

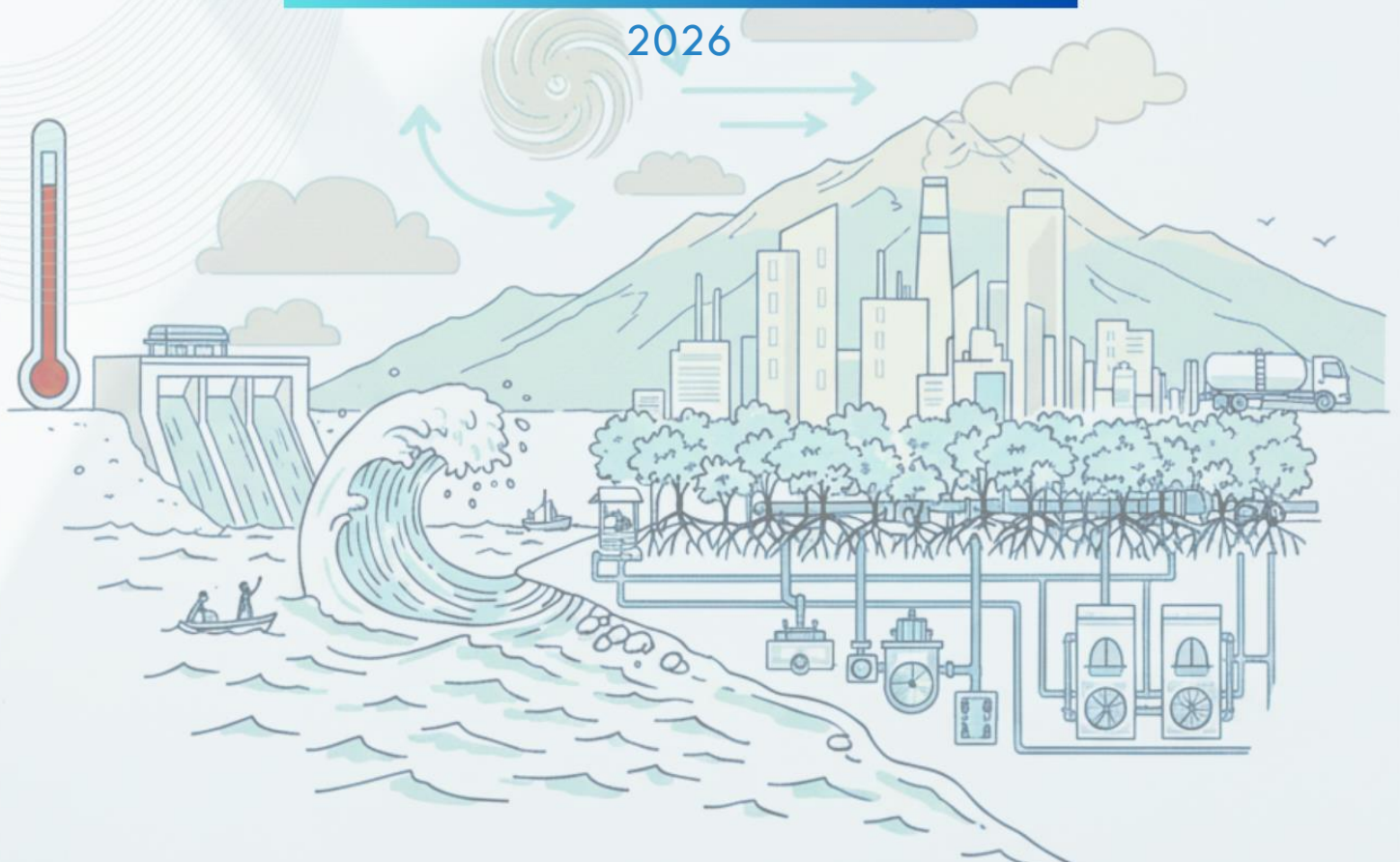


Towards Climate-Resilient Urban Water & Sanitation Systems

Situational Assessment Report

MORMUGAO, GOA

2026



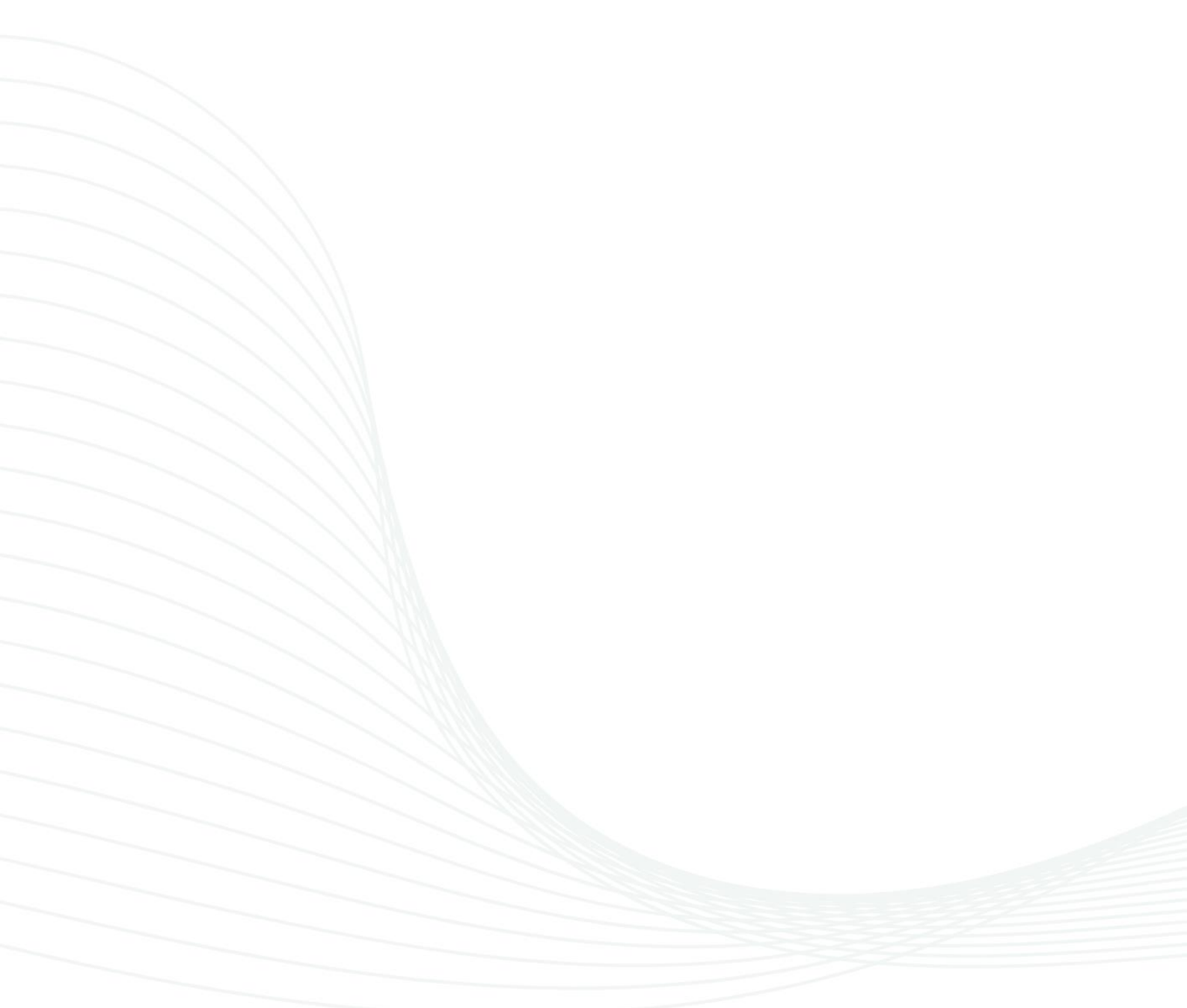
Edited by:

N C Narayanan

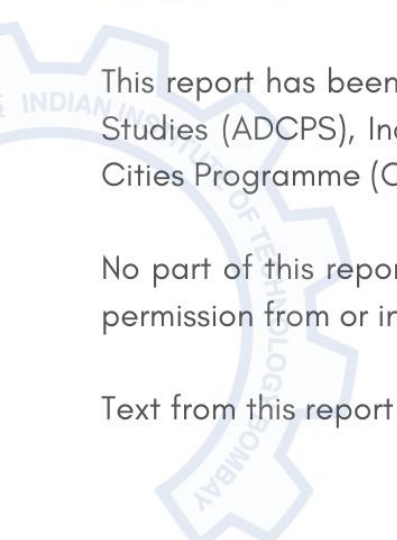
Contributing Authors:

Neelam Rana, Ashish Dangi, Abhay Junaghare, Priyakshi Gogoi, Sucharita Roy & Tejash Anand

Ashank Desai Centre for Policy Studies, Indian Institute of Technology Bombay



DISCLAIMER



This report has been prepared and authored exclusively by the Ashank Desai Centre for Policy Studies (ADCPS), Indian Institute of Technology Bombay, under the Climate Resilient Coastal Cities Programme (CRCCP), supported by HSBC India.

No part of this report may be reproduced in any form (electronic or mechanical) without prior permission from or intimation to ADCPS, IIT Bombay.

Text from this report can be quoted provided the source is acknowledged.

TITLE

Towards Climate-Resilient Urban Water and Sanitation Systems: Situational Assessment of Mormugao, Goa

AUTHORS

Dr. NC Narayanan, Professor, ADCPS, IITB - Principle Investigator (PI) CRCC Project

Dr. Neelam Rana, Senior Project Research Scientist, ADCPS, IITB

Ashish Dangi & Abhay Junaghere, Research Scholars, ADCPS, IITB

Priyakshi Gogoi, Sucharita Roy & Tejash Anand, Project RAs, ADCPS, IITB

DESIGN & LAYOUT

Ashish Dangi

SUGGESTED CITATIONS

For the full report:

Narayanan, N.C. (Ed.). (2026). *Towards Climate-Resilient Urban Water & Sanitation Systems: Situational Assessment of Mormugao, Goa*. (Report No. CRCC-GA-02-2026). Ashank Desai Centre for Policy Studies, Indian Institute of Technology Bombay. Mumbai, Maharashtra. India. Available at: <https://www.cps.iitb.ac.in/research-report-series/>

For a chapter: (Example Chapter 1)

Dangi, A., Rana, N., Gogoi P., & Narayanan, N.C. (2026). Urban Water & Sanitation Systems in a Changing Climate. In Narayanan, N.C. (Ed.), *Towards Climate-Resilient Urban Water & Sanitation Systems: Situational Assessment of Mormugao, Goa* (pp. 1-16). (Report No. CRCC-GA-02-2026). Ashank Desai Centre for Policy Studies, Indian Institute of Technology Bombay. Mumbai, Maharashtra. India. Available at: <https://www.cps.iitb.ac.in/research-report-series/>



**Ashank Desai
Centre for Policy Studies**
Indian Institute of Technology Bombay
Insight ♦ Dialogue ♦ Impact

ACKNOWLEDGEMENTS

This report is part of a landscape analysis of climate-resilient water, sanitation, and hygiene (WASH) infrastructure across four coastal states under the **Climate Resilient Coastal Cities Programme (CRCCP)**, financially supported by **HSBC India**.

We are grateful to **Government of Goa**, and officials from the Water and Sanitation Departments (PWD, Goa), Goa State Urban Development Agency (GSUDA), the Mormugao/Vasco Municipal Council, and the District Disaster Management Authority for their support and for providing data and information, without which this study would not have been possible.

We acknowledge the support of the **Swachh Bharat Mission (Urban) Mission Directorate** for their guidance in the selection of the town for this study.

We also thank the water supply and wastewater treatment **plant operators** for facilitating site visits and sharing valuable insights into the functioning of the infrastructure. We acknowledge the contributions of **frontline and street-level workers** across the water and sanitation service chain, whose practical knowledge and on-ground experience informed our understanding of system operations.

We are thankful to the **residents who participated in the field studies** for generously sharing their time and perspectives.

We express our sincere gratitude to the **domain experts and practitioners** who participated in the knowledge dissemination-consultation workshop, offering valuable and critical feedback that helped strengthen the analysis and improve the overall quality of the study.

Finally, we thank other project partners, the India Sanitation Coalition (ISC) and the Centre for DEWATS Dissemination (CDD) India, for their respective roles in communication and outreach, and in project implementation.

Supported by



Ashank Desai
Centre for Policy Studies
Indian Institute of Technology Bombay
Insight ♦ Dialogue ♦ Impact

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, Goa 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.

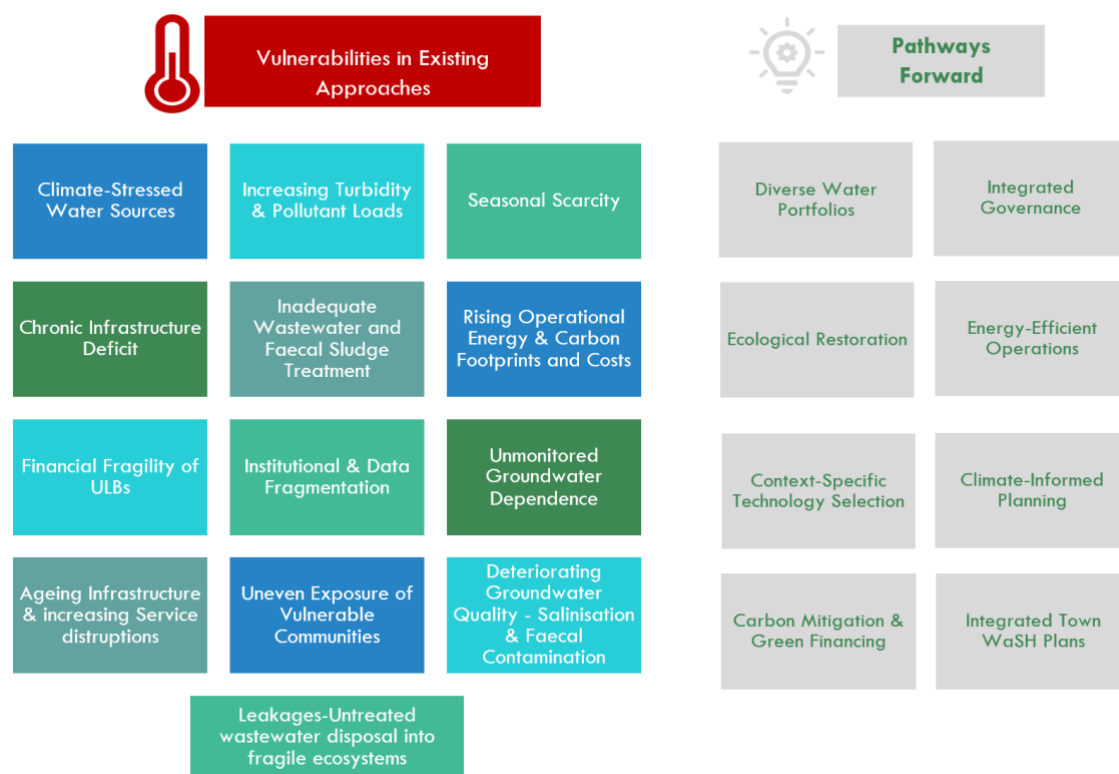


Figure 1: Systemic Vulnerabilities in existing approaches to WaSH and Pathways forward.

The report presents the study findings for **Mormugao**, a Class-II town, in the Mormugao Taluka of South Goa District. Our assessment of Mormugao revealed some critical challenges of WaSH infrastructure & services:

WATER SUPPLY:

Critical Source Vulnerability: Mormugao's over-reliance on a single, distant surface water source (Salaulim Dam) leaves the town acutely vulnerable to climate-induced hydrological changes and reservoir sedimentation. Simultaneously, a surge in unregulated groundwater extraction risks severe aquifer depletion and saline intrusion in estuarine zones.

Fragile Infrastructure and High Losses: Ageing infrastructure and the town's geographic position at the tail-end of the transmission system lead to chronic service interruptions. Furthermore, a staggering 38% Non-Revenue Water (NRW) rate heavily wastes treated water and significantly inflates the carbon footprint of the municipal supply.

Reactive Maintenance and Competing Demands: A predominantly reactive approach to operation and maintenance (O&M) leaves the network highly susceptible to cascading failures during power fluctuations or climate disruptions. This fragility makes it

increasingly difficult to balance growing domestic needs with heavy port and industrial demands.

Urgent Need for Structural Reform: While demand-side incentives (such as free water schemes) aim to promote conservation, they are insufficient on their own. Bridging the demand-supply gap and ensuring equitable, reliable access requires urgent, long-term capital investments and comprehensive governance reforms.

SANITATION:

Infrastructure Gaps in Vulnerable Zones: Informal settlements and low-lying areas suffer from acute service disparities and chronic monsoon waterlogging, compounding public health risks and climate vulnerability. Decentralised and nature-based solutions are needed where traditional infrastructure is unfeasible.

High-Impact Climate Liabilities: Unmanaged pits and septic tanks act as massive methane hotspots due to inadequate Faecal Sludge Management (FSM). This is worsened by significant, often overlooked nitrous oxide (N₂O) emissions from untreated greywater and sewer network leakages.

Inequitable Maintenance Burdens: The current operational model places the financial and daily labor burden of maintaining community toilets entirely on marginalized users. The Urban Local Body (ULB) must take ownership through subsidies or direct management to ensure equitable service delivery.

Governance Limits and Revenue Potential: Inadequate devolution of administrative and financial powers to the ULB fragments sanitation management. Empowering the municipal council would not only improve context-specific planning but also unlock new revenue streams, such as the sale of treated wastewater and dried sludge.

GHG EMISSIONS:

Supply-Side Carbon Intensity: Water treatment and conveyance are the largest sources of supply-related emissions, heavily exacerbated by staggering distribution losses (38%) that inflate the carbon footprint of every liter delivered.

Methane Hotspots in Sanitation: Because of infrequent desludging and limited Faecal Sludge Management (FSM), widespread on-site sanitation systems (pits and septic tanks) act as the city's largest unmanaged source of methane.

Hidden Nitrous Oxide Risks: Uncontrolled greywater discharge, sewer network leakages, and even treated effluents generate substantial nitrous oxide (N₂O) emissions, presenting a major but frequently overlooked climate threat.

Complexities in Centralised Treatment: While centralised sewage treatment plants (STPs) emit fewer GHGs per unit of waste compared to on-site systems, their ongoing energy consumption and residual methane release remain significant contributors to the overall municipal footprint.

FINANCIAL HEALTH:

Declining Capital for Infrastructure: A concerning drop in capital receipts severely restricts the funding available for long-term projects. Furthermore, while capital expenditure has seen a slight increase, overall spending remains too conservative to support the urgent modernisation and expansion of the water network.

Operational Deficits and Instability: Despite steady growth in revenue income, it consistently fails to cover ongoing operational costs. This widening gap between revenue generation and expenditure, coupled with fluctuating fiscal surpluses, signals systemic inefficiencies and long-term financial instability.

Volatile Reliance on External Grants: The department remains heavily dependent on external financial support, with the ratio of grants to self-generated revenue fluctuating drastically over recent years. This unpredictability undermines sustainable, long-term planning.

Urgent Need for Fiscal Reform: Securing the future of municipal water and sanitation services requires a strategic overhaul of financial management. This must include stricter cost controls, enhanced internal revenue generation, and sustained capital investment to reduce grant dependency and close operational deficits.

Ultimately, securing Mormugao's urban resilience requires a paradigm shift from reactive, fragmented management to an integrated, climate-sensitive approach. The compounding vulnerabilities across water scarcity, sanitation inequities, escalating greenhouse gas emissions, and financial instability demand urgent structural reform. By empowering the Urban Local Body with greater administrative and fiscal autonomy, aggressively targeting infrastructural inefficiencies, and transitioning towards low-carbon, decentralised solutions, the municipality can successfully bridge the widening demand-supply gap. Transforming these systemic liabilities into opportunities will not only safeguard public health and ecosystem integrity, but also establish a financially sustainable foundation for the town's future.

TABLE OF CONTENTS

1. URBAN WATER & SANITATION SYSTEMS IN A CHANGING CLIMATE	1
1.1 BACKGROUND	1
1.2 THE RISING CLIMATE THREAT TO INDIA'S WEST COAST	4
1.3 SYSTEMIC VULNERABILITIES AND THE CLIMATE MULTIPLIER EFFECT	6
1.4 REIMAGINING URBAN WATER RESILIENCE IN THE FACE OF CLIMATE CHANGE	7
1.5 METHODOLOGY	9
1.5.1 Analytical Framework	9
1.5.2 Town selection criteria	10
1.5.3 Step-by-step Approach to Situational Assessment	13
1.5.4 Data Collection	14
2. TOWN PROFILE	17
3. STATUS OF WATER INFRASTRUCTURE AND SERVICES	23
3.1 SURFACE WATER SOURCES	24
3.2 GROUNDWATER	25
3.3 WATER INFRASTRUCTURE	32
3.4 WATER DEMAND & SUPPLY	39
3.5 CLIMATE RISKS AND CHALLENGES	43
4. URBAN SANITATION SYSTEMS IN MORMUGAO: STATUS, INSTITUTIONS AND CHALLENGES	48
4.1 BACKGROUND	48
4.2 SANITATION SERVICE CHAIN	50
4.3 INSTITUTIONAL ARRANGEMENTS	56
4.4 CHALLENGES AND OPPORTUNITIES IN SANITATION INFRASTRUCTURE AND SERVICES	58
5. CLIMATE IMPACTS OF WATER & SANITATION SYSTEMS	62
5.1 BACKGROUND	62
5.2 SOURCES OF GHG EMISSIONS IN URBAN WATER AND WASTEWATER SYTEMS	64
5.3 SCOPE OF GREEN HOUSE GAS ESTIMATION	64
5.4 GREENHOUSE GAS EMISSIONS FROM WATER SUPPLY	66
5.5 GREENHOUSE GAS EMISSIONS FROM SANITATION	68
5.6 CONCLUSION & WAY FORWARD	71
6. PERFORMANCE AND FINANCIAL ANALYSIS OF WATER SUPPLY AND SANITATION	74
6.1 INTRODUCTION	74
6.2 PERFORMANCE ANALYSIS: SERVICE LEVEL BENCHMARKS	75
6.2.1 Water Supply	75
6.2.2 Sewerage & Sanitation	77
6.3 REVENUE STREAMS	79
6.3.1 Retail Water Tariff – PWD, Goa	79
6.3.2 Retail Sewerage Tariff – PWD, Goa	81
6.3.3 Ratio of Grants to Own Revenue	82
6.4 ASSESSMENT OF FINANCES	84
6.4.1 Water Supply	84
6.4.2 Sewerage and Sanitation	86
6.5 KEY FINANCIAL CHALLENGES	88
7. RESILIENCE ASSESSMENT OF WASH INFRASTRUCTURE	90
7.1 BACKGROUND	90
7.2 METHODOLOGY FOR RESILIENCE ASSESSMENT	91

7.3 EXPOSURE TO CLIMATE RISK	92
7.3 VULNERABILITY OF THE WASH INFRASTRUCTURE	98
7.3.1 Adequacy of Infrastructure	98
7.3.2 Reliability, Flexibility and Redundancy	99
7.3.3 Infrastructure Risk Governance and Finance	100
ANNEXURE-I: DATA COLLECTION & VALIDATION	102
ANNEXURE-II: DATA GAPS	105
ANNEXURE-III: POPULATION PROJECTIONS	108
ANNEXURE-IV: STAKEHOLDER CONSULTATION WORKSHOP: KEY HIGHLIGHTS AND WAY FORWARD.....	113
ANNEXURE-V ABBREVIATIONS AND GLOSSARY	118
.....	123

LIST OF FIGURES

FIGURE 1:GLOBAL ANNUAL AVERAGE LAND TEMPERATURE (1979-2025).	1
FIGURE 2:INTENSIFICATION OF THE WATER CYCLE DUE TO GLOBAL WARMING AND ITS IMPACT ON URBAN WATER SECURITY.	3
FIGURE 3: ANNUAL TIME SERIES OF AIR HUMIDITY OVER INDIAN LANDMASS.....	5
FIGURE 4: CASE STUDY TOWNS ACROSS 4 WEST COASTAL STATES OF INDIA.....	8
FIGURE 5: THE WATER-ENERGY-CLIMATE NEXUS IN URBAN WATER SYSTEMS.....	9
FIGURE 6: METHODOLOGICAL FRAMEWORK FOR THE SITUATIONAL ASSESSMENT AND RESILIENCE EVALUATION OF URBAN WASH SYSTEMS.	13
FIGURE 7: LANDCOVER AND BUILT-UP FOOTPRINT OF MORMUGAO.....	18
FIGURE 8: ADMINISTRATIVE DIVISIONS OF GOA.....	19
FIGURE 9 : FLOOD VULNERABILITY OF TALUKA OF GOA.....	20
FIGURE 10: GEOGRAPHICAL SETTING OF MORMUGAO MUNICIPAL COUNCIL AREA.	23
FIGURE 11: SALAULIM SPILLWAY DAM, KUDRI, GOA.....	24
FIGURE 12: PRINCIPLE AQUIFER SYSTEMS IN GOA.....	26
FIGURE 13: PRE MONSOON(MAY 2023) AND POST MONSOON (NOV 2023) DEPTH TO WATER LEVELING MORMUGAO TALUK.	28
FIGURE 14: SEASONAL VARIATION IN GROUNDWATER LEVELS IN MORMUGAO TALUK (2017-18).....	28
FIGURE 15: GROUNDWATER LEVEL FLUCTUATIONS (SHALLOW AQUIFER): PRE-MONSOON (MAY 2022 TO MAY 2023) & POST-MONSOON (NOV 2022 TO NOV 2023).....	29
FIGURE 16: DECADAL WATER LEVEL FLUCTUATIONS (SHALLOW AQUIFER): PRE-MONSOON (MAY 2013 TO MAY 2023) & POST-MONSOON (NOV 2013 TO NOV 2023).....	30
FIGURE 17: GROUND WATER RESOURCE ASSESSMENT (2022) FOR MORMUGAO BLOCK	31
FIGURE 18: COVERAGE OF THE SALAULIM WATER SUPPLY SCHEME.	33
FIGURE 19: LOCATION OF SALAULIM DAM AND WATER TREATMENT PLANT ON A HILLOCK.....	34
FIGURE 20: SCHEMATIC DRAWING OF THE WATER SUPPLY NETWORK SHOWING KEY INFRASTRUCTURE	36
FIGURE 21: LONGITUDINAL SECTION OF THE SALAULIM GRAVITY MAIN TRANSMISSION SYSTEMFROM WTP IN SANGUEM TO SADA VASCO.....	37
FIGURE 22: SCHEMATIC OF TRANSMISSION SYSTEM OF THE SALAULIM WATER SUPPLY SCHEME.....	37
FIGURE 23: DISTRIBUTION NETWORK FOR WATER SUPPLY IN MURMAGAO / VASCO ZONE.	39
FIGURE 24: CATEGORY WISE DAILY AVERAGE WATER CONSUMPTION BY INDIVIDUAL METERED CONNECTIONS IN VASCO-ZONE.....	41
FIGURE 25 : SANITATION SERVICE CHAIN IN MORMUGAO	50

FIGURE 26: WARD-WISE DISTRIBUTION OF HOUSEHOLDS (%) WITH SEWERAGE CONNECTION AND ON-SITE SANITATION SYSTEMS.....	52
FIGURE 27: THE WATER-ENERGY-CLIMATE NEXUS IN URBAN WATER CYCLES.....	63
FIGURE 28: GRAPHICAL REPRESENTATION OF VARIOUS STEPS AND PROCESSES IN A TYPICAL URBAN WATER CYCLE SHOWING SOURCES OF ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS.....	64
FIGURE 29: CARBON AND ENERGY FOOTPRINT OF MORMUGAO'S WATER SUPPLY.	66
FIGURE 30: CARBON AND ENERGY FOOTPRINT ACROSS SANITATION SERVICE CHAIN IN MORMUGAO.....	70
FIGURE 31: RATIO OF OWNED REVENUE TO GRANTS AT PWD GOA.....	83
FIGURE 32: TREND ANALYSIS OF COST RECOVERY IN WATER SUPPLY CHARGES AT MMC.....	84
FIGURE 33: TREND ANALYSIS OF COLLECTION EFFICIENCY IN WATER SUPPLY CHARGES AT MMC	85
FIGURE 34: TREND ANALYSIS OF COST RECOVERY IN SEWERAGE & SANITATION CHARGES AT MMC	86
FIGURE 35: TREND ANALYSIS OF COLLECTION EFFICIENCY IN SEWERAGE & SANITATION CHARGES AT MMC.....	87
FIGURE 36: EMERGING VULNERABILITY HOTSPOTS OF MORMUGAO CITY TO CLIMATE HAZARDS	93
FIGURE 37: LOCATION OF CRITICAL COMPONENTS OF THE WASH INFRASTRUCTURE WITHIN ADMINISTRATIVE BOUNDARY	97

LIST OF TABLES

TABLE 1: TOWN SELECTION CRITERIA.....	12
TABLE 2 : SELECTED TOWNS	12
TABLE 3 : WARD LEVEL BUILT-UP FOOTPRINT (BASED ON REMOTE SENSED DATA).....	18
TABLE 4: MULTI-HAZARD VULNERABILITY (LEVEL OF SEVERITY) IN MORMUGAO TALUKA OF GOA.....	20
TABLE 5: DISTRICT WISE DISTRIBUTION AND CHARACTERISTICS OF BASALT & METABASALT AQUIFER SYSTEMS.....	27
TABLE 6 : POPULATION PROJECTIONS.....	40
TABLE 7: TOTAL NUMBER OF CONNECTIONS DIVISION IX PWD.....	42
TABLE 8: ZONE-WISE / TALUKA-WISE DAILY CONSUMPTION STATEMENT OF WATER DURING 2023-24 (AS ON 31-03-2024).....	42
TABLE 9: INSTITUTIONAL ARRANGEMENTS IN SANITATION SERVICES.....	57
TABLE 10: SCOPE OF EMISSIONS METHODOLOGY FOR CARBON FOOTPRINT ASSESSMENT OF THE URBAN WATER CYCLE	65
TABLE 11: PERFORMANCE INDICATORS FOR WATER SUPPLY AT MMC	76
TABLE 12: PERFORMANCE INDICATORS FOR SEWERAGE & SANITATION AT MMC.....	78
TABLE 13: NEW WATER CONNECTION FEES FOR DOMESTIC CONSUMERS	80
TABLE 14: NEW WATER CONNECTION FEES FOR NON-DOMESTIC CONSUMERS.....	80
TABLE 15: SEWERAGE TARIFF STRUCTURE AT GOA	81
TABLE 16: NEW SEWERAGE CONNECTION CHARGES AT GOA.....	82
TABLE 17: WARD LEVEL VULNERABILITY TO FLOODING BASED ON ELEVATION PROFILE.....	94

