CLIMATE RESILIENT INFRASTRUCTURE SERVICES

CASE STUDY BRIEF: PANAJI

CONTENTS

PREFACE

Infrastructure plays an important role in sustaining the development of a city. Infrastructure assets provide critical social and economic services not only to the city where they are located but also to the surrounding areas. The degree to which a city is vulnerable to climate hazards depends on the frequency and intensity of climate related events as well as the local capacity to anticipate and respond to them. Quality, access, and efficiency of infrastructure services play an important role in determining this local capacity of the city as well as the magnitude of structural and economic loss that a city will have to bear in times of adversities. The vulnerability of coastal regions to climate change is an issue which has gained attention recently. Increase in the Sea- Level Rise (SLR), and the frequency and intensity of storms are two primary impacts of climate change faced by coastal communities.

This document is a result of a year long study conducted by The Energy and Resources Institute (TERI) granted by USAID as part of their Climate Change Resilient Development (CCRD) project's climate adaptation small grants program. This grant was in support of the Climate Resilient Infrastructure Services (CRIS) program within the CCRD project. The work was reviewed by ICF International and Engility which is leading USAID's small grants program under the CCRD initiative. The goal of this study was to help the cities of Panaji and Visakhapatnam to plan for and implement climate risk management strategies as an integral part of city development. The aim was to understand the kind of infrastructure that Panaji and Visakhapatnam house and their vulnerability to climate change and sea-level rise, in particular. The study focused on the following thematic components:

1. Develop and demonstrate an urban infrastructure inventory and linkages along with other considerations to support climate resilient planning efforts
2. Develop and demonstrate a rapid climate vulnerability assessment approach for infrastructure services

This case study presents the learning and project outcomes from Panaji.

INTRODUCTION: PANAJI (GOA, INDIA)

Goa with a land area of 3,702 sq km and a coastline of 105 km is India's smallest state located on the west coast along the Arabian Sea (*Figure 1*). Spread over just 812 hectares, Panaji, the capital of Goa, is a prime tourist spot both for national as well as international tourists and houses critical infrastructure that supports vast tourism activity in the area. Though the population of Panaji is 114,405 as per the latest census,the city has a high floating population since it receives about a thousand international and five thousand domestic tourists every day. As per the City Development Plan, the floating population of the city in 2004–2005 was 639,177[1]. Panaji has been identified as one of the coastal

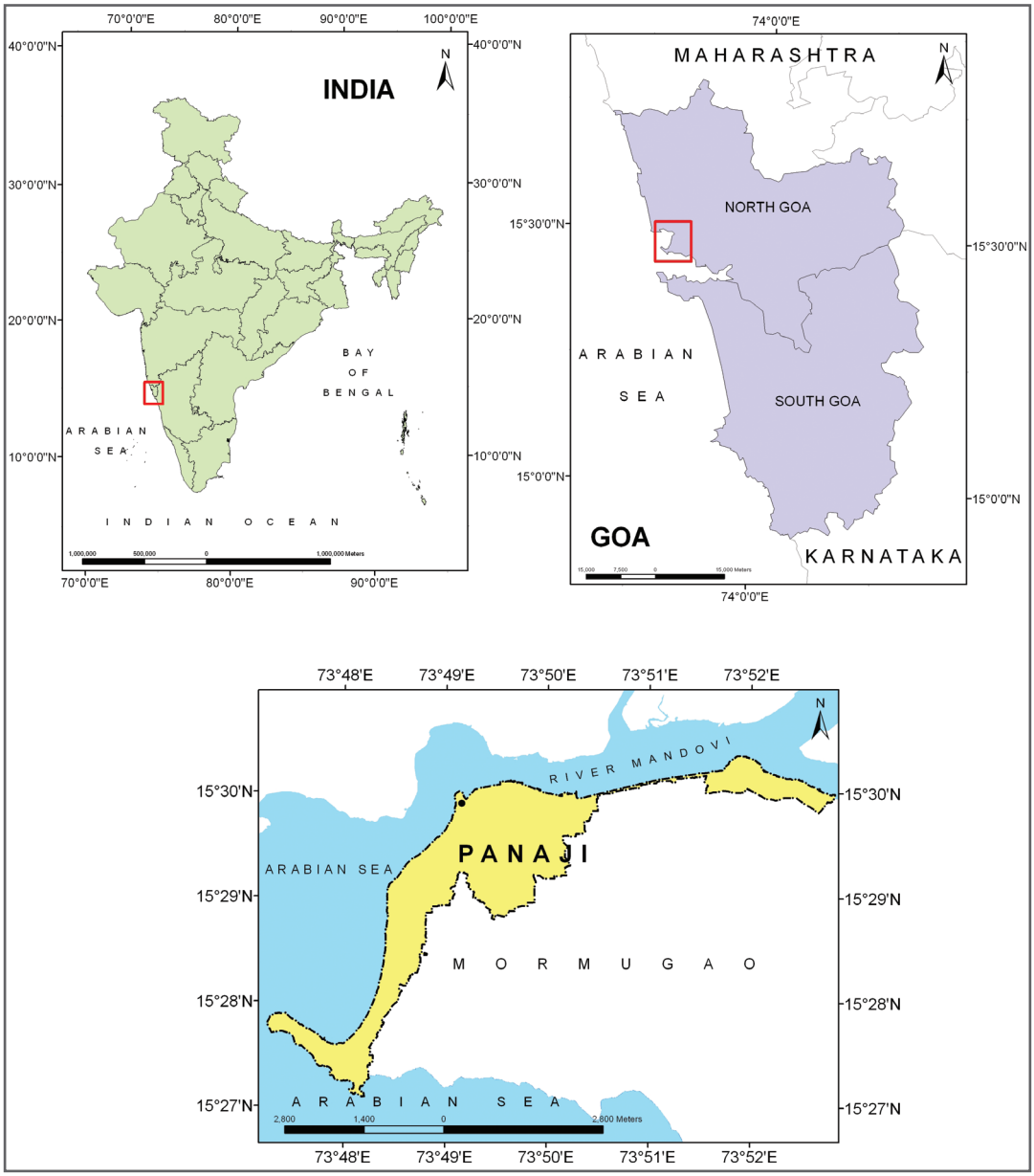

Figure 1: Location map of Panaji, Goa

[1] http://jnnurm.nic.in/wp-content/uploads/2010/12/panaji_Chapter-3.pdf

cities vulnerable to flooding due to the predicted sea-level rise. The rapidly increasing urbanization and growing tourism pressure on city's infrastructure clubbed with future risks posed by climate change make the city highly vulnerable. Loss of green spaces due to illegal constructions, inefficient basic service provision, and growth of urban slums in an unplanned manner are some of the factors responsible.

SCOPE OF THE STUDY

The scope of this study included developing and demonstrating a methodology for assessing the vulnerability of infrastructure services of coastal cities to sea-level rise and how this assessment can support climate resilience planning efforts. This was done by taking up case studies of two coastal cities- Panaji on the west coast and Visakhapatnam on the east coast of India. This document presents the outcomes of the case study of Panaji.

OBJECTIVES AND OUTCOMES

Objectives

The vulnerability assessment of Panaji was carried out with an objective to:

1. Understand the impact of sea-level rise and vulnerability of the city to climate change induced events like extreme precipitation
2. Identify hotspots and critical infrastructural services infrastructure and services.
3. Identify actions to address climate criticality and plan for climate resilience and
4. Inform planning decisions at the level of the local government (city government) to achieve the same

Outcomes

This assessment resulted in the identification of vulnerable hotspots and critical infrastructure on spatial scale and a Database Management System (DBMS) to support the city government to address the impacts of sea-level rise in its planning strategies. The study also gives broad sector-wise recommendations to the city as a starting point to initiate climate resilience planning and retrofitting of infrastructure assets and services. However, further detailed studies and expert consultation will be required to appropriately implement these actions.

Relevance of Development Goals

The purpose of the study is to inform and support the city decision-makers for planning the infrastructural services infrastructure and services of the city such that the climate threats are addressed appropriately at all levels—structural, planning, investment, and governance.

Key sectors identified in the study

- Heritage and Tourism
- Water supply
- Sewerage and drainage
- Solid waste management
- Transport
- Social Infrastructures (Schools and Hospitals)
- Ecologically sensitive areas
- Energy and communications
- Disaster management

Key Stakeholders and Target Groups

1. **Stakeholders and end users:** The city government including the Town and Country Planning Department and the Corporation of the City of Panaji
2. **Target groups and key sectors:** The study targets the City Corporation and the concerned departments that plan, build, and manage infrastructure and basic services in the city

PRIMARY PROFILING OF THE CITY: ESTABLISHING BASELINE INFORMATION

Preparing an Urban Infrastructure Inventory of the City

The non-climatic information of the city was included as part of the inventorization exercise wherein a detailed framework for inventorization of infrastructure assets has been developed which basically draws out the infrastructure specific list of information that the city is maintaining at present. The data was collected from various city level departments and collated at one point in excel sheets. The difference of data collection fields/infrastructure related information storage was noted and the missing fields were updated in the excel sheets for the city to understand the gaps as well as populate the data in future. The broad fields for the inventory include man-made infrastructure (transport systems, electricity, water, social infrastructure, communications systems, and industries). The inventory prepared in excel was then developed into a Microsoft Access-based DBMS. All the infrastructure and services considered for the study was mapped spatially using GIS and linked to the DBMS. Detailed forms have been created for each sector in the DBMS. The next section provides an overview of the waste water supply sector as an example. *Figure 2* provides a snapshot of the inventory of the waste water sector in Panaji.

