Vulnerability of Coastal Cities to Climate Change: Case Study of Surat to Develop Adaptation Framework

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Vulnerability of Coastal Cities on Rivers to Climate Change: Case Study of Surat to Develop Adaptation Framework

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Abbreviations

ACCCRN	Asian Cities Climate Change Resilience Network
ADB	Asian Development Bank
AMSL	Above Mean Sea Level
AR4	The Fourth Assessment Report
CC	Climate Change
CGCM3	Coupled Global Climate Model
CCF	Climate Change Finance
CDP	City Development Plan
GCM	Global Climate Models
GIS	Geographic Information System
GPS	Global Positioning System
GDP	Gross domestic product
IMD	Indian Meteorological Department
IPCC	Inter-governmental Panel on Climate Change
IITM	Indian Institute of Tropical Meteorology
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
LECZ	Low Coastal Elevation Zone
MC	Municipal Corporation
MoES	Ministry of Earth Sciences
MSL	Mean Sea Level
NAPCC	National Action Plan for Climate Change
NATMO	National Atlas and Thematic Mapping Organisation
NGO	Non-governmental organization
NSSO	National Sample Survey Organisation
RCM	Regional Climate Model
SMC	Surat Municipal Corporation
SRES	Special Report on Emissions Scenarios
TAR	Third Assessment Report

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Executive Summary

I. Introduction

India is one of the most vulnerable and risk prone countries in the world to projected climate change. Rapid population growth, high population density, poverty and high differentials in access to housing, public services and infrastructure have led to an increase in vulnerability over the last few decades, especially in India's urban centers. It has been predicted that climate change has potential to intensify the frequency and intensity of current hazards and the probability of extreme events, and also stimulate the rise of sea level and new vulnerabilities with differential spatial and socio-economic impacts. The impact of climate change on urban areas can be serious. We need to take adaptive measures to strengthen resilience of our cities. This is particularly important as our urban population is expected to increase by hundreds of millions in the coming decades. Due to vagaries of climate, increased anthropogenic activities and encroachments, and unmindful constructions along the river-banks cities often face disasters like floods. These will impact socio-economic conditions, leading to loss of livelihoods, infrastructure and property damage in affected areas, and hardship for vulnerable communities. At the same time, the rapid growth of urbanization offers an opportunity to take proactive measures to adapt urban growth to make our cities more resilient to climate change.

The analysis of the projected impact of climate change in urban areas and examining a way forward towards building a climate resilient city is a complex task. It requires interdisciplinary research work involving the hydrodynamic analysis, socio-economic assessment, understanding the techno-economic constraints and urban system simulation. It also requires the integration of these various aspects in a coherent framework. Fortunately, some of the building blocks are available, but what is missing is an integrating framework. The study develops a methodology to integrate outcome of available city specific analysis and expands it to generate a procedure to introduce climate change concern in the existing framework for decision support system (DSS), for identification of adaptation options given the uncertainties of projection and scenarios to generate robust results.

In this project, analytical methods have been developed in the context of a specific case study of Surat city. As the hydrology of the region is shaped by Tapi River, Ukai Dam at upstream (~100 Km east) of Tapi River, proximity to sea-shore, and frequent rainfall especially in July and August, the findings of the project are quite relevant for Surat city as well as other cities having more or less similar conditions and which are in transition and on a development path. It is hoped that these findings are shared with the larger group of policy makers, academia and local community to initiate a meaningful dialogue on climate risks, general perceptions about the adaptive capacity and how adaptation can be mainstreamed in these policy processes. There by, the study will help further policy formulation, especially the formulation of city development plans to understand how climate risks and adaptation can be incorporated into these plans to make cities climate change resilient and minimize damage to cities' vulnerable sections.

II. Objectives of the Project

1. To develop an integrated analytical framework for urban areas in the background of a specific case study of Surat City;

2. To assess the flood vulnerability of the city, its infrastructure and its people; and

3. To develop a procedure to incorporate climate change concerns and adaptation measures that can make a city resilient to climate change induced vulnerability.

III. The Approach Taken

To address these problems for cities on river-banks and adjacent to seacoast, the hydrology and hydrodynamics of the region is to be understood scientifically in the context of climate change. Extreme events are correlated to major changes in climate. If the probability of an extreme event and its magnitude is greater than normal by current standards, then additional adaptation actions can be planned proactively. The aim is to carry out multidisciplinary analysis facilitated by a case study of Surat city.

The approach we adopted to assess the flood vulnerability of Surat city has been multi-pronged. The data have been organized on a GIS platform. Simulations are carried out with a hydrological model (Hydrologic Engineering Centers River Analysis Systems-HEC RAS model) to identify extent and depth of flood waters in various parts of the city. This is done for three Tapi river water inflows, one corresponding to the 2006 flood and another that may occur under climate change, which is taken as 50% larger flow and the third one with 50% lesser flow than 2006 flood to see the impact in a relatively normal year.

The main steps taken to assess the vulnerability of the city are as follows:

1) **Assessment of the hydrology, climatology, and built environment of Surat city:** This has been done with the help of the data available from various institutes like Surat Municipal Corporation (SMC); Indian Meteorological Department (IMD); Irrigation Department (Surat); National Remote Sensing Centre (NRSC), Hyderabad; IPCC SRES Climate Scenarios, etc. In conjunction with GIS, the climate hydrology analysis results have been connected with land use pattern, city topography, socio-economic characteristics, and infrastructure facilities to assess vulnerability.
2) **Hydro-Climatic Scenarios:**

- IPCC-Special Report on Emission Scenarios (SRES) climate scenarios of Surat region from 2000 to 2100 are analyzed to assess the likely maximum inflow in the Tapi River due to climate change, which was considered to be 50% larger than the inflow due to the 2006 flood.
- Using CARTOSAT Imagery of NRSC, Hyderabad, on GIS platform with the integration of HEC-RAS, hydro-climatic scenarios for the study region have been developed. Hydrological models serve primarily the role of a link between climate scenarios and river water discharge simulations as well as for estimating the magnitude and risk of floods.
- Analyses of hydrological profiles and flood intensity levels for the region have been conducted for different inflow scenarios.

3) **Critical infrastructure and sectors vulnerability:** This has been done by sample surveys of basic infrastructure services and their facilities, e.g. schools, hospitals, buildings (public and private), slums, and industries. Sample surveys and interviews of persons covering households, administrators, professionals, slum dwellers, etc. in selected locations of the city were carried out to identify and assess the different vulnerabilities of various facilities and groups to flood risk. Vulnerability indices were developed to get our idea of vulnerability under projected scenarios.

IV. Vulnerability Mapping

Keeping the objectives of the project in mind we have assessed the vulnerability of Surat city and its people to climate change. We have also carried out the socio-economic vulnerability surveys of the city to find out level of vulnerabilities in the city in context of flood due to water discharge from the UKAI dam into the Tapi river. For identifying and assessing the hydro-meteorological vulnerability of the city, we have performed HEC RAS simulation modeling on ARC GIS platform. Tools for vulnerability mapping and assessing the impacts of climate change on the region in the study include Hydrological modeling tools (HEC RAS, HEC GeoRAS and HEC HMS), Statistical tools (MS Excel and SPSS), Remote Sensing and GIS Tools (ERDAS Imagine-LPS, ARC GIS and AutoCAD Map) and IPCC SRES models. We have also assessed the flood vulnerability of the city in various water discharge scenarios from the UKAI dam. In this project we have mainly focused on the flood analysis and flood related vulnerability of the city.

Moreover, vulnerabilities of coastal cities to climate change related risk exposure is explored in this project. With natural growth as well as push migration from rural hinterlands, most of the cities are likely to expand significantly over the next few decades and the risk profile expected to worsen. Following are the few observations with regard to growing risks in the cities:

- Improved access from new bridges and growing real estate demand, the cities have expanded from one bank to both banks of rivers, thereby constricting the flood plains. As the city expands, the demand for high value land within and periphery leads to blockage of natural drainage, encroachment of flood buffers (reservoirs and tanks) by landfills, narrowing of river channels and flood plains. These encroachments increase the flood risks of the cities.

- The haphazard peripheral growth led by the private sector and individual houses by multiple land owners further add to the complexity of the challenge. As the cities expand by multitude of land developers, natural drainage is often blocked and increase in impervious areas as well as filling of lakes have increased the pluvial flood risks. Growing gap between master plan projections and actual expansion of the cities can lead to increased risks of floods, water logging as well as water scarcities in many cities over coming decades even without any significant change in rainfall pattern. The recurrent floods and water scarcities in cities like Delhi, Ahmedabad, Vadodara, Pune, Surat, Bhubaneswar, Cuttack, Vishakhapatnam, and others highlight this challenge. While urban planners are expected to incorporate these issues in developing expansion plans and master plans, in practice the hydrological issues are still not incorporated the way city needs in master plans.

V. Flood Inundation Scenarios in Surat city

Floodplain mapping results are shown using the flood inundation map. Surat is highly vulnerable to flooding as much of it is in low lying areas. To know the flood vulnerability due to river flow and peak water discharge from the UKAI dam, the analysis of inundation of the Surat city has been done and floodplain-mapping results are shown using the flood inundation map. Two scenarios are developed, scenario-1 with the inflow corresponding to the 2006 flood and scenario-2 where that inflow is raised by 50%. Due to large uncertainty, as explained earlier we take 50% increase in Tapi inflows as reflecting the impact of climate change. Preliminary observations of these two scenarios of Tapi river water discharge show the submergence zones. When we compare the two discharge scenarios we find that with the change in river water discharge from Ukai dam at 2006 level to 50% level higher level, more areas get submerged.

The inflow in Tapi at Surat is largely determined by discharges from the UKAI dam. The extent to which the reservoir can be used is limited by its capacity. It is seen that inflow increased from 1, 00,000 cusecs (2900 cumecs) to 4, 00,000 cusecs in six hours and to 12, 00,000 cusecs (35,000 cumecs) in 30 hours. It remained above 4, 00,000 cusecs for more than 4 days. The reservoir got filled up in two days even though discharge level was raised to 8, 00,000 cusecs (23,000 cumecs) and remained above that for 2 days.

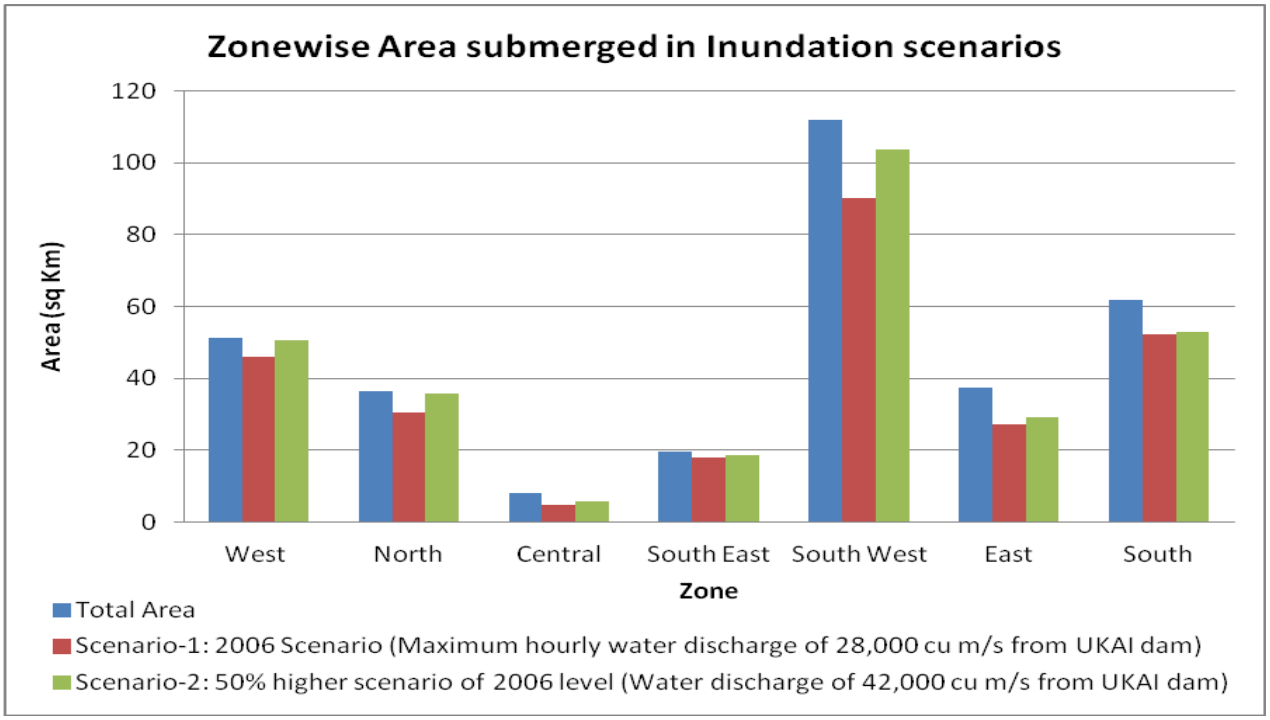

Figure 1: Zonewise Area submerged in Inundation scenarios of Surat City

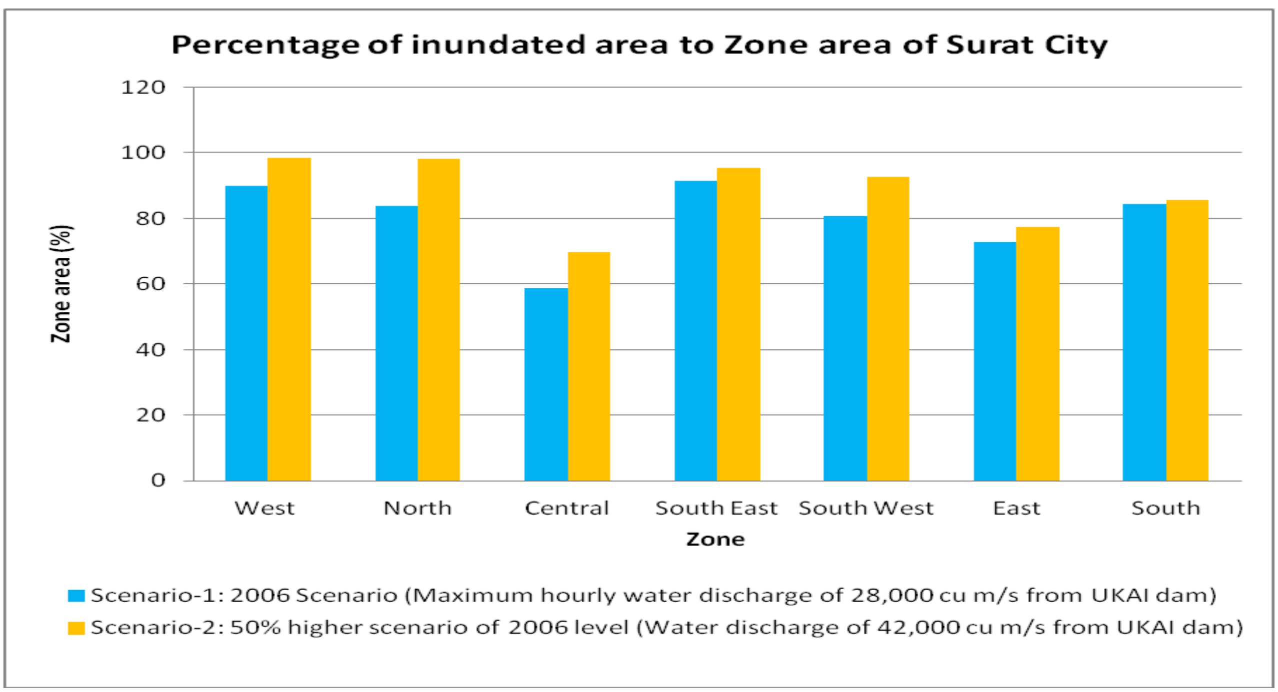

Figure 2: Zonewise percentage of area submerged in Inundation scenarios of Surat City

Figures 1 and 2 show area submerged of diffeerent zones. A sbstantial part of all zones get submerged even in scenarios 1 and more in scenario 2.

- In **scenario-1**, when 28,000 cu m per sec water is discharged from Ukai dam, then almost 270 sq km area out of a total area of 320 sq km would get submerged affecting mainly the west, north, central and southeast zones of Surat city. Even in the central zone, which is the least vulnerable, nearly 60% of the area is submerged. After studying the inundation map closely, the following zones and important locations have been identified as vulnerable to floods. West and North zones have been identified as highly affected with more than 90% area under water, whereas Central and Southeast zones are moderately affected to inundation. Some areas of Southwest and East zones are vulnerable to inundation due to discharge of 28,000 cu m per second.

- In **scenario-2**, when 50% higher i.e. 42,000 cu m per sec water is discharged from Ukai dam, then almost 295 sq km area would get submerged, an increase of 9.25% than that of 2006 level. The choropleth clearly depicts most of the parts of west and north zones will get submerged with the increase of 50% in discharge. East and Southeast zones will also be at great risk of flooding.

The Hope Bridge has a bank level of 4.1 m; therefore there will be about 3–4 m water over the right-bank area. Hence, the major parts of the Adajan area would get inundated. The Rander area, having experienced fury of 2006 flood, will also be inundated by 1–2 m depth of water in scenario-2.

- In **scenario-3**, when 50% less i.e. 14,000 cu m per sec water is discharged from Ukai dam, even then almost 228 sq km area would get submerged largely affecting the west, north, some areas of central and southeast zones of Surat city. There is only 15.5% decrease in submerged areas if the discharge is 50% less than that of 2006 level.

It is not just area submerged that paints a grim picture for Surat, but the depth of water shows a grimmer picture. Figure 3 shows areas submerged by depth of water.

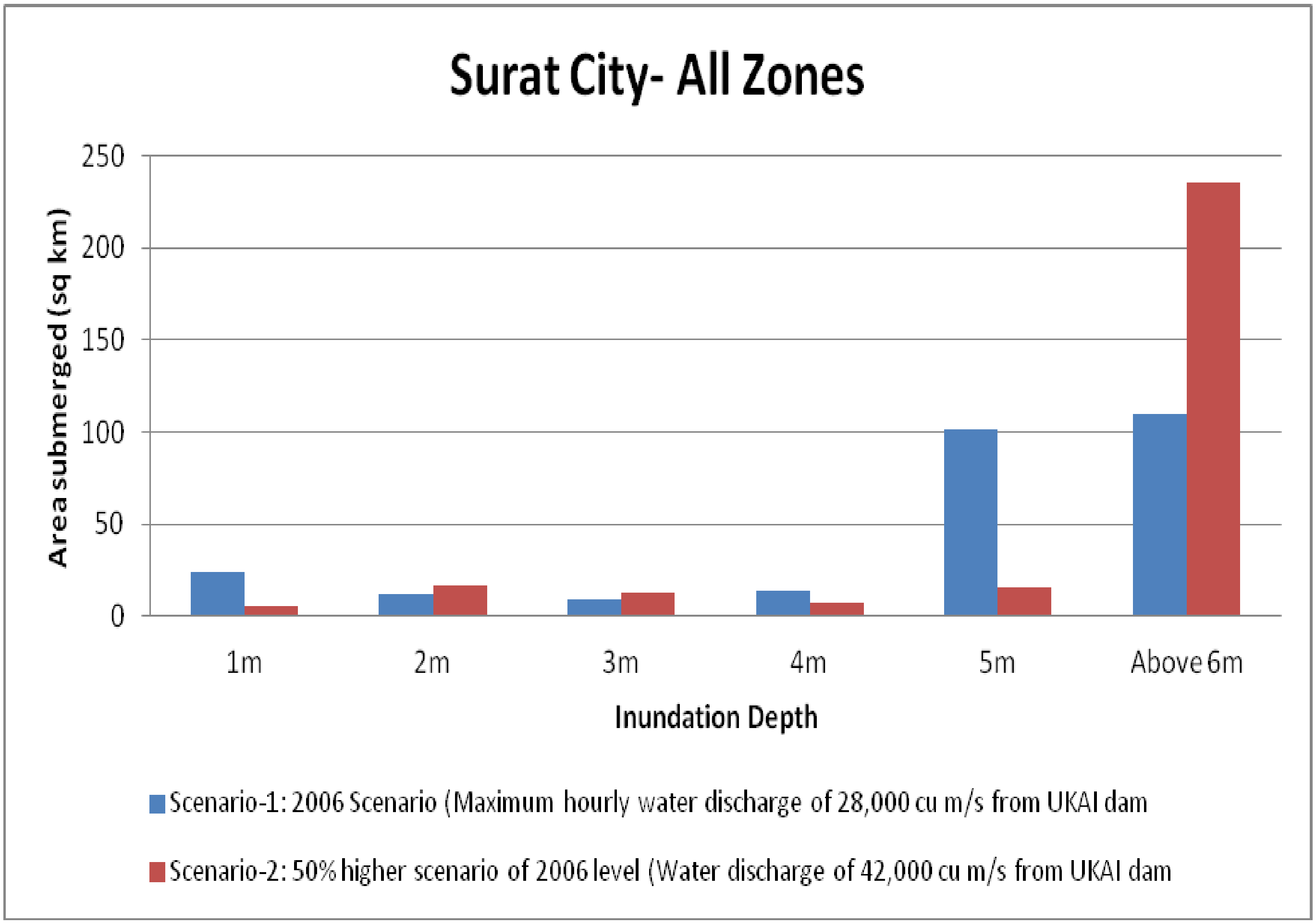

Figure 3: Area submerged in Inundation scenarios of Surat City-All Zones

It is found that under climate change and the distribution of area submerged by depth of water in the two scenarios, 230 sq km of Surat city would be under more than 6 meter of water, compared to only 100 sq km in 2006 flood. Even in 2006 floods around 210 sq km was under 5 feet or more water.

Important highlights of the submerged regions are:

- Low lying areas like Ved Road, Katargam, Singhanpore, Kadar Shah naal, etc
- Adjoining regions of Weir-cum-Causeway due to overflow
- Adjoining regions of Nehru Bridge at Chowk Bazaar
- Areas along the bridges and the river ghats always at threats with rising water level due to discharge from UKAI dam

- Creeks like Kakra, Bhedwad, Mithi, Bhatena and Simada overflow due to excessive water discharge from Ukai dam and heavy rainfall in the catchment areas

VI. Socio-economic Impacts on Facilities and Communities

To know the socio-economic aspect of the devastating flood of 2006 in Surat, a field survey has been conducted with a variety of questions to identify the key vulnerable locations in Surat, to understand the impacts of flood in 2006 and to know and suggest various adaptation measures needed to minimize the damage due to flood in the future. We have identified four important vulnereable facilities and communities such as schools, hospitals, slums and industries becuase of the very role played by them for the society and economy, and these are most susceptible in the event of flooding. This study attempts to create a composite vulnerability index for these from the different indentified vulnerability indicators specific to each of them. Since vulnerability calculated is dynamic over time hence all the indicators are related to a particular time point only. However, the vulnerability index developed is related to depth of inundation and will help to identify human suffering and the economic loss related to providing social services and public assistance after flooding for another flood scenario.

The index is based on the probability of damages due to flood based on the intensity of damages incurred in flood in the year 2006. Vulnerability Index also takes into account problem faced immediately after floods, duration and level of inundation.

The vulnerability index provides an input to government machineries at different levels, such as Municipal Corporation, State Government and other stakeholders dealing with natural hazards and city planning to make an informed decision and take appropriate advance actions or plan for actions when there is the menace of flood.

Vulnerability of Schools

Schools play a multiple role, be it for education or for safe shelter to the flood affected people. Schools face three types of impacts- educational impact, physical impact and economic impact. Educational impact includes the damage to the school infrastructure, disruption in educational activities, reduced quality of education due to loss of time, etc. Physical impact portrays that students lose their sense of continuity and their hopes and plans for the future are disturbed. Economic impact reveals the loss of income and reinvestment for repairing damaged parts of the school. Educational infrastructure often plays a significant role in ensuring sustainable development. Chapter seven of the report delves into the flood vulnerability and adaptation measures for schools.

Vulnerability Index for the schools are based on the primary data collected from 56 sample schools surveyed from the various zones of the city. These sample schools are spread across different inundation levels during the 2006 flood in the city. The sample composition tried to represent the various categories of schools such as government funded, privately funded. Sample composition also consists of primary, secondary and higher secondary schools.

Vulnerability of Hospitals

Vulnerability of hospitals is important due to the significance of their role in the recovery of community after disaster. In this study, the hospitals that were partially or fully affected by the unanticipated flood of 2006 were surveyed and analyzed. This study has emphasized the impact of flood on hospitals as hospitals play a vital role in providing essential medical care during disaster, but they also tend to be highly vulnerable being a highly complex and infrastructure intensive facility.

The ability to assess vulnerability to flood is an essential prerequisite for taking advance action. The measurement of vulnerability in this study is aimed at identifying the vulnerability of hospitals due to flood and provide an index that can help assess it in different flood scenarios. The vulnerability index of the hospitals are based on the data collected through primary survey conducted by IRADe from 50 sample hospitals spread across the zones, namely North, East, West, South and Central zone of the city. Sample comprises both government and privately funded hospitals from the selected zones. During the field survey, it was found that 50 percent of the hospitals from the selected sample have only the ground floor, which shows that they are the ones which are more vulnerable to flooding, because in case of flood they don't have any other place except for the building's roof to rescue themselves. 10 percent hospitals reported that existing practice of building construction is not proper and safe with respect to floods.

The major damage to hospitals occurs in the form of physical and economic damage. Our survey results show the significant damage to the boundary walls, doors, windows and wiring. Damage to wiring can result in short circuit of the electric system, often leading to fire. Damage to communication system leads to mismanagement that hampers the networking system among the hospitals. It is also found during the survey that flood interrupted the transportation system of most of the hospitals. The damage to the transportation system of the hospitals often results in much more disastrous situation, as patient care gets disrupted and the essential medical care could not reach the affected people at an appropriate time. The results show significant damage to the flooring of the building along with others damages to the building, the reconstruction and repairing will put another economic burden.

Vulnerability of Slums

Rapid growth of labour intensive industries such as textile and diamond industry in India is happening in Surat, which is attracting labourers from the rural areas of Gujarat as well as from other states of the country. Despite the growth of housing and expansion of the city area, a number of slum settlements are there in the city. Slum populations are clustered around the industrial area Udhna-Pandesara, which accounts for 41% of total slum populations.

Most slum dwellers are nuclear family engaged primarily in unorganized sector for their livelihood, having lesser means to cope with natural disasters like a flood. Slum houses are semi-pucca and located in low lying areas having a poor drainage system where water logging is a regular menace. The slums located on the bank of river Tapi and on the banks of creeks are severely affected by flood almost every year. Moreover, the slums on the roads, canal banks and on the important reserved plots are highly vulnerable to extreme events like floods.

To understand the socio-economic issues further and explore the flood risk reduction for the slum dwellers, we have created vulnerability index for the slum settlements in different zones of the city. The vulnerability indices for the slums are based on the primary data collected from the 50 sample slum dwellers from the slums located in North, Central, South and West zone of the city.

Flood in 2006 severely affected the slum households across all the zones, almost all the households covered in the primary survey reported that they were affected during the flood and faced property losses. Approximately 70 percent of the households reported that the water level inside their houses was more than 50cm and the rest of the respondents reported that the level of water was at least 10 cm in their houses during the flood. The entry of water inside the houses causes damage to the walls and the flooring. A large number of slum dwellers also reported vehicle damage.

Our study clearly indicates that recurrent floods pose several hardships to the slum dwellers. Fragile livelihood and disadvantageous living conditions make the situation grimmer. The vulnerability index analysis of slum shows that South and West zones are relatively more vulnerable at the same inundation levels than Central zone.

Vulnerability of Industries

Surat is primarily dominated by small and medium scale industries. Industries having high exposure, sensitivity to the impacts and lack of limited ability to cope or adapt to the floods need to be aware of the possible future disaster events. The severity of the impacts not only depends on the exposure, but also on the sensitivity of the exposed and on the capacity to cope or adapt.

Having a prior knowledge will help to reduce the likely severity of the impacts of the events through planned adaptation measures.

Industrial facilities of Surat city are structurally exposed to flooding. The vulnerability index for the industries are based on the data collected through a primary survey from the industry about the tangible damage to industry due to flooding to which monetary values can be assigned. The magnitude of the damage may be taken as the cost of restoration of the property to its condition before the flood event, or its loss in market value if restoration is not worthwhile. To construct the vulnerability index 30 sample industries spread across North, East and South zones of the city were surveyed to collect data about the loss of capital and loss of working days during the 2006 flood in the city.

Vulnerability analysis shows that the vulnerability of the industries to floods in the city is moderate. Vulnerability index shows that industries in the east zone are least vulnerable whereas industries in the North and South zones are the moderately vulnerable to floods. Vulnerabilities also depend upon the industry types (main products).

It is, therefore, necessary for all the stakeholders to improve their understanding of potential impact of flooding, and develop a suitable strategy to mitigate/minimize the loss caused by such natural events in future.

VII. Vulnerability and Adaptation: Concerns and Challenges

Although the level of exposure to hazard in India is high, vulnerability typically contributes more to overall risks in cities of India. Reducing such vulnerability will mean a shift in public policy towards mitigation and adaptation. This needs to focus on the most vulnerable aspects through a mix of policy, regulatory, fiscal and financial, institutional, socio-cultural and political instruments. Flood is a major and frequent problem for Surat. However, Surat particularly, has the advantage of efficient city administration, strong political consensus and fairly healthy municipal finances. Surat is one of the few cities with higher credit rating, which enables it to raise funds for infrastructure development. The city has also demonstrated its capacity to build resilience by improving the quality of the lifeline services like water supply, sewerage, solid waste disposal and health. The future target is to strengthen the existing infrastructure to withstand flood risk, to build redundancies and improve resilience.

Surat city experiences floods frequently. During flood events 1998 and 2006, there was considerable destruction of the city and most of the area of the city was under water. In order to reduce the intensity of unfavorable conditions and to reduce flood effect certain measures are recommended. Because of increasing industrialization in the peripheral area of Surat, it is experiencing rapid growth of population. Due to industrialization, migrant population has also increased rapidly. A study on migrants in Surat reveals that almost every second family of the city is an outsider settled here. It is noteworthy that, in year 1974, north zone had only two villages and west zone was almost half of what it is today. But with the increasing population pressure and to accommodate the pace of development in the city, all the new settlements are found around the river, riverbanks and the banks near west zone. In the last decade the migrant population increased rapidly. The poor migrants often reside in slums generating illegal settlements. Pal Patiya, New Haveli Temple, Bhulka Vihar School, Hanuman Temple, RTO building are some of the settlements which are undesirable and make the river narrower. Rehabilitation or resettlement of these slums to reclaim the riverbank could be a promising option for decreasing the death toll in future floods (Mankodi 1992).

Some natural drainages carrying rain water which were used to meet the Arabian sea some years before are facing serious threat from the rampant construction to facilitate urban development. The airport, constructed few years ago, is an obstacle for the drainage, which is passing under it. Same way, a shipyard constructed near the mouth of the river is a barrier for one of the major natural drainages. Such infrastructures should be avoided and if they are necessary then feasible alternative arrangement for the rainwater discharges must be made before constructing them.

Parallel to the left bank of river Tapi, is Mithi-Khadi River, which ultimately meets the Arabian Sea. An existing waterway between Tapi and Mithi-Khadi River could be a possible option to absorb large amount of water at least cost by dredging the waterway, maintaining the slope, and constructing suitable structures where needed on the way. Kim and Sena Creek are the two rivers on right bank of the river Tapi, which lead the runoff of the surrounding area. As origins of these two Creeks are nearby the right bank of the river Tapi, they can be easily interlinked by excavating a channel at comparatively small cost. For irrigation purpose, Kakrapar canal network is already there on both sides of the river Tapi. Parallel to sub branch canal of Kakrapar, one moderate river leads the water and meets the sea. By providing the canal escape at suitable location as well as excavating channel between the escape and this river, an inter-linkage can be provided. Such planning can be helpful to run the canal at FSL in order to reduce water level at Kakrapar, which increases rapidly due to discharge from Ukai during heavy rain fall in the upstream. As discussed earlier, Mithi-Khadi river is flowing parallel to the left bank of river Tapi. It is proposed to construct some water storage structure in the form of reservoir and polder dams. In order to reduce water level of Tapi during peak discharge, considerable amount of water can be diverted and stored into reservoir no. 1 to 5.[1]

[1] Dhruvesh P. Patel & Prashant K. Srivastava: Flood Hazards Mitigation Analysis Using Remote Sensing and GIS: Correspondence with Town Planning Scheme, 2013.

VIII. Adaptation Measures and Strategy for Flood Risks

In order to reduce existing risk levels, adaptation measures must be considered a fundamental part of sustainable urban development. The adaptation measures can be classified as planned and autonomous. Planned adaptation is the result of deliberate policy decision, based on the awareness, and would progress from the top-down approach, through regulations, standards, and investment schemes. Autonomous adaptation refers to those actions that are taken as individual institutions, enterprises, and communities independently.

An important finding is that the huge monetary costs of these impacts are the uninsured losses borne by households belonging to poor strata of society and the private sector mostly engaged in informal activities. The study also examines the responses of local government institutions as well as people to cope with flooding. There are a number of public and private adaptation strategies that have been identified in this study. A significant finding is that all private initiatives and responses are a direct out-of-pocket expense for the concerned individuals or establishments. There is virtually no insurance cover that helps them to deal with the adverse impacts of floods and bring about changes or improvements in the existing infrastructure. Some of the public and private responses have the potential to enhance the medium to long-term adaptation capacity of the city to cope with future floods. However, there is a need to address the larger issues of climate risks and adaptation in the long-term development planning for the cities.

Measures of Adaptation option and Economic Implications:

Adaptation scenario is location specific requirement. Most of the systems, whether human or natural, automatically adapt to accommodate some deviations from the normal climatic conditions. But when the impacts of climate change and climate variability are expected to fall outside the coping range of a particular system, then “planned adaptation” response is required.[2]

Climate change and climate variability, together with other stresses on coastal environment produce actual impacts and can be shown to have future potential impacts. These impacts trigger efforts of mitigation, to remove the cause of impacts, and/or adaptation to modify the impacts.

