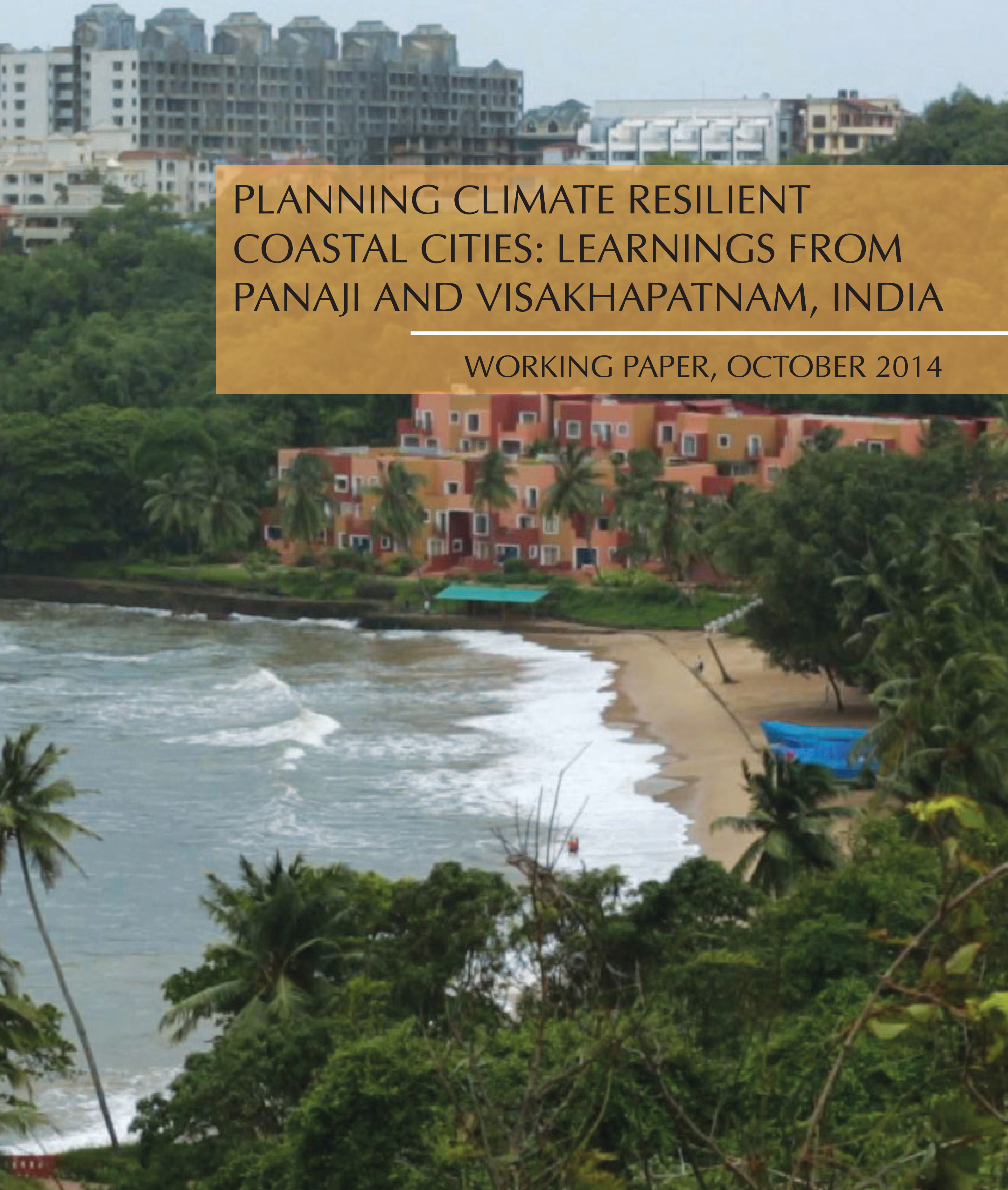
The Energy and Resources Institute

PLANNING CLIMATE RESILIENT COASTAL CITIES: LEARNINGS FROM PANAJI AND VISAKHAPATNAM, INDIA

WORKING PAPER, OCTOBER 2014



About the Project:

It is a study granted by USAID's 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.

Program focus:

Sea-Level Rise (SLR) and its impact on infrastructure and services of coastal cities.

Project cities:

1. Panaji, Goa
2. Vishakhapatnam, Andhra Pradesh

Other Publications from the Project:

Case study briefs on the study outcomes of Panaji and Visakhapatnam have also been prepared as part of this project.

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Suggested citation:

TERI, 2014. Planning Climate Resilient Coastal Cities: Learnings from Panaji and Visakhapatnam, India

Disclaimer:

This activity is made possible by the support of the American people through the United States Agency for International Development (USAID). The contents are the sole responsibility of grantee and do not necessarily reflect the views of USAID or the United States Government.

PLANNING CLIMATE RESILIENT COASTAL CITIES: LEARNINGS FROM PANAJI AND VISAKHAPATNAM, INDIA

ACKNOWLEDGEMENT

We are grateful to the US Agency for International Development (USAID) for granting this study to TERI as part of their Climate Change Resilient Development (CCRD) project's climate adaptation small grants program. We are particularly thankful to Mr Christopher Evans, Deputy Program Manager, CRIS Program and Manager, ICF International, Ms Michelle Colley, Senior Manager, ICF International and Ms Lana Lightle, CCRD Grant Manager for their constant involvement and support to TERI during the course of this study.

The study could not have taken place without the approval and continuous participation of Corporation of the City of Panaji (CCP), Town and Country Planning Department, Government of Goa, Greater Visakhapatnam Municipal Corporation (GVMC) and Visakhapatnam Urban Development Authority (VUDA); who formally supported the project and facilitated data collection, stakeholder consultations and provided inputs from time to time. We are thankful to Mr. Sanjit Rodrigues, Commissioner, Corporation of the City of Panaji and Mr ST Puttaraju, Chief Town Planner, Town and Country Planning Department, Government of Goa for their continuous support to the study in Panaji city. We are thankful to Mr M V Satyanarayana, Commissioner, GVMC, Ms M Janaki, Additional Commissioner, GVMC and Mr N Yuvaraj, District Collector and Former Vice Chairman, VUDA for guiding and facilitating our work in Visakhapatnam city. We are also thankful to various officials from city level and state line departments who were consulted for the study for their valuable inputs and insights. We are grateful to Gangavaram Port Limited, Visakhapatnam Port Trust, Indian Meteorological Department's Cyclone Warning Center in Visakhapatnam; and Public Works Department, Goa Industrial Development Corporation, Directorate of Health, and Captain of Ports in Panaji for their support and involvement in the project.

Special mention and thanks to Dr A S Unnikrishnan, Chief Scientist, National Institute of Oceanography (NIO) for providing his technical inputs and sharing his scientific work, and to Mr Swayan Pal Chaudhuri, Director (Projects), CCP for his personal attention and unstinting support for smooth execution of the study in the city of Panaji.

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Structure of the Working Paper

Chapter 1 of the working paper provides a brief introduction to the project. Chapter 2 and 3 provide an overview of the broad approaches adopted for this year-long assessment in the project cities of Visakhapatnam and Panaji. For each step of the study, the experiences and challenges have been summarized with an objective of sharing the learning from the project and deriving lessons for practitioners. Chapter 4 highlights a methodology called the Climate Vulnerability Assessment for Coastal Cities (CVACC) which was developed as part of this study. Chapter 5 discusses the approach for developing the recommendations for the project cities. And, Chapter 6 provides the key lessons and scope for future work in this area which could further strengthen this research.

1. INTRODUCTION

Infrastructure plays an important role in sustaining the development and requirements of a growing number of cities. It provides critical social and economic services not only to the city where they are located but also to regions beyond that. Infrastructure assets of a city, such as roads, bridges, drains, water, and power supply networks, buildings, etc., have long operational lifetime and are vulnerable to climate impacts like storm surges, floods and sea-level rise. While the location and design of new infrastructure could be based on probable climate change impacts, the existing infrastructure could be maintained and managed such that it is prepared to withstand climate impacts that it may be subjected to during its operational lifetime.

India has a 7,517 km long coastline with many low-lying and densely populated pockets with nearly 260 million people living within 50 km of the sea coast. A total of 130 towns and cities within 84 coastal districts contribute significantly to the nations' economy. These highly vulnerable areas house a web of infrastructure including transport and freight networks, road and rail corridors, industrial zones and parks, maritime and port facilities, petroleum industries and refineries. According to the recent report of the Planning Commission of India (2011) the rise in sea-level in the north of the Indian Ocean has been observed to fall in the range of 1.06-1.75 mm per year in the past century. As per the 12th Five year Plan of the Government of India, substantial chunk of planned infrastructure investment is poised to go to the coastal areas for the development of Special Economic Zones (SEZs), tourism development, port, rail and road corridors, and housing.

It is highly pertinent to start climate proofing infrastructure and services, given the climate sensitive nature of the existing infrastructure systems in the city, for example water management, transport, and energy. These also require a significant amount of lead time to implement because of the longer period of design life and hence call for immediate action (UNDP 2011).

Vulnerability of coastal areas to climate change is an issue which has gained attention recently. Coastal areas face multiple risks related to climate change and variability (IPCC 2007a). The Intergovernmental Panel for Climate Change Fourth Assessment Report (IPCC 2007a) has identified several low-lying deltas of Asia and Africa which are highly urbanized and also vulnerable to climate-related impacts. *"Thirteen of the world's 20 largest cities are located on the coast, and more than a third of the world's people live within 100 miles of a shoreline"* (World Bank 2010). The report on coastal mega cities (World Bank 2010) states that about 2 per cent of the world's land area is represented by low-lying coastal areas .This 2 per cent coastal land area contains 13 per cent of the urban population (McGranahan *et al.*, 2007). A study on 136 port cities showed that developing countries, especially cities in East and South Asia would face increase in exposure of population and assets to coastal flooding (Nicholls *et al.*, 2008).

This working paper is a result of TERI's year-long study granted by USAID's Climate Change Resilient Development (CCRD) project's Climate Adaptation Small Grants Program . This grant supported the Climate Resilient Infrastructure Services (CRIS) program within the CCRD project. The aim of the study was to develop and test approaches that can increase resilience of infrastructure assets and the services they provide in developing nations. In partnership with cities and USAID's missions, CRIS works towards mainstreaming climate risk management strategies into the development approach.