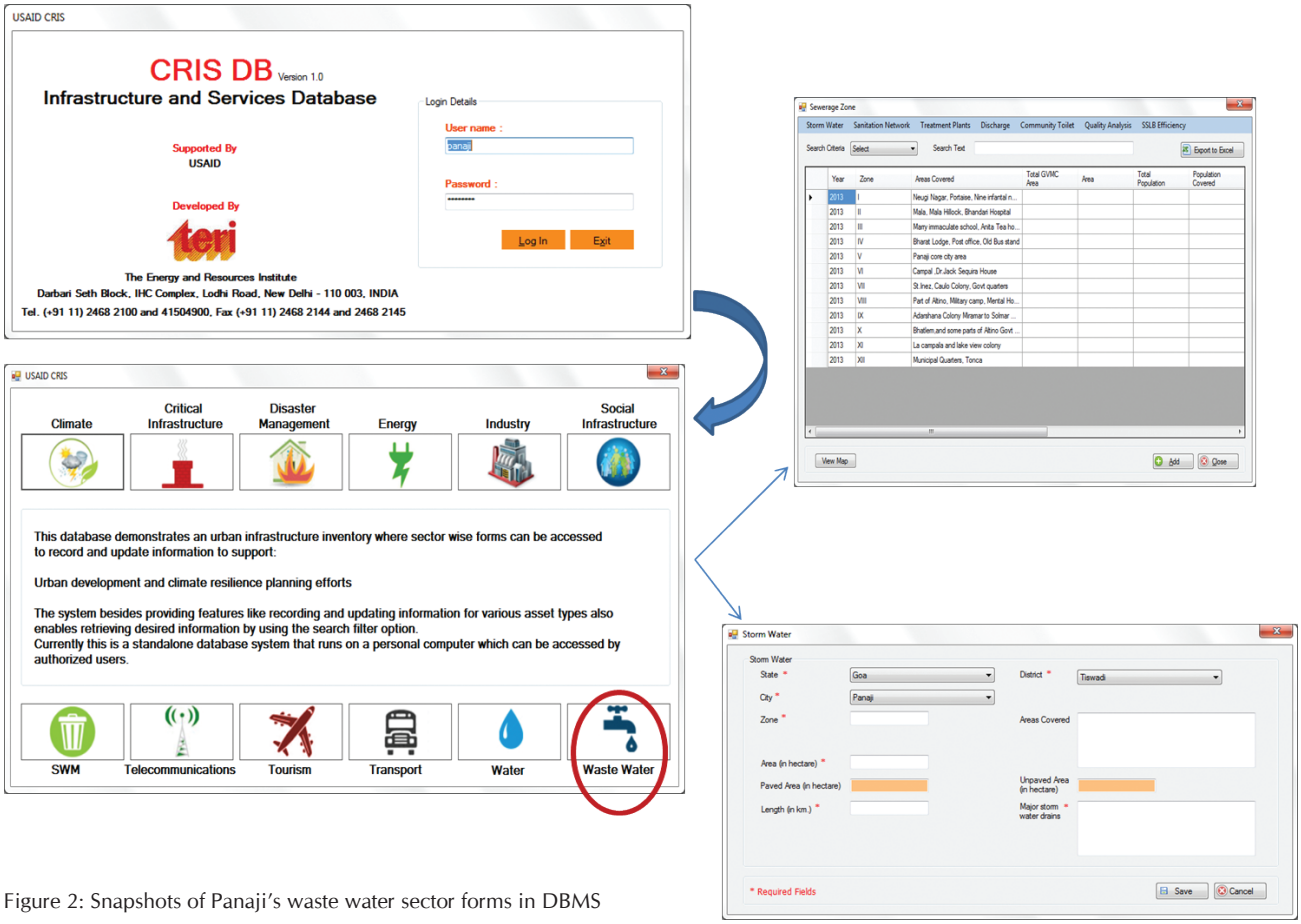

Figure 2: Snapshots of Panaji's waste water sector forms in DBMS

Overview of WasteWater Sector in DBMS

i) Sewerage Zones

A form (*Figure 3*) records the basic details of the sewerage zones delineated by the city in terms of:

a) List of areas covered under each zone

b) Number of connections and length of network

c) Sewage processing capacity in each zone

d) Coverage details are recorded, in terms of the area covered by the sewerage network and the population served in that zone. The percentage coverage values are displayed in the form after filling the total area and the total population of that zone.

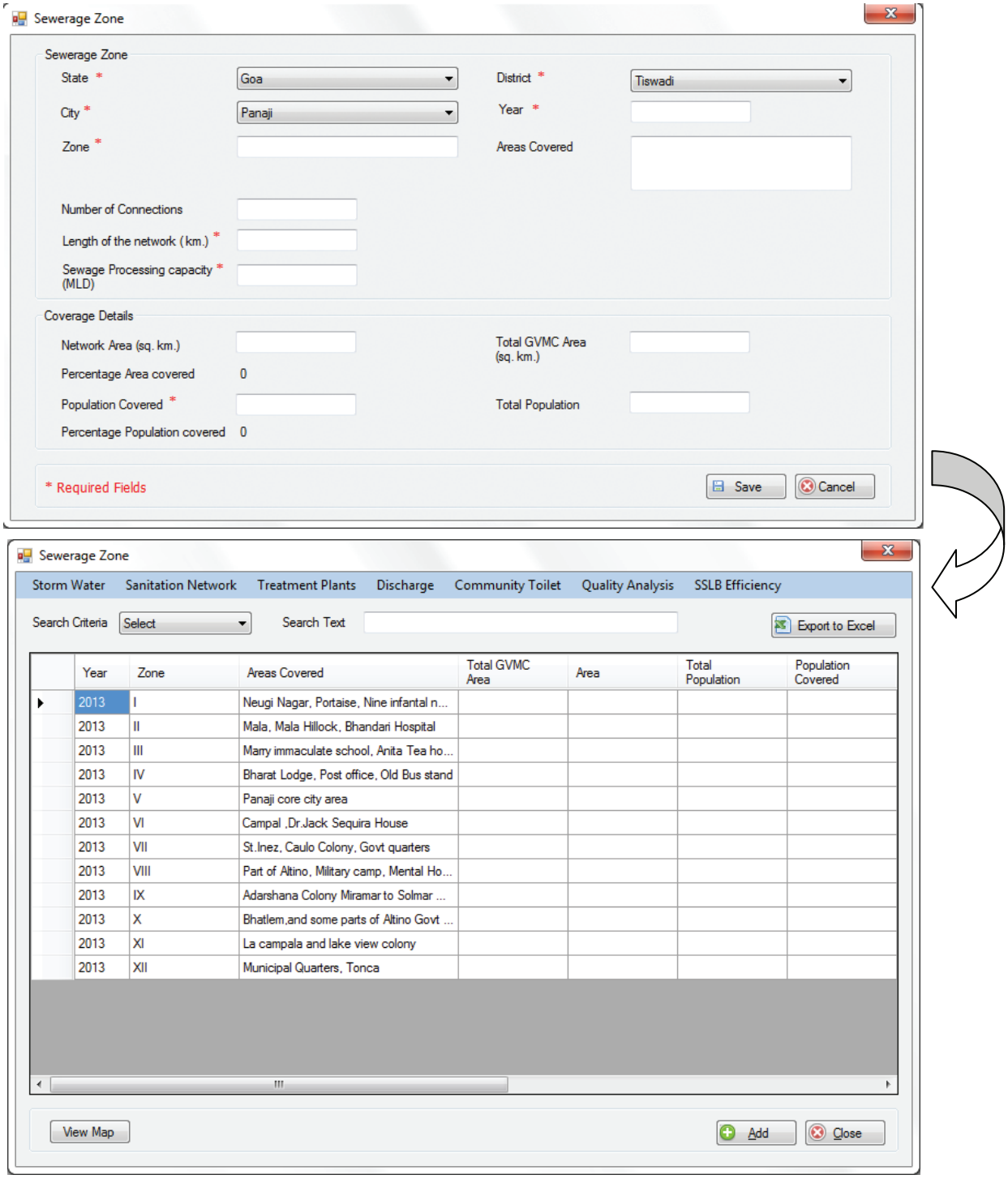

Figure 3: Snapshots from DBMS depicting the Sewerage Zone form and the corresponding information captured for Panaji

ii) Storm Water Zones

A form has been created to record information on the storm water zones in the city. It records information on the major storm water drains in a given zone along with the total length and area of the network. Each storm water zone has a prescribed area and it is recommended that the city further records this information as paved and unpaved areas. Though Panaji has not yet delineated separate storm water zones, but in case such a decision is taken in future, the city will be able to record information pertaining to these zones in this form.

iii) Sanitation Network

The sewerage network form seeks to record details of the piped network in the city (*Figure 4*). After selecting a zone, the user needs to select the type of the drainage system (open/surface or underground) and the type of network (whether existing, new, or proposed).The following details need to be filled in:

a) Capacity and age of the network

b) Details of diameter categories and length of that particular pipe in the network along with the corresponding material of the pipeline

c) Efficiency values can be recorded for the desired parameters along with the source of this data

d) The form also seeks to record the frequency and cost of each maintenance activity undertaken by the authority

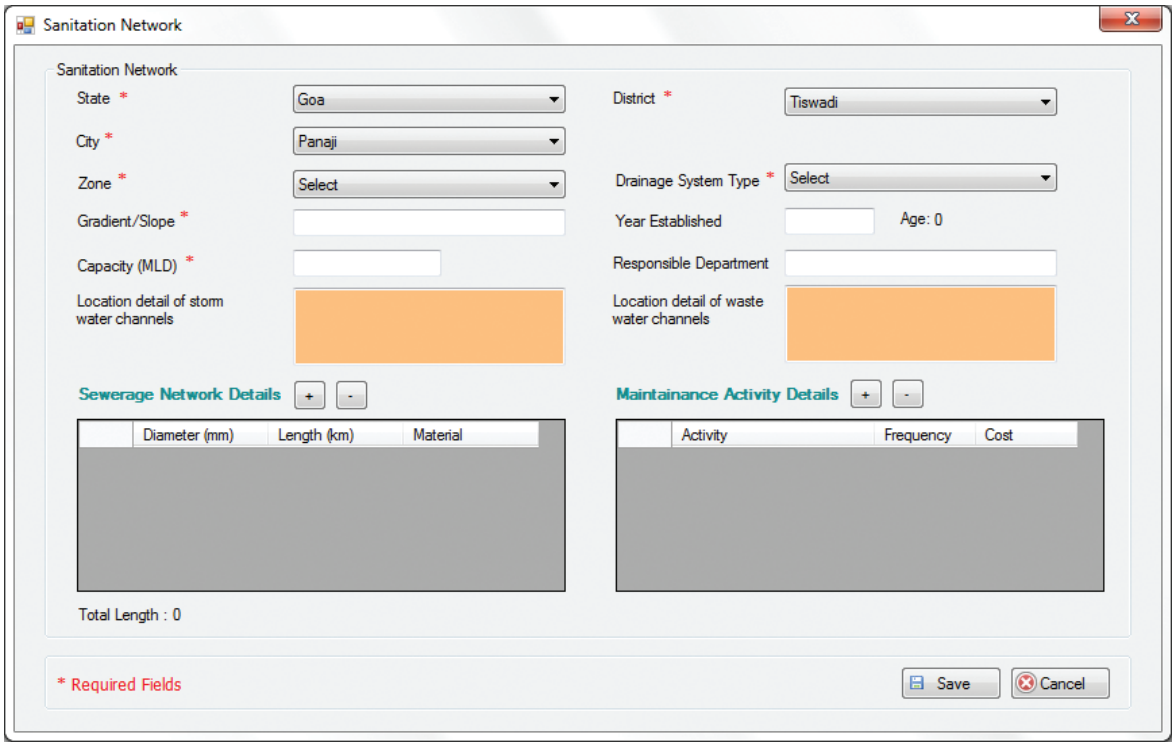

Figure 4: Snapshot of the Sanitation Network form in the DBMS

iv) WasteWater Treatment Plants

The form on treatment plants seeks to record the following details (*Figure 5*):

a) Name, location, and age of the treatment plant

b) The coverage area of the plant

c) The design capacity and operational capacity

d) The type of treatment process followed

e) The form also seeks to record the frequency and cost of each maintenance activity undertaken by the authority