Important Adaptation Measures

What can cities do to minimize damage from flooding? What adaptation measures cities can take to minimize the damage from flooding? These are the few questions that pose challenges to find out various adaptation options.

Among the various options that one might consider are:

[2] Anand Patwardhan, et al.: Impacts of Climate Change on Coastal Zones

1) **Reducing inflows:** Scope to increase the capacity of UKAI reservoir should be explored. Also models to forecast inflows in UKAI in advance should be made so that capacity to absorb inflows can be increased. Between UKAI and Surat large flood plains can be developed. This may be difficult as the areas required may be large. If one metre depth of water is to be permitted, a flood plain of some 2000 sq km would be needed. Similar kind of strategy can be adopted for other coastal cities or cities having reservoir nearby to them.

2) **Raising embankment:** The cost may be huge as the length and height of needed embankments need to be worked out.

3) **Early warning for evacuation:** As releases from UKAI reach Surat in about 8 hours, thus, a system of early warning and shelters could be created. The submergence level of the scenario suggests the nature of shelters required in different zones.

4) **Control future expansion:** Optimal land use planning to protect vulnerable population and commerce can be promoted. Wide public distribution of the risk and extent of flooding will make buyers aware and builders would be required to build in flood risk free areas. Of course, regulatory authorities should play a role in directing development.

5) **Flood proofing infrastructure facilities:** Knowing the risk and extent of possible flooding can help in their task. Plan for infrastructure and facilities needed for countering and protection against adverse natural event depending on (i) probability and likelihood; and (ii) techno-economic analysis. Flood proofing of infrastructure for water supply, power and energy, storm water drainage and storage, heat stress; sea-level rise, etc can be developed in flood prone cities.

Apart from the above adaptation measures, water storage and ground water recharging facilitations can be considered and promoted. Administrative procedures and strategies, incompliance with status of climate sensitive resources can also be taken into consideration. Development of contingency plans for abnormal natural situation to support the livelihood structure and ability of the people to function in adversity can also be strategized. Hence, an holistic approach together with the economic implication analysis is needed for selected adaptation options in consultation with stakeholders. Stakeholders at various stage of decision making should be consulted to select adaptive measures and priority of action required for the particular city.

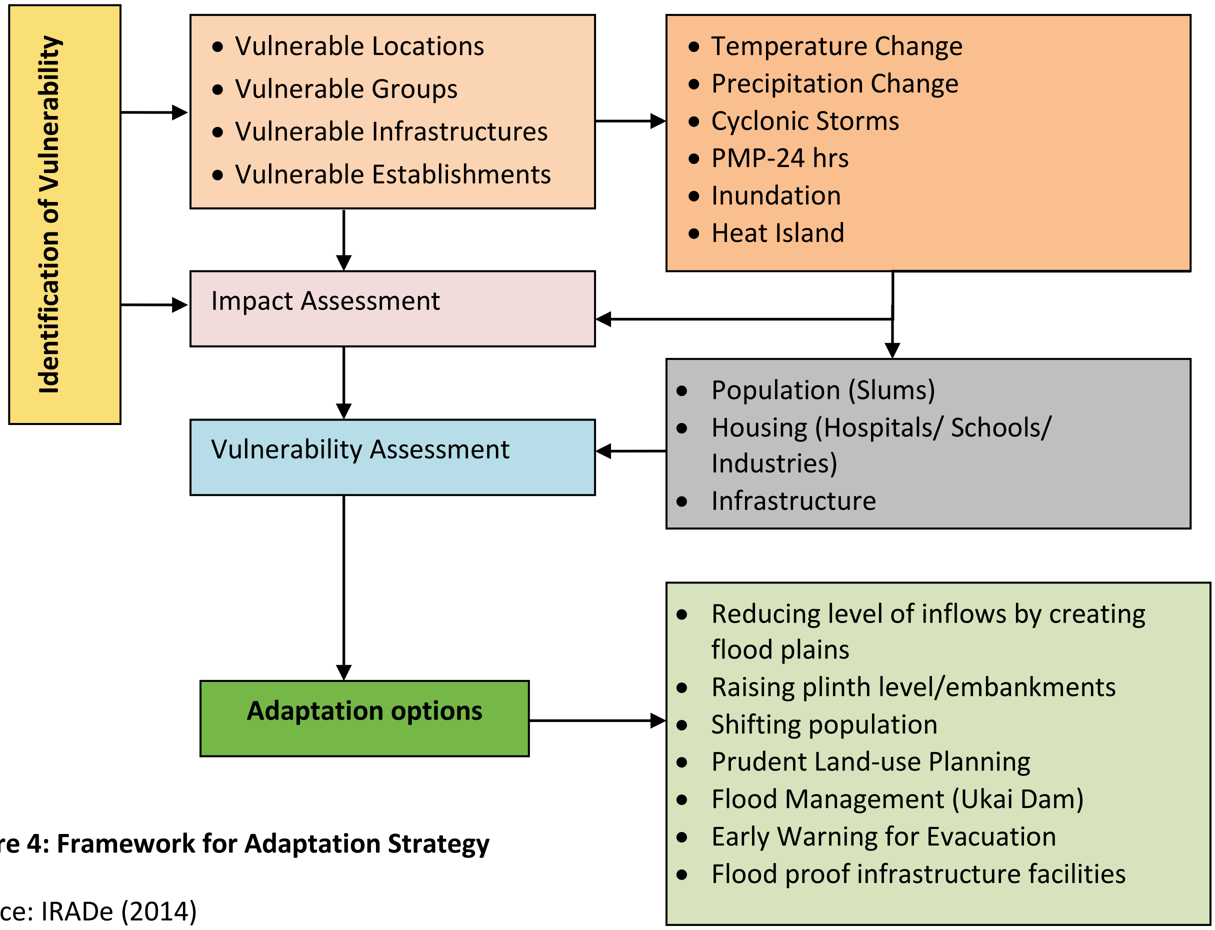

Figure 4: Framework for Adaptation Strategy

Source: IRADe (2014)

IX. Conclusion

This research is anchored on applying appropriate models and tools that connect climate change, hydrology, land use, infrastructure related to basic services for vulnerability mapping/ assessment. The output and analysis of appropriate solutions to manage hazards suggest measures to enhance resilience to climate change. In the process we have augmented analytical capability of the stakeholders that helps them to foresee climate variability and change and to assess socio-economic vulnerability to climate change. These suggest ways to develop climate resilient city and update the "Decision Support System" framework also for initiating action at local, state, and national level involving stakeholders. This may facilitate designing of a resilient development plan that provides proactive safeguards to Climate Change.

The methodology developed and used in the project to identify and analyze the immediate to medium-term impacts and responses of flooding events is expected to improve the understanding of adaptation interventions coming from the government as well as communities. The project will help in enhancing the ministry's initiative in identifying and developing effective methodologies in different areas of global change research and transferring the knowledge base to the scientific community and policy makers. Better characterization of post-event impacts and the recovery process would further help in improving the disaster management interventions. The findings of this project will also help inform the authorities of other Indian coastal cities and other climate networks.

The study measures the hydro-meteorological and socio-economic impacts of selected extreme weather events and inflows scenarios of flooding. It will help identify the public and private responses in the short to medium-term and explores their policy implications for long-term adaptation capacity, city resilience and development plans. The case study of Surat also identifies the immediate to medium-term post disaster responses of the civic administrations, concerned authorities as well as the citizens to cope with future floods.

Key Conclusions

- The existing Central Water Commission (CWC) flood forecasting system seems inadequate because the agency has limited information in terms of rainfall record and not enough inflow data. Modern technology for flood forecasting is developed day by day. It is not clear if the CWC uses recent techniques useful for river monitoring and forecasting system. Moreover, rapid population growth in the region, intensification of agriculture, climate change induced events, changes in land use and river morphology and rapid technology development make it essential to keep upgrading the forecasting system. In the existing system, river is gauged at Kakrapar weir, Mandavi, Ghala , Kathor-Singanpur weir and at Hope bridge. It is suggested to establish more rain gauge stations at Amlidam, Godadha dam, Godsamba village and at Luharpur. All these stations should be interlinked with each other and real time data during critical period should be monitored.
- The analysis under this study shows that west zone and south-west zone are highly flood prone while east zone is least. Topographically, west zone is the lowest zone and hence it has more chances to get flooded severely. As per Town Planning, Rander-Adajan is low rise area in the west zone,. Illegal and unauthorized settlements on the bank of river Tapi are constructed in river flood plains, which can be affected by even a low intensity flood event.
- Due to urbanization, some natural drainage is blocked by constructions. If such constructions are a must, then alternate routes must be provided for natural drainages to flow. Data shows that town growth is observed in the area (mostly sprawling inside the flood plains) and if preventive measures are not taken into account, the death toll due to flood will be increased in future flood events.
- Peak discharge can be reduced in Tapi by diverting some water into other rivers or reservoirs. Hydrological information as presented in this report will be beneficial for policy makers and

modelers in designing strategies for controlling flood hazards. It will be helpful for development of advance flood forecasting system and preparedness of disaster relief packages and therefore should be integrated with the current system, which will in turn reduce flood damages and loss of human lives.

The key conclusions that emerge from the study are as follows:

Firstly, downstream flood inundation models considering the meteorological aspect need to be regularly updated with the changing environmental parameters including land use, urban development and UKAI dam conditions. Detailed modeling of future flood inundation under various hydro-climatic scenarios needs to be explored to assess impacts of climate change on the people and resources.

Secondly, UKAI dam management and its regular situation and forecast reports should be available to all concerned decision makers. A multi stakeholder body should take appropriate action based on the real-time model results.

Thirdly, there should be a risk-based infrastructure and building use planning to minimize the damage cost.

Fourthly, there should be various levels of flood danger mark at the visible places of the city to make the people of the city aware of the impending threat, if any.

Lastly, Surat city has ward level Disaster Management Plan. This plan needs to be taken down to the lowest strata of the society through various means such as drills, education, community involvement, school curriculum, hospital catalogue, etc.

X. Way Forward

1) Towards an Integrated Approach: Linking Science and Society

Science can provide objective scientific and technical advice to the society and policy makers, especially for a complex processes like climate change and the socio-economic vulnerability of the region. Beyond the sectoral and disciplinary assessments of climate change, an urgent need is to integrate the diverse scientific assessments and link them with policy-making. While some experience of using integrated assessment models does exist in India, the capacity building in this area still remains a priority in two respects:

Firstly, it is to provide policy orientation to the scientific assessments; and

Secondly, it is to provide robust scientific foundation to policy making.

The development of assessment tools taking into consideration various parameters related to hydro-meteorology, socio-economic conditions, hazard-risks vulnerability, urban morphology and infrastructures, institutional set up, etc. would need commitment of sustained resources and institutionalization of multi-disciplinary and networking efforts within the scientific and policy-making establishments.

The status and key vulnerability concerns in India, more specifically the coastal cities, response strategies, and assessment challenges for diverse sectors and regions require integrated approach for climate change vulnerability assessment and adaptation challenges. Integrated approach refers to considering the full range of stresses that affect a resource or system, including climate variability and change, land use change, and many other natural and human impacts (NAST, 2000).[3] For example, in deciding policy for flood hazard management in a particular place, integrated scientific advice should include the direct and indirect effect of urban development, agricultural run-offs, and climate change-induced increase in heavy precipitation events, along with many other related factors. Integrated approach also refers to integration over regions, sectors, and time-scales. For example, the analysis of water availability may be first integrated at individual sub-basin levels, further integrated into individual river basin levels, and finally integrated into national level. Such integration across both multiple stresses and multiple scales is needed to provide the type of comprehensive analysis that policy makers need.

Integrated assessment attempts to present the full range of consequences of a given policy- economic or environmental, prompt or delayed- in order to determine whether the action will make the society better or worse-off, resilient or non-resilient to climate change. A more progressive adaptation framework for integrated assessment of climate change and vulnerability at national, state and local levels has to be compulsorily included in policy/ strategy towards climate resilient urban development. Networking is a critical requirement for integrated assessment. The NATCOM project has made a beginning where more than a hundred inter-disciplinary research teams spread across the country have been networked together for a shared vision on climate change related research (Shukla et al., 2002). Such initiatives have to be strengthened.

2) Incorporation of Urban Growth and Climate Change Scenarios in City Development Plan (CDP) and Master Plan

The urban populations as well as their incomes are expected to grow rapidly over coming decades. The average income of 112 largest cities across India was estimated to be about 66,252 Rs/capita in

[3] NAST, 2000. Climate Change Impacts on the United States: The potential Consequences of climate variability and change. A Report on the National Assessment Synthesis Team. US Global Change Research Programme, Washington D.C.

2008-09 (Indicus Analytics, 2011). Most of the cities face severe capacity constraints to generate city development scenarios under a rapidly transforming urban economy in the globalized world. This limits more systematic approach to master planning process informed by future growth scenarios. The current master planning process for each area is no longer valid in the fast changing urban contexts. Paradigm shift from the conventional population growth rate calculations and archaic (single use) land use planning based master planning process to integrated infrastructure and land use planning optimizing water, energy and land resources as well as services like transportation in the resources, demographic and economic context. Development of such scenarios and exploration of alternate futures would necessitate multi-stakeholder engagement starting from city levels to national level. Enabling environment for incorporation of such concern is slowly emerging with increased focus on urban rejuvenation efforts and investments.

3) Rapid Vulnerability Assessment Strategy (RVAS) Framework

Nowadays, cities are growing very fast, so are their risks. To make cities climate resilient we need to assess their vulnerabilities in a rapid mode. Every city is different. No two cities are same. A formal strategy for rapid vulnerability assessment is needed which would support the decision makers for prudent policy measures to make cities sustainable and climate resilient. As part of the adaptation development process objective, this project research has studied the impacts of flood disaster under the changing discharge scenarios in Surat city. There is a limitation in using tools for vulnerability assessment and adaptation evaluation, therefore, one of the simplest tools and strategies for RVA has been developed by IRADe.

Moreover, secondary data about impacts of floods to the city, existing flooding management, adaptation capacity against vulnerability; and methods to prevent, prepare, mitigate and respond those disasters and hazards need to be analysed in terms of vulnerability assessment of city to flood water. The analysis results can be applied in assessing appropriate adaptation measures to flood risks in other cities. This RVAS can be applicable especially to cities that have regular floods as a natural disaster and as man-made hazards.

Rapid expansion of Indian cities and climate induced risks to them pose several challenges to resource management and infrastructure planning. And it is a matter of paramount concern for the country. It also displays an urgency of the need to adapt city level operations to both current climate variability and future climate change. Since overall risk in Indian cities typically is associated more with vulnerability than hazard exposure. It is, therefore important to understand a number of processes that are rapidly changing the Indian urban landscape, making cities more prone to the natural disasters, altering the course of development, that as result affect the vulnerability of many communities. Due to geographical diversity of the country, vulnerability to climate change would vary from city to city. Some cities would be more prone to flooding and other would be more affected by sea level rise and so on so forth. Impacts of variation in precipitation would also not have uniformity. Therefore, there is an urgent need to assess the vulnerability to climate change of major Indian cities in order to facilitate the adaptation at the city level.

This RVAS framework incorporates the project methodology and lessons learnt during the study. It is designed to help assess rapid vulnerability of a city by identifying vulnerable populations and locations; and anticipate how they will be affected by likely hazards and develop strategies for reducing its vulnerability. This RVAS framework provides a step-by-step process for preparing an assessment of a city's physical and social vulnerability to disasters, both natural and technological, and includes detailed instructions for conducting an assessment, a list of information that is needed to complete the assessment, and worksheets for compiling and organizing data collected.

It can be used by the central and state government ministries; various stakeholders such as city administration, city planners, etc seeking to understand and reduce a city's vulnerability to disasters, as well as by central, state, and local emergency preparedness or hazard mitigation offices to help cities become better prepared for disasters. It can be used, for example, in preparing a local hazard mitigation plan.

We recognize, however, that not all local governments have the same level of resources and expertise to carry out the vulnerability assessment. Similarly, most cities do not have the staff or equipment to conduct a highly technical assessment. We have designed this RVAS framework so that a vulnerability assessment can be conducted using information and maps that are readily available, e.g., from government agencies and from the web. In some cases, a city administration may choose to conduct a more sophisticated analysis, using in-house GIS capabilities to generate original maps and more detailed and up-to-date analysis of vulnerable populations and locations as the case with the Surat Municipal Corporation.

PART I: INTRODUCTION

CHAPTER 1: INTRODUCTION TO PROBLEMS AND ISSUES

1.1 *Rationale and Background of the Study*

The flood is a common and disastrous event in human life. It occurs due to overflow of river banks and leads to destruction of human property and life. It may be defined as "a relatively high flow which overflows the natural channel provided for the runoff". Flood is also defined as the body of water which rises to overflow land which is not permanently submerged. In many parts of the country, flooding reaches catastrophic proportions during the summer monsoon season. River is said to be in flood when its water level overflows its banks at the particular site. Flooding is not just confined to the Indian subcontinent but is a globally pervasive hazard. Therefore, lots of initiatives have been taken from time to time to develop the understanding and mitigation measures of flood. In 1967, UNESCO and WMO supported international symposium on "Floods and their computation", organized in Leningrad to draw attention of scientists and engineers to this continually destructive hazard. It has been found that flooding is increasing with time. In earlier days, the size of population was smaller and the impact of a flood was also less causing less property damage and destruction. Increasing population and growing economic activities, development of settlements and economic establishments along the riverside results into overflowing of the banks due to excessive sedimentation, constriction of the river cross-sections and disturbance of its natural meandering. Thus anthropogenic activities are somehow responsible for destruction due to flood.

Floods have been classified on the basis of duration into a single event, multiple events and seasonal floods. Single event flood is the one in which widespread heavy rains for a longer duration than normal over a drainage basin results in severe floods whereas multiple event floods are ones which occur when successive weather disturbances follow each other closely. Seasonal floods occur during different seasons, like summer monsoon season experiences many floods as major storm activity occurs during this season. Typical characteristics of floods are largely dependent on the extent, duration, depth and frequency. "Extent" of the flood includes the area it covers, larger the extent, larger will be the area of under submergence. "Duration" is the total time of flood occurrence, the duration with which it is occurring, largely controls the destruction of the area. Its continuity is sometimes largely controlled by the intensity of rainfall. Therefore flood along with long duration may results in larger extent and thus causing havoc in the affected area. "Depth" of flood is also an important parameter as it signifies the danger level. Excessive depth may not only destroy the property but also the lives of the people, which mostly occur during the flood of long durations. "Frequency" is another important characteristic of flood as it describes the expected time interval between floods of the same magnitude. All these factors are correlated and depend to some extent on each other.

Vulnerability and risk of flood are the most important factors which should be assessed in flood management. “Risk” is considered as a measure of the expected losses due to a hazard event of a particular magnitude occurring in a given area over a specific time period. It is a function of the probability of particular occurrences and the losses each would cause. The level of risk depends upon:

- Nature and Type of the hazard
- Vulnerability of elements which are affected
- Economic value of the elements at risk

“Vulnerability” is the level of exposure of persons and property to hazards. Timmenmen (1981) and Prasad (2007) reviewed vulnerability at the society or community scale and defined it as the degree to which a system, or part of a system, may react adversely to the occurrence of a hazardous event. There is physical vulnerability which is related to the physical location of the people and elements at risk and their physical proximity to the hazard. So the properties of people which are exposed to the destruction due to flood are considered as ‘physical vulnerability’. Hence people are somewhat vulnerable to flooding because they live in flood-prone areas. ‘Socio-economic vulnerability’ indicates that the degree to which a population is affected by a calamity will not purely lie on the physical components but also has a contextual realization to the prevailing social and economic conditions. Settlements or buildings which are near to the river are more prone to flooding due to overflow of river embankment at the time of flooding event.

Climate change is now a widely recognized and accepted issue that is impacting multiple facets of how cities are structured and operated.[4] The Fourth Assessment Report of Intergovernmental Panel on Climate Change states that “*warming of the climate system is unequivocal, as is now evident from the observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level*”.[5] The same report also states that the linear warming trend over the 50 years from 1956 to 2005 is nearly twice that for the 100 years from 1906 to 2005.[6]

IPCC (2007) also noted the following with high confidence:

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[4] UNEP (2010)

[5] *IPCC AR4, (2007: 30), Climate Change 2007: Synthesis Report, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.) IPCC, Geneva, Switzerland. pp 104*

[6] IPCC (2007), Climate Change 2007: The Physical Science Basis, Cambridge University Press, U.K.

"The most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources, and those in areas prone to extreme weather events, especially where rapid urbanization is occurring. Poor communities can be especially vulnerable, in particular those concentrated in high-risk areas. They tend to have more limited adaptive capacities, and are more dependent on climate-sensitive resources such as local water and food supplies" (p.7).

Nearly, half of the world's current population live in urban cities[7] compared to less than 15 per cent in 1900[8] and this figure is expected to rise to more than 60 per cent by 2030 (United Nations, 2006). According to IPCC Third Assessment Report (2001), coastal cities will be at greater risk as climate change and sea level rise increases hazards from coastal flooding and erosion.[9] Climate change has the potential to increase flooding risks in cities in three ways: from the sea (higher sea levels and storm surges); from rainfall – for instance by heavier rainfall or rainfall that is more prolonged than in the past; and from changes that increase river flows – for instance through increased glacial melt (Satterthwaite et al., 2007). Coastal mega cities are exposed to the more frequent severe windstorms; the heavy rains often result in intense and sometimes lethal flash floods (Pandve, 2010). The IPCC Working Group II observed that heavy precipitation events are very likely to increase in frequency and will augment flood risk and the growing evidence of increased runoff and earlier spring-peak discharges in many glacier- and snow-fed rivers (Adger et al., 2007). It has been estimated that 23% of the world's population lives both within 100 km distance of the coast and <100m above sea level, and population densities in coastal regions are about three times higher than the global average (Small and Nicholls, 2003). The attractiveness of the coast has resulted on disproportionately rapid expansion of economic activity, settlements, urban centers and tourists resorts (IPCC TAR, 2001). Between 1994 and 2004, Asia has faced almost one-third of the 1,562 flood disasters, death of about 60,000 people, and 98 per cent of the 2 million people got affected by flood disasters (Few et al., 2006).

1.2 *Overview of the Problems*

1.2.1 The Conceptual Framework

It is necessary to understand scientifically the impact and threats of climate change on urban areas and take measures to strengthen resilience of cities. To do this we need to identify actions for adaptation and to increase the capacity of cities to take them in time. Moreover, some of

[7]Satterthwaite D., Huq S., Pelling M., Reid H.and Lankao P.R. (2007), Adapting to Climate Change in Urban Areas, Working paper produced by the Human Settlements Group and the Climate Change Group at the International Institute for Environment and Development (IIED).
[8] Graumann (1977)
[9] IPCC TAR (2001)

these problems have to be addressed scientifically for cities on river basins and adjacent to sea coast. The hydrology and hydrodynamics of the region under the threat of climate change has to be understood along with economic constraints and opportunities and demographic dynamics. Vulnerabilities of different wards or localities, groups of people, industries, commerce, and city infrastructure are to be assessed to identify what actions can reduce their vulnerability and make our cities resilient to climate change. Locations of schools, hospitals, slums and industries are vulnerable hot-spots. Nowadays, bridges and flyovers play an important role in planning and capacity building of city. Thus, it is an urgent need to strengthen these bridges and flyovers by designing carefully and keeping these to a certain height to face the threat of flooding event.

1.2.2 Case Study Area

The case study area under this project is Surat city which is located at a latitude of 21.0° to 21.23°15 North and longitude of 72.38° to 74.23° East on the bank of Tapi River. It has about 6 km long coastal belt along the Arabian Sea and therefore serves as an important trade centre. The river Tapi is merging to the Arabian Sea at about 15kms away from Surat City. The city of Surat is the commercial capital of the state and is of significant importance to the country. It is located at the mouth of Gulf of Khambhat and therefore experiences tides of a tidal range of about 5-6 m.

Surat has a tropical savanna climate, moderated strongly by the Arabian Sea. The summer begins in early March and lasts till June. April and May are the hottest months, the average maximum temperature being 40°C. Monsoon begins in late June and the city receives about 1,000 mm of rain by the end of September, with the average maximum being 32°C during those months. October and November see the retreat of the monsoon and a return of high temperatures till late November. Winter starts in December and ends in late February, with average temperatures of around 23°C, and little rain.

Very often heavy monsoon rain brings floods in the Tapi basin area. In last two decades, the city has witnessed major floods every four years, the worst being the flood of August 2006, perhaps the costliest in the city's history. In the second week of August 2006, a massive flood caused severe damage to the city of Surat. According to a report released by Indian Institute of Management – Ahmedabad (IIM-A), massive flood after release of water from Ukai Dam had caused major human tragedy and property damage estimated at Rs 220 billion on that day. In less than three days, at least 150 people died directly due to flood and many others due to water-borne diseases that followed. More than 1500 animal carcasses were later hauled out of the mud.[10]

[10] "IIM-A Report on Flood". IIM-A. Retrieved 2008-07-06.

1.3 *Objectives of the project*

1. To develop an integrated analytical framework for urban areas in the background of a specific case study of Surat City.
2. To assess the vulnerability of the city and its people to climate change, and
3. To develop a procedure to incorporate climate change concerns and adaptation measures that can make a city resilient to climate change induced vulnerability.

1.4 *Outline of IRADe Approach and Methodology*

The study measures the physical, economic and social impacts of selected extreme weather events of flooding, identifies the public and private responses in the short to medium-term and explores their policy implications for long-term adaptation capacity, city resilience and development plans. This study is based on the analysis of primary and secondary data pertaining to the selected events of the flooding and their resultant physical, economic and social impacts. The case study of Surat also identifies the immediate to medium-term post disaster responses of the civic administrations, concerned authorities as well as the citizens to cope with future floods.

To assess the impacts and adaptation needs it would require integrated assessment that involves various set of data and analytical approaches. Data on urban structure, land use, roads and transport infrastructures, basin and channel, drainage systems, settlement pattern, vulnerability profiles have to be collected, organized and analyzed to evaluate capacity and assess vulnerability. Such an integrated assessment considers the interaction between climate change and other change processes to assess the social, economic and environmental impacts of climate change. It requires a wide understanding of natural and human systems. This is important because demographic profile, economic development and land use and land cover of a region have a significant influence on how changes in climate are likely to impact and the capacity to adapt to any such future changes. It is also necessary to take into account the concerns of the stakeholders and priorities of the concerned authorities because the extent of impacts and scope of adaptation are strongly influenced by their actions[11].

The data have been organized on a GIS platform and analyzed with statistical techniques and mathematical models. The main steps taken to assess the vulnerability of the city are as follows:

1) **Assessment of the hydrology, climatology, and built environment of Surat city:**

[11] BASIC, 2007. Garg, A., Rana, A., Shukla, P.R.,et al.,.Handbook of Current and Next Generation Vulnerability and adaptation Assessment Tools

This has been done with the help of the data available from various institutes like Surat Municipal Corporation (SMC); Indian Meteorological Department (IMD); Irrigation Department (Surat); National Remote Sensing Centre (NRSC), Hyderabad; IPCC SRES Climate Scenarios, etc. In conjunction with GIS, the climate hydrology analysis results have been connected with land use pattern, city topography, socio-economic characteristics, and infrastructure facilities to assess vulnerability.

2) **Hydro-Climatic Scenarios:**

- IPCC-Special Report on Emission Scenarios (SRES) climate scenarios of Surat region from 2000 to 2100 are analyzed to assess the likely maximum inflow in the Tapi River due to climate change, which was considered to be 50% larger than the inflow due to the 2006 flood.
- Using CARTOSAT Imagery of NRSC, Hyderabad, on GIS platform with the integration of HEC-RAS, hydro-climatic scenarios for the study region have been developed. Hydrological models serve primarily the role of a link between climate scenarios and river water discharge simulations as well as for estimating the magnitude and risk of floods.
- Analyses of hydrological profiles and flood intensity levels for the region have been conducted for different inflow scenarios.

3) **Critical infrastructure and sectors vulnerability:**

This has been done by sample surveys of basic infrastructure services and their facilities, e.g. schools, hospitals, buildings (public and private), slums, and industries. Sample surveys and interviews of persons covering households, administrators, professionals, slum dwellers, etc. in selected locations of the city were carried out to identify and assess the different vulnerabilities of various facilities and groups to flood risk. Vulnerability indices were developed to get our idea of vulnerability under projected scenarios.

1.5 *Value of climate information*

Climate information is of immense value to the Surat-city administration. The Surat region has been identified as one of the Future-City of India and a center of economic growth of India. It is important that in view of the economic potential, and expected accelerated development of the city, resilient urban development is needed. The planning procedure could incorporate relevant climate adaptation schemes for scientific land use planning. Proactive actions based on climate scenarios and weather forecasts can minimize social and economic damages due to natural hazard to a large extent. These proactive adaptation actions will be facilitated by the results of this study.

1.6 *Information Processing Procedure*

The impact of climate change will alter hydrological regimes and the frequency and intensity of extreme natural events. The extent of the changes will vary from place to place. The parameters associated with climate change are increasing in temperature, change in precipitation, heat stress, health & infectious diseases, air pollution, glacial melt (not relevant to our study), sea level rise, and coastal storms.

The Surat district has man-made infrastructure (Ukai Dam upstream of Tapi river, river embankments, irrigation projects, port at downstream Hazira), which alter hydrological regimes of the region.

1.7 *Methodology*

The analysis of the projected impact of climate change in urban areas and examining a way forward towards building a climate resilient city is a complex task. It requires interdisciplinary research work involving the hydrodynamic analysis, socio-economic assessment, understanding the techno-economic constraints and urban system simulation. It also requires the integration of these various aspects in a coherent framework. Fortunately, some of the building blocks are available, but what is missing is an integrating framework. The study develops a methodology to integrate outcome of available city specific analysis and expands it to generate a procedure to introduce climate change concern in the existing framework for decision support system (DSS), for identification of adaptation options given the uncertainties of projection and scenarios to generate robust results.

1.7.1 Steps in Methodology:

A. **Database Development**: for integration and analysis
   - Collection of data from various sources for the regional and peripheral area on geographical features, topography, ecosystem of the region, land use, river basin, extreme events, and socio-economic profiles.
   - Collection of data on history of climate elements, catchments area of Lower Tapi basin, and Hydrological & hydrodynamic data for the Lower Tapi river basin from IMD, and State Irrigation Department.

B. **Hydro-Climatic Scenarios:**
   - Using CARTOSAT Imagery of NRSC, Hyderabad on GIS platform with integration of HEC-RAS, hydro-climatic scenarios for the study region have been developed.
   - Analysis of hydrological profiles and flood intensity levels for the region have been conducted for different hyro-climatic scenarios using various tools.

C. **Economic & Demographic projections:**
   - Taking perspectives of at least 20 to 30 years, the situation has to be visualized as it will show how city will grow in terms of population and economic activities.
   - Climate scenarios by earlier and contemporary researchers have been reviewed.
   - The impact of climate change on socio-economic aspects, and city development plan have been assessed coupled with hydro-climatic scenarios for vulnerability analysis.
   - GIS mapping procedure has been followed for vulnerability analysis.

D. **Map Vulnerability of the regions and community groups:**
- Different infrastructure facilities and sectors (targets groups) vulnerable to adverse natural events have been assessed for each climate change scenario.
- The vulnerability analysis has been correlated to risk perception.
- The analysis is carried out for various probabilities of climate change induced abnormal natural events.

E. **Identify adaptation response options:**
- Suitable adaptation response options for the region have been studied and analysed for their economic implications.
- Provide inputs for scientific analysis of adaptation options to plan climate resilient city.

1.8 *Impact of Climate Change in India*

Indian annual mean temperature shows significant warming trend of 0.51°C per 100 year, during the period of 1901–2007 (Kothawale et al., 2010). The analysis of data done by IMD for the period 1901-2009, suggests that annual mean temperature for the country as a whole has risen by 0.56°C over the period (Attri & Tyagi, 2010). This warming is primarily due to rise in maximum temperature across the country. Warming trend over globe of the order of 0.74°C has been reported by IPCC (2007). The trend for India's annual and monsoon rainfall for the period from 1901 to 2009 do not show any significant trend (Attri & Tyagi, 2010). However, the projections of precipitation indicate a 3% to 7% overall increase in all-India summer monsoon rainfall in the 2030's with respect to the 1970's (INCAA Report, 2010). Significant increasing trend was observed in the frequency of heavy rainfall events over the west coast (Sinha Ray & Srivastava, 2000). Most of the extreme rainfall indices have shown significant positive trends over the west coast and north-western parts of Peninsula. For India, on an average the mean sea level rise along the coasts is estimated to be 1.3mm/year (INCAA Report, 2010).

