some instances of saltwater intrusion in wells were reported from the estuary region of the Kali River during the field exploration in ward 26, 27 and 28. Media report from March 2025 records that mixing sea water with river water, and saline water inflows into low-lying areas in Karwar region led to damage of crops. [78] Similarly, the accumulation of saline influents in treatment units and sanitation pits—including septic tanks—can impair the removal of pollutants like organic matter and nutrients. High electrical conductivity, a hallmark of saltwater, has been found to adversely affect microbial diversity and the efficiency of organic matter breakdown.[79]

The aging infrastructure in some parts of Karwar compounds these risks. Specific wards along the backwaters of Kali estuary on the eastern part of the city, such as wards 26 - 28, are particularly vulnerable to inundation and saltwater intrusion, as noted during field visits. These locations are low lying and salinity intrusion in wells has been reported here. For coastal wards where extending underground sewer networks is impractical due to depth requirements, upgrading individual or community-level sanitation solutions like safely contained septic tanks with regular desludging services is essential.

7.4 VULNERABILITY OF THE WASH INFRASTRUCTURE

The vulnerability of the WaSH infrastructure analyses the status of the infrastructure with respect to its adequacy, reliability and risk governance. Adequacy has been investigated respect to coverage of the services, suitability of technology, safety of infrastructure based on its age. Reliability of the services has been studies based on data where available on outages, response and recovery including contingencies and redundancies, ownership and accountability and provision of monitoring and regulation of the systems. The infrastructure risk governance looks at the financial stability and safeguards, autonomy in decision making, and jurisdictions regarding preparedness and recovery in the context of disasters.

Figure 45: Location Of Critical Components of the WaSH Infrastructure within the Administrative Boundary



Data Source: CDRI; Sentinal 2; Open Street Map; Census, 2011; Karnataka Land Record; Landsat

7.4.1 ADEQUACY OF INFRASTRUCTURE

The WaSH infrastructure in Karwar is neither adequate nor resistant to climate risks. Only half of the city's demand is met through treated water supply, the gap is met through ground water. While Karwar has access to adequate safe freshwater sources, treated and piped water supply access to the coastal wards 4–9 and river flooding-prone wards 17, 20, and 24 need to be prioritized. Areas further away from the coastline face seasonal shortages in well water levels and are then completely dependent on piped water supply. Low water pressure in terminal areas of the distribution network has been reported, and the risk of disruptions during the summer season is high.

Water is sourced from 40 kms away and lifting and transmission of water is dependent on high intensity pumping systems due to the intervening topography from location of source to the city. The operational cost of water supply system has a rising trend; expenditure is higher than revenue indicating fund crunch little availability of funds for upgradation or expansion of water supply systems. The city employs a mix of technology solutions, primarily on-site sanitation and a partly centralised sewerage network servicing around 13 % of the properties in the city and a centralized MBR-based STP with capacity to treat 1.5 MLD of the total 5.2 MLD wastewater generated by the city (Refer Chapter 4 on sanitation). Transitioning from individual pits to underground conveyance-based sewerage systems requires a capital-intensive overhaul and effective stakeholder management. Currently, safe sanitation facilities with adequate containment, conveyance, and treatment of sewage are inadequate, with significant gaps that necessitate the exploration of cost-effective and modular decentralized solutions in a fund-limited scenario. Karwar city, as a coastal city facing climate risks, is susceptible to sewage contamination and disease outbreaks.

7.4.2 RELIABILITY, FLEXIBILITY AND REDUNDANCY

Flexibility in water systems can ensure reliable services even during climate events and disasters. Redundancy ensures that systems can withstand failures and continue to operate during disruptions. It minimizes the chances of a single point of failure leading to a catastrophic breakdown.

Source sustainability is an emerging concern for Karwar like many other smaller and emergent coastal towns depending on ground water. While ground water is increasingly contaminated due to saltwater intrusion, fluctuating water tables and contamination through improperly built and unmonitored on- site sanitation systems, at household levels, flooding and storm surges resulting in contamination of surface and sub surface aquifers, monitoring, protection and sustainability of ground water sources is an emerging need. The river water sourced from Gangavalli River which is at a significant distance from the city can be unreliable in case of shock events like landslides and landslips which are common occurrences in the Karwar region have historically seen landslides. The main trigger of landslides is intense or prolonged rainfall, and the region is witnessing increasing intense rainfall events. Diversified sources can help reduce risks. Continuity and redundancy planning of water infrastructure shall help minimize disruptions as well help with quick recovery of services post a shock increasing reliability of the services in the face of climate events.