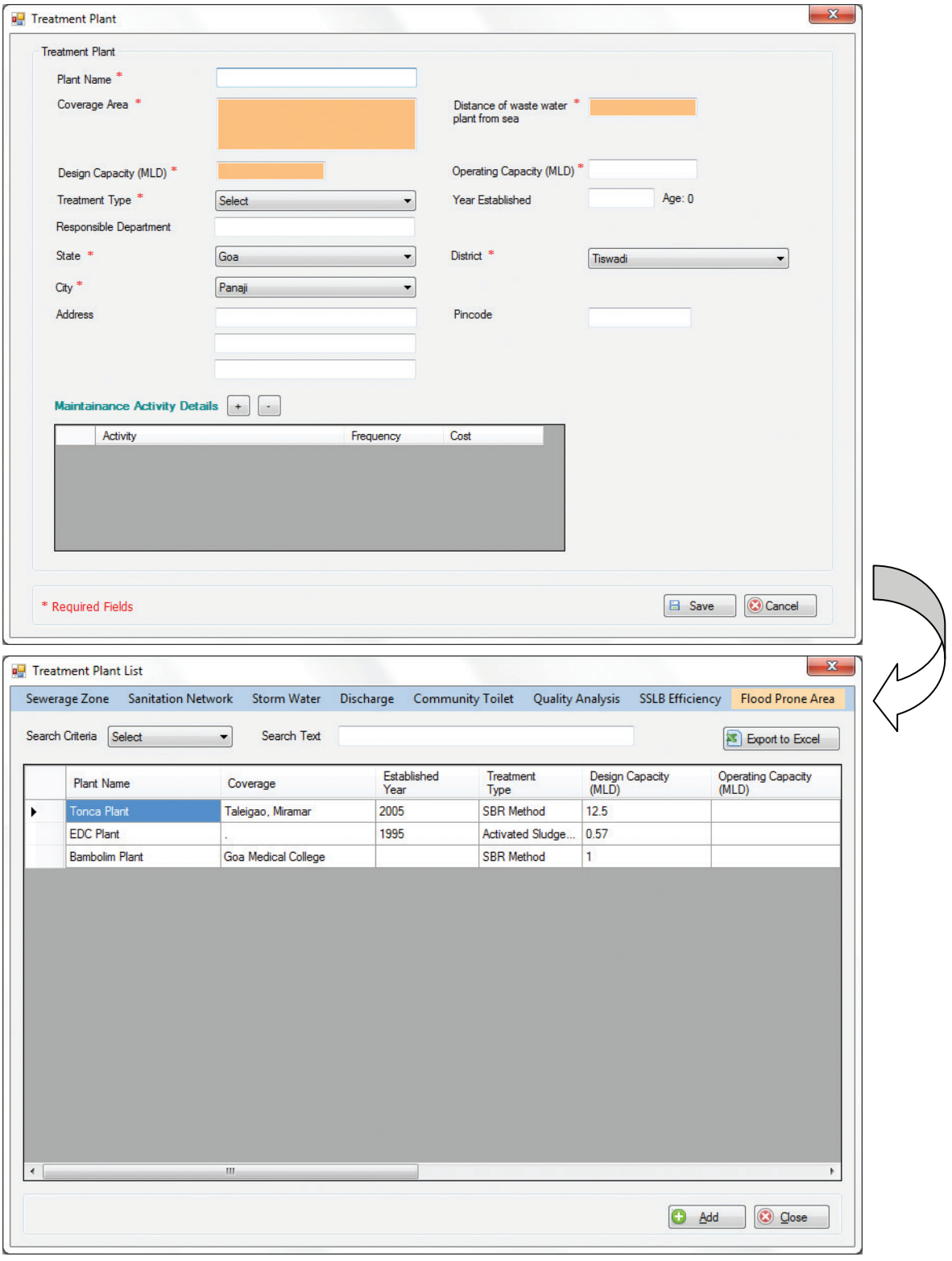

Figure 5: Snapshots from DBMS depicting the Treatment plant form and the corresponding information captured for Panaji

v) Discharge

The form on Discharge(*Figure 6*) aims at recording the following details of the discharge points for each treatment plant:

a) The location and diameter of the discharge points

b) The material used in the pipelines

c) The reduced level (height of outfall point with respect to mean sea level)

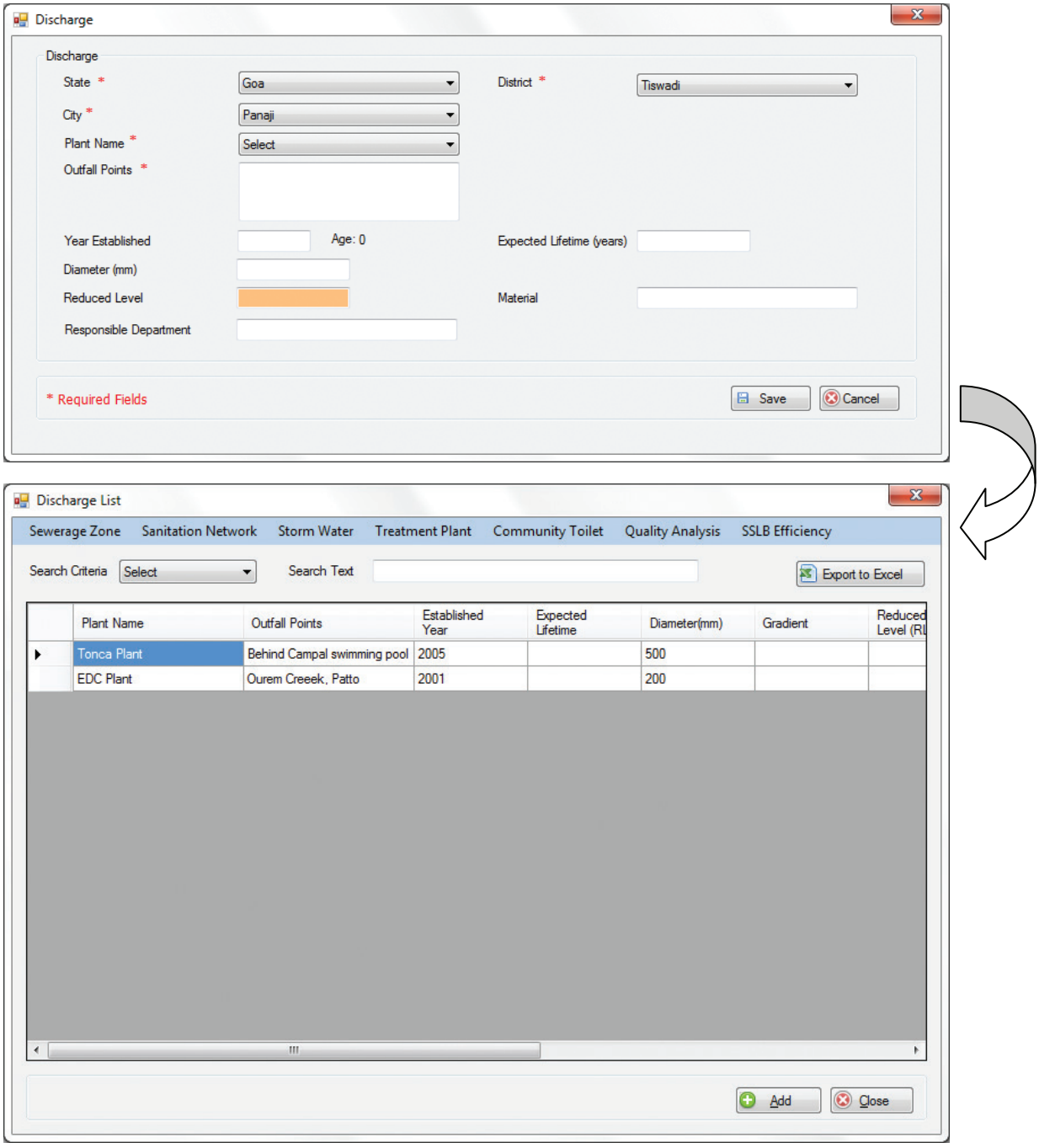

Figure 6: Snapshots from DBMS depicting the Discharge form and the corresponding information captured for Panaji city

vi) Community Toilets

A form has been created to record the location details of all the community toilets in a city. The current database for Panaji records this information (*Figure 7*).

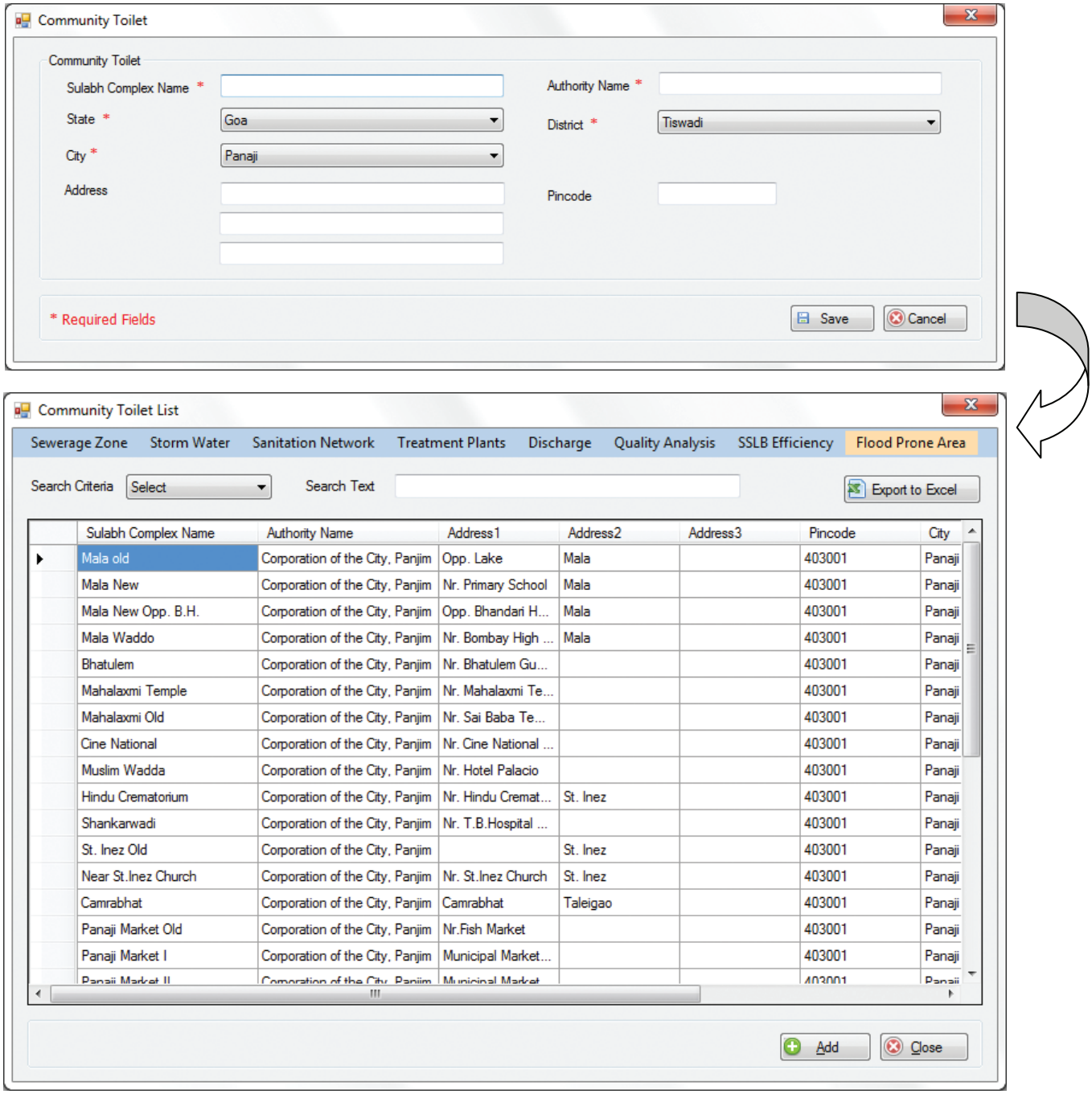

Figure 7: Snapshots from DBMS depicting the Community Toilet form and the corresponding information captured for Panaji

vii) Sanitation Quality

It is recommended that the city maintains the quality records of the treated effluent as per the prescribed standards. The existing data from quality records maintained by Public Works Department (PWD) in Panaji has been fed into the database and the same format of recording these quality reports has been incorporated in the forms (*Figure 8*).