1. URBAN WATER & SANITATION SYSTEMS IN A CHANGING CLIMATE

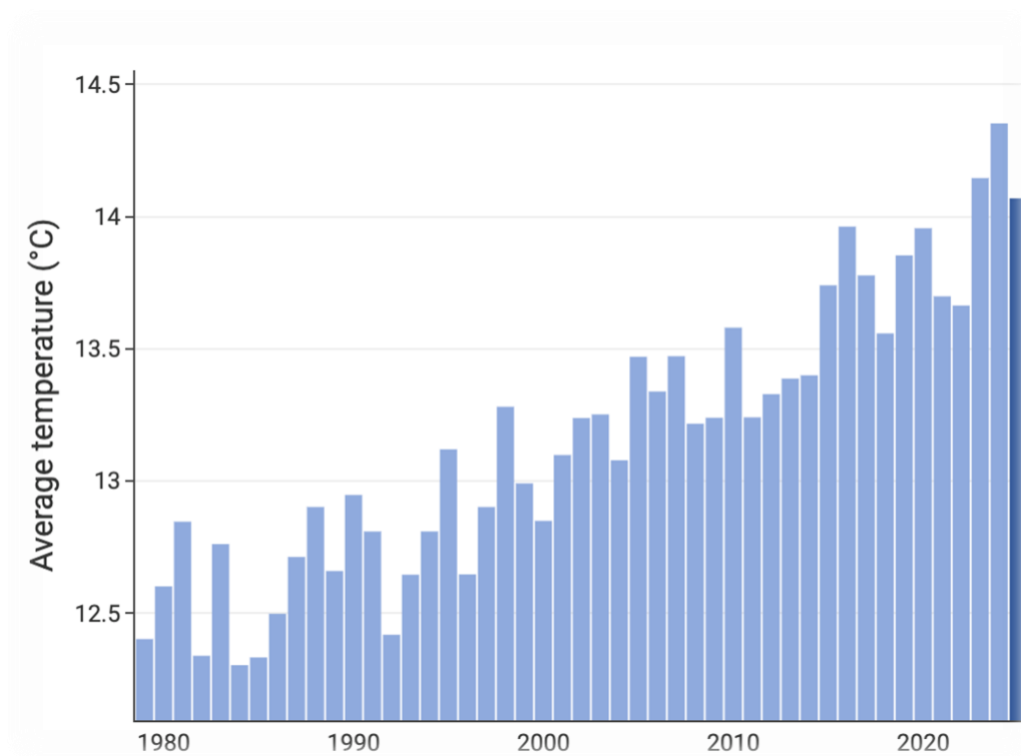
ASHISH DANGI, NEELAM RANA, N.C. NARAYANAN AND PRIYAKSHI GOGOI

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 year¹ (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 Monitor¹

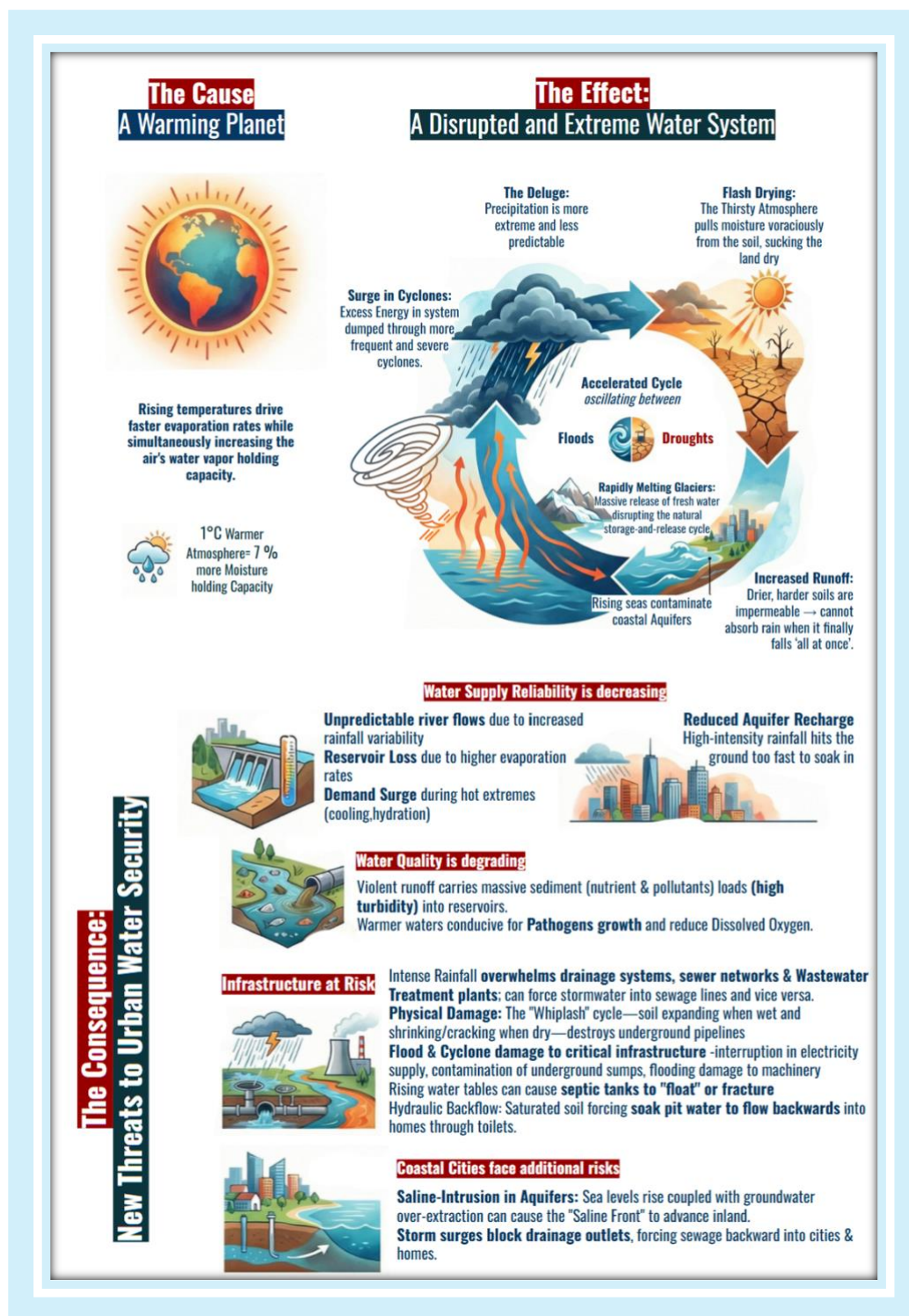
This leads to a volatile cycle: during dry periods, the 'thirstier' atmosphere aggressively evaporates moisture from soil and reservoirs, deepening drought conditions. However, once this moisture-laden air is triggered to release by a cyclone or orographic lift, it discharges with explosive intensity. 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 extremes⁴. 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 billion⁵. 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 areas⁷. 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 districts⁸.

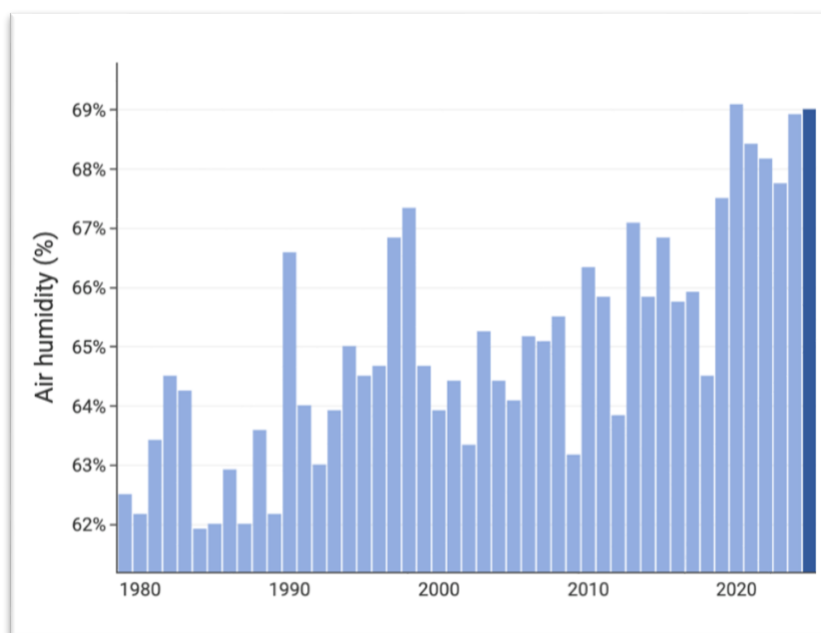
This escalating hydro-climatic volatility inevitably converges on Water management, particularly in cities, where dense populations, concentrated infrastructure, and increasingly fragile ecosystems intersect. Urban water systems spanning water supply, wastewater management, drainage, and groundwater 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 capacity¹¹. 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 Explorer¹²

Along India's west coast, the coastal districts of Gujarat specifically have become increasingly vulnerable to tropical cyclones in recent years¹³. Further, west coast states are more exposed to sea level rise; every one-metre rise in sea level can inundate almost 5,763 km² of land¹⁴. 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 report¹⁵.

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 in 12 coastal towns across Maharashtra, Gujarat, Goa, and Karnataka (Figure 4).

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

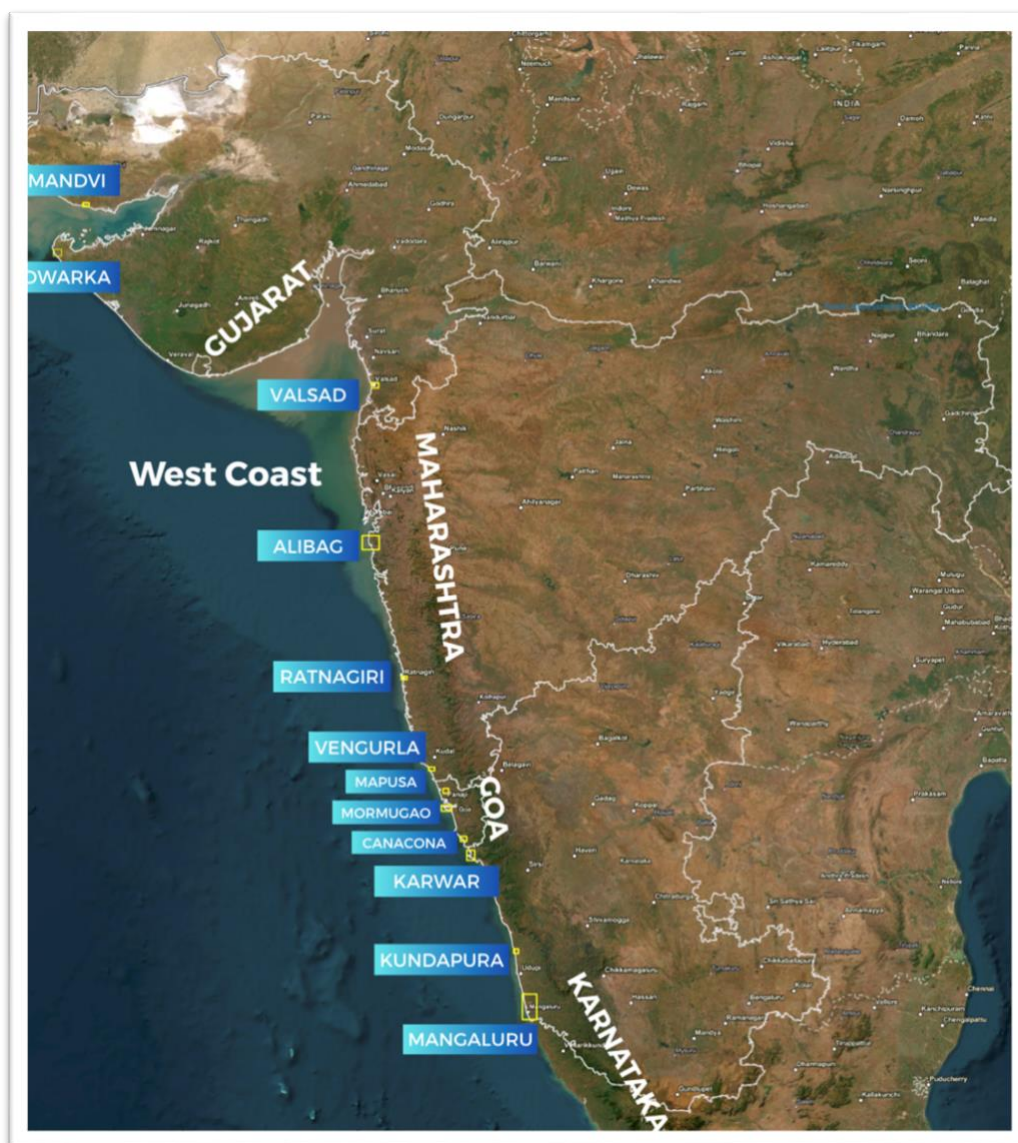


Image Source: Author's Illustration

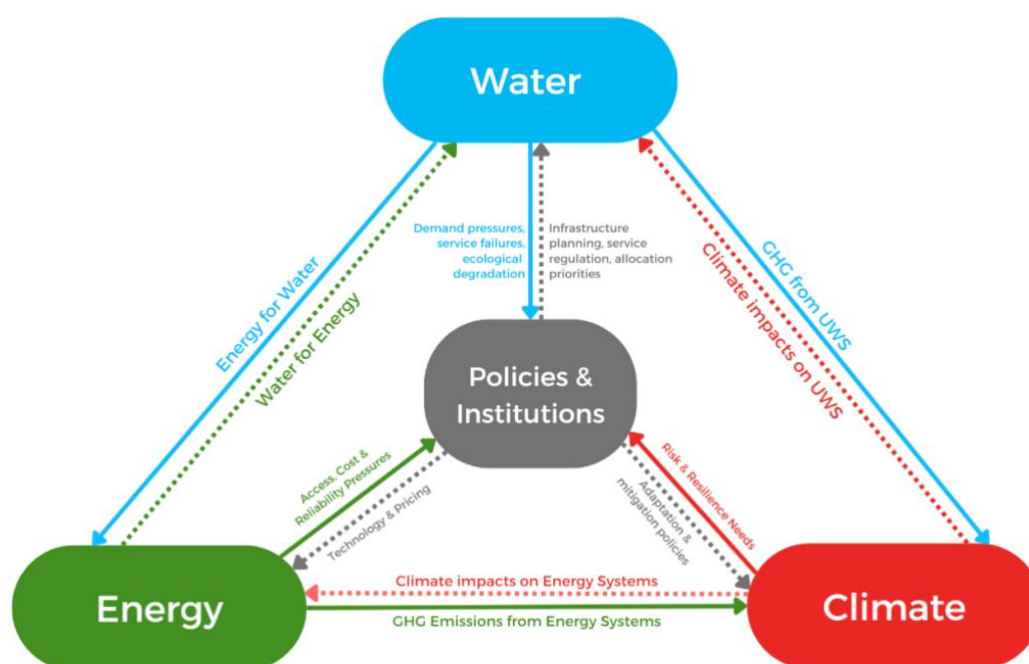
1.5 METHODOLOGY

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

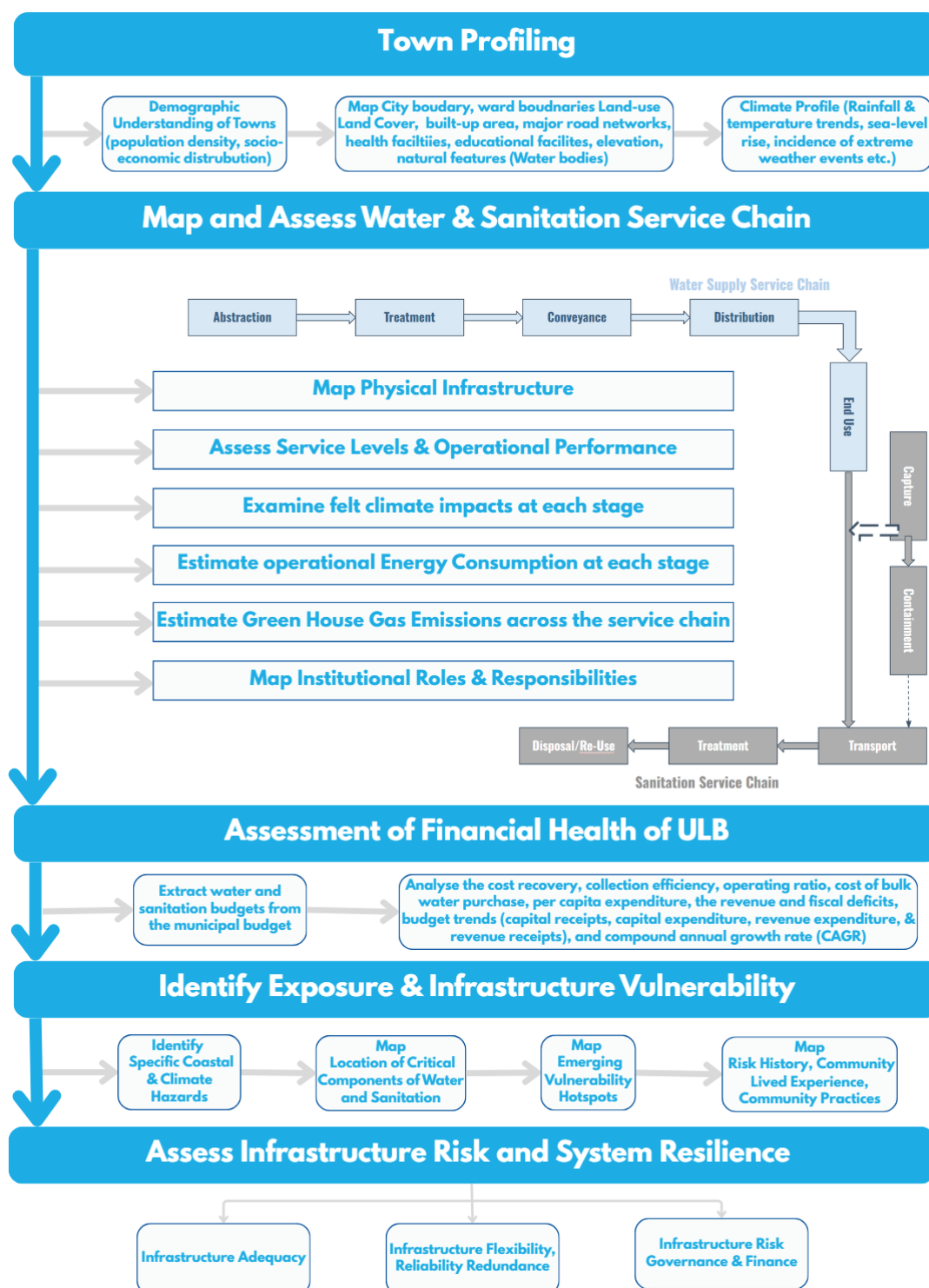
Key Parameters	Selection criteria		
Administrative status	Municipal Corporation	Municipal Council (A and B)	Nagar Panchayat (C and D)
City Size based on population	Class-I to Class IV		
Socio-economic profile	Capturing variability in socio-economic profile of the town population		
Climate Change Exposure 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 **Mormugao**, a Class-II town, in the Mormugao Taluka of South Goa District. The city is strategically positioned between the Arabian Sea and the Western Ghats. Jutting into the Arabian Sea and with high coastal elevation, the city is counted among India's top natural harbours. Mormugao is exposed to hazards such as sea level rise, coastal flooding, saltwater intrusion in low lying areas, storm surges, cyclones and landslides due to heavy precipitation in some vulnerable locations identified in recent years. The Goa State Climate Change Action Plan has prioritised the taluks of Mormugao, Bardez, Tiswadi and Salcete for adaptation efforts, as these regions host most of the state's population and economic activities, and are at higher risk due to climate change (NABCONS, 2023, p. 147)²⁰.

NOTES & REFERENCES

- ¹ Van Dijk, A.I.J.M., H.E. Beck, E. Boergens, R.A.M. de Jeu, W.A. Dorigo, C. Edirisinghe, E. Forootan, E. Guo, A. Güntner, J. Haas, J. Hou, S. Mo, W. Preimesberger, J. Rahman, P. Rozas Larraondo (2026) Global Water Monitor, 2025 Report. Published by Global Water Monitor Consortium, available at www.globalwater.online
- ² EM-DAT, CRED. (2019). The International Disaster Database.Center for Research on the Epidemiology of Disasters. Disponivel Em. [Https://Www.Emdat.Be](https://Www.Emdat.Be)
- ³ Lee, Jiseon, Duminda Perera, Talia Glickman, and Lina Taing. (2020). Water-Related Disasters and Their Health Impacts: A Global Review. *Progress in Disaster Science* 8:100123. doi: 10.1016/j.pdisas.2020.100123.
- ⁴ Global Climate Risk Index 2021. Who suffers Most from Extreme Weather Events? Weather-related Loss Events in 2019 and 2000 to 2019<https://www.germanwatch.org/en/19777> .
- ⁵ Mohanty, S. K., Bhagat, R. B., Dwivedi, L. K., Sharma, S., Jose, J., Nair, A., &Chandrasekar, R. (2020). Assessing Urban Vulnerabilities In Maharashtra. Government Of Maharashtra, UNICEF, IIPS.
- ⁶ Mohanty, Abinash. 2020. Preparing India for Extreme Climate Events: Mapping Hotspots and Response Mechanisms. New Delhi: Council on Energy, Environment and Water.
- ⁷ Jiménez Cisneros, Blanca E., Taikan Oki, Nigel W. Arnell, Gerardo Benito, J. Graham Cogley, Petra Doll, Tong Jiang, and Shadrack S. Mwakalila. (2014). *Freshwater Resources*.
- ⁸ SagarMala - Coastal Community Development Ministry of Shipping, GOI, Government of India. n.d. Retrieved February 9, 2026. <https://sagarmala.gov.in/project/coastal-community-development>.
- ⁹ Shamim, Sarah. 13 Jan 2025. "Why Fire Hydrants and Water Supply Failed during Los Angeles Wildfires." Retrieved October 23, 2025. <https://www.aljazeera.com/news/2025/1/13/why-fire-hydrants-and-water-supply-failed-during-los-angeles-wildfires>.
- ¹⁰ Deshpande, M., Singh, V. K., Ganadhi, M. K., Roxy, M. K., Emmanuel, R., & Kumar, U. (2021). Changing status of tropical cyclones over the north Indian Ocean. *Climate Dynamics*, 57, 3545–3567.
- ¹¹ Albert, Jiya, Venkata Sai Gulakaram, Naresh Krishna Vissa, Prasad K. Bhaskaran, and Mihir K. Dash. 2023. "Recent Warming Trends in the Arabian Sea: Causative Factors and Physical Mechanisms." *Climate* 11(2):35. doi:10.3390/cli11020035.
- ¹² Global Water Monitor Consortium. (2025). Global Water Monitor Data Explorer [Interactive data portal]. Australian National University. Retrieved November 23, 2026, from <https://www.globalwater.online/global-water/>
- ¹³ Boragapu, R., Guhathakurta, P. &Sreejith, O.P.2023. Tropical Cyclone Vulnerability Assessment ForIndia. *Nat Hazards* 117, 3123–3143. <https://doi.org/10.1007/S11069-023-05980-5>

- ¹⁴ Woodruff, S., Bendor, T. K., & Strong, A. L. (2018). Fighting The Inevitable. *Infrastructure Investment And Coastal Community Adaptation To Sea Level Rise. System Dynamics Review*, 34(1), 48–77.
- ¹⁵ IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 184 pp., doi: 10.59327/IPCC/AR6-9789291691647.
- ¹⁶ Rumbach, A. (2018). At The Roots Of Urban Disasters: Planning And Uneven Geographies Of Risk In Kolkata, India'. *Journal Of Urban Affairs*, 39 (6), 1–17.
- ¹⁷ Yenneti, K., Tripathi, S., Wei, Y. D., Chen, W., & Joshi, G. (2016). The Truly Disadvantaged? Assessing Social Vulnerability To Climate Change In Urban India. *Habitat International*, 56, 124–35.
- ¹⁸ Braks, M. A., & Husman, A. M. (2013). Dimensions Of Effects Of Climate Change On Water-Transmitted Infectious Diseases. *Air Water Borne Diseases*.
- ¹⁹ Central Pollution Control Board . (2021). National Inventory Of Sewage Treatment Plants. New Delhi: Ministry Of Environment, Forest And Climate Change. Government Of India.
- ²⁰ NABCONS. (2023). State Action Plan For Climate Change - For the State of Goa -From 2023 - 2033. Panaji: Goa State Biodiversity Board.

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.

Mormugao is a coastal town covering an area of 27.36 sqkm, located in the South Goa district of India. It serves as the administrative hub of the Mormugao taluka and is renowned for its deep, natural harbor, which remains Goa's primary port. As one of India's largest and oldest ports (commissioned in 1885), Mormugao plays a crucial role in the state's economy. The town is also the headquarters of the Mormugao sub-division and is strategically situated along the banks of the Zuari River, as well as the seacoast.

Demographic Profile: Mormugao town is the most populous urban centre in the South Goa district²¹, has 90% of the state's slum population, as per Census 2011. The Mormugao Municipal Council, according to the 2011 Census, has a population of 94,393, with 49,633 males and 44,760 females. The female sex ratio stands at 902, compared to the state average of 973. The Municipal Council oversees 21,524 households. Out of the total population, 36,929 individuals are involved in work or business activities, with 28,739 males and 8,190 females. Among the working population, 87.22% are engaged in main work, while 12.78% are involved in marginal work. The estimated population of Mormugao Municipal Council in 2025 is around 134,000²². The town has 20 wards (ibid).

Topography: The topography of Mormugao is a combination of rocky outcrop and sediment rich, low-lying areas at the mouth of the Zuari River. This results in a sheltered natural harbour and a bay like formation. The funnel is bay shaped. The clayey sediment at the mouth of the Zuari river and the coastal rocks which form the outcrop define the topography.

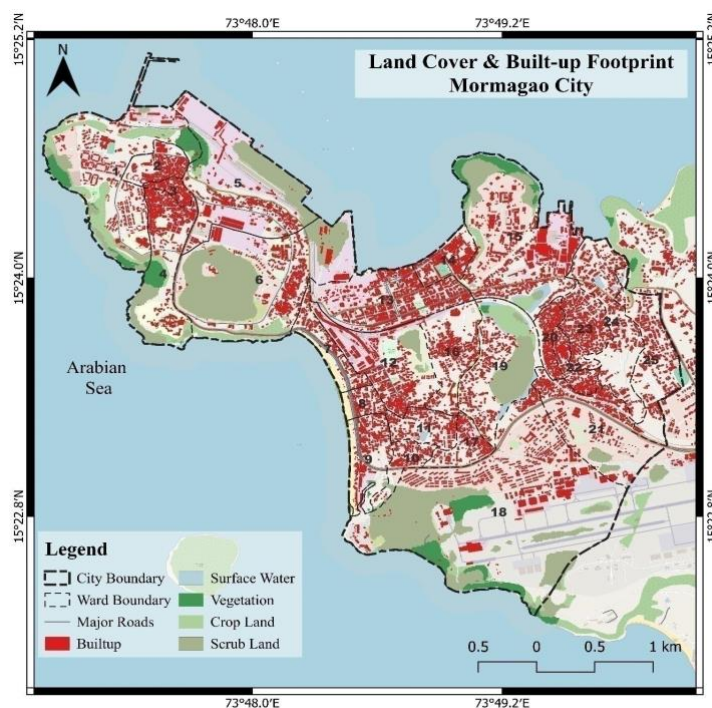
Land use and Landcover: Mormugao has primarily residential, institutional and commercial landuse. The Vasco port and the Dabolim airport are two significant features of the city. The institutional landuse includes port and defence based landuse. The built up landcover is the most significant classification. A ward wise distribution of built-up footprint reveals wards 1 – 6 are located on a plateau shaped projection into the sea with a high coastal elevation and hosts institutional and defence-based land use. Ward 3 has the highest built-up footprint followed by ward 2, and wards 4, 5, 6 were found to have high rise residential developments. Wards 7, 8 and 9 are low elevation coastal wards adjacent to the narrow beach with ward 8 having a significant built-up density. Ward 11 – 14 are contiguous low-lying wards. Wards 20, 22, 23 towards the east of the town also exhibit dense development. (Ref. Figure 7 and Table 3)

Table 3 : Ward level Built-up footprint (based on remote sensed data)

Ward No	Total Ward Area	% of total town area	Built up footprint (%)	Ward No	Total Ward Area	% of total town area	Built up footprint (%)
1	1.0	8%	19.2%	14	0.2	1%	65.5%
2	0.2	1%	57.4%	15	1.1	9%	32.8%
3	0.1	0%	91.5%	16	0.3	3%	45.0%
4	0.5	4%	32.7%	17	0.1	1%	56.2%
5	0.9	7%	20.0%	18	2.4	19%	15.0%
6	1.2	10%	17.0%	19	0.6	5%	23.4%
7	0.2	1%	39.8%	20	0.1	1%	78.2%
8	0.1	1%	52.0%	21	0.6	5%	30.8%
9	0.3	2%	38.8%	22	0.1	1%	82.5%
10	0.1	1%	47.5%	23	0.2	2%	75.2%
11	0.2	1%	56.8%	24	0.5	4%	39.0%
12	0.5	4%	43.7%	25	0.4	3%	38.9%
13	0.5	4%	53.5%				

Source: GIS Analysis

Figure 7: Landcover and Built-up Footprint of Mormugao.



Source: Sentinel 2 10m (LULC), 2024; Open Street Map; Survey of India; Mormugao Municipal Council

Climate Profile: MMC falls under the coastal agro-climatic zone (Ref. Figure 8) within Mormugao taluka and South Goa District. Mormugao Taluk has negligible area covered under forest²¹. On average, the town receives 2,982.21 mm of annual rainfall, with a maximum temperature of 31.33°C and a minimum temperature of 24.17°C (ibid).

Figure 8: Administrative Divisions of Goa



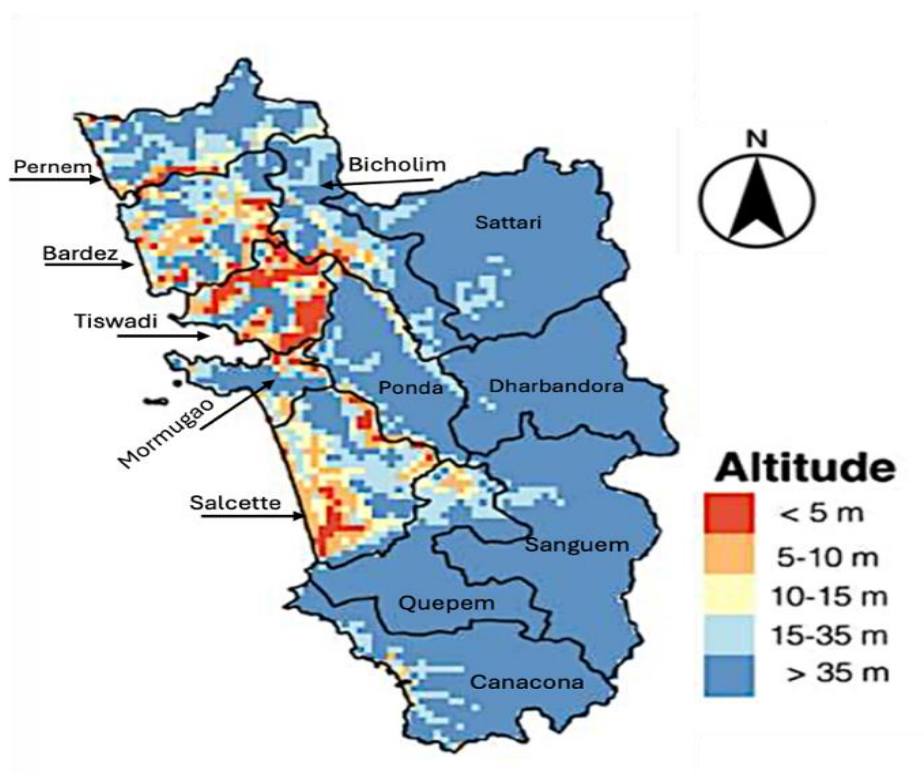
Source: Census Digital Library, 2021²²

Climate Change and Disasters: Town-level data on climate change impacts and disasters is limited; therefore, this study relies on district and taluka-level secondary data. According to NITI Aayog's Climate and Energy Dashboard, South Goa District fall within a moderate damage risk zone for wind hazards (with wind speeds reaching up to 39 m/s) and moderate cyclonic activity (featuring maximum sustained wind speeds ranging from 48 to 63 knots)²³. The coastal belt of Goa is the only area vulnerable to cyclones.