A diversified water portfolio ensures communities have alternative supply options, reducing risks associated with climate variability, rising demand, and resource conflicts. Strengthening both imported and local sources is critical for achieving long-term water security amid climate uncertainty. However, groundwater contamination poses a challenge, with saltwater intrusion, fluctuating water tables, and poorly constructed sanitation systems during flooding leading to higher TDS levels.

Aging pipelines, salt corrosion, and a heavy reliance on pumps due to hilly terrain are further challenges for Karwar's water supply. (Refer chapter 3)

The current technology adopted for sewerage treatment of MBR based STP with holding tanks and sludge beds adopts a natural and mechanical treatment process. This system is unreliable for a city exposed to storm surges, inundation and salinity ingress and high-water tables during intense monsoon rainfall which extends for 4 to 5 months in a year. Safe containment of sewage in on-site sanitation systems, which is the most prevalent in Karwar, can be compromised by the increasing coastal risks.Flexibility in water systems can ensure reliable services during disruptions. Coastal cities like Karwar, with existing dug wells and positive groundwater tables and which have traditionally used ground water, can explore protected wells as redundant water sources within its formal systems. Heavy reliance on pumps in procuring water from distant sources due to the undulating and hilly terrain exposes the system to risk of disruption due to electricity failure. It increases the costs of procurement and increases emission from the water supply system.

7.4.3 INFRASTRUCTURE RISK GOVERNANCE AND FINANCE

Effective governance is essential for resilient infrastructure. This involves the policies, frameworks, norms, processes, and tools that public bodies use to plan, decide on, implement, and monitor the entire lifecycle of public infrastructure. In the context of resilience, governance transformation may include progressive decision-making, regular updates to codes and standards, comprehensive regulatory frameworks, and dedicated risk and resilience funding. Karwar is an emerging and transitioning city in terms of WASH infrastructure, presenting a significant opportunity to integrate resilience through agile governance and innovative finance models.

Karwar is an emerging and transitioning city in terms of WASH infrastructure, presenting a significant opportunity to integrate resilience through agile governance and innovative finance models. The Water Supply Scheme to Karwar is maintained by the Karnataka Urban Water Supply and Drainage Board (KUWSDB). KMC undertakes O&M and distribution. (Refer Chapter 3). The involvement of multiple agencies, the limited role of municipal bodies and dependence on external funds has led to fragmented development and significant underutilisation of assets and facilities. This is a finding from the multiple towns and cities explored to assess the resilience in WaSH infrastructure.

Fluctuations in operating ratios, fiscal revenue, and expenses indicate that service operations have not reached a sustainable stage. Dependence on non-revenue sources of water remains high.

KMC lists the collection, removal, treatment, and disposal of sewage; establishing and maintaining compost plants for sewage disposal; supplying, constructing, and maintaining receptacles, fittings, pipes, and other appliances for receiving and conducting sewage and drains, public toilets, and urinals as obligatory functions in sanitation services. At the household level, KMC is not involved in the design, construction, or enforcement of standards for toilets and OSS. For a flood and storm surge-exposed city that primarily depends on OSS for sanitation coverage, this leaves a significant gap in regulatory control and governance.

As per municipal officials, the lower demand for sewerage connections could be due to the one-time sewage connection fee, which is considered high for many. The cost of desludging septic tanks adds to the sanitation cost burden for residents and households, deterring many residents and leading to the adoption of unlined pit latrines. City-wide safe sanitation planning is dependent on central, state government, and IFIs for capital funds. This has resulted in fragmented development of the sanitation infrastructure. For example, while STPs are being funded by SBM 2.0 while KMC is struggling to mobilize funds for extending the sewerage network to vulnerable locations, which accounts for approximately 70 - 75 % of the cost for developing complete sanitation infrastructure, including collection, conveyance, and treatment.