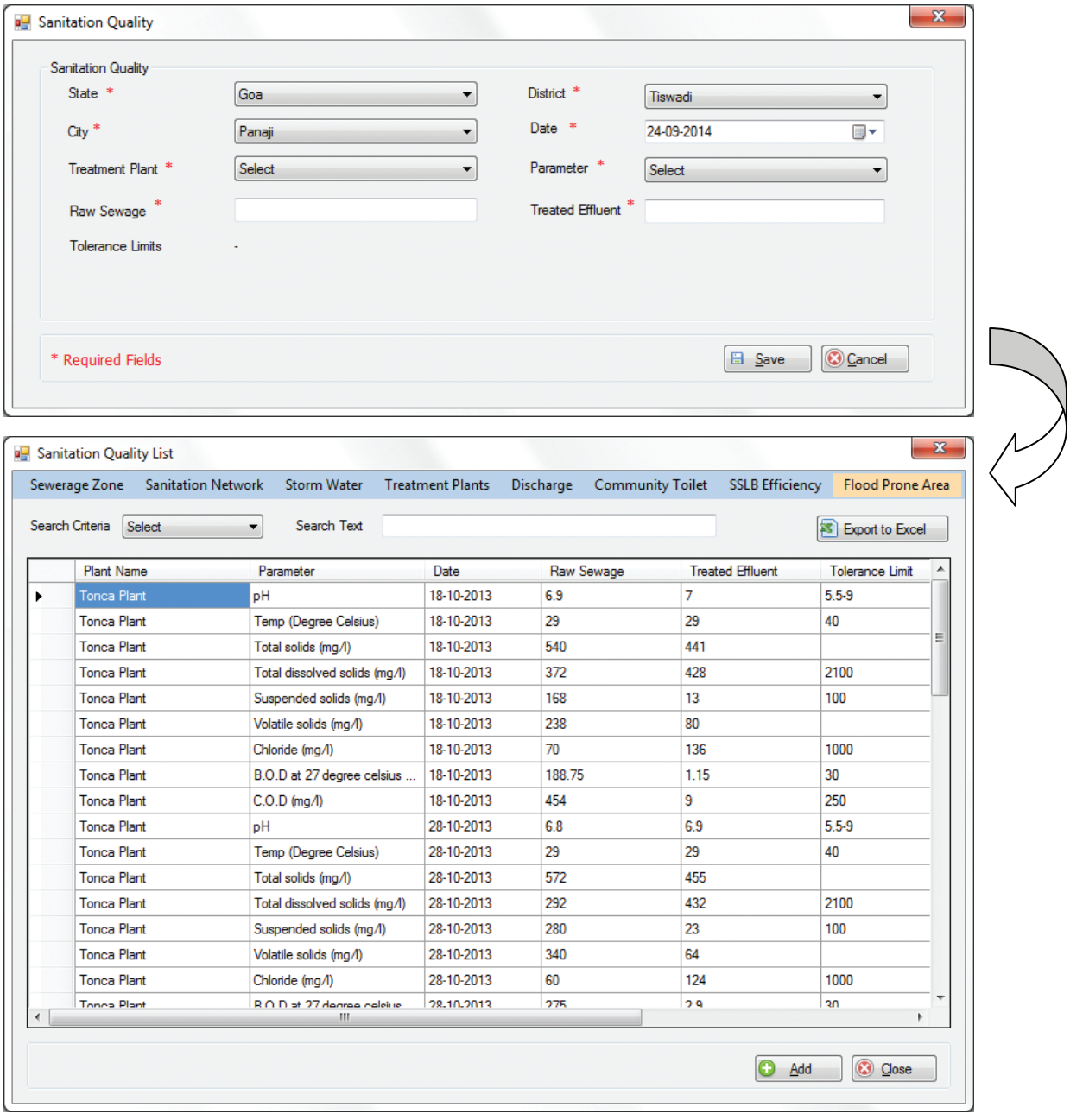

Figure 8: Snapshots from DBMS depicting the Sanitation Quality form and the corresponding information captured for Panaji

Preparing a Spatial Inventory of Urban Infrastructure and Services of the City

The second component of the DBMS was a spatial inventory of urban infrastructure services in the city, wherein sector-wise infrastructure assets and service networks in the city were mapped in Arc GIS platform. The dataset used for creation of the spatial database was sourced from various city level departments including the Corporation of the City of Panaji (CCP) and other sectoral city level and state line departments. This dataset included maps obtained in Auto CAD format, images (.tiff/ .jpeg) or in hard copy. In addition to this, the locational information on different infrastructure assets was also received in form of lists of addresses and geographical coordinates. The spatial dataset so received were pre-processed through geo-referencing and geometrical structuring and corrections in Arc GIS platform to come up with land use and sector-wise infrastructure maps for Panaji (*Figures 9–18*). For a ready reference to the city planners and decision-makers, these maps were integrated in the DBMS and linked to respective sector-wise inventories.

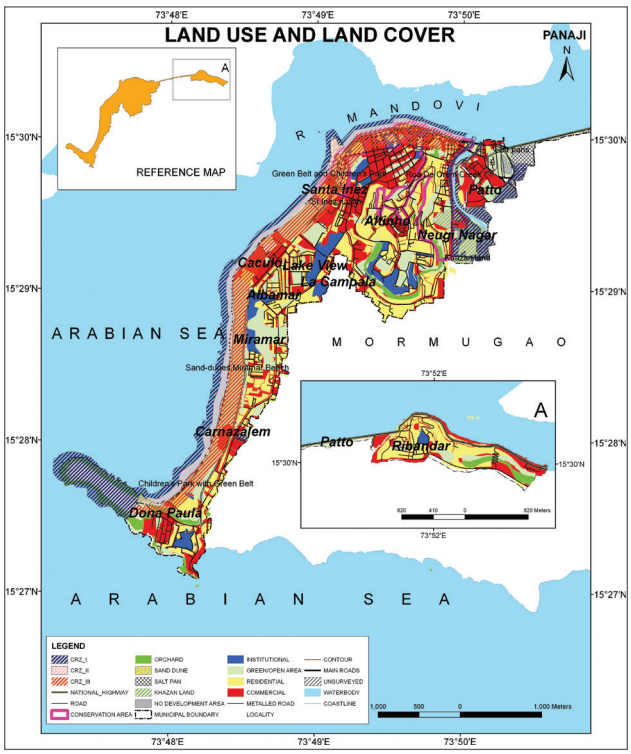

Figure 9: Land use and land cover map of Panaji

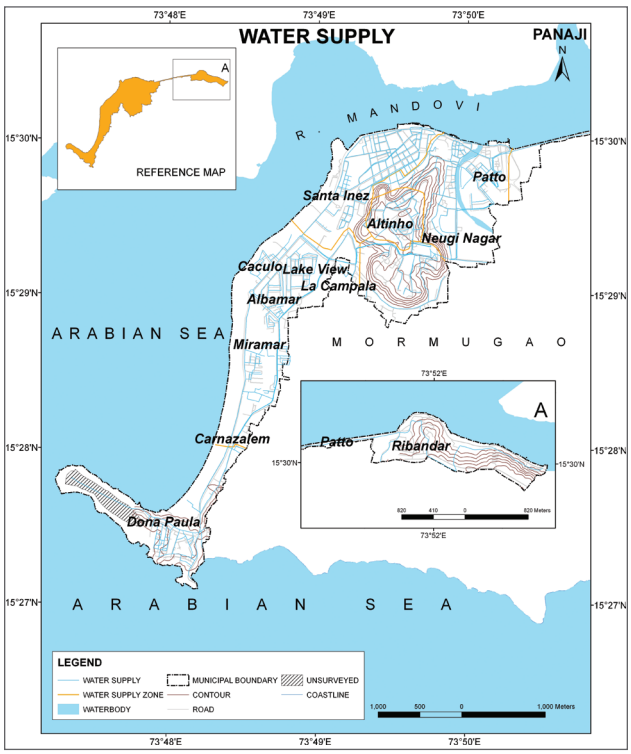

Figure 10: Map depicting the water supply network in the city

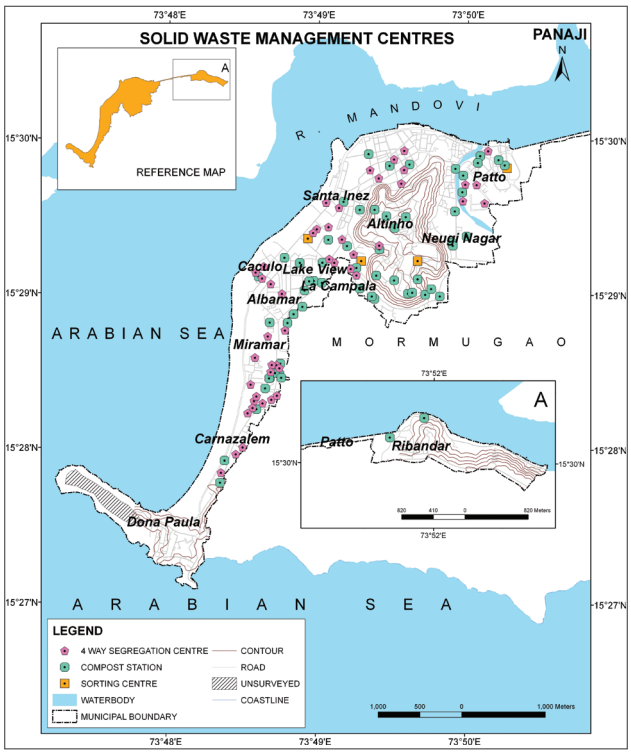

Figure 11: Map depicting the four-way segregation centres
4 way segregation centres

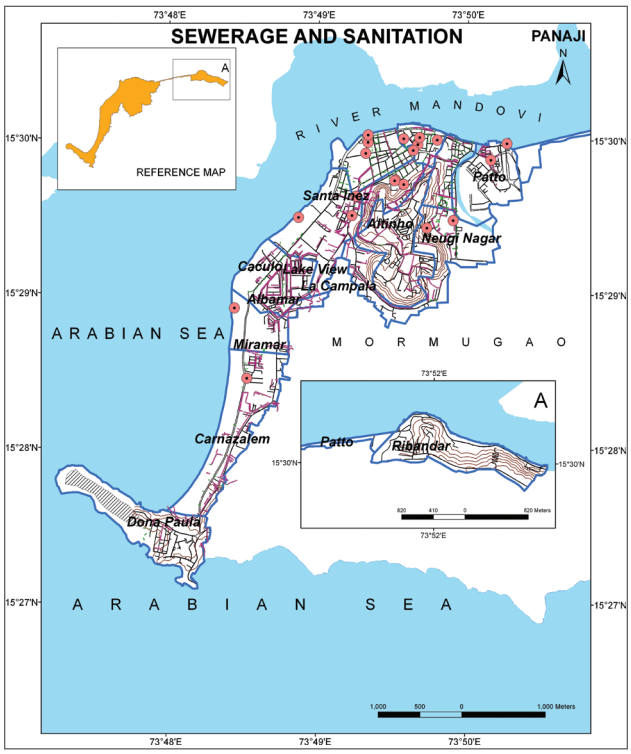

Figure12: Map depicting the sewerage and drainage network sorting centres, and compost stations in the city and community toilets