Six out of the 12 talukas in the state, including Mormugao, which includes Mormugao town, are considered highly vulnerable to cyclones, based on the severity of the impacts (Ref. Table 4). As shown in the figure 9, the 0-5 meter elevation zone is considered the most vulnerable to flooding in Goa²⁴. Consequently, Mormugao taluka is more susceptible to flood-related hazards.

For instance, the impact of cyclones like Tauktae and heavy rains received widespread media coverage, reporting widespread destruction such as uprooted trees, damaged 36 houses, and toppled electricity poles. The strong cyclonic winds tragically resulted in the loss of two lives. In certain areas, intense rainfall and gusty winds led to severe waterlogging, causing significant damage to both public and private property ^{25,26,27}.

Figure 9 : Flood Vulnerability of Taluka of Goa



Source: (NABCONS, 2023)

Mormugao taluka has a relatively low vulnerability to flood severity, refer table given below.

Table 4: Multi-hazard vulnerability (level of severity) in Mormugao taluka of Goa

Taluk	Cyclone	Floods	Drought	Landslides	Soil Erosion
Mormugao	High	Low	Low	Low	Low

Source: (Goa State Disaster Management Authority, 2024)²⁸

During our fieldwork in the town, we identified low-lying areas, which are frequently prone to flooding and waterlogging during the monsoon season. However, as outlined in the State Disaster Management Plan, flooding in Goa is not solely caused by intense rainfall events. It is further exacerbated by unregulated urban expansion, insufficient maintenance of natural water storage systems (such as tanks), and poor management of drainage infrastructure, particularly within municipal areas. These factors collectively amplify the destructive potential of increasing flood hazards (Goa State Disaster Management Authority, 2024, pp. 71-72)²⁸. This appears to be a recurring issue, as media reports highlight frequent blockages in the drainage network, leading to urban flooding during monsoons in almost all areas of the Mormugao town^{29,30}.

Mormugao town and Taluk are particularly vulnerable to disasters and climate change-induced extreme weather events due to their high population density and substantial slum population. Slum communities often have limited coping capacities, making them more susceptible to the impacts of climate change²⁴. In the event of sea-level rise, densely populated areas, particularly in coastal talukas like Mormugao, would face significant challenges. Notably, Mormugao taluka is home to 10% of Goa's population and has the highest population density in the state. In addition to being densely populated, Mormugao is a major tourist destination, which has led to a marked increase in water demand and greater exploitation of groundwater resources (NABCONS, 2023, pp. 102-103)²⁴. The region has also experienced coastal erosion, posing a direct threat to local livelihoods, the tourism industry, and the area's overall resilience to climate change.

NOTES & REFERENCES

- ²¹ International Institute For Population Sciences And ICF. (2021). National Family Health Survey (NFHS-5)-India (2019-20). Ministry Of Health And Family Welfare. Mumbai: IIPS.
- ²² Census Digital Library. (2021, January 16). Administrative Division Map of Goa (Census - 2011). Retrieved 2025, from Office of the Registrar General & Census Commissioner, India Ministry of Home Affairs, Government of India: <https://censusindia.gov.in/nada/index.php/catalog/1376>
- ²³ Niti Aayog. (2025, January 1). Natural Disasters In India. Retrieved from India Climate and Energy Dashboard: <https://iced.niti.gov.in/state-report/karnataka>
- ²⁴ NABCONS. (2023). State Action Plan For Climate Change - For the State of Goa -From 2023 - 2033. Panaji: Goa State Biodiversity Board.
- ²⁵ O Herlado. 2021. Cyclone Tauktae Renders Heavy Blow To Mormugao Taluka. 18 May 2021. <https://www.heraldgoa.in/Goa/Voice-Of-Southgoa/Cyclone-Tauktae-Renders-Heavy-Blow-To-Mormugao-Taluka/175010>. Accessed On 16th March 2025
- ²⁶ Asian Lite. 2021. 2 Killed As Cyclone Tauktae Batters Goa. 17 May 2021. <https://asianlite.com/2021/India-News/Goa/2-Killed-As-Cyclone-Tauktae-Batters-Goa/>. Accessed On 17th March 2025
- ²⁷ The New Indian Express. 2021. Cyclone Tauktae: Two Dead InGoa; Houses Damaged, Highways Blocked Due To Gusty Wind. 17 May 2021. <https://www.newindianexpress.com/Nation/2021/May/16/Cyclone-Tauktae-Two-Dead-in-Goa-houses-damaged-highways-blocked-due-to-gusty-wind-2303339.html>. Accessed On 16th March 2025
- ²⁸ Goa State Disaster Management Authority. (2024). State Disaster Management Plan-2024. Porvorim: Government of Goa.
- ²⁹ Times Of India. 2024. New Vaddem Houses Flooded Again. 12 May 2024. <https://timesofindia.indiatimes.com/City/Goa/New-Vaddem-Homes-Flooded-Again/ArticleShow/110042482.Cms>. Accessed On 16th March 2025
- ³⁰ O Herlado. Rainfall Hits Goa: Mormugao Tops With 68.2mm. 2024. 20 May 2024. <https://www.heraldgoa.in/News-Today/Rainfall-Hits-Goa-Mormugao-Tops-With-682mm/221592>. Accessed On 16th March 2025

3. STATUS OF WATER INFRASTRUCTURE AND SERVICES

ASHISH DANGI³¹ AND NC NARAYANAN

This chapter provides a situational assessment of Mormugao's water sector, mapping the town's existing infrastructure from source to consumer. By analysing the systemic challenges along with emerging climate risks, the chapter uncovers the structural and environmental pressures that define the town's current water security landscape.

Mormugao is a distinctive peninsula, bordered on three sides by water (Ref. Figure 10). To the west and south lies the Arabian Sea, while to the north, it is bordered by the tidal Zuari–Mandovi estuarine network which is dense with mangroves and supporting rich coastal biodiversity. Its peninsular geography feeds into a layered groundwater system. Upland lateritic plateaus support shallow phreatic aquifers, while coastal zones sit atop alluvial and estuarine aquifers, especially near the tidal channels. Deeper fractured rock aquifers are found further inland.

Figure 10: Geographical setting of Mormugao Municipal council Area.



Image Source: Municipal boundary of Mormugao plotted in Google Earth

Mormugao is a distinctive peninsula, bordered on three sides by water (Ref. Figure 4). To the west and south lies the Arabian Sea, while to the north, it is bordered by the tidal Zuari–Mandovi estuarine network which is dense with mangroves and supporting rich coastal biodiversity. Its peninsular geography feeds into a layered groundwater system. Upland lateritic plateaus support shallow phreatic aquifers, while coastal zones sit atop alluvial and estuarine aquifers, especially near the tidal channels. Deeper fractured rock aquifers are found further inland.

This hydrological complexity, shaped by Mormugao’s peninsular setting and estuarine ecology, underscores both its rich water resources and high vulnerability, particularly to saline intrusion during dry periods, seasonal variability in recharge, and pollution risks to mangroves and estuarine waters from urban runoff, untreated sewage, and port-related industrial activities. The sensitive balance between freshwater and saline flows, essential to the health of mangroves and aquifers alike, is increasingly threatened under pressure from urbanisation and climate change.

3.1 SURFACE WATER SOURCES

The Salaulim Dam, located near Sanguem town in South Goa, serves as the primary surface water source for Mormugao and much of South Goa. Constructed across the Salaulim River, a tributary of the Zuari River, it is a central component of the Salaulim Irrigation Project, which now serves both irrigation and urban-industrial water supply functions (Figure 11).

Figure 11: Salaulim spillway dam, Kudri, Goa

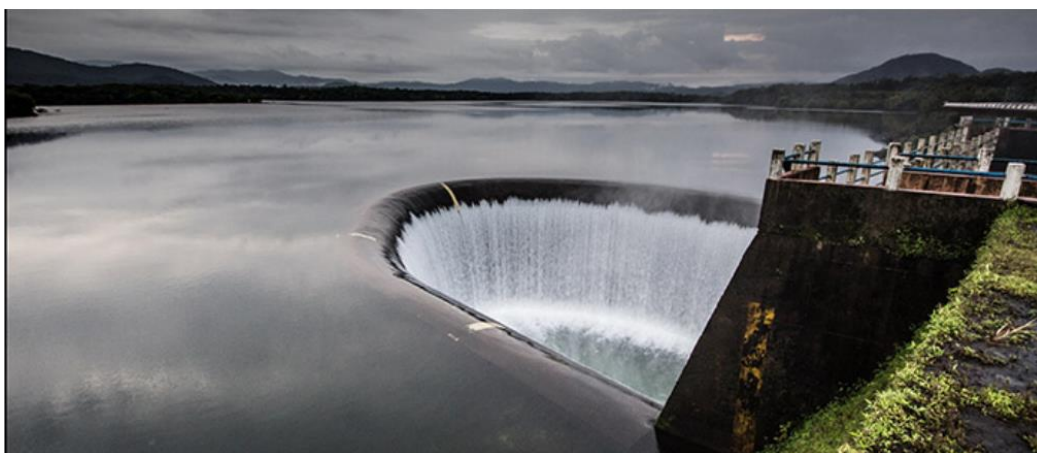


Image Source: Goa Water Resource Department

The dam currently supplies up to *380 million liters per day (MLD)*, meeting domestic and industrial water needs for approximately *70% of South Goa's population*, while also irrigating over 9,500 hectares in the talukas of Sanguem, Salcete, and Quepem. Structurally, it is a composite earth-cum-masonry dam with a height of 42.7 meters, length of 1,003 meters, and gross storage capacity of 234.36 million cubic meters. Its construction came with significant trade-offs submerging 2,964 hectares, including 706 hectares of forest and 1,240 hectares of cultivated land, displacing 643 families across nine villages. Cultural heritage sites such as centuries-old temples and sculptures were relocated as part of the project. Despite these social and ecological costs, the dam has evolved into a regional lifeline, not only securing water supply and irrigation but also supporting fisheries, local livelihoods, and ecotourism. Its duckbill spillway and adjacent botanical gardens have made it a popular tourist attraction.

The catchment area of the dam, spanning approximately 209–227 km², lies in the ecologically sensitive Western Ghats. It includes three key watersheds: Guleli, Kumbhari Nala, and Curpem, characterized by steep terrain (150–500 m elevation), dense forests (68.5%), and high drainage density. Other land uses include agriculture (10%), plantations (8.3%), and mining-related zones (13.2%)³².

While active mining operations have ceased, the presence of abandoned and old mines, particularly in the Curpem watershed, poses ongoing risks. These include non-point source pollution, sediment runoff, and potential groundwater contamination, particularly during the monsoon season.

Climatically, the catchment experiences a humid tropical climate, with temperatures ranging from 20°C to 36°C and relative humidity reaching 90–95% during the monsoon. The monsoon season (June–September) brings intense rainfall, with the catchment receiving over 3,600 mm annually. This seasonal deluge is vital for recharging aquifers, sustaining reservoir levels, and maintaining freshwater flows.

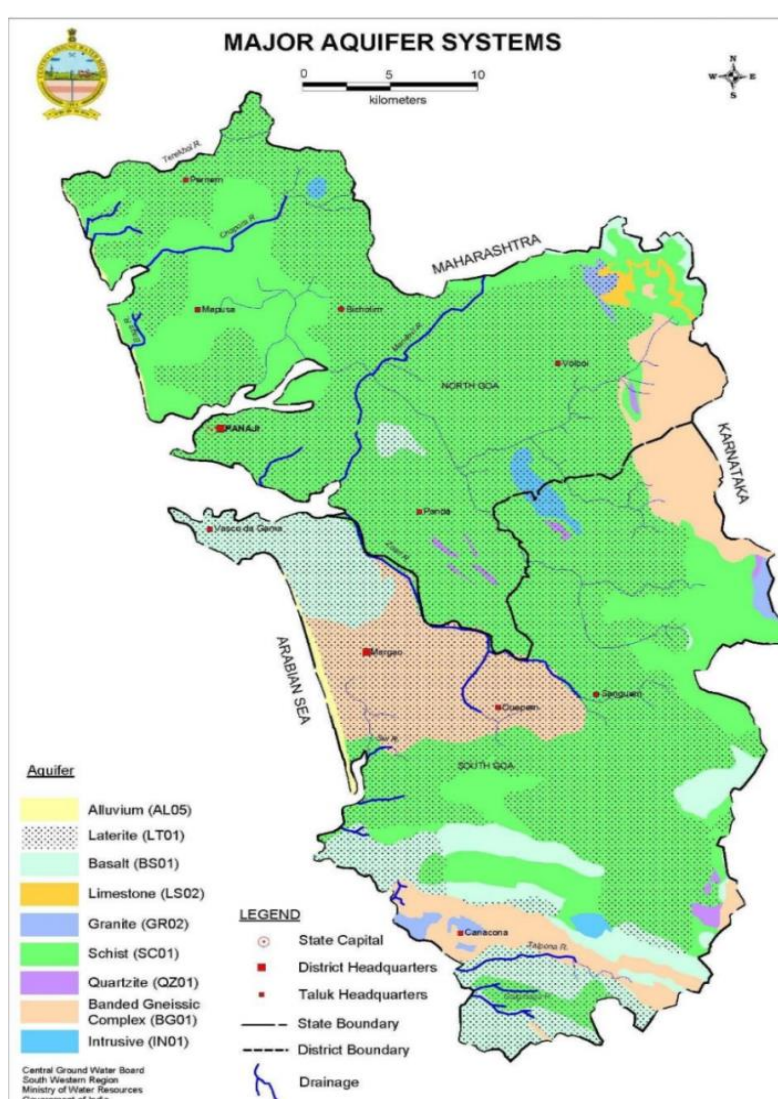
The reliance on monsoonal inflows increases the dam's climate sensitivity, raising concerns over inter-seasonal water security, and the resilience of water infrastructure under a changing climate. While the dam remains a critical water source, emerging pressures including legacy mining impacts, sedimentation, and seasonal variability, underscore the importance of proactive catchment protection to ensure sustainability of this vital source.

3.2 GROUNDWATER

In Mormugao, as in much of Goa, the groundwater system is characterised by a **layered geological profile** where **laterite formations** commonly overlie **basaltic bedrock** (Figure 12). Laterite, a highly weathered and porous rock rich in iron and aluminium, forms under hot and humid tropical conditions through the prolonged chemical weathering of underlying Deccan basalt. Hydrogeologically, the laterite functions as a phreatic aquifer, storing and transmitting water but with limited retention during dry seasons. In contrast, the underlying fractured or weathered basalt serves as a confined aquifer, offering more dependable groundwater

reserves if appropriately tapped. Additionally, Mormagao's coastal geography supports the presence of saline and brackish aquifers, particularly in areas close to estuaries, creeks, and the coastline. These aquifers are highly vulnerable to saline intrusion, especially during dry seasons or under excessive groundwater extraction. According to the Central Ground Water Board (CGWB), to protect freshwater quality in such low-lying coastal areas, it is recommended to maintain a minimum distance of 0.5 km from creeks and at least 400 m from the coastline when siting wells.

Figure 12: Principle aquifer systems in Goa.



Source: Central Ground Water Board³³

As per Figure 12, the principle aquifer systems in Mormugao region are:

1. **Laterites:** These are the dominant shallow aquifers, occurring both as in-situ layers on plateaus and as detrital deposits in valleys. These formations are highly porous and fractured, enabling moderate groundwater storage. Water occurs under phreatic conditions, with water levels ranging from 1.3 to 19 mbgl. The thickness of laterite extends up to 40 meters, with dug wells typically tapping depths of 3–20 meters.
2. **Basalt & Metabasalt:** These are found beneath the laterite layer, form confined to semi-confined systems. Groundwater is stored in the weathered mantle (10–20 m) and fractured zones (20–45 mbgl). Depth to water ranges from 1.8 to 18.9 mbgl, with borewell discharges varying widely depending on fracture connectivity.

Table 5: District wise Distribution and Characteristics of Basalt & Metabasalt Aquifer Systems

District Name	Major Aquifers (Area in Sq.km.)	Aquifer Properties							
	Basic -Basalt	Aquifer System	Type of Aquifer	Thickness of Weathered Zone	DTWL (Dec.Avg)	Fractures encountered	Transmissivity	Yield	S
	BS01			m	mbgl	m bgl	m ² /day	m ³ /day	Quality (EC in µS/cm)
North Goa	13	Single	Semi-confined / Confined	NA	-	NA	NA	NA	NA
South Goa	318	Single	Semi-confined / Confined	10-20	1.79-18.88	20-45	1-232	15-850	1X10 ³⁻⁵
Total	331	Single	Semi-confined / Confined	10-20	1.79-18.88	20-45	1-232	15-850	1X10³⁻⁵

Hilly Area is not included in the Aquifer Category, NA- Not Available

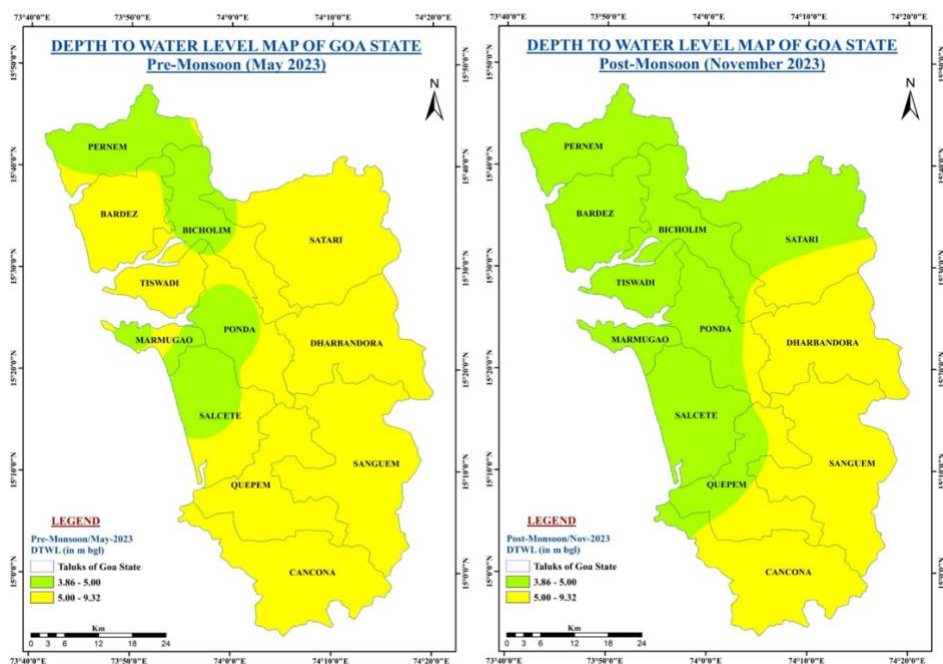
Source: Central Ground Water Board³³

Depth to Water Level:

The depth to water level ranges between 3.86-5 metres below ground level (mbgl) pre-monsoon (May 2023) in most areas except for in the higher elevation regions on the western tip of the peninsula as well as on the eastern boundary of the city where it ranges from 5-9.32 mbgl. The aquifers get significantly recharged during monsoon with depths decreasing within a range of 3.86-5 post monsoon (Nov 2023). (See figure 13)

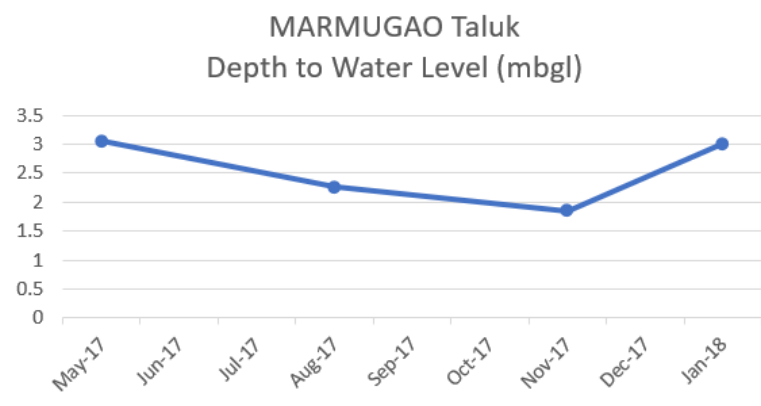
The seasonal variation in groundwater levels in Mormugao Taluk shows a clear dependence on monsoonal recharge. As shown in Figure 14, in May 2017 just before the onset of the southwest monsoon, the water table was at its lowest, with depths reaching approximately 3.0 meters below ground level (mbgl). As the monsoon progressed, the depth to water level steadily decreased, reaching its shallowest point (~1.7 mbgl) in November 2017, indicating significant recharge from rainfall. However, post-monsoon, the water levels began to decline again, returning to around 3.0 mbgl by January 2018. This sharp drop within two months highlights the limited retention capacity of the aquifers or high seasonal extraction, especially during the dry months. The pattern underscores the critical reliance on monsoon rainfall for groundwater sustainability and the need for improved recharge interventions and demand-side management to ensure year-round water security.

Figure 13: Pre monsoon(May 2023) and Post Monsoon (Nov 2023) Depth to Water Leveling Mormugao Taluk.



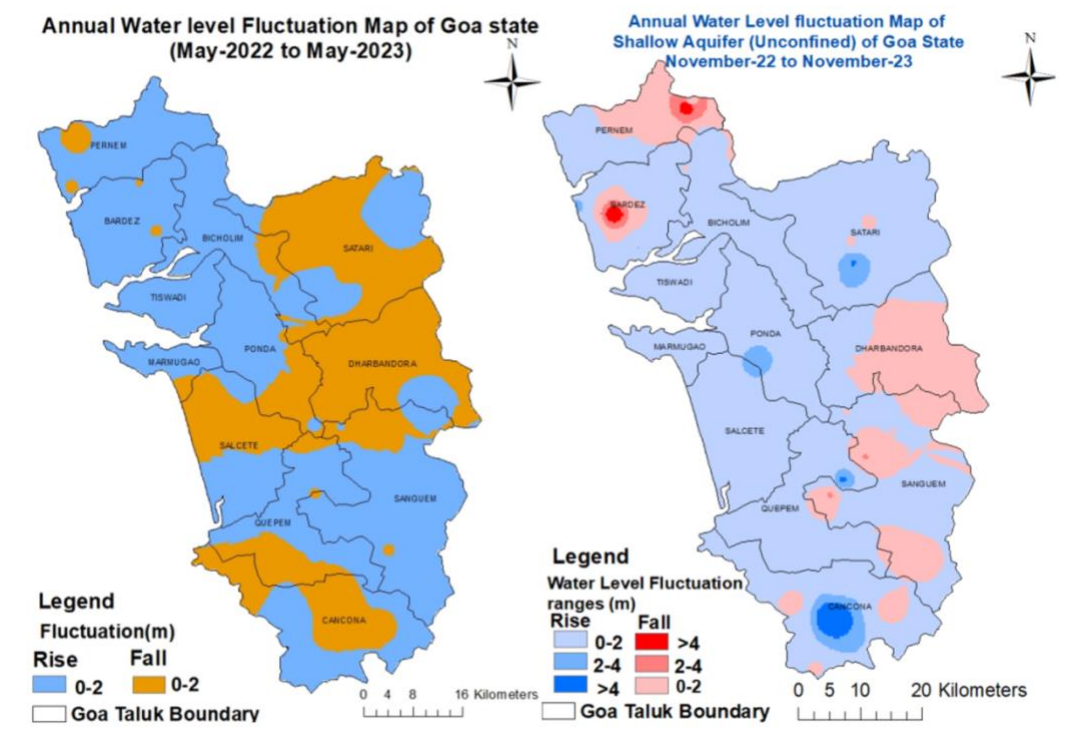
Source: Water Resource Department, Government of Goa & Central Ground Water Board³⁴.

Figure 14: Seasonal variation in groundwater levels in Mormugao Taluk (2017-18)



Source: Ground Water Year Book Goa State 2017-18, CGWB³⁵

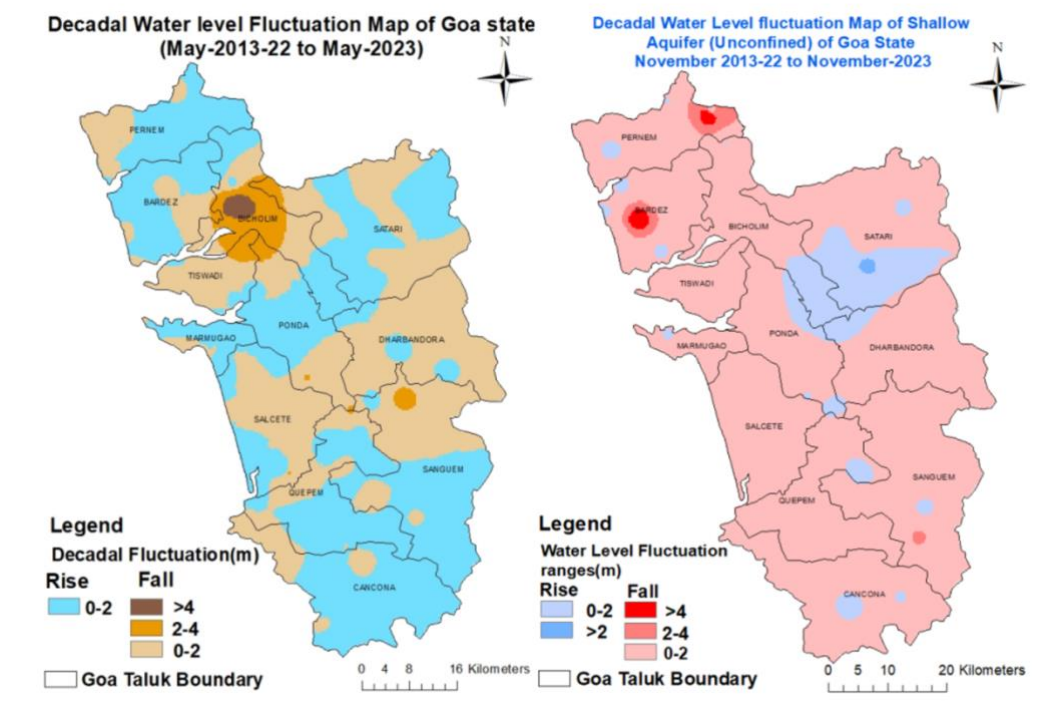
Figure 15: Groundwater Level Fluctuations (Shallow Aquifer): Pre-monsoon (May 2022 to May 2023) & Post-monsoon (Nov 2022 to Nov 2023)



Source: Water Resource Department, Government of Goa & Central Ground Water Board³⁴.

Groundwater level fluctuations in the shallow aquifers of Mormugao indicate both short-term and long-term trends that have implications for water resource sustainability in the region as showing in Figure 15. Between May 2022 and May 2023 (pre-monsoon), and again from November 2022 to November 2023 (post-monsoon), water levels showed a rise of 0–2 meters, suggesting positive recharge. The rise is likely due to increased rainfall and/or reduced extraction. However, a decadal analysis (2013 to 2023) reveals a more nuanced picture (Figure 16). While most of the taluka experienced a rise of 0–2 meters in pre-monsoon shallow water levels, a localized decline was observed in the southern part of the Mormugao block, pointing to possible over-extraction or urban stress in these zones. Post-monsoon levels across the taluka show a fall of 0–2 meters, indicating reduced retention or increased drawdown after monsoon recharge, possibly due to increased draft or reduced percolation linked to urbanization. These patterns underscore the need for localized groundwater management, particularly in urbanized pockets where aquifer stress may be masked by broader district-level “safe” categorizations.

Figure 16: Decadal water Level Fluctuations (Shallow Aquifer): Pre-monsoon (May 2013 to May 2023) & Post-monsoon (Nov 2013 to Nov 2023)



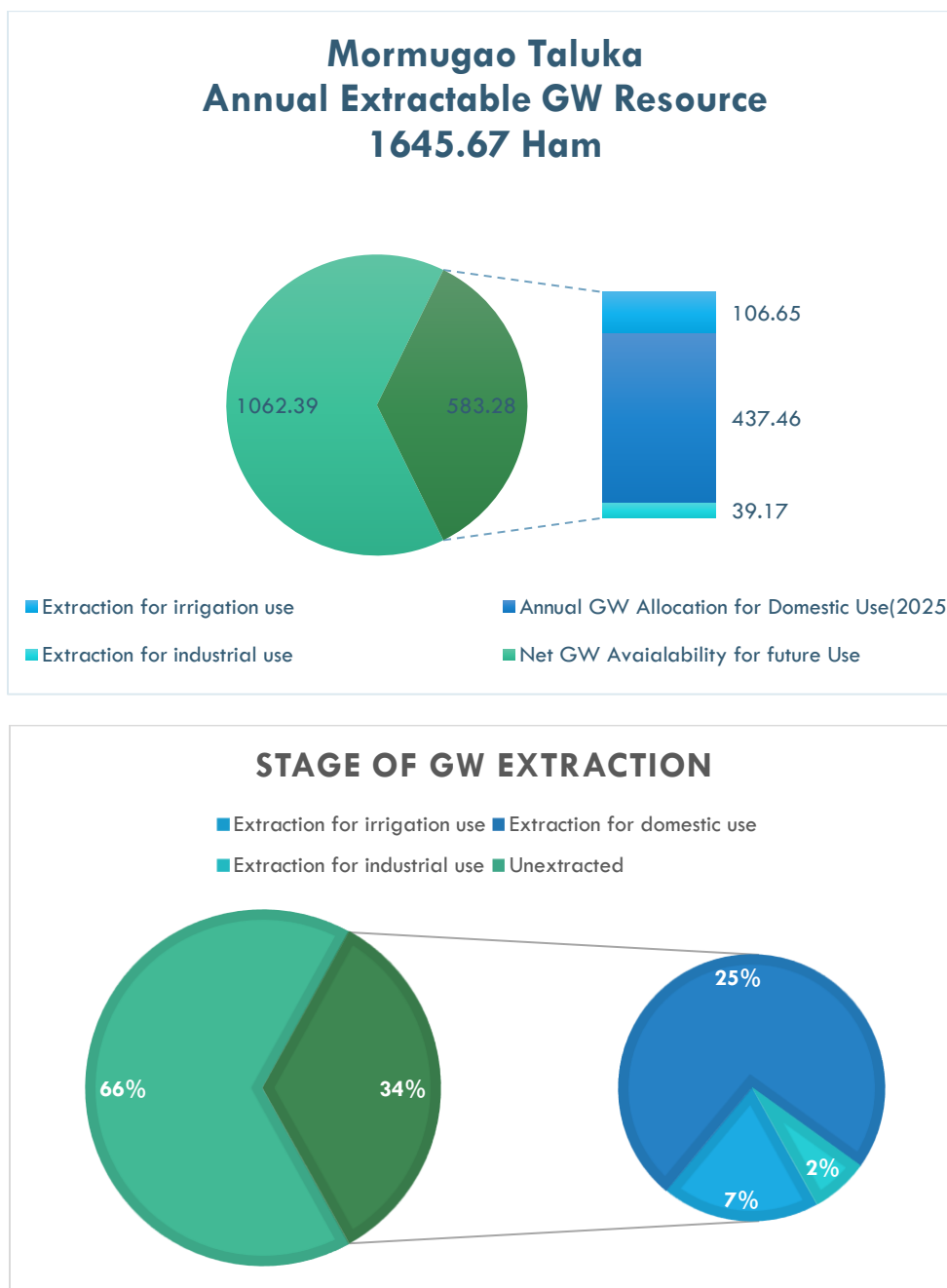
Source: Water Resource Department, Government of Goa & Central Ground Water Board³⁴.