Treating wastewater up to the secondary stage and releasing it into the sea (Refer Chapter 4) could be a missed opportunity for a city like Karwar.KMC has very limited roles defined for future climate risks, such as preventing and checking dangerous diseases, removing dangerous buildings, taking measures to meet any calamity, and promoting public safety, health, convenience, or instruction, as listed on its website. The DDMP envisages ULBs to participate in rescue and response however preparedness functions are primarily restricted to the central, state and district levels. There is need to evaluate the systemic risks and contingent liabilities, adopt redundancy and continuity planning and establish protocols for infrastructure recovery post crisis. There is need for of handholding support for transitioning settlements.

The role of municipalities in Emergency Operation Centres, data mapping and management functions, integrating alert and systems in the city infrastructure and ring faced budgeting for disaster risk reduction and climate change adaptations are not clearly specified. There are no alerting systems for system failures, energy outages, or creeping disasters. Information flow is top-down, missing ground intel and early warnings.

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ANNEXURE-I: DATA COLLECTION & VALIDATION

Desk Based Research: An extensive desk study was conducted to review existing literature and collect secondary data from various government sources. The study utilized secondary data and information from a range of national, state, district, and town-level sources, including the Census, National Family Health Survey, Swachh Bharat Mission (Urban), Central Pollution Control Board, Performance Assessment System for urban water and sanitation (PAS) website, District Disaster Management Plans, and the municipality website. Additionally, the review was instrumental in mapping key stakeholders, defining their roles and responsibilities, and developing the analytical framework for various thematic studies, including GHG emission estimation.

The desk study not only informed the overall research design but also facilitated the identification of data gaps and discrepancies, which subsequently guided the development of data collection protocols as well as the planning and execution of the fieldwork.

Field Work: To address data gaps, validate secondary data, and resolve data discrepancies, the study incorporated rapid field assessments, site visits, and semi-structured interviews. These interviews were conducted with local residents, as well as district and municipal officials from the town planning, water and sanitation, sewerage, public works, and disaster management departments. These interviews were conducted with local residents, as well as district and municipal officials from the town planning, water and sanitation, sewerage, public works, and disaster management departments. Field work also involved mapping of the critical infrastructure in the water and sanitation sector.

The vulnerability assessment began by identifying low-lying zones and areas with high population density, using building proximity and elevation as primary indicators. Areas that exhibited both low elevation and compact construction were marked as high-priority hotspots. The field studies including visual assessment and semi-structured interviews with residents of three towns were undertaken at different hotspot locations to capture the diversity of issues across different wards and communities and ground truthing of secondary data.

- **Secondary Data Collection from Town Water and Sanitation Departments:** Meetings with ULBs were held to collect a wide range of documents and data, including city maps, land-use and land cover maps, UGD (Underground

Drainage) maps, and electricity bills. Additional information was gathered on SLB indicators, SBM-U, Atal Mission for Rejuvenation and Urban Transformation (AMRUT), financial reports, and other relevant datasets.

We also obtained detailed information on sewage treatment plants (STPs), such as their capacity, collection and treatment volumes, and water reuse practices. Furthermore, data on the number, condition, and O&M structures of community toilets (CTs) and public toilets (PTs) in the city were collected to better understand the scale and performance of the existing sanitation infrastructure.

- **Semi-Structured Interviews:** In Karwar Municipal Council (KMC), we interviewed (semi-structured interviews) key ULB officials—including the Commissioner (3), Assistant Executive Engineer (2) and Environmental Inspector (3), Junior Environmental Inspector (2), Accountant (2), Electrical Engineer (2), System Operators (1) to understand the status of water and sanitation infrastructure and services, as well as to gather information on recent and past extreme events—such as floods, droughts, cyclones and heavy rainfall—and their impacts. These discussions also provided insights into the effects of climate change as experienced locally. Importantly, the interviews helped identify vulnerable areas and communities within the town, which informed the design of the rapid assessment study.

- **Site Visits:** Site visits were conducted to validate the functioning of critical water and sanitation infrastructure, such as water treatment plants (WTP), STPs, Pumping stations and disposal, and Treated water storage pond. These visits focused on gathering information on operational status, environmental compliance, and electricity consumption. These site visits also facilitated the integration of critical infrastructure into the GIS platform for further spatial analysis.