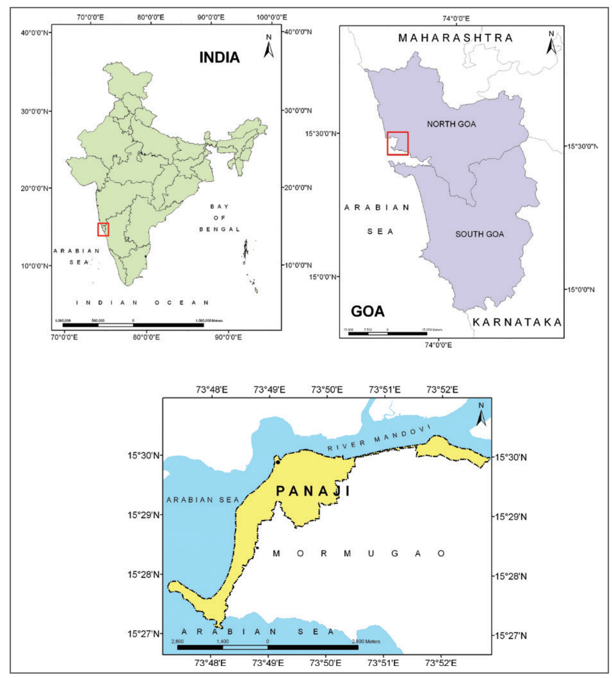
Project Objectives

Project objectives as defined under the grant were:

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

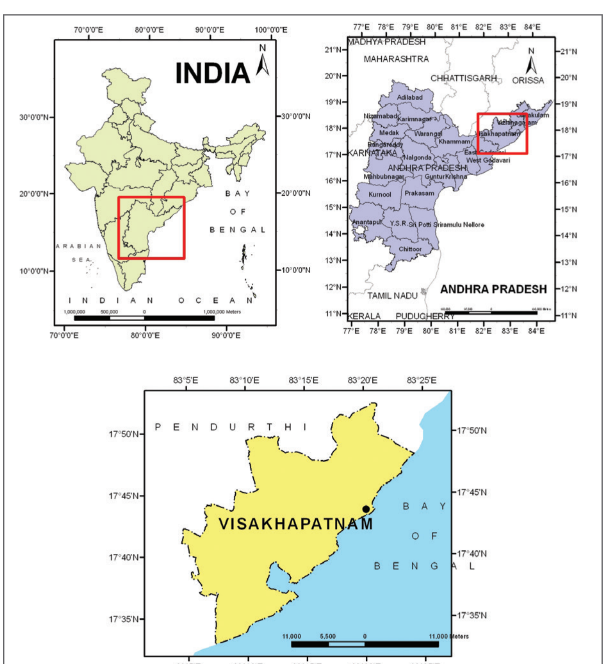
Project Cities

Since the objectives of the project required demonstration of city-specific infrastructure inventory and impact assessments for climate parameters like SLR, etc., it was necessary to base the work in some cities. Considering the time frame available, two coastal cities were chosen; Panaji the state capital of Goa on the west coast of India; and Visakhapatnam a medium-sized coastal city on the east coast of India.



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. Spread over just 812 hectares, Panaji (also known as Panjim), the capital of Goa is a prime tourist spot both for national as well as international tourists. It houses critical infrastructure that supports vast tourism activity in the area. The city is located on an ecologically fragile island[1]. Panaji has been identified as one of the coastal cities vulnerable to flooding due to the predicted sea-level rise. The population of Panaji is 114,405, as per the latest census. However, the floating population of the city is high since the city receives about a thousand international and five thousand domestic tourists every day. The rapidly increasing urbanization and growing tourism pressure on the city's infrastructure clubbed with future risks posed by climate change make it highly vulnerable.



Visakhapatnam, Andhra Pradesh (India)

Visakhapatnam (also known as Vizag) with a land area of 515 sq km is among the five major harbours in the state of Andhra Pradesh. The population of Visakhapatnam Urban Agglomeration is 1,730,320 (Census 2011). The city, which appears like a small basin, is surrounded by the Yarada hill popularly known as the Dolphin's nose (358m) on the side of the Kailasgiri hills on the north, with the Bay of Bengal forming the eastern wall. Visakhapatnam is facing long-term threats in terms of sea-level rise. The city has experienced high population growth and rapid industrialization with the growth of major industries, including steel, petroleum refining, and fertilizer (CDP, 2006). The city is also a major tourist destination which adds further pressure on the city's existing infrastructure. Developmental activities like off-shore jetties, small ports, the maintenance of entrance channels, offshore drilling activities for hydrocarbon resources have their own impact on the shallow bathymetry, coastal and near shore

[1] http://lists.goanet.org/pipermail/goanet-news-goanet.org/2007-March/002014.html

processes and living and non-living natural resources. This results in unprecedented and unexpected dynamics in shoreline migration and coastal morphology (NCSCM, 2010).

Broad Approach

A key component of climate proofing cities is the development of climate resilient infrastructure. In order to strategically develop or adapt infrastructure to help cities reduce their vulnerability to climate change impacts, an analysis of interactions between infrastructure, urban development, and the environment is essential. This should be done with a view to understand the current vulnerabilities that drive development actions and decisions in a city and also to ascertain the gaps and challenges. Climate resilience, could work on a larger time-scale that addresses current gaps and challenges and future vulnerabilities in a concerted manner.

Creation of a baseline of existing assets and services becomes a starting point for such analysis where multiple components are taken together and their interactions are studied. Therefore, to assess the baseline, as the first step, an inventory of critical infrastructure in a city was developed. Subsequently a vulnerability assessment of these assets and services to climate change impacts for urban resilience planning was conducted. Extensive use of Geographical Information Systems (GIS) was made to spatially analyse city systems and its interactions. *Figure 1* shows the broad approach followed for the study.

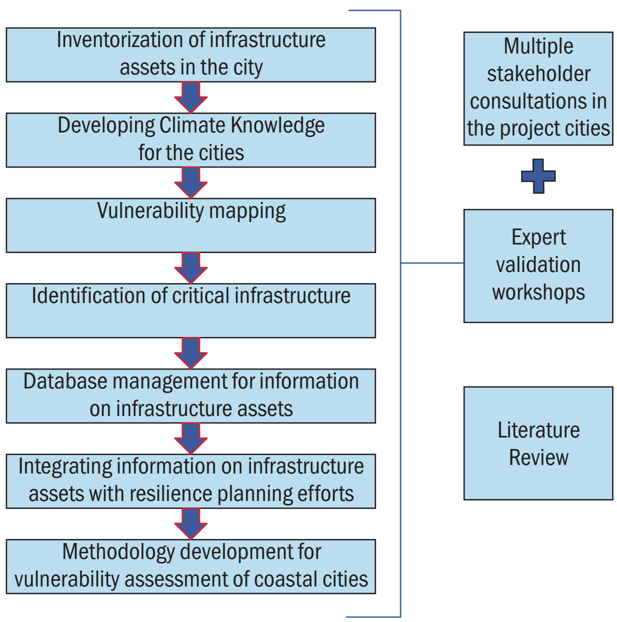


Figure 1: Approach followed for the study

Outcomes of the Study

- **Inventory on urban infrastructure** assets and its sources
- **Climate knowledge** on coastal cities /project cities
- **Identification of vulnerable hot spots** in the city
- **Critical infrastructure** in the project study cities for urban resilience planning
- **Demonstration of methods and tools** for development and management of database to support climate resilience planning
- **Recommendations** for project cities on climate proofing infrastructure and services
- **A generalized methodology for vulnerability assessment** of coastal cities to climate variability and sea-level rise

2. INVENTORIZATION OF INFRASTRUCTURE ASSETS IN THE CITY

The inventorization of infrastructure is not a regular practice in Indian cities as the data is stored department-wise and sector-wise with various government departments. Even the urban planning and management agencies like municipal bodies and development authorities do not maintain the entire data on infrastructure and services at one place. A comprehensive database or inventory is therefore not available while planning and data has to be collected, updated, and sometimes re-collected during subsequent planning phases in a city. Besides this, infrastructures of different kinds are usually managed by several agencies which include various city and state line departments and parastatals. Each agency may follow a different record keeping procedure (Rosenzweig *et al.*, 2011) and hence, inventorization holds promise to provide for collated data and information in an 'easy to retrieve and use' format.

Climate change is an emerging concern for city governments across the world. Though, in India, climate change does not yet figure as one of the primary considerations while urban planning. Besides this, even if a city has an environmental or sustainability goal outlined in its vision statement, it is often observed that it is not translated into the design elements of infrastructure and services. For instance, data fields which represent linkages of the physical and built assets to potential climate impacts are not recorded upfront. However, studies show (Rosenzweig *et al.*, 2011 and Chang 2009) that infrastructure inventories are a starting point and the very basis for preparation of risk inventories for climate change. Studies (Chang 2009) also suggest that infrastructure inventories provide a basis for understanding interdependencies of various sectors. It would help planners and decision-makers to understand how a failure of one sector will impact the other. For example, impact of power failure on water supply.

Objectives and Format of the Inventory

The focus of the infrastructure inventory was on collecting baseline information on infrastructure assets and services at the city level and collating inter-departmental data at one place. The infrastructure inventory does not look into micro level details but provides generic overview of sectoral information.

The inventory was prepared and planned with the following objectives:

1. To develop an inter-sectoral and inter-departmental urban infrastructure inventory to be housed at the Municipal Corporation.
2. To capture sector-wise locational and coverage details of basic infrastructure assets and services in the city
3. To develop the inventory into a Database Management System (DBMS)
4. To demonstrate the applicability of the DBMS to the city by enabling features of storing, retrieving, and updating information in the database

Figure 2 gives the basic format of the inventory. The inventory was developed into an MS Access-based Database Management System (DBMS) in which the entire data of the city infrastructure and services is stored in a retrievable format. The spatial data is also linked to the DBMS. Currently, this is a stand-alone system and can easily be installed on any computer.

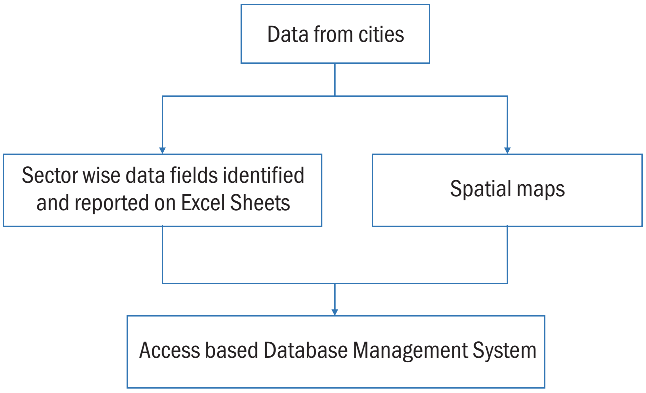


Figure 2: Format of the inventory

Methodology

The overall methodology for the preparation of the inventory is given in *Figure 3*.