1.9 *Vulnerabilities of Coastal Cities to Climate Change*

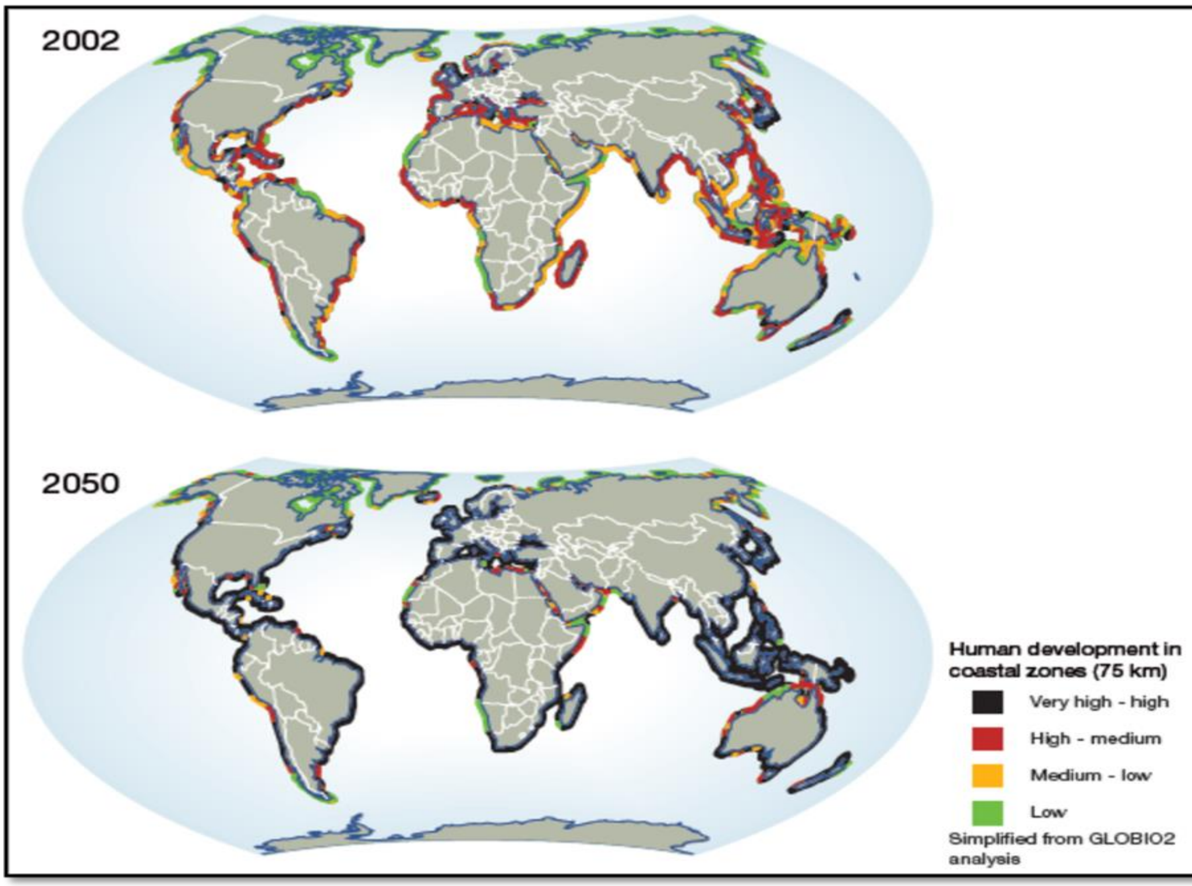
1.9.1 Population Density and Growth in World's Coastal Zones

Coastal zones attract more people in comparison to other regions around the world. According to Sterr H. et al., 2000 "urbanization and the rapid growth of coastal cities have therefore been a dominant population trend over the last decades, leading to the development of numerous megacities in all coastal regions around the world" (p.2). In 1990, around million people were estimated to live in the coastal floodplain (in the area inundated by a 1 in 1000 year flood) and probably this number could increase up to 600 million by the year 2100 (Nicholls and Mimura, 1998). As a whole, this will put pressure on coastal resources through growing demands and surge people's exposure to coastal disasters.

1.9.2 Human Impact in the Coastal Zones

Infrastructure development, intensive agricultural expansion, urbanization and coastal developments are increasing the flow of sediments and sewage into the ocean. The situation is most severe around Europe, the East coast of the United States, East of China and in Southeast Asia. These are also primary fishing grounds. Coastal zones are identified as approximately 75 km from the coastline, and this map identifies the most common impact class in this zone.

Figure 1.1: Scale of Human Impact in the Coastal Zones

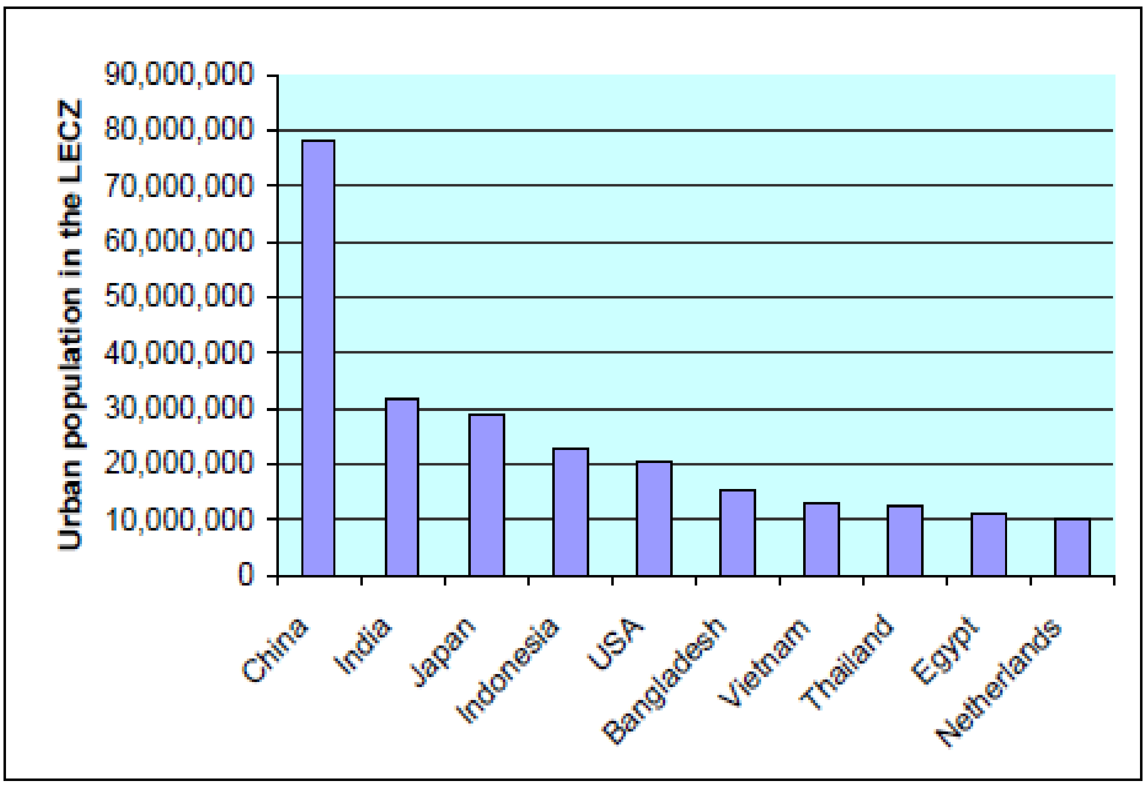


Source: Hugo Ahlenius,UNEP/GRID-Arendal(2008), Available:**http://maps.grida.no/go/graphic/human-impact-in-the-coastal-zones**

1.9.3 Vulnerabilities of Indian Coastal Cities to Climate Change

India is one of the vulnerable and multi-hazard risk prone countries in the world (IFRC, 2005; Parasuraman & Unnikrishnan, 2000). Rapid population growth, high densities, poverty and high differentials in access to housing, public services and infrastructure have led to an increase in vulnerability over the last few decades, especially in India's urban centers (Revi, 2007). In addition, it is expected that climate change could increase the frequency and intensity of prevailing hazards and the possibility socio-economic of extreme events (e.g. sea-level rise) thereby adding to the existing vulnerabilities with differential spatial and impacts. This is expected to further degrade the resilience and coping capacities of poor and vulnerable communities, who make up from a quarter to half of the population of most Indian cities (Satterthwaite et al., 2007). With its huge and growing population, a 7500-km long densely populated and low-lying coastline, and an economy that is closely tied to its natural resource base, India is considerably vulnerable to the impacts of climate change (DOD, 2002). It is evident from Figure *1.2*, that India is among the ten nations with largest urban populations and the largest proportion of its urban population live in Low Elevation Coastal Zone (LECZ).

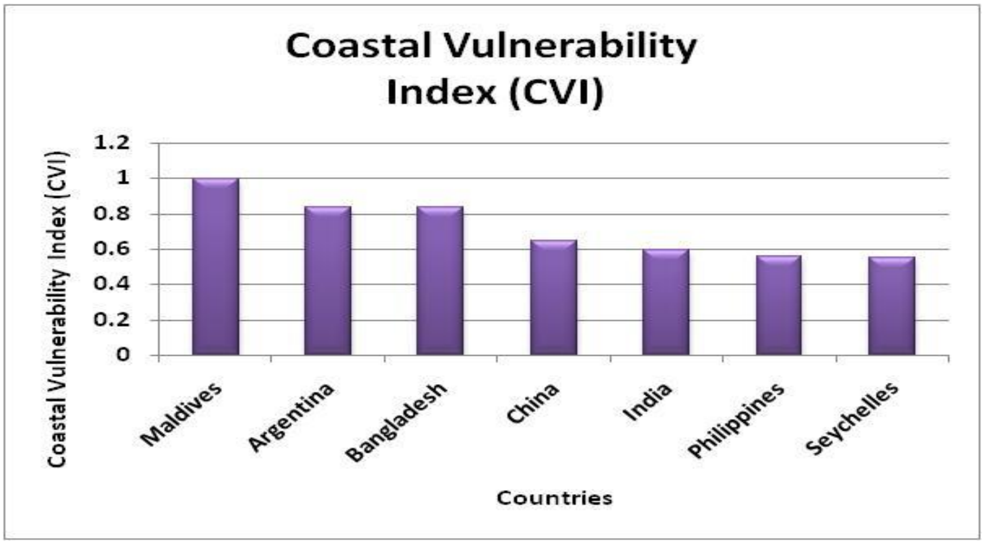
Figure 1.2: Nations with the largest urban populations in the Low Elevation Coastal Zone (LECZ)



Source: Satterthwaite et al., (2007: 22)

Length of the coastline of India including the coastlines of Andaman and Nicobar Islands in the Bay of Bengal and Lakshadweep Islands in the Arabian Sea is 7517 km (Pandve, 2010). Coastline of Indian mainland is surrounded by Arabian Sea in the west, Bay of Bengal in the east and Indian Ocean in the south.

Figure 1.3: Vulnerability in Global Coastal Zones



Source: Adapted from UNEP, 2005

Figure 1.3 clearly shows that India is among the nations that shows high levels of coastal vulnerability. High population densities and geographic exposure, a low proportion of forests in coastal areas, and a low human development index ranking are some of the factors that contribute to its high vulnerability value.

Climate change is expected to increase the severity of flooding in many Indian River basins, especially in the Godavari and Mahanadi basins, along the eastern coast (Gosai et al., 2006). Floods are also expected to increase in north-western India adjoining Pakistan, and in most coastal plains in spite of upstream dams. Extreme precipitation is expected to increase substantially over a large area over the west coast and in central India (Kumar et al., 2006). Cities that lie on the river banks are vulnerable particularly to floods from rivers, incessant rain, water release from upstream dam, and high tide etc. The sea level rise can compound the impact further. Floods affect a city in many ways. Houses get submerged and damaged, people lose their possessions, economic life gets disturbed, livelihoods get disturbed and city's life gets disrupted.

Gujarat, one of India's most prosperous states, got hit by severe flooding for three consecutive years starting in 2004, causing large economic losses, major damage to life and increased vulnerability of people in its cities due to extreme precipitation in upstream catchments (GSDMA/TARU, 2005). Surat City, which lies in the flood plain of Tapi River, is highly prone to floods.

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CHAPTER 2: LITERATURE SURVEY AND IRADe APPROACHES

2.1 Introduction

Extreme weather events affect vulnerable urban areas adversely, with substantial damage, disruption of normal economic and social activities and services and loss of human life and can also alter the medium or long-term development trajectory of the cities. Thus, disaster management is an important context for integrating adaptation into decision-making for the cities at risk. The Ministry of Earth Sciences (MoES), Govt. of India funded research project to Integrated Research and Action for Development (IRADe) with the primary objective of identifying and measuring the short to medium-term impacts and responses to extreme weather events and their policy implications for long-term adaptation measures needed the other coastal cities of the country. The project includes analysis of primary and secondary data to measure the physical, economic and social losses due to floods taking Surat city as a case study. We also examine the short to medium-term responses from the local government and citizens and evaluate if they enhance the adaptation capacity of the cities to cope with future weather events and flood risks. This analysis has policy implications for disaster management, city resilience and adaptive capacity of the cities in long term. The project is particularly relevant to the coastal cities similar to Surat city where natural disasters have long-term socio-economic implications for overall development of the city.

Coastal areas are dynamic and complex multi-function systems. A wide number of often conflicting human socio-economic activities occur in these areas. These include urbanisation, industrial production, energy production and delivering, and agriculture. Coastal systems are also characterised by important ecological and natural values; their high habitat and biological diversity is fundamental to sustain coastal processes and provide ecosystem services which are essential also for human well-being (MEA, 2005). In the context of climate change, highly urbanised and infrastructure coastal areas are of particular concern since they can drastically limit and even impede natural adaptive processes, such as inland migration or vertical accretion of wetland systems.

Climate change adds additional pressures on coastal systems (Richards and Nicholls, 2009) by increasing vulnerability on already highly vulnerable areas. This can include the development of new impacts, intensification of already occurring impacts, and synergic and cascading effects. The main impacts of climate change in the coastal zone are expected to be related to sea-level rise and other key meteorological changes such as flooding[12].

[12] Nicholls, R. J. et al. (2008), "Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates", OECD Environment Working Papers, No. 1, OECD Publishing. doi:10.1787/011766488208

Hence, there is a need to enhance our understanding of vulnerability and to develop methodologies and tools to assess vulnerability of these regions. One of the most important goals of assessing flood vulnerability, coastal flood vulnerability in particular, is to create a readily understandable link between the theoretical concepts of flood vulnerability and the day-to-day decision-making process and to encapsulate this link in easily accessible tools. A literature review is conducted to facilitate and strengthen the study background and in order to develop a theoretical framework of the study that will also inform the data needs and data analysis of the study. Different frameworks are discussed to help understand and apply the topic of vulnerability reduction and building resilience to floods in Surat City.

2.2 Mapping out National Knowledge

2.2.1 Global Context

The Ancient communities along the Nile River, the Indus River, the Tigris-Euphrates Rivers, and the Ganges River relied on periodic flooding to replenish nutrients in deficit and to improve the fertility of soil for agricultural activities. However, in modern time, gone are the benefits of flooding and the changing land use pattern. In recent centuries, coastal areas around the globe have undergone rapid transformations and evolved into the most densely populated and economically vital areas on earth. In many countries, such as the United Kingdom, the United States, China, India, Japan, Brazil, South Africa, and Australia, the largest economic centre centres are often located within the coastal zone and are expanding both landwards and seawards. Yangtze River Flood of 1935 (Wu, 2004[13]), North Sea Flood of 1953 (Deltawerken, 2004[14]) and Bangladesh Flood of 1991 (Hofer and Messerli, 2006[15]) are examples of historic flood events at different parts of the world that had gobbled thousands of lives and had caused physical damages that worth millions. However, the bad news is the severity of coastal flooding problem is escalating over the last century and will continue to worsen in the future[16].

Flood disasters account for about a third of all natural disasters throughout the world and are responsible for more than half of the fatalities (Berz, 2000). Flood events cause major damage in terms of human life loss, property damage, agriculture productivity, industrial production, communication network, and infrastructure break-down. Floods are posing a great concern and challenges to design engineers, re-insurance industries, policy makers and to the government (Singh et al, 2009). Therefore, it is becoming very important to minimize the property damage,

[13] Wu, Daoxi. 2004. Evaluation of the Yangtze Flood Control System. Office of Flood Control and Drought Relieve, CWRC, Wuhan, China. http://kepler.ia.ac.cn/seminars/FOCYR/fullpaper/Wu%20Daoxi.pdf
[14] Deltawerken Online. The Flood on 1953. On 2004. http://www.deltawerken.com/89
[15] Hofer, T., Messerli, B. 2006. Floods in Bangladesh: History, Dynamics, and Rethinking the Role of Himalayas. United Nations University Press. http://www.unu.edu/unupress/sample-chapters/floods_in_Bangladesh_web.pdf
[16] Cutter S.L. ,1996, Vulnerability to environmental hazards.Progress in Human Geography 20(4):529-539

reduce infrastructure disturbances, and identify zones and building structures having greater flood hazard and flood risk potentials through flood vulnerability analysis which is part of floodplain management studies. It is important to note that the actual amount of flood damage of a specific flood event depends on the vulnerability of the affected socio-economic and ecological systems (Cutter 1996, Mitchell 1989). Flood vulnerability analysis gives us flood hazard maps of study area which help us in identifying floodplains which are low elevation areas subjected to flooding resulting into economic losses. These areas (buildings, properties, commercial & industrial establishments, education and health amenities) need to be regulated to minimize threats to loss of lives and properties major component of floodplain-management studies is assessment of the impacts of flooding. One purpose of flood risk assessment is zonation of study area falling under various risk levels based on hydrology/hydraulic studies for various return period such as 1% (100 year-) and 0.2% (500 year-) frequency floods (Singh et al, 2009).

The recent advances in Geomatics techniques have explored new horizons for flood assessment, flood forecasting and flood mapping. It is at the strategic planning level that the possibility of utilizing information available in cartographic forms assumes significant importance for urban flood mapping (Singh et al 2009). However, a major contribution to flood mapping and planning is derived from the information made available by use of remote sensing (RS) techniques and its integration with Geographical Information System (GIS) (Prasad 2006). The high resolution satellite imageries, relief map and land use, hydraulic characteristics of river channel and floodplain surveys, and probable water levels can be considered for predictive flood hazard mapping. Geodatabase generated from Geomatics application can further be exported in various hydrological and hydraulic models for flood hazard map preparation. Therefore, Geomatics techniques with other hydrologic and hydraulic models have been proposed for hazard mapping in this research work.

In 2008 Dr Ahmed Shaker a, W.Y. Yan a, b, M.S. Wong c, Nagwa El-Ashmawy d, Bahaaeddin IZ Alhaddad have conducted a study on Nile Valley in Egypt for flood hazard assessment using panchromatic satellite imagery. The research aimed to study and facilitate the use of the PAN satellite imagery in image classification for flood hazard assessment application. In particular, this research is investigating the potential use of PAN satellite imagery for flood hazard assessment of one of the high floods of the Nile River occurred in Year 1998. Several existing techniques and approaches used for digital image processing were examined and assessed for PAN image classification. The study focuses on four different approaches that could be used for PAN image classification and flood hazard assessment:

a) image interpretation,

b) edge detection,

c) pixel-based image classification, and

d) texture analysis (TEX).

The described approaches were investigated for PAN satellite imagery covering a part of the Nile Valley in Egypt. Two SPOT PAN satellite images covering part of the Nile Valley in Egypt before and after the 1997/1998 Nile flood have been utilized. Different areas of interest (islands, coastal areas, etc.) have been identified to study the efficiency of the previous classification approaches for PAN image classification. The results of four PAN image classification approaches are presented and assessed for the study sites using area and sample comparative analysis. The results revealed that Contextual Classifier on PAN imagery and Maximum Likelihood Classifier on TEX imagery offer the nearest estimation of flooding areas. The study shows high integrity of the tested approaches for PAN image classification and accuracy comparable to conventional signature-based classification technique of multi-spectral images could generally be achieved.

2.2.2 Indian Context

India is the seventh largest country in the world with the Land area of about 3.3 million sq km area and coastline of 7,517 kms. The rapid growth in population and urbanization compounded by deforestation has enhanced the threat of flood hazard in last four decades. Every year the floods in some or other areas cause loss of life, property, crops, and health hazards. The erosion of top fertile soil due to floods is a major long-term problem reducing the fertility of agriculture land. The frequency of urban floods have significantly increased in recent years due to rapid unplanned organization with poor drainage system. Hence the national disaster management authority of India prepared flood hazard maps that will provide information about the return period associated with the aerial extent of inundation for a reach of a river. The flood hazard maps are prepared delineating areas subjected to inundation by floods of various magnitudes and frequency by using traditional techniques of floodplain mapping Conventional dynamic flood frequency analysis techniques have been developed to quantitatively assess flood hazards over the past half century. These traditional techniques yield dynamic historical flood data which, when available, is used to accurately map floodplains. In addition to a record of peak flows over a period of years (frequency analysis), a detailed survey (cross sections, slopes and contour maps) along with hydraulic roughness estimates is required before the extent of flooding for an expected recurrence interval can be determined (NDMA).

Surat is a coastal city located in the state of Gujarat along the tidally influenced Tapi river in western India, approximately 250 kilometres north of Mumbai. In the last four decades the city recorded one of the highest growth rates in the country and a 10 fold population rise. About 20 percent of the city’s population lives in 420 slums. The Surat city and villages around are part of flood drainage of Tapi River. The river can contain about 6 Lakh cusecs flood within banks in major areas of city and around. Since 1882, 8 and 16 floods are recorded in Aug and Sept months. Major floods of 1933, 1959, 1968, 1970, 1998 and 2006 recorded floods of 9 Lakh cusecs. The dates and trends of unit hydrograph for 1968 and 2006 floods in August associated with storm East to West. River regime in Surat has capacity of 4 Lakh cusecs within banks, 6.5 Lakh cusecs corresponding to Hope bridge flood level 9.5 m is critical for floods in city and surrounding (1968). In general city is safe for floods up to 6 L cusecs and with proposed Pala it can pass flood of 8.5 L cusecs without major spills to city. The 1968 floods of 15 Lakh cusecs were worst and economically disastrous for flood plain17. This forced new strategy based on CWPRS hydraulic model studies.

IITM, Pune; IISc, Bangalore; IIT, Mumbai & Delhi are the leading institutions conducting research on climate change, and its impact on hydrology. Similar researches for glacier, hydrology, river basin studies are being conducted by National Institute of Hydrology, Roorkee. The institutions doing sectoral research are IARI, New Delhi (Agriculture); IISc, Bangalore (Ecology & Forest); IIT, Delhi (Water); TERI (Energy); National Institute of Oceanography (sea level rise) etc. The institutions have done Case Studies of Indian River basins such as Mahanadi Basin, Godavari Basin, Tapi Basin. The studies relevant for the project are the following:

- The coastline of the state of Andhra Pradesh is one of the most vulnerable zones for floods associated with heavy rain fall in the river catchments and in coastal areas due to cyclones. This occurs in both Godavari and Krishna basins. Dr. Ramesh, K J et al have worked on framework development of hazard mitigation modeling systems in respect of floods covering 24 river systems of Andhra Pradesh. Their fully customized system of modeling and GIS based Decision Support System (DSS) tools have shown that the flood hazard maps on dynamic basis are possible to generate with limitations of model design and spatial data resolutions.

- There has been significant research work conducted under Professor P P Mujumder, IISc, Bangalore on climate change impacts on hydrology/water resources, statistical downscaling of GCM outputs, urban flooding, planning and operation of large scale water resources systems, and uncertainty modelling for river water quality control. They have simulated their model on Mahanadi basin, Orissa. Similar work is being pursued at IIT, Mumbai under guidance of Prof. S Ghosh. studies are available on the net on “Direct Statistical Downscaling to Rainfall and Stream flow and Uncertainty Modeling: Ghosh, S. and P P Mujumdar 2007,2008, 2009 {IIT, Mumbai, IISc, Bangalore}”.

- World Bank has released a report on climate change impact based on case studies in India, focused on drought-prone regions of Andhra Pradesh, Maharashtra, and flood-prone districts in Orissa on the edge of climate tolerance limits.

[17] Agnihotri P.G and Patel J.N.2011, Improving carrying capacity of river tapi (surat,india) by channel modification, International Journal of Advanced Engineering Technology, IJAET/Vol.II/ Issue II/April-June, 2011/231-238

- Significant researches are being carried out under the guidance of Prof A K Gossain on hydro-climatic issues. Some of their work includes dynamic downscaling with PRECIS package, and using PRECIS output in Soil and Water Assessment Tool (SWAT) to evaluate emerging hydrology scenarios: Gosain et al (2006) & Gosain and Sandhya Rao (2007) [IIT,Delhi]

A study[18] was carried out by the World Bank, ADB, and JICA with association of regional partners on "Coastal Cities and Adaptation to Climate Change". The objective of study was to provide options to local, national and municipal decision makers with respect to scale of Climate Change related impacts, associated costs and policy measures needed to address them. The project studied climate change impact on four cities (a) Manila, Philippines (JICA) (b) Ho Chi Minh city, Vietnam (ADB) (c) Kolkata, India (World Bank) and (d) Bangkok, Thailand (WB). Impact of climate change are likely to affect the economic role played by all (four) cities in the regional/national economies (a) Poor are more vulnerable to likely impacts from flooding linked with Climate Change (b) it is important to build on existing social protection systems to develop adaptation measures specifically targeted to socially vulnerable groups. The messages emerging from the study were (a) impact of climate change likely to effect the economic role played by cities in the regional/national economies (b) it is Important to build on existing social protection systems to develop adaptation measures specifically targeted to socially vulnerable groups (c) Many coastal cities have long history of developing infrastructures for responding to natural disasters (e.g. dykes, early warning systems, etc.). However, climate change needs to be incorporated into existing flood protection plans/ broader urban planning (d) There is need to focus not just hard protection measures, but also natural protection and absorption afforded by specific urban/local ecosystems and it is (e) important to identify flood prone areas and implement land use regulations to minimize losses.

A research study "GIS and a remote sensing based approach for urban flood-plain mapping for the Tapi catchment, India" has been carried out by Anupam K. Singh & Arun K. Sharma; Hydro-informatics in Hydrology, Hydrogeology and Water Resources (Proc. of Symposium JS.4 at the Joint IAHS & IAH Convention, Hyderabad, India, September 2009- IAHS Publ. 331, 2009). It demonstrates the utility of high resolution remote sensing images combined with field data to delineate flood prone areas (The paper abstract is in the foot-note).[19] This has been done for past data. In our

[18] Presentation by Senior Environment Specialist, World Bank

[19] **Abstract** In India, floods typically occur during the monsoon season due to heavy tropical storm downpours and unregulated urban development. The floods during August 2006 in Tapi catchment caused great damage to people and property, resulting in 300 people being killed and US$ 4.5 billion worth of property damage. In this paper, geospatial technologies such as remote sensing, GIS, and GPS have been utilised to prepare urban flood hazard maps and to handle entity-specific query and analysis. The research methodology employed is based on statistical probabilities of flood frequency, maximum discharge carrying capacity at river cross-section, mapping of inhabited areas based on high-resolution images, and terrain mapping using global position system. It is estimated that for a mean flood height of 10 m (35-year return period), more than 80% of land in the west and southwest zone will be under flood against 40% in the central, 33% in the northern and 15% in the eastern zones.

study we will extend their methods to delineate flood prone areas under alternate hydro-climatic scenarios.

Surat City has been studied by many research groups having various strengths. In our study, we have taken into consideration all these researches and their findings to bridge the gap, if any, in the best possible manner. The references of some of the major research institutions are:

(a) Nirma University and ISRO, Ahmedabad[20] (The project relevant information of the paper are highlighted in Appendix.). This is the work that we have taken further.

(b) TARU, Gurgaon, India for ACCCRN project. Their experience is an important resource base for us.

(c) SVNIT, Surat: The team is conversant with the problem and database.

(d) CEPT, Ahmedabad: Professor R Parthasarthy has been consultant to Institute of Economic Growth, Delhi to prepare a report on Socio-Economic Scenarios for Surat City for the larger project on Climate Change sponsored by the Ministry of Environment and Forests, Government of India, April – July 2009.

In 2010, *Dr.Desai D. Mahesh & Tailor. M Ravin* analyzed present management approach as available from Literature, Practice and Press reports. The system is based on:

a) prediction of daily inflow (CWC),

b) processing of data and decision making (Gov. of Guj.), and

c) rules for operation of reservoir to meet specified objective.

It does not permit scope for considering changes in environment, floodplain, drainage (due to urbanization), economic analysis of overall national loss against benefits and torture to 3 million people for a month[21].

Agnihotri and Patel (2008) carried out a critical study of the flood in Surat city that wrought heavy devastation during August 5-9, 2006. Ninety percent area of Surat was flooded because of heavy rains and sudden releases from the Ukai dam which is situated at a distance of around 100 km from Surat. Their study of city topography confirmed that the depth of water induced by the flood varied in different parts. Their analysis revealed that the flood was due to the excessive outflow of

[20] GIS and a remote sensing based approach for urban flood-plain mapping for the Tapi catchment, India; Dr Anupam Singh et al

[21] Dr. Mahesh D. Desai & Shri Ravin M. Tailor,2006, Feasibility of tapti basin floods moderation with updated technology and management, retrieved from http://mddesai.com/Paper_2000_2010/6%20-%20IITBombay%20Paper%20-%2016-11-06.pdf

25711.38 m^3/s (9.08 lakh cusecs) from Ukai dam. They suggested preventive remedial measure such as reservoir operation policy, warning system from upstream, water release from the dam etc[22].

Another study undertaken by *Agnihotri and Patel (2008)* was based on 'Preparation of Flood Reduction Plan for Surat City and Surrounding Region'. The research presented the study of floods at Surat City in general and the flood that occurred in 2006 in particular along with a flood reduction plan for the Surat City.

Indian Institute of Tropical Meteorology (IITM) pune studied the vulnerability by considering the Longest possible instrumental area-averaged monthly, seasonal (winter JF, summer MAM, monsoon JJAS and post-monsoon OND) and annual rainfall series have been developed for each of the 11 major and 36 minor basins as well as the west coast drainage system of India using highly quality-controlled data from well spread network of 316 rain gauges. For the period 1901-2005 with complete data of all stations the area-averaged series has been prepared from simple arithmetic mean of the gauges in the particular basin, and for period prior to 1901 (sometimes going back to 1813) with lesser observations the series is constructed by applying established objective method. (Wigley et.al., 1984)[23].

Praful Kumar V. Timbadiya, 2011, used RAS Model on Prediction of Flood for Lower Tapi River. The calibrated model, in terms of channel roughness, has been used to simulate the flood for year 2006 in the river. The performance of the calibrated HEC-RAS based model has been accessed by capturing the flood peaks of observed and simulated floods; and computation of root mean squared error (RMSE) for the inter-mediated gauging stations on the lower Tapi River. On the basis of assessment of topographic features of the lower Tapi River (Ukai dam to Hope Bridge) and simulation of past floods, following findings can be summarized in brief:

1) Topographic assessment of river bed features and simulation of past floods of year 1998 and 2003 for single value of Manning's roughness coefficient, it became evident that different Manning's roughness coefficients are required for upper and lower reaches of the lower Tapi River for simulation of flood.

2) Further, simulation of aforesaid flood for multiple values of Manning's roughness coefficient along the river reach has revealed that a value n = 0.035 up to Kakrapar weir and n = 0.025

[22] Agnihotri P.G and Patel J.N.2011, Improving carrying capacity of river tapi (surat,india) by channel modification, International Journal of Advanced Engineering Technology, IJAET/Vol.II/ Issue II/April-June, 2011/231-238

[23] Ashwini A. Ranade, Nityanand Singh, H.N. Singh & N.A. Sontakke,2007, Characteristics of Hydrological Wet Season over Different River Basins of India, ISSN 0252-1075, Contribution from IITM, Research Report No. RR-119

downstream of Kakrapar weir would be suitable for simulation of future flood in the lower Tapi River[24].

Dhruvesh P Patel, Mrugen B Dholakia in their study of Surat stated that Varekhadi, a group of 26 mini watersheds lead water into river Tapi and the flow takes a small time period to reach near Surat city. Due to which, the city gets flooded once in a 4 to 5 years and losses large amount of property and lives. Present work describes the flood potential of Varekhadi watershed group by application of Soil and Water Assessment Tool (SWAT) model, using Remote Sensing (RS) and Geographical Information System (GIS). In order to minimize the effect of flood, in and around Surat city, feasible structural and non-structural measures are suggested[25].

Some researchers in developed countries have developed standard hydrological modeling packages for analysis of future hydrological scenarios. These packages can be expanded for specific applications. Some of them have interfaces to connect with GIS software. These packages can accept climate parameters of interest as inputs such as historical information of temperature, rainfall, etc at a local/regional scale. The hydrologic variables are stream flow, variation in stream flow due to precipitation in the catchments area, and Ground Water Table, etc. In conjunction with GIS, the climate hydrology analysis results can be connected with land use pattern, city topography, socio-economic characteristics, infrastructure facilities to assess vulnerability.

The hydrological software packages simulate basin level rainfall, runoff, flood, storm water and water quality. Most of theses packages accept climate change, environmental parameters, land use pattern, precipitation in the catchment's area as well as non – point pollution. Some of the available analytical tools for hydrology are SWAT, MIKE SHE, HYSIM, HEC-GeoHMS and/or HEC-GeoRAS.

Patel and Dholakia (2010) have also carried out another research on 'Identifying Probable Submergence Area of Surat City Using Digital Elevation Model and Geographical Information System'. Nehru Bridge was taken as a reference point in order to identify the probable area of submergence as per the zone water level observed near the bridge. The study concluded that if the flood plain again faces the flood of the same frequency as it faced in 2006, then almost 85% of the area would get submerged.

Singh & Sharma (2009) conducted a similar research study on "GIS and a remote sensing based approach for urban flood-plain mapping for the Tapi catchment, India". Their study demonstrated the utility of high resolution geospatial technologies such as remote sensing and GIS combined

[24] Prafulkumar V. Timbadiya, Prem Lal Patel, Prakash D. Porey, 2011, Calibration of HEC-RAS Model on Prediction of Flood for Lower Tapi River, India, Journal of Water Resource and Protection, 2011, 3, 805-811)

[25] Dhruvesh P Patel, MrugenB Dholakia,2010, Feasible Structural and Non- Structural Measures to Minimize Effect of Flood in Lower Tapi Basin, WSEAS TRANSACTIONS on FLUID MECHANICS, ISSN: 1790-5087, Issue 3, Volume 5, July 2010

with field data to delineate flood prone areas. The study was done for the flood that occurred in 2006 in Tapi Catchment Area.

G. I. Joshi & A. S. Patel in 2010 studied in detail, the morphological processes in Tapi River Basin. They also studied presently available mathematical models by proving them for Tapi flood data and to develop an “Optimization Process” to minimize the flood impacts. It is further attempted to validate the model with studies on physical model development with studies on physical model developed/constructed by any Govt. or Semi Govt. organization like CWC, GERI, and CWPRS etc. Subsequent to construction of Ukai dam large urban developments have taken place along Tapi river banks. With the moderation of flood at Ukai reservoir, no major floods were experienced at Surat and Hazira till 1994. During 1994, 1998 and 2006 floods of the order of 14870 m3/s (5.25 lakh cfs), 19820 m3/s (7.00 cfs) and 28315 m3/s (9.10 lakh cfs) were experienced. Large portion of Surat area was inundated along with large scale flooding at Bhata, Bharatpur, Surat, and surrounding areas. There were heavy damages of industrial and urban properties costing 21,000 Crores. This paper presents CHARIMA mathematical model for prediction of water levels in Tapi Creek under influence of flood and tide. This mathematical model is capable of handling unsteady floods in river channel network validated for September 1998 flood situation and then applied for predictions with 28,315 m3/s (10 lakh cfs flood discharge)[26].