- **Rapid assessment:** The assessment process included on-ground observations and semi-structured interviews with the residents, with a particular focus on hot-spots such as low-income neighbourhoods, areas vulnerable to extreme events, low-lying areas and densely populated clusters. These were determined during interviews with the ULB officials and using spatial proximity between WaSH structures to highlight zones with high vulnerability. Areas exhibiting both low elevation and high building density were mapped as potential hotspots for field investigation. Municipal officials were asked to suggest locations that would yield greater diversity for sampling. These interviews were designed to validate and triangulate data gathered from secondary sources on WaSH, offering valuable insights into the state of local infrastructure and the lived experiences of residents—particularly during past high-precipitation events, cyclones, and storms—with a focus on vulnerable communities.

The emphasis was on understanding challenges related to access, affordability, and reliability of water and sanitation services in the context of climate change. Residents were asked whether they had private toilets on their premises, and if so, whether these were connected to the sewage network. For those not connected, questions focused on how and where human waste was disposed of. In cases where onsite sanitation systems (OSS) were used, we gathered information on the type of system, frequency and of septic tank cleaning, service providers involved, and other challenges of these services. Additional questions covered methods of greywater disposal, sources of tap water, costs associated with water connections, and any support received from the ULB during disaster events. For households without individual toilets, we explored the alternative sanitation arrangements they relied on.

The team engaged with residents across the city, carefully selecting locations to cover a range of socio-economic backgrounds. Our questions with residents focused primarily on service access and quality.Additionally, the team visited 1 public toilet and 1 Community toilet to assess their condition firsthand. During our rapid field assessment, we visited the public toilet located in a busy market area and the community toilet located near by a law income informal settlement to observe their condition and usage.

The study findings were shared during a stakeholder and expert consultation workshop held on 13th August 2025, with participation from State Public Works Departments, ULBs, and State Pollution Control Boards. The feedback and comments received have been incorporated into the town assessment reports, details of which are provided in the annexure-III. The workshop also helped define the way forward for the research team.

ANNEXURE-II: DATA GAPS

The project design necessitated a comprehensive review of secondary data sources pertaining to the water and sanitation sector and climate change across various levels—national, state, district, and town. This exercise highlighted several significant data gaps, which are detailed below.

Water

1. **Inadequate Granular Water Consumption Data :** Household-level water consumption is not metered in many areas; bulk metering data (number of connections × billed consumption) does not accurately capture per capita usage or disparities across income groups or geographies (e.g., slums vs. apartments).
2. **Unaccounted for Water (UFW) and NRW :** Accurate estimation of transmission and distribution losses is hampered by the absence of metering at intermediate system points and outdated infrastructure records, making it difficult to precisely attribute inefficiencies or quantify water losses.

Sanitation

1. **Typology of Individual Household Toilets and On-site Sanitation Systems** Understanding the typology of individual household toilets and on-site sanitation systems is essential for assessing current levels of access to sanitation infrastructure and determining whether these constitute improved sanitation services. This information is a key indicator for tracking progress towards the SDGs and is relevant for climate adaptation frameworks. Additionally, it plays a critical role in estimating GHG emissions from the sanitation sector. However, the last comprehensive assessment of household toilet typologies was conducted during the 2011 Census, and no updated data is currently available from national, state, or city-level sources. The National Family Health Survey-5 (2019–2020)[80] provides district-level data on access to improved sanitation facilities, defined as the "population living in households that use an improved sanitation facility." However, disaggregated data at the town or municipal level is not available. Collecting such data would require a detailed household-level survey.

2. **Operational Status of Community and Public Toilets** Community and public toilets are intended to serve populations without access to individual sanitation facilities, as well as the floating population in public spaces. The operational status of these facilities—including aspects such as functionality, availability of water supply, and cleanliness—is a key requirement under the ODF+ certification framework. According to MoHUA guidelines, ULBs are mandated to conduct regular audits of these facilities. However, data on the coverage and adequacy of community and public toilets and operational status is not available with the ULB.

3. **Data on Storm Water Drainage:** The role of stormwater drainage systems in urban resilience is well recognized. However, the data available at the town level is limited to information on overall coverage and does not provide details on the typology of the drainage systems—such as whether they are open or closed, underground or surface-level, mapped or unmapped, or man-made or natural. A comprehensive understanding of these aspects would require detailed studies.

4. **Integrated role of Sewerage Network, Creeks, and *Nallahs*:** It is essential to determine whether natural and man-made water bodies—such as creeks and nallahs—are integrated into the town's wastewater and stormwater management systems, and to clarify their functional roles, whether they carry greywater, blackwater, stormwater, or a combination of these. Equally important is evaluating the degree of interconnection between these natural channels and engineered infrastructure. However, such information is not available through secondary data sources, and the (ULB does not maintain a detailed sewerage network map.