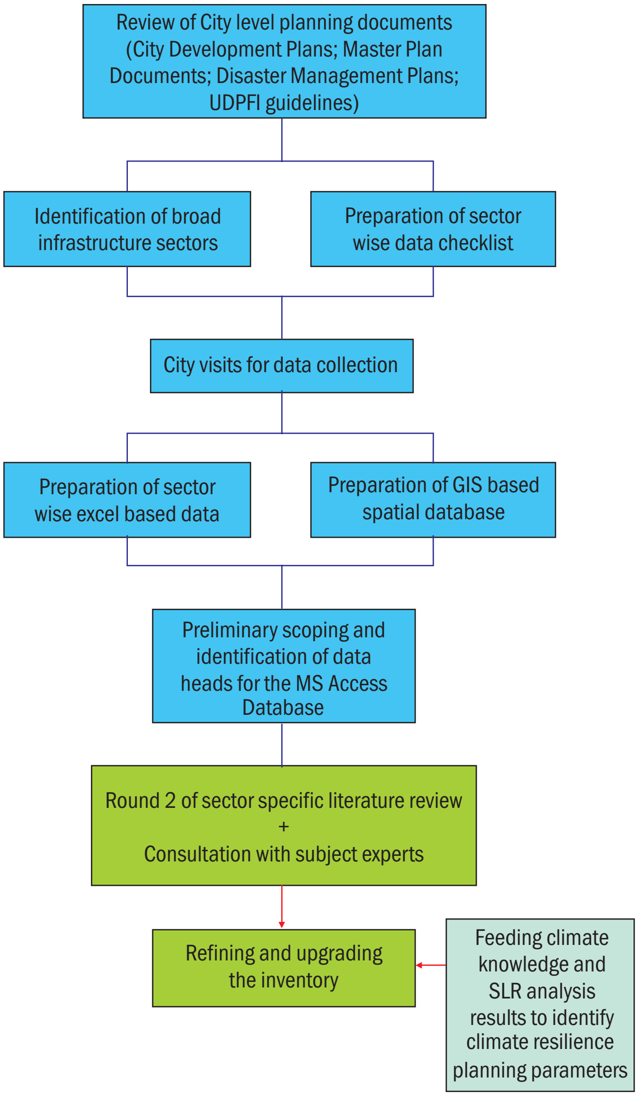


Figure 3: Methodology for inventorization

Approach

An inventory of key infrastructure and services for the cities of Panaji and Visakhapatnam was prepared. The data was collected from various government departments of the project cities. However, some of the data was not available, and some were not in the required format. To overcome this challenge the following approaches were adopted:

1. The available data was included in MS excel sheets (sector-wise) for both the cities
2. A uniform nomenclature was used for similar data fields of each sector
3. In certain instances, where data of one city was better organized than the other, such data heads were identified and included wherever applicable. Fields with data gaps were left vacant to be populated by the city government at a later stage. This will enable the cities to improve their databases in future.
4. It is also to be noted that contextual adjustments have been made to the inventory. The levels of detail vary, based on the scale and extent of infrastructure assets and services. For example, Visakhapatnam has multiple sources of water supply and so the water sector inventory for Visakhapatnam is much more detailed than Panaji. Whereas in the case of solid waste management sector, Panaji's inventory is more detailed.
5. The literature review, consultations with the sector experts, and review of available guidelines and norms enabled identification of necessary data that the cities need to maintain. These new parameters were also added to the inventory apart from the existing data that was collected from the cities.

Data Base Management System (DBMS)

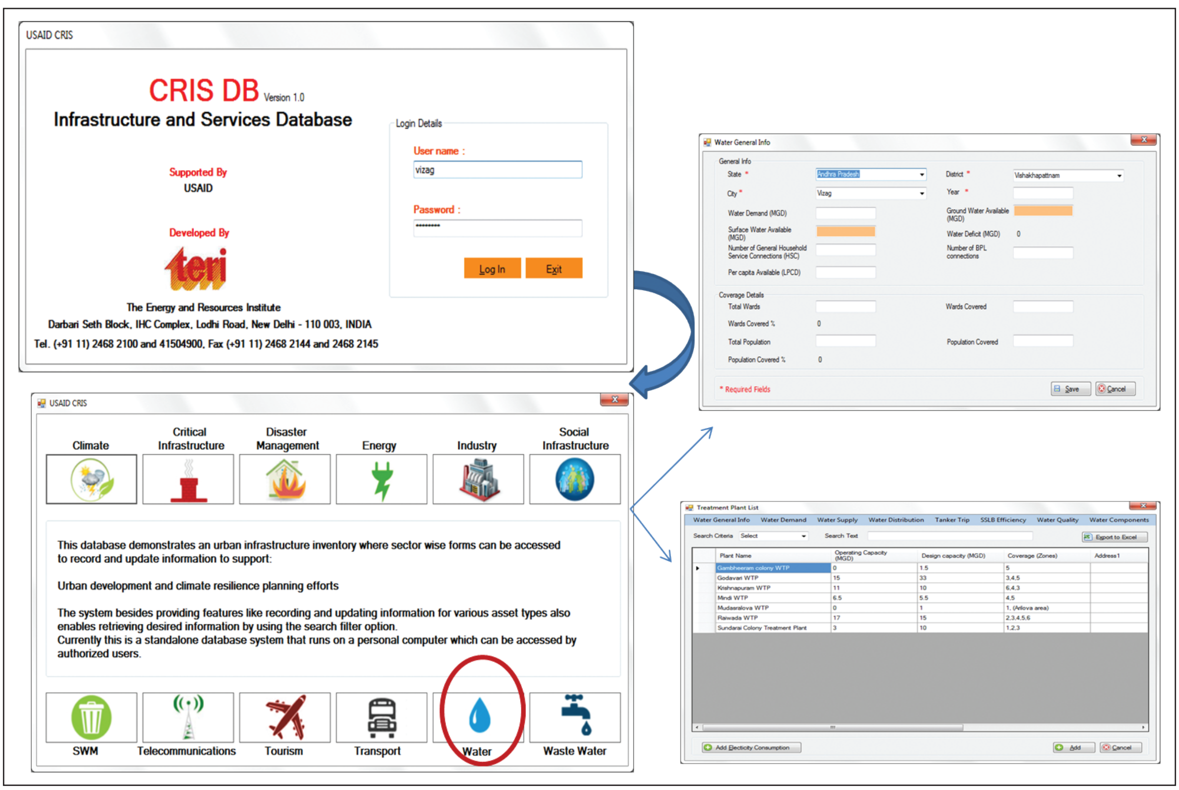
The basic objective of the DBMS was to demonstrate an urban infrastructure inventory where sector-wise forms could be accessed to record, retrieve, and update information to support urban development and climate resilience planning efforts. The baseline information collected from the city departments in both the cities was fed into the DBMS to provide a broader overview of the data available to the cities when they plan for climate resilience. The data fields which are important from the climate resilience planning perspective were colour coded separately within the sectoral forms.

The DBMS application provides three levels of access to the system. The Super Administrator has access to data of all cities; the City Administrator can access and make changes to the data for his own city only. Similarly, a general user has rights to view his/ her city only.

This database is developed as a Windows-based application, which can be easily installed on a stand-alone computer. The application has been developed using Microsoft technologies, i.e., .NET Framework 4.0 for front-end coding and Microsoft Access as a back-end database. It helps in easy maintenance and future enhancements, if any.

Key sectors identified in the study

- Water supply
- Sewerage and drainage
- Solid waste management
- Transport
- Social infrastructure (schools and hospitals)
- Heritage and tourism
- Ecologically sensitive areas
- Energy and communications
- Disaster management



Spatial Inventory of Urban Infrastructure Services in the City

Another component of the DBMS was a spatial inventory of urban infrastructure services for the two cities, wherein sector-wise infrastructure assets and service networks in the city were mapped in Arc GIS platform. The data set used for creation of the spatial database was sourced from various city level departments including Greater Visakhapatnam Municipal Corporation (GVMC), Corporation of the City of Panaji (CCP), Visakhapatnam Urban Development Agency (VUDA), Public Works Department (PWD), Gangavaram Port and other sectoral city level and state line departments. This data set included maps obtained in an Auto CAD format, images (.tiff/ .jpeg) or in hard copy. The locational information on different infrastructure assets was also received in the form of lists of addresses and geographical coordinates. The spatial data set was pre-processed through geo-referencing and geometrical structuring and corrections and included into the GIS platform. The addresses from the lists were located using ancillary sources like Google Earth and GPS and plotted in GIS (Figure 4). This exercise resulted in the GIS-based spatial database (Figure 5) which includes the shape files (.shp) on various infrastructure assets and service networks. For a ready reference to the city planners and decision-makers, these maps (in .jpeg format) were integrated in the DBMS and linked to respective sector-wise inventories.

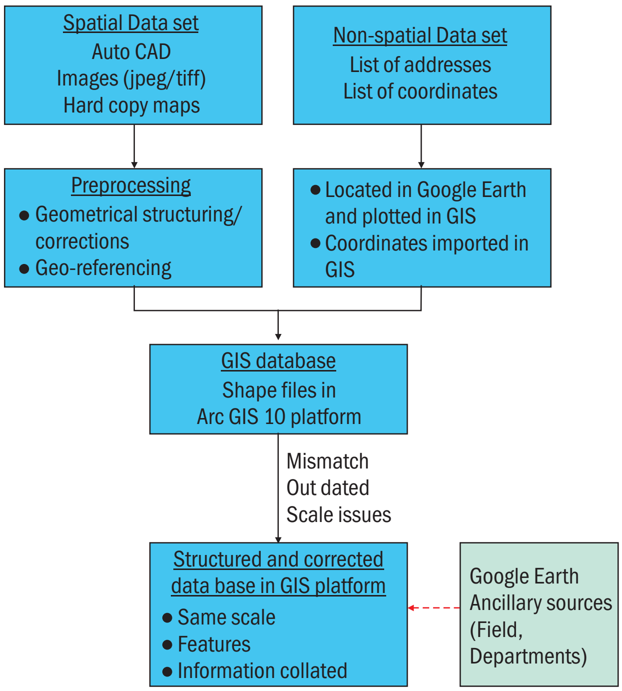


Figure 4: Methodology for preparing the spatial database

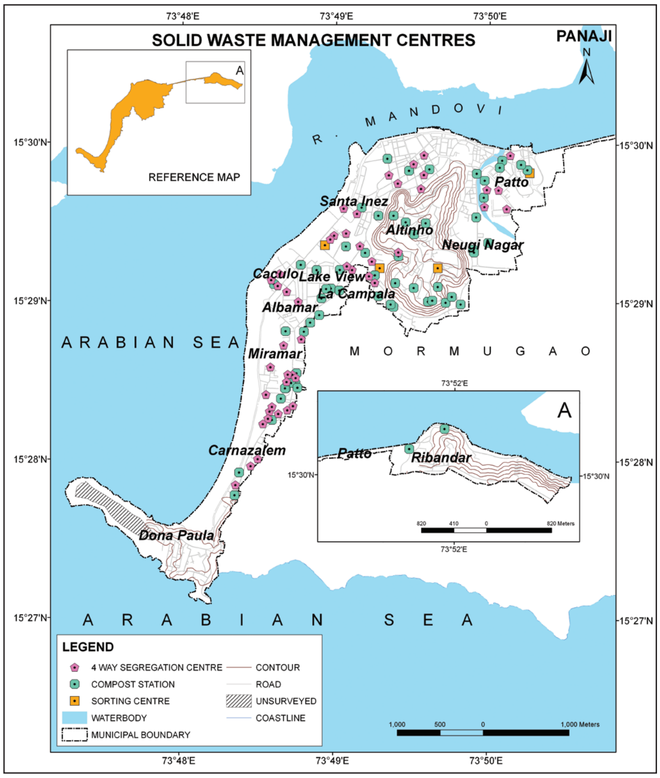


Figure 5: Map depicting the solid waste management centres in Panaji city

Challenges and Limitations

Spatial Database

A key step in the study was to collect the locational information of each infrastructure asset since it required GIS-based spatial assessment. However, the coastal zones are classified as 'strategically sensitive' hence, spatial information on these areas is not available in public domain. It requires channelized permissions from relevant public authorities for data sharing which could not be obtained due to the limited timeline of the study. Therefore, the lists of names and addresses that were received in the excel format had to be located on Google Earth and the location information was then exported to the GIS platform.