Roman U.C.et.al in 2012 said that estimation of rainfall for a desired return period is one of the pre-requisites for any design purposes at a particular site, which can be achieved by probabilistic approach. In his study, six probability distributions such as extreme value type-1 (EV1), normal, lognormal (LN2), gamma, pearson type-3, log pearson type-3 (LP3) are used to fit to annual 1-day maximum rainfall (ADMR) for Atner, Multai and Dharni sites in upper Tapi basin. Goodness-of-Fit tests such as Anderson Darling, Chi-square and Kolmogorov-Smirnov are used to judge the applicability of the distributions for modelling recorded ADMR data. Diagnostic test, involving D-index, is used for selection of suitable distribution for estimation of rainfall for different return periods. The study shows the EV1 distribution is better suited, amongst six distributions studied, for estimation of design storm for Atner while LN2 for Multai and LP3 for DharniThe GoF test results uniformly supported the use of EV1, LN2, G2 and LP3 distributions for modelling ADMR data recorded at Atner and Dharni while EV1 and LN2 distributions for Multai. Diagnostic test results indicated that EV1, LN2 and LP3 are better suited for rainfall estimation for Atner, Multai and Dharni respectively. The study showed that the 1000-yr return period estimated rainfalls of 250 mm, 365 mm and 555 mm could be considered as the design parameter for planning and operation of hydraulic structures at Atner, Multai and Dharni respectively. The study also showed that the

[26] G. I. Joshi A & A. S. PatelB, 2010, Flood Water Surface Profile in Tapi River- Surat, Journal of Rangeland Science, 2010, Vol. 1, No. , 24 / J. of Rang. Sci., 2010, Vol. 1, No. 1

hydrographs derived from the estimated rainfall values could be served as input in the design of storm water drainage systems at the sites under study[27].

Dinesh Kumar (2006) used sea-level rise scenario for calculating the potential vulnerability for coastal zones of Cochin, southwest coast of India, and concluded that climate induced sea-level rise will bring profound effects on coastal zones.

Rajawat et al. (2006) delineated the hazard line along the Indian coast using data on coastline displacement, tide, waves, and elevation.

Pradeep Kumar and Thakur (2007) assessed the role of bathymetry in modifying the propagation of the tsunami wave of 26 December 2004 and concluded that undersea configuration has an important role in enhancing the wave height because some coastal stations on the eastern margin of India have suffered maximum damage wherein bathymetry has shown an anomalous pattern.

Hegde and Reju (2007) developed a Coastal Vulnerability Index (CVI) for the Mangalore coast using geomorphology, regional coastal slope, shoreline change rates, and population. However, they opined that additional physical parameters like wave height, tidal range, probability of storm, etc., can enhance the quality of the CVI.

2.3 IRADe Approach

The impact of climate change on urban areas can be serious. We need to take adaptive measures to strengthen resilience of our cities. This is particularly important as our urban population is expected to increase by hundreds of million in the coming decade. At the same time, the rapid growth of urbanization offers an opportunity to take proactive measures to adapt urban growth to make our cities more resilient to climate change. The local repercussions of climate change are poorly understood. There is willingness by the decision makers to deal with climate induced vulnerability along with other issues and take adaptation measures. Yet one does not find scientific inputs merging into this willingness; provide guidelines on course action on short and long term.

Climate change will lead to increase in average temperature, heat stress, changes in precipitation (quantity, intensity, and pattern), glacial melt, sea level rise, storms, and increased frequency of extreme events, etc. These will impact socio-economics, leading to loss of livelihoods, infrastructure and property damage in affected areas, and hardship for vulnerable communities. Analytical methods are better developed and can be tested in the context of a specific case study. Surat Region, Gujarat is proposed for case study in this project. The

[27] Roman U.C, Porey P.D., Patel P.L and Vivekanandan N., 2012, Assessing Adequacy of Probability Distributional Model for Estimation of Design Storm, *ISCA Journal of Engineering Sciences*, Vol. 1(1), 19-25, July (2012)

hydrology of the region is shaped by Tapi River, Ukai Dam at upstream (~100 Km east) of Tapi River, proximity to sea-shore, and incessant rainfall especially in July.

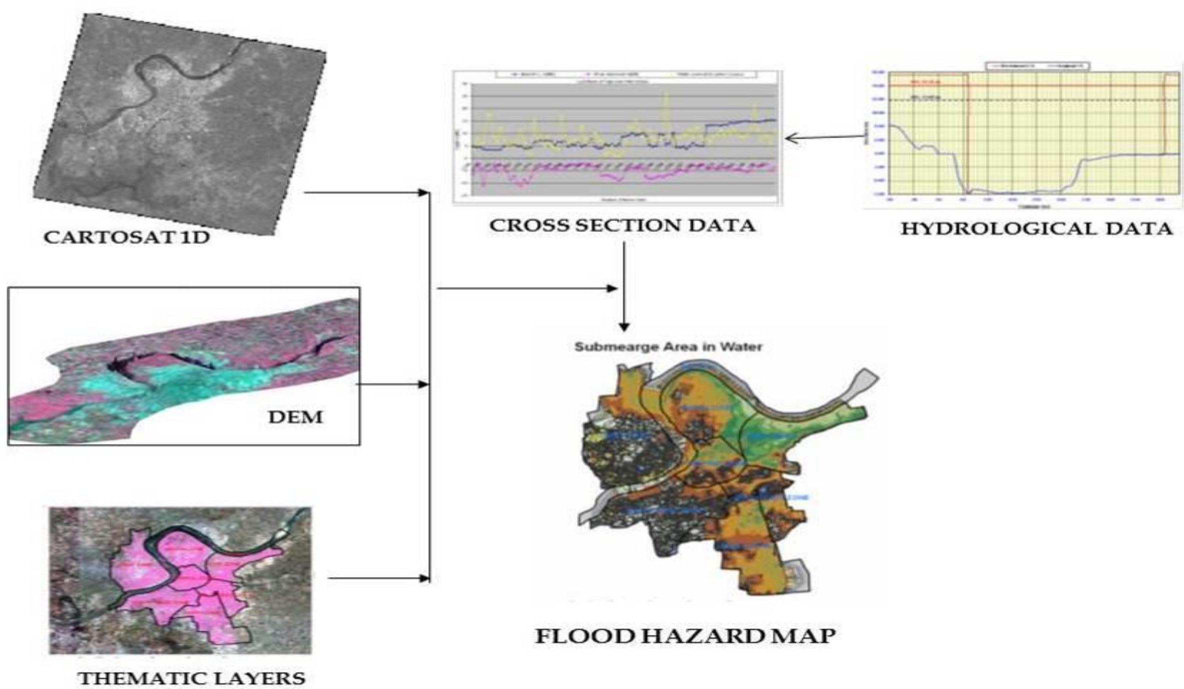
To address these problems for cities on river basins and adjacent to sea coast, hydrology and hydrodynamics of the region has to be understood scientifically in the context of climate change. The extreme events are correlated to major changes in climate. If the probability of extreme events and its magnitude is greater than normal by current standards, then additional adaptation actions have to be planned proactively. The aim is to carry out multidisciplinary analysis facilitated with case study involving collaborating institutions. Research is anchored on applying appropriate model and tools that connect climate change, hydrology, land use, infrastructure related to basic services for vulnerability mapping/ assessment. The output and analysis of appropriate solutions to manage hazards will suggest measures to enhance resilience to climate change. In the process we will augment analytical capability of the stakeholders that helps them to foresee climate variability and change and to assess socio-economic vulnerability to climate change. These will suggest ways to develop climate resilient city and update the "Decision Support System" framework also for initiating action at local, state, and national level involving stakeholders. This will facilitate designing of a resilient development plan that provides proactive safeguards to Climate Change.

The project findings in the case study of Surat city highlight its vulnerability to climate risks due to its geographic location, flood prone topography, large population with a major percentage living a life of poverty in informal settlements, changing land use pattern, rapid infrastructure development often by reclaiming land from sea (as in case of Surat) and inadequate civic amenities. The study has examined the physical, economic and social impacts of selected extreme weather events leading to flood in Surat city. An important finding is that the huge monetary costs of these impacts are the uninsured losses borne by households belonging to poor strata of society and the private sector mostly engaged in informal activities. The study also examines the responses of local government institutions as well as people to cope with flooding. There are a number of public and private adaptation strategies that have been identified in this study. A significant finding is that all private initiatives and responses are a direct out-of-pocket expense for the concerned individuals or establishments. There is virtually no insurance cover that helps them to deal with the adverse impacts of floods and bring about changes or improvements in the existing infrastructure. Some of the public and private responses have the potential to enhance the medium to long-term adaptation capacity of the city to cope with future floods. However, there is a need to address the larger issues of climate risks and adaptation in the long-term development planning for the cities.

The methodology developed and used in the project to identify and analyze the immediate to medium-term impacts and responses of flooding events is expected to improving the understanding of adaptation interventions coming from the government as well as communities. The project will help in enhancing the ministry's initiative in identifying and developing effective methodologies in different areas of global change research and transferring the knowledge base to the scientific community and policy makers. Better characterization of post-event impacts and the recovery process would further help in improving the disaster management interventions. The findings of this project will also help inform the authorities of other Indian coastal cities. This project will also contribute directly to the activities of other climate Network.

2.3.1 Methodological Approach:

Figure2.1 : Methodology for Flood Hazard Mapping for Surat City



The step-wise methodology adopted for generation of flood simulation, flood mapping and zone level flood hazard assessment can be described using below steps;

Step-1: Collection of high resolution remote sensing images for CARTOSAT 1D

Step- 2: Collation of topographical features such as contours, river channel sections, and water level and discharge data,

Step- 3: Inter-linking of spatial and temporal data using GIS software and customized DBMS tools for DEM creation

Step- 4 Generation of thematic maps and

Step- 5: Analysis of results and delineation of areas under various degrees of floods.

The findings of the project are quite relevant for Surat city as well as other coastal cities having more or less similar conditions and which are in transition and on a development path. It is extremely important that these findings are shared with the larger interest of policy makers, academia and local community to initiate a meaningful dialogue on climate risks, general perceptions about the adaptive capacity and how adaptation can be mainstreamed in these policy processes. Therefore, the study will help further in policy formulation, especially the formulation of city development plans to understand how climate risks and adaptation can be incorporated into these plans to make cities climate change resilient and minimum damage to cities vulnerable sections.

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CHAPTER 3: SURAT: CITY PROFILE

3.1 Introduction

Surat city is located at a latitude of 21.0° to 21.23°15 North and longitude of 72.38° to 74.23° East on the bank of Tapi River. It has about 6 km long coastal belt along the Arabian Sea and therefore serves as an important trade centre. The river Tapi is merging to the Arabian Sea at about 15kms away from Surat City. The city of Surat is the commercial capital of the state and is of significant importance to the country. It is located at the mouth of Gulf of Khambhat and therefore experiences a tidal range of about 5-6 m.

Figure 3.1: Map showing location of Surat

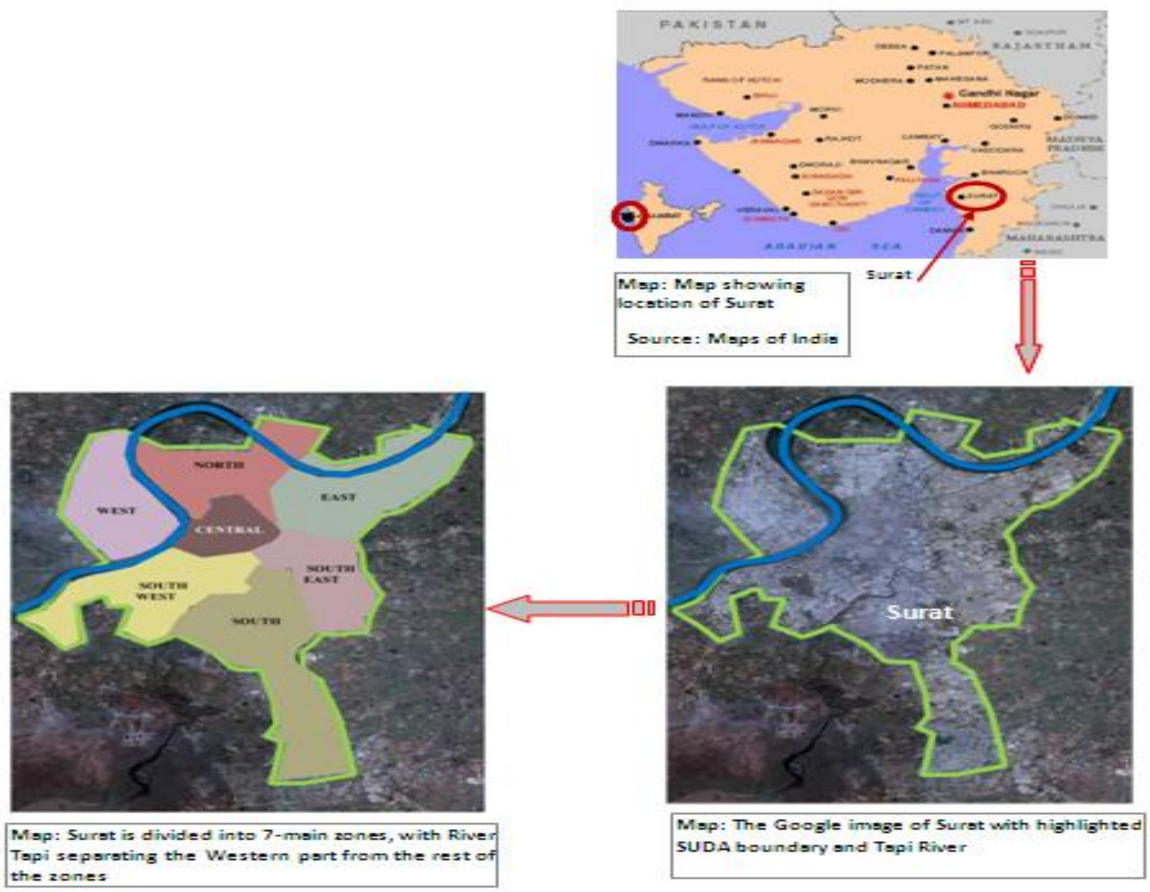
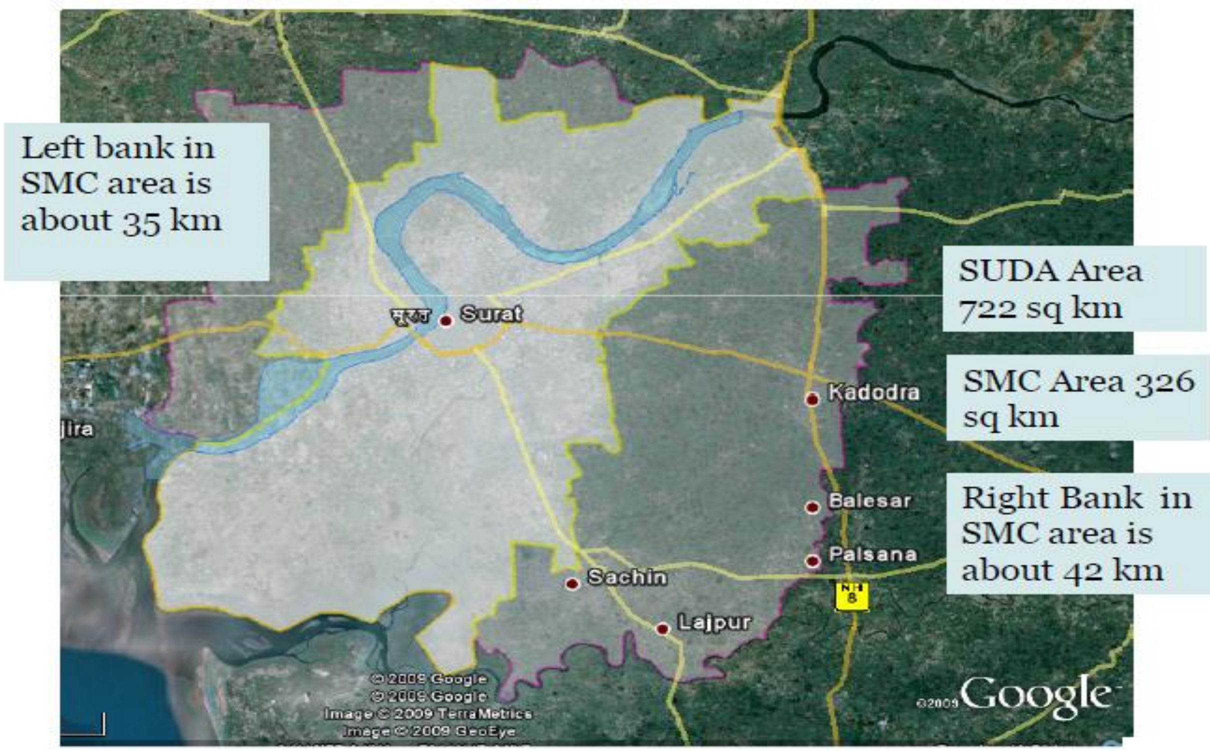


Table 3.1: Surat City at a glance

S. No.	Category	Figures
1.	SMC Area (sq.km)	326 sq Km
2.	Population	4.46 Million (As per 2011 Census)
3.	Population Density	13,662 persons per sq. Km
4.	Zones	7
5.	Average rainfall (mm)	1000-1200 mm
6.	Rivers	Tapi
7.	Dams	Ukai, Kakrapar Weir

Source: SMC, Surat

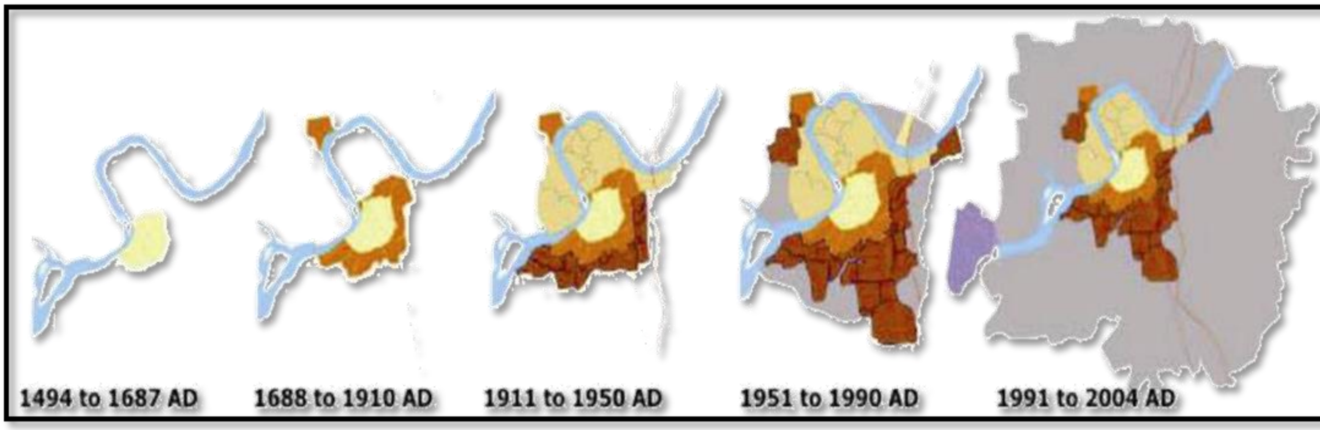
Figure 3.2: Map showing Surat City Boundary



3.2 History

The city of Surat has glorious history that dates back to 300 BC. The origin of the city can be traced to the old Hindu town of Suryapur, during 1500 – 1520 A.D., which was later colonized by the Brigus or the King from Sauvira on the banks of River Tapi. Surat has experienced considerable growth in industrial activities (especially textiles) along with trading activities. Concentration of these activities combined with residential developments has resulted in considerable expansion of the city limits. Prior to 1961, Surat's area was only 8.12 sq. km., while in 2009 it had expanded to 326.5 sq. km. The city was originally established on the southern bank of the River Tapi with a castle on the eastern bank of the river.

Figure 3.3: Surat Growth Map



Source: Surat, Trans -Vision 2030

3.2.1 Commercial Importance

The city of Surat is the commercial capital of the state and is of significant importance to the country. The city is a pivotal centre on the Ahmedabad-Mumbai regional corridor as well as on the 225 km long industrial belt (Surat CDP, 2006-12).

3.3 Physiographic Aspect

Surat has a tropical savanna climate, moderated strongly by the Arabian Sea. The summer begins in early March and lasts till June. April and May are the hottest months, the average maximum temperature being 40°C. Monsoon begins in late June and the city receives about 1,000 mm of rain by the end of September, with the average maximum being 32°C during those months. October and November see the retreat of the monsoon and a return of high temperatures till late November. Winter starts in December and ends in late February, with average temperatures of around 23°C, and little rain.

3.3.1 Temperature

The summers are quite hot with temperatures ranging from 37.78°C to 44.44°C. The climate is pleasant during the monsoon while autumn is temperate. The winters are not very cold but the temperatures in January range from 10°C to 15.5°C.[28]

3.3.2 Rainfall

The average annual rainfall of the city has been 1143 mm.

[28] http://www.suratmunicipal.org/content/city/weather_main.shtml

Table 3.2: Annual Rainfall in Surat City

ANNUAL RAINFALL (1990 TO 2007)			
Year	**Seasonal Rainfall (mm)**	**Highest Rainfall (mm)**	**Date of Highest Rain**
2007	76.22	6.29	27/07/2007
2006	**55.62**	**6.71**	**28/07/2006**
2005	74.46	8.07	27/06/2005
2004	77.31	13.01	2/8/2004
2003	68.12	6.57	20/06/2003
2002	44.57	4.68	26/06/2002
2001	46.5	3.84	16/06/2001
2000	30.92	3.92	6/7/2000
1999	73.56	7.76	19/07/1999
1998	56.39	4.36	6/7/1998
1997	40.6	3.74	6/23/1997
1996	44.67	8.19	7/20/1996
1995	54.28	8.63	7/18/1995
1994	82.5	9.68	7/21/1994
1993	52.43	7.55	6/24/1993
1992	85.4	15.78	9/2/1992
1991	32.48	3.75	7/18/1991
1990	42.32	5.67	8/17/1990

Source: SMC

Table 3.3: Year wise Monthly Rainfall (2002-2008)- (mm)

Year		2008	2007	2006	2005	2004	2003	2002
Jan	In/D	--	--	--	--	--	2.12	--
	M.M.		--	--	--	--	53.9	--
Feb	In/D	--	0.29	--	--	--	--	--
	M.M.		7.6	--	--	--	--	--
Mar	In/D	--	--	--	--	--	--	--
	M.M.	--	--	--	--	--	--	
Apr	In/D	--	--	--	--	--	--	--
	M.M.	--	--	--	--	--	--	
May	In/D	--	--	0.45	--	--	--	--
	M.M.		--	11.6	--	--	--	--
June	In/D	14.94	7.16	12.44	37.7	16.77	19.47	16.38
	M.M.	380.8	182.2	316.7	958.8	426	494.5	415.4
Jul	In/D	16.59	21.16	29.05	15.97	20.88	26.7	1.88
	M.M.	424.4	538.2	739.2	406.5	529.4	678.2	47.6
Aug	In/D		26.38	10.12	10.34	33.76	13.3	21.93
	M.M.		672.4	259	263.5	857.5	337.5	555.6

Sep	In/D		19.52	2.47	10.45	2.73	6.28	4.38
	M.M.		498.4	63.6	265.2	69.2	159.6	111.2
Oct	In/D		--	0.7	--	3.15	0.25	--
	M.M.		--	18	--	80.1	6.3	--
Nov	In/D		1.71	0.39	--	--	--	--
	M.M		41.8	10	--	--	--	
Dec	In/D		--	--	--	--	--	--
	M.M.		--	--	--	--	--	--
TOTAL	**IN**		**76.22**	**55.62**	**74.46**	**77.31**	**68.12**	**44.57**
	M.M.		**1940.6**	**1418.1**	**1894**	**1962.2**	**1730**	**1129.8**

Source: SMC

Table 3.4: Year wise Monthly Rainfall (1995-2001)- (mm)

Year		2001	2000	1999	1998	1997	1996	1995
Jan	In/D	--	--	--	--	0.37	0.61	--
	M.M.	--	--	--	--	9.4	15.5	--
Feb	In/D	--	--	--	--	--	--	--
	M.M.	--	--	--	--	--	--	--
Mar	In/D	--	--	--	--	--	--	--
	M.M.	--	--	--	--	--	--	--
Apr	In/D	--	--	--	--	0.47	--	--
	M.M.	--	--	--	--	12	--	--
May	In/D	1.88	0.1	--	--	0.29	--	--
	M.M.	47.6	2.5	--	--	7.4	--	--
June	In/D	17.17	4.01	8.27	3.78	14.6	6.77	--
	M.M.	436.3	101.8	209.9	96	380.8	172	--
Jul	In/D	15.59	18.66	14.98	24.46	8.89	25.89	43.43
	M.M.	396.1	474.2	380.7	621.2	225.6	657.9	1105.4
Aug	In/D	10.52	7.52	3.67	12.63	12.25	6.99	5.21
	M.M.	269.2	191.3	93.6	320.8	311.2	177.4	130.8
Sep	In/D	1.02	0.23	4.17	11.25	3.99	1.42	4.28
	M.M.	25.7	5.8	105.8	286	101.6	36.1	108.6
Oct	In/D	0.22	--	6.47	3.5	0.04	3.17	0.75
	M.M.	5.6	--	164.2	89	1	77	19.1
Nov	In/D	--	--	--	0.77	--	--	--
	M.M.	--	--	--	19.6	--	--	--
Dec	In/D	--	0.4	--	--	0.07	--	--
	M.M.	--	10.2	--	--	1.8	--	--
TOTAL	**IN**	**46.5**	**30.92**	**37.56**	**56.39**	**40.6**	**44.3**	**53.67**
	M.M.	**1180.5**	**785.8**	**954.2**	**1432.6**	**1031.4**	**1125.4**	**1363.9**

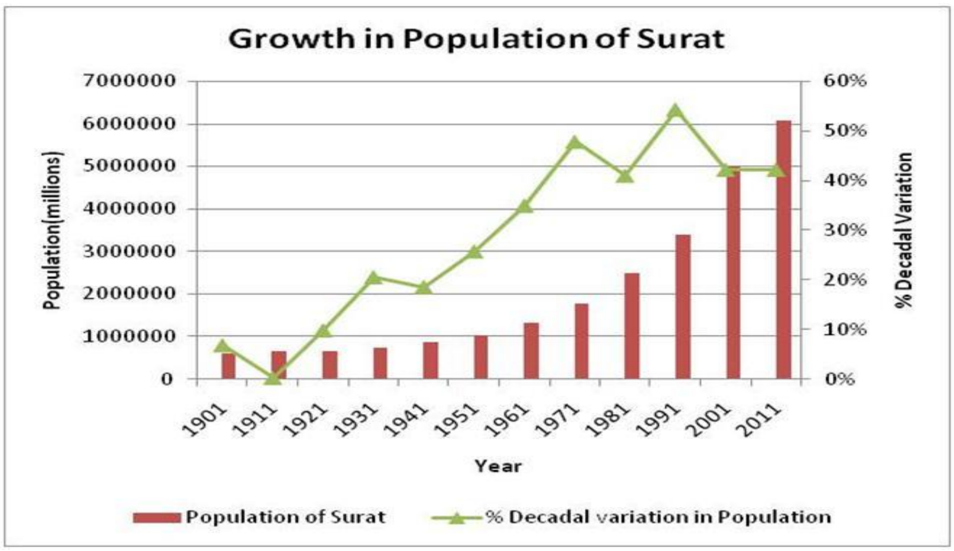
Source: SMC

3.4 Socio-economic Status

3.4.1 Demographic Features

Surat is India's eighth and Gujarat's second most populous city after Ahmedabad.[29] It became a metropolis in 1991, along with eleven other major cities across the country, by crossing with the population of more than one a million-population mark. Surat has experienced very rapid population growth during the last 20 years. This rapid growth in a very short time span is actually the hallmark of Surat's demographic trends (Surat CDP, 2006-12).

Figure 3.4: Population Growth in Surat from 1901 to 2011

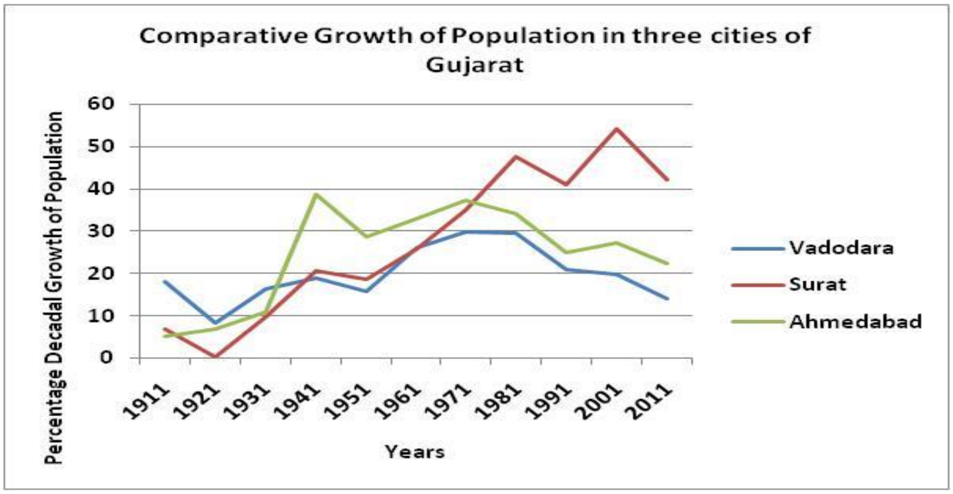


Source: http://www.suratmunicipal.org/content/city/stmt9.shtml; http://censusindia.gov.in/2011-prov-results/prov_data_products_gujarat.html

The city has been experiencing rapid growth in population during past three decades, which is clear from the comparative graph given below depicting the population growth in three cities of Gujarat. Among the three cities i.e., Vadodara, Surat and Ahmedabad; Surat shows a significant growth in population over the years.

[29] Census of India (2011)

Figure 3.5: Growth of population in three cities of Gujarat



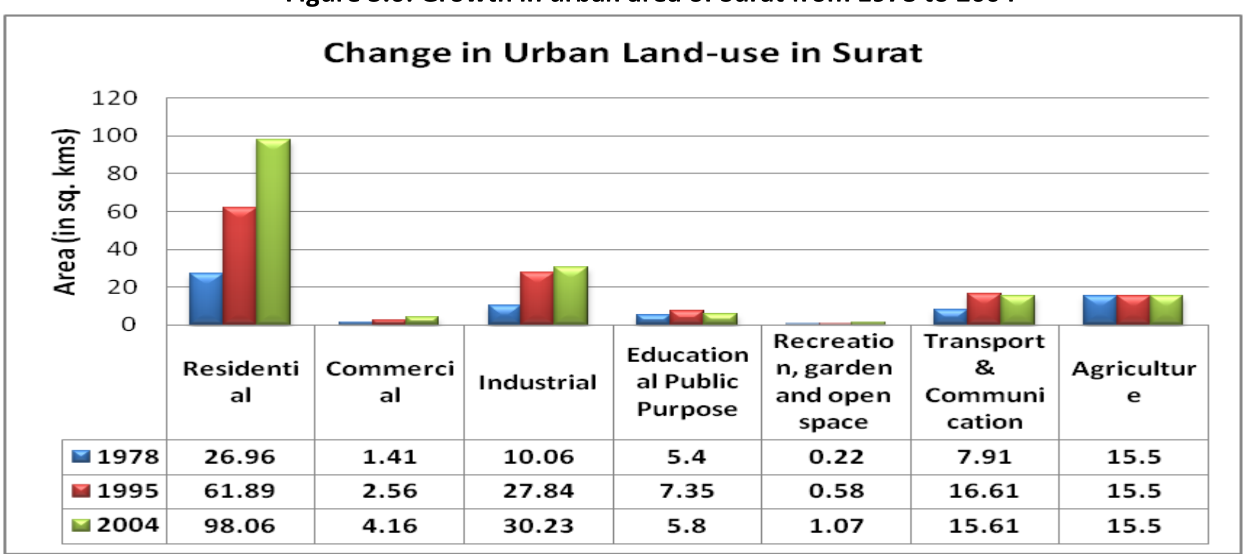
Source: http://censusindia.gov.in/2011-provresults/prov_data_products_gujarat.html

3.4.2 Change in land use pattern

Surat city has witnessed a rapid growth and development after 90’s wherein extensive parts of residential localities were developed under the SUDA area[30].

The total area under Surat Urban Development Authority (SUDA) is 722 sq. km. It is clear from the figure that the urban area in the city has shown an increase over a period of 36 years. The percentage of residential area has increased considerably from less than 50% in 1978 to more than 50% in 2004. Industrial area is also on increase since 1978. The area for transport and communication increased after 1978, but remained more or less same after 1995.