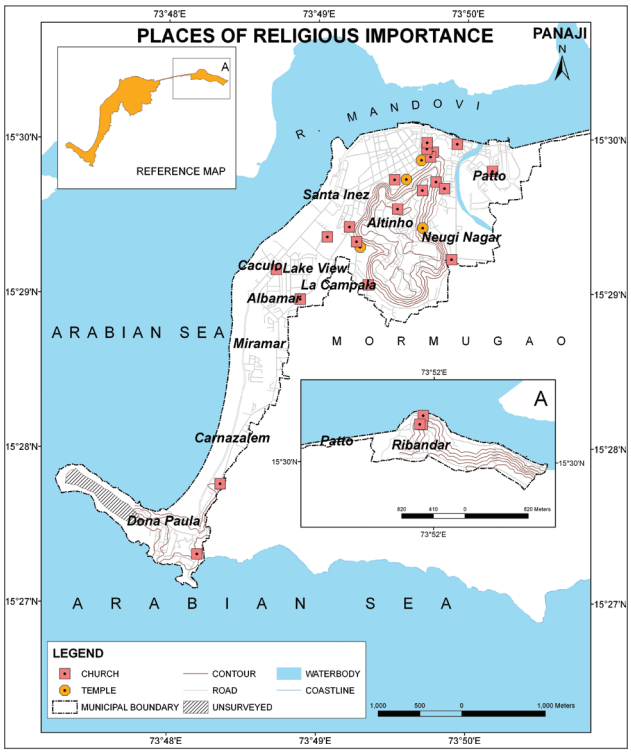

Figure 13: Map depicting the places of religious importance

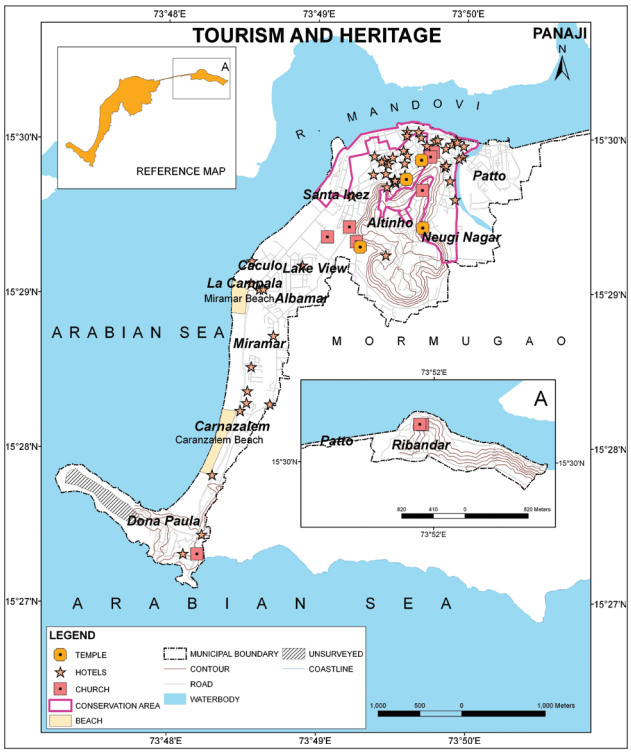

Figure 14: Map depicting the beaches and conservation area in the city

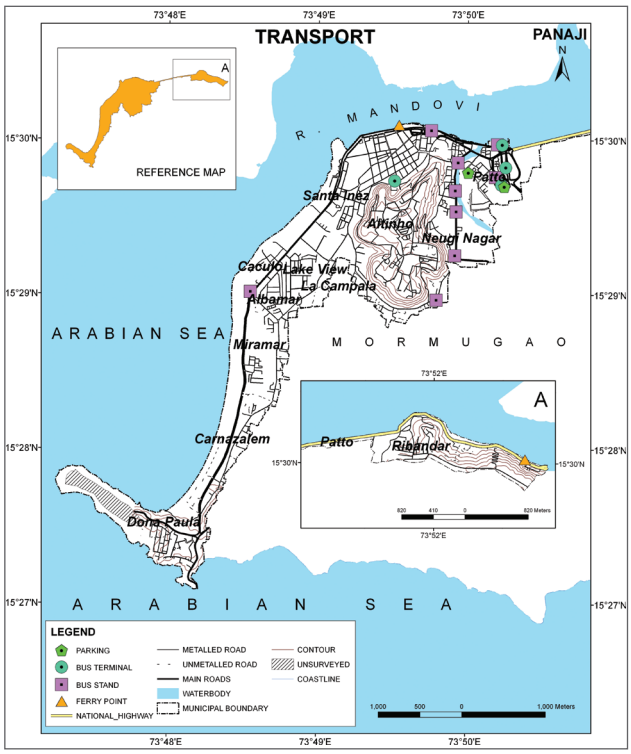

Figure 15: Map depicting the major transport infrastructure (parking areas, bus terminals and stands, and ferry points)

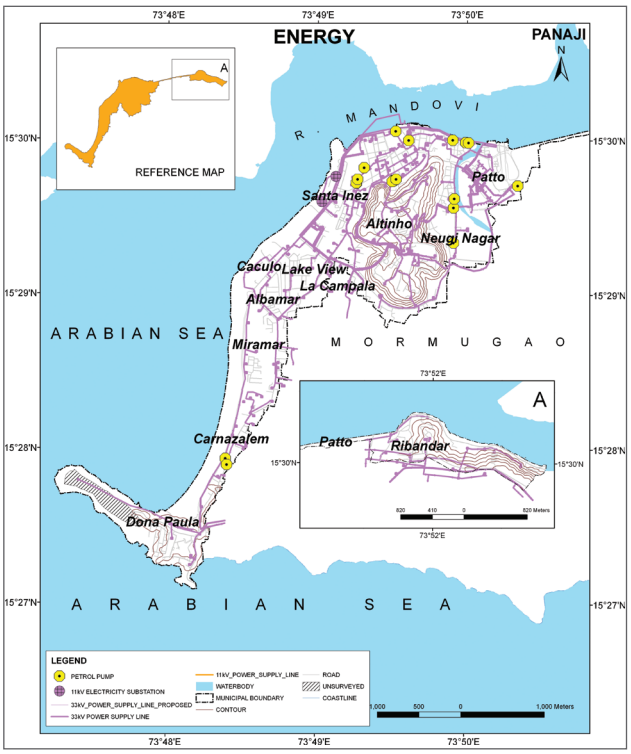

Figure 16: Map depicting the electricity substations, power supply lines, and petrol pumps in the city

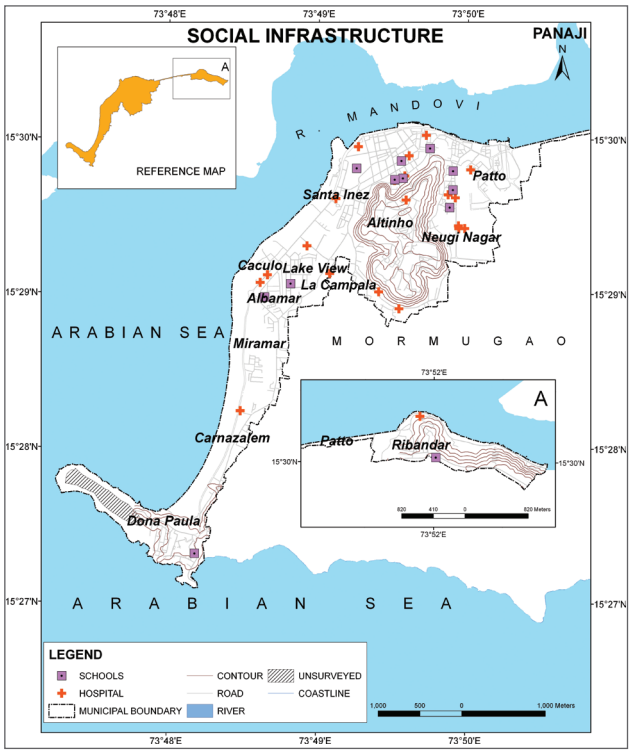

Figure 17: Map depicting the schools and hospitals in the city

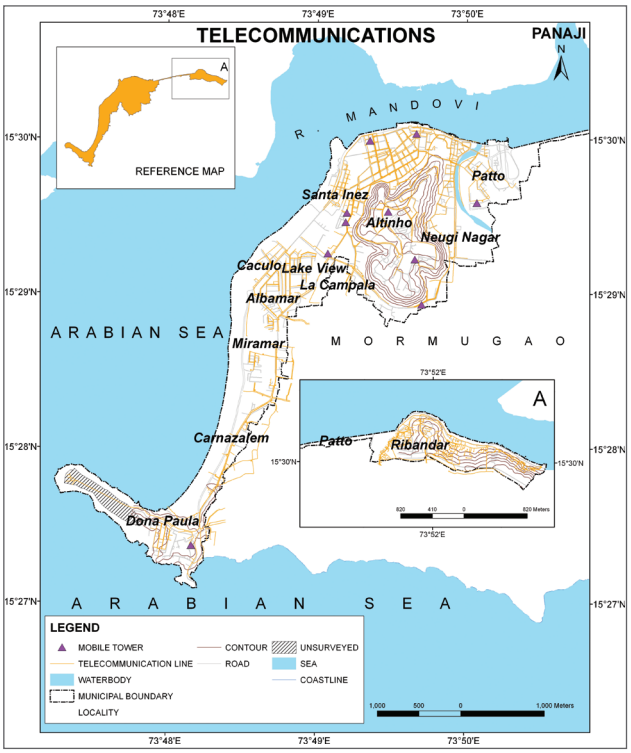

Figure 18: Map depicting the mobile towers and telecommunication lines in the city

DEVELOPING CLIMATE KNOWLEDGE

The study particularly looks at SLR as a component of climate change and how it affects the infrastructure and services of the city. Sea-level rise coupled with extreme rainfall events lead to inundation, water logging, and floods in the city. Hence, exposure of the city to SLR as well as heavy rainfall in terms of frequency of extreme precipitation, increase in the precipitation level, if any, were assessed. The key points highlighted in this study are as follows:

i. **The precipitation trends for the last three decades** for Panaji were studied. The dataset sourced from the Indian Meteorological Department were analysed to understand the rainfall anomalies—annual as well as for monsoon months of June, July, August, and September (JJAS). An extreme rainfall analysis was also done to understand the trend of occurrence of extreme precipitation events which may aggravate the vulnerability of infrastructure assets. The analysis result shows a decreasing trend for total monsoonal rainfall for the period 1989-2009 (*Figure 19*). Panaji also shows a decrease in the highest 24 hourly rainfall annually and for monsoon months (*Figure 20*). The rainy days however, also show a slight decrease in the city.

ii. The observed sea-level trends over the coast of Panaji, using freely available tide gauge data sourced from PSMSL[2] website,consisted of large gaps due to missing values. Therefore, for Panaji coast, the data from the Mumbai port has been used as proxy (Unnikrishan et al., 2007) due to similarity in the trends and coastlines. The trend for Panaji (1875-2010) shows an increase in the sea-level based on the tide gauge data. A smoothening filter was applied to overcome the missing gaps in data. The trend estimated from the dataset is about 0.83mm/year which after Glacial Isostatic Adjustment (GIA) correction comes out to be 1.26mm/year (*Figure 21*).