GHG Emission Estimations

1. Groundwater Use Estimation Uncertain: There is no systematic monitoring of groundwater abstraction volumes, especially from private borewells and tankers. The growing reliance on groundwater is not reflected in official supply data, resulting in underestimation of its energy and carbon footprint.

2. Missing Real-Time Energy Consumption Data: Energy data for various components (pumping, treatment, household-level usage) are often estimated based on assumed intensities (MWh/MLD) due to a lack of sub-metering across the water supply system.

3. Limited Data on On-Site Sanitation Systems: There is no centralized inventory of septic tanks, pits, or their design standards. Emission estimates rely on assumed containment

types, desludging frequencies, and containment conditions, introducing uncertainty in CH_4 and N_2O emissions from faecal waste.

4. Industrial and Tourism Sector Use Opaque: Water and wastewater usage and discharge data from hotels, industries, and large commercial establishments are often not disaggregated or reported, masking the full impact of tourism and commercial activity on urban emissions.

5. Stormwater and Greywater Flows Untracked: Greywater is often discharged into storm drains without treatment or monitoring, leading to nutrient loading and emissions not captured in inventories.

6. Sanitation GHG Methodology Limitations: Emission estimates are based on global default emission factors and standard GWP values (IPCC 2013), which may not reflect local climatic, operational, or containment-specific variables.

ANNEXURE-III: STAKEHOLDER CONSULTATION WORKSHOP: KEY HIGHLIGHTS AND WAY FORWARD

WORKSHOP TITLE: ‘CLIMATE RESILIENT URBAN WATER AND SANITATION INFRASTRUCTURE SERVICES IN COASTAL TOWNS’

Programme Highlights

On ***13th August 2025***, the ***Stakeholder Consultation Workshop on Climate Resilient Urban Water and Sanitation Infrastructure Services was*** held at ***VMCC, Room No. 21, Indian Institute of Technology Bombay, Mumbai, Maharashtra***, in a ***hybrid format*** accommodating both in-person and online participation. The workshop brought together ***policymakers, experts, practitioners, and project partners*** from Maharashtra, Karnataka, Gujarat, and Karnataka to discuss challenges and opportunities in enhancing the resilience of water and sanitation systems in coastal towns. It provided a platform to ***share project findings, examine policy and governance frameworks, and explore strategies for integrated, climate-responsive urban infrastructure planning***, fostering dialogue aimed at strengthening the adaptive capacity of urban water and sanitation services.

The workshop commenced with **registration from 9:00 AM to 9:30 AM**, followed by a **welcome address by Prof. NC Narayanan, Ashank Desai Centre for Policy Studies, IIT Bombay**, at 9:30 AM, who set the context for the discussions ahead. This was followed by an overview of the project by **Mr. Romit Sen, HSBC-India**, highlighting the objectives, scope, and significance of the Landscape Analysis for Climate Resilient Coastal Cities.

From ***9:55 AM to 10:50 AM***, the ***project highlights*** were presented. Prof. NC Narayanan began with an overview of the background, tracing the history of water and sanitation research conducted by the lab, which laid the foundation for the HSBC project. He highlighted the rationale for the project, the significance of the West Coast, and why this region was chosen. This was followed by a presentation on the ***Urban Water-Energy-Climate Nexus*** by Mr. Ashish Dangi, which outlined the research framework and underscored the interconnections between water, energy, and climate. Subsequently, ***Dr. Neelam Rana*** presented on ***Policy, Governance, and Finances in WaSH and Climate Change***, providing a comprehensive overview of the current landscape, key challenges, and potential opportunities for enhancing climate resilience. The presentation highlighted that policies remain largely focused on ***adaptation***, which is appropriate in a developing country context where ensuring access to basic services such as water and sanitation continues to be a priority. The session emphasized the importance of generating evidence on GHG reductions in the WaSH sector to inform mitigation policies. The session concluded with a ***discussion and Q&A***, allowing participants to clarify key aspects of the study and share preliminary observations.

The session was followed by **tea and town-level poster presentations from 10:50 AM to 11:25 AM,** enabling participants to engage directly with the project team and explore data, findings, and visual insights from individual coastal towns.