Ground Water Resource Estimation for Mormugao Block:

Groundwater extraction in Mormugao reflects a growing and potentially unsustainable dependence on subterranean sources, especially for domestic use. As shown in the extraction profile (Ref. Figure 17), **74% of the extracted groundwater is for domestic purposes**, followed by **20% for irrigation**, and **6% for industrial use**. This highlights the critical role of groundwater in meeting everyday needs, especially in areas underserved by piped surface water supply. Mormugao block was categorised as 'safe' by CGWB with about 34% of annual extractable ground water being drawn in 2022.

A recent assessments shows that **extraction in Goa has increased by 65% over the past 12 years**, rising from 4,114 hectare-metres (ham) in 2011 to 6,775 ham in 2023³⁶. While Goa as a whole remains in the 'safe' category with a groundwater development stage of 21.3%, **Mormugao and Bardez talukas exhibit the highest extraction levels relative to their availability**, signalling **localised groundwater stress**.

Figure 17: Ground Water Resource Assessment (2022) for Mormugao Block



Source: Water Resource Department, Government of Goa & Central Ground Water Board³⁴

In Mormugao specifically, the groundwater availability for future use is the lowest among all talukas at just **1,021.7 ham** (2023), indicating limited buffer capacity to absorb further extraction increases. The rise in use is linked to an **increase in abstraction structures**, such as

borewells, and growing **urban demand**, particularly in **peri-urban areas and slums**, where dependence on private borewells and tankers is high due to limited municipal coverage.

Additionally, **climate variability** in the form of erratic monsoons and rising temperatures poses a serious threat to recharge rates. This is further compounded in **coastal and low-lying zones** by **saline and brackish aquifers**, which are highly vulnerable to seawater intrusion, especially during dry months.

Overall, while the categorization may suggest low groundwater stress, **Mormugao's specific context reveals a much more vulnerable picture**, demanding urgent attention to **demand management, source protection, and aquifer recharge interventions** to ensure long-term water security.

3.3 WATER INFRASTRUCTURE

Traditional Groundwater Systems: Dug Wells

Before the advent of piped supply systems, dug wells formed the cornerstone of domestic and agricultural water access in Mormugao and broader South Goa. Typically carved into laterite rock, these wells tapped shallow phreatic aquifers replenished by monsoon rains and local springs. Known for their cultural and functional importance, community wells locally called “*dha zannachibaim*” were larger and shared by multiple households.

Water drawn from wells was usually sweeter near hilly terrain and saline closer to the coast, reflecting the influence of geology and proximity to the Arabian Sea. Traditional water-drawing methods used coconut coir ropes (*razu*) and earthen or copper pots, with seasonal community-led cleaning using salt or potassium permanganate.

Despite increased piped coverage, dug wells continue to be used in some localities, especially during supply interruptions. However, many have fallen into disrepair or been decommissioned due to urbanization, contamination risks, and growing reliance on modern systems.

Shift to Borewells

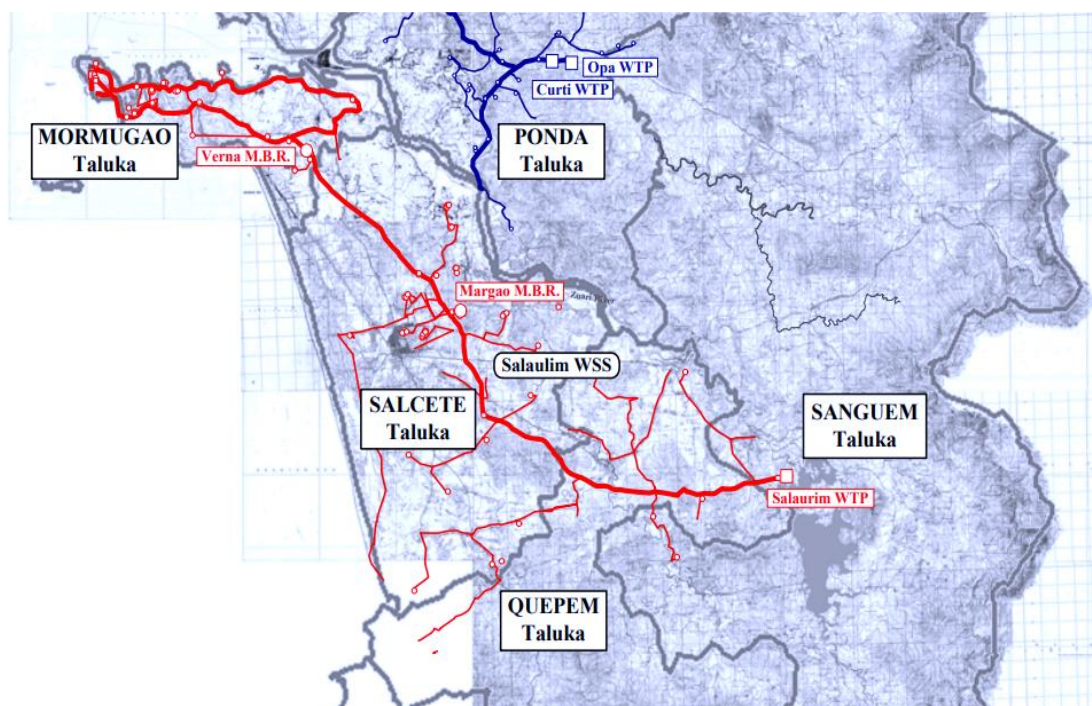
Over the past two decades, Mormugao has witnessed a rapid increase in borewell installations driven by rising demand, unreliable municipal supply in some zones, and increased construction. According to data from the Goa Water Resources Department (WRD), over 962 borewells are currently registered across the state, with **Mormugao recording the highest number of both new and illegal borewells**. Since 2020, 36 new borewells have been approved in the constituency, while 28 illegal borewells have been identified, often constructed without prior permission from WRD³⁷. Many of these unauthorized structures have emerged in response to growing water demand in urbanizing localities such as Vasco and

Dabolim, where supply gaps are increasingly filled by private or commercial groundwater extraction. Enforcement remains a challenge while 70 illegal borewells have been sealed and fines imposed under the Goa Ground Water Regulation Act (2002), the persistent growth of unauthorized drilling points to weak monitoring and governance frameworks. The pressure on groundwater in such areas not only exacerbates over-extraction and saline intrusion risks but also undermines efforts toward equitable and sustainable water supply management in Mormugao.

The Salaulim Water Supply Scheme (WSS):

Today, Mormugao's primary source of piped water is the Salaulim Water Supply Scheme (WSS), a major regional infrastructure project that supplies treated water to Mormugao, Salcete, Quepem, and Sanguem talukas servicing over **110,000 metered connections** (as of March 2024, PWD). Commissioned in **1989**, the scheme draws water from the Salaulim Dam and has undergone subsequent upgrades to meet growing demand.

Figure 18: Coverage of the Salaulim Water Supply Scheme.



Source: Public Works Department, Works Division – XII, Sub-Division-IV

Water Treatment Plant (WTP):

Located adjacent to Salaulim Dam in Sanguem. (Figure 19)

Design capacity: 160 MLD, with peak output reaching 170 MLD.

Figure 19: Location of Salaulim dam and Water treatment plant on a hillock.



Source: Google earth satellite imagery

The schematic (Ref. Figure 20) reveals a conventional treatment sequence with multiple clarifiers, filters, and chemical dosing units arranged to ensure high-quality water output.

Raw Water Intake and Conveyance

- Source: Raw water is drawn from Salaulim Dam Intake located 1 km from WTP.
- Intake Infrastructure: A jackwell/pump house with 4 pumps × 2 lines lifts water.
- Transmission: Water is conveyed to the WTP via 1000 mm diameter mild steel rising mains.

Pre-Treatment and Chemical Dosing

- Aeration Units: Each line passes through an aerator to improve oxygen levels and remove volatile compounds.
- Parshall Flumes: Used for flow measurement and flow regulation.
- Flash Mixers (RL 119.00 m): For rapid mixing of coagulants with raw water.
- Alum & Lime Dosing: Chemical dosing is done post-aeration and before sedimentation to facilitate coagulation and pH control.

Clarification and Flocculation

- The plant includes:
 - 4 units of 40 MLD clarifiers for a total of 160 MLD.
 - Each clarification unit includes flocculation chambers (RL 118.50 m) to promote aggregation of suspended particles before settling.
- Water from clarifiers flows to the filtration units.

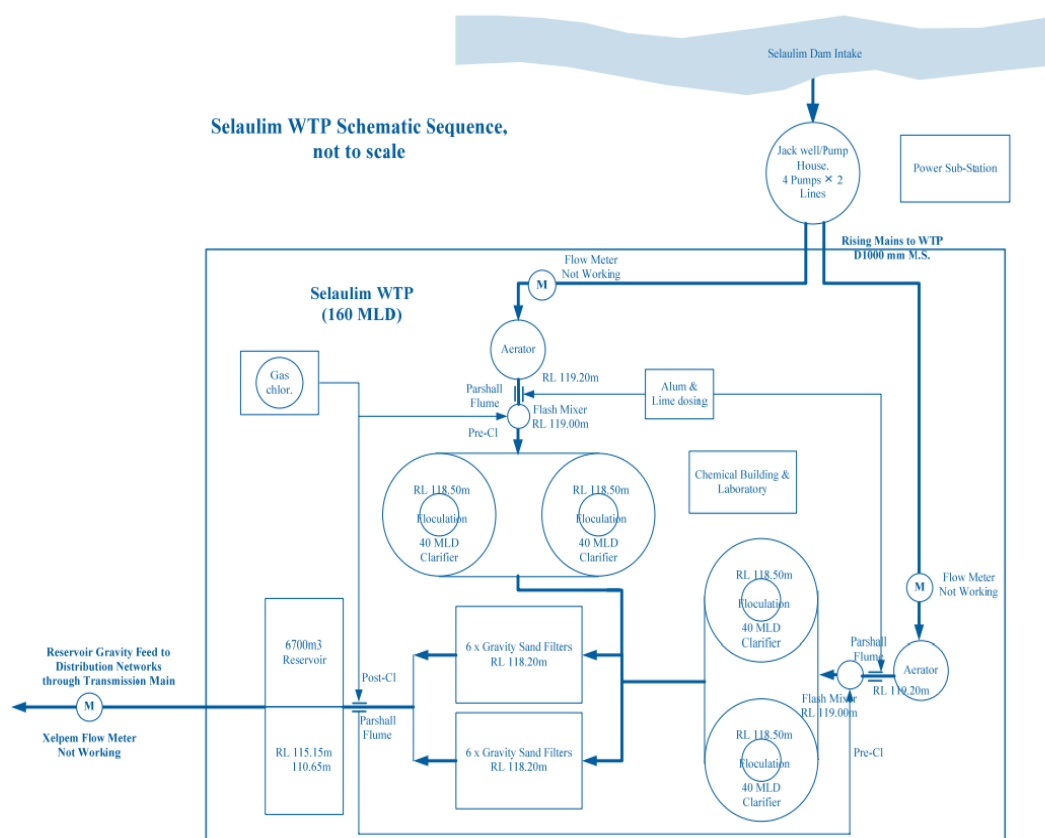
Filtration

- The clarified water is directed to 12 gravity sand filters arranged in two banks of six.
- Each filter is located at RL 118.20 m, indicating a gravity-driven process.
- Filters remove remaining suspended solids and microorganisms.

Post-Treatment and Disinfection

After filtration, water passes through a Post-Chlorination Unit (Post-Cl) for final disinfection and finally into a 6700 m³ treated water reservoir (storage levels from RL 115.15 m to 110.65 m) for distribution.

Figure 20: Schematic drawing of the Water Supply Network showing key infrastructure

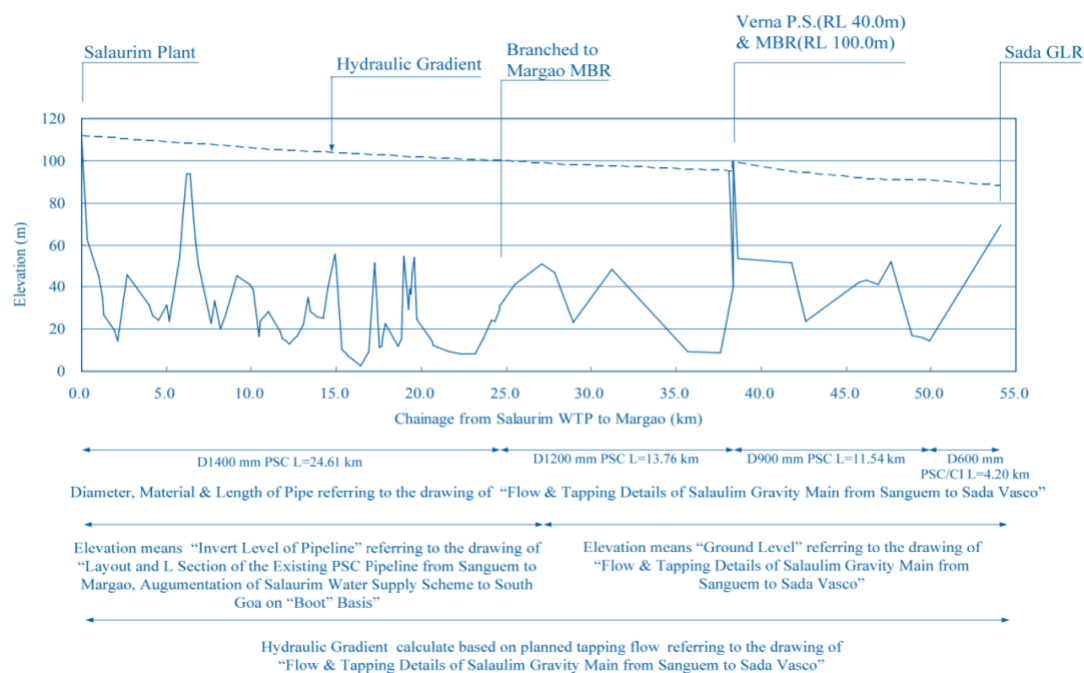


Source: Public Works Department, Works Division – XII, Sub-Division-IV

Transmission:

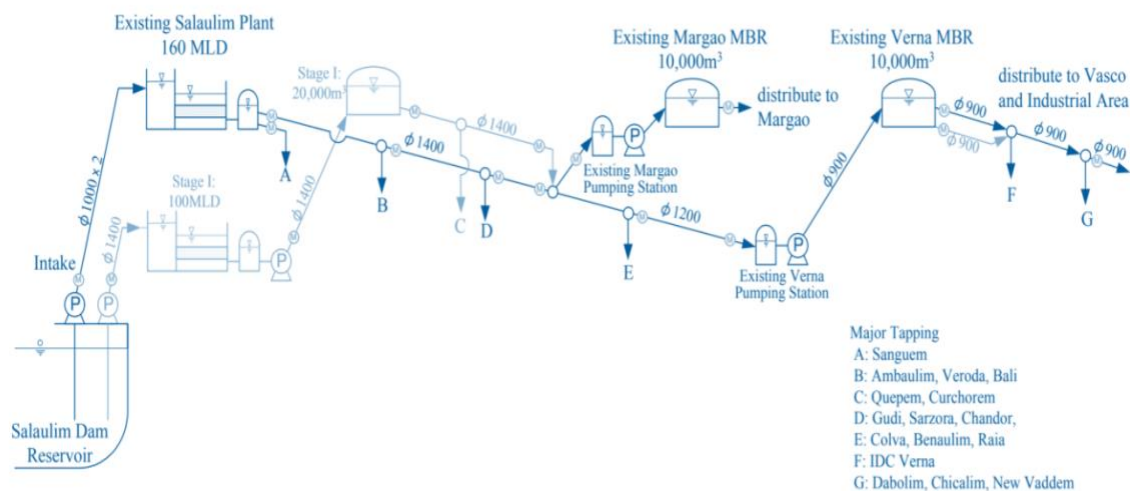
The transmission system from the Salaulim 160 MLD WTP to Sada Vasco operates primarily through gravity, leveraging the region's natural elevation profile (Figure 21). Spanning approximately 55 km, the pipeline transitions through varying diameters, from 1400 mm to 600 mm, using prestressed concrete and cast iron to manage flow and pressure. The hydraulic gradient, maintained above the ground elevation throughout, ensures consistent gravity-fed flow with minimal pumping, except at key locations like the Verna Pumping Station. Branching points, such as the one leading to the Margao Master Balancing Reservoir, support distribution across multiple zones. This elevation-sensitive design allows for efficient water conveyance across undulating terrain while minimizing energy use.

Figure 21: Longitudinal section of the Salaulim Gravity Main Transmission System from WTP in Sanguem to Sada Vasco.



Source: Public Works Department, Works Division – XII, Sub-Division-IV

Figure 22: Schematic of transmission system of the Salaulim Water Supply Scheme



Source: Public Works Department, Works Division – XII, Sub-Division-IV

As shown in Figure 22, the clear water from the 160 MLD WTP is conveyed approximately 36 km to the Verna Pumping station using gravity. Water is then pumped to the Verna Master Balancing Reservoir (MBR) of capacity 10,000 m³. From there water is once again conveyed through gravity to the Vasco/Murmagao area for further distribution.

The pipeline is composed of Prestressed Concrete (PSC) and Cast Iron (CI) segments of varying diameters and lengths:

- D1400 mm PSC – 24.61 km (from Salaulim to ~25 km)
- D1200 mm PSC – 13.76 km
- D900 mm PSC – 11.54 km
- D600 mm PSC/CI – 4.20 km (final stretch to Sada)

The decreasing diameters help regulate flow velocity and pressure as demand tap-offs reduce the total volume downstream.

The scheme's capacity was expanded by an additional 100 MLD under the Goa Water Supply and Sewerage Project, supported by the Japan Bank for International Cooperation (JBIC). This upgrade was critical in ensuring that the scheme could meet future water demand across the rapidly urbanizing coastal belt. The expansions added a new 100 MLD WTP and a 20,000 m³, MBR at Sirvoi rock hill. It also added a new transmission main along the existing one, total length of 26.7 km DI pipe of 1400 mm diameter from new WTP to Margao. A new section of 0.85 km 900 mm diameter DI main was also installed between Verna MBR and the tapping point to IDC Verna. Rehabilitation of 13.8 km of existing transmission mains (Dia 1200 mm from Margao to Verna PS) and replacement of 4 units of Pumping Equipment at Verna Pumping Station was also completed under the expansion project.

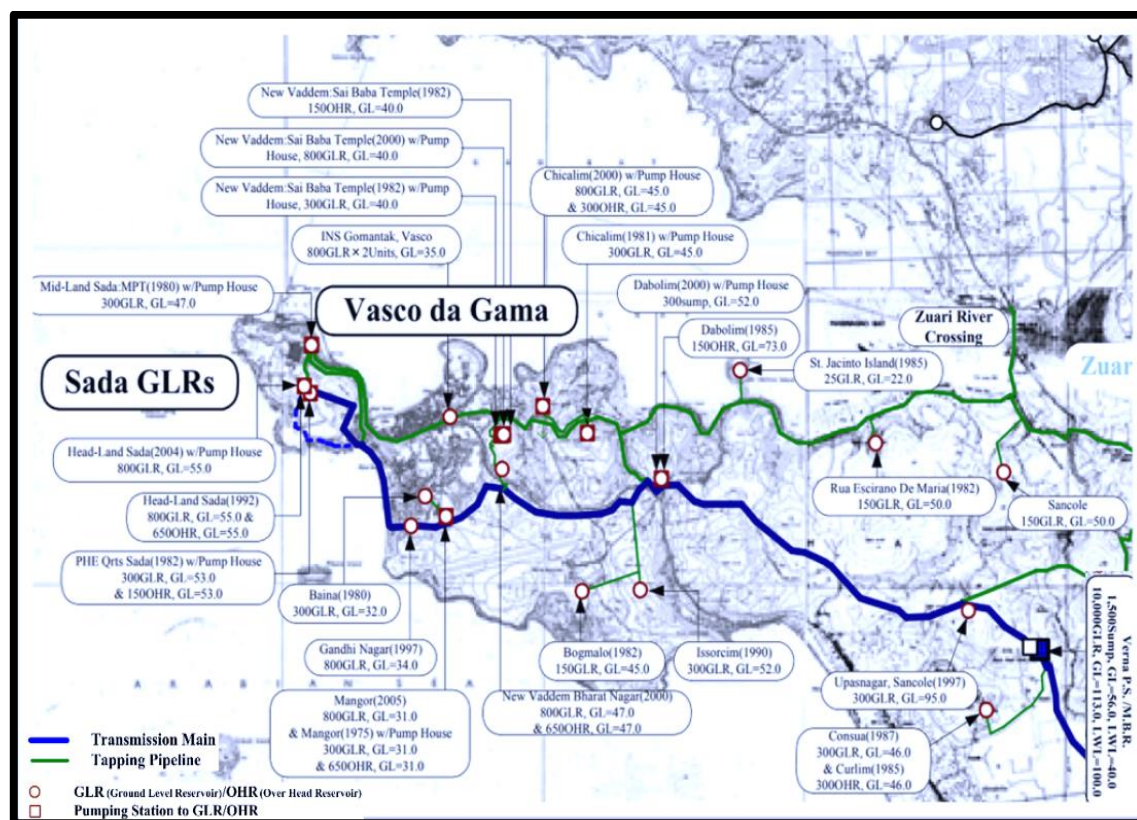
The replacement of existing Transmission Main ϕ 1400 ~ 25 km from Salaulim 160 MLD WTP to Margao is currently ongoing under Stage II expansion of the scheme.

Distribution system:

The distribution system for Mormugao and surrounding areas operates through a network of GLSRs and ELSRs which act as intermediate storage and pressure-balancing structures. As illustrated in the system layout (Ref. Figure 20), water from the main transmission pipelines is tapped into these reservoirs, either by gravity or via booster pumps depending on the elevation and pressure requirements. Higher elevation areas or zones located farther from

the transmission mains typically require pumping to ensure adequate supply, while low-lying areas can be served through gravity flow.

Figure 23: Distribution network for water supply in Murmagao / Vasco zone.



Source: Public Works Department, Works Division – XII, Sub-Division-IV

3.4 WATER DEMAND & SUPPLY

Mormugao Municipal Council (MMC) has a population of 94393 spread across 21524 households as per census 2011. In the absence of recent census data, we use standard population projection methods to estimate current population and consequently, the water demand. The estimated water demand based on projected population (Annexxure-III) for the town is shown in [Table 6](#).

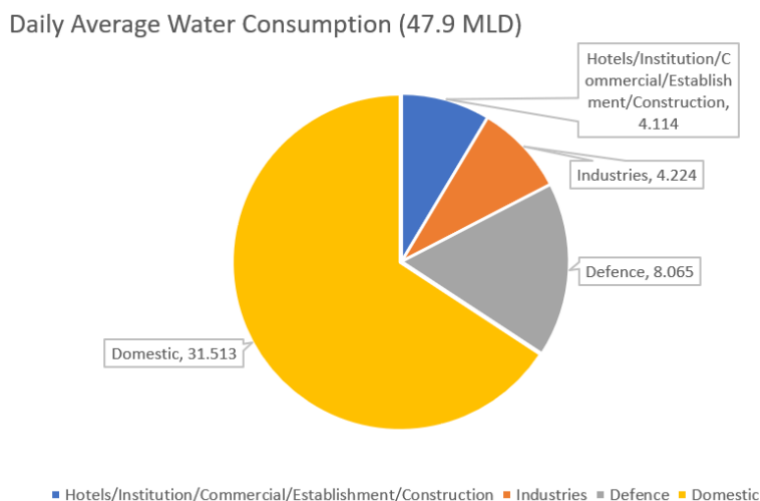
Table 6 : Population Projections

	2025	2031	2041	2051
Estimated Population**	97249	96081	91084	82303
Domestic Demand ¹	13.1	13.0	12.3	11.1
Floating Population Demand ²	0.44	0.43	0.41	0.37
Commercial Demand ³	1.31	1.39	1.54	1.70
Institutional Demand ⁴	1.31	1.31	1.31	1.31
Fire Demand ⁵	0.03	0.03	0.03	0.03
Defence Establishments⁶	8	8	8	8
Industries⁶	4.2	4.2	4.2	4.2
Total Demand (MLD)	28.4	28.3	27.8	26.7
¹ Estimated at 135 liters per capita / day (lpcd) ² Floating population assumed to be 10 % of population and demand estimated @ 45 lpcd. ³ Commercial demand estimated @ 10 % of domestic demand growing @1% / year as per CPHEEO (2024) ⁴ Water demand by institutions estimated @ 10 % of domestic demand. ⁵ Fire demand = $100 \sqrt{P}$ m ³ /day where P is the population. (CPHEEO 2024) ⁶ Demand by defence establishments and industries in the area is based on actual consumption data provided by the operator -PWD DIV IX. ** While we maintain strong reservations about the capacity of static models to capture the highly fluid realities of coastal growth, we employ this averaged methodology primarily out of pragmatic necessity: it is the established industry standard for Detailed Project Reports (DPRs) for WaSH projects, ensuring our analysis remains interoperable with existing municipal frameworks and policy planning.				

The water consumption statement provided by PWD Division IX for the Vasco-zone (Mormugao Taluka) water supply for the year 2023-2024 indicates 27994 water meter connections given to individuals. The category wise daily average water consumption is shown in Figure 24.

PWD Division IX oversees the water supply for the Vasco zone, which includes the entire Mormugao Taluka. For the year 2023–2024, the division recorded 27,994 metered water connections across all categories. While disaggregated supply data specific to MMC is unavailable, the information still offers useful insights into coverage and consumption patterns.

Figure 24: Category wise daily average water consumption by individual metered connections in Vasco-zone



Source: Public Works Department, Works Division IX

In the MMC area, 10,103 domestic and 550 non-domestic connections have been recorded (Ref. Table 7). As per the 2011 Census, there are 21,524 households, including 4,974 slum households with a population of 23,625. Field surveys indicate that slum households typically rely on shared community taps (each serving 15–25 households) while high-rise apartments are often registered under a single connection. Thus, the actual number of end-user households served is likely much higher than the number of connections reported.

According to the MMC's service level benchmark data, 100% of households have access to water supply, with a reported per capita supply of 200 lpcd. However, billed consumption for 2023–24 shows a total of 47.9 MLD consumed by 27,994 individual connections in the Vasco zone (Table 8). The domestic consumption for the zone is 31.5 MLD which is around 66% of the overall billed consumption. The data also reveals a high unaccounted-for Water (UFW) at 38 % throughout the water supply service chain for Vasco zone.

The total connection count includes both domestic and non-domestic users (e.g., commercial, institutional, and industrial consumers), which may have very different usage patterns. Moreover, slum households and large apartment complexes often registered as single connections may draw significantly more water than the average. This disparity is not captured in the aggregated consumption data, which masks important differences in usage intensity and service adequacy across consumer categories.

Table 7: Total number of connections Division IX PWD

DIV IX TOTAL NO. OF CONNECTIONS AS ON 29-01-2025					
DIV	REV_SD	CONSTITUENCY	DOMESTIC	NON DOMESTIC	GRAND TOTAL
IX	I	BENALIM	10962	667	11629
IX	I	FATORDA	7443	612	8055
IX	I	MARGAO	6740	922	7662
IX	I	NUVEM	10379	341	10720
IX	II	CUNCOLIM	8106	154	8260
IX	II	CURTORIM	10809	418	11227
IX	II	NAVELIM	7974	261	8235
IX	II	VELIM	10909	341	11250
IX	III	CORTALIM	9570	238	9808
IX	III	DABOLIM	5211	157	5368
IX	III	MORMUGAO	3464	104	3568
IX	III	VASCO-DA-GAMA	6639	446	7085
GRAND TOTAL			98206	4661	102867

Source: Public Works Department, Works Division IX

Table 8: Zone-wise / Taluka-wise daily consumption statement of water during 2023-24 (as on 31-03-2024)

ZONE-WISE / TALUKA-WISE DAILY CONSUMPTION OF WATER DURING 2023-24 (as on 31-03-2024)												
Sr.No.	Network / Zone	Taluka	WD	Total Water Produced / Capacity (in cu.m.)	Total No. of Water Meter Connections given to Individuals (not Population or No. of Family Members benefitted by Water Meter Connections) (in nos.)	Daily Average of Water Consumed (in cu.m.)					by Public Taps	Total Water Consumed (in cu.m.) (11 +12)
						by Individual Metered Connections						
						Hotels/ Institution/ Commercial/ Establishment / Construction	Industries	Defence	Domestic	Total (7 to 10)		
1	2	3	4	5	6	7	8	9	10	11	12	13
6	SALAULIM NET-WORK											
d)	Margao - Zone	Salcete	IX	132000	82688	6880	5294	839	83021	96034	0	96034
e)	Vasco - Zone	Mormugao	IX	77000 including 10000 (Cuelim Pressure filter)	27994	4114	4222	8065	31513	47915	0	47915
	TOTAL			209000	110682	10994	9516	8904	114534	143949	0	143949

Source: Public Works Department, Works Division IX

3.5 CLIMATE RISKS AND CHALLENGES

Mormugao faces a complex and growing set of climate and infrastructure-related risks that threaten its urban water security and sustainability. These challenges are not only shaped by **changing climatic patterns** but also by long-standing issues related to **systemic inefficiencies, source vulnerabilities, and governance gaps** in water service delivery.

Surface Water Source Vulnerability

Mormugao's primary source of water is the **Salaulim Dam**, which supplies treated water through a long-distance transmission system. This dependency on a single, distant surface water source makes the town acutely vulnerable to climatic and operational disruptions.

The dam is increasingly vulnerable to sedimentation and climate-induced hydrological changes. A sedimentation survey by the WRD of Goa revealed that **the reservoir has lost over 25.5 million cubic meters (MCM) of capacity over 37 years** due to sediment deposition up to its full reservoir level (FRL), with an annual deposition rate of 0.69 MCM³⁸. The study also projects that, at current rates, dead storage will be completely depleted within 50 years and up to 33% of live storage could be lost within a century, raising serious concerns about long-term water security. These findings are reinforced by a separate study conducted under the Framework Agreement between the Norwegian Ministry of Foreign Affairs (MFA) and The Energy and Resources Institute (TERI)³⁹, which used hydrological models to simulate future inflows into the Salaulim Dam under various climate scenarios. While the study predicts increased rainfall and reservoir inflows in the future, it also warns that **combined impacts of rising inflows and sedimentation could reduce effective storage capacity**, limiting the ability to store water during lean periods and heightening the risk of both flooding and drought. Together, these studies underscore the dual threat of catchment degradation (notably from past mining activity) and climate variability, both of which compromise the dam's capacity to sustainably serve growing domestic, industrial, and agricultural demands.