Figure 3.6: Growth in urban area of Surat from 1978 to 2004

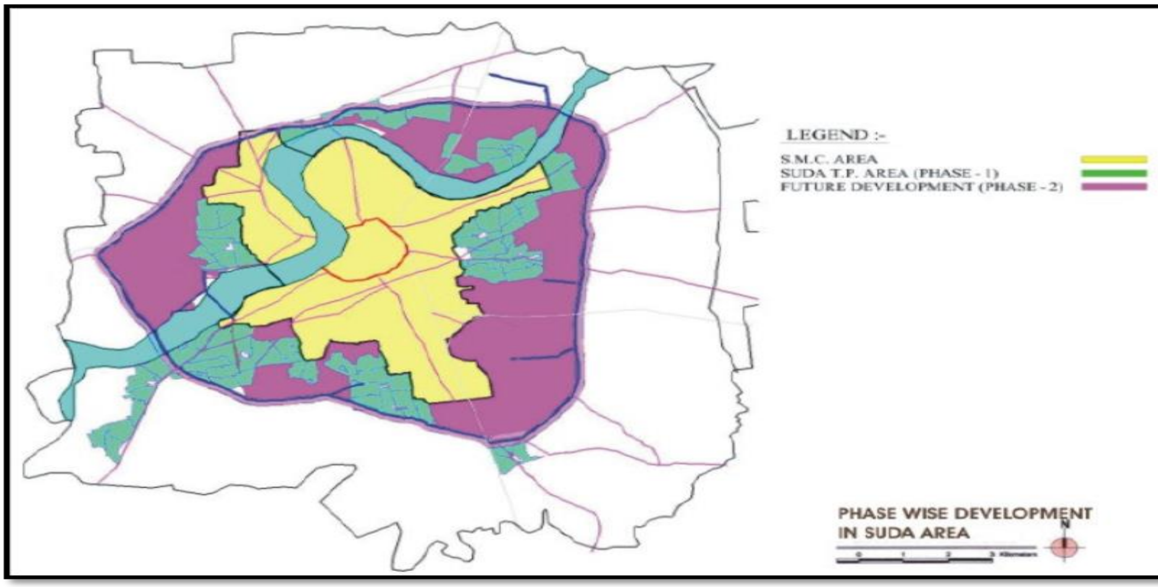


	Residential	Commercial	Industrial	Educational Public Purpose	Recreation, garden and open space	Transport & Communication	Agriculture
1978	26.96	1.41	10.06	5.4	0.22	7.91	15.5
1995	61.89	2.56	27.84	7.35	0.58	16.61	15.5
2004	98.06	4.16	30.23	5.8	1.07	15.61	15.5

[30] City Development Plan (2006-2012), Chapter 3: Urban Planning and Growth Management

Source: Adapted from City Development Plan (2006-2012)

Figure 3.7: SUDA area – Phased wise development

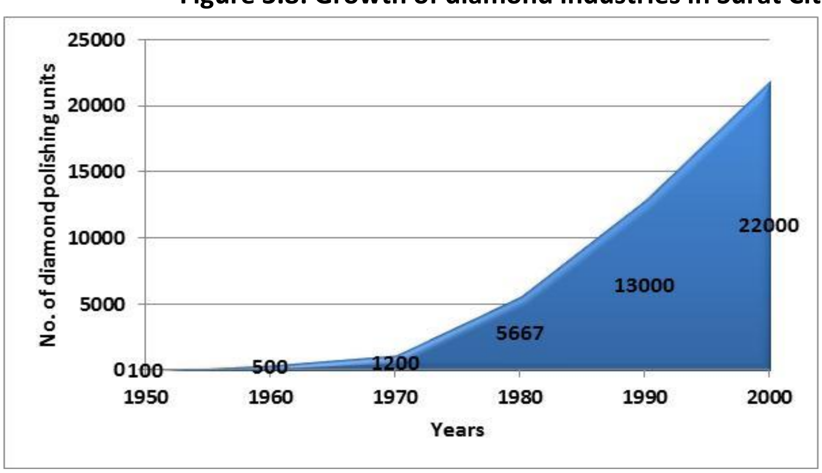


Source: Surat City Development Plan (2006-12: 19)

3.4.3 Industrial Development

Industrial development in Surat district could be attributed to the presence of a large number of diamond processing, textiles and chemical & petrochemical industries. During 2006-07, Surat contributed a maximum of 11.5% of Gross Domestic Product (GDP) to the State, as compared to any other district of India. There are about 6,500 diamond polishing units in Gujarat, employing about 0.7 million people. Out of these, 38% of the units and 57% of the workforce are located in Surat (RBI, 2009). More than 1.5 million people are directly or indirectly dependent on the diamond cutting and polishing industry of Surat (SCRS, 2011).

Figure 3.8: Growth of diamond industries in Surat City



Surat CDP, (2006-12: 10)

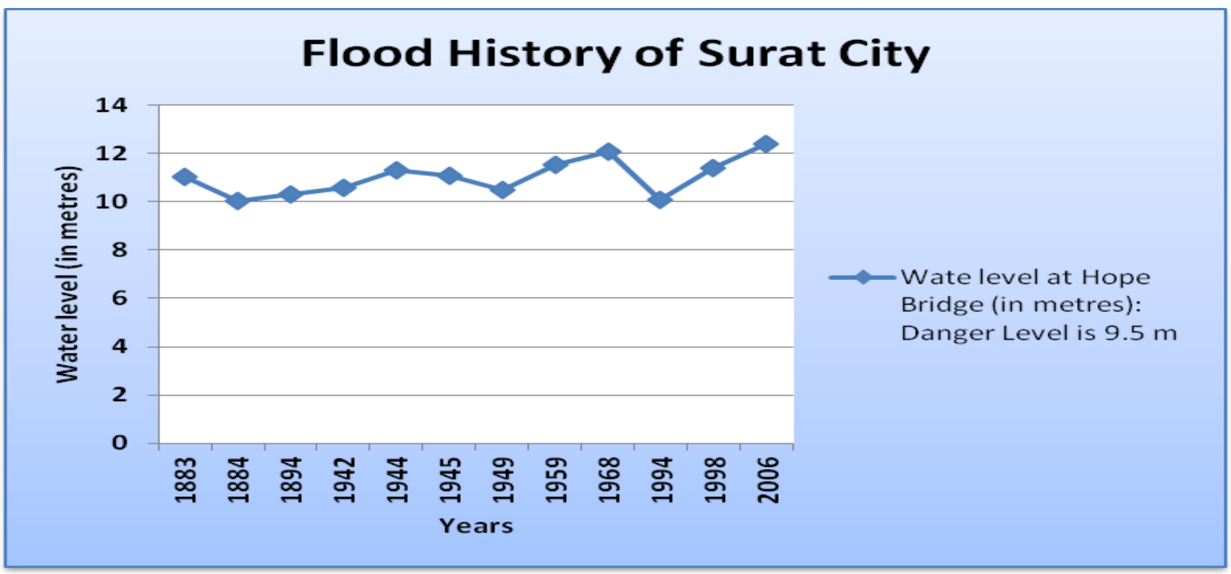
3.5 Disaster Profile of the city

Very often heavy monsoon rain brings floods in the Tapi basin area. In last two decades, the city has witnessed major floods every four years, the worst being the flood of August 2006, perhaps the costliest in the city's history. In the second week of August 2006, a massive flood caused severe damage to the city of Surat. According to a report released by Indian Institute of Management – Ahmedabad (IIM-A), massive flood after release of water from Ukai Dam had caused major human tragedy and property damage estimated at Rs 220 billion on that day. In less than three days, at least 150 people died directly due to flood and many others due to water-borne diseases that followed. More than 1500 animal carcasses were later hauled out of the mud.[31]

3.5.1 Flood frequency

Surat City has got affected by many devastating floods since past several years *(Table 1).* These flood events resulted in both economic and humanitarian losses. It can be clearly seen from the graph that the frequency of floods in Surat city show a considerable variation in their occurrence.

Figure 3.9: Flood History of Surat City



Source: Agnihotri & Patel (2008)

The 1968 flood had been the biggest flood witnessed so far and had a highest flow of about 42,475 cumecs (1.5 million cusecs). Water level at Hope Bridge, Surat reached 12.01 m. With this in mind, the Ukai dam, located about 100 km upstream of Surat, was completed in 1972. The major purposes of the dam being essentially irrigation, power generation and partial flood control. However, heavy Rainfall in the catchment area of Ukai Dam in the upstream (mainly in Maharashtra) which leads to heavy inflow in the Ukai Dam has often resulted in heavy discharge of

[31] "IIM-A Report on Flood". IIM-A. Retrieved 2008-07-06.

water from the Ukai Dam, responsible for flooding in Surat in the past 20 years. This is largely caused by the competing objectives of the Ukai dam, which designed mainly for irrigation and power generation with partial flood control. To meet the first two objectives, the dam has to be able to hold as much water as possible leaving a limited cushion for flood control, especially during the later parts of the monsoon. The floods of 1998, 2004 and 2006 occurred following emergency discharges from Ukai dam. Out of these years, floods of August 2006 remained devastating for Surat in terms of the extent of damage, during which nearly 75% of the city was inundated. Anthropogenic changes including building of bridges, embankments and the Singanpore weir have reportedly increased the siltation and reduced the carrying capacity of the river channel, as evident from the increasing flood levels for the similar amount of the discharge over last few decades (Flood Risk Management Study, Centre for Social Studies. 2009)

3.6 Vulnerability of the City to Climate Change:

The climate model indicates that precipitation is likely to increase in the region along with increase in frequency of extreme events. The city lies towards northern most part of the western coastal humid zone, and arid zone is only few hundred km towards north. Slightest deviation in climate either ways is likely to impact Surat, which already falls under flood risk prone zone. Surat lies in a flat terrain at an altitude about 10 m above the mean sea level. Sea level rise of even couple of meters will shift the tidal zone towards the city which can worsen the flood situation.

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Surat, Trans -Vision 2030

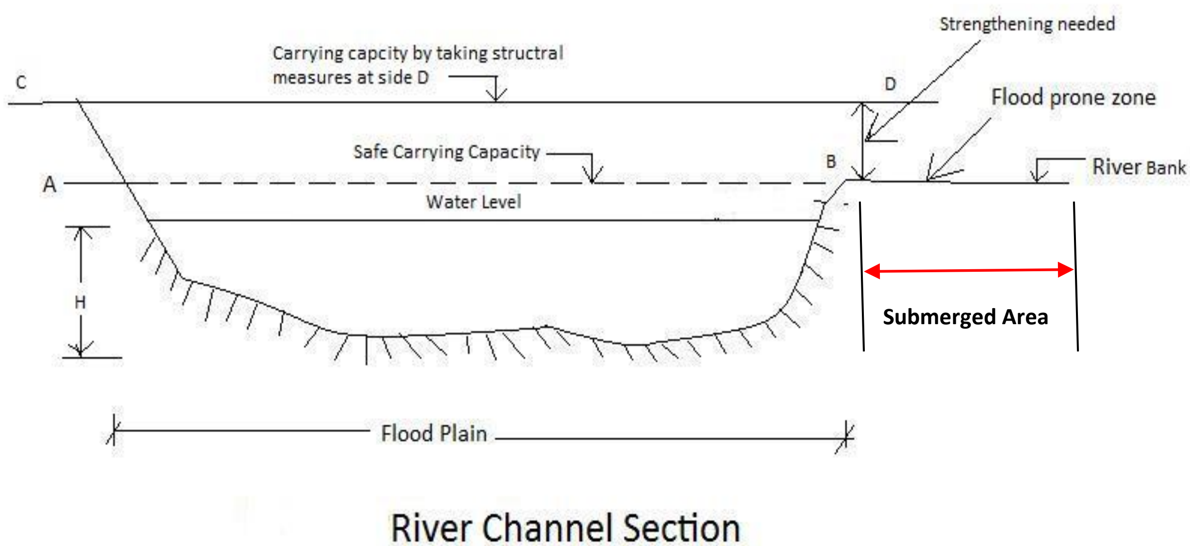
PART II: CLIMATE VULNERABILITY DUE TO FLOODS

CHAPTER 4: CARRYING CAPACITY OF RIVER TAPI AT SURAT

4.1 Introduction

Carrying capacity of a river section can be defined as “the capacity of the river to handle the maximum water discharge without causing the damage to the nearby areas”. The significance of river carrying capacity can be attributed to estimation and mapping of flood prone areas. For example, if the carrying capacity of a river or part of the river is higher than the discharge then there is no flood. Whereas, if the carrying capacity is lower than the discharge occurred at given section or part of river then the bank over spilling will occur resulting into flood. The area coverage of such flood will depend upon excess volume of water spilling from the river channel and elevation of the area. The extent of the area under submergence for a given flood event indicates its impact.

Figure 4.1: Cross section of River Bed and Floodplain



Tapi basin has been associated with recurrent floods, which in turn affected the growth and urban dynamics of Surat city- a regional business hub in Gujarat state. This chapter will cover basic concept, data used for calculating carrying capacity, step-by-step procedure for methodology used, analysis being carried out for lower Tapi basin and in particular for Surat city, and finally significance of carrying capacity for Surat city.

Figure 4.1 shows the conceptual representation of the river bed, river bank, flow depth (h), river carrying capacity and flood plain. It is to be noted that there is clear difference between two river banks ends (right bank and left bank) levels which in term helps in estimating the carrying capacity of the river sections. The banks having the less safe flow height as compare to other side can be more flood prone and high flood vulnerability. Let us consider a case, where if the water level in this river channel increases above lower side of river bank, the water will be getting overflowed to the river bed (called flood). The safe water level which does not overflow from the river channel is called safe carrying capacity of the river channel. In short, the carrying capacity for the river channel as shown in Fig 4.1 is the safe discharge (volume per time) of water up to water line AB. The line CD indicates the line of maximum carrying capacity at river section 1-1 with necessary structural measures by strengthening river bank.

4.2 Hydrological Analysis on Carrying capacity for Tapi River

4.2.1 Data requirements for carrying capacity:

As depicted in Fig 4.1 above, the carrying capacity of a river depends on cross-section (length, width, depth) of the river, river slope and mean flow velocity in the river. The carrying capacity should be calculated at various points along the river. This is important to know the sections where flood vulnerability is high, or sections where engineering interventions are required, or areas where social groups at large are under threat.

The analysis carried by Singh et al (2009) for lower Tapi basin indicates varying degree of carrying capacity. It shows that the accuracy of the carrying capacity estimate depends on the accuracy of the input data as water level, river depths from hydrographic survey, and flow velocity in the river measured using current meter. Utmost care needs to be taken so that the value of the river carrying capacity will be accurate. This research suggests that the data should have following quality:

1. Cross section locations should be selected very accurately and at regular interval for entire river length including in urban area and rural settlements.

2. Special cross-sections should be considered at permanent landmarks locations including bridge, electrical high tension lines, communication towers, and temples for measuring cross-sections.

3. At locations such as sudden change in the river width, places of river meandering, excessive curves in the river points should be at shorter intervals. In general, river cross-sections each 200-300m will be appropriate for a river length of 100-150km.

4. The depth data of the river cross-section in perpendicular direction should be selected at regular interval in such a way that it can represent the actual profile of the cross section. In general, for a river width of 600-750m an interval of 10m can be considered as appropriate.

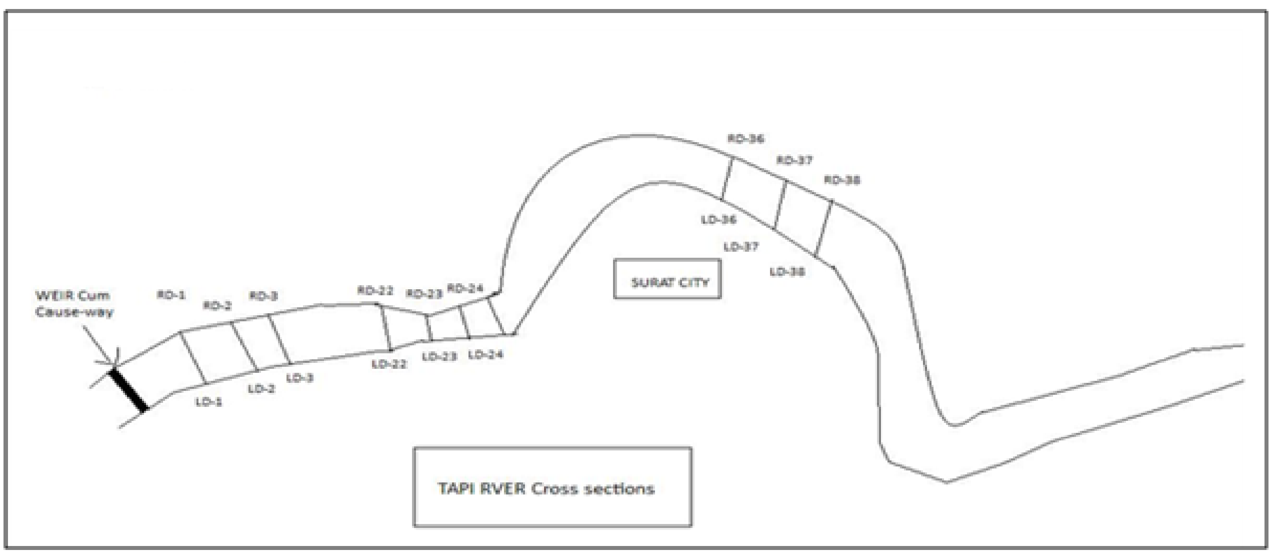
5. The depth reading should be noted very accurately and width of the river should be also measured accurately. River hydrographic survey forms a major part of this exercise and should be carried out using sounding methods. A detailed description on hydrographic survey using sounding method is given in section 4.2.3 below.

Table 4.1 below describes the parameters and data needs for calculation of river carrying capacity.

Table 4.1: Parameters and data needs for calculation of carrying capacity

Sr	Parameter	Data needed to find parameter
1.	Area	Reduced levels for each cross-section using hydrographic survey
2.	Perimeter	Width of river cross-sections and reduced levels for cross sections using AutoCAD and excel software
3.	Slope	Reduced level at every consecutive cross section and length between 2-consecutive sections of the river
4.	Roughness	River roughness coefficients are being considered from table based river properties
5.	Velocity	Calculate using hydraulic radius (function of area and perimeter), Slope, and Roughness coefficients

Figure 4.2: Part of river cross-sections and data being collected for Surat city



The data collection process carried out for lower Tapi basin can be summarized as below. The cross sections along the river at regular intervals, designated as RD-1, RD-2, RD-3……. at right side of the river and corresponding intervals at left side as LD-1, LD-2, LD-3….. have been depicted in the map as Fig 4.2 which was surveyed earlier.

The followings data were collected from Surat Municipal Corporation data archive/ cell. A detailed description on data types, data properties, and data interval etc has been listed in Table 4.2.

Table 4.2: Description of data types and data properties

S No	Name of Data	Interval	Remarks	Source
1.	River cross-sections data (which is mentioned as RD-1/LD-1 to RD-76/LD-76 from weir to Magdalla and RD-6 to RD-54 from weir to Kamrej) along the entire river length between Ukai dam and Hazira including river stretches in Surat city	Each 200m along the river	Very unique data base, good data quality, sufficient horizontal interval, reliable data for carrying capacity analysis	Surat Municipal Corporation, Hydraulic Division (2011)
2.	Reduce level data across the river width for all the sections as discussed in Sr-1 above	Each 10m interval across the river width	Accurate reduced levels and reliable for analysis	Surat Municipal Corporation, Hydraulic Division (2011)

The above data authorized by SMC are very useful to find out various parameters for the carrying capacity of River cross sections.

4.2.2 Survey requirements for carrying capacity:

To take the readings of the cross profile of the river, hydrographic survey is to be held. The hydrographic survey is to find the horizontal reading (width) of the river and vertical depth measurement at regular interval.

There are so many methods to do the hydrographic survey like Theodolite and DGPS and sounding system methods. These are described in Annexure 4.1.

4.3 Methodology For River Carrying Capacity

The flow in river is governed by open channel flow theory and methods for calculation of carrying capacity of the river follow these fundamental principles. Chezy's and Manning's formula are two most common equations for calculation of discharge in an open channel. However, due to popularity, we will use Manning's equation to calculate average cross-section velocity flow in open channels.

Let us assume that A, P, s, R(=A/P) are area, perimeter, slope and hydraulic radius of a trapezoidal channel. The mean flow velocity (v) can be written as;

$$v = \frac{1}{N} R^{2/3} s^{1/2} \text{ .... (1)}$$

If A is the area of cross-section then channel discharge (Q) can be written as;

$$Q = v.A = \frac{1}{N} R^{2/3} s^{1/2}.A \text{ .... (2)}$$

Thus, the channel discharge for highest flow can be described as carrying capacity of the river cross-section. Therefore, it employs calculating river carrying capacity for each cross-section whose data are available.

The methodology used for calculation of river carrying capacity has been described below;

Step 1: Data provided for the River cross section is in the AutoCAD format, which cannot be used directly to calculate cross section carrying capacity and it is not supported by GIS database or in Excel. And hence the first step is to input the data manually from AutoCAD to excel sheet.

In excel sheet, all the cross sections are mentioned column wise and all the reduce levels for each cross section are entered row wise below to particular cross section.

Step 2: Calculation of each cross section area using reduce level entered manually.

There are total 130 cross sections in the Surat city (from weir to Magdalla 76 c/s and from weir to Kamrej 54 c/s). Data contain horizontal measurements (Chainage) as well as vertical height measurements (reduce levels).

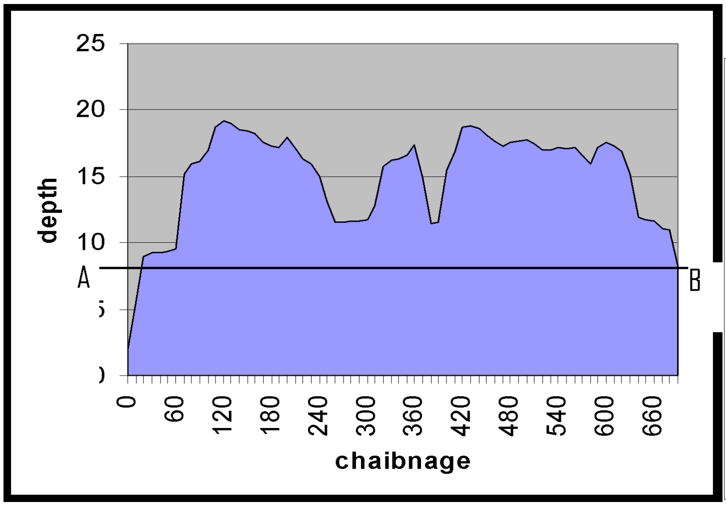
Area can be calculated by using 'Area under curve method' using simple geometry discussed below.

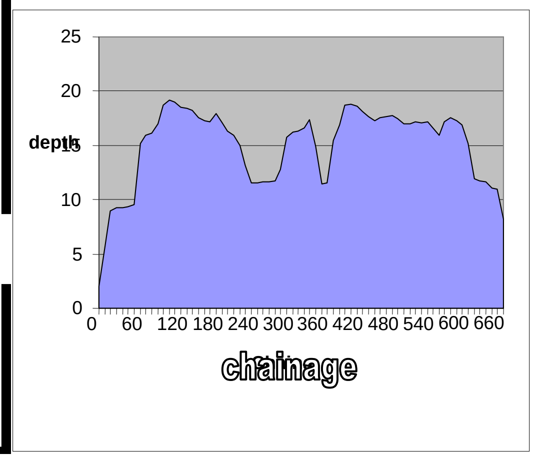
- First task is to find out the max. Height for the point from all the reading of cross sections across the river.
- According to that height calculation of the depth for all the points (at 10m interval) and generation of the depth area graph.
- Calculation of the area under this graph would be the area of whole cross section. But there are cases in SURAT where, one river bank falls short as compare to another river bank. So taking the whole area under curve is not significant, because water can be safely stored up to the shorter end of the river bank. So in the calculation, area up to shorter end should be calculated. So the significant area of cross section would be:

Area under curve – area below the shorter end

The figure 4.3 below shows the river cross section having one end shorter than another. So area should be calculated up to line AB.

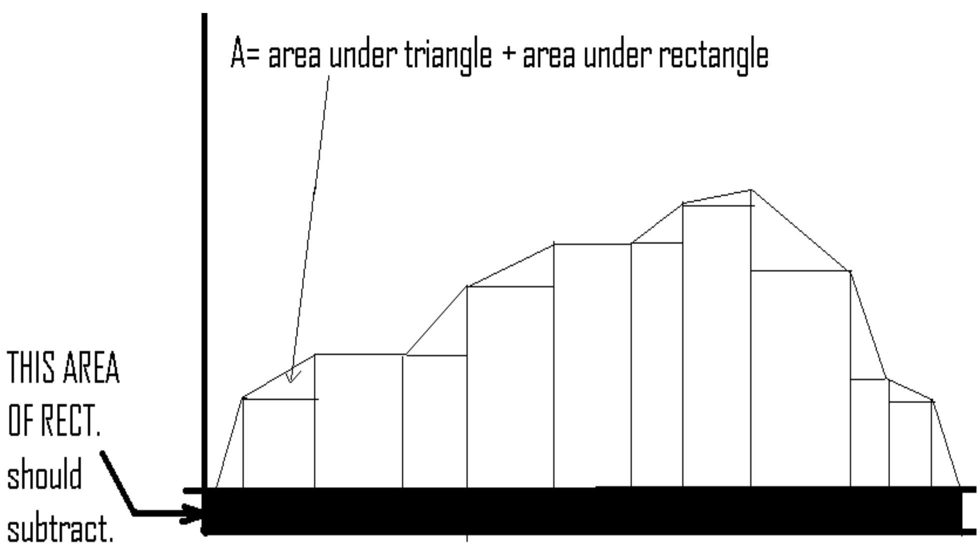
Figure 4.3: Depth area graph and the area under curve up to shorten end





Area under curve, up to line AB (in fig: 4.4) can be find out by simple geometrical rule shown below. We have reading at each 10m interval. And we assume that the line between two points is straight.

Figure 4.4: Area under curve calculation



As the figure 4.4 shown the area under curve should be combine summations of area of triangles and area of rectangles. So area under curve is the summation of area of total triangles in the curve and the summation of area of all the rectangles included in the depth graph of cross sections.

Area of triangles = ½ * base * height

Area of rectangles = length * width

Step 3: calculation of the slope (S) and hydraulic radius (R)

Relative slope for each cross section is the ratio of difference between two consecutive cross sections to the distance between two consecutive cross sections. Difference between two cross section has been calculated in excel sheet in each row for each cross section. And distance between two cross section are approx. 200m. So the slope can be finding out by ratio of elevation difference to the distance for each cross section.

Hydraulic radius (R) is the function of area of the cross section and the perimeter of the cross section. And R is defined as the ratio of area to the perimeter of cross section. Perimeter of the cross section has been found out by combination of Excel and AutoCAD. The ratio of each cross section area to the perimeter of each cross section in the excel row gives the Hydraulic radius for each cross section.

Step 4: After finding all the parameters separately in excel, those values have been substitute in the manning's formula discussed above. The output value of the manning's formula will be the mean velocity at the cross section. And the mean velocity in multiplication with the cross section area will give the carrying capacity of the cross section.

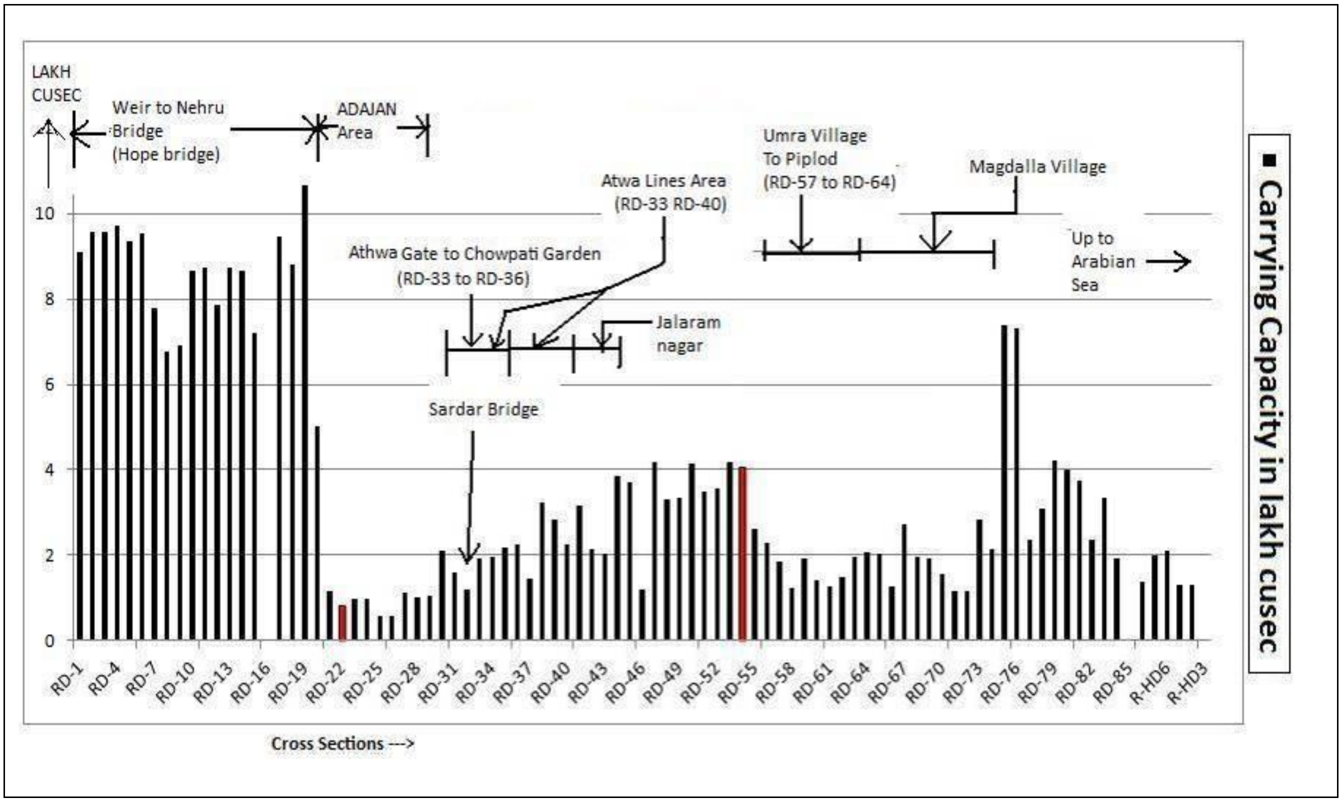
4.4 Outputs and Analysis

4.4.1 Carrying capacity

For the TAPI River cross sections, area is varying vastly for various cross sections from Magdalla to Weir and from Weir to Kamrej.

The carrying capacity for various cross sections from weir to Magdalla has been generated and it gives the following result for the carrying capacity.

Figure 4.5: Cross sections carrying capacity from weir to Magdalla



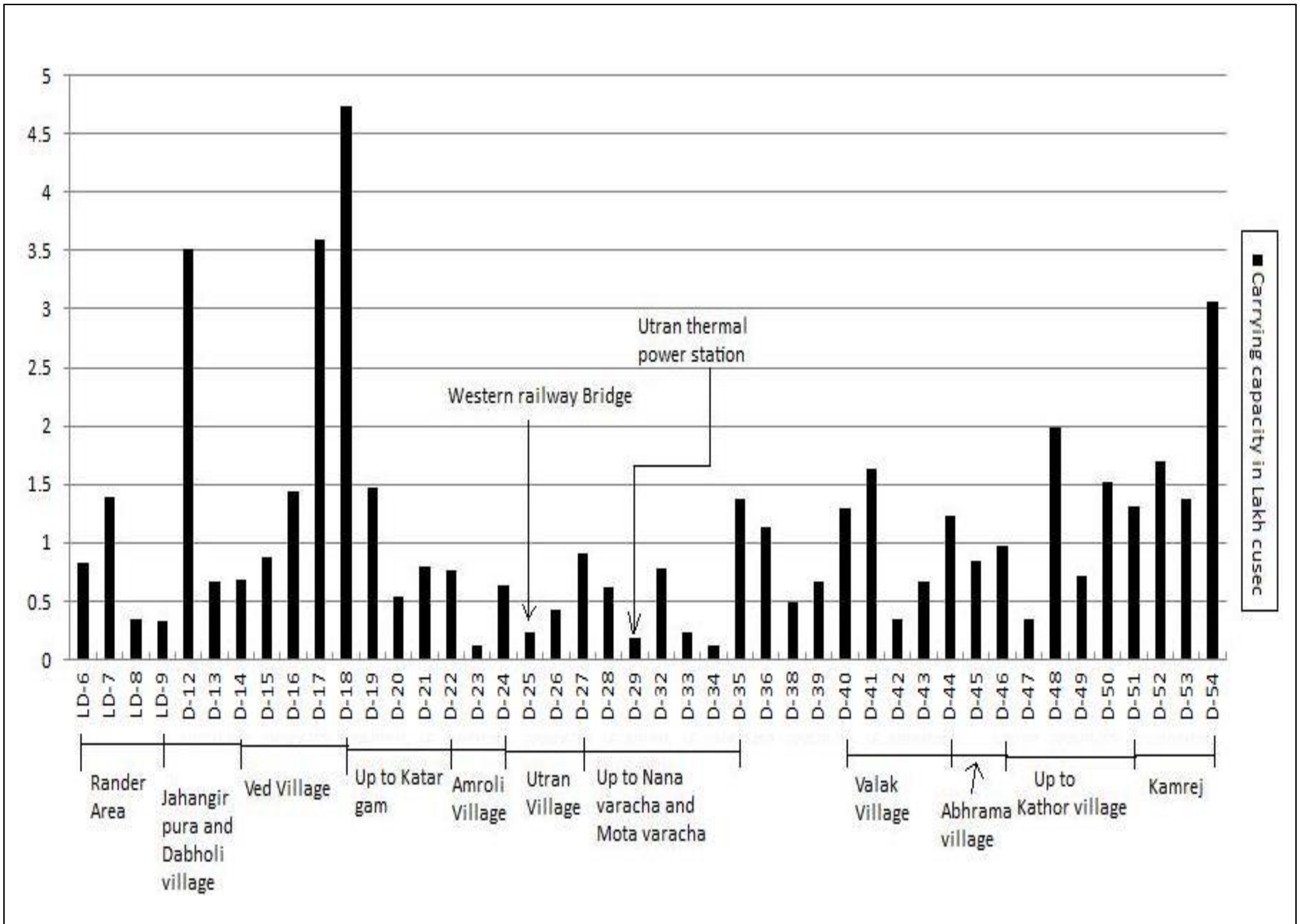
- The graph shows the scenario of the carrying capacity from Weir cum cause way to Magdalla area in surat city. The graph clearly denotes that carrying capacity from Weir to Nehru bridge (Hope Bridge) is nearly 10 Lakh cusec. And after Hope Bridge, near to Adajan area (RD-22 to RD-30) the carrying capacity suddenly decreases due to the low depth and short river bank at Adajan Side of the TAPI River and it falls up to 0.4-1 Lakh cusec.

- So on an average the safe carrying capacity of the tapi river from weir (cum cause way) to SEA is around 4-5 Lakh cusec.