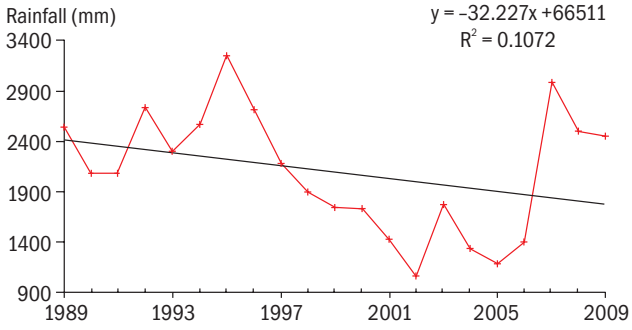

Figure 19: Total annual rainfall in monsoon months in Panaji, 1989 –2009

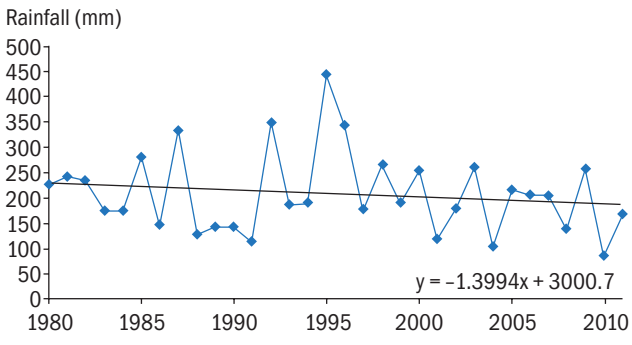

Figure 20: Annual highest 24hr rainfall, Panaji

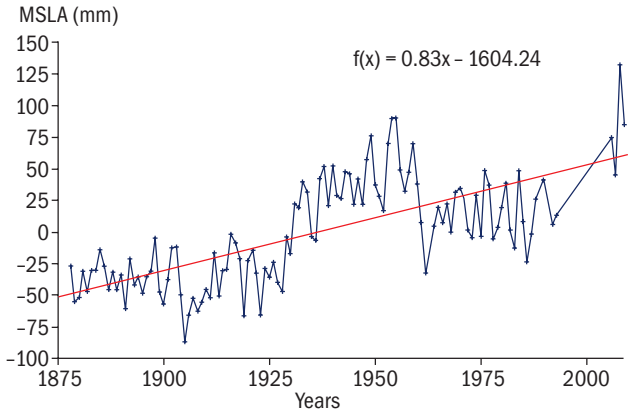

Figure 21: Annual MSL anomaly for Panaji, 1875–2010

iii. The Mean Sea-Level (MSL) rise for future—The CMIP3 (Meehl et al., 2007) datasets presented in IPCC Ar4 report, which are the global models having typical horizontal resolution of 1–3 degree were used. Since the domain of the study area was based on a regional scale, utilization of the relatively coarse global models and dataset increases the uncertainty of the projections. Therefore, an ensemble approach using six IPCC AR4 models was used. This kind of ensemble approach is globally accepted as a key measure to reduce model uncertainty. For this purpose, a total of 15models were analysed and the models which had over 70 years of consistent projections available for the "business as usual" scenario were selected. This ensemble mean was used to plot the trends for the future (Year 2100). The Mumbai/Goa coast shows a trend of ~0.3mm/yr (*Figure 22*).

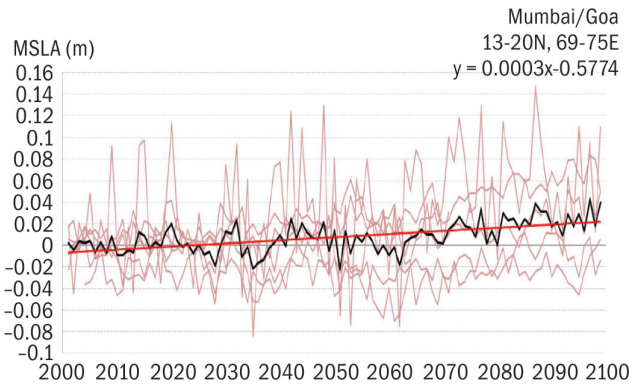

Figure 22: Projected sea level anomaly for Panaji

[2] Permanent Service for Mean Sea Level

Due to the element of high uncertainty in future SLR at smaller scales using coarse global models and lack of GIA corrections, a multiple-scenario approach was further applied to understand the impact of SLR on Panaji. Based on extensive literature review and results of the modelling exercise, three scenarios were considered for vulnerability assessment of the city.

SLR Scenarios

- **Scenario 1: Based on TERI's SLR projections without GIA corrections** of 0.3mm/yr
- **Scenario 2: Based on observed SLR trend (with GIA corrections)** which was found to be 1.26mm/year for Panaji
- **Scenario 3: Based on 1 meter sea-level rise in 100 years** (Byravan et al., 2010; MoEF 2010, and USGCRP 2009)

The MSL for the baseline scenario was calculated from the tide gauge data obtained from the PSMSL website. For Panaji, the MSL value was found to be 7.02m based on tide gauge data since 1878. The projected trend for the three SLR scenarios was added over and above these MSL values for the year 2000 to come up with the estimated MSL for the year 2100.

VULNERABILITY ASSESSMENT

Exposure Profile

Exposure is the nature and extent of changes that a region's climate is subjected to with regard to variables such as temperature, precipitation, extreme weather events, sea level (Brenkert and Malone [2005]). This study particularly looks at the impact of SLR on infrastructure and services of Panaji. Sea-level rise coupled with extreme events like extreme rainfall will lead to inundation, water logging, and floods in the city.

To understand the exact spatial extent of the impact of SLR and other extreme events on Panaji, the three SLR scenarios were overlayed on the Digital Elevation Model (DEM) of the city. This led to identification of hotspots, areas, and assets that are likely to be affected under different SLR scenarios, providing a concise spatial exposure profile for Panaji.

Figure 23 highlights the areas and uses that are vulnerable in Panaji. Few areas, like Ribandar, Patto, Fontainhas, Nuegi Nagar, St Inez, La Campala, Miramar, Carnazalem, Dona Paula are found to be partially vulnerable. In terms of the uses/activities that are likely to be affected, these areas have land uses ranging from residential, commercial, institutional

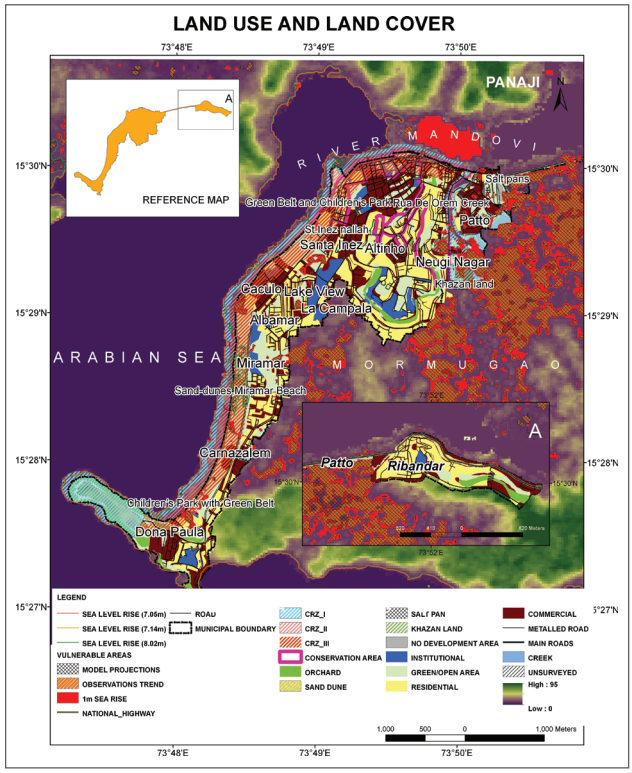

Figure 23: DEM overlay on land use and land cover map of Panaji

to heritage, conservation areas and also ecologically sensitive areas like khazan lands, salt pans, sand dunes, creeks, and estuaries and also Dr Salim Ali Bird Sanctuary. Major city roads, NH 4A, and the Patto Bridge that connects Panaji to Ribandar and Old Goa are also likely to be affected, in case of SLR.

Non-climatic stressors as found in the study are:

1. Impact of development activities on khazan lands, salt pans, and creeks
2. Impact of development on the natural drainage of the city causing floods during rains
3. Impact of high floating population on the infrastructure and services of the city

MAJOR THREATS TO NATURAL RESOURCES OF PANAJI

i) Khazan land and mangroves

The khazan lands are saline flood plains in Goa's tidal estuaries (below sea level at high tide) which have been reclaimed over centuries with an intricate system of bunds and sluice gates (Alvares 2002). They are community managed, integrated agro-fishery-saltpan ecosystems. These are mostly mangroves areas, reclaimed using a system of dykes, canals, and gates. The important natural anti-erosive barrier is provided by the mangrove vegetation near the external or internal

bunds. Mangroves act as wave breakers and reduce the net erosive energy of the tides. The biota of estuaries, mangrove swamps and forests, intertidal zones, mud flats, embankments, and the productive khazan farms constitute very vulnerable elements of the system. These lands serve as emergency storm water receptacles. If this land is destroyed or filled up, flooding (in surrounding area) is bound to occur. In present times, management of khazan ecosystems are impaired by various factors. These factors can be broadly divided into natural (infestation by boring agents and mud crabs), ecological (growth of mangroves and weeds), intensive agriculture and mining, and other socio-economic factors.

ii) Creeks

The Ourém creek is located in the east of Panaji in an area called Fontainhas. A historic bridge called Patto runs over the creek. The creek is dominated by mangroves on both its banks. The creek extends to Mala and St. Cruz region. Urbanization and construction in the vicinity of the creek is exposing it to increasing pollution.TheSt. Inéz Creek in Panaji opens up into the Mandovi River which further joins the sea at Miramar. The St. Inéz creek is 3.7 km in length, with surface area of 65,750 sq m with an average width of 12.6 m. This beautiful creek in the past has now turned into a *nallah* since it has been receiving untreated sewage and garbage over the years. At present, the depth of the creek has been reduced and is found in the range of 1- 4.5 m along its course. The city garbage and floating litter getting stuck at various points along the length of the creek is being observed. With the creek blocked up with garbage, it leads to flooding in some parts during monsoon. New mega projects that are coming up near the creek would further aggravate the problem.

iii) Sand dunes in and around Panaji

A stretch of about 4.5 km of sandy shore exists from Miramar, Carnazalem to Panaji town. Due to rapid urbanization and tourism, most of the dunes are destroyed.

Khazan land along National Highway 4 near Kadamba bus stand

Salt pan at Ribandar

Ourem creek

Mangroves near Pattobridge

Sand dunes at Miramar

Sensitivity

After preparing the exposure profile of the city, the next step in the vulnerability assessment was to identify and assess the sensitivity of the city systems to the identified exposure levels. Sensitivity is the degree to which a system or species is affected, either adversely or beneficially, by climate stressors. The effect may be direct (for e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (for e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise) (IPCC2014).

To understand this, 'vulnerability mapping' exercise was undertaken where SLR scenarios and sector-wise infrastructure assets and services were superimposed on the DEM of the city (*Figures 24–30*). This led to identification of sector-wise assets that are likely to be impacted in the SLR scenario and hence are sensitive. *Table 1* summarizes sector-specific sensitivity of the city.