Furthermore, as Mormugao lies at the **fag-end of the transmission system**, after multiple enroute tapplings serving other talukas, it is particularly prone to **supply inadequacies** during high demand periods or system breakdowns. This geographic positioning combined with climate-induced risks makes **source diversification and resilience planning** a critical priority.

Groundwater Stress and Salinity Intrusion

Groundwater sustainability in Mormugao is increasingly under strain due to rising extraction pressures, limited recharge capacity, and growing dependence in areas with inadequate piped supply. Despite Goa's overall classification as a 'safe' state, government data reveals

a 65% increase in extraction between 2011 and 2023, with Mormugao among the highest-extraction talukas. This surge driven by the proliferation of private and often unauthorized borewells, especially in peri-urban and slum areas, raises concerns of long-term aquifer depletion and saline intrusion, particularly in estuarine zones. The region's aquifer systems, dominated by lateritic and basaltic formations, have variable yields and limited recharge potential. These hydrogeological vulnerabilities are further compounded by erratic rainfall, mining-affected catchments, and rising urban demand. Pollution risks add another layer of complexity: poorly managed on-site sanitation systems, limited sewerage coverage, greywater discharge into storm drains, and port-related industrial activities all contribute to the contamination of surface and groundwater, threatening both human health and the ecological integrity.

High Non-Revenue Water and System Losses

According to PWD Division IX, Mormugao's **NRW** was as high as **38%** in 2023–2024. This represents a significant loss of treated water due to **leakages, illegal tapping, and metering errors**. NRW not only reflects inefficiency but also increases the **carbon footprint of water supply**, as energy used in abstraction, treatment, and conveyance does not translate into actual service delivery. These losses are especially concerning in a town where many areas still face **intermittent and unreliable supply**.

Infrastructure Fragility and Service Interruptions

Mormugao's water distribution network, encompassing over 100,000 connections, is susceptible to system shocks, including those induced by climate change. Aging infrastructure exacerbates these vulnerabilities, leading to frequent supply interruptions. For instance, in January 2025, the entire Mormugao taluka experienced a two-day water outage due to PWD's repair works on the main pipeline from the Salaulim water treatment plant⁴⁰.

Specific areas like Baina and parts of Sada have reported receiving water late at night, sometimes after midnight, with residents enduring prolonged periods without water, occasionally up to three to four days⁴¹. Power fluctuations further disrupt water supply. In August 2022, areas including Cortalim, Zuarinagar, New Vaddem, Vaddem Nagar, Chicalim, and Shantinagar faced water shortages due to such issues⁴².

The topography of certain regions, such as Headland Sada, contributes to water scarcity. Residents there have adapted to receiving water for only one hour daily over the past 14 years⁴³.

Supply Constraints and Competing Demands

Mormugao's water infrastructure must cater to **diverse and competing demands** from domestic users to port operations and industries. However, **expansion projects such as the proposed 100 MLD WTP** have faced **delays and financial hurdles**, intensifying supply stress. This tension between demand and infrastructure capacity underscores the need for **long-term investment** and **effective resource allocation** strategies.

Operation and Maintenance Deficiencies

The current **O&M** system, managed by the PWD, remains **largely reactive**. Preventive maintenance is limited to routine activities such as greasing and oiling, and **systematic breakdown logging or condition monitoring is absent**. As a result, service delivery is **vulnerable to cascading failures**, especially during peak demand or climate-related disruptions.

Policy Responses and the Need for Structural Reform

Although recent initiatives like the **"Save Water to Get Free Water"** scheme (which offers households 16,000 liters of free water per month) aim to promote conservation, the town continues to grapple with fundamental challenges in **equity, adequacy, and reliability** of water supply. Without infrastructure upgrades and strategic governance reforms, **policy incentives alone cannot bridge the demand-supply gap** or ensure long-term resilience.

NOTES & REFERENCES

³¹ 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.

³² Western Ghats Ecology Expert Pane/ (WGEEP) Report.(201 L), (Parts I And II). Submitted To The Ministry Of Environment And Forests , Government Of India

³³ Aquifer Systems Of Goa, Sep 2013. Central Ground Water Board, Ministry Of Water Resources , Government Of India, South West Region , Bangalore. Accessed On June 25 2025
https://www.cgwb.gov.in/Old_Website/AQM/Goa.Pdf

³⁴ Dynamic Groundwater Resources Of Goa – 2024. MARCH 2025. Water Resource Department Government Of Goa & Central Ground Water Board, South Western Region, Department Of Water Resources, River Development & Ganga Rejuvenation, Ministry Of Jal Shakti, Government Of India. Accessed On June 25 2025

<https://www.cgwb.gov.in/Cgwbpm/Public/Uploads/Documents/174823987024232641file.Pdf>

³⁵ Ground Water Year Book Goa State 2017-18. CENTRAL GROUND WATER BOARD, SOUTH WESTERN REGION, BANGALORE. Ministry Of Water Resources, Government Of India. Accessed On June 25 2025

https://www.cgwb.gov.in/Old_Website/Regions/SWR/Reports/GOA/Gwyar%20Book_%20Goa%202017-18%20-%20PDF.Pdf

³⁶ The Times Of India. (2025, April 4). “65% Increase In Groundwater Extraction In Goa Over 12 Years, Shows Govt Data.” <https://timesofindia.indiatimes.com/City/Goa/65-Increase-In-Groundwater-Extraction-In-Goa-Over-12-Years-Shows-Govt-Data/Articleshow/119955817.Cms>

³⁷ Times Of India. (Jul 29, 2024). Gauree Malkarnekar. ‘Most Of Goa’s Illegal Borewells In Calangute, Mandrem, Mormugao’ Retrieved June 20, 2025.

<https://timesofindia.indiatimes.com/City/Goa/Most-Of-Goas-Illegal-Borewells-In-Calangute-Mandrem-Mormugao/Articleshow/112105677.Cms>

³⁸ Water Resources Department (2021). Sedimentation Survey Report Of Salaulim Dam Under NHP. Executive Engineer, Works Division III, Water Resources Department, Government Of Goa. Accessed On 22 June 2025.

<https://nhp.mowr.gov.in/Docs/NHP/Sedimentation%20Studies/Report/1053/Sedimentation%20Report%20of%20Salaulim%20Dam.Pdf>

- ³⁹ Ensuring Reservoir Sustainability Under A Changing Climate. 2020. <https://www.norway.no/en/india/norway-india/news-and-events/newsde/ensuring-reservoir-sustainability-under-changing-climate/>.
- ⁴⁰The Times Of India. 2025, January 14. Mormugao Taps Run Dry As PWD Repairs Main Line. <https://timesofindia.indiatimes.com/City/Goa/Mormugao-Taps-Run-Dry-As-Pwd-Repairs-Main-Line/ArticleShow/117214271.cms>
- ⁴¹The Goan. Erratic Water Supply Continues To Haunt Mormugao Taluka. SEPTEMBER 22, 2024, Retrieved June 11, 2025. https://www.thegoan.net/Goa-News/%EF%BB%Bferratic-Water-Supply-Continues-To-Haunt-Mormugao-Taluka/119183.html#Google_Vignette
- ⁴²The Times Of India, September 2, 2022 .Water Supply Hit In Mormugao. Retrieved June 11, 2025. <https://timesofindia.indiatimes.com/City/Goa/Water-Supply-Hit-In-Mormugao/ArticleShow/93936291.cms>
- ⁴³Team, Herald. 2024. "WHAT- A CRISIS! For 14 Years Headland Sada Has Got 'Used To' 1 Hr Daily Water." <https://www.heraldgoa.in/Goa/What-A-Crisis-For-14-Years-Headland-Sada-Has-Got-Used-To-1-Hr-Daily-Water/218380>.

4. URBAN SANITATION SYSTEMS IN MORMUGAO: 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 Mormugao, 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^{44,45,46}. *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*⁴⁷. WaSH services are essential for preventing disease outbreaks, particularly in the aftermath of climate hazards such as heavy rainfall and flooding^{48, 49}. 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*⁵⁰. 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 role⁵¹.

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'⁵². 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.

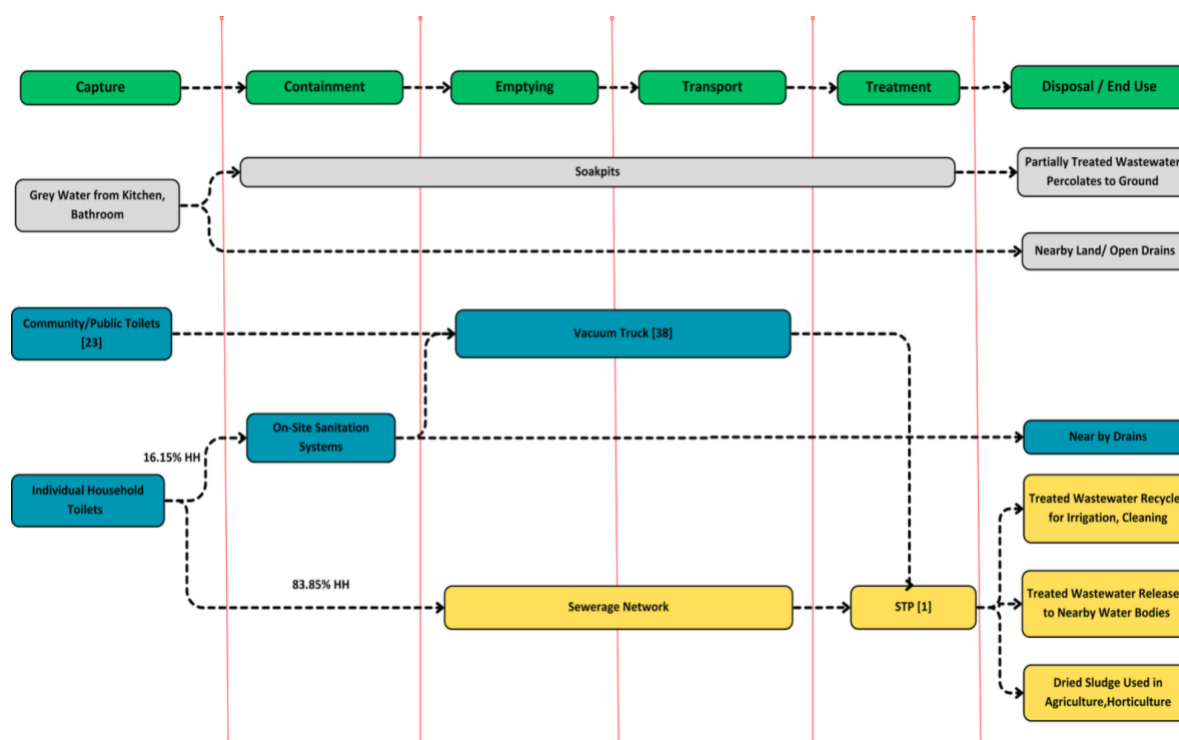
Hence, assessing the current state of sanitation services is essential for identifying infrastructure gaps, vulnerabilities, and climate-related risks. Such an assessment supports the design of proactive adaptation measures, promotes efficient resource use, and enables low-carbon development strategies. 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 *Mormugao*. 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 use⁵³. This section outlines the service chain and identifies the key gaps. The entire service chain is depicted in *Figure 25*.

Figure 25 : Sanitation Service Chain in Mormugao



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 21524 households in the area, 2317 households did not have **individual toilets**. However, the latest data from the Mormugao Town Council, as reported in the SLB 2022-23 report, confirms 82% of households have access to individual toilets. And the rest of the population is dependent on community toilets. 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.

The fieldwork conducted in a predominantly fishing community in Ward 9, where the STP is located, revealed significant discrepancies. Despite the proximity to the STP, many households in this community were not connected to the sewerage network, lacked individual toilets and piped water connections, and instead relied on a nearby community toilet installed by the community.

Detailed information on toilet typologies is essential—not only to evaluate the quality and adequacy of sanitation services but also to accurately estimate the GHG emissions associated with different sanitation systems. However, the most recent comprehensive assessment was conducted during the 2011 Census, and no updated data has been made available since, at the national, state, or city levels. Gathering this information would necessitate a dedicated household-level survey, which lies beyond the scope of routine assessments.

- **Community Toilets and Public Toilets¹**: According to the SBM Urban Dashboard data, the city does not have any CT but has 13 PT. However, information provided by the ULB officials indicates that, currently, the city has 11 community toilets spread across Wards 6, 7, 12, 14, 16, 21, and 22, as well as 12 public toilets located in Wards 8, 11, 12, 13, 14, 15, 17, and 22. Of these public toilets, two are slated for reconstruction, while two others remain non-functional due to deteriorating infrastructure.

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

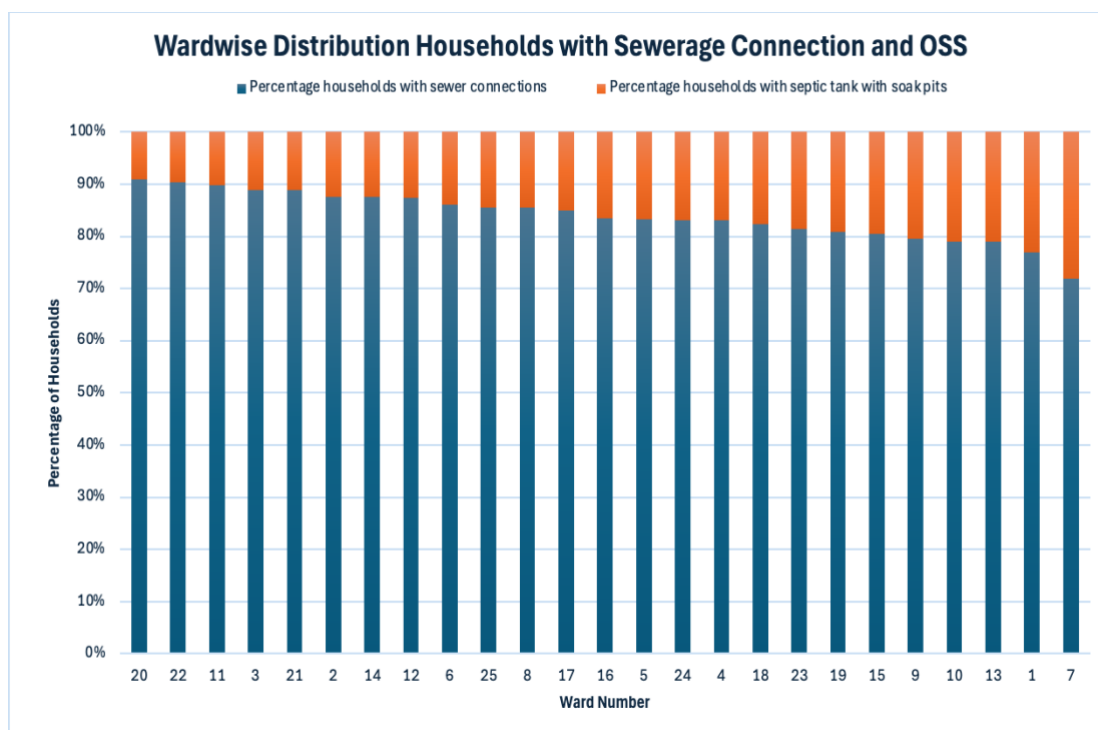
¹as per SBM guidelines “public toilets are toilets which are provided for the floating population/ general public in places such as markets, train stations, tourist places, near office complexes, or other public areas where there are a considerable number of people passing by. Pts are to be accessible to one and all and well-connected to important areas and pedestrian junctions. Community toilets are the shared facilities provided by and for a group of residents or an entire settlement. Ct facilities are used primarily in low-income and/or informal settlements / slums, where space and/or land are constraints in providing individual household toilet. These are for a fixed user group.”

CPHEEO. (2018). Advisory on Public and Community Toilet . New Delhi: Ministry of Housing and Urban Affairs.

tracking the number of users or whether the facilities are **able to cater the demand**.

- **Containment:** According to the secondary data provided by the ULB, approximately 83.85% of households are connected to sewer networks, while about 16.15% have septic tanks with soak pits. The figure 26 below illustrates the ward-wise distribution of percentage households with sewerage connections and septic tank + soak pit systems. While the average percentage of households in the town connected to the sewerage system is 83.8%, there is a noticeable variation across different wards. Specifically, nine wards out of the total 25 have between 80% and 85% of households connected to the sewerage network. In contrast, five wards (1, 7, 9, 10, and 13) report sewerage connection rates below 80%. This disparity indicates that authorities may need to focus more on these specific wards to improve sewerage coverage. Further, our fieldwork in certain areas such as Ward 1 revealed that some households have diverted their septic tank drainage into open drains that discharge directly into nearby water bodies, raising environmental and public health concerns. The discharge of partially treated wastewater could contribute to GHG emissions.

Figure 26: Ward-wise Distribution of Households (%) with Sewerage Connection and On-site Sanitation Systems



Source: Data from Mormugao Municipal Council

Photo : Status of water and sanitation services in low-income area Ward 14 Source: IIT-Bombay Team



Bathrooms and toilets in high density residential



Sewerage connection lines to the households



Water storage for secondary use

Understanding the typology of OSS is crucial for accurately assessing GHG emissions. We inquired with ULB officials about the availability of such data; however, they were unable to provide any. Consequently, collecting this information would require a dedicated household-level survey, which falls beyond the scope of the current project.

- **Emptying and Transport:** As mentioned in the previous section, currently, the city's sewerage network covers 84.3% of households, which corresponds to approximately 60% of the city's area as per PWD official. The remaining 40% of the city lacks sewer network connections as some of these areas are low-lying areas. Approximately 16.15% of households rely on septic tanks with soak pits, which are emptied by vacuum trucks. These services are provided by 38 private trucks registered with the state PWD. Each truck is required to pay a one-time registration fee of INR 5,000 for lifetime use. Households are typically charged between INR 1,000 and INR 2,000 per trip for vacuum truck services, with the charges varying based on the distance travelled. As per the ULB officials, the wastewater from CT and PT gets collected in the sewerage network.

Waterlogging remains a persistent problem in Mormugao, with media reports (Tol, 2024) highlighting frequent drainage blockages that caused urban flooding across all 25 wards in 2024^{lix}. Same is corroborated during field work. For instance, in Ward

12, where approximately 12.5% of households are not connected to the sewerage network, some areas are prone to flooding and waterlogging. During the monsoon season, waterlogging persists for 2-3 days, with water levels reaching up to 2 feet. In response, residents have raised the foundations of their homes, and they report that their sanitation infrastructure remains unaffected by the flooding (refer Photo below).



Flood marks, physical indicators of past flood

*Photo : Flood marks and elevation modifications adopted by residents as adaptive measure to address waterlogging
Source: IIT-Bombay team*

As far as typology of sewerage network, it wasn't within the scope of the study, as it is not possible to **assess the drainage network, including whether it is underground or overground**. Additionally, the ULB does not have any maps of the sewerage network and information regarding the type of drainage system and is also unavailable in any secondary sources.

- **Treatment:** The city of Mormugao operates a STP that was commissioned in 2017, utilizing Sequencing Batch Reactor (SBR) technology and supported by 7 pumping stations. The STP has an installed capacity of 20 MLD. However, despite its substantial capacity, the plant is underutilized, treating only 7 MLD during the non-monsoon season and 9 MLD during the monsoon season. The underutilization of the STP's capacity, according to both PWD and Municipal Officials, is largely attributed to the Mormugao Municipality's lack of jurisdiction over specific areas, such as Mormugao Port Authority, Sailing Colony, and Defence Colony. As a result, these areas are not connected to the sewerage system, leading to a lack of sewage collection.

As far as the **management of greywater** from kitchens and bathrooms is concerned, field visits revealed significant variation across households. In some homes, greywater is effectively directed into separate soak pits, while in others, it is discharged into nearby drains. Additionally, a few households directly channel greywater into the sewerage network.

According to secondary data provided by the ULB, the STP appears to comply with the CPCB's 'Treated Sewage Quality for Specified Activities at Point of Use standards (CPCB, 2021, p.59), specifically for horticultural use.

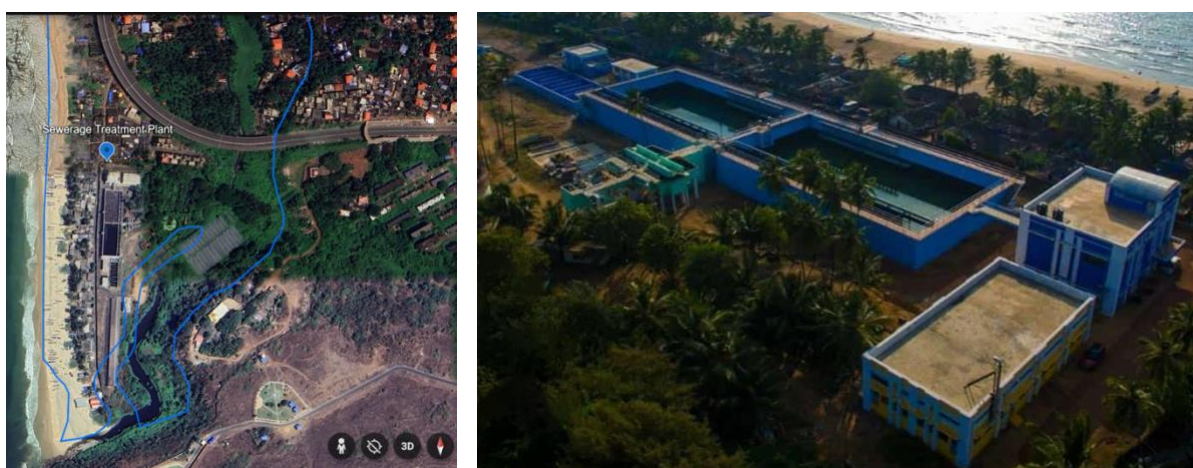


Photo: Location of STP in ward 9 Source: Mapped using Google Earth, Image collected from PWD Mormugao division

- **End-use Disposal (Septage and Sludge Management)^{ix}:** The city currently lacks a dedicated Faecal Sludge and Septage Treatment Plant (FSSTP). Instead, it relies on 38 private desludging trucks registered with the PWD. The septage collected by these trucks is transported to the STP, where it undergoes treatment. After treatment, the resulting sludge is further processed and dried in sludge drying beds. They use the dried sludge for their own STP plantation. Occasionally, nearby residents collect the treated and dried sludge free of charge to use as fertilizer. However, a significant portion of the sludge remains unutilized.
- **Recycling and Reuse:** The city currently uses a portion of the treated wastewater for cleaning the STP premises and occasionally for maintaining roads and parks. However, the remaining treated wastewater is directly discharged into nearby water bodies. Additionally, there are plans to supply treated wastewater free of charge to the Mormugao Port Authority (MPA) for reuse and recycling. The treated wastewater will

not be sold; rather, it will be provided exclusively for reuse purposes, with the MPA having already laid the necessary pipelines for this initiative.

4.3 INSTITUTIONAL ARRANGEMENTS

This sub-section examines the institutional arrangements, outlining the various departments, agencies, and organizations, along with their respective roles in delivering sanitation infrastructure and services (refer Table 9). 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, a multi-stakeholder, multi-level governance framework involved in the provision of sanitation infrastructure and services was observed.

This town has a distinct institutional arrangement for sanitation infrastructure and service delivery, with the PWD taking the lead in nearly all aspects of water and sewerage planning, implementation, and O&M. This framework is further reinforced through inter-city collaborations and central government funding, especially for larger infrastructure. The study findings are consistent with the Comptroller and Auditor General of India's (CAG) Assessment Report for Goa (Comptroller and Auditor General of India, 2024), which underscores that the partial or inadequate devolution of essential functions, as well as administrative and financial powers, from the state to Municipal Councils (MCs) under the 74th CAA remains a widespread challenge across the state².

Sanitation infrastructure such as toilets and on-site sanitation systems at the household level is largely the responsibility of the household itself. For sludge management, households may opt to rely on vacuum trucks, typically provided by the registered private operators. However, there is a lack of regulation concerning both on-site sanitation systems and toilet designs. At the ULB level, smaller sanitation interventions like CT and public toilets PT are primarily the ULB's responsibility, with independent decision-making power in key areas such as land selection, technology choice, operation and maintenance (O&M), and funding. SBM, capital funding was provided for some CTs and PTs. The environmental compliance of CTs and PTs is uncertain. The O&M specifically day-to-day cleaning of some of the CTs is given to the communities. The O&M of public toilets have been outsourced to private vendors, who recover the costs through user charges.

² Comptroller and Auditor General of India. (2024). Performance Audit of Implementation of 74th Constitutional Amendment Act in Goa for the year ended 31 March 2021. Government of Goa.

Table 9: Institutional Arrangements in 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	HH
						Septage removal by Private vehicles	
CT [11]	ULB	ULB	ULB	ULB	ULB	Day to day cleaning by communities	ULB
		State Land	Central Government [SBM 1.0]				
PT[12]	ULB	ULB	Central Government [SBM 1.0]	ULB	ULB	Private agency [Sulabh international]	Recovers the costs through user charges.
		Petrol pump					
Sewerage Network	PWD	Public	State Fund	PWD	PWD	PWD	SIDCGL
	SIDCGL		State Fund		No information		
STP [1]	SIDCGL	PWD	State Fund	SIDCGL	SIDCGL	PWD	PWD
		Donated by church					
Note: SIDCGL = Sewage & Infrastructure Development Corporation of Goa Ltd.							

Source: Authors' Analysis

For large infrastructure development projects, such as the sewerage network and STP, the Mormugao Municipal Council has no direct involvement. As illustrated in the table below, the entire process—including technology selection, land acquisition, capital funding, technology implementation, and operations and maintenance (O&M)—is managed by the central government, state-level departments (such as the Public Works Department), and SIDCGL. This relegates the Mormugao Municipal Council to a passive role, undermining the spirit of the 74th CAA and its intended autonomy. Furthermore, this centralized approach disrupts the flow of critical information and finances, limiting the ULB's ability to make informed decisions, take ownership, and actively manage sanitation infrastructure. As a result, the council's capacity to effectively address the specific needs of its local population is severely compromised. 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

While the town performs relatively well in terms of sanitation infrastructure and services, there is still considerable room for improvement in addressing sanitation challenges in certain areas. The challenges outlined below are key barriers to achieving the required service levels, but they also present valuable opportunities to provide equitable and affordable sanitation services to all residents.

- **Infrastructure and Services Gaps:** The study identified infrastructure and service gaps in specific areas, particularly in informal settlements, low-income fishing communities, marginal daily-wage worker settlements, and low-lying regions. Addressing these disparities is essential to ensuring equitable access to basic sanitation services, improving public health, and reducing environmental pollution. This is also critical for achieving SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities). Moreover, addressing these gaps will reduce vulnerabilities to climate change, especially in areas prone to flooding and waterlogging. By tackling these infrastructure challenges, we can foster equitable development, enhance climate change adaptation, and build resilience across all communities. Additionally, these challenges offer opportunities to explore non-conventional solutions, such as decentralized and nature-based approaches, particularly in areas where land title issues complicate the development of traditional infrastructure.

- **Inadequate Drainage in Low-Lying Areas:** Certain low-lying areas (Ward number 16), face persistent water logging issues, particularly during the monsoon season. While this does not directly affect access to essential infrastructure, prolonged waterlogging can pose significant public health risks. This highlights the need for improved drainage systems as part of building adaptive capacity and urban resilience, ensuring that vulnerable communities are better equipped to withstand climate-related challenges and minimizing the impact of extreme weather events on their well-being.
- **Disproportionate Burden of Maintaining Sanitation Services on Vulnerable and Marginalized Communities:** All 11 community toilets are day to day cleaning is given to the communities who are using it. The SBM-Urban guidelines suggest that communities have the option to take on O&M activities themselves, stating that "Instead of a private agency, the community themselves (SHG/NGO/CBO on their behalf) could choose to take up O&M activities"^{lxvii}. However, the field study found that, in practice, the responsibility for the daily O&M and day-to-day cleaning of all 11 community toilets rests entirely on the communities. Previous work on community management models for sanitation and wastewater management in marginalized communities indicates that such interventions place a substantial burden on low-income and marginalized groups, who are already dealing with significant financial challenges^{lxviii}. As the primary authority responsible for ensuring the provision of essential services, the ULB should take ownership of managing sanitation infrastructure and ensure that the responsibility for maintenance does not disproportionately fall on vulnerable communities. The ULB could explore alternative solutions, such as subsidizing cleaning costs or offering economic incentives to communities for maintaining these facilities.
- **Opportunity in Enhance Revenue Base:** Considering that most ULBs in Goa have a limited role in sanitation infrastructure and services and are primarily dependent on higher governance levels for funding, the municipal council has a unique opportunity to expand its revenue base by selling dried treated sludge and treated wastewater. To fully realize this potential, the municipality can focus on creating and nurturing a market for these products.
- **Inadequate Devolution of Administrative and Financial Powers to Municipal Council:** The study highlights a multi-stakeholder, multi-governance framework with limited devolution of administrative and financial powers to ULBs in areas such as sanitation infrastructure and services, as outlined in the 74th CAA. These findings align with the CAG-2024 report on Goa (Comptroller and Auditor General of India, 2024). Enhancing devolution would empower municipal councils, fostering greater

participatory governance and clearer accountability. By taking an active role in the planning, implementation, and operation & maintenance (O&M) of sanitation infrastructure, ULBs can better utilize their grassroots knowledge to create tailored, context-specific solutions. Furthermore, exclusion from sanitation responsibilities also prevents ULBs from accessing crucial revenue streams, such as user fees, which are vital for the long-term sustainability of services. This fragmented institutional framework limits the ability of ULBs to manage resources efficiently and address local needs effectively. As highlighted in the CAG report, the state government must take proactive measures to ensure the effective devolution of administrative power, funds, and functions to ULBs, in alignment with the provisions of the 74th CAA.