State-wise discussions were held from 11:25 AM to 12:45 PM, moderated by domain experts:

- **Karnataka:** Mr. Vishwanath S, BIOME Environmental Solutions
- **Karnataka:** Mr. Depinder Kapur, National Institute of Urban Affairs (NIUA)
- **Maharashtra:** Ms. Lubaina Rangwala, World Resources Institute (WRI)
- **Gujarat:** Prof. Ajay Deshpande, IIT Bombay

These sessions facilitated a deep dive into state-specific and town-specific challenges, opportunities, and lessons learned from local implementation of urban water and sanitation systems, including climate and disaster resilience considerations.

From ***12:45 PM to 1:15 PM***, participants gained practical insights from ***field implementation in three coastal towns of Maharashtra—Malvan, Dhanu, and Guhagarh***. The session was presented by ***Mr. Irfan from the Centre for DEWATS Dissemination (CDD), India***, highlighting on-the-ground experiences, key challenges in service delivery, and innovative approaches adopted to enhance the resilience of water and sanitation infrastructure in smaller towns. Additionally, Mr. Irfan showcased the ***vulnerability assessment tool developed by CDD-India as part of the project***, which aids in evaluating climate and disaster risks to water and sanitation infrastructure at the local level.

After the ***lunch break***, the ***Feedback and Way Forward Session*** was held from ***2:15 PM to 4:15 PM***. This session brought together ***key partners and experts***, including Mr. Amit Mishra (India Sanitation Coalition), Mr. Irfan (CDD India), Mr. Romit Sen (HSBC India), Mr. Vishwanath S, Mr. Depinder Kapur (NIUA), Ms. Lubaina Rangwala (WRI), and Prof. Ajay Deshpande (IITB), who discussed ***actionable recommendations, capacity-building needs, and strategies for future collaboration***. The session also featured contributions from ***state and city representatives***, such as **PWD officials from Karnataka, CO Vengurla, MPCB officials, and officials from Mangaluru and Karwar**, whose feedback, suggestions, and observations provided valuable insights and guidance for the project team.

The workshop concluded with a **vote of thanks from 4:15 PM to 4:30 PM,** followed by **high tea at 4:30 PM,** marking the close of a productive day of knowledge sharing, deliberation, and collective strategizing for climate-resilient urban water and sanitation infrastructure in coastal towns.

Key Discussion Points

1. Maharashtra

During the Maharashtra session, several observations and recommendations were shared. Ms. Lubaina Rangwala emphasized that climate financing currently favors large cities, while small and medium-sized towns remain underserved. She highlighted the need to make tier-3 cities future-ready, through cross-sectoral and networked thinking, incremental funding, and decentralized options that generate co-benefits, particularly for coastal livelihoods.

Mr. Irfan from CDD shared insights from work in Malvan, Dhanu, and Guhagarh, emphasizing the importance of source strengthening in smaller towns and accounting for tourism's impact on local water, sanitation, and solid waste management systems. He noted technical and financial gaps in implementing infrastructure plans and suggested the development of localized, climate-resilient treatment systems.

Alibag, Vengurla, and Ratnagiri: While no specific sectoral recommendations were recorded for these towns, the general discussion reinforced the importance of focusing on smaller towns with limited service delivery infrastructure.

2. Karnataka

Mr. Vishwanath S highlighted the potential of treated wastewater for groundwater recharge, emphasizing co-benefits in cost savings, water conservation, energy savings, and climate change mitigation. He noted that political and operational challenges often limit the functionality of STPs and stressed the need to incorporate these challenges into reports.

Groundwater recharge in coastal towns was flagged as challenging due to high salinity levels. Discussions around financial sustainability highlighted discrepancies in cost recovery, with **Mangaluru** and Kundapura achieving over 95%, whereas Karwar had not yet reached the 50% mark. Mr. Vishwanath S also underscored the low level of service delivery and the need for adaptation-focused interventions.

Karwar: The Commissioner noted that STPs frequently stop functioning due to drought, monsoon flooding, and high tides, which cause corrosion in metal components. It was recommended to replicate models from Mangaluru and Kundapura, including engaging private vendors for utility management.

Mangaluru Officials highlighted that STPs are outdated, with end-of-life expected by 2026, and suggested adopting modern sewerage network techniques to detect and fix missing connections. Pricing and cost recovery remain a challenge, with reported O&M losses of INR 15–16 crore, although updated data indicates higher recovery.