Since data sets of different formats were sourced from various departments, there were some limitations:

- Positional errors: Horizontal shifts in the database which arises due to use of multiple data sets and their raster to vector conversion
- Gap in database due to lack of details in the used data set and inability to locate all points on Google Earth

The layers obtained in form of spatial data sets like Auto CAD and image files were converted into vector (shape files) format and geo-referenced using Arc GIS 10 software. To correct the spatial extent of the base layer, reference points (coordinates) were collected from Google Earth and used to perform spatial adjustment techniques. All layers were extracted in form of polylines and edited to join some missing lines or transformed into polygons, wherever required.

Scope of the Inventory

It was beyond the scope of the study to cover all the identified sectors in detail, especially for sub-sectors like airports, railways, and ports which fall under the purview of independent authorities. However, the project team in their final report tried their best to advice on the type of database to be maintained by these authorities. For instance, it is recommended that the port authorities maintain spatial and locational details of port infrastructure and undertake assessments on impact of sea-level rise and other climatic hazards on port activities (like berth operability assessment during cyclones).

It is also to be noted that the data fields recommended are demonstrative and have definite scope for addition and alterations. A city may decide to add to these lists of infrastructure and assets, given the nature and extent of vulnerability and the resilience measures that they choose to integrate in their planning framework. Moreover, infrastructure resilience would require exploring dependability of one infrastructure on another. For example, water supply systems depend on the electricity provision for the operations of treatment plants and pumping stations. Likewise, the failure of drainage system in times of extreme rainfall will have an impact on the transport systems. Such kind of inter-sectoral dependability needs to be explored through separate and more focused studies.

3. IDENTIFICATION OF CRITICAL INFRASTRUCTURE

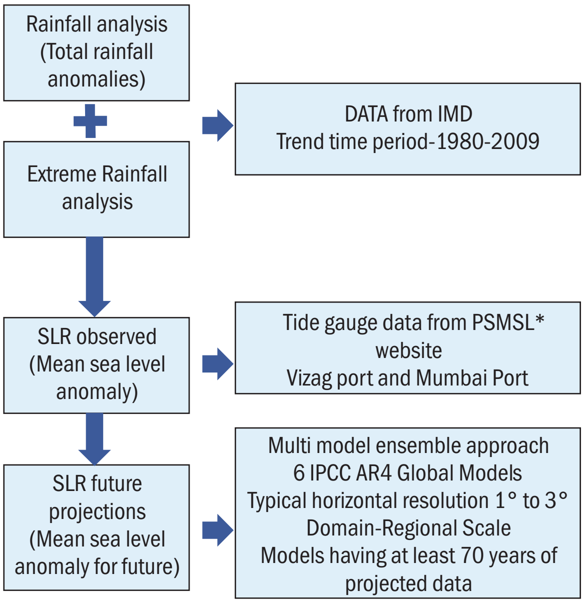
The knowledge of climate, particularly in the context of SLR and other factors impacting SLR levels like rainfall, storm surges, etc., is an essential component of this study. The level and type of impacts of SLR would determine the criticality of infrastructure and services of a coastal city. The next step therefore, in this study was to make an assessment of future SLR by use of projection models and literature in the knowledge domain. It was also essential to conduct vulnerability mapping of the two project cities under different SLR and extreme scenarios like a storm surge.

A detailed literature review was conducted to understand the impacts of SLR on coastal areas, particularly on cities and their infrastructure. Sector-specific impacts like effects of SLR on ports, tourism, buildings, etc., were studied through various research papers available in the knowledge domain. The SLR assessments for future were conducted using IPCC models for both the cities. Besides this, the past trends for rainfall pattern and extreme rainfall events were conducted to ascertain the composite climate vulnerability. The results were overlaid on the digital elevation model to mark spatially the vulnerable zones and to identify the infrastructure and services that are critical in addressing these impacts.

Climate Analysis

Climate Analysis (observed)

Each city may have climatic exposure apart from exposure to SLR and increased precipitation when combined with SLR or a storm surge may result in high-level risk at the coastal level. Therefore, precipitation trends for the last three decades for the two project cities were studied. The data set sourced from the Indian Meteorological Department (IMD) 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 (Figure 6). This analysis provides an indication towards the kind of risk the cities are likely to face in future.



*Permanent Service for Mean Sea Level (PSMSL)

Figure 6: Methodology for climate analysis

Mean Sea Level Anomaly (observed)

To analyse the observed sea level trends on the coasts of Visakhapatnam and Panaji, freely available tide gauge data was sourced from PSMSL[2] website for the period 1935–2010, in the case of Visakhapatnam, and 1875-2000, in case of Panaji.

[2] Permanent Service for Mean Sea Level

Future SLR Projection

To assess the mean SLR for future, the CMIP3 (Meehl *et al.*, 2007a) data sets presented in IPCC Ar4 report were used. The global models have a typical horizontal resolution of 1-3 degrees. Since the domain of the study area was based on a regional scale, utilization of the relatively coarse global models and data set increased the uncertainty of the projections. Therefore, an ensemble approach using six IPCC AR4 models was used. This kind of approach is globally accepted as a key measure to reduce model uncertainty. For this purpose, a total of fifteen models were analysed and the models which had over 70 years of consistent projections available for the "business as usual" scenario were selected.

Development of Multiple Scenarios

For SLR projections, global models with coarse resolution were downscaled to smaller domains which led to increased uncertainty of the results. It has been observed through literature review that this is a typical limitation of regional climate modelling and SLR projection studies. Besides this, SLR projections did not accept corrections like Glacial Isostatic Adjustment (GIA) into account. To address these limitations, multiple SLR scenarios were considered for understanding the impact on infrastructure assets in the two cities.

An extensive literature review of similar studies was undertaken in order to come up with different SLR scenarios. Since no regional level models/projections were available prior to AR5 assessments, some of the regional level studies in India like Byravan *et al.*, (2010) and MoEF (2010) have assumed a worst case scenario of 1m SLR in 100 years to conduct a vulnerability assessment of the coastline at state/district level. The 1m SLR scenario has also been used in other studies (USGCRP 2009) to assess impacts of SLR on ecosystems, urban systems and communities.

The vulnerability of coastal areas is further increased in case of extreme events like cyclones and accompanying storm surges. As per IPCC (2007) and MoEF (2010), there is a high likelihood of increase in the intensity of cyclonic events on the east coast of India in future. It is also understood that a Category 5 cyclone can cause surge height of 6m and above, depending on the wind speed (MoEF 2010). This means, in case of Visakhapatnam, a mean SLR of say 1m, will increase by more than 7m when a storm surge occurs due to a cyclonic event. Based on these considerations, the following four scenarios were taken into account to identify infrastructure assets that are likely to be affected due to SLR in the project cities:

- Scenario 1: Based on TERI's SLR model projections without GIA corrections
- Scenario 2: Based on observed SLR trend (with GIA corrections). This scenario considered that SLR continues to be at the same rate in future as that in the past.
- Scenario 3: Based on 1m SLR in 100 years.. This scenario was based on the findings of the literature review (Byravan *et al.*, 2010; MoEF 2010, and USGCRP 2009).
- Scenario 4 (For Visakhapatnam only): In case of cyclonic events, with surge height of 4m – Based on findings of literature review as discussed above, a Category 5 cyclone can cause a storm surge of 6m and more, depending on the speed of the winds. As per observations, Visakhapatnam has typically witnessed surges of 2-4m in the past (MoEF 2012). This scenario considered a moderate surge height of 4m over and above the MSL.

Vulnerability Mapping

In the next step, these scenarios were spatially plotted on the cities to identify areas and assets that are likely to be affected. For this purpose, the four SLR scenarios were plotted on the Digital Elevation Model (DEM) of Panaji and Visakhapatnam. The DEM data set at 30m resolution for 2011 sourced from the ASTER Global Digital Elevation Map[3] Website was used. The SLR scenarios were plotted on this DEM data set in Arc GIS 10 platform. Figure 6 shows the approach followed for vulnerability mapping of the two cities (see *Figures 7 and 9*). In order to plot the scenarios on the DEM for the two cities, the sea level anomaly was estimated taking the year 2000 as the baseline scenario. All the areas in the two cities which were found to have an elevation of less than the projected MSL values were demarcated as 'vulnerable' or the areas that are likely to be affected in these scenarios (Figure 8 depicts the methodology).