- Carrying capacity is increasing up to 2.5 lakh cusec as going to the Athwa gate to Chowpati Garden and in overall Athwa Lines area maximum carrying capacity reaches up to 3.2lakh cusec.

- At the Sardar Bridge the carrying capacity is hardly 1.2 lakh cusec.
- As moving ahead from Umra Village to Piplod area (RD- 57 to RD-64) the carrying capacity of the Tapi River is decreasing from 4lakh cusec to 2lakh cusec.
- And finally moving towards the Magdalla Area (RD-64 to RD-76), carrying capacity is increasing gradually and it reaches up to 6lakh cusec.
- So from the above graph it can be depicted that the minimum carrying capacity is at near to Adajan, Athwa lines area, and Piplod area.

Figure 4.6: cross sections carrying capacity from weir to Kamrej (LD-6 to LD-54)



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- Figure 4.6 shows the cross sections carrying capacity between weir and Kamrej area. Tapi river's carrying capacity is nearly 0.4 to 1.5 Lakh cusec near to Rander area just next to weir.

- Near to Jahangir pura and dabholi village carrying capacity varyies between 3.5 lakh cusec to 0.7 lakh cusec.

- As we go ahead carrying capacity reaches up to its max. Value of 4.5 lakh cusec and it is average 1.5 lakh cusec up to Katargam.

- At the starting of the Amroli village there is a sudden fall in the carrying capacity and it gets down to a minimum of 0.1 lakh cusec in Amroli as well as its nearby Utran village.

- The average carrying capacity value near to Nana Varacha an Mota Varacha is around 1 lakh cusec.

- As we go ahead along the Tapi River the carrying capacity increases near to Valak Village, Kathor village and Kamrej area. And it reaches up to 3 lakh cusec at the Kamrej area.

4.4.2 Cross section Area

- At the starting from the weir, the river section is wide and deep and it has more topographical area as compared to when river enters near to Adajan area. The width of the Tapi River varies from 600 m – 1020 m from Weir to Adajan Aea. And near to Adajan area width varyies from 300 m-600 m up to Athwa Lines area then river averages between 600 m -900 m width up to the sea.

- Area at various cross sections varies from 2,000 sq. meter to 10,000 sq. meter from Weir to Nehru Bridge. Near to Adajan, Athwa Lines area and near to Piplod area it varyies from 2000 - 4000 sq. meter. And near to Magdalla area it reaches a maximum of 8000 sq. meter.

  The table below shows the area and carrying capacity (in lakh cusec) for each of the cross sections.

Table 4.3: Carrying Capacity of Tapi River at Various Points in Surat City (in Lakh Cusecs)

Cross Section	Area (sq m)	Carrying Capacity (lakh cusec	Cross Section	Area (sq m)	Carrying Capacity (lakh cusec	Cross Section	Area (sq m)	Carrying Capacity (lakh cusec
RD-1	9120.33		RD-31	2836.17	2.09	RD-61	2641	1.42
RD-2	8193.34	9.07	RD-32	2305.59	1.58	RD-62	2487.97	1.28

RD-3	9097.89	9.55	RD-33	2057.81	1.21	RD-63	2636.89	1.47
RD-4	9162.81	9.56	RD-34	2293.02	1.93	RD-64	3011.85	1.98
RD-5	9311.62	9.7	RD-35	2349.97	1.95	RD-65	3237.92	2.05
RD-6	8902.53	9.35	RD-36	2540.6	2.17	RD-66	3145.2	2.02
RD-7	9128.93	9.54	RD-37	2752.34	2.25	RD-67	2414.43	1.26
RD-8	8174.32	7.77	RD-38	2245.33	1.44	RD-68	3741.62	2.71
RD-9	7575.4	6.77	RD-39	3565.82	3.23	RD-69	2858.5	1.96
RD-10	8183.14	6.9	RD-40	3513.22	2.81	RD-70	2823.35	1.92
RD-11	8702.55	8.65	RD-41	2884.75	2.25	RD-71	2488.3	1.56
RD-12	8844.08	8.73	RD-42	3598.53	3.15	RD-72	2177.62	1.17
RD-13	8737.16	7.85	RD-43	2921.18	2.15	RD-73	2271.89	1.15
RD-14	9390.39	8.72	RD-44	2770.64	2.02	RD-74	3591.08	2.8
RD-15	8972.12	8.67	RD-45	4372.74	3.83	RD-75	3051.64	2.14
RD-16	8767.88	7.2	RD-46	4210.49	3.69	RD-76	8075.1	7.36
RD-17	8812.14	7.1	RD-47	2021.4	1.2			
RD-18	9774.24	9.44	RD-48	4243.89	4.17			
RD-19	9934.17	8.78	RD-49	3761.39	3.32			
RD-20	10687.17	10.67	RD-50	3905.96	3.35			
RD-21	5847.39	5	RD-51	4554.94	4.16			
RD-22	2255.98	1.17	RD-52	4149.86	3.49			
RD-23	1995.3	0.81	RD-53	4334.43	3.56			
RD-24	2198.28	0.97	RD-54	4874.84	4.16			
RD-25	2160.52	0.96	RD-55	5070.6	4.05			
RD-26	1457.32	0.57	RD-56	3180.55	2.63			
RD-27	1435.79	0.58	RD-57	3295.91	2.27			
RD-28	2020.75	1.12	RD-58	2929.4	1.83			
RD-29	1996.16	1.03	RD-59	2407.39	1.24			
RD-30	2041.7	1.06	RD-60	3125.73	1.92			

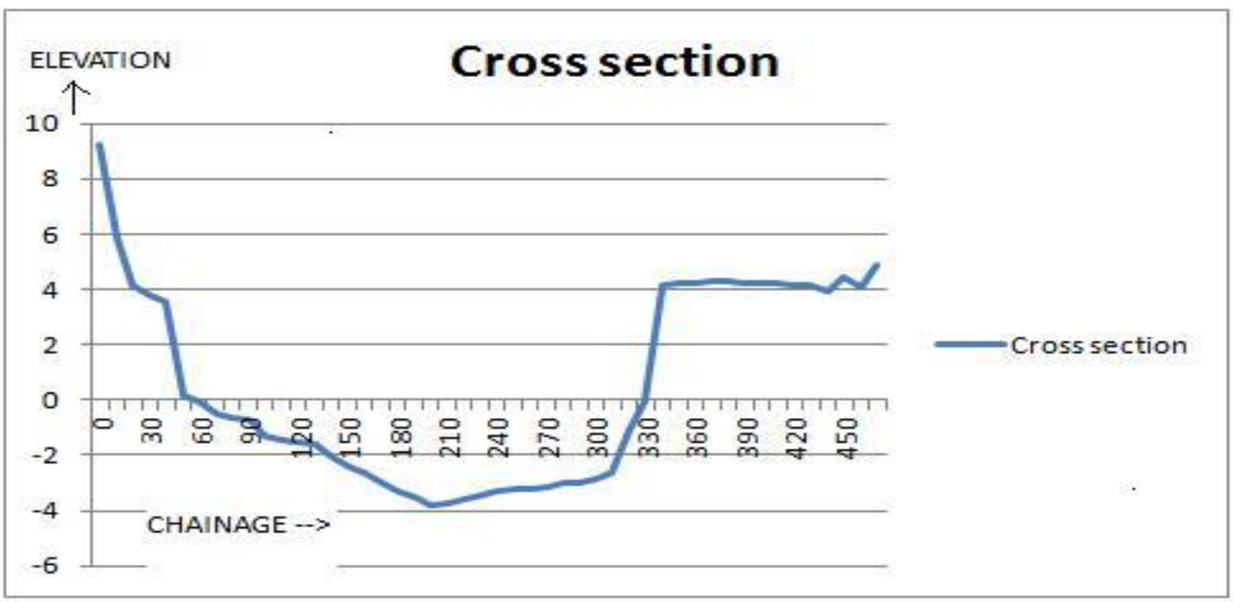
4.5 Results and Discussions

From the carrying capacity values the following points emerge:

- Starting from the weir-cum- causeway the carrying capacity is around to 10 lakh cusec. This is noticed to have increased as comparison to the previous estimate based on 2006 cross section data of SMC, which is around 8 lakh cusec. This is an increase of 2 lakh cusec. The reason behind this is the erosion of the river channels due to the high discharge from the weir.

- When the river reached Adajan area, the carrying capacity decreased suddenly. This is because of the encroachment and resulting reduction width of the river cross sections. The same situation is at the Athwa lines Area.
- Another reason for the low carrying capacity near the Athwa Lines Area, Adajan, Rander and some other areas are the river bank difference at both sides. So the area situated at the lower bank is the more vulnerable as compared to its opposite side.
- Low carrying capacity in Surat city like Amroli, Rander and near Ved village is because of the C-shape of the Tapi River at these areas. So the velocity near to these areas is near to zero meter/sec. and hence the carrying capacity also gets down.
- Sedimentation is taking place near to the weir and it reduces the velocity and leads to more sedimentation to riverbed and hence further decreases the carrying capacity.

Figure 4.7: Rander area cross section



- In above figure 4.7 a Rander area cross-section of the river channel is shown. The river bank on Rander side has much lower compared to its opposite river bank. So in case of flood, Rander area is more vulnerable.
- Similar situation is at at various sections near to Athwa Lines, Adajan, and Nana Varacha. These areas are more vulnerable due to the low height of river bank.

4.5.1 Carrying Capacity and its significance for Surat City

Flood prone areas and highly vulnerable areas can be identified easily from the carrying capacity of the river at different cross-sections. This also helps in identify measures that can be taken to avoid flooding:

- In Adajan and Atwa lines areas width of the cross sections are nearly 500 m, which affects the carrying capacity of the cross section. At these places widening and deepening of the river bed can help to increase the carrying capacity and to decrease the vulnerability to nearby areas.

- In the case of Rander and Nana varacha areas, where differences in river bank heights are large. In these cases provision of retaining walls, providing bunds, or provision of flood gates can decrease the vulnerability of nearby areas.

- In the cases from Jahangir Pura to Amroli village where encroachment is there and river is turning the carrying capacity are very low because of the lower velocity and sedimentation. In such cases, provision of flood gates or provision of reservoir or widening of the river banks are the best structural measures to reduce vulnerability.

4.5.2 Implications

While analysis of carrying capacity cross-section by cross-section helps identify critical areas, the extent and level of flooding need to be assessed to identify in detail vulnerability of different parts of the city. For this the flow in the river has to be simulated as what happens at a cross-section affects what will happen at other cross-sections. In the next chapter we describe the simulation of river flows and flooding under alternative scenarios.

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CHAPTER 5: MAPPING OF FLOOD VULNERABLE ZONES IN SURAT

5.1 Introduction

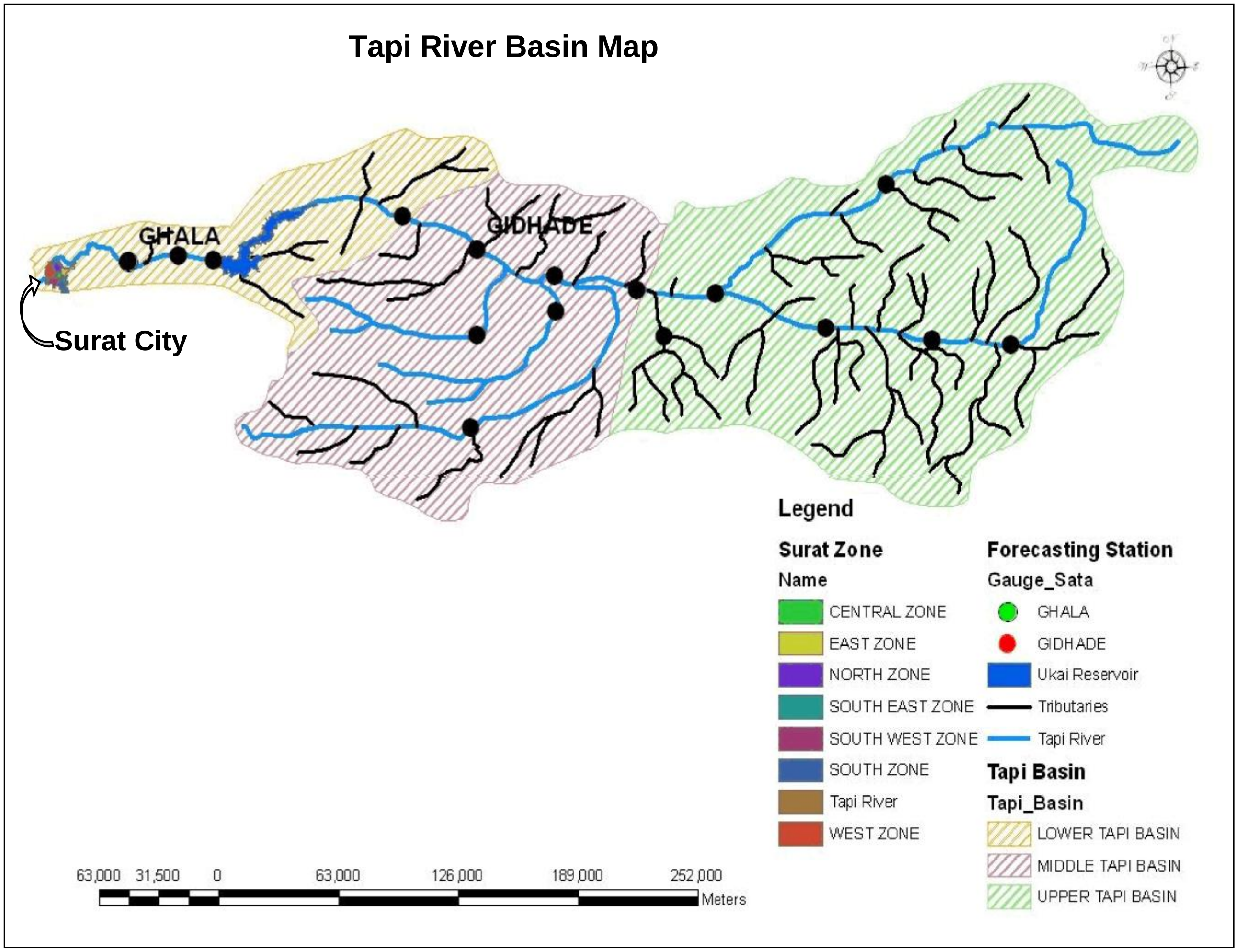
Tapi is the second largest westward-draining inter-state river in India after the mighty Narmada River. The total area of Tapi basin is 65,145 km^2 covering approximately 51,504 km^2 (79%) in Maharashtra state, 9,804 km^2 (15%) in Madhya Pradesh and 3,837 km^2 (5%) in Gujarat state. The basin finds its outlet in the Arabian Sea and is bounded on three sides by ranges of hills. The Tapi River and its tributaries flow over the plains of Vidharbha, Khandesh and later to Gujarat, and can be divided into three zones, viz. Upper Tapi basin, Middle Tapi Basin, and Lower Tapi Basin (LTB). The portion between Ukai Dam to the Arabian Sea is considered as LTB, mainly occupying the Surat and Hazira twin cities along with tens of small towns and villages by the river. Surat city is almost 100 km downstream of Ukai Dam and is affected by the recurrence of floods at regular intervals.

The LTB receives an average annual rainfall of 1376 mm, and these heavy downpours result in devastating floods and water logging downstream. The LTB contains the Ukai and Kakrapar reservoirs and part of the flow is diverted for irrigation from Kakrapar weir. The major crops grown are cotton and maize, followed by soybeans. The prevailing land use is mixed forest, agricultural land, rural and urban settlements. The topography in LTB comprises narrow valleys and gently sloping ground. Figure 5.1 shows the location of the study area, Surat City. The main reasons for flooding in LTB are the heavy rainfall and discharge due to high water levels from Ukai Dam. Therefore, the flood problems of the river system are inundation due to the overflowing of the banks, inadequate drainage capacity of the river, congestion at the point of confluence, and an excessive silt load factor.

In order to assess the geographical impact of floods, CARTOSAT-1 stereo-pair satellite data of 2.5 m resolution has been procured from National Remote Sensing Centre (NRSC), Hyderabad. Besides CARTOSAT data, high resolution Google-earth data at the sub-meter scale have been downloaded from the Internet. The hydraulic data on river cross-sections including channel levels and hourly gauge discharge measurements, for three stations in and around Surat City, have been collected from several sources including SMC. GIS analysis is being conducted for all seven zones of the Surat Municipal Corporation. The data used for conducting the present research include geo-coded CARTOSAT-1 satellite imagery of April 2008, Survey of India USGS' SRTM DEM data of 90m resolution, high resolution Google-Earth images and various maps developed by the SMC. Contour maps for various city zones at 0.5 m interval have been collected from the SMC in AutoCAD format. [More than 200 river channel sections at a mean distance of 150 to 200 m have been measured by the Irrigation Department for LTB between the Ukai Dam and Magdala weir.] The water level and river discharge data from hourly to daily scales for discharge stations: Ukai Dam, Kakrapar weir, and Hope (Nehru) Bridge have been collected from the Flood Control Cell, SMC for the period from

2006 to 2010. [All the data have been attributed ready to put into a digital database management system (DBMS) using GIS software for further analysis with ARCGIS software-based Spatial Analyst tools.]

Figure 5.1: Location of the study area and Surat Zone



A large number of hydrological models and hydraulic models are available in literature for flood modelling and preparation of flood hazard maps. They are simple to complex in processes, use single to multi-parameters, and vary from minute to monthly time scale. A combination of Arc GIS and HEC-RAS model have been used for preparing flood hazard maps for Surat city. Both models have advantages as compared to several existing hydrological models, as they are dependent on limited number of parameters and can be easily customized to Indian conditions.

Arc GIS data model helps us in developing many hydrographical dataset from digital elevation models (DEMs), extracting drainage networks, delineating watersheds, and deriving geometric networks of drainage features for flow tracing. The geographic features, thus delineated can be linked to time-series data (e.g., stream flow records) in the database, thus providing the base for simulation modelling for inundation mapping of the river basin.

Whereas, HEC-RAS help us to calculate water surface elevation at all cross-sections of interest for either given set of flow data or routing hydrograph through the hydrological system. This model requires various geometric parameters, flow characteristics such as steady and unsteady flow data. These geometric data includes River system schematic, River cross section data, River reach length, energy loss coefficients, and stream junction information. Locations of various hydraulic structures are also one of input parameters either for flood storage or for flood release. Steady flow data includes flow regime, boundary conditions and peak discharge information. The HEC-RAS program computes water surface elevations along the channels, and the results are transferred back to the GIS, where the floodplain limits are automatically delineated and flood hazard areas are accurately mapped.

Therefore, a combination of Arc GIS and HEC-RAS models will result into hydrologic database development, delineation of flood hazard areas, maps for identification of floodplain, and mapping susceptibility to flood for the vulnerable locations/targets identified such as schools, hospitals, slums and industries. In this project high-resolution remote sensing images from CARTOSAT-1 have been combined with river hydraulic analysis and digital elevation model (DEM) to identify the flood susceptible areas.

5.2 Processes Involved in Mapping

The process involves the following steps:

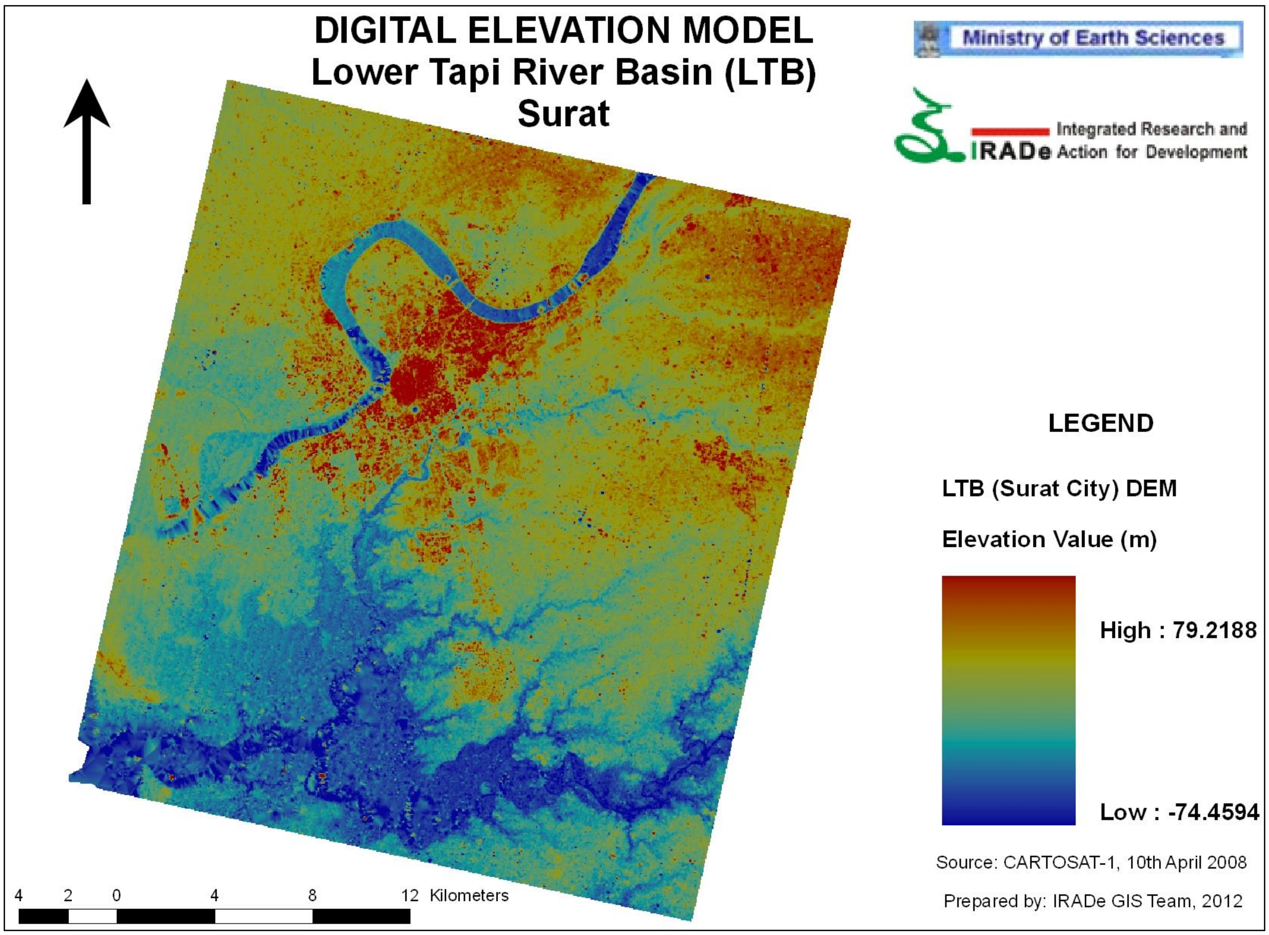
5.2.1 Step-1: Terrain Mapping:

Terrain mapping of Surat city is done by using Digital Elevation Model (DEM). A DEM is a gridded array (raster) of elevations. Rasters represent the world as regular arrangements of pixels (cells). In a DEM, each cell has a value corresponding to its elevation. The fact that locations are arranged regularly permits the raster GIS to infer many interesting associations among locations: Which cells are upstream from other cells? Which locations are visible from a given point? Where are the steep slopes?

This chapter presents the overall results of the comparison with the higher-grade reference DEM. An automatic “raster to vector” approach (Kay et al, 2005) was applied using bilinear interpolation to determine the elevation of each Cartosat-1 DEM 27x27m cell position in the reference data set. The processing chain delivers the standard deviation and mean of the elevation differences (between the Cartosat-1 DEM point and corresponding interpolated vertex) and stores the raster results for further analysis. (Fig.5.4)

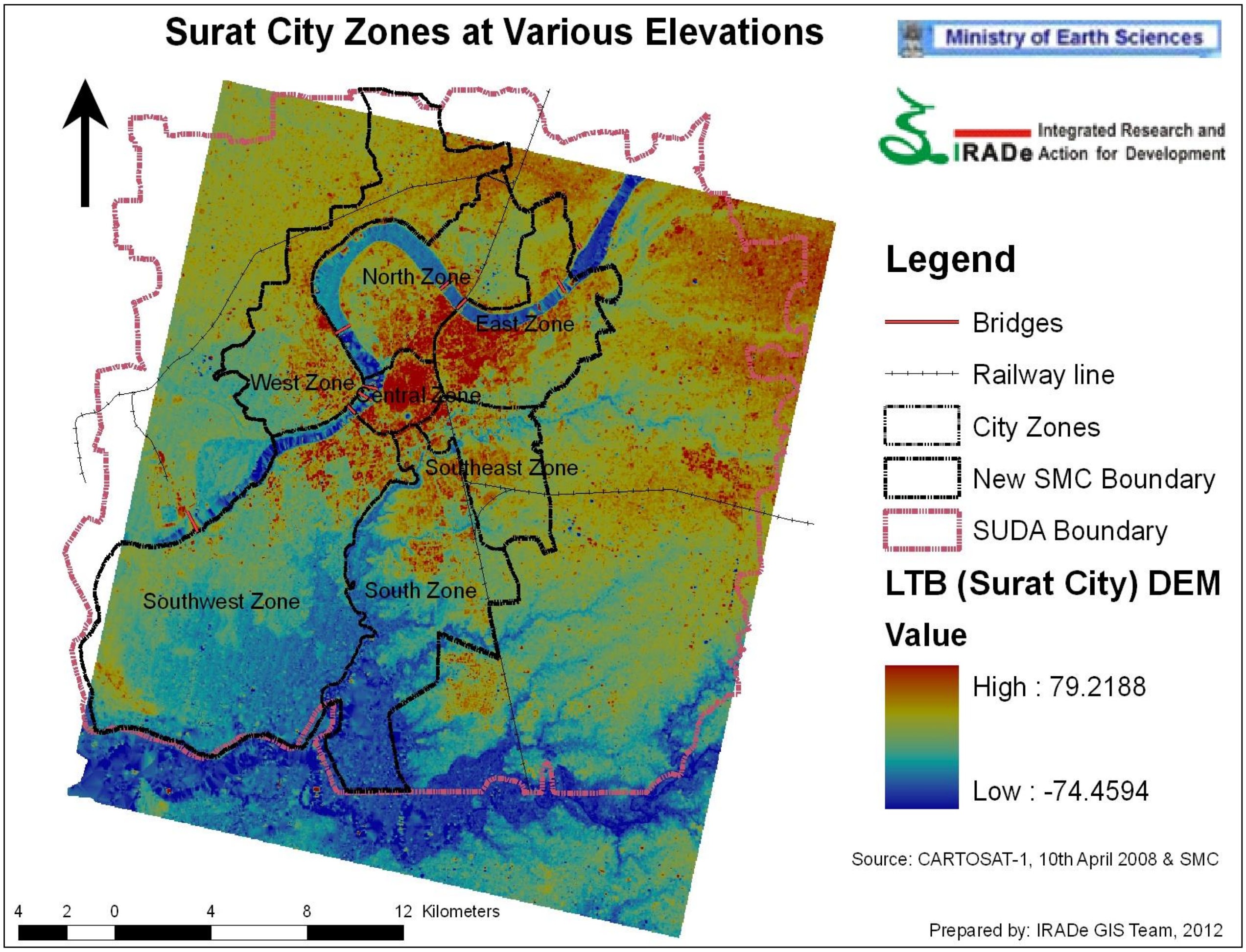
Digital representations of landscape topography as digital elevation models (DEMs) incorporate series of reduced level values so that terrain features can be evaluated using specialized numerical algorithms and the GIS visualizations rendered. The major issues with DEM-derived hydrographic data are related to the resolution and quality of the DEM and to the derivation of surface drainage. Here, ERDAS Imagine-LPS (Leica Photogrammetic Suit) and ARC GIS software have been used for various feature extraction from DEM.

Figure 5.4: DEM of Lower Tapi Basin



As can be seen in Fig.5.4, the DEMs generated from Cartosat-1 image pairs gives clear picture of the topography of the region. As seen in DEM, West zone is low lying area of the city with compared to East zone. There is a significant slope direction found in the city and that is from east to west. DEM shows that west zone is low lying area and its topography varies from 2m to 15m. Major parts of Adajan region lie in the west zone and the region had experienced 2m to 4m water submergence during 2006 floods.

Figure 5.5: Surat City Zones at Various Elevations



5.2.2 Step-2: Inundation Mapping of Surat city of three inflow scenarios:

The primary objective of this study is to provide a hydrological assessment of Surat city's people and public infrastructure. The elements of infrastructure under consideration include- buildings (schools, hospitals, slums, and industries) within and adjacent to the flood plains, roads, bridges, etc. An original systematic procedure is used in the study to gather and examine available data in order to develop an understanding of the relevant climatic effects and their interactions with infrastructure. The purpose of the work presented in this report is to provide the assessment procedure with the extent of inundation and water depths for three discharge scenarios (actual Tapi river water discharge from Ukai Dam in 2006, 50% less of 2006 discharge level, and 50% higher of 2006 discharge level) under consideration. The integrated hydraulic modelling system and spatial analysis software have been used in the study.

In addition to the fact that climate change has been considered in the development of current Floodplain maps. Current floodplain maps have been generated by using one of the most advanced imageries of the region developed by the National Remote Sensing Agency (NRSA), Hyderabad and acquired by CARTOSAT-1 satellite. Inundation depths that are required for an assessment of infrastructure vulnerability have been developed by using the CARTOSAT Imagery and Discharge data of UKAI Dam collected by the Surat Municipal Corporation (SMC) and Irrigation Department, Surat. Geometric data have been developed by using the GIS and Hydrological computer software for spatial analyses.

A set of tools and utilities provided with the ArcGIS computer package is utilized in the preparation of spatial data for the hydraulic analyses. HEC-GeoRAS is an extension of ArcGIS, which is used for the preparation of spatial data for input into hydraulic model HEC-RAS and the generation of GIS data from the output of HEC-RAS software.

The spatial extension of the assessment of the project is limited to city of Surat. The study area is determined based on the population and infrastructure threat perception due to the floods. The lower Tapi river enters the city from the eastern side and exits to western side tapering through the northern part of the city. The river finally meets the ocean at the western side of the city. The Tapi river model starts at the downstream cross section, which is located 142.19 m away from the starting of the river to be modelled and the last downstream cross section is located 540.14 m away from the preceding cross section. Almost 34 km length of the lower reach of the river is taken into consideration for the hydraulic modelling study which covers the entire city.

5.2.2.1 Summary of the flood plain mapping results:

Table 5.2 shows the inundation area for the three water discharge scenarios [2006 level; 50% lesser; and 50% higher discharge w.r.t. 2006]. For lower Tapi river especially from UKAI dam, the difference in flow between three scenarios is significant. Therefore, the difference between inundated areas is also significant. The flow of Tapi river is managed and controlled at UKAI Dam. Only at some exceptional and unwarranted situations water is discharged excessively from the dam.