Table 1: Sector-specific sensitivity of Panaji

Area	Sensitive sectors	Factors causing sensitivity
St. Inez	Solid Waste Management Social Infrastructure Tourism and Heritage Water Supply Transport Sewerage and Drainage Ecologically Sensitive Areas Energy and Telecommunication	SLR Low elevation Flood prone
Patto	Solid Waste Management Transport Sewerage and Drainage Ecologically Sensitive Areas Social Infrastructure Water Supply Energy and Telecommunication Tourism and Heritage	SLR Low elevation Flood prone High-density
Neugi Nagar	Social Infrastructure Tourism and Heritage Sewerage and Drainage	SLR Flood prone Low elevation

	Ecologically Sensitive Areas Water Supply Transport Energy and Telecommunication	
Altinho	Tourism and Heritage	SLR Flood prone
Near Mala Lake	Solid Waste Management	SLR Flood prone Low elevation
Fontainhas	Tourism and Heritage Water Supply Sewerage and Drainage Solid Waste Management Transport	SLR Flood prone Heritage area
Ribandar	Ecologically Sensitive Areas Energy and Telecommunication	SLR Flood prone Conservation area
La Campala Zone	Ecologically Sensitive Areas Sewerage and Drainage Transport Water Supply Social Infrastructure Solid Waste Management Energy and Telecommunication	SLR Flood prone Low elevation
Carnazalem	Ecologically Sensitive Areas Sewerage and Drainage Transport Water Supply	SLR Flood prone
Miramar	Ecologically Sensitive Areas Transport Water Supply Sewerage and Drainage Solid Waste Management Tourism and Heritage	SLR Flood prone Low elevation
Dona Paula	Ecologically Sensitive Areas Water Supply Sewerage and Drainage Tourism and Heritage	SLR Flood prone

From the above table,the identified critical infrastructure for resilience planning are identified as follows:

Water Supply

Water supply network is getting affected partially in some areas of the city as listed in *Table 1*.

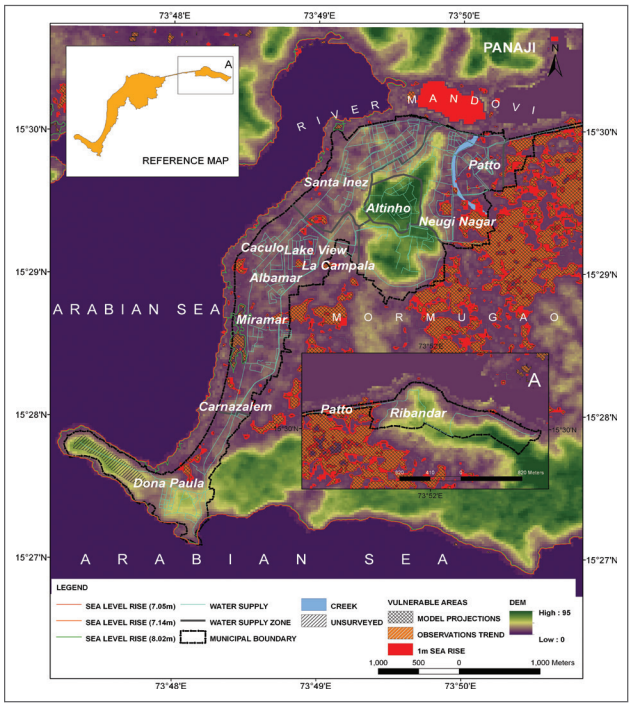

Figure 24: DEM overlay on water supply map of Panaji

Sewerage and Sanitation

Trunk drains, surface drains, and community toilets in the listed areas of the city might get affected due to the impact of SLR.

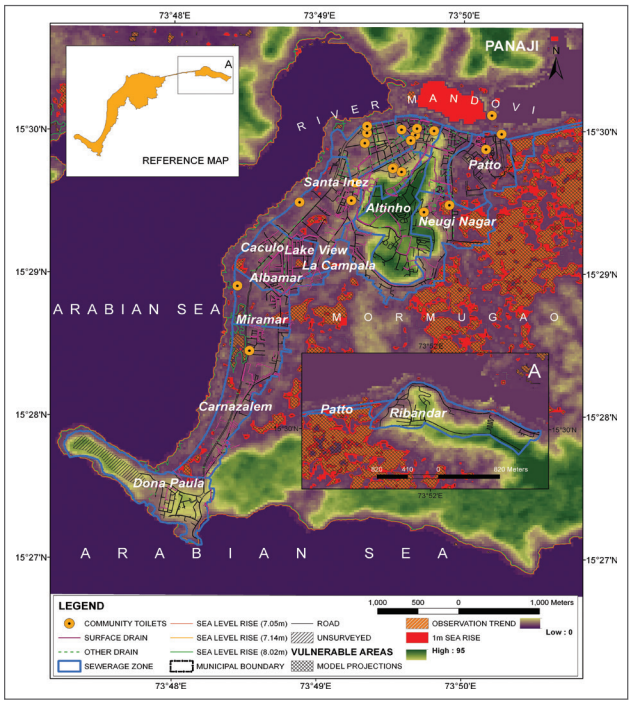

Figure 25: DEM overlay on sewerage and sanitation map of Panaji

Solid Waste Management

Vulnerable infrastructure includes sorting centres, four-way segregation centres, and compost stations.

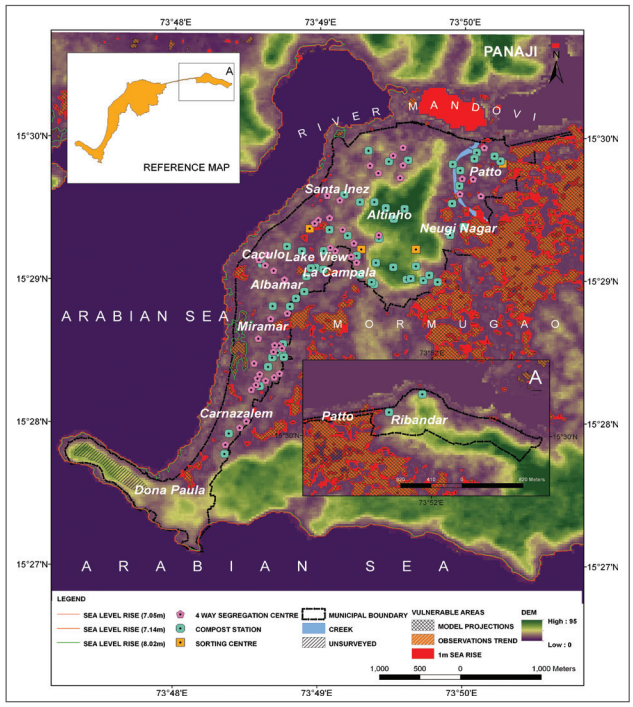

Figure 26: DEM overlay on solid waste management map of Panaji

Transport

NH 4A and the Patto Bridge that connects Panaji to Ribandar and Old Goa are likely to be affected. The Interstate Bus Terminal and the upcoming multi-level parking at Patto, and

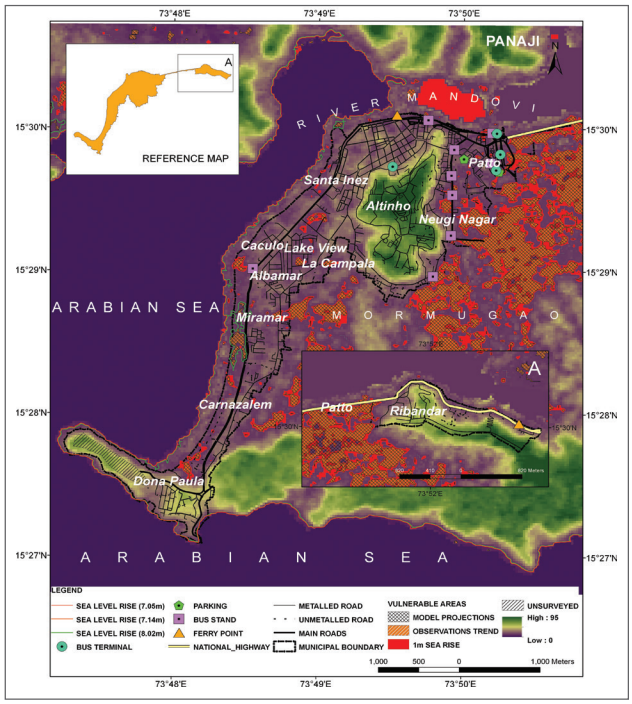

Figure 27: DEM overlay on transport sector

the Betim Ferry point may also be vulnerable. Apart from this, major and minor roads, bus stands, and parking areas might also get affected in SLR scenario.

Heritage and Tourism

The conservation area in the northern part of the city is likely to be partially affected. Apart from this, beach-facing hotels in the areas listed in *Table 1* will also get affected.

Ecologically Sensitive Areas

Ecologically sensitive areas like khazan lands, salt pans, creeks, and estuaries in the northern part of the city are more likely to be affected. Apart from this, tidal influenced water bodies like the St. Inez creek, Rua de ourém, and River Mandovi will also be affected due to SLR. Sand dunes and beaches in Miramar, Dona Paula, and Caranzalem, and also Dr Salim Ali Bird Sanctuary are likely to be affected partially.

Social Infrastructure

Vulnerable infrastructure includes schools, hospitals, and clinics. They will be affected by flooding either due to extreme rainfall or SLR in the affected areas as listed in *Table 1*.

Energy and Telecommunications

Vulnerable infrastructure includes electricity substations, gas stations, telecommunication lines, and towers in the affected areas as listed in *Table 1*.