[3] http://asterweb.jpl.nasa.gov/data.asp

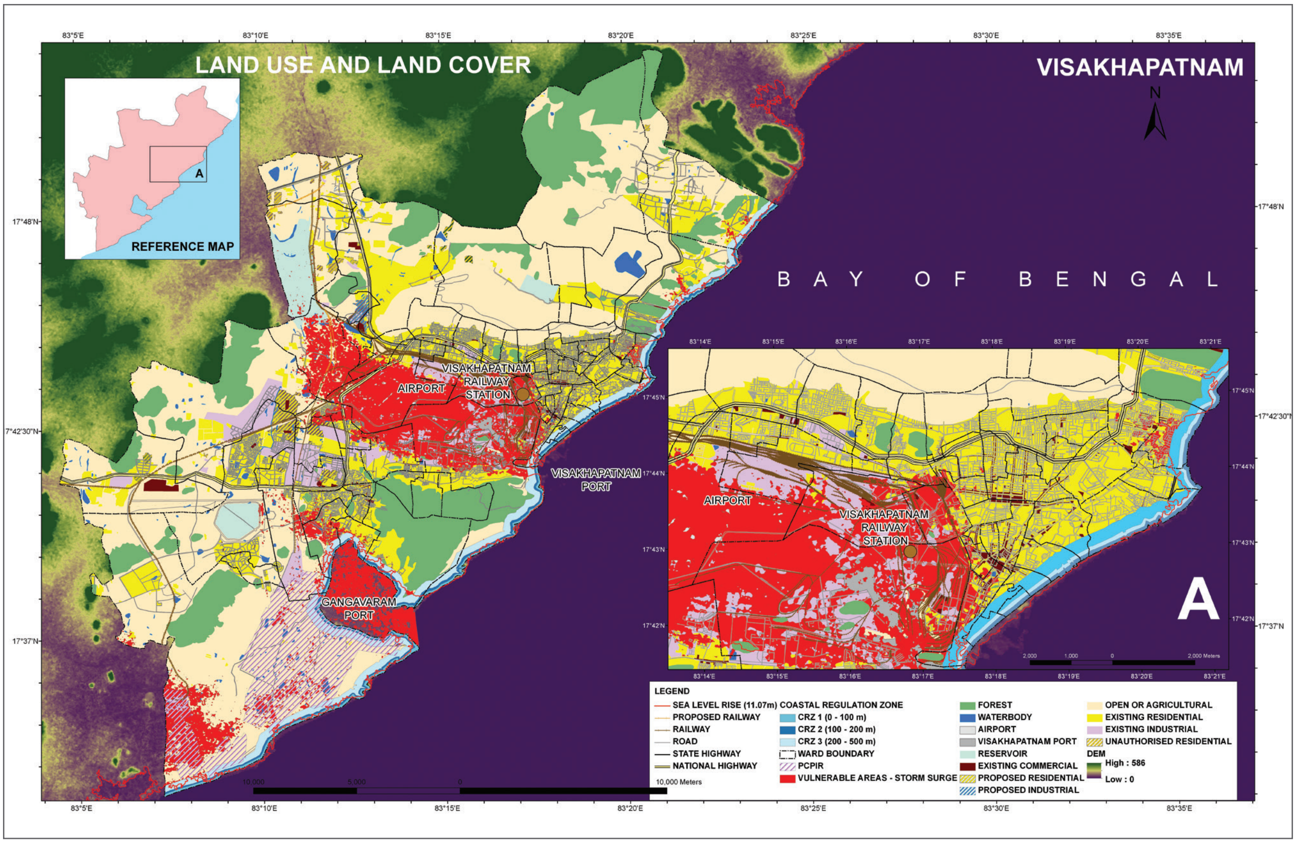


Figure 7: Exposure of Visakhapatnam under Storm surge scenario

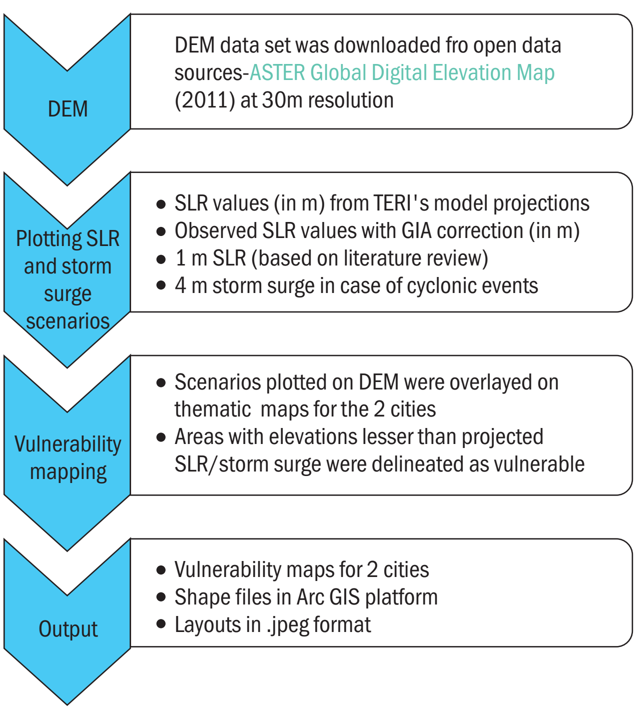


Figure 8: Methodology for vulnerability mapping

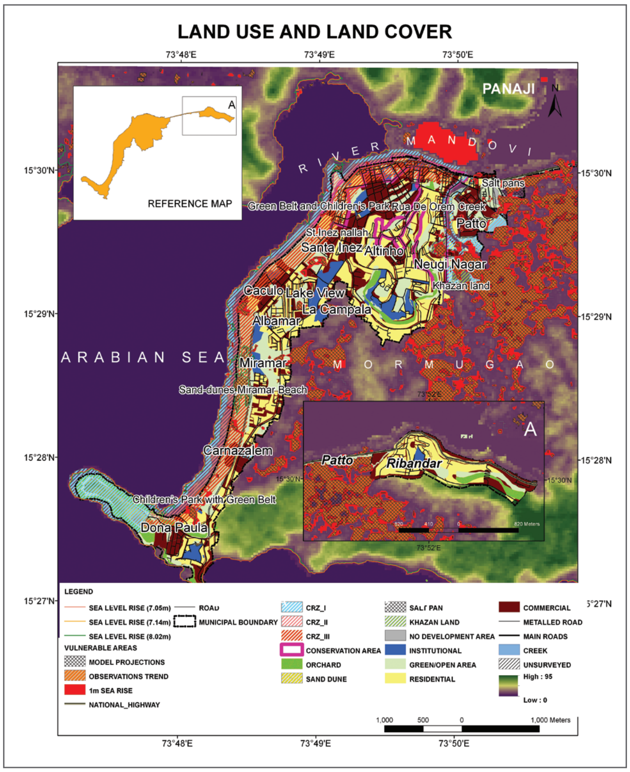


Figure 9: DEM overlay on Land use and Land cover map of Panaji

Identification of Critical Infrastructure

For identification of critical infrastructure, certain parameters were required. In order to identify these parameters, again, a literature review was carried out. Similar studies which assessed the impacts of climate change and SLR on infrastructure assets and urban settlements were analysed. This included studies by IPCC (2007, 2014), MoEF (2010), UNDP (2011), the National Academy of Sciences, Washington DC (2009), Government of the UK (2011), and Byravan *et al*. (2010). Based on this review, the following criteria were selected to identify critical infrastructure assets in Panaji and Visakhapatnam:

- **Infrastructure assets which are likely to be affected due to flooding, exposure to sea water, and sea water ingress caused by SLR and extreme events like storm surges**— This criterion was applied on the outcomes of the vulnerability mapping exercise as discussed above. Primarily all the infrastructure assets and service networks lying in the areas demarcated as 'vulnerable' in the SLR and storm surge scenarios for the two cities have been enlisted as assets that are likely to be affected and hence, are critical.
- **Infrastructure assets which are critical for relief/ response in case of extreme events like cyclones**— These include road networks, hospitals/clinics, schools, open areas/public spaces/parks, emergency response stations, administrative headquarters, etc.
- **Infrastructure assets lying in the Coastal Regulation Zones[4] (CRZ) or ecologically sensitive/vulnerable areas**— Both for Visakhapatnam and Panaji, various plan documents (city/district/state level) like JNNURM CDP, Master Plans, Disaster Management Plans, Petroleum Chemical Petrochemical Investment Region (PCPIR) Master Plan (in case of Visakhapatnam), Coastal Zone Management Plans, etc., have identified and demarcated the ecologically sensitive and conservation areas at the city level. As part of this zoning, the compatible land uses/ activities have also been suggested or regulated. As a third criterion, this study identifies all the infrastructure assets lying in these sensitive or vulnerable zones as 'critical'.

It is important to note that TERI's "assessment of criticality" for this study encompasses the three criteria mentioned above and differs from other approaches that define "criticality" as simply "important" infrastructure, in terms of the significance of the service it provides—regardless of whether it is exposed or vulnerable to climate impacts. This analysis helped in ascertaining exposure of various areas in the case study cities and sensitivity of various sectors to climate impacts. The sensitivity analysis also leads to an understanding of the exact climate parameters which will impact that particular sector in question. Annexure 1 provides a list of the sensitive areas and sectors in the two cities.

Challenges and Limitations

One of the limitations of the study was the use of global models because of non-availability of regional models during the study. This was addressed by using the six model ensemble approach. Moreover, due to the limited resources and timeline of the study, precipitation and storm surge modelling exercise could not be conducted. Hence, the study considered a storm surge height of 4m as one of the scenarios, only on the basis of the available literature for the project city of Visakhapatnam. As discussed in Chapter 2, due to the gaps in the spatial data sets received by the city level departments and limited time and resources, datasets with a lower resolution of 30m were used from the open access ASTER Global Digital Elevation Map website[5]. Though this scale is optimum for devising planning and strategic measures, however, for design level interventions, it is advisable to carry out a detailed micro level analysis.

[4] The Coastal Regulation Zone Notification 2011 under the Environment (Protection) Act 1986 of the Government of India has delineated coastal regulation zones along the Indian coastline with an objective of 'conservation and protection of coastal stretches, its unique environment and its marine area and to promote development in a sustainable manner, taking into account the dangers of natural hazards in the coastal areas and sea-level rise due to global warming'. The notification also restricts uses and activities in the various CRZs (I, II, III, IV & V) and defines the permissible uses and activities for each of the zones.

[5] http://asterweb.jpl.nasa.gov/data.asp

4. RECOMMENDATIONS

The identification of vulnerable areas and critical infrastructure sectors led to formulation of sector-specific recommendations for the city. For this purpose, an extensive review of good practices and other literature was conducted. The study suggests both structural and non-structural recommendations for short, medium, and long-term. However, it was realized that a lot of problems can be addressed by better planning and management of the city. A broad assessment of institutional and policy/regulatory framework was also conducted to derive enabling policy and institutional recommendations for resilience planning. The proposed recommendations were reviewed and validated by the Expert Committee constituted under the project and also through city stakeholder consultation. The participation of city stakeholders in the validation process ensured that their inputs were fed in to the project stages, well in time. The committee comprised 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 expert validation workshops not only helped in strengthening and validating the project work but also accounted for supplying of local as well as expert knowledge into this new area of research. The project team has also tried to capture this community knowledge and local opinions in their documentary. The list of recommendations for some of the critical infrastructure sectors has been presented in Annexure 2[6].

[6] Please refer to the case study briefs (published as part of this study) for a detailed overview of city specific results.