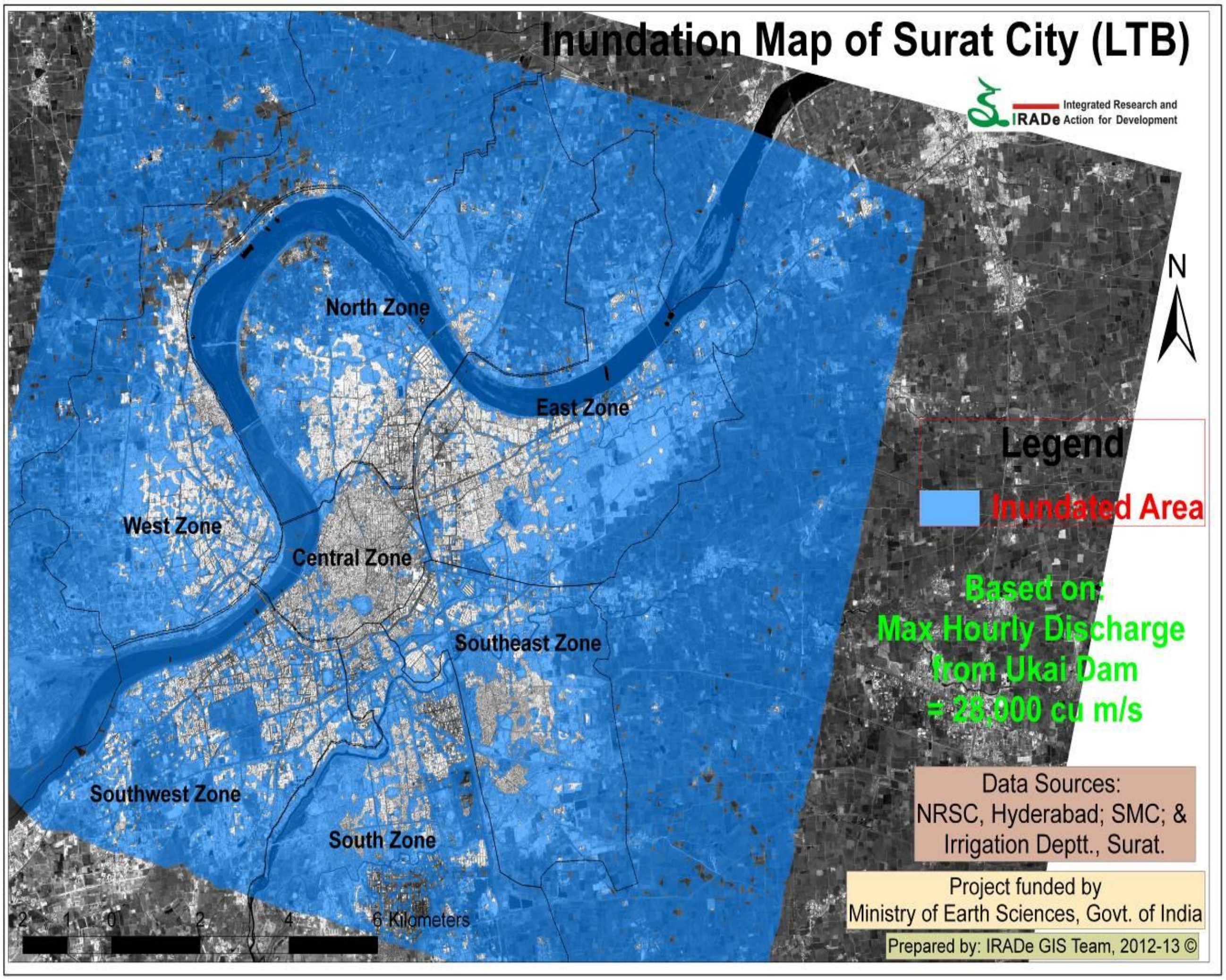
Table 5.2: Summary of floodplain mapping results under various water discharge scenarios

<table>
<tr><th rowspan="3">River</th><th colspan="3">Area of Flooding (km²)</th></tr>
<tr><td>Historical Scenario</td><td colspan="2">Futuristic Scenario</td></tr>
<tr><td>Tapi River water discharge level from Ukai dam in 2006</td><td>50% lesser discharge of 2006</td><td>50% higher discharge of 2006</td></tr>
<tr><td>Lower Reach of Tapi River (Surat City)</td><td>270</td><td>228
(a decrease of 15.5% from 2006)</td><td>295
(an increase of 9.25% from 2006)</td></tr>
</table>

5.2.2.2 Floodplain mapping results:

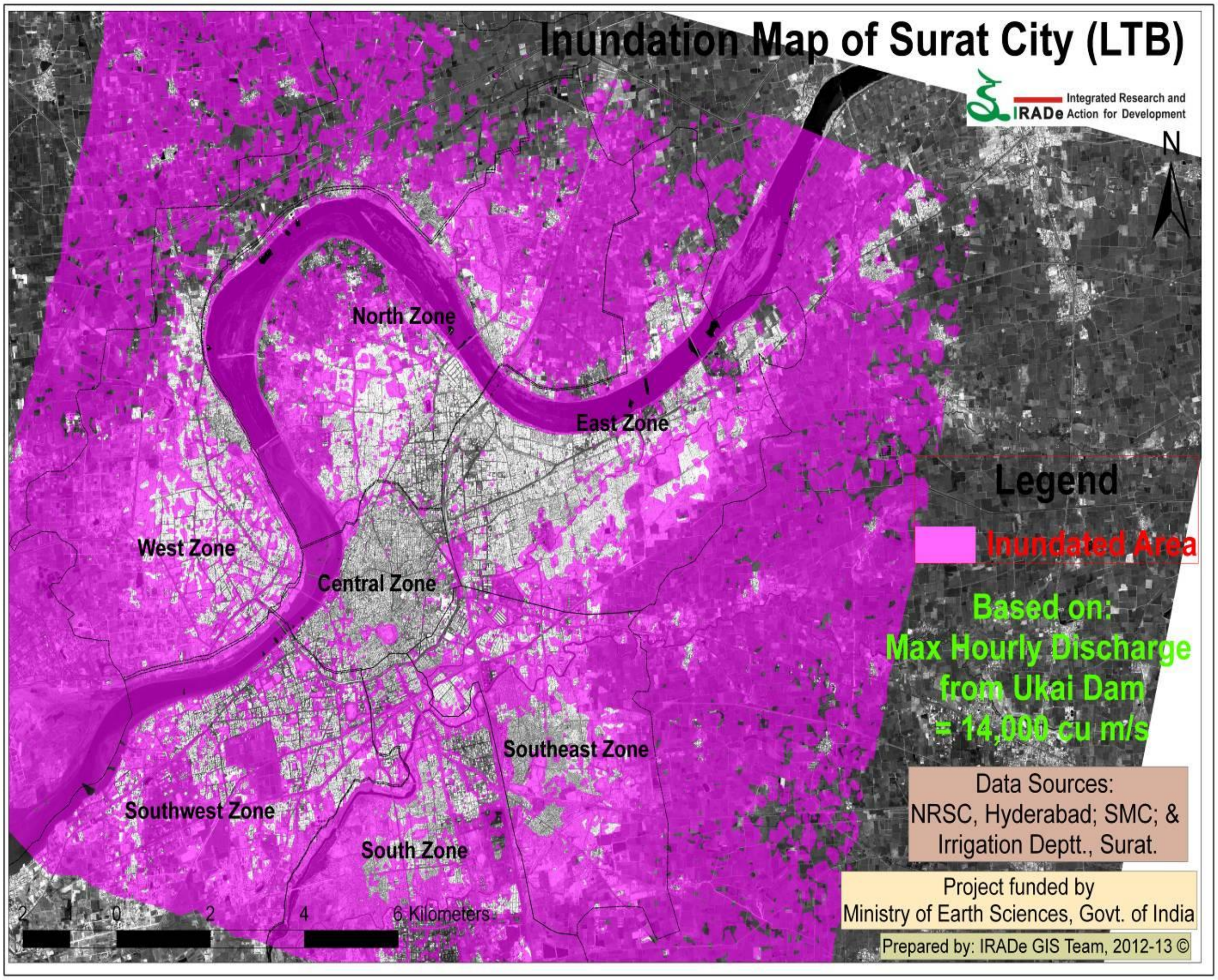
Floodplain mapping results are shown using the flood inundation map. Preliminary observations of all the three scenarios of Tapi river water discharge show the submergence zones. When we compare all the three maps we would find that with the change in river water discharge from Ukai dam at 2006 level to 50% level higher level, more areas would get submerged with water.

Figure 5.24(A): Scenario 1: 28,000 cu m/s Water Discharge from Ukai dam (Year 2006 level)



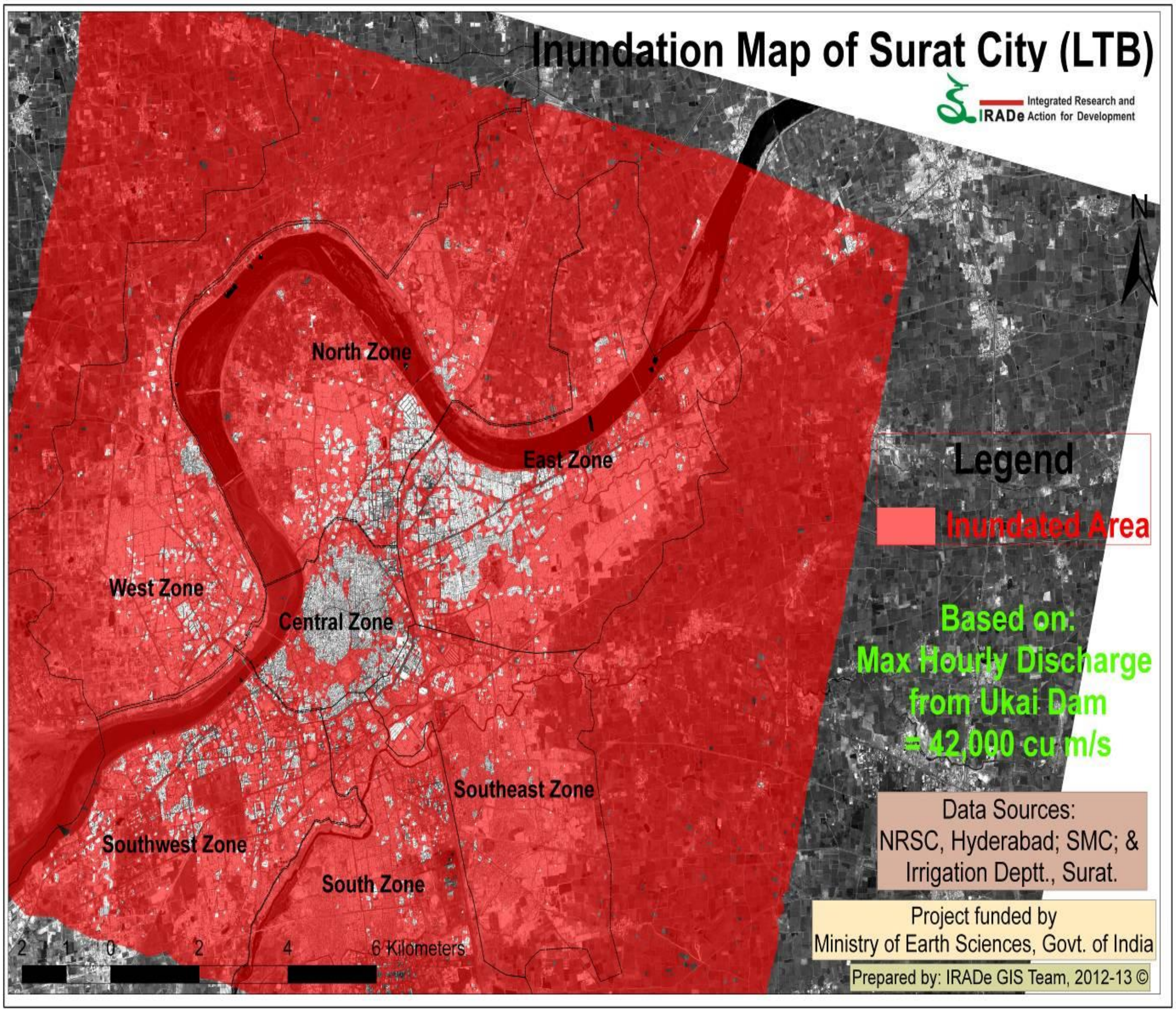
In scenario 1, when 28,000 cu m per sec water is discharged from Ukai dam, then almost 270 sq km area would get submerged affecting mainly the west, north, central and southeast zones of Surat city. After studying the inundation map closely, the following zones and important locations have been identified as vulnerable to floods. West and North zones have been identified as highly affected whereas Central and Southeast zones are moderately affected to inundation. South zone has been identified as least vulnerable to inundation. Some areas of Southwest and East zones are vulnerable to inundation due to discharge of 28,000 cu m per second.

Figure 5.24(B): Scenario 2: 50% less Water Discharge from Ukai dam of Year 2006 level (14,000 cu m/s)



In scenario 2, when 50% less i.e. 14,000 cu m per sec water is discharged from Ukai dam, then almost 228 sq km area would get submerged majorly affecting the west, north, some areas of central and southeast zones of Surat city. There is almost 15.5% decrease in submerged areas if the discharge is 50% lesser than that of 2006 level.

Figure 5.24(C): Scenario 3: 50% higher Water Discharge from Ukai dam of Year 2006 level (42,000 cu m/s)



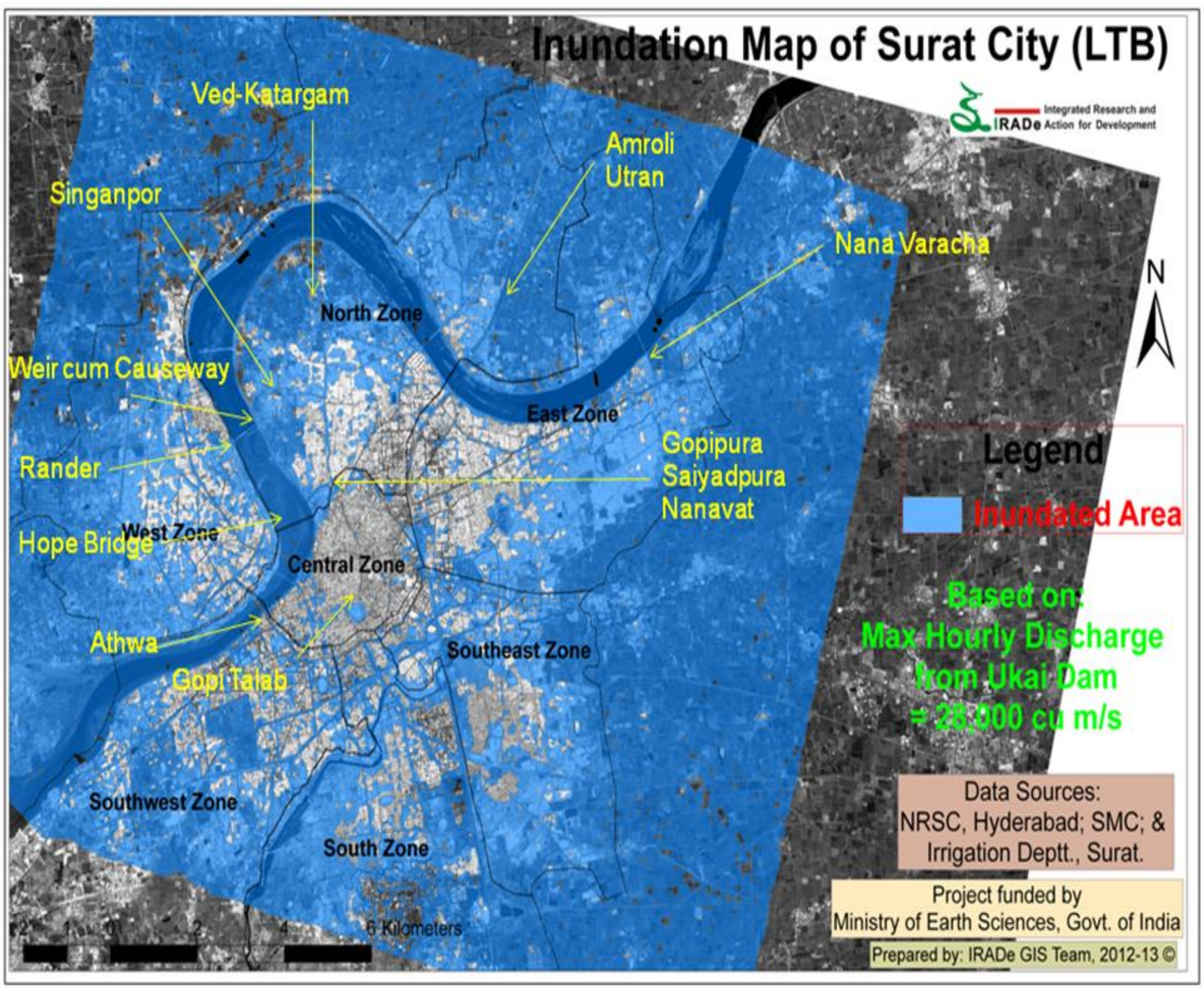
In scenario 3, when 50% higher i.e. 42,000 cu m per sec water is discharged from Ukai dam, then almost 295 sq km area would get submerged, an increase of 9.25% than that of 2006 level. The choropleth clearly depicts most of the parts of west and north zones will get submerged with the increase of 50% in discharge. East and Southeast zones will also be at great risk of flooding.

5.2.2.3 Identification of vulnerable zones due to submergence

City of Surat, located on River Tapi, lies in the flood plain and in an estuarial region. City has a number of creeks in south-west part. Surat has been historically susceptible to flooding- both risk exposure and vulnerability have increased over the past few decades. Surat has witnessed three major floods in the 20th century (1968, 1994 and 1998) and recently in 2006. The 2006 flood was the biggest in the last 34 years after the construction of the Ukai Dam in 1971. 2006 devastating flood covered almost the entire city and more than 75% populations were affected.

Moreover, it is interesting to find out the results of regional and global climate models which indicate an increase in total precipitation as well as increase in extreme precipitation events that in turn would increase frequency and intensity of floods (*ACCCRN Report*). The results of A2 and B2 scenarios of PRECIS model also indicate 20% to 30% increase in current precipitation in the region along with increase of extreme events (*ACCCRN Report*). Surat city has a distinctive characteristic of being close to the sea at the western side and an intruding river which shapes the whole city. Sea-level rise is another major risk that city faces. Having located <13m AMSL and 15km from the coast, even with 1m sea-level rise can impact western parts of the city, the area under high tide zone.

Figure 5.25: Submerged regions in Zones of Surat City



Some highlights:

❖ **Submerged regions are:**

- Low lying areas like Ved Road, Katargam, Singhanpore, Kadar Shah naal, etc
- Adjoining regions of Weir-cum-Causeway due to overflow
- Adjoining regions of Nehru Bridge at Chowk Bazaar
- Areas along the bridges and the river ghats always at threats with rising water level due to discharge from UKAI dam
- Creeks like Kakra, Bhedwad, Mithi, Bhatena and Simada overflow due to excessive water discharge from Ukai dam and heavy rainfall in the catchment areas

The sample flood mapping potential areas for all the zones of the city have been demarcated. The possible areas under each water level height are depicted with different colours in the zone map. After generating the flood inundation map, the water levels of the 2006 flood have been compared with Hope (Nehru) Bridge. Moreover, it is found that Hope Bridge has a bank level of 4.1 m; therefore there will be about 3–4 m water over the right-bank area. Hence, the major parts of the Adajan area will be submerged. The Rander area will also be submerged by 1–2 m depth of water, as was experienced during the August 2006 flood.

After analysis of the inundation map and flooding conditions in 2006 (based on the flood water level) in Surat, city zones have been categorized as follows:

I. Highly affected zone:

(i). West Zone (Adajan):

❖ ***Above 5m-*** Varun Hospital (Panchratna Anand Mahal Rd), Nehru Nagar, Bapu nagar, Nurani Masjid

❖ ***3-5m-*** Krishna nagar, Bhulka Bhawan School (Adajan Rd), Aakanksha Hospital, most parts of Adajan area, Hanuman Tekri crossing, Area near Rander Idgah, Sardar Patel Vidyalaya, Sadi material factory

❖ ***1-3m-*** Adajan Rd, Rander zone office area, Mahadev Steel emporium (Seemanagar), Telephone exchange (Ramnagar), Varigruh Rander, Causeway control room, Sanskar Bharti school area, UHC (Rander), Fire St (Rander), Ramnagar ward office, Most of the housing society complex

- ***Below 1m-*** Near Palgam Talav, Variyav Main rd, Jahangirpura area

(ii). North Zone (Ved-Katargam):

- ***Above 5m-*** Katargam area; some of the industries of diamond, cement, and cloths; Bapunagar area
- ***3-5m-*** Ved Rd, Singanpore, Utaran, Kosad Rd, Sayan Rd, Gujarat Housing Board, Ambedkar nagar, Jalaram nagar, Dabholi crossing area, S V Girls Vidyalaya
- ***1-3m-*** Katargam Fire station, Amroli Crossing, Utaran village area, Kosad Village area, Gajera school area, GIDC area
- ***Below 1m-*** Ayurvedic College,

II. Moderately affected:

(iii). Central Zone:

- ***Above 3m-*** Kadarshahnal circle, Nanpura circle, Chock Bazaar, Rudrapura main road
- ***1-3m-*** Near Athwagate, Majura Gate, Badekha Chakla, Near Gopipura, Nanpura Machhiwad
- ***Below 1m-*** Gopipura School area, Judges Colony, Kharwawad, Nanpura post office area

(iv). South East Zone (Limbayat):

- ***Between 3-5m-*** Nehru nagar, jawahar nagar, Salim nagar, Koyali Khadi, Khwaja nagar slum, Bhatena slums, Jayanti bagh slum, Sanjay Nagar, market area
- ***Between 1-3m-*** APMC market area, Rajiv nagar slum, Apna nagar, Girnar house
- ***Below 1m-*** Abhishek market area

III. Affected areas:

(v). South West Zone (Athawa):

- ***1-3m-*** Colleges near Ring Rd, Surat Dumas Rd, near Athawa gate, Umargam, Piplod, Circuit House, Police HQ, Athawa Flyover Bridge
- ***Below 1m-*** Majura Fire Station Gate, Income Tax Bhawan, Vesugam

(vi). East Zone (Varacha):

- ***1-3m-*** Fulpada Gamtal, Navagam, Umarwada, Karanj, Nanavarcha-Kapodara, Dindayal nagar slum, Magob-Dumbhal, Vidyabharti school, Punagam

- ***Below 1m-*** Umiya Circle, Varacha Zone office, Surat Textile Market

IV. Least affected:

(vii).South Zone (Udhana):

- ***Below 2m-*** Udhana Darwaja, Udhana Magdalla Rd, Shivaji nagar slum, Sadanand Industrial estate (Khadi border), South zone office, some industries

The methodological details of these steps are described in Annexure 5.1

Simulation provides for any given set of inflows in Tapi, mapping of flood vulnerable zones of Surat city, i.e. it provides the level of flood water in different parts of the city.

5.2.3 Step-3: The Climate Change Scenarios:

The most severe flood in terms of damage in recent years was the flood of 2006. The first scenario takes the inflows in Tapi of that year. A conventional flood frequency analysis using GUMbel's method shows that the 2006 flood was slightly bigger than one in a 100 year flood. This analysis is given in Annexure 5.2.

For a scenario that reflects possible inflows due to climate change, we take inflows which are 50% higher than the 2006 inflows. This is based on analysis of projection made till 2100 by various regional climate models for the region in which Surat city is located. This analysis is given in Annexure 5.3.

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CHAPTER 6: FLOODING UNDER CLIMATE CHANGE

6.1 Potential Climate Change impacts on Surat

The Climate Change risk associated with Surat includes floods, sea level rise, etc. Flood risk is among the key risks since it occurs almost once in four to five years, since 1990, six flood events have affected Surat. The biggest flood was in 2006.

6.1.1 Floods due to River flow and peak discharges

The future precipitation trends as explained above can potentially increase flood frequency and peak discharges in to Ukai dam, which is a matter of concern since Surat's population has been growing at a rate of more than 60% per decade and the population at risk is going to grow proportionally. With the flood plains getting narrowed by human interventions and sea level rise, the inundation levels are likely to increase. Modeling these events is likely to be a challenge since Surat's flood plain is being modified with embankments, land filling and raising the ground level of Hazira industrial area, which will modify flood routing significantly. The observed relationship between discharges and inundation is expected to be amplified significantly due to loss of flood plain area as well as sea level rise.

6.1.2 Sea level rise

Surat is a coastal city and lies near the estuary of Tapi River. Several tidal creeks cut cross the city. Surat lies at an altitude of about 10 m above mean sea level with a tidal range of Surat is about 5.8m. During rainy months, the sea wave action often causes the sea water to inundate the slums located along the creeks. During last five years, the slums are being evacuated during mid-July period due to above normal tidal inundation. According to the recent study of the sea level changes in Arabian Sea by Unnikrishnan (2007)[32], during the last century, there has been an increase in sea level along the Gulf of Cambay by around 0.67 m. If such increase prolongs into the future, they may have a major impact on the city.

Sea level rise will raise the water level in Tapi downstream of Surat. That will have an impact on overflow and submergence. We have not assessed likely extent of sea level rise. However, in the hydrological simulation the downstream water level has been taken as the maximum observed water level during the 2006 flood.

Cyclones are not common and only two events of cyclones passing through Gulf of Khambhat are reported over the last 140 years, the recent being 1976. Surat has been reporting rising highest high tide levels during July, with some of the Khadi areas are evacuated during July high tide days

[32] Unnikrishnan 2007, Observed Sea level rise in the North India Ocean coasts in the past Century, Physical Science 91-92

as a precaution. The highest tide of 2007 inundated some of the coastal areas never before submerged during tides. The sea level rise is also likely to impact coastal aquifers and also erode parts of Dumas beach, which already has been reporting coastal erosion.

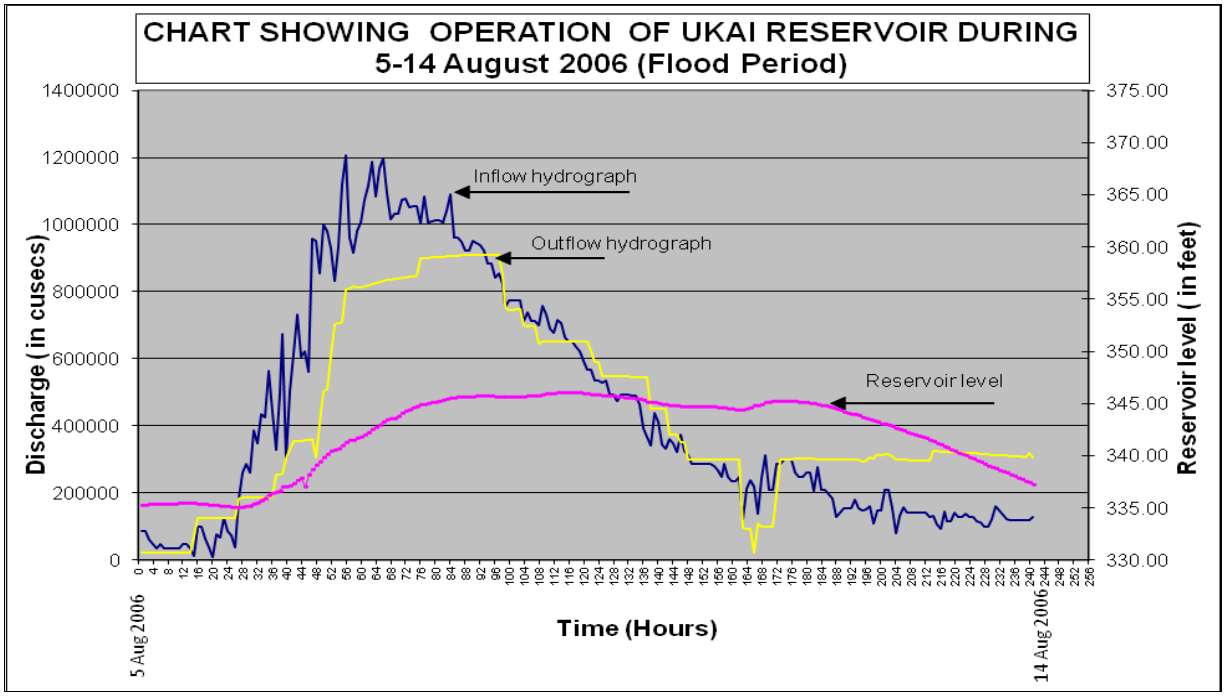
Sea level rise will increase the level of water in the tail end of Tapi river. This will increase flooding of the city. While in our scenario we have not accounted for it, if we had an idea of by how much water level will increase we could easily make a scenario simulation.

6.2 Flood Vulnerability Due To River Flow And Peak Discharges

To know the flood vulnerability due to river flow and peak water discharge from the UKAI dam, the analysis of inundation of the Surat city has been done and floodplain-mapping results are shown using the flood inundation map. Two scenarios are developed, scenario-1 with the inflow corresponding to the 2006 flood and scenario-2 where that inflow is raised by 50%. Due to large uncertainty, as explained earlier we take 50% increase in Tapi inflows as reflecting the impact of climate change. Preliminary observations of these two scenarios of Tapi river water discharge show the submergence zones. When we compare the two discharge scenarios we find that with the change in river water discharge from Ukai dam at 2006 level to 50% level higher level, more areas get submerged.

The inflow in Tapi at Surat is largely determined by discharges from the UKAI dam. The extent to which the reservoir can be used is limited by its capacity. Figure 6.1 (a) shows inflows discharges and reservoir level during the 2006 flood. It is seen that inflow increased from 1,00,000 cusecs (2900 cumecs) to 4,00,000 cusecs in six hours and to 12,00,000 cusecs (35,000 cumecs) in 30 hours. It remained above 4,00,000 cusecs for more than 4 days. The reservoir got filled up in two days even though discharge level was raised to 8,00,000 cusecs (23,000 cumecs) and remained above that for 2 days.

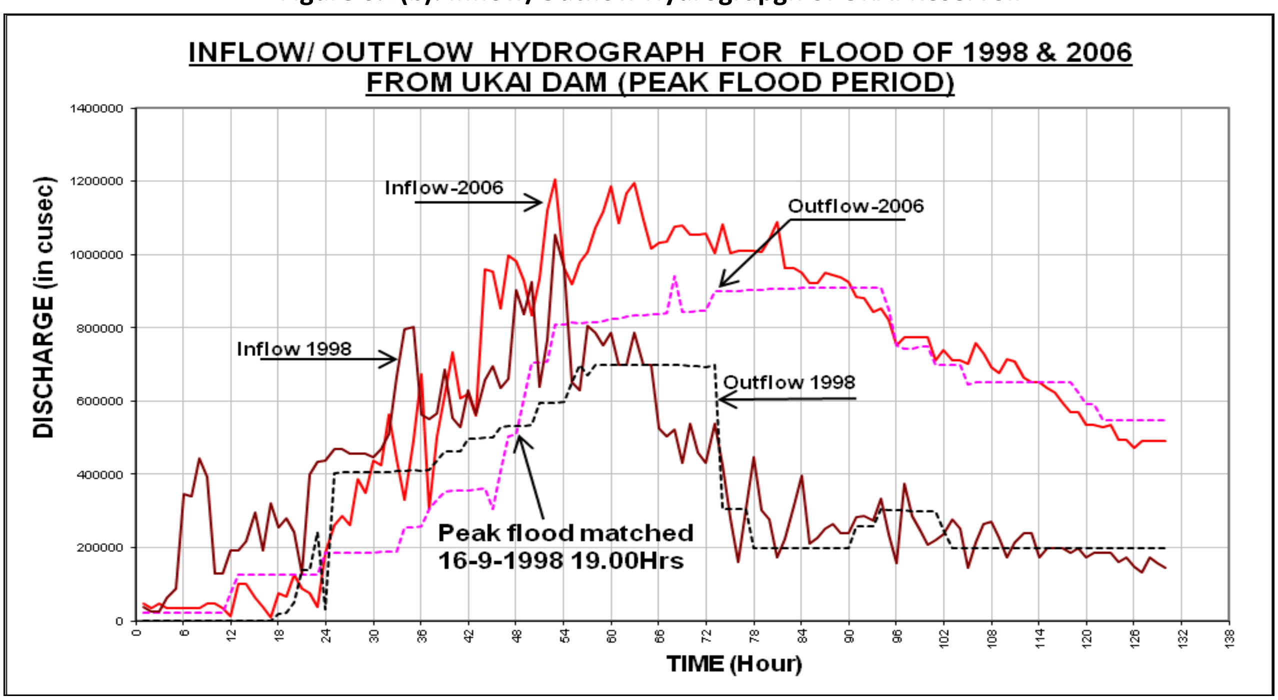
Figure 6.1(a): Operation of UKAI Reservoir during 5-14 August 2006



Source: Irrigation Department, Surat

Given that the capacity of the reservoir is fixed, once the reservoir is full, discharges will reflect rainfall. Thus we have taken 50% higher inflows compound to 2006 as our climate change scenario.

Figure 6.1(b): Inflow/Outflow Hydrograpgh of UKAI Reservoir

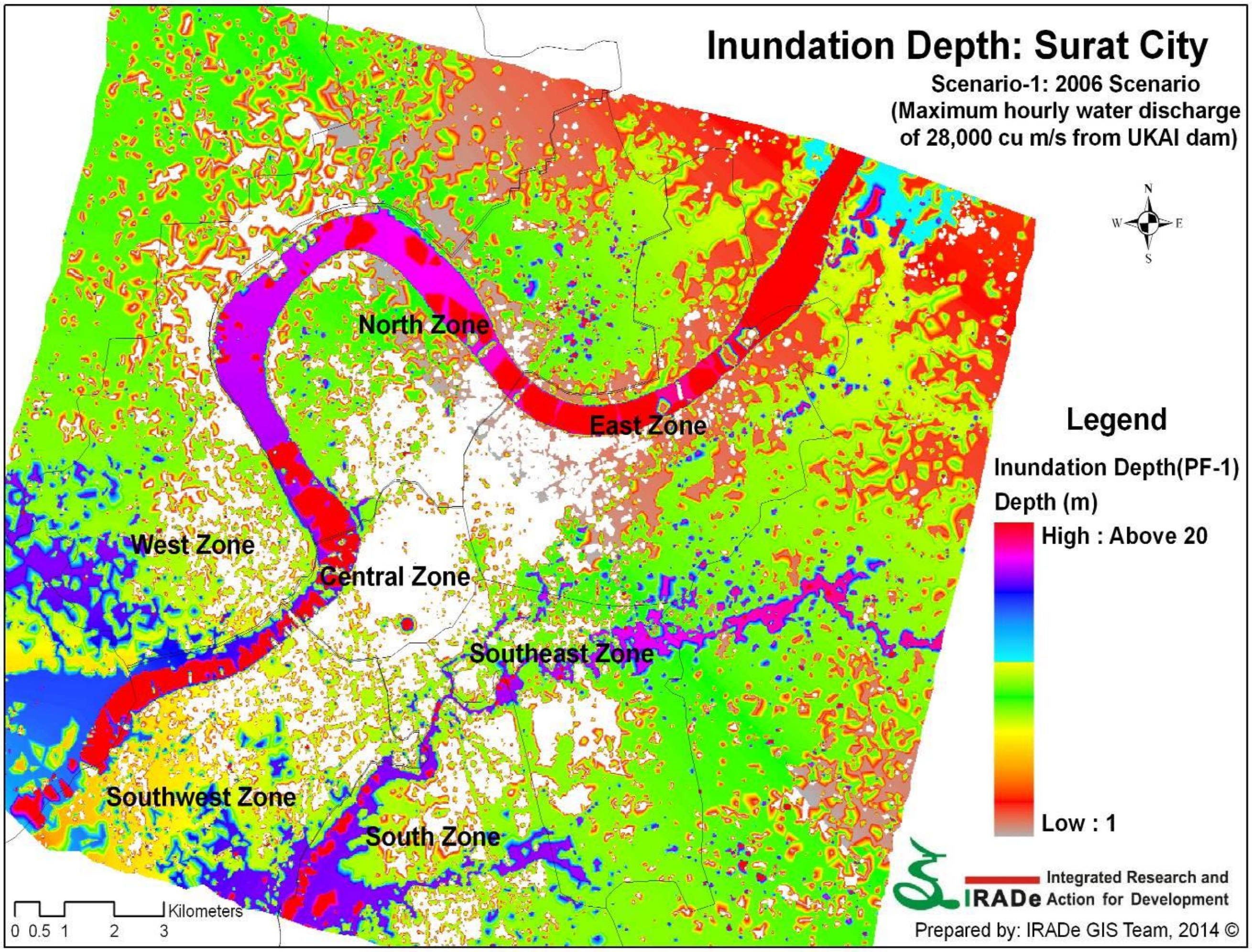


Source: Irrigation Department, Surat

6.2.1 The Reults: Inundation under Differen Scenarios

In scenario 1, when 28,000 cu m per sec water is discharged from Ukai dam, then almost 270 sq km area would get submerged affecting mainly the west, north, central and southeast zones of Surat city. Figure 6.2 shows the inundation map depicting areas submerged and the depth of water.