NOTES & REFERENCES

- ⁴⁴ Rumbach, A. (2018). At the Roots of Urban Disasters: Planning and Uneven Geographies of Risk in Kolkata, India'. *Journal of Urban Affairs*, 39 (6), 1–17.\.
- ⁴⁵ Yenneti, K., Tripathi, S., Wei, Y. D., Chen, W., & Joshi, G. (2016). The Truly Disadvantaged? Assessing Social Vulnerability to Climate Change in Urban India. *Habitat International*, 56, 124–35.
- ⁴⁶ Central Pollution Control Board . (2021). National Inventory of Sewage Treatment Plants. New Delhi: Ministry of Environment, Forest and Climate Change. Government of India.
- ⁴⁷ Braks, M. A., & Husman, A. M. (2013). Dimensions of Effects of Climate Change on Water-Transmitted Infectious Diseases. *Air Water Borne Diseases*.
- ⁴⁸ Carlton, E.J., Et Al., (2014). Heavy Rainfall Events And Diarrhea Incidence: The Role Of Social And Environmental Factors. *Epidemiologic Reviews*. , 179 (3), 344–352, Doi:10.1093/Aje/Kwt279.
- ⁴⁹ Jones, N., Et Al., (2020). Water, Sanitation And Hygiene Risk Factors For The Transmission Of Cholera In A Changing Climate: Using A Systematic Review To Develop A Causal Process Diagram. *J. Water Health*, 18 (2), 145–158, Doi:10.2166/Wh.2020.088.
- ⁵⁰ Cutter, S., Osman-Elasha, B., Campbell, J., Cheong, S. M., McCormick, S., Pulwarty, R., . . . Ziervogel, G., (2012). Managing The Risks From Climate Extremes At The Local Level. In: *Managing The Risks Of Extreme Events And Disasters To Advance Climate Change Adaptation. A Special Report Of Working Groups I And II Of The Intergovernmental Panel On Climate Change*. [Field, C. B., V. Barros, T. F. Stocker, Q. Dahe, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G. K. Plattner, S. K. Allen, M. Tignor And P. M. Midgley (Eds.)]. Cambridge University Press, Cambridge, United Kingdom And New York, NY, USA, Pp. 291–338.
- ⁵¹ Caretta, M.A., A. Mukherji, M. Arfanuzzaman, R.A. Betts, A. Gelfan, Y. Hirabayashi, T.K. Lissner, J. Liu, E. Lopez Gunn, R. Morgan, S. Mwanga, And S. Supratid, (2022). Water. In: *Climate Change 2022: Impacts, Adaptation And Vulnerability. Contribution Of Working Group II To The Sixth Assessment Report Of The Intergovernmental Panel On Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (Eds.)]. Cambridge University Press, Cambridge, UK And New York, NY, USA, Pp. 551–712, Doi:10.1017/9781009325844.006.
- ⁵² Ministry of Housing and Urban Affairs. (2008). National Urban Sanitation Policy-2008. New Delhi.
- ⁵³ UNICEF. (2020). What do safely managed sanitation services mean for UNICEF programmes? WASH Discussion paper.

5. CLIMATE IMPACTS OF WATER & SANITATION SYSTEMS

ASHISH DANGI⁵⁴ 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

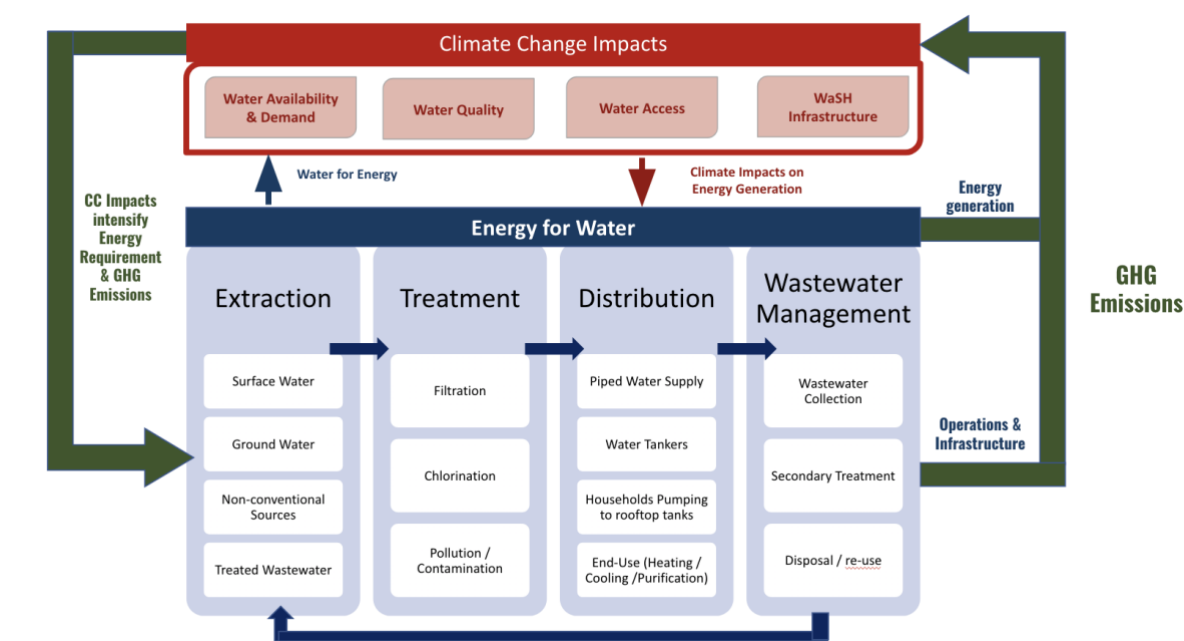
Globally, the water and sanitation systems are increasingly recognised not only as climate victims, but also significant contributors to climate change as the GHG emissions from WaSH continue to grow. Energy is the key input to every step in an urban water cycle right from water extraction to conveyance, 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*⁵⁵. According to another estimate, wastewater treatment plants alone are estimated to account for 3% global electricity consumption⁵⁶. 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) emissions⁵⁷. *Direct emissions in wastewater treatment are estimated to be significant at ~1.57% of global GHG emissions*⁵⁸.

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 cycle⁵⁹. 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%⁶⁰. 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 East⁶¹. 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 WWTPs⁶². *With the increased variability posed by climate change the emission in WWTPs could further increase*⁶³.

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*⁶⁴. *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 27: The Water-Energy-Climate nexus in Urban Water Cycles.



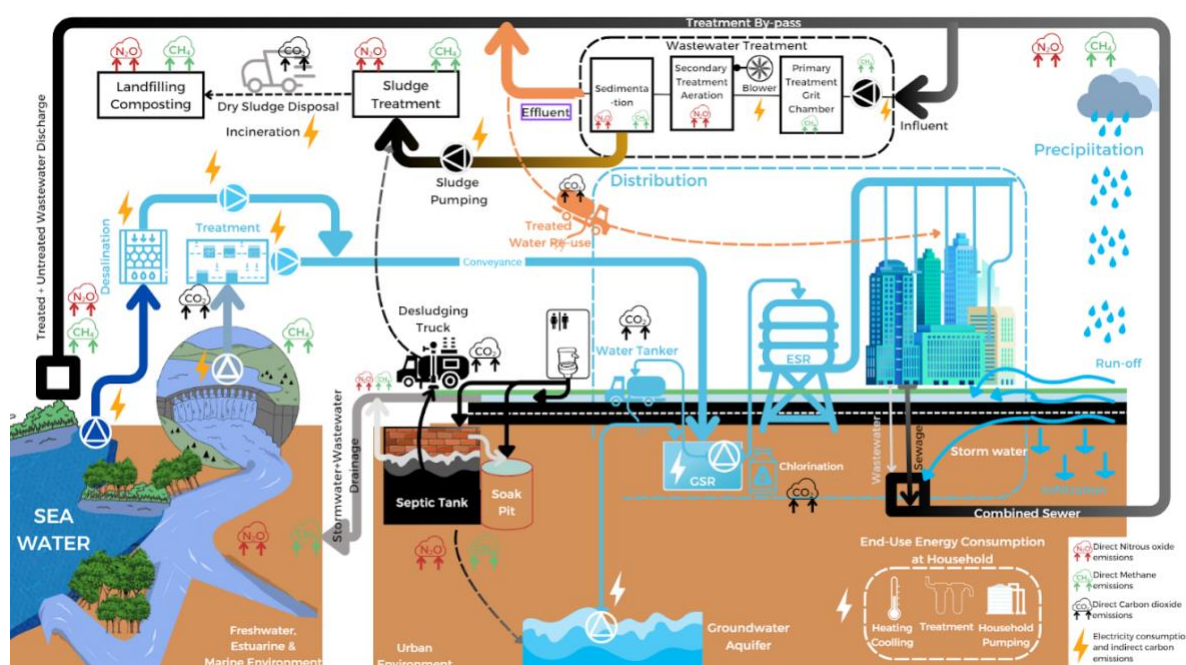
Source: Author's Illustration.

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 management⁶⁵. *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 goals 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 28: 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.

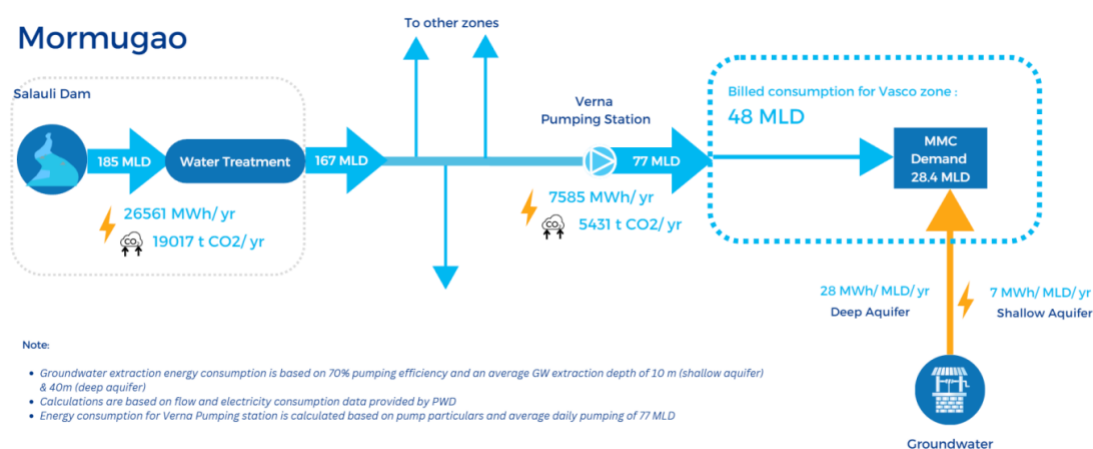
Table 10: Scope of emissions methodology for carbon footprint assessment of the urban water cycle

Category	Possible Sources of Emissions	Methodology
Direct Emissions	- Methane (CH₄) emissions from anaerobic decomposition of organic matter in wastewater. - Nitrous Oxide (N₂O) Emissions from nitrification and denitrification of nitrogen compounds wastewater - Methane (CH₄) emissions from the decomposition of organic matter in anaerobic sediments in freshwater reservoirs*	2006 IPCC Guidelines for National Greenhouse Gas Inventories ⁵⁷ (2019 Refinement ⁶⁶)
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)⁶⁷ 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 sediments⁶⁸. 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 29*.

Figure 29: Carbon and energy footprint of Mormugao's water supply.



Source: Dangi & Narayanan, forthcoming⁶⁹

Surface Water Abstraction and Treatment:

Mormugao's water is primarily sourced from the Salaulim Dam, with an average of 185 MLD abstracted daily. After accounting for 10% in-plant losses, the system delivers approximately 167 MLD of treated water. This process consumes **26,561 MWh/year**, resulting in **19,017**

tCO₂/year in emissions. This makes treatment and abstraction the most carbon-intensive stage in the water supply chain, driven by high energy use for pumping and filtration.

Conveyance to Distribution Zones:

Water is transported across a complex topography, with much of the system leveraging gravity-based conveyance. However, to reach specific areas like the Vasco zone, intermediate pumping is required—particularly at the Verna Pump House, which supplies 77 MLD. Conveyance activities consume **7,585 MWh/year**, emitting **5,431 tCO₂/year**. Although this is lower than treatment-related emissions, it still represents a substantial energy burden.

Distribution Network and Losses:

While the exact electricity consumption for pumping to GLRs and OHRs is unavailable, field assessments suggest this energy use is relatively modest compared to treatment and conveyance. What is more significant, however, is the distribution loss of 38%, arising from leakages, illegal tapping, and unmetered consumption. These losses mean a substantial share of treated water never reaches end users, effectively inflating the system's overall carbon footprint.

Groundwater Extraction: A Low-Carbon Alternative:

Although accurate consumption data for groundwater use in Mormugao is lacking, it is evident that borewells and tanker-supplied water play an increasingly important role, particularly in underserved and peri-urban areas. Based on standard energy intensity estimates, groundwater abstraction requires far less electricity—approximately 7 MWh/MLD/year for shallow aquifers and 28 MWh/MLD/year for deeper ones—compared to surface water supply, which consumes a high 285 MWh/MLD/year due to long-distance pumping and elevation-related lift.

To put this into perspective, if Mormugao's entire estimated demand of 28.4 MLD were met through surface water alone, and accounting for 38% unaccounted-for water (UFW), about 45.8 MLD would need to be produced. This would consume approximately 13,055 MWh/year and emit around 9,347 tonnes of CO₂ per year - equivalent to carbon sequestered by 154,553 tree seedlings grown for 10 years.

These figures underscore the potential climate benefit of diversifying the water supply portfolio. Judicious integration of groundwater, particularly in areas where aquifers remain safe and sustainable, can not only enhance supply reliability but also significantly reduce the energy and emissions footprint of urban water systems. This makes a strong case for integrated, low-carbon water planning in the face of escalating climate challenges.

Key Insights

- **Treatment and conveyance stages are the largest contributors** to Mormugao's urban water-related GHG emissions.
- **High distribution losses** (38%) not only result in water wastage but also amplify the carbon intensity of water delivered.
- **Groundwater, where available and safe, offers a low-carbon supplement** to surface water supply, particularly in high-elevation or difficult-to-serve zones.
- Addressing infrastructure inefficiencies, upgrading pumping systems, and **exploring decentralised supply models** could significantly reduce emissions.
- Future assessments should consider **direct emissions from reservoirs** and treatment processes, as well as household-level energy use, to better capture the full emissions profile.

5.5 GREENHOUSE GAS EMISSIONS FROM SANITATION

Figure 30 presents a comprehensive annual GHG emission profile for the sanitation system in Mormugao, accounting for both direct emissions (methane and nitrous oxide) from faecal sludge and wastewater treatment, and indirect emissions from energy consumption in sewage conveyance and treatment. Emissions are expressed in carbon dioxide equivalent (CO₂e) using IPCC's global warming potentials.

On-site Sanitation: Dominant Source of Methane Emissions

On-site systems, including septic tanks and lined/unlined pits, are the largest contributors to methane emissions in Mormugao:

- **Lined/Unlined Pits:** Emit **1,283 tCO₂e/year** through anaerobic decomposition of faecal matter.
- **Septic Tanks:** Emit **868 tCO₂e/year**, also due to methane generation. Another **45.2 tCO₂e/year** due nitrous oxide emissions.
- These emissions occur in the absence of oxygen due to limited desludging and poor maintenance.

Nitrous Oxide from Nitrogen-rich Greywater and Effluent

Nitrous oxide (N₂O) emissions, with a GWP nearly 300 times that of CO₂, originate from nitrogen discharge into the environment:

- **Direct emissions at STP:** Contributes **2,778 tCO₂e/year** of N₂O emissions, fugitive emissions during treatment processes.
- **STP Effluent to Estuarine Waters:** Contributes **1979 tCO₂e/year** of N₂O emissions, despite treatment.
- **Greywater Discharge into Stormwater Drains:** Adds **158 tCO₂e/year**, mainly from nitrogen in household waste and kitchen effluent.
- This illustrates the hidden climate impact of unmanaged nitrogen pathways.

Centralized Sewage Treatment Emissions

The 20 MLD STP contributes:

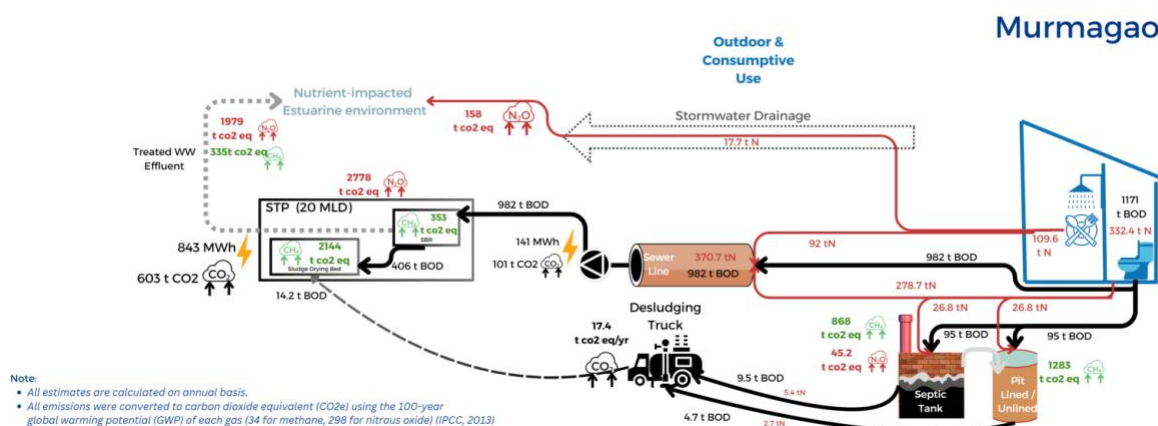
- **Methane (CH₄):** **353 tCO₂e/year** from biological treatment.
- **Methane from Sludge Drying Beds:** **2,144 tCO₂e/year**, showing the importance of post-treatment handling.
- **Electricity Consumption:** 843 MWh/year leads to **603 tCO₂e/year** in indirect emissions from power use.
- **STP Effluent to Estuarine Waters:** Contributes **335 tCO₂e/year** of methane emissions, despite treatment.

Desludging Operations and Transportation

Desludging trucks, which remove waste from on-site systems, contribute:

- **Emissions:** **17.4 tCO₂e/year** from fuel combustion.
- These emissions are small but point to the need for expanding coverage and improving operational efficiency.

Figure 30: Carbon and energy footprint across sanitation service chain in Mormugao.



Source: Dangi & Narayanan, forthcoming⁶⁹

Key Insights:

- On-site sanitation systems are the largest source of methane emissions, highlighting the urgent need to strengthen faecal sludge management (FSM).
- Nitrous oxide emissions from greywater and treated effluent are a major hidden climate risk and are often overlooked in emissions accounting.
- Centralised treatment emits less GHG per unit of waste treated but still contributes through both methane and electricity use.
- Desludging operations have low emissions but limited reach, making most pits and tanks significant, unmanaged sources of GHGs.
- Leakages in the sewer system and uncontrolled greywater discharge reduce treatment effectiveness and increase environmental burden.
- Improving FSM, greywater treatment, and STP efficiency offers high-impact mitigation opportunities for climate-resilient sanitation.

Strengthening faecal sludge management (FSM) is critical, as on-site sanitation systems remain the largest source of methane emissions in urban sanitation. Most pits and septic tanks continue to function as unmanaged emission hotspots due to infrequent desludging and limited-service coverage. In parallel, nitrous oxide emissions from untreated greywater and even treated effluent represent a significant yet often overlooked climate risk, warranting greater attention in emissions accounting. While centralized treatment systems emit less GHG per unit of waste treated, they still contribute to emissions through methane release and energy consumption.

Additionally, leakages in sewer networks and uncontrolled discharge of greywater compromise treatment efficiency and increase environmental stress. Addressing these gaps by improving FSM systems, enhancing greywater treatment, and upgrading STP performance presents a high-impact opportunity to advance climate-resilient sanitation while safeguarding both public health and ecosystem integrity.

5.6 CONCLUSION & WAY FORWARD

The GHG estimation for Mormugao identifies the treatment, conveyance, and sanitation stages as the most critical drivers of the city's urban water carbon footprint. Transitioning to a climate-resilient model requires urgently addressing both supply-side inefficiencies and neglected sanitation emissions.

Key Infrastructural Vulnerabilities:

- **Water Supply:** Staggering distribution losses (38%) multiply the carbon intensity of delivered water, exacerbating the already high energy demands of treatment and conveyance.
- **Sanitation:** Unmanaged pits and septic tanks are the largest source of methane, while nitrous oxide from untreated greywater and treated effluent remains a massive, hidden climate risk.

High-Impact Mitigation Strategies:

- **Optimise Water Delivery:** Aggressively reduce network losses, upgrade pumping infrastructure, and utilise low-carbon groundwater to serve high-elevation or difficult zones.
- **Modernize Sanitation & FSM:** Drastically expand the reach of desludging operations to manage methane hotspots, repair sewer leakages, and improve greywater management.
- **Expand Emissions Accounting:** Future assessments must also incorporate direct emissions from reservoirs, treatment processes, and household energy use to capture the true climate footprint.

By closing the loop on FSM and infrastructure efficiency, Mormugao can simultaneously reduce its environmental burden and secure sustainable, low-carbon water access.

NOTES & REFERENCES

- ⁵⁴ 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.
- ⁵⁵ IEA (2018), The energy sector should care about wastewater, IEA, Paris <https://www.iea.org/commentaries/the-energy-sector-should-care-about-wastewater>
- ⁵⁶ Dickin, Sarah, Moustafa Bayoumi, Ricard Giné, Kim Andersson, and Alejandro Jiménez. 2020. "Sustainable Sanitation and Gaps in Global Climate Policy and Financing." *Npj Clean Water* 3(1):1–7. doi: 10.1038/s41545-020-0072-8.
- ⁵⁷ IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. <https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html>
- ⁵⁸ Lu, Lu, Jeremy S. Guest, Catherine A. Peters, Xiuping Zhu, Greg H. Rau, and Zhiyong Jason Ren. 2018. "Wastewater Treatment for Carbon Capture and Utilization." *Nature Sustainability* 1(12):750–58.
- ⁵⁹ Kenway, S. J., P. A. Lant, A. Priestley, and P. Daniels. 2011. "The Connection between Water and Energy in Cities: A Review." *Water Science and Technology* 63(9):1983–90. doi: 10.2166/wst.2011.070.
- ⁶⁰ He, Guohua, Yong Zhao, Jianhua Wang, Yongnan Zhu, Shan Jiang, Haihong Li, and Qingming Wang. 2019. "The Effects of Urban Water Cycle on Energy Consumption in Beijing, China." *Journal of Geographical Sciences* 29(6):959–70. doi: 10.1007/s11442-019-1639-5.
- ⁶¹ Anon. 2017. "WEO-2016 Special Report: Water-Energy Nexus – Analysis." IEA. Retrieved September 27, 2024 (<https://www.iea.org/reports/water-energy-nexus>).
- ⁶² Du, Mingxi, Qiuhan Zhu, Xiaoge Wang, Peng Li, Bin Yang, Huai Chen, Meng Wang, Xiaolu Zhou, and Changhui Peng. 2018. "Estimates and Predictions of Methane Emissions from Wastewater in China from 2000 to 2020." *Earth's Future* 6(2):252–63. doi: 10.1002/2017EF000673.
- ⁶³ Khalkhali, Masoumeh, and Weiwei Mo. 2020. "The Energy Implication of Climate Change on Urban Wastewater Systems." *Journal of Cleaner Production* 267:121905.
- ⁶⁴ IEA (2016). *World Energy Outlook 2016*. International Energy Agency, Paris. https://www.oecd.org/content/dam/oecd/en/publications/reports/2016/11/world-energy-outlook-2016_g1g6fcae/weo-2016-en.pdf
- ⁶⁵ Han, X., Shi, W.-Y., & Yao, Y.-X. (2023). A Review of the Water–Carbon Nexus in Urban Systems. *Water*, 15(6), 1005. <https://doi.org/10.3390/w15061005>

- ⁶⁶ IPCC 2019, 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. (eds). Published: IPCC, Switzerland. <https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol5.html>
- ⁶⁷ Central Electricity Authority (CEA). December 2023. CO2 Baseline Database for the Indian Power Sector. Ministry of Power. Government of India. New Delhi https://cea.nic.in/wp-content/uploads/baseline/2024/01/User_Guide__Version_19.0.pdf
- ⁶⁸ Mäkinen, Kirsi, and Shahbaz Khan. (2010). "Policy Considerations for Greenhouse Gas Emissions from Freshwater Reservoirs." *Water Alternatives* 3(2):91–105.
- ⁶⁹ Dangi, Ashish & Narayanan, N. C. (forthcoming). Findings from ongoing doctoral research on Urban water systems in a changing climate. Ashank Desai Centre for Policy Studies (ADCPS), Indian Institute of Technology Bombay.

6. PERFORMANCE AND FINANCIAL ANALYSIS OF WATER SUPPLY AND SANITATION

ABHAY JUNAGHARE⁷⁰ 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 mandated by PWD Goa 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 INTRODUCTION

To analyse the financial performance against the SLBs for urban water supply and sanitation by the MoHUA, we *examine the revenue streams available to the PWD, Goa, for water supply, sewerage, and sanitation, as MMC does not play any role in water and sanitation infrastructure or service provision*. 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 analysed 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 budget 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)⁷¹. The above given ratios are essential to identify the financial health of the water utility and sewerage & sanitation at ULB.

6.2 PERFORMANCE ANALYSIS: SERVICE LEVEL BENCHMARKS

6.2.1 WATER SUPPLY

The performance indicators for water supply at MMC reveal both strengths and areas for improvement (Table 11). When compared to relevant benchmarks and the national average for India, there are some notable discrepancies that reflect the need for targeted interventions in certain areas. MMC achieves a 100% coverage of water supply connections, which aligns perfectly with the benchmark and India's average. This is a clear strength for the council, indicating that every household in the city has access to a water supply connection, ensuring inclusivity in water distribution. This metric shows that MMC has successfully addressed the issue of access to water, which is a fundamental aspect of urban water management. The per capita water supply at MMC stands at 135 litres per capita per day (lpcd), which is 15 lpcd below the benchmark of 150 lpcd, and slightly below the national average of 114 lpcd. This suggests that while the supply is somewhat above the national average, there is still a shortfall when compared to the desired benchmark. Improving the per capita water supply could help meet the growing water needs of the population and improve overall public health and well-being.

MMC has achieved a 100% metering rate for water connections, meeting both the benchmark and India's average. Metering is crucial for ensuring efficient water use and preventing water wastage. It also enables accurate billing and monitoring of water consumption, contributing to better revenue generation and system management. The NRW rate for MMC is 31%, which is significantly higher than the benchmark of 15% and the India average of 30%. High NRW indicates inefficiencies in the water supply system, such as leakage, theft, or unbilled consumption. This is a critical area for improvement, as reducing NRW would directly contribute to better water conservation, lower production costs, and enhanced service sustainability. MMC faces a major challenge in the continuity of water supply, with an average of just 2.7 hours of water supply per day, far below the 24-hour benchmark and the expected 4-8 hours range. This is a significant gap and indicates severe limitations in the water supply system's capacity to meet the demand for uninterrupted service. Improving the continuity of supply should be a priority, as this directly impacts the quality of life and overall satisfaction of residents.

The quality of water supplied by MMC is relatively strong, with 95% of the samples meeting specified potable water standards. This is slightly below the benchmark of 100%, but still a high percentage. While the water quality is generally good, a small gap remains, and further efforts could be made to ensure that every sample consistently meets the highest standards. MMC performs well in terms of addressing customer complaints, with 89% of complaints being resolved, which exceeds the benchmark of 80%. However, it is slightly below the India average of 94%. This indicates that while the complaint resolution system is effective, there is still room for improving responsiveness and efficiency in addressing water-related issues.

While MMC has made significant strides in areas such as water supply coverage, metering, and customer complaint redressal, there are critical gaps in water supply continuity, and non-revenue water.

Table 11: Performance Indicators for Water Supply at MMC

#	Water Supply	Calculations	Benchmarks	India Average*	2023-24**	Gaps
1	Coverage . Connections	(Total no. of HHs with water supply connections)/(Total no. of HHs in the City)	100%	70.00%	100%	0%
2	Per capita . supply (lpcd)	(Water supplied)/(Population served)	135 lpcd	114 lpcd	150 lpcd	15 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%	100%	0%
4	Non-revenue . water (NRW)	(Total water produced) - (Total water sold)/(Total water produced)	15%	31%	45%	30%
5	Continuity of . water supply (hours)	Average hours of water supply	24 hours	2.7 hours	4 to 8 hours	-16 hours
6	Quality and . treatment	(Number of samples that meet the specified potable water standards)/(Total number of water supply related complaints received)	100%	95%	100%	0%
7	Redressal of . customer complaints	(Total number of complaints redressed)/ (Total number of water supply related complaints received)	80%	89%	94%	14%

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

6.2.2 SEWERAGE & SANITATION

The analysis of the sewerage and sanitation performance indicators for MMC highlights both strengths and areas where improvements are necessary (Table 12). When compared to the relevant benchmarks, several indicators show that while MMC performs well in some areas, there are gaps that need to be addressed to ensure comprehensive and sustainable sewerage and sanitation services for the city. MMC's coverage of toilets stands at 83%, which is below the benchmark of 100%. This means that a significant portion of the population still lacks access to individual or community toilets within walking distance. The gap of 17% indicates a need for improved sanitation infrastructure, especially for underserved areas. Ensuring universal access to toilets is critical to preventing open defecation, improving public health, and meeting sanitation goals. Similarly, MMC's sewage network coverage is at 82%, which is 18% below the benchmark of 100%. This suggests that a substantial number of households in the city are not yet connected to the sewage network, which can lead to improper wastewater disposal and environmental contamination. Expanding the sewage network to cover all households would significantly improve public health outcomes and contribute to better urban sanitation.

The collection efficiency is reported as 100%, which aligns perfectly with the benchmark. This indicates that all wastewater generated within the city is being effectively collected by the sewage network, ensuring that wastewater is transported to treatment plants and is not left untreated or mismanaged. MMC meets the benchmark for sewage treatment capacity, with a 100% adequacy rating. This means that the city has sufficient treatment plant capacity to handle the total volume of wastewater generated, which is crucial for preventing untreated sewage from polluting water bodies and the environment. Ensuring that sewage treatment plants operate at full capacity is vital for maintaining public health and environmental quality. The quality of sewage treatment is also at a strong 100%, meeting the benchmark. This shows that the treated wastewater meets specified secondary treatment standards, ensuring that the treated effluent is safe for discharge into the environment or further reuse. This is a positive indicator of effective sewage management and treatment processes in the city.

One significant gap is in the extent of reuse and recycling of sewage, with MMC reporting a 0% recycling rate against the benchmark of 20%. The absence of a reuse and recycling mechanism for treated wastewater represents an opportunity missed in terms of water conservation and sustainability. Implementing systems to reuse and recycle treated sewage could alleviate pressure on freshwater resources and contribute to a more sustainable water management strategy. MMC performs excellently in redressing customer complaints, with a 100% resolution rate, which is well above the benchmark of 80%. This indicates that the municipal council is responsive to residents' concerns and takes effective measures to address sewage-related complaints promptly. High efficiency in complaint redressal enhances customer satisfaction and trust in the sanitation services provided. However, there are some

critical areas that need attention, such as the coverage of toilets and sewage network services, which currently fall short of the benchmark. The lack of sewage recycling and reuse, along with the gaps in toilet and sewage network coverage, present significant challenges.

Table 12: Performance Indicators for Sewerage & Sanitation at MMC

#	Sewerage and Sanitation Indicators	Calculations	Benchmarks	2023-24*	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%	83%	-17%
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%	82%	-18%
3.	Collection Efficiency of the Sewage Network	(Wastewater collected)/ (Total water supplied + Estimated water use from other sources)	100%	100%	0%
4.	Adequacy of Sewage Treatment Capacity	(Treatment plant capacity)/ (Total water consumed + Total number of HHs with direct connection to sewage network)	100%	100%	0%
5.	Quality of Sewage Treatment	(Number of samples that pass specified secondary treatment standards)/ (Total number of wastewater samples tested in a month)	100%	100%	0%
6.	Extent of Reuse and Recycling of Sewage	(Wastewater recycled or reused after appropriate treatment)/ (Wastewater received at STPs)	20%	0%	-20%
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%	100%	20%

Source: Mormugao Municipal Council, 2025

6.3 REVENUE STREAMS

This sub-section analyses the revenue streams available to PWD, Goa at MMC 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 analysed 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 trends for cost recovery and collection efficiency. This helps assess MMC's preparedness to meet current and future demands for water supply and sewerage & sanitation infrastructure and services, and to enhance climate resilience of WASH. These actions ultimately contribute to improved public health outcomes and more sustainable urban environments. This sub-section is structured viz., 1) retail water tariff (PWD), 2) retail sewerage tariff (PWD), 3) Ratio of grants to own revenue at PWD, Goa for water supply and sewerage & sanitation, and 4) Assessment of Finances for Water Supply and Sewerage & Sanitation at Mormugao.