5. DEVELOPMENT OF A METHODOLOGY FOR CLIMATE VULNERABILITY ANALYSIS

The second focus area of this study was to develop a generalized methodology which could be used by city level practitioners for conducting vulnerability assessment of critical infrastructure for coastal cities. This chapter discusses the methodology prepared and also presents its key components with examples on its application in the two project cities.

Approach and Key Insights

The approach for development of the generalized methodology involved two key steps:

1. Literature review of existing methodologies for conducting vulnerability and risk assessment at city level
2. Integrating learning from Visakhapatnam and Panaji to come up with a methodology that suits coastal cities in the Indian context

A literature review of the various methodologies and approaches was conducted. It should be noted that these approaches have been developed and applied for managing vulnerability and risk assessment for infrastructure services in cities.

A number of relevant case studies and research papers were reviewed, in this context. Besides this, some of TERI's research studies were also reviewed to understand the essential elements which could be used for assessing infrastructure related vulnerability to climate change. The criteria on which the papers and reports were reviewed include:

- Applicability in coastal region
- Applicability for infrastructure services
- Ease of use by local practitioners
- Applicability in the context of hazards in consideration (such as SLR)
- Applicability at city level

Review of various methodologies gave an understanding of the type of approaches used in assessing vulnerability, in the context of coastal regions and cities. A comparison was conducted among these methodologies to analyse their applicability.

The literature review gave a clear insight on the type of processes and methods being used at present to estimate vulnerability towards climate change. The challenge was to identify or develop the best approach whose outcome is an easy-to-use methodology that coastal cities could tap to assess their vulnerability to climate change impacts, particularly SLR and coastal storms.

The objective of developing a methodology for vulnerability assessment was to provide city level practitioners and decision-makers with a tool that could be easily applied to any coastal city. For this purpose, it was essential to ensure that the methodology was simple and flexible enough to be applied in diverse spatial and institutional context. Experiences and learning from Visakhapatnam and Panaji helped in this direction. Keeping these considerations in mind, the methodology proposed as part of this study broadly follows the standard framework for vulnerability assessment, based on the IPCC definition of vulnerability.

According to the definition, vulnerability is described as 'a factor of exposure, sensitivity, and adaptive capacity[7]'. Based on this definition, assessment of vulnerability can be done by analysing the three factors which define vulnerability. Appropriate indicators were identified broadly under these factors of vulnerability.

One of the essential features of this methodology developed for coastal cities draws from the Climate Resilient Development (CRD) framework and approach developed by the USAID[8].

The first stage of the CRD framework, is the 'Scope' stage which includes understanding development goals, identifying the key inputs and enabling conditions for meeting those goals, and identifying climate and non-climate stressors that may put key inputs at risk and undermine the enabling environment, compromising the development goals (USAID, 2014). In the context of cities, this finds direct relevance as most of the medium-sized cities in India are in the process of rapid development. Adopting such a framework can assist in achieving development outcomes while addressing climate change considerations.

Methodology Description

This section presents the components of the Climate Vulnerability Assessment for Coastal Cities (CVACC) methodology.

I. Scoping Phase

The scoping phase is characterized by understanding the objectives of the assessment and the potential use of results from such an assessment. Besides this the vulnerability assessment methodology will also be determined on the basis of the capacity of the end user, the data availability and quality, and expected time taken to process the assessment. The scoping phase would involve conducting a primary profiling of the study area to understand the key systems that drive the city. Developing and assessing the past and future climate information for the city in question will comprise another part of this phase.

Objectives, Goals, and Expected Outcomes

1. **Objectives:** The purpose of carrying out a vulnerability assessment should be clearly defined. For instance, the purpose of assessment can be:
    a. To inform policy and planning parameters adopted for the city;
    b. To assess , plan, and implement adaptation option as part of a larger development plan for the city, and /or;
    c. To substantiate and base the overall sustainability vision of the city on such an assessment;
    d. To understand the vulnerability of a particular sector in a city. For example, in the current study, the vulnerability of the city's infrastructure and services to the likely rise in sea levels and storm surges are assessed.
2. **Relevance in development goals:** Drawing from the CRD framework, it is essential to identify the key development goals and decisions to which the assessment will contribute. This will also help in understanding the level of detail and the spatial and temporal scale of assessment required. Then it can be accordingly matched with the requirements of decision-making. For instance, the land-use planning exercise is carried out for the time frame of 15-20 years and hence the assessments must define vulnerability within a similar time frame.
3. **Expected outcomes:** It is important to determine the expected outcomes and the expected types of results from the assessment. For instance, the expected results can be in the form of policy recommendations or identification of vulnerable hotspots on a spatial scale.

Identifying Key Requirements for the Assessment

1. **Stakeholders and end users:** Most of the cities face the challenge of coordination between different government departments involved in the process of city development. Identification of all the relevant stakeholders in the process of the accomplishment of key development goals and involving them in the assessment process is imperative to ensure that the

[7] This definition is according to the FAR. In AR5, the definition of vulnerability has been modified as 'the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt' (IPCC, 2014). However, for the purpose of consistency with earlier studies and for the adoption of CRD framework, we followed the earlier definition.

[8] The approach provides broad guidelines for assessing the exposure, sensitivity, and adaptive capacity and finally vulnerability while concentrating on a 'development-first' approach.

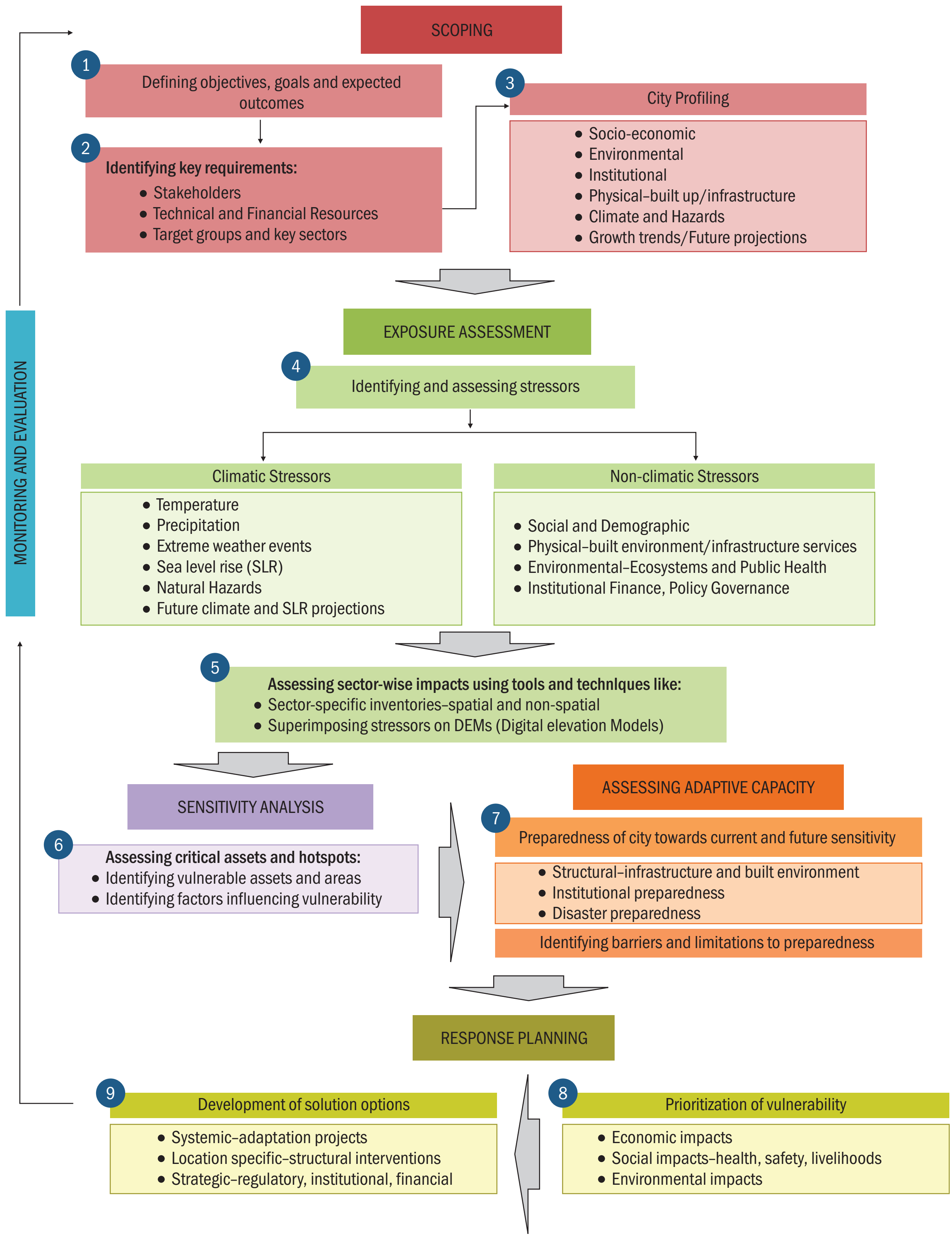


Figure 10: The Climate Vulnerability Assessment for Coastal Cities (CVACC) methodology

objectives are met. It is also important to know who will be the end user of the results of the assessment to clearly have an idea of their requirements.

2. **Technical and financial resources:** One of the key steps of the scoping phase is to determine the kind of resources which will be required for carrying out the assessment. This would include understanding the information/data requirement, and the technical as well as financial resources required for the assessment.
3. **Target groups and key sectors:** The key sectors coming in the ambit of the objectives of the assessment and which may likely be affected by climate variability should be identified to ensure that the study is holistic and covers all the major aspects of vulnerability. It is also required to understand the linkages between the sectors and all the threads leading to vulnerability.

In the current study, following were the key starting points:

1. Stakeholders and end users: City government
2. Financial resource: The study commissioned by USAID
3. Technical resource: TERI
4. Target groups and key sectors:
    a. Water supply and sanitation
    b. Solid waste management and waste water
    c. Transport
    d. Industries
    e. Tourism
    f. Natural infrastructure
    g. Land use planning
    h. Climate
    i. Energy
    j. Health
    k. Education

Primary Profiling of the City—Establishing Baseline Information

This stage involves preparation of a detailed city profile. The city profile may be categorized as non-climatic and climatic.

The non-climatic profiling involves collecting information and understanding the following:

1. Socio–economic profiling— Demographic, social, health, and economic parameters
2. Environmental profiling— Natural assets of the city, environmental issues like quality of rivers, water bodies, waste treatment and disposal, etc.
3. Institutional profiling— This would involve an institutional analysis of all the major city departments and their functions like the municipal corporation, urban development authority, parastatals responsible for roads, urban services , health department, etc.
4. Major functions/sectors— An assessment of the major function of the city in terms of religious city, industrial city, tourist destination, etc., and subsequent sectors.
5. Growth trends (Physical and demographic)—Growth trends of the city in terms of population increase, spatial expansion of the city. A detailed study of the land-use/master plan would be necessary to understand the growth trends.
6. Future projections for growth— While the vulnerability of a city would affect the current population, any adaptation /resilience planning would take into account the future expansion, demands and population growth of the city. It is therefore, pertinent to include socio-economic, demographic, and growth projections in the scoping phase.