3. Goa

PWD officials shared that Goa relies heavily on deep borewells and has implemented a 100% metering system with annual tariff increases of 5%. NRW is estimated at 25%, with 15% attributable to manual errors. Initiatives include smart metering (3,000 units in Panaji), free water up to 16m^3, and slab-wise tourism tariffs. They aim to supply 24×7 water and are planning energy audits to optimize energy use per cubic meter.

Mr. Vishwanath S and Goa, PWD officials noted that energy audits for water supply are underway, but GHG emissions are not currently a primary focus for the state. Challenges include high turbidity in raw water and local religious constraints on supply timing. Officials emphasized the need for unified platforms for dialogue and knowledge-sharing to improve WASH infrastructure performance.

Mapusa: The town sources water primarily from the Sal River, with a high water table and salinity concerns. Financial challenges were noted regarding one-time settlement schemes for water revenue, which were not continued after 2021–22.

4. Gujarat

Prof. Ajay Deshpande highlighted models for small and medium towns to assess WASH systems and evolve into climate-resilient cities. He recommended standards for abstraction and infrastructure and suggested policy advocacy measures. Ms. Nagma Modi, representing Valsad town, noted severe waterlogging and flooding in coastal areas of Valsad, requiring immediate attention. Mr. Depinder Kapur explained methods used to estimate population growth and future water demand for planning purposes.

5. Expert Panel Comments and General Observations

Across states, several general observations emerged. Prof. Satish Agnihotri suggested triaging ODF data with health metrics to identify towns where sanitation systems are failing or where positive outcomes can be studied. Mr. Vishwanath S emphasized the need to ring-fence water utilities and upgrade tariffs to achieve economies of scale. Prof. Ajay Deshpande recommended differential vulnerability assessments, highlighting that ULBs often lack the capacity to interpret complex assessments. Updated CRZ regulations were noted as an important tool for empowering ULBs.

Lubaina stressed the need for future-ready cities, equitable distribution of climate finance to smaller towns, and community awareness. Vishwanath S highlighted low-cost technologies and the importance of understanding groundwater extraction and aquifer potential. Mr. Depinder Kapur underscored the need to consider both sewer-connected and non-sewered decentralized systems as viable solutions.

PWD officials from Karnataka noted ongoing energy audits, while Gujarat representatives stressed the importance of industrial wastewater management in Valsad and policy-led sewage treatment.

Way Forward

In the ***short term***, the team will incorporate the suggestions and feedback received, including additional town- and state-specific information, into the respective reports. In the ***medium term***, the team plans to develop research papers, publications, and other outreach and communication materials in collaboration with advocacy and implementation partners, namely the ***India Sanitation Coalition (ISC)*** and ***CDD-India***, aiming to achieve broader recognition and secure buy-in from government stakeholders and the academic community. In the **long term**, the team aims to engage governance stakeholders and local academic institutions through targeted capacity-building exercises, leveraging the forthcoming toolkit designed to assess and enhance the resilience of water and sanitation infrastructure and services in coastal towns across India.

[80] International Institute for Population Sciences. 2020 National Family Health Survey – 5 (2019-2020). District Fact Sheet. Ministry of Health and Family Welfare.

ANNEXURE-IV ABBREVIATIONS AND GLOSSARY

ABBREVIATIONS

ADB	Asian Development Bank
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
CCA	Climate Change Adaptations
CT	Community Toilet
CDRI	Coalition for Disaster Resilient Infrastructure
DDMP	District Disaster Management Plan
DM	District Magistrate
DRR	Disaster Risk Reduction
ESLR	Elevated Level Storage Reservoir
FSSTP	Faecal Sludge and Septage Treatment Plant
GIRI	Global Infrastructure Risk Model and Resilience Index
GIS	Geographic Information System
GLSR	Ground Level Storage Reservoir
IFIS	International Financial Institutions
IPCC	Intergovernmental Panel on Climate Change