6.3.1 RETAIL WATER TARIFF – PWD, GOA

The tariff structure for new domestic water connections outlines the fees based on the diameter of the connection (Table 13). For smaller connections (15/20 mm), the total fees amount to INR 1,000, with a meter rent of INR 50 and a water rate of INR 3.50 per kilolitre (KL). As the connection size increases, so do the fees: for connections between 20 mm and 25 mm, the total fee is INR 3,000 with a water rate of INR 9.00 per KL, and for connections between 25 mm and 50 mm, the total fee rises to INR 4,000 with a water rate of INR 15.00 per KL. Larger connections (50 mm to 100 mm) incur a total fee of INR 7,000, with a water rate of INR 25.00 per KL, while connections over 100 mm require a deposit of INR 10,000, but the water rate is not specified in the table. Additionally, the connection and labour charges are not applicable in this structure.

The tariff structure for new non-domestic water connections varies based on the diameter of the connection, with higher fees reflecting the larger volume of water typically consumed by non-domestic users (Table 14). For a 15/20 mm connection, the total fee is INR 5,000, which includes a meter rent of INR 50 and a water rate of INR 3.50 per kilolitre (KL). As the connection diameter increases, the fees rise, i.e., for connections between 20 mm and 25 mm, the total fee is INR 9,000 with a water rate of INR 9.00 per KL, and for connections between 25 mm and 50 mm, the total fee is INR 20,000 with a water rate of INR 15.00 per KL. For larger connections (50 mm to 100 mm), the total fee is INR 25,000 with a water rate of INR 25.00 per KL, while connections over 100 mm require a total fee of INR 30,000, but the water rate is not specified.

Table 13: New water connection fees for Domestic consumers

#	New Domestic Connection Fees					Inspection Charges (INR)	Meter Rent (INR)	Water rates per unit (INR)
	Diameter (mm)	Deposit (INR)	Connection Fee (INR)	Labour Charges (INR)	Total (INR)			
1.	15/20	1,000	0	0	1,000	Rs. 100 per connection per year	50.00	3.50 per KL
2.	>20 till 25	3,000	0	0	3,000		80.00	9.00 per KL
3.	>25 till 50	4,000	0	0	4,000		125.00	15.00 per KL
4.	>50 till 100	7,000	0	0	7,000		350.00	25.00 per KL
5.	>100	10,000	0	0	10,000		1,000.00	

Source: Department Public Works (PWD), Government of Goa, 24-17/PWD/PCE-EO/2023-24/73

Table 14: New water connection fees for Non-Domestic consumers

#	New Non-Domestic Connection Fees					Inspection Charges (INR)	Meter Rent (INR)	Water rates per unit (INR)
	Diameter (mm)	Deposit (INR)	Connection Fee (INR)	Labour Charges (INR)	Total (INR)			
1.	15/20	5,000	0	0	5,000	Rs. 500 per connection per year	50.00	3.50 per KL
2.	>20 till 25	9,000	0	0	9,000		80.00	9.00 per KL
3.	>25 till 50	20,000	0	0	20,000		125.00	15.00 per KL
4.	>50 till 100	25,000	0	0	25,000		350.00	25.00 per KL
5.	>100	30,000	0	0	30,000		1,000.00	

Source: Department Public Works (PWD), Government of Goa, 24-17/PWD/PCE-EO/2023-24/73

The connection and labour charges are not included in the fees, and a significant annual meter rent applies, particularly for the smallest connection size.

6.3.2 RETAIL SEWERAGE TARIFF – PWD, GOA

The Goa Sewerage System and Sanitation Services Management Rules, 2010, outline a clear tariff structure for the provision of sewerage services in the state (Table 15). The tariff is categorized based on the type of service, with domestic users being charged Re. 1 per cubic meter (Cu. M.) of wastewater generated, while commercial and industrial users face higher rates of Rs. 5 per Cu. M. Public places are charged Rs. 3 per Cu. M. In addition to the per-unit charges, a one-time security deposit is required based on the category: domestic users pay Rs. 500, commercial and public places pay Rs. 1,000, and industrial users pay Rs. 3,000 per connection. A surcharge of 2% on the billed amount is applied for delayed payments, rounded to the next higher rupee.

Table 15: Sewerage Tariff Structure at Goa

#	Category	Tariff *	Security Deposit (One Time)
1.	Domestic	Re. 1 per Cu. M. of wastewater generated	Rs. 500 per connection
2.	Commercial	Rs. 5 per Cu. M. of wastewater generated	Rs. 1,000 per connection
3.	Industrial	Rs. 5 per Cu. M. of wastewater generated	Rs. 3,000 per connection
4.	Public Places	Rs. 3 per Cu. M. of wastewater generated	Rs. 1,000 per connection

*Surcharge for delayed payment 2% of billed amount. Rounded to next higher rupee.

Source: The Goa Sewerage System and Sanitation Services Management Rules, 2010, Government of Goa

Regarding new connection charges, these are determined by the diameter of the pipe used for the connection (Table 16). Domestic connections with pipes up to 150 mm are charged Rs. 200, while those with pipes greater than 150 mm incur a charge of Rs. 350, along with a Rs. 100 per unit fee. Commercial and industrial connections follow a similar structure, with higher rates for larger diameter pipes and additional per-unit costs based on the pipe size. Public places, like commercial and industrial categories, incur a one-time connection fee depending on pipe size, with no per-unit charges applicable.

Table 16: New Sewerage Connection Charges at Goa

#	Category	Connection Charges Based on Pipe Diameter		Per Unit in Group
		Upto 150 mm	More than 150 mm	
1.	Domestic	Rs. 200 per connection	Rs. 350 per connection	Rs. 100 per unit
2.	Commercial	Rs. 500 per connection	Rs. 750 per connection	Rs. 250 per unit
3.	Industrial	Rs. 1,000 per connection	Rs. 2,000 per connection	Rs. 500 per unit
4.	Public Places	Rs. 1,000 per connection	Rs. 2,000 per connection	Not Applicable

Source: The Goa Sewerage System and Sanitation Services Management Rules, 2010, Government of Goa

The tariff structure aims to maintain fair and consistent charging based on usage and connection specifics. These charges are collected by the PWD at Goa.

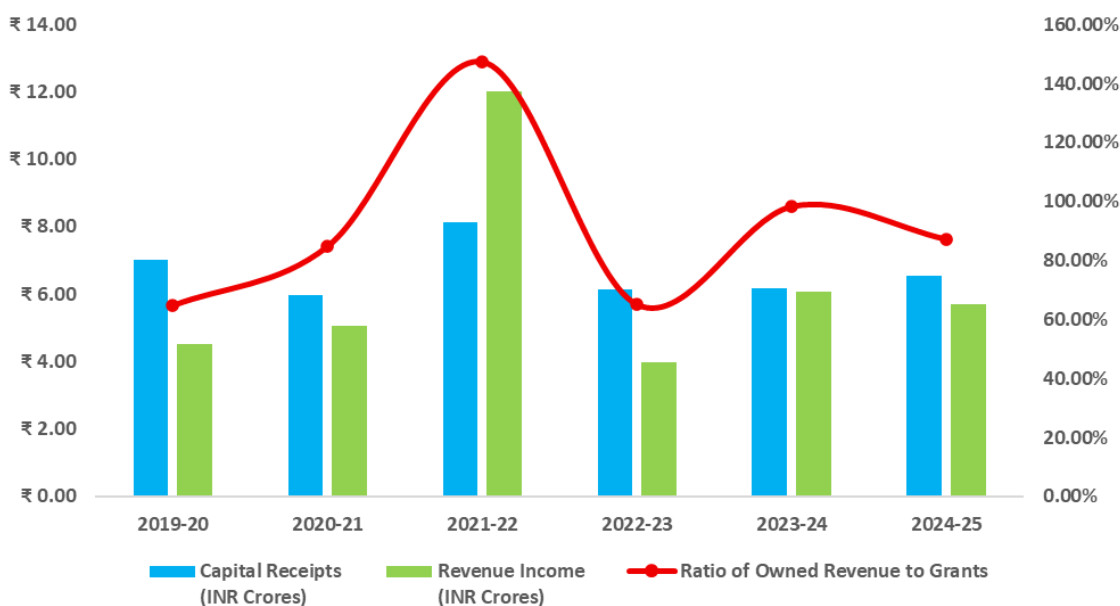
6.3.3 RATIO OF GRANTS TO OWN REVENUE

The data presented provides a clear view of the ratio of owned revenue generated by the PWD for Water Supply and Sewerage, Goa to the grants received over a period of six years, i.e., from 2019 to 2025. The ratio, expressed as a percentage, is a key indicator of the department's financial autonomy, highlighting how much of the water supply and sewerage revenue is self-generated as opposed to being reliant on external grants. In 2019-20, the ratio of owned revenue to grants was 64.70%, meaning that for every rupee of grant received, the department generated around 65 paise of revenue on its own. This figure indicates a moderate dependency on grants, with owned revenue being just over half of the total funding required for water supply operations. However, the subsequent year, 2020-21, saw a significant improvement in the ratio to 84.83%. This increase suggests that the department was able to enhance its revenue generation while reducing its reliance on grants, indicating a more efficient or expanded revenue model.

A major jump occurred in 2021-22 (Figure 31), where the ratio spiked dramatically to 147.45%. In this year, the revenue income outstripped the capital receipts, with owned revenue more than compensating for grants. This unusually high ratio points towards the one-time settlement offer given by the PWD to the consumers having backlogs. This fiscal strategy has improved the internal revenue collection. This period marked the highest level of financial self-sufficiency observed in the data. However, the ratio reverted to more modest levels in 2022-23, dropping to 64.99%, which was nearly identical to the 2019-20 figure. This suggests that the department might have faced challenges in maintaining the revenue generation momentum from the previous year, possibly due to fluctuations in water consumption, tariff adjustments, or other operational issues. From 2023-24 onward, the ratio

shows a steady improvement, reaching 98.33% in 2023-24, which indicates near independence from grants. By 2024-25, the ratio stands at 87.16%, which remains strong but lower than the peak achieved in 2021-22. This suggests a trend where the department is consistently improving its revenue generation capabilities, even if it cannot fully eliminate its dependence on grants.

Figure 31: Ratio of owned revenue to grants at PWD Goa



Source: Municipal Budget Documents

When looking at the total over the six years, the department's ratio of owned revenue to grants is 93.48%. This means that, on average, for every rupee of grants received, the department was able to generate nearly 93 paise on its own. This is a strong performance overall, but it also reflects a gradual reliance on grants, especially in the years where the ratio dropped significantly (2022-23). Thus, the department has made notable progress in improving its financial self-sufficiency over the years, especially from 2020-21 to 2021-22. However, the fluctuations in the ratio across the years suggest that while the department is moving toward greater independence, there are external factors that continue to influence its ability to generate owned revenue consistently. The overall trend is positive, indicating a growing ability to reduce reliance on grants, but more work is needed to sustain and possibly improve these results in the future.

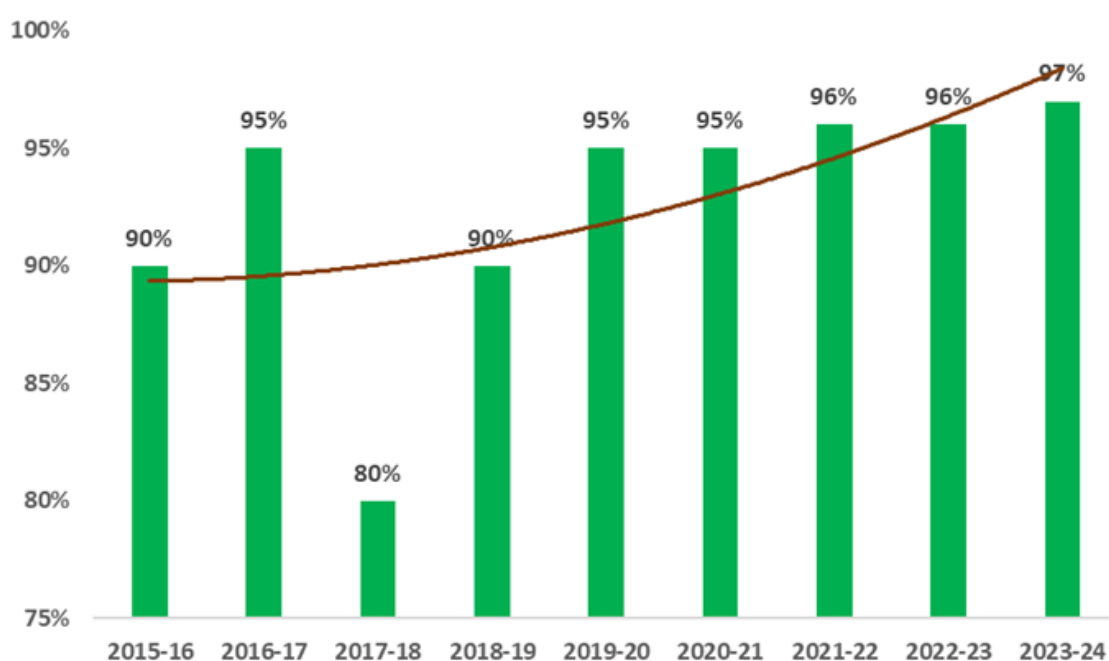
6.4 ASSESSMENT OF FINANCES

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

6.4.1 WATER SUPPLY

Over the past nine years, MMC has consistently maintained a high-cost recovery rate for water supply, generally above 80%, reflecting a strong financial performance (Figure 32). Notable improvements occurred between 2015-16 and 2016-17, with cost recovery rising from 90% to 95%, but a brief dip to 80% in 2017-18 was quickly addressed, recovering to 90% in 2018-19.

Figure 32: Trend analysis of cost recovery in water supply charges at MMC



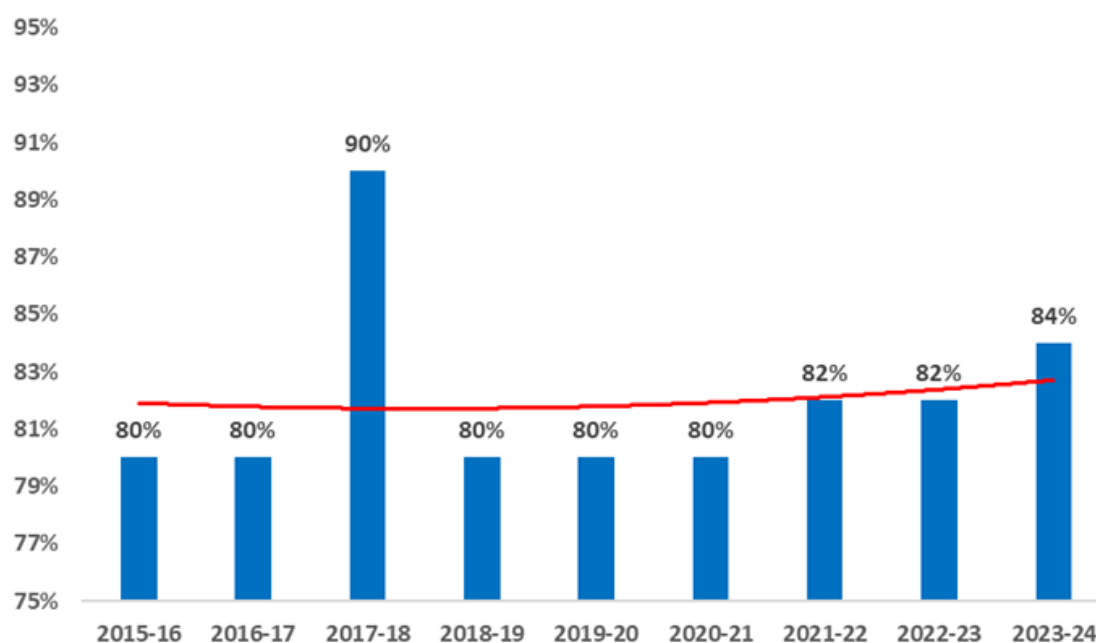
Source: Mormugao Municipal Council (MMC), 2025

From 2019-20 to 2021-22, the recovery rate stabilized at 95-96%, showcasing effective management of expenditures and revenues. The rate further improved to 97% in 2023-24, suggesting continued efforts to optimize billing and reduce losses. Overall, MMC's cost

recovery trend indicates a positive shift towards full cost recovery, ensuring long-term sustainability and enhanced water service delivery.

The collection efficiency for water supply charges at MMC has shown a generally stable trend with some fluctuations, reflecting varying levels of success in revenue recovery (Fig. 33). From 2015-16 to 2016-17, efficiency remained steady at 80%, indicating moderate success in collecting billed revenue but highlighting challenges in achieving higher collection rates. A significant improvement occurred in 2017-18, when efficiency rose to 90%, but this gain was not sustained, dropping back to 80% from 2018-19 to 2020-21, possibly due to relaxed efforts or consumer payment issues.

Figure 33: Trend analysis of collection efficiency in water supply charges at MMC



Source: Mormugao Municipal Council (MMC), 2025

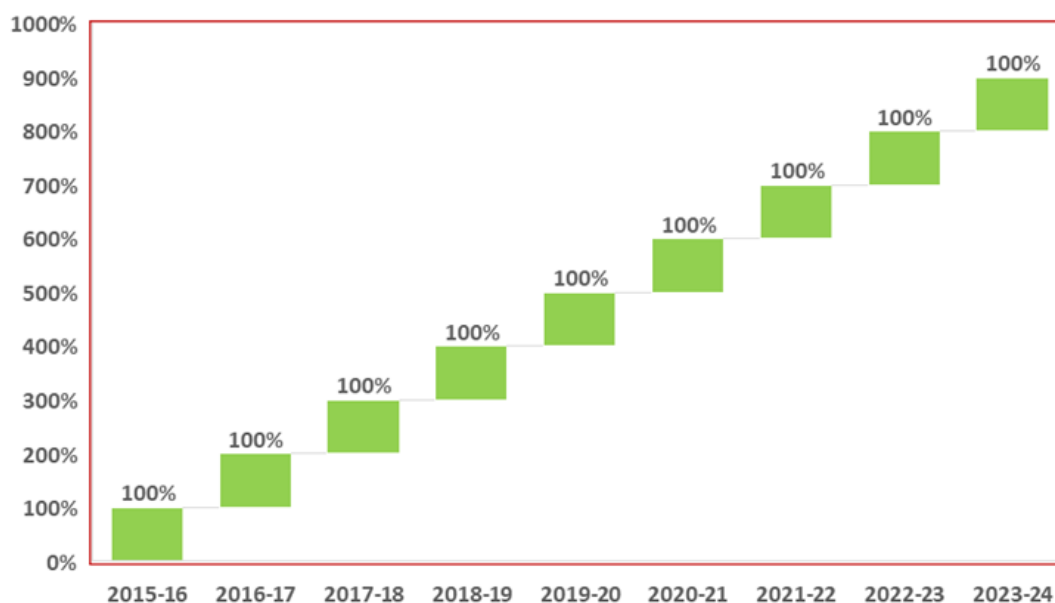
However, by 2021-22, efficiency increased slightly to 82%, and by 2023-24, it reached 84%, showing a steady improvement. Despite this positive trend, the efficiency remains below optimal levels, suggesting that further improvements could be made through better billing

practices, digital payment options, and stricter enforcement measures to ensure full revenue recovery and financial sustainability for the water supply system.

6.4.2 SEWERAGE AND SANITATION

From 2015-16 to 2023-24, MMC consistently achieved 100% cost recovery for sewerage and sanitation services, demonstrating strong financial management and sustainability (Figure 34). This indicates that the revenue generated from user fees has been more than adequate to cover both operational and capital costs for maintaining and upgrading sewage infrastructure. The sustained 100% recovery reflects efficient billing and collection systems, successful cost management, and the minimization of losses, such as leakage or illegal connections.

Figure 34: Trend analysis of cost recovery in sewerage & sanitation charges at MMC



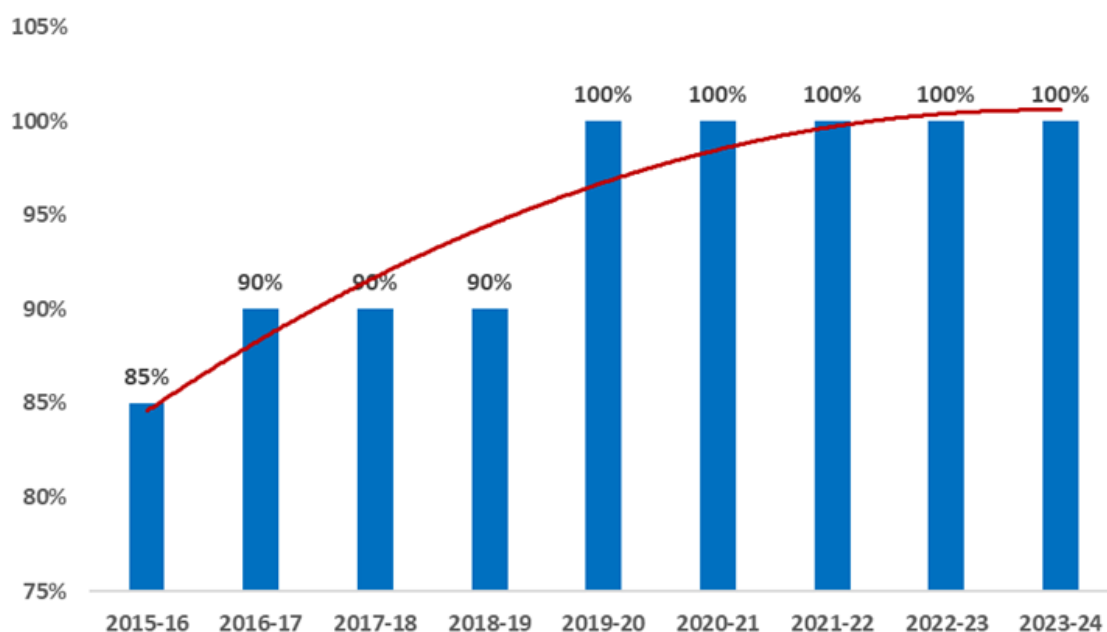
Source: Mormugao Municipal Council (MMC), 2025

Additionally, MMC's ability to maintain this level of recovery suggests that user charges are well-aligned with service costs and that the council has implemented best practices, including modern technologies for waste treatment. This high level of cost recovery also reduces the

council's dependence on external grants, ensuring financial resilience, and supporting both current operations and future infrastructure development as the urban population grows.

From 2015-16 to 2023-24, the collection efficiency for sewerage and sanitation services at MMC improved significantly, rising from 85% in 2015-16 to a consistent 100% from 2019-20 onwards (Figure 35). This improvement reflects the council's successful efforts in refining billing practices, enhancing consumer outreach, implementing online payment options, and enforcing stricter payment deadlines.

Figure 35: Trend analysis of collection efficiency in sewerage & sanitation charges at MMC



Source: Mormugao Municipal Council (MMC), 2025

The steady increase in efficiency suggests better administrative capabilities, improved management of consumer accounts, and effective follow-up on overdue payments. Achieving 100% collection efficiency has strengthened the financial sustainability of the sewerage system, ensuring the availability of funds for operation, maintenance, and expansion without relying on external financial support. This consistent achievement also demonstrates MMC's commitment to providing high-quality services and effective governance.

6.5 KEY FINANCIAL CHALLENGES

The key financial challenges faced by PWD, Goa in water supply services at MMC include fluctuations in cost recovery and collection efficiency. Although cost recovery has generally been strong, with rates fluctuating between 80% and 97%, the dip to 80% in 2017-18 suggests periods of higher operational costs, inefficiencies, or issues in revenue collection that temporarily impacted financial performance. Similarly, while collection efficiency has steadily improved over time, it has faced challenges in sustaining high levels of performance, with fluctuations between 80% and 90% during certain years. These fluctuations reflect potential issues such as economic challenges affecting consumers' ability to pay, inefficiencies in billing and collection processes, and the need for stricter enforcement measures. To strengthen financial sustainability, PWD could focus on improving billing systems, expanding digital payment options, and addressing collection inefficiencies.

The key financial challenges faced by PWD, Goa at MMC in sewerage and sanitation services primarily revolve around maintaining consistent and efficient revenue collection and cost recovery. Despite achieving 100% cost recovery over the years, challenges such as ensuring the continued alignment of user charges with operational and capital costs, and effectively managing non-revenue sewage, remain crucial. The initial fluctuations in collection efficiency, which ranged from 85% to 90% before achieving 100% efficiency, indicate issues related to delayed payments, administrative inefficiencies, and consumer awareness. Furthermore, as the urban population grows, the PWD and MMC faces the ongoing challenge of managing increasing demand for sewerage services while maintaining the financial stability of the system. Ensuring that both cost recovery and collection efficiency remain high without relying on external financial support is critical for the long-term sustainability of these essential services.

NOTES & REFERENCES

⁷⁰Author's Note: This chapter is based on ongoing doctoral research by Abhay Junaghere 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.

⁷¹ 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.

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 Mormugao. 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 Mormugao'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 Mormugao 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 Mormugao, a class III town and an important regional settlement in North Goa district of Goa. 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)⁷², *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 overlaid 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.

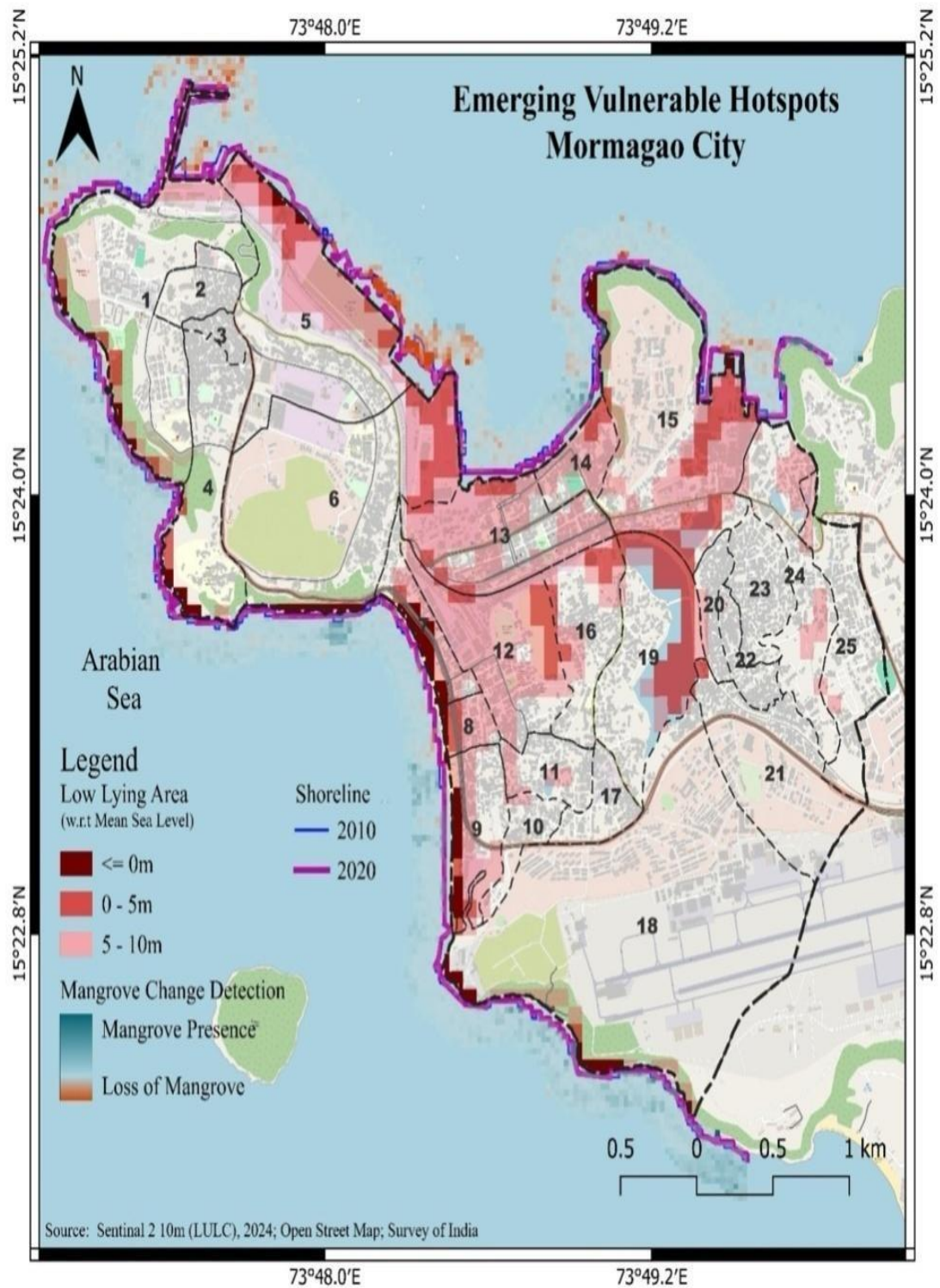
7.3 EXPOSURE TO CLIMATE RISK

Mormugao has tropical – maritime climate with warm and humid conditions prevailing for most parts of the year. The temperature varies between 19.2°C to 34°C with the mean at 26.92°C. The months of April-May are relatively the warmest months and December; January and February are the coolest months. There is regular and sufficient rainfall during the southwest monsoon season, mainly from June to September. The average annual rainfall is of around 2400 mm. Over 90 per cent of the annual rainfall occurs during the monsoon months of June to September. The month of July is the rainiest month when about 36 per cent of the annual rainfall is recorded.

Goa is already experiencing sea level rise. Long-term station data from Mormugao suggests that the sea level at this station in Goa is rising at a rate of 1.45 mm/year. Risk from rising sea levels is slightly lower for Mormugao compared to other coastal towns in the state due to its elevation. The coast of the taluka Mormugao has experienced the lowest erosion rates. Coastlines such as the Quepem, Mormugao and Mormugao are backed by headlands or cliffs and are thus the least vulnerable to coastal inundation.⁷³

The elevation profile of Mormugao (Ref. Figure 36) reveals the wards 7, 8, 9, 12, 13, 14, 15 and 16 as low-lying wards with a elevation less than 10 m above sea level (Ref. Table 17). These are part of the low-lying coastal elevation zone and susceptible to coastal inundation and flooding. Due to a significant presence of population these wards can also be considered as the most vulnerable zones of Mormugao city. With a depletion of mangroves observed over the last decade along the shoreline, the exposed wards are prone to storm surges and inundation due to sea level rise.