In the case study cities in the CRIS study, a detailed infrastructure inventory was prepared for the city of Panaji and Visakhapatnam to understand the status and level of urban infrastructure and services. The impact of SLR and other climatic parameters like rainfall and storm surges was then assessed on the infrastructure and services of the city in question. In the study the following outputs were used for city profiling:

- Sector specific data inventory
- Spatial mapping of infrastructure and service present in the cities
- DEM mapping to locate the rise in sea level (past and future)

Besides the non-climatic profile, the climate related profile of the city would not only provide information about the past climatic trends, frequency of extreme events, and observed variability but will also form basis for the modelling of future climate scenarios. Therefore, this stage would look at past trends for rainfall and temperature as well as observed data for sea-level rise.

In the current study, the observed data for sea-level rise was assessed for the last 100 years.

II. Vulnerability Assessment

Exposure

Exposure refers to the nature and degree to which target groups or sectors are exposed to climate variability. IPCC's Special report on extreme events defines exposure as the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected. Brenkert and Melone (2005) have defined exposure in their case study as the nature and extent of changes that a place's climate is subjected to, with regard to variables such as temperature, precipitation, extreme weather events, sea level; exposure is location-dependent.

The objective of assessing the exposure of a city system to climate change and variability would be:

- To understand the specific climate stressors to which the city is exposed
- To identify the important non-climate stressors
- To identify and understand potentially important interactions between climate and non-climate stressors

Assessing exposure would thus, essentially look into the major types of climate and non-climatic stressors which are having an impact on the key sectors. Since a complete city profiling has been done in the scoping phase, so in this step, the requirement would be to identify the climate and non-climatic stressors based on the collected information and draw out a link between the two.

Some of the indicators and guiding questions identified under exposure are:

Indicators	Guiding Questions
Temperature	Have there been changes in the observed temperature pattern of the city in the past few decades which has resulted in adverse impacts on people or key sectors?(increase/ decrease; positive/negative)
Precipitation	Have there been changes in the observed precipitation pattern of the city in the past few decades which has resulted in adverse impacts on people or key sectors?
Extreme weather events (heavy rainfall, heat wave) (Yoo *et al.*, 2011)	Has the city faced extreme weather events? Has there been a change in the frequency or severity of such extreme weather events? If yes, then specify time— last 5 years, 10 years, 30 years? ; input specific year of occurrence of such events
Hazards (Angell and Stokke 2013) Storm surge Sea-level rise observations and future scenarios (Yoo *et al.*, 2011); subsidence Tropical cyclones Flooding Drought	Has the city faced or has been facing hazards in the past? Has there been a change in the frequency or severity of such hazards? What extent of damage has been caused due to these hazards? Has the city experienced sea-level rise (based on observation data)? Has there been land subsidence due to sea-level rise?
Future projections for climate	Do future projections for key climate parameters, such as temperature, precipitation, and extreme weather events indicate likely threats for the city?
Non-climatic stressors (economic, social, physical, environmental, institutional)	What are the key non-climatic stressors affecting the growth and development of the city?

The answers to the above questions would generally emerge from the data and information base developed in the scoping phase. However, stakeholder consultations could be designed to receive inputs from experts and city practitioners to include local knowledge and city history.

Once the above information is available with the city, the same should be collated and summarized to build an exposure profile. This exposure profile should essentially provide the city with the near exact exposure levels for the city in question.

Sensitivity

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) (IPCC 2014). Brenkert and Melone (2005), in their case study, have defined sensitivity as how systems could be negatively affected by the change in climate, for e.g., how much land could be inundated by sea-level rise, how much crop yields might change, or how much human health might be affected.

The objective of the sensitivity analysis would be:

- To understand the impacts of climatic and non-climatic stressors on specific sectors which are making them more sensitive to further climate variability
- To understand the factors that influence most the sensitivity of the sectors to climate variability and change. For example, effect of density of population in hazard-prone zones/coastal areas.

Some of the indicators of sensitivity with respect to key sectors and their respective guiding questions are as follows:

Indicators	Guiding Questions
Demographics and social High population density (*Yoo et al.*, 2011; Farhan and Lim 2011; Angell and Stokke, 2013; Saxena, *et al.*, 2013)	Are there dense pockets of population/high density residential use pockets in the city, especially near coastal areas, which have been affected or are likely to be affected by climate variability or hazards? • Has the population growth in last 10 years been unprecedented and do future projections of population indicate rapid growth? (bringing major changes in the landscape of the city and putting pressure on resources) • Does the city have high percentage of urban poor population? Or what percentage of the population of the city is below poverty line? • What has been the extent of casualties/ impacts on urban poor population because of past climate-related events or hazards?
Economic	• What are the key economic activities within the city, especially in coastal stretches which have been affected/likely to be affected by climate events/hazards (for e.g., tourism, marine fishing, or aquaculture)? Top three sectors of economic importance (based on contribution to city GDP) and to what extent are these climate-sensitive? • What is the primary source of livelihood of people in the city, especially in coastal areas and are these areas climate-sensitive? Are there enough alternative livelihood options?

Ecosystem and environmental (Saxena *et al.*, 2013)	• Do the topographical features of the city make it sensitive to climate variability (mean sea level , distance from sea, natural coastal protection) • Are there informal settlements, slums or poor housing structures in vulnerable zones of the city and in coastal areas? • Are there fragile stretches of land sensitive to any of the identified climate hazards? What are the key issues which have made the land sensitive? • Has the expansion of built-up areas affected the ecosystem in terms of increasing its sensitivity? • Has there been impact on the ecosystem of the city due to extreme events or hazards? • Has there been shoreline erosion or any impact of sea-level rise? This stage could also look at assessing the flood hazard to the coast and the city in terms of return period of floods .This will then help the city draw out a composite hazard line which could then be used for defining development regulations or reassessing the existing coastal regulations and zones.
Infrastructure and basic services (USAID 2014)	• Can energy systems(power infrastructure) withstand higher temperatures and more intense storms? • Are precipitation projections likely to surpass drainage capacity? • Do building design codes sufficiently account for climate variability and change? Are they enforced? • Is the drainage of the city efficient to handle extreme climate events such as heavy rainfall? • Would hazards like floods hamper the basic services like drinking water supply/supply lines?
Health (USAID 2014)	• Are communities or sub-sectors of the population malnourished, making them more sensitive to climate-related stressors such as drought? • Will the exposed population be affected by change in frequency or severity of any of the extreme events or hazards? • Will climate variability cause any change in the occurrence of any of the communicable or non-communicable diseases? • What are the frequency, seasonality, and duration of incidences of vector /water-borne diseases in the city? Can these be attributed to the precipitation changes/ flooding and waterlogging events.

Exposure Profiling and Sensitivity in Project Cities

In project cities, once the digital elevation models were prepared, the three scenarios for sea- level rise were overlaid on the cities' maps, which are as follows:

- TERI SLR future projections in mm/year
- Observed SLR with GIA corrections in mm/year
- 1m SLR increase in 100 years

For Visakhapatnam, an SLR coupled with 4 m storm surge was additionally depicted over DEM maps. All sector maps for both the cities were overlaid on these DEM maps to understand the exposure of various locations in the city and to understand the extent of exposure to the various sectors. For example, the map depicting the solid waste management centres was overlaid over the DEM map to see which centres were falling under the vulnerable zones. The exposure itself was assessed in terms of partial/full impact.

Also since the project looks at infrastructure vulnerability, the combined sensitivity of the services, in terms of their current efficiency levels and coverage and their future resilience was also assessed.

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 take advantage of opportunities, or to cope up with the adverse consequences. Brenkert and Melone (2005) have defined adaptive capacity as how much capability a society has to adapt to the changes so as to maintain, minimize loss, or maximize gain in welfare.

Adaptive Capacity in Project Cities

In the project cities, assessment of the adaptive capacity was a continuous process and relied mostly on stakeholder consultations and discussions with sector experts in the project cities.

However, such an assessment when carried out by the city could use the indicators list given in this methodology description and take it up as a separate exercise.

The objective of this stage of the assessment would be:

- To identify important components of adaptive capacity unique to the city in question like institutional, regulatory, disaster preparedness, infrastructure and services quality and efficiency
- To assess the level of adaptive capacity of the system in terms of these components
- To understand the obstacles, barriers, or limitations that could affect the city's ability to respond to climate or non-climate stressors, disasters, or impacts

Some of the indicators for assessing adaptive capacity could be:

Indicators	Guiding Questions
Disaster preparedness	• Is the city having a disaster management plan in place and have there been adequate measures taken to implement the management plan? • Does the city have experience in using or implementing preparedness measures in terms of early warning system, administrative responsiveness and others? • Are adequate steps being taken for generating awareness towards climate change risks?

Institutional (*Yoo et al.*, 2011, Angell and Stokke 2013)	• Are there plans and policies existing in the city governance regime to address climate change risks and implement adaptation? • Is there a clear division of responsibilities between different government levels and sectors in terms of taking adequate measures to address climate change and related hazards and risks? • Are there regulations to support climate actions already present at city/state level? • If yes, how those could be leveraged to increase the adaptive capacity of the city?
Infrastructure (*Yoo et al.*, 2011)	• Is there adequate infrastructure response in place to address climate change risks such as flood protection infrastructure? Is infrastructure enough to provide basic services such as hospitals and health services, public water services supply/population, sewage supply population/population, groundwater usage/potential groundwater resources?
Economic (*Yoo et al.*, 2011)	• Are there special allocations for disaster risk reduction in the city? If yes, what is the source (state government/national government assistance)? • Has the city built the component of disaster recovery and reconstruction into the city budget itself? • Are the city facilitating options like insurance for increasing the adaptive capacity of the population, particularly the poor?

III. Response Planning

Based on the above exercise of identifying vulnerabilities through key questions under Exposure, Sensitivity, and Adaptive Capacity, a city can have an understanding of the key vulnerabilities it faces. A city might face a number of vulnerabilities but there will be a need to prioritize these vulnerabilities so that they can be addressed accordingly through adaptation measures and integration into the city development plans. This can be done through consultation with key stakeholders such as city planners, policymakers, and funding agencies.