KIUWMIP	Karnataka Integrated Urban Water Management Investment Program
KUIDFC	Karnataka Urban Infrastructure Development and Finance Corporation
KUWSDB	Karnataka Urban Water Supply and Drainage Board
LPCD	Litres Per Capita per Day
LULC	Land Use Land Cover
MLD/ KLD	Million Litres per Day/ Kilo Litres per Day
MSL	Mean Sea Level
MOHUA	Ministry of Housing and Urban Affairs
NBIS	Nature-Based Infrastructure Solutions
NRW	Non-Revenue Water
ODF	Open Defecation Free
O&M	Operation and Maintenance
OSS	On Site Sanitation Systems
OHR	Overhead Reservoirs
PT	Public Toilet
PWD	Public Works Department
RIS	Risk Information Systems
SAPCC	State Action Plans on Climate Change

SBM	Swachh Bharat Mission
SBR	Sequence Batch Reactors
SLBS	Service Level Benchmarks
SOP	Standard operating Procedure
STPS	Sewage Treatment Plants
UGD	Underground Derange
UNDRR	United Nations Office for Disaster Risk Reduction
WTP	Water Treatment Plant
WRD	Water Resources Department
WASH	Water, Sanitation, and Hygiene

GLOSSARY

Term	*Definition*
ADEQUACY	Making available in a universal and equitable manner which is sufficient, acceptable and affordable for all.
BASIC INFRASTRUCTURE	Infrastructure that provides essential services to individuals, households, communities, and businesses and includes water, drainage, sanitation networks, local road, river, and rail networks, health and education facilities, post-harvest processing and storage facilities etc. (CDRI, 2023)[81]
CLIMATE ADAPTATION	Adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects. It refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change

	(UNFCCC, https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/introduction).
EXPOSURE	The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected. (UNDRR)
FLEXIBILITY	Ability of an infrastructure asset or system to perform the desired function based on specified requirements over time without interruption or degradation. (CDRI, 2023)
GREY INFRASTRUCTURE	Engineered physical structures that underpin energy, transport, communications (including wireless and digital), built form, water and sanitation, and solid-waste management systems and that protect human lives and livelihood. (CDRI, 2023)
HAZARD	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. (UNDRR)
INFRASTRUCTURE	CDRI has defined infrastructure as "Individual assets, networks and systems that provide specific services to support the functioning of a community or society" (CDRI, 2023)
INFRASTRUCTURE GOVERNANCE	Infrastructure governance can be understood as the policies, frameworks, norms, processes and tools used by public bodies to plan, make decisions, implement and monitor the entire life cycle of public infrastructure. (OECD)
INFRASTRUCTURE RESILIENCE	Infrastructure systems and networks, the components, and assets thereof, and the services they provide, that can resist and absorb disaster impacts, maintain adequate levels of service continuity during crises, and swiftly recover in such a manner that future risks are reduced or prevented. (CDRI,2023)
NATURE BASED INFRASTRUCTURE SOLUTIONS	Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, and resilience and biodiversity benefits (UNEP, 2022c).

ODF	A city / ward can be notified/declared as ODF city/ ODF ward if, at any point of the day, not a single person is found defecating in the open (Ministry of Housing and Urban Affairs, 2020)[82]
ODF+	A city / ward / work circle can be notified/declared as SBM ODF+city/SBMODF+ward/SBMODF+work circle if, at any point of the day, not a single person is found defecating and/ or urinating in the open, AND all community and public toilets are functional and well maintained (Ministry of Housing and Urban Affairs, 2020).
REDUNDANCY	Alternative or back-up means created within an infrastructure system to accommodate disruption, extreme pressures, or surges in demand. (CDRI)
RELIABILITY OF SERVICES	The ability of the system to maintain its required capacity and performance during a given period under stated conditions or disastrous events. (CDRI, 2023)
RESILIENCE	The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. (AR6, IPCC)
SENSITIVITY	The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. (AR6, IPCC)
SYSTEM RESILIENCE	The resilience of social, economic, territorial and environmental systems, at all scales, that conditions the ability of infrastructure assets and the services they provide to resist and absorb disaster impacts. (Definition adopted in CDRI Biennial Report)

[81]CDRI. (2023). Map Viewer. Retrieved from Global Infrastructure Risk Model and Resilience Index, Measuring Risk and Resilience in Infrastructure Solutions: https://giri.unepgrid.ch/map

[82]Ministry of Housing and Urban Affairs. (2020). Declaring your City/Town SBM ODF+ and SBM ODF++ Toolkit for Urban Local Bodies. New Delhi: Government of India.

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