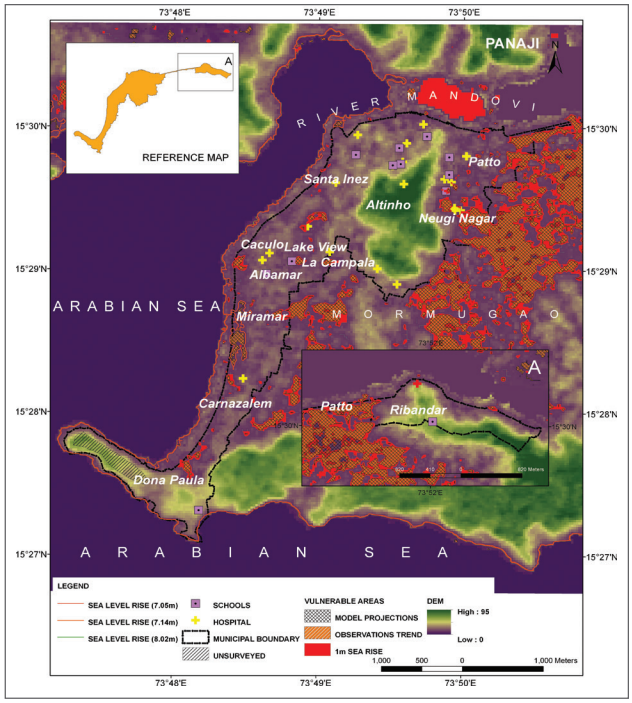

Figure 29: DEM overlay on social infrastructure sector

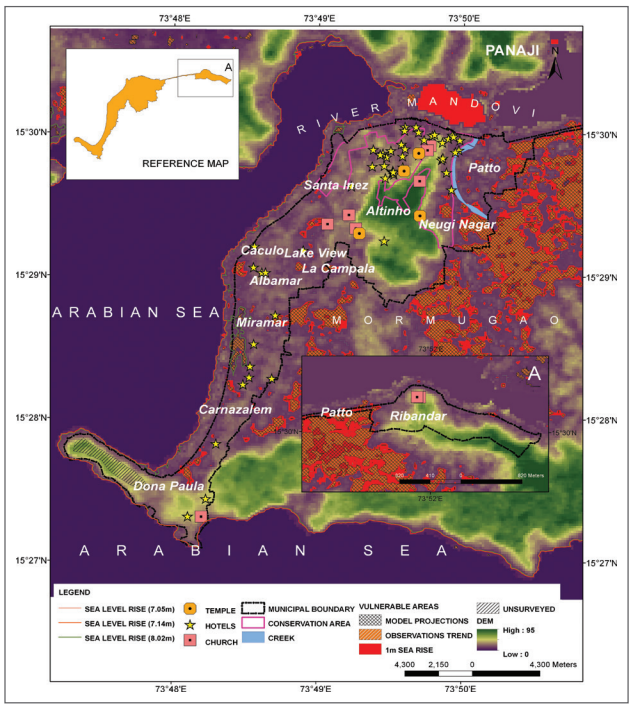

Figure 28: DEM overlay on heritage and tourism sector

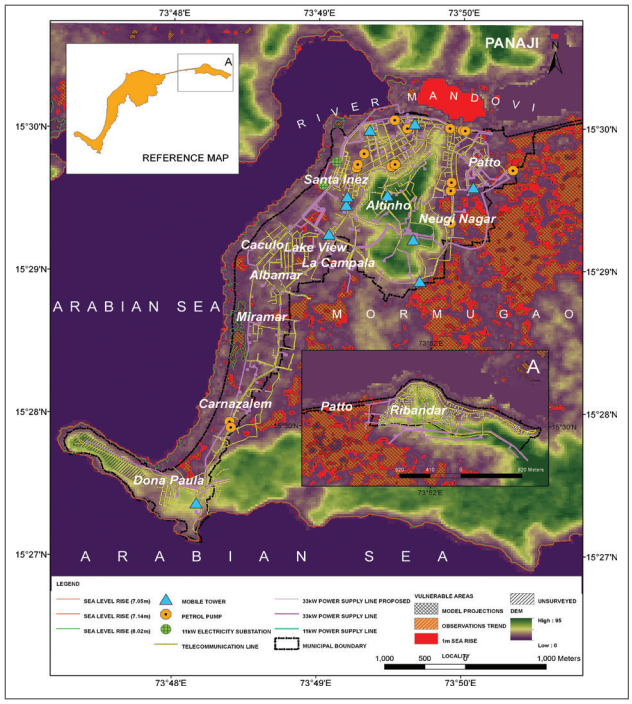

Figure 30: DEM overlay on energy and telecommunications sector

ADAPTIVE CAPACITY

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) so as to moderate potential damages, to fully utilize the opportunities, or to cope with adverse consequences. As part of this project, assessment of the adaptive capacity of Panaji city was a continuous process and relied mostly on review of relevant city level plan documents, state level policies, acts and rules, stakeholder consultations, and discussions with sector experts. For instance, two Expert Review Committee workshops contributed in assessing the adaptive capacity and validating the methodology and recommendations proposed in this study (See Box).

A broad assessment of institutional and policy framework, disaster preparedness, infrastructure and services adequacy, and efficiency was conducted in order to understand the adaptive capacity of the city. Based upon this assessment, structural recommendations and enabling policy, and institutional recommendations have been suggested for resilience planning and increasing the adaptive capacity at city level. Besides this, the DBMS developed as part of this study provides baseline information for 10 sectors on coverage, location, capacity aspects. The inventory also colour codes certain data fields to be maintained by the city that will help in formulating and implementing policy and engineering decisions for increasing the adaptive capacity of Panaji. This inventory can further be refined/developed in consultation with multiple departments/sectors to include several other infrastructure planning parameters as relevant to the particular city. The study also recommends a detailed analysis of critical infrastructure sectors to understand the obstacles, barriers, or limitations that affect the city's ability to respond to climate and non-climate stressors, disasters, or impacts to implement measures for increasing its adaptive capacity.

Box: Validation/Expert Review Committee

An Expert Committee was constituted comprising a mix of experts and professionals working in the areas of coastal cities/ settlements, disaster management, climate resilience planning, urban planning, representation from USAID and officials from various sectoral departments at city level. The Committee met twice during the year-long project timelines to review the work carried out and provide inputs for its improvement.

RECOMMENDATIONS

Having identified the vulnerable areas and sector-wise infrastructure assets and services, broad recommendations addressing specific sectors of the city have been formulated and suggested. The recommendations are said to have been 'broad' since structural adaptation interventions as well sector-specific adaptation interventions would need expert advice, planning, and detailed analysis, both technical and financial, to arrive at a decision for implementation. In addition to this, the study also highlights the primary enabling and supporting considerations like institutional and regulatory frameworks, financing mechanisms, and capacity-building, which would be required for planning of new infrastructure or retrofitting/climate proofing of the existing one. *Table 2* presents the key structural and non-structural measures and key data fields suggested for addressing the future sea-level rise and current and future vulnerabilities associated with SLR in the city.

Figure 31: Overview of recommendations

Table 2: Sector-wise recommendations for addressing vulnerabilities associated with SLR in the city

Sector	Structural measures	Non-structural measures	Suggested data fields
Ecologically Sensitive Areas (khazan lands; mangroves; creeks)	• Rehabilitation and preservation measures around sand dunes and mangroves. For instance, plantation of vegetation along the dunes can help restore and stabilize the dunes • Immediate need of identifying and curbing the point and non-point sources of pollution along its course, de-silting, and cleaning of the creek	• Spatial maps of natural assets like khazan lands, salt pans, mangroves, creeks, etc., should be maintained. The entire shore line ecosystem should be demarcated in a GIS framework • The natural assets of the city should be demarcated and preserved and no construction /man-made interventions should be allowed in the ecologically sensitive areas	• Sea-level rise will change the coastal morphology and soil characteristics. Cities must, therefore, maintain beach erosion information.
Solid Waste Management	• Introducing waterproofing measures, like barriers to reduce contact from flood water, waterproof covers and rain shelters • Creating elevated storage spaces	• Framing up of siting regulations (for landfill sites, sorting centres and compost stations) after assessing the vulnerable areas with respect to the impact of sea-level rise • Identifying a number of alternate disposal sites in case of restricted access due to flooding	• Elevation of important disposal and treatment sites • Location of curb side refuse collection bins, primary collection, and segregation centres • The bins and centres located in flood prone areas

Heritage and Tourism	• Reducing the impact of flooding • Addressing the requirements after the flood has receded • Checking for building stability and efficiency	• Flood proofing and conservation programmes based on expert advice • Emergency plan for the safety of the tourists, for example emergency evacuation, safe transport facilities, and health facilities • Assessments regarding impact of sea-level rise on tourism activities for siting of upcoming infrastructure like hotels and beach tourism, etc. • All future tourism infrastructure projects must comply with the Coastal Regulation Zone rules.	• Data on intensity of tourist inflows in the city at a particular time of the year • Age, condition, and last maintenance carried out in heritage sites • An inventory of informal sector that supports tourism should be maintained
Water Supply	• Prevent water leakage and infiltration of flood water into the pipelines—marking and monitoring the infiltration points to facilitate maintenance	• An emergency supply plan with demarcated network routes as well as alternate modes of supply to restore water supply in the affected zones • Quality monitoring has to be frequently carried out during rainy season.	• Data on the age and capacity of treatment plants • Data on incidences of shutting down of pumps • Influent and effluent data from the treatment plant • Emergency supply plan • Seasonal reports on water quality should be maintained • Regular maintenance details
Sewerage and Drainage	• The vertical elevation of the outfall channel should be above the high tide level to avoid back flows from sea • Planning the gradual augmentation of the sewerage system—New drains to take into account the vulnerable zones of the city and appropriately in-built resilience features	• Identifying alternate energy sources in vulnerable zones housing pumping stations • Regular maintenance— The drains must be cleaned periodically to avoid blockages during peak time • Integrating vulnerability assessment and resilience planning in institutional framework and plans, acts, rules, bylaws, building codes, etc.	• Data on flood-prone areas • Yearly data on water logged areas • Locational details of drainage • Height of outfall sewers from the mean sea level/ high tide level • Maximum capacity of pumps and treatment plants • Distance of waste water plant from sea
Transport	• Retrofit and adaptation of airport and sea port systems • Appropriate design of public transport systems— siting, entry and exits, drainage, manholes, considerations for safety of structures, equipment, and operations.	• Emergency transport arrangements and alternative route planning— SOPs • Emergency operations and control measures— SOPs • Planning new infrastructure: avoiding low-lying vulnerable hotspots	• Road infrastructure—Location and elevation of roads, bridges, subways, tunnels, etc, data on age, type of structures, building materials, etc., drainage information

	• Building elevations and materials for structural safety • For transport networks, appropriate drainage provisions with optimum design capacity, length, depth, and the gradient are required • If the parking lot is not to be used for retaining water, provision of drains, impervious surface area and adequate slope at strategic locations to prevent flooding and water logging would be required	• Integrating vulnerability assessment and resilience planning in institutional framework and plans, acts, rules, by-laws, building codes, etc. • Enforcement of CRZ Notification 2011 while development and siting of transport infrastructure and networks • Siting of processing and industrial units in and around port areas as per the CRZ Notification 2011	• Railways– Information on location and networks, maintenance plan and frequency, elevation, flood prone areas, data on disruptions due to extreme weather phenomena, data on railway buildings • Airport— Capacity, footfalls, age, building material, elevation, plinth level, entry to runway/taxi ways, details of low-lying/ flood-prone areas
Social Infrastructure	• Reducing the impact of flooding through appropriate building design solutions • Addressing the requirements after the flood has receded • Checking for building stability and efficiency	• Planning for evacuation, response and relief in case of extreme events—SOPs • Planning new infrastructure: Avoiding low-lying vulnerable hotspots • Integrating vulnerability assessment and resilience planning in institutional framework and plans, acts, rules, by-laws, building codes, etc.	• Health— Information on location of hospitals and health centres, ambulances, medicine stocks, doctors, nursing and paramedical personnel, yearly data on diseases, etc. • Education — Information on location of schools, number of students, available rooms and infrastructure, transport facilities, etc.
Energy and Telecommunication	• Appropriate building design solutions for reducing flood damage in vulnerable areas • Appropriate on-site drainage on production and refuelling stations • Maintaining safe heights for infrastructure assets like Electric Substation and for leak- proof equipment storage • Appropriate reinforcement measures for the safety and stability of towers and cables/ lines	• Planning new infrastructure: Avoiding vulnerable hotspots for siting • Integrating vulnerability assessment and resilience planning in institutional framework and plans, acts, rules, by-laws, building codes, etc. • Enforcing state level Renewable Portfolio Obligation (RPO) in line with The Electricity Act of 2003 for promoting smaller, distributed power generation units to minimize and manage impact on grid and develop climate resilient power infrastructure	• Location and elevation of facilities— production sites, substations, etc • Details of transmission lines— location of towers, network, underground cabling details for flood prone and low-lying areas

THE WAY FORWARD

The study undertaken by TERI resulted in a factual, updated, and multi-sectoral DBMS, a scientific vulnerability mapping exercise with the help of which broad recommendations were suggested. However, it is only a first step in demonstrating and initiating climate action at Panaji city level and for coastal cities in India, in general. It is really upto the city to take this forward while envisioning and planning for a development that takes cognizance of the future shocks and stressors. In order to implement the suggested measures and build climate resilience, the city will need to come up with detailed recommendations and action points for short, medium, and longterm period, based on expert advice, scientific studies, and financial considerations. Supporting and enabling mechanisms in terms of policy and regulatory frameworks, finance allocation, and sensitization and capacity-building of stakeholders will be an integral part of climate resilience planning efforts. Besides, since infrastructure development and management for a number of sectors and services is beyond the powers and functions of the ULB, an integrated multi-sectoral approach with dedicated institutional framework needs to be formulated for coordinating infrastructure development and management at city level.

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All activities in TERI, the largest developing-country institution working towards sustainability, move from formulating local- and national-level strategies to shaping global solutions to critical issues.

Buoyed by more than 30 years of excellence in research and innovation, TERI is now poised for future growth, with a philosophy that assigns primacy to sustainable development

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