Figure 36: Emerging Vulnerability Hotspots of Mormugao City to Climate Hazards



Source: Analytics derived from Open Street Map; Landsat 9 (Shoreline), 2020; Land

Table 17: Ward Level Vulnerability to Flooding based on Elevation Profile

Ward	% Built-up	very high vulnerability, Elevation below MSL	High vulnerability, Elevation < 10 m above MSL	Low Vulnerability, Elevation > 10 m above MSL	Ward	% Built-up	very high vulnerability, Elevation below MSL	High vulnerability, Elevation < 10 m above MSL	Low Vulnerability, Elevation > 10 m above MSL
1	0.2	4.2%	18.0%	82.0%	14	0.7	0.0%	80.6%	19.4%
2	0.6	0.0%	0.0%	100.0%	15	0.3	1.4%	45.6%	54.4%
3	0.9	0.0%	0.0%	100.0%	16	0.5	0.0%	41.3%	58.7%
4	0.3	5.2%	11.6%	88.4%	17	0.6	0.0%	0.0%	100.0%
5	0.2	0.4%	35.8%	64.2%	18	0.2	2.3%	6.2%	93.8%
6	0.2	2.7%	17.8%	82.2%	19	0.2	0.0%	37.1%	62.9%
7	0.4	33.7%	73.6%	26.4%	20	0.8	0.0%	21.6%	78.4%
8	0.5	13.5%	95.8%	4.2%	21	0.3	0.0%	2.1%	98.0%
9	0.4	18.6%	66.7%	33.3%	22	0.8	0.0%	0.0%	100.0%
10	0.5	0.0%	18.7%	81.3%	23	0.8	0.0%	0.0%	100.0%
11	0.6	0.0%	23.6%	76.4%	24	0.4	0.0%	24.1%	75.9%
12	0.4	0.0%	86.3%	13.7%	25	0.4	0.0%	9.8%	90.2%
13	0.5	0.0%	79.8%	20.2%					
Source: GIS analysis based on Digital Elevation Mapping									

As per media reports highlight frequent blockages in the drainage network, leading to urban flooding during monsoons in almost all areas of the Mormugao town. Water logging appears to be a recurring issue, as media reports highlight frequent blockages in the drainage network, leading to urban flooding across all 25 wards of Mormugao in 2024. During the monsoon season, waterlogging persists for 2-3 days, with water levels reaching up to 2 feet.

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.⁷⁴

Though Goa is in high precipitation zones, it has one of the lowest per capita freshwater availabilities. The draft state water policy 2015 presents various challenges the state faces in utilizing water resources. The rivers are prone to tidal variations up to 40 km inland and seasonal water availability variations. Water sources in the mining zones, water scarcity has been increasing due to the withdrawal of groundwater and the non-replenishment of wells (NABCONS, 2023).

According to NITI Aayog's Climate and Energy Dashboard, South Goa District fall within a moderate damage risk zone for wind hazards (with wind speeds reaching up to 39 m/s) and moderate cyclonic activity (featuring maximum sustained wind speeds ranging from 48 to 63 knots). However, Mormugao, which includes Mormugao town, has been identified as highly vulnerable to cyclones, based on the severity of the impacts.⁷⁵

Mormugao is in a relatively safe zone with respect to earthquakes and falls under seismic zone III (MSK intensity VII), which means it is exposed to moderate seismic activity and is more prone to minor to medium-intensity earthquakes. Seismic activities can compound coastal risks like subsidence of land, change in ecological system, diversion of river flow or tsunami leading to extreme high waves as has been witnessed in Kutch coasts. Similarly, co- occurrence of two or more hazards has often been witnessed for example earthquakes and landslides, earthquakes and heavy precipitation. In a recent study appearing in Science Advances, the researchers report that episodes of heavy snowfall and rain likely contributed to a swarm of earthquakes over the past several years in northern Japan. The study is the first to show that climate conditions could initiate some quakes.⁷⁶

Draft State Water Policy (2015) for Goa states that despite copious annual rainfall, rivers of Goa have very low flow for the non-monsoon months resulting in scarcity of drinking water for the period especially in the months of April to start of June. Moreover, the narrow width of the state, steep slopes of Western Ghats, porous sub-stratum, non-uniform distribution of rainfall over time and space cause temporal imbalances of water

availability in the state. This also explains the paradox that though Goa is situated in high precipitation zones, it has one of the lowest per capita freshwater availabilities.⁷⁷

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. The city's administrative Wards 5, 7, 8, 9, 13, 14 and 15 along the northern and western shores are particularly vulnerable to storm surges due to the low elevation and proximity to the sea as can be seen on map depicting the emerging vulnerability hotspots.

Change detection based on Sentinel data spanning 10 years reveals significant changes in status of mangroves and the coastal shoreline. These changes increase risks such as saltwater intrusion into groundwater and exposure of the coasts to erosion.

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.

It has been found that the low-lying alluvial areas close to the rivers have a higher susceptibility to the seawater intrusion due to tidal activity. Based on finite element model, the extent of seawater intrusion has been predicted up to 300 m away from the coastline. Besides tidal activity, marine depositional environments also contribute to groundwater salinity in the state. The depositions are enhanced by high sediment influx by the rivers due to mining activities in upstream. The withdrawal of groundwater is increasing over time, with a rapid increase in the infra structure development for tourism, which may cause serious ground water problems in the state.⁷⁸

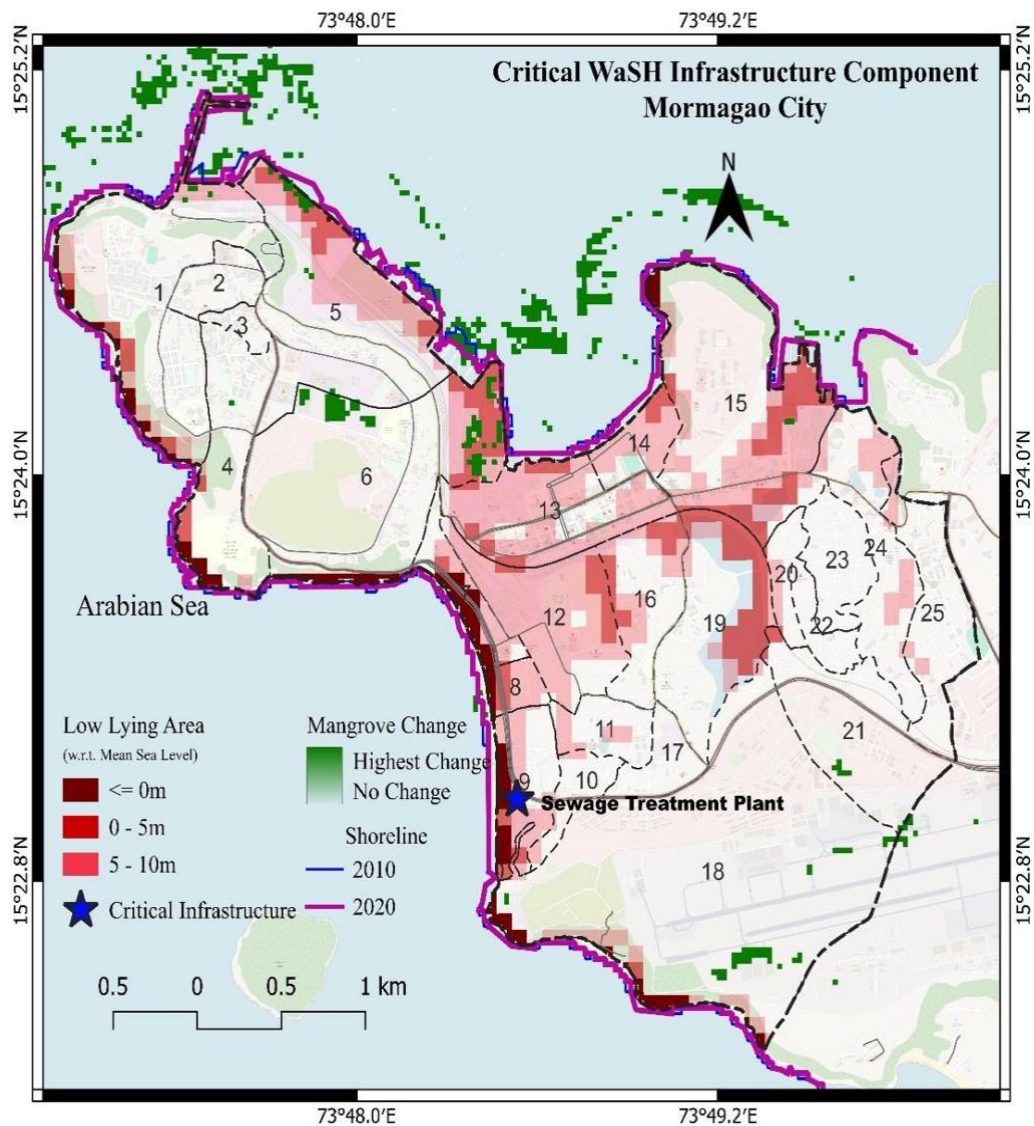
The saltwater intrusion presents a critical challenge for Mormugao in two primary ways. For areas without piped water, it compromises access to safe, fresh water. Additionally, the increased conductivity of groundwater caused by saltwater accelerates the corrosion of underground water and wastewater 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.⁷⁹

The aging infrastructure in some parts of Mormugao compounds these risks. Specific wards such as ward 7 - 9, 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. These vulnerabilities necessitate decentralized yet monitored sanitation solutions. Scientifically advanced community level sanitation systems, such as

septic tanks with regular monitored desludging services, are preferable in such locations to prevent contamination. The STP of Mormugao is in a low-lying region and is exposed to coastal inundation.

Saltwater accumulation in treatment units—such as wastewater treatment plants, activated sludge tanks, sanitation pits, or septic tanks—can reduce their efficiency in removing pollutants like organic matter and nutrients. High electrical conductivity, characteristic of saltwater, adversely affects microbial diversity and organic matter removal efficiency⁸⁰. Septic tanks and STPs in the region are particularly at risk of failure as is seen in Mormugao (Ref. Figure 37).

Figure 37: Location of Critical Components of the Wash Infrastructure within Administrative Boundary



Source: Derived from Open Street Map; Landsat 9 (Shoreline), 2020; Landsat 5 (Shoreline), 2010; Mormugao Municipality; SRTM DEM.

7.3 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 were 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.

7.3.1 ADEQUACY OF INFRASTRUCTURE

The WASH infrastructure in Mormugao is vulnerable to climate risks w.r.t. coverage and technology adopted.

Mormugao has access to adequate safe freshwater sources and the municipality provides treated and piped water supply to all. According to service level benchmarks, the water supply is considered adequate. Although supply is intermittent, residents engaged during fieldwork generally expressed satisfaction with both the quality and quantity of water. However, some reported pressure fluctuations and a reliance on supplementary sources.

Mormugao's water distribution network has aging infrastructure and vulnerabilities, leading to supply interruptions. For instance, in January 2025, the entire Mormugao taluka experienced a two-day water outage due to PWD's repair work on the main pipeline from the Salaulim water treatment plant. Specific areas like Baina and parts of Sada have reported receiving water late at night, sometimes after midnight, with residents enduring prolonged periods without water, occasionally up to three to four days (timesofindia, 2025)⁸¹.

The city's increasing water footprint, since it is one of the densest cities of Goa and attracts the largest number of migrant livings in slum like condition, results in significant non-revenue water, and hence requires the augmentation of its sourcing at regular intervals. The access to safe sanitation in vulnerable locations is poor. Low-lying wards rely on community-managed toilets.

The current technology adopted for sewerage treatment of SBR-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, salinity ingress, and high-water tables during intense monsoon rainfall, which extends for more than four months. The STP, based on SBR technology, is located on low lying land which is prone to flooding (Ref. Figure 32). While SBR technology, effectively treats wastewater and is easy to control in case of incidents, flexible in operation and energy efficient too, but SBR tanks require

sophisticated and modern monitoring systems hence shall need to be safeguarded from unprecedented flooding and other shock events.

Wastewater is not reused, leading to a high probability of it being released into the sea.

7.3.2 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. SAPCC in its Sectoral Adaptation Strategies for Water Supply specifically mentions that though Goa is situated in high precipitation zones, it has one of the lowest per capita freshwater availabilities. The rivers are prone to tidal variations up to 40 km inland and lead to seasonal water availability variations.

Strengthening both distant sourcing and local sourcing is critical for achieving long-term water security amid climate uncertainty. A diversified water portfolio ensures communities have alternative supply options, reducing risks associated with climate variability, rising demand, and resource conflicts. The dependence on distant water sources, the per capita distribution benchmarks adopted, and the burgeoning population can contribute to water stress and result in inequitable distribution of treated water. Aging pipelines, salt corrosion, and a heavy reliance on pumps due to hilly terrain can complicate Mormugao's water supply. Continuity and redundancy planning of water infrastructure shall help minimize disruptions and aid in quick recovery of services post a shock event, increasing the reliability of the services in the face of climate events.

Coastal cities often face disruptions during strong winds and cyclones, as overhead electrical networks can fail, impacting pumping and treatment facilities.

Long networks of centralized sewerage are not only difficult to maintain for undulating and low-lying terrains but can be unfeasible due to corrosion, leakages, reverse flows, and need for frequent uphaul.

Electricity networks can fail, impacting water pumping and treatment facilities. To ensure continuity, water systems should incorporate alternative energy sources as backups to reduce dependency on the main power grid.

Dependencies on power supply for pumping stations in water supply and sewerage systems result in a lack of reliability at times. Goa does not produce any power and is dependent on NTPC plants in other states for supply of power whereas demand for power due to increased urbanization, industrialization, a boom in construction activity, commercialization, consumerism is constantly increasing.⁸² Power fluctuations have disrupted water supply. As per media reports, In August 2022, many areas faced water shortages due to such issues.

7.3.3 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.

The involvement of multiple agencies in WaSH infrastructure development, like state PWD in case of Goa, has limited the ability of ULBs to efficiently manage resources and address local needs. This is a finding from the multiple towns and cities explored to assess the resilience in WaSH infrastructure.

Governance arrangements, in many contexts, too fragmented across administrative boundaries and sectors to provide integrated responses to the increasing and cascading risks from climate-related changes in the ocean and/or cryosphere. The capacity of governance systems is not sufficiently rapid or robust to adequately address the scale of increasing projected risks. Intensifying cooperation and coordination among governing authorities across scales, jurisdictions, sectors, policy domains and planning horizons can enable effective responses to change in the ocean, cryosphere and to sea level rise (high confidence)⁸³.

Government grants account for the highest proportion of income, amounting to 50% share of revenue, which indicates a significant reliance on external funding sources for municipal operations and development projects. However Municipal Council of Mormugao has been able to maintain expenditure within the limits of available receipts ensures financial sustainability and minimizes dependency in operations.

Treating wastewater up to the secondary stage for release into the ecosystem could be a missed opportunity for a city like Mormugao. With a vibrant tourism and port-based economy and the possible emergence of a water scarcity, Mormugao needs to explore the reuse of wastewater through tertiary treatment as a source of revenue.

The State Action Plan for Climate Change mentions e key adaptation strategies for water sectors outlined are adaptation of water-related infrastructure appropriate planning of water to ensure water supply to all, maintenance of water resources to avoid flooding and to keep related infrastructure functional during peak events and disasters and raising awareness (NABCONS, 2023). Since Mormugao is one of the four talukas containing most of the state population, slum population and economic activity and is at the highest risk due to climate change, it has been identified for prioritized adaptative action by State Climate Action Plan.

NOTES & REFERENCE

- ⁷²UNDRR, C. (2023). Global Methodology for Infrastructure Resilience Review. United Nations Office for Disaster Risk Reduction (UNDRR) and Coalition for Disaster Resilient Infrastructure (CDRI).
- ⁷³Unte, P. D. (2014). Multi-Hazards Coastal Vulnerability Assessment Of Goa, India, Using Geospatial Techniques. Elsevier, Volume 95, Pages 264-281.
- ⁷⁴Chakrabarti, A. K. (2009). Urban Floods And Case Studies. Disaster & Development.
- ⁷⁵GSDMA. (2024). State Disaster Management Plan. Porvorim, Goa: Goa State Disaster Management Authority, Government Of Goa.
- ⁷⁶Wang, Q.-Y. (2024). Untangling The Environmental And Tectonic Drivers Of The Noto Earthquake Swarm In Japan. Science Advances.
- ⁷⁷SANDRP. (2016, November 25). Goa River Profile. Retrieved From SANDRP - South Asia Network On Dams, Rivers And People: <https://Sandrp.in/2016/11/25/Goa-River-Profile/>
- ⁷⁸P Prusty, S. H. (2020). Seawater Intrusion In The Coastal Aquifers Of India-Areview. Hydroresearch.
- ⁷⁹Berrin Tansel, K. Z. (2022). Effects Of Saltwater Intrusion And Sea Level Rise On Aging And Corrosion Rates Of Iron Pipes In Water Distribution And Wastewater Collection Systems In Coastal Areas. Journal Of Environmental Management.
- ⁸⁰Alvaro Javier Moyano Salcedo, M. C.-A.-C.-B. (2024). Assessing The Effects Of Salinity On Microbial Communities And Pollutant Removal In Urban Wastewater Treatment Plants. Journal Of Water Process Engineering, Volume 66.
- ⁸¹Timesofindia. (2025, Jan 13). Mormugao Taps Run Dry As PWD Repairs Main Line. Vasco, Goa.
- ⁸²GSCCC. (2023). State Action Plan For Climate Change For The State Of Goa - From 2023 - 2033. Panjim: Goa State Biodiversity Board .
- ⁸³IPCC. (2019). Summary For Policy Makers, Special Report: Special Report On The Ocean And Cryosphere In A Changing Climate, Sixth Assessment Report. IPCC.

ANNEXURE-I: DATA COLLECTION & VALIDATION

Desk Based Research:

As a preliminary step, 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, SBM-U, Central Pollution Control Board, Performance Assessment System for urban water and sanitation (PAS) website, District Disaster Management Plans, and the municipality website.

The desk study was instrumental in mapping key stakeholders, defining their roles and responsibilities, and developing the analytical framework for various thematic studies, including GHG emission estimation. This step also informed the overall research design via the identification of data gaps and discrepancies, which lead to 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 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 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 pre- assessment in Mormugao began with the identification of low-lying and densely populated areas, based on visual cues such as the proximity of structures and elevation patterns. Potential exposure and flood vulnerability hotspots were identified for field study. Field study included visual observation, interviews and primary surveys conducted using semi- structured questionnaire to capture service coverage, access and efficiency. During the visits, particular attention was given to documenting spatial and social diversity across different wards. Mormugao has the highest concentration of slum populations and migrant communities among all the cities surveyed in Goa. Approximately 19 hotspots were studied across the city.

- **Secondary Data Collection:** 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. Detailed information on sewage treatment plants (STPs), such as their capacity, collection and treatment volumes, and water reuse practices was also obtained. Furthermore, data on the number, condition, and operation and maintenance (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 Mormugao Municipal Council (MMC), semi-structured interviews with key ULB officials were conducted – including the Chief Officer (1), two Environment Inspectors, one Swachh Bharat Mission (urban) Coordinator, and one System Operator – 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.

As Goa is primarily governed at the state level, major infrastructures such as STPs and Water Treatment Plants (WTPs) are operated and maintained by state authorities. Accordingly, interviews were held with three Chief Engineers from the Public Works Department (PWD), one PWD Sub Division Engineer, Engineers with the Sewage & Infrastructure Development Corporation of Goa Ltd., the Director of DMA, and the two Senior Project Engineers of GSUDA.

Detailed information on STPs, such as their capacity, collection and treatment volumes, and water reuse practices was also obtained. Furthermore, data on the number, condition, and operation and maintenance (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.

- **Site Visits:** Site visits were conducted to validate the functioning of critical water and sanitation infrastructure, such as WTPs, ESR and GSR, STP, Pumping stations and disposal, and reuse and recycle. 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 field assessment:** The process involved on-ground observations and in-depth conversations with 20 residents, particularly from low-income neighbourhoods and areas identified as vulnerable to extreme events during interviews with ULB officials. These engagements were aimed at validating and triangulating data gathered from secondary sources. This approach yielded valuable insights into both the state of infrastructure and the lived experiences of residents, especially those from 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, information on the type of system, frequency and cost of septic tank cleaning, service providers involved, and affordability, and other challenges in relation to these services were gathered. 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, the research team explored the alternative sanitation arrangements they relied on.

The team engaged with 20 residents across the city, carefully selecting locations to cover a range of socio-economic backgrounds. Questions with residents focused primarily on service access and quality.

A preassessment of the town was undertaken to low-lying zones through digital elevation mapping and identification of densely built-up localities using spatial proximity between buildings. These areas where both criteria overlapped were designated as vulnerability hotspots and prioritized for field visits. Eleven hotspots were identified through this method. These locations were further explored through semi structured surveys, visual observations and consultation with municipal officers to understand the coverage and type of access to basic services, disparities if any and efficiency of the services and any emerging concerns with respect to emerging risks.

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 study on Mormugao was primarily 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.

Sanitation

- **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)^{xiv} 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.
- **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 the Ministry of Housing and Urban Affairs (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.
- **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.

- **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.

Water

- **Inadequate Granular Water Consumption Data:** Household-level water consumption is not metered in many areas; bulk metering data (number of connections $\times$ billed consumption) does not accurately capture per capita usage or disparities across income groups or geographies (e.g., slums vs. apartments).
- **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.

GHG Emissions

- **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.
- **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.
- **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 CH₄ and N₂O emissions from faecal waste.
- **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.

- **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.
- **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.

Overall

- **Research Boundaries:** While the scope defines what this report covers, the limitations reflect aspects that could not be addressed. These should not be viewed as research gaps but as boundaries determined by data availability and by differing approaches adopted by the research and implementation partners of the 'Climate Resilient Coastal Cities' project^{xv}. Variations in this report and those based on research by CDD-India reflect these methodological differences.
- **Town-level Focus:** This report addresses issues specific to the town studied. The 'Climate Resilient Coastal Cities' initiative comprises a National Report, four State Reports, and fifteen Town Reports. This document represents one of the three town-level studies from Goa. A broad level state analysis of Goa is provided separately in the Goa State Report, which draws on all three town studies.
- **Data Availability:** The study relies primarily on secondary research, and the extent of analysis is therefore dependent on the quality and availability of published data and literature. Wherever possible, secondary information has been supplemented with primary inputs.

ANNEXURE-III: POPULATION PROJECTIONS

Population forecasting is a critical component of water infrastructure planning. Accurate projections help in determining future demand, sizing infrastructure appropriately, and ensuring climate-resilient water service delivery. In this appendix, population projections for the town are made using historical census data from 1981, 1991, 2001, and 2011. To improve robustness, four standard projection methods have been applied:

1. Arithmetic Increase Method

This method assumes that population increases by a constant absolute number in each decade, based on the average of past increases.

$$P_n = P_0 + n \times \bar{I}$$

Where:

- P_n : Projected population after n decades
- P_0 : Last known population
- $\bar{I}$: Average increase per decade = (Sum of past population increases) ÷ (Number of decades)

Strengths:

- Useful where population growth is stable and linear

Limitations:

- Does not account for accelerating or decelerating growth
- May underestimate or overestimate population in dynamic urban areas

2. Incremental Increase Method

This method improves upon the arithmetic method by incorporating the average increment in population increase, assuming growth is accelerating or decelerating.

$$P_n = P_0 + n \times \bar{I} + \frac{n(n-1)}{2} \times \bar{R}$$

Where:

- $\bar{R}$: Average incremental increase per decade = (Sum of changes in decadal increases) ÷ (Number of increments)

Strengths:

- Captures trend in rate of growth
- More reflective of population dynamics than the arithmetic method

Limitations:

- May become inaccurate if future trends deviate sharply from past patterns

3. Geometrical Growth Rate Method

This method assumes the population grows at a constant percentage (compound) rate, calculated from historical growth.

$$P_n = P_0 \times (1 + r)^n$$

Where:

- r : Average decadal growth rate = [(Population in latest year ÷ Population in previous year) – 1]

Strengths:

- Suitable for rapidly growing urban areas
- Accounts for compounding effects of growth

Limitations:

- May overestimate population if growth slows in future
- Sensitive to anomalies in historical data

4. Graphical Method

In this method, historical population data is plotted on a graph, and a curve is drawn to best fit the trend. Future population is estimated by extrapolating the trend line.

Strengths:

- Visually intuitive & Can reflect non-linear growth patterns

Limitations:

- Subjective: results depend on visual judgment and quality of trend fit
- Requires careful interpretation of curve shape

Final Projection Approach

To establish a baseline in the absence of recent census data, we adopt an average four distinct projection methods. This mitigates individual model extremes and balances simplicity with compounding trends to offer a rather stabilised estimate. While we maintain strong reservations about the capacity of static models to capture the highly fluid realities of coastal growth, we employ this averaged methodology primarily out of pragmatic necessity: it is the established industry standard for urban planners and Detailed Project Reports (DPRs), ensuring our analysis remains interoperable with existing municipal frameworks and policy planning.

Detailed Calculations:

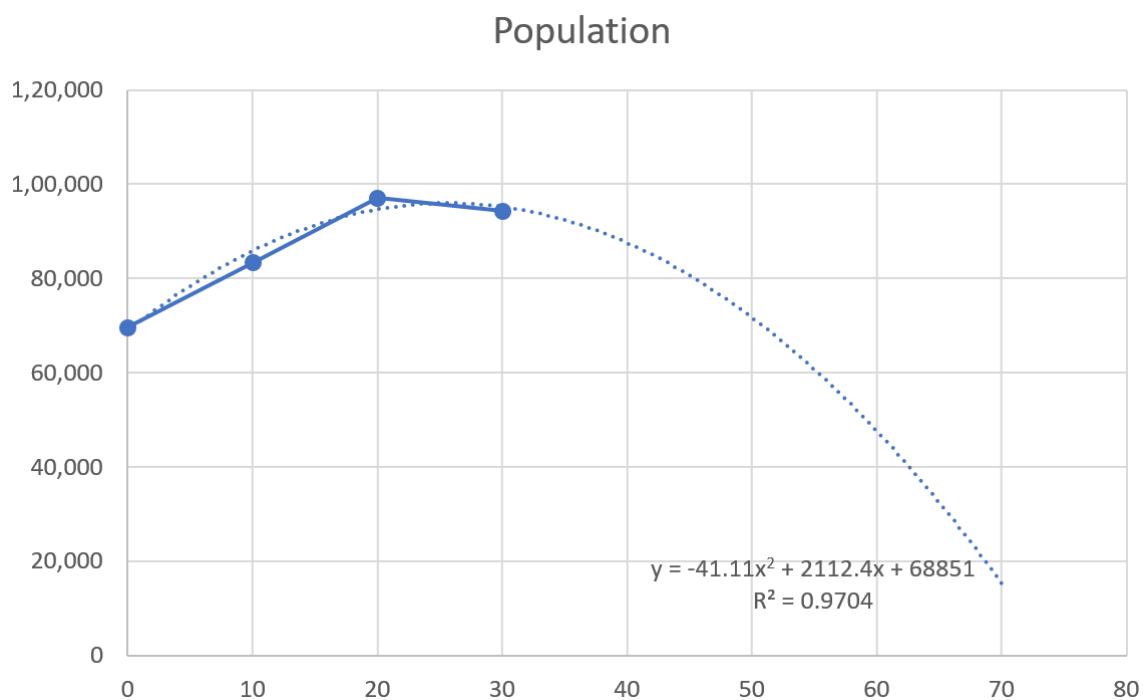
Year	Population	Increment	Incremental Increase	Decadal Growth Factor
1981	69,684			
1991	83,367	13683		1.19635784
2001	97,154	13787	104	1.16537719
2011	94,393	-2761	-16548	0.9715812

Average Increment 8236.333333

Average Incremental Increase -8222

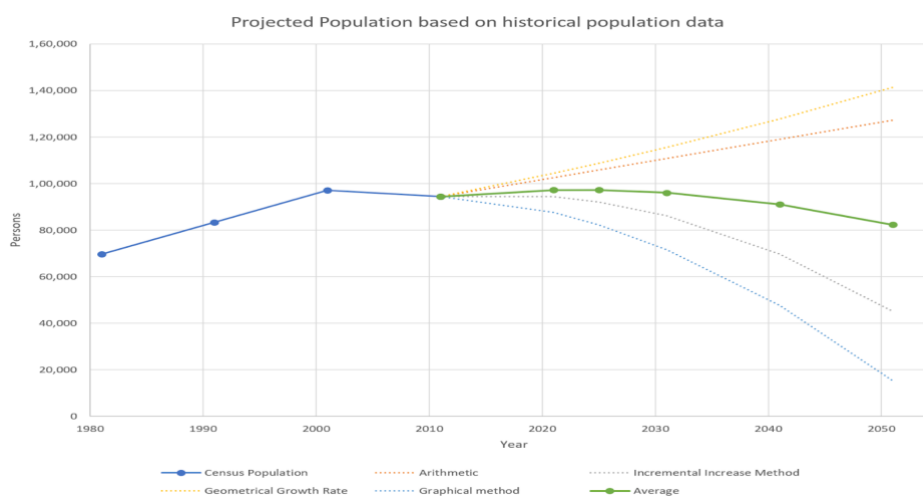
GM Decadal Growth rate 1.106459628

Graphical Method:



For X-axis 1981 is the base year: X=0 (1981) X=10 (1991)

Year	Census Population	Projected Population				
		Arithmetic	Incremental Increase Method	Geometrical Growth Rate	Graphical method	Average
1981	69,684					
1991	83,367					
2001	97,154					
2011	94,393					
2021		102629	94407	104442	87571	97262
2025		105924	92111	108755	82208	97249
2031		110866	86200	115561	71696	96081
2041		119102	69770	127863	47599	91084
2051		127338	45118	141476	15280	82303



ANNEXURE-IV: 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, Goa, 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
- **Goa:** 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 Goa, 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%. Non-revenue water (NRW) is estimated at 25%, with 15% attributable to manual errors. Initiatives include smart metering (3,000 units in Panaji), free water up to 16m³, 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 Goa 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.

ANNEXURE-V ABBREVIATIONS AND GLOSSARY

ABBREVIATIONS

AMRUT	Atal Mission for Rejuvenation and Urban Transformation
CCA	Climate Change Adaptations
CDRI	Coalition for Disaster Resilient Infrastructure
CST	Community Septic Tanks
CT	Community Toilet
DDMP	District Disaster Management Plan
DM	District Magistrate
DRR	Disaster Risk Reduction
ESLR	Elevated Level Storage Reservoir
FSSTP	Faecal Sludge and Septage Treatment Plant
FSTM	Faecal Sludge Treatment and Management
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
MMC	Mormugao Municipal Council
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
NBIS	Nature-Based Infrastructure Solutions
NRW	Non-Revenue Water
ODF	Open Defecation Free
OSS	On Site Sanitation Systems
O&M	Operation & Maintenance
PT	Public Toilet
RIS	Risk Information Systems
SAPCC	<i>State Action Plans on Climate Change</i>
SBM	Swachh Bharat Mission
SBR	Sequence Batch Reactors
SLBS	Service Level Benchmarks

SOP	Standard operating Procedure
SPV	Special Purpose Vehicle
STPS	Sewage Treatment Plants
UNDRR	United Nations Office for Disaster Risk Reduction
WRD	Water Resources Department
WTP	Water Treatment Plant
WASH	Water, Sanitation, and Hygiene

GLOSSARY

<i>Term</i>	<i>Definition</i>
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) ⁸⁴
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) ⁸⁵
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)

⁸⁴CDRI. (2023). Map Viewer. Retrieved from Global Infrastructure Risk Model and Resilience Index, Measuring Risk and Resilience in Infrastructure Solutions: <https://giri.unepgrid.ch/map>

⁸⁵Ministry 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.



Ashank Desai Centre for Policy Studies

II Floor, Old CSE Building
Indian Institute of Technology Bombay
Powai, Mumbai, Maharashtra
400076

www.cps.iitb.ac.in

Email: office.cps@iitb.ac.in

Phone: +91 22 2576 5061