On basis of the identified major vulnerabilities of a city, it is also important to recognize adequate response measures and include it in the planning process. This will need prioritization of vulnerabilities that could be carried out on the basis of the following:

1. Perceived/ Identified economic impacts
2. Social impacts (health, safety, livelihood)
3. Environmental impacts

This will subsequently lead to preparation of response plan that includes measures at various levels, for example:

1. Systemic solutions (adaptation projects)
2. Location-specific solutions (structural interventions)
3. Strategic solutions (regulatory, institutional, and financial measures)

Monitoring and Evaluation

An integral part of the response planning is the aspect of dynamic vulnerability. Since there are a lot of uncertainties associated with climate change as well as the development pattern of the city, it is important to regularly revisit the designed policies and programmes being implemented to factor in the variability and uncertainty and avoid maladaptation.

6. LESSONS LEARNT AND THE WAY FORWARD

Though studies in the past have focused on the impacts of climate change on specific infrastructure sectors, a single integrated study (at a city level) linking climate knowledge to identification of vulnerable infrastructure and further linking it to planning interventions is a new area of work. This chapter discusses the lessons learnt with the aim of guiding future research in this area.

Political Buy-in and Local City Champions

Vulnerability assessments at a city level are a multi-departmental exercise involving multi-stakeholder engagements. The successful implementation of these studies requires the support of local city stakeholders who have the power to coordinate with various departments which ensures their cooperation at all levels. These local champions can either be individuals or designated heads of the city's ULB like Mayor and Municipal Commissioner who have the power to convene city level inter-departmental coordination meetings. In both the cities, the Municipal Corporation played a key role in driving the study by ensuring the involvement and buy-in of as many departments as possible. Thus, the role of local city champions in taking up the overall ownership of the process is important from the perspective of long-term internalization of the results and recommendations emerging from these studies.

Need for Detailed and Downscaled Climate Assessments

Sea-level rise is a gradual long-term process and its impact needs to be assessed along with other factors like storm surge and cyclones, and changes in precipitation. The assessments generally give SLR projections for the next 100 years. However, development planning is carried out considering the next 10-15 years horizon. It is important therefore, that the SLR analysis is combined with storm surge analysis, flood modelling, and precipitation forecasting for not only making a holistic assessment of likely impacts but also to reduce the uncertainty of the results. Such kinds of assessments are also useful for policymaking and decision-making for development planning. For instance, detailed flood modelling exercise for cities could provide inputs on exact locations that are flood-prone within the city to base decisions on new development and selection of design features for future infrastructure development. It is also important that the impact of SLR is studied using a downscaling approach which takes into account the regional estimates rather than the coarser global estimates.

Need for Detailed Sector-specific Impact Assessments

Once the detailed climatological studies are conducted at a regional scale, and results from flood modelling, storm surge analysis and other climate parameters—rainfall and temperature— are known, the detailed sector-specific impact assessments should be carried out to identify micro-level design interventions for infrastructure assets in order to make them resilient. Different scenarios, such as worst case, medium case, etc., could also be developed to initiate investment planning for infrastructure adaptation and augmentation. This exercise would also help in analysing how stresses or damages of one infrastructure sector can have an impact on others. Also their collective impact on the city functions and population could be ascertained. The strategies should be developed based on city resources, capacity of the city government, and ownership and management of infrastructure.

Roadmap and Handholding for Resilience Planning Efforts

Vulnerability assessment studies should be followed up with a detailed policy and institutional assessment that provides a roadmap for implementation of the suggested recommendations. This ensures a logical culmination to the outcomes of such studies and has the potential for bringing in desired changes in the planning and design framework of the infrastructure assets and services in the city. Mainstreaming climate change considerations into the planning framework of city and state governments can go a long way in building resilience. For instance, accounting for climate change impacts in zoning and master planning efforts; adopting measures in building by-laws, siting norms and regulations, etc., can help in increasing the resilience of existing and future infrastructure assets.

The current study outcomes have provided the city with a detailed picture of its vulnerability to SLR impacts. However, it is now pertinent that the city mainstreams the resilience efforts into their development planning processes. Besides this, handholding for implementation of detailed sectoral interventions proposed in this study along with consultation and partnership with the responsible institutions could be another step forward in this direction.

Optimization of Inventory

The current study puts emphasis on availability of data and risk assessments results to the city planners. As part of this study, data was not only collected but was also synthesized and given back to the city in a structured format with a vision for future maintenance and upkeep of the data. At present, multiple agencies are recording this data at the city level. The current database attempts to collate this information at one place. It also provides a starting point to the city and demonstrates how an integrated database of city's infrastructure and assets will look like. The idea was not to burden the city authorities by simply recommending new data fields but to ensure that the new data fields (for climate resilience planning) are presented alongside the existing ones so as to enable recognition of these data heads for climate resilience planning efforts. If a city has access to information such as locations of vulnerable areas and infrastructure assets within these areas, then it can adopt better siting norms and plan for the upcoming infrastructure along with its design and safety features well in advance (as per the likelihood of flooding or inundation in those areas). While the current project has helped the cities in developing their basic urban infrastructure inventories, however, for further building this database, the city would have to assign a nodal person at the ULB level who will administer the management of this database. This person should also coordinate the task of recording and updating the missing data gaps as well as recording the new data fields proposed for climate resilience planning. One enabling step in this direction could be to develop a web-based system that permits data preservation, data retrieval, and data updation from anywhere and anytime by authorized users. The key features of a web-based system are described below.

Online data entry forms

The data entry forms to add, edit, or view details of any assets would be made available on the internet to authorized users. These forms would be in user-friendly web formats and would provide common functionalities across sectors.

Department-based access

The system currently has city-based access where a single user submits data related to all the infrastructure services of the city. The department-based user profiles would be created as per the assigned responsibilities among different departments. A user of the specific department will be able to submit the data related to their departments.

Workflow automation

The data updation activity can be further broken into different stages where data entry, data verification, and data publishing could be distributed among different users. Even the access of data beyond the set limit may be made available after the approval from an authorized person.

Robust search

There will be a facility to search asset information based on various parameters and free-text search facility would also be built for identified asset parameters.

- **Parameterized search:** Parametric search means user can frame the search criteria by specifying/ selecting values for listed parameters. It could be a range, selection from a drop-down list, or a specific value of a parameter. After selecting the criteria, user will click the search button to search the desired data. A reset button will initialize the selection criteria.

- **Free text search:** This is also known as 'Natural Language Search' where user will enter the terms for which information is needed. The system will search the keyword(s) in the entire database. After selecting the criteria, user will click the search button to search the desired data. A reset button will initialize the selection criteria.

Notifications, Alerts, and Reminders

The system can be integrated with email system to send automated notifications, alerts, and reminders at different stages of the processes for better involvement of user by sending forewarning for the forthcoming activities and reminders for delayed activities for timely completion of activities.

Cross Platform Compatibility

A web-based application is far more compatible across platforms then desktop applications as they typically need a web browser like Internet Explorer, Firefox, Netscape, etc., which are available for a multitude of operating systems like Windows, Linux, or Mac OS.

Easy Manageability

A web-based system needs to be installed on a server having minimal dependency on end-user workstation. This makes administration, maintenance, and updation of a system much simpler as it usually is done on the server and the client receives updates deployed on the server.

Security

A web-based application would be deployed on a server, which is monitored and maintained by server administrators. End users do not have access to server resources and can only interact through system only after successful authentication and authorization. The architecture makes the system and data highly secure.

Administrator Control

The system would be controlled by a system administrator who would be able to configure the system by providing control information (master data) like creating more cities, creating city specific-users, etc.

This exercise under the CRIS program supported by USAID, has provided new insights on the kind of vulnerability coastal cities and its systems might face. The study also confirms that the benefits of adaptation of infrastructure and services for slow onset climate impacts like SLR, would go a long way in increasing and ensuring improved coping capacity of the city systems as well as the population residing in the city. Although it is a broad study based on global scale modelling assessments, it does highlight the importance of data and inventory in planning decisions based on concrete analysis and proposes further work by in-depth analysis using advanced modelling tools for sector-specific assessments. This study is useful for the broad based land use and planning decisions for the coastal cities and provides recommendations accordingly. However, the study recommends detailed and sector specific analysis for designing adaptation interventions that would involve changes in design features of infrastructure and services in a city. Our experience also shows that involving multiple stakeholders in analysis and decision- making for climate adaptation and resilience-building exercise not only brings in sector-specific knowledge and wisdom but also helps in understanding the interdependency of various infrastructure assets and services for better coordinated and improved systems within a city. Such consultations did not only provide subject knowledge but also helped in uncovering institutional challenges that a city might face in dealing with climate impacts.

There is a long way to go in ensuring climate resilient infrastructure and services in coastal cities. Indeed more work is needed and the team hopes this work would contribute as a starting point for further research, supporting policies, mandates and investments towards a more resilient future.

ANNEXURE 1: RESULTS FROM THE VULNERABILITY ASSESSMENT EXERCISE

Table 1.1: Sensitive areas and sectors in Panaji city

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 Ecologically Sensitive Areas Water Supply Transport Energy and Telecommunication	SLR Flood prone Low elevation
Altinho	Tourism and Heritage	SLR Flood prone

Near MalaLake	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 CampalaZone	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 Transpor 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

Table 1.2: Sensitive areas and sectors in Visakhapatnam city

Area	Sensitive sectors	Factors causing sensitivity
Visakhapatnam Airport Area and Vicinity	Airport Infrastructure Social Infrastructure Stormwater Drainage Industries	SLR Storm surges Low elevation Flood prone

Port Areas – Visakhapatnam and Gangavaram and Vicinity	Port Infrastructure Industries including HPCL Refinery, Visakhapatnam Steel Plant, NTPC Simhadri Power Plant, Hindustan Shipyard, Naval Dockyard, Petrochemical Industries, (Petroleum, Chemical and Petrochemical Investment Region) Heritage (Built and Natural) Energy and Telecommunication	SLR Storm surges Low elevation Flood prone
Beach Road	Sewerage Buildings Tourism Heritage (Built and Nnatural) Transport Infrastructure	SLR Storm surges Low elevation and High density development
Gajuwaka	Sewerage Storm Water Drainage Energy and Telecommunication	SLR Storm surges Low elevation Flood prone
Visakhapatnam Railway Station and Vicinity	Railway and Road Infrastructure Buildings Tourism Heritage (Built and Natural) Sewerage Drainage Social Infrastructure	SLR Storm surges Flood prone Low elevation and high density development

ANNEXURE 2: SUMMARY OF RECOMMENDATIONS

Table 2.1: List of recommendations for some of the critical infrastructure sectors

Sector	Structural measures	Non-structural measures	Suggested data fields
Ecologically Sensitive Areas (khazan lands, mangroves, creeks, etc)	• 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, such as 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 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 e.g., 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 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 support 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 inbuilt 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, by-laws, building codes, etc.	• Data on flood-prone areas • Yearly data on areas water logged • 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

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