Figure 6.2: Inundation Depth map of Surat City: Scenario-1



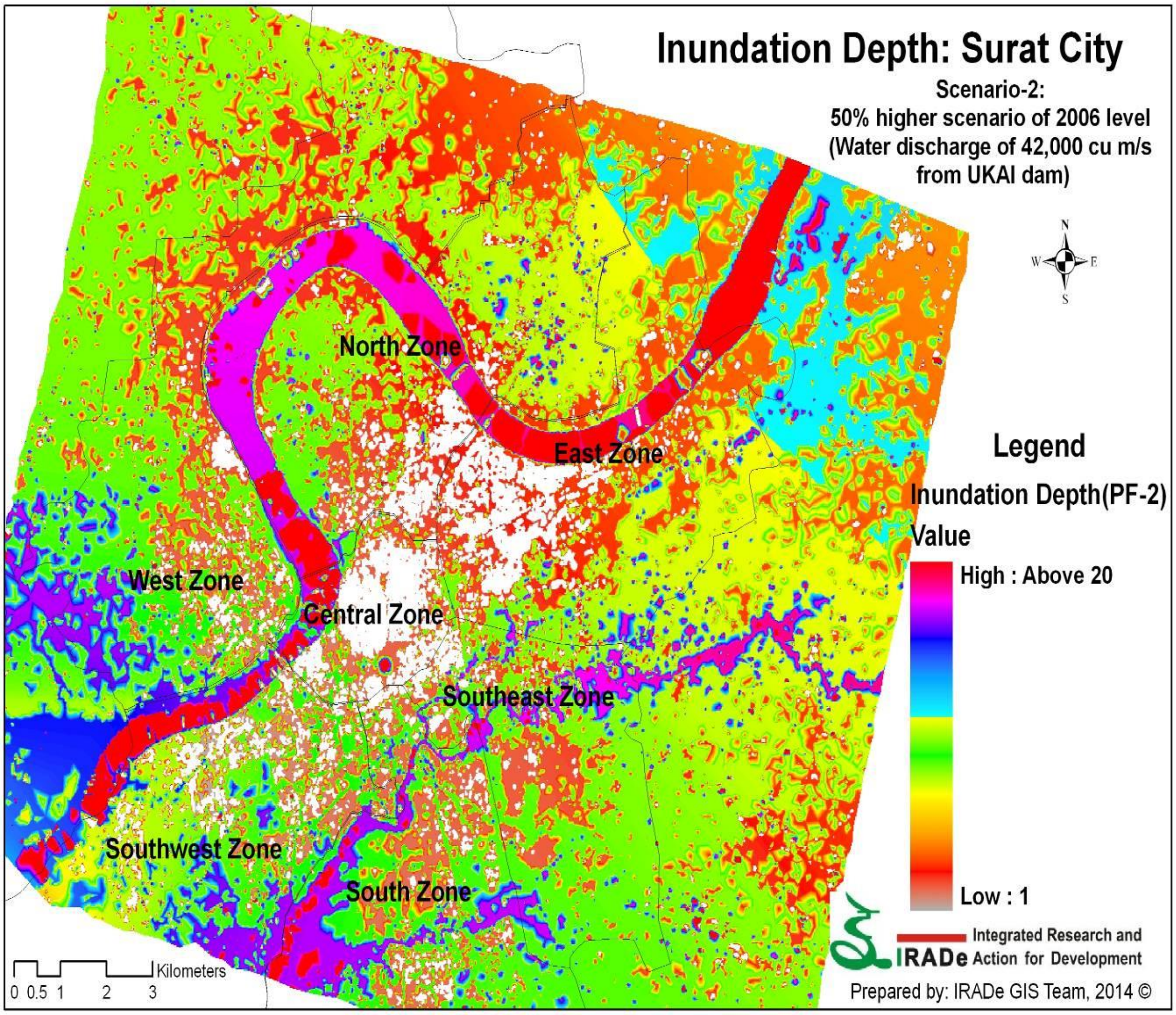
<u>Scenario-1: 2006 Scenario (Maximum hourly water discharge of 28,000 cu m/s from UKAI dam</u>

<u>Scenario-2: 50% higher scenario of 2006 level (Water discharge of 42,000 cu m/s from UKAI dam</u>

From the inundation map, the following zones and important locations have been identified as vulnerable to floods. West, Southeast and North zones have been identified as highly affected whereas Central and Southwest zones are moderately affected to inundation. South zone has been identified as vulnerable to inundation. Some areas of East zones are also vulnerable to inundation due to discharge of 28,000 cu m per second.

In scenario-2, see figure 6.3 when 50% higher i.e. 42,000 cu m per sec water is discharged from Ukai dam, then almost 295 sq km area would get submerged, an increase of 9.25% than that of 2006 level. The analysis clearly depicts most of the parts of west, southwest and north zones will get severely submerged with the increase of 50% in discharge. East and Southeast zones will also be at great risk of flooding.

Figure 6.3: Inundation Depth map of Surat City: Scenario-2

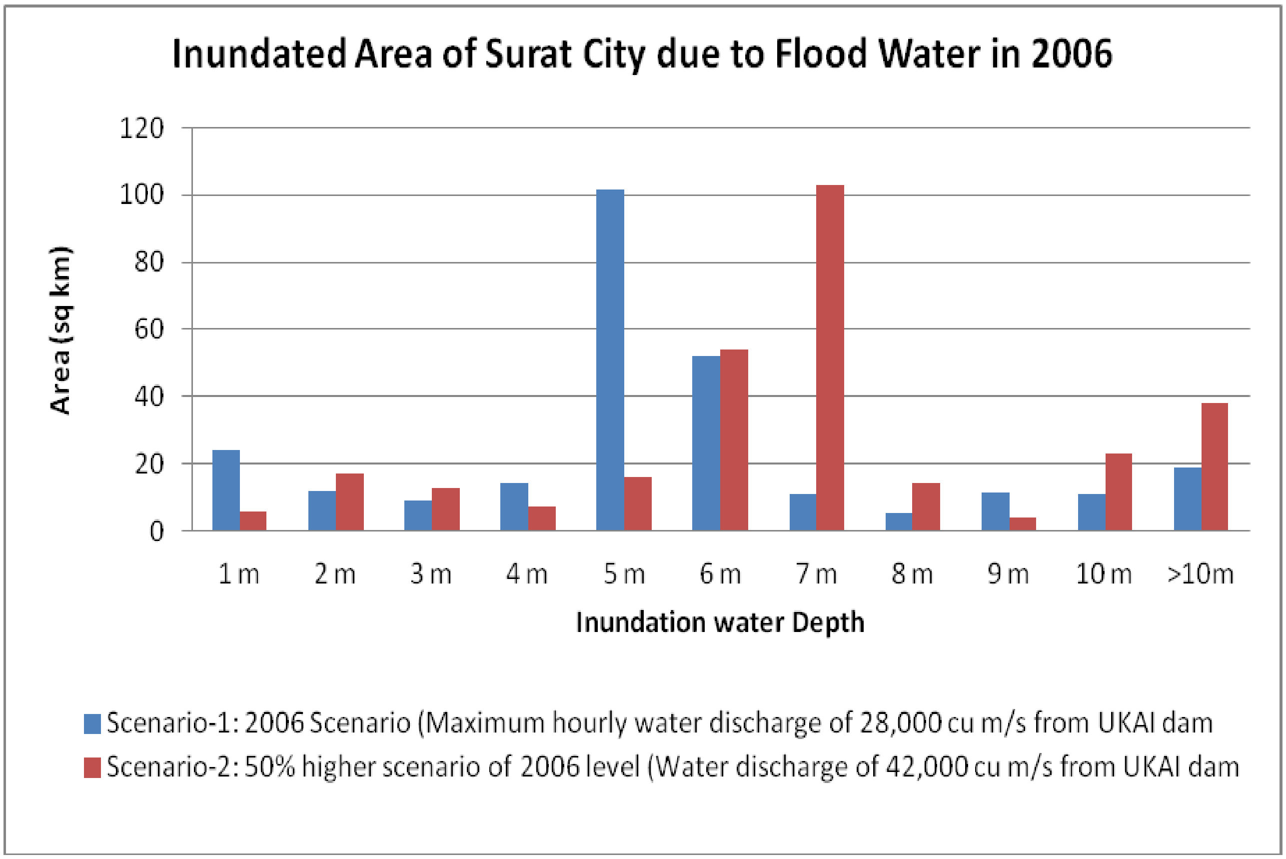


The flood mapping of potential areas after increased discharge for all the zones of the city have been analysed. The possible areas under each inundation depth are depicted with different colours in the zone map. After analysing the flood inundation map, the water levels of the 2006 flood have been compared with Hope (Nehru) Bridge. Moreover, it is found that Hope Bridge has a bank level of 4.1 m; therefore there will be about 3–4 m water over the right-bank area. Hence, the major parts of the Adajan area would get inundated. The Rander area, having experienced fury of 2006 flood, will also be inundateded by 1–2 m depth of water in scenario-2.

Figure 6.4 shows the distribution of area submerged by depth of water in the two scenarios. Under climate change, 230 sq km of Surat city would be under more than 6 meter of water, compared to only 100 sq km in 2006 flood.

After analysis of the inundation map and flooding conditions in 2006 (based on the flood water level) in Surat, the city zones and inundation have been categorized as follows:

Figure 6.4: Inundated Area of Surat City



Submergence in different zones is shown in figure 6.5 and 6.6. Submergence increases in South West zone from around 90 sq km to 103 sq km in scenario 2. In percentage term it increases from 81% to 93%.

Figure 6.5: Zonewise Area submerged in Inundation scenarios of Surat City

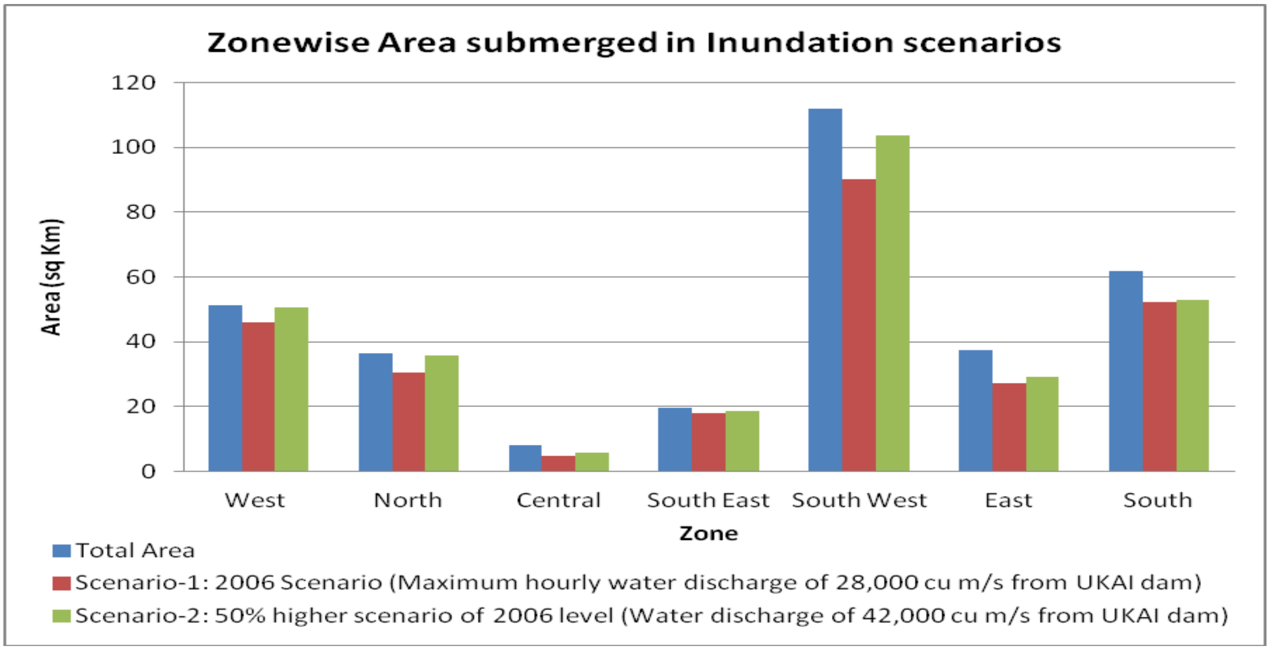
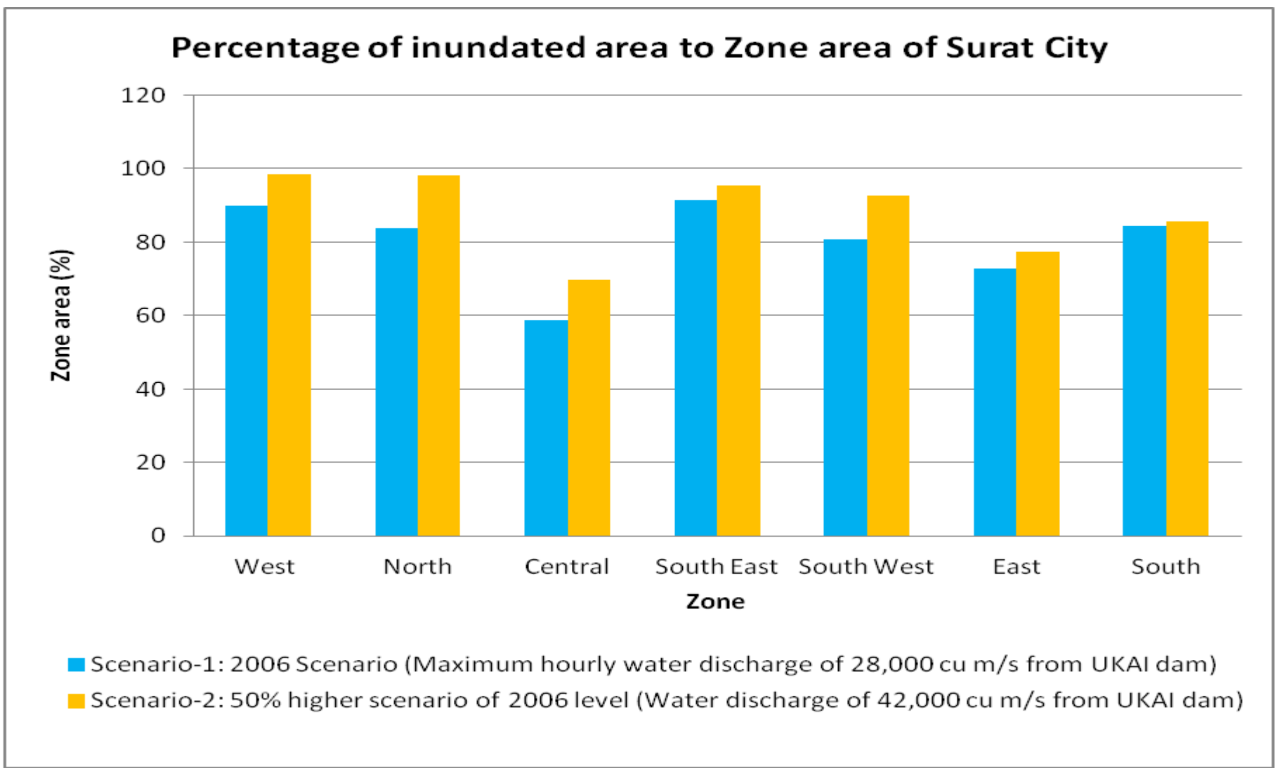


Figure 6.6: Zonewise percentage of area submerged in Inundation scenarios of Surat City



6.2.2 Zone wise Inundated areas:

Following figure 6.7 shows area submerged of each zone at varying inundation depth based on our analysis.

Figure 6.7: Zonewise Area submerged in Inundattion scenarios of Surat City

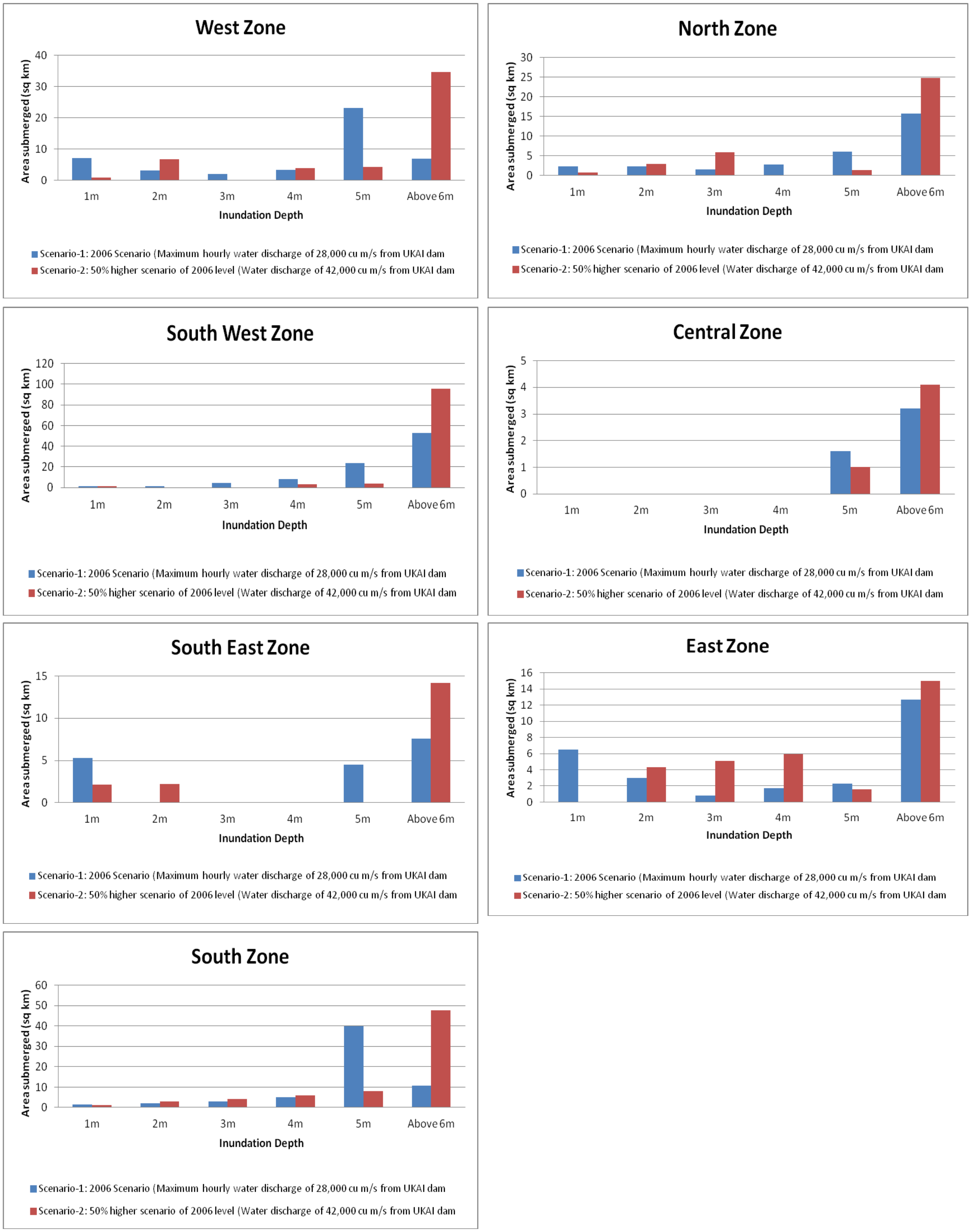
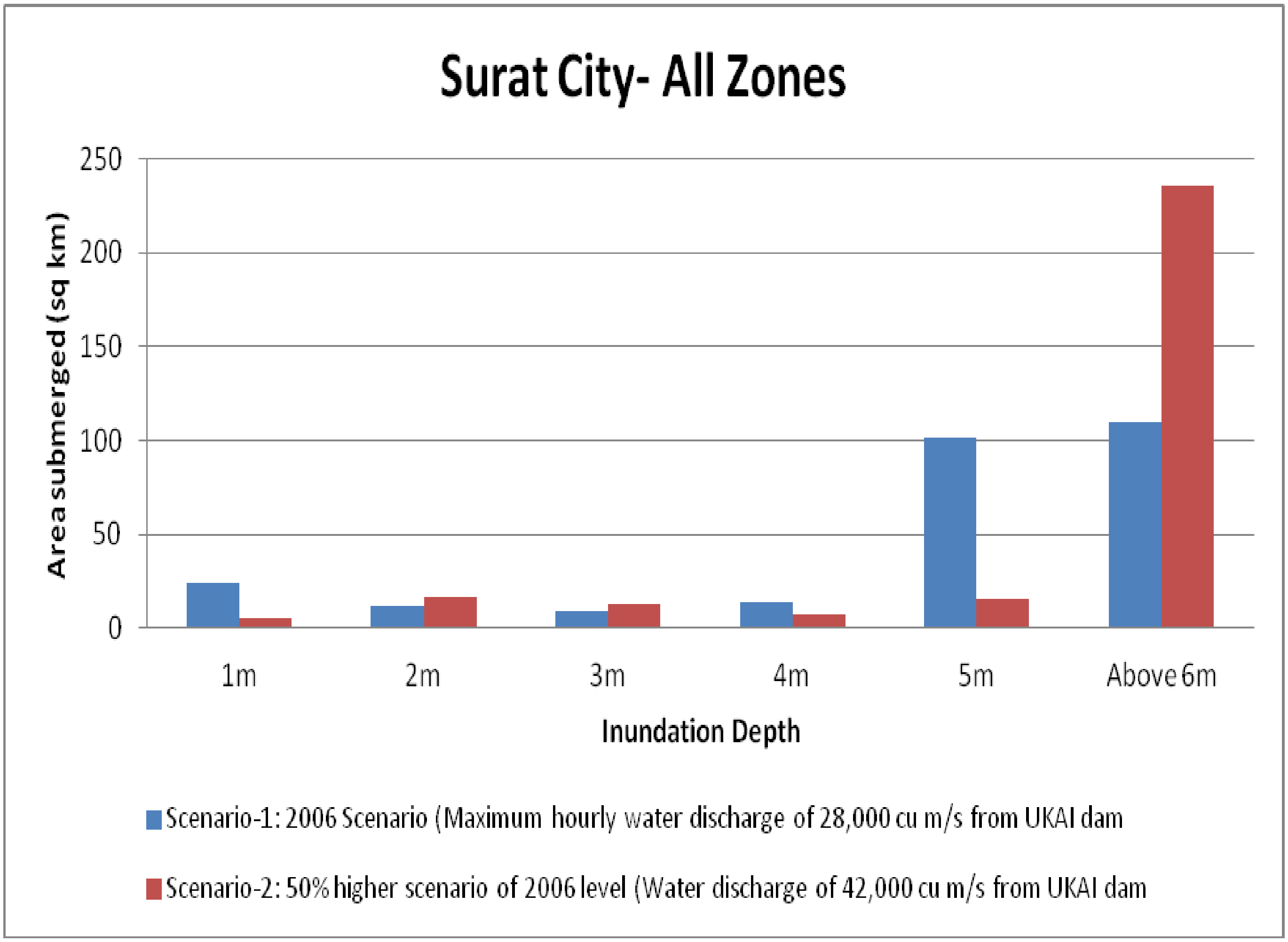


Figure 6.8: Area submerged in Inundattion scenarios of Surat City-All Zones



6.3 Adaptation Measures:

What can Surat do to minimize damage from flooding?

What adaptation measures Surat can take to minimize the damage from flooding?

Among the various options that one might consider are

a) Reducing level of inflows by creating flood plains

b) Raising embankments

c) Early warning to evacuate people to minimize loss

d) Control future expansion in areas that are not flood prone

e) Flood proof infrastructure facilities

a) Reducing inflows: Scope to increase the capacity of UKAI reservoir should be explored. Also models to forecast inflows in UKAI in advance should be made so that capacity to absorb inflows can be increased. Figure 6.9 shows that a flow level of 7 lakh cusec or more will fill the UKAI reservoir in less than three days. Thus if high rainfall continues for few days discharge will correspond to rainfall.

Between UKAI and Surat large flood plains can be developed. This may be difficult as the areas required may be large. If one metre depth of water is to be permitted, a flood plain of some 2000 sq km would be needed.

b) Raising embankment: The cost may be huge as the length and height of needed embankments need to be worked out.

c) Early warning for evacuation: As figure 6.11 shows, releases from UKAI reach Surat in about 8 hours. Thus a system of early warning and shelters could be created. The submergence level of the scenario suggests the nature of shelters required in different zones.

d) Control future expansion: Wide public distribution of the risk and extent of flooding will make buyers aware and builders would be required to build in flood risk free areas. Of course, regulatory authorities should play a role in directing development.

e) Flood proofing infrastructure facilities: Knowing the risk and extent of possible flooding can help in this task.

Figure 6.9: Time required to fill up UKAI Reservoir at different floods

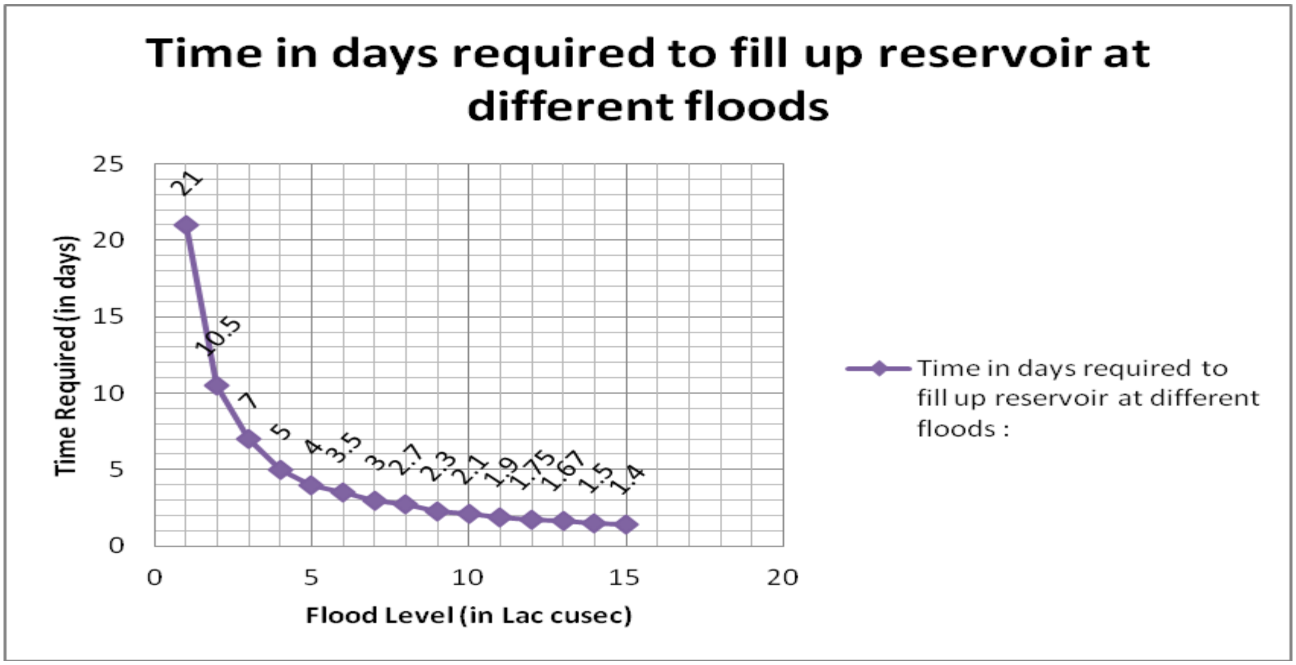
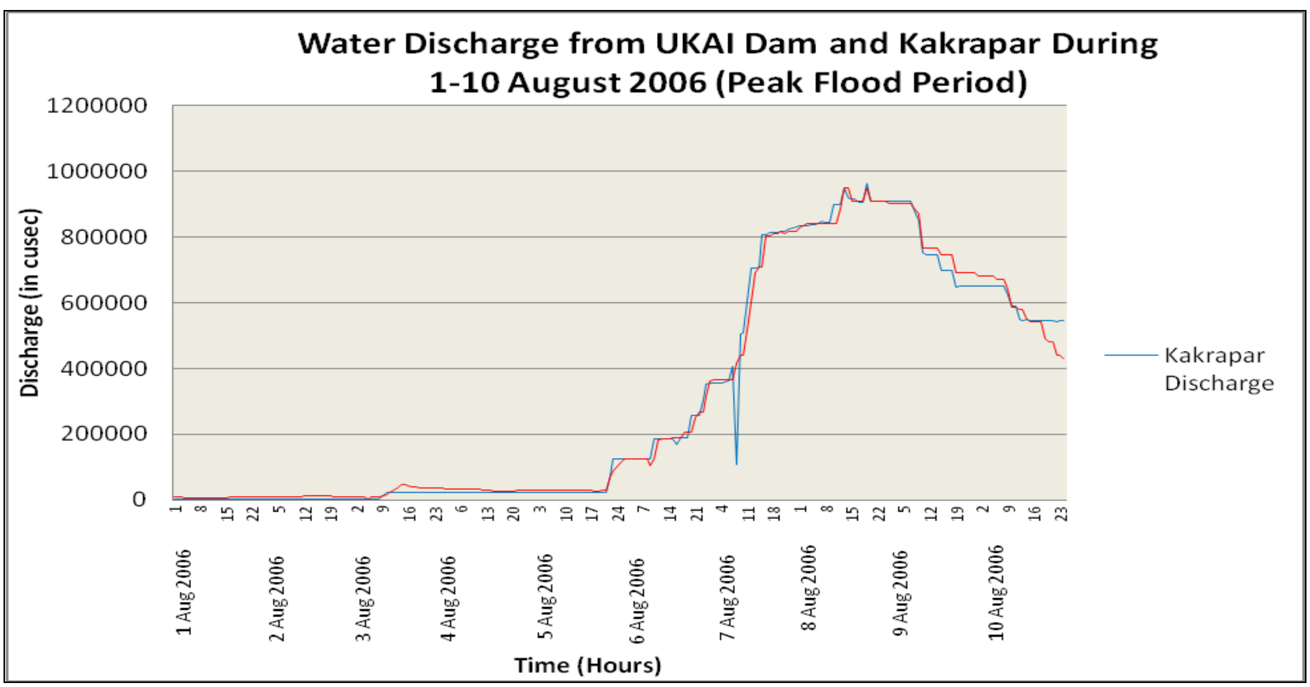


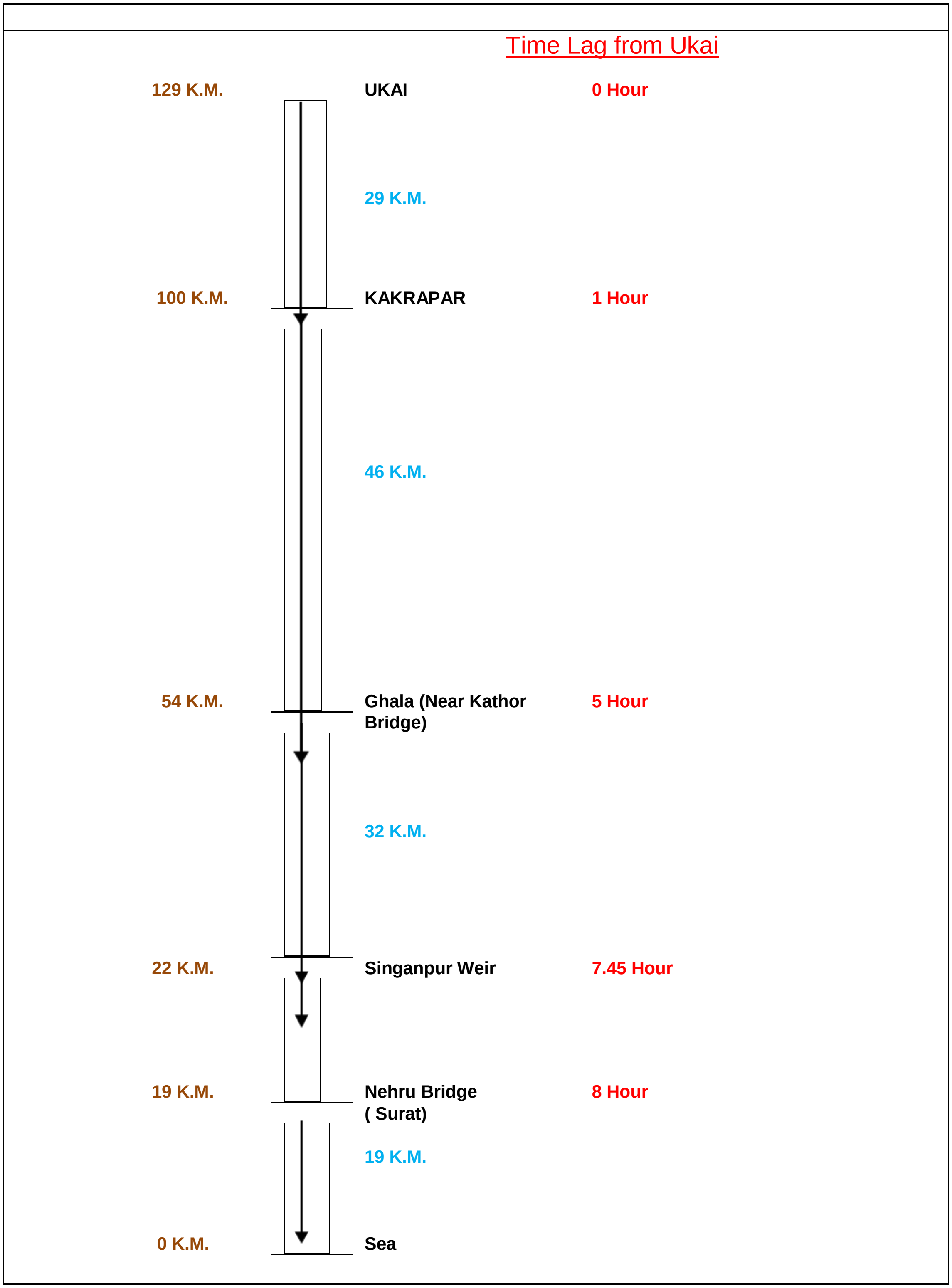
Figure 6.10 shows how much time it will take to fill the UKAI reservoir with different rates of inflows. With inflows above 5,00,000 cusecs it will be filled in 4 days. This is provided if it is empty.

Figure 6.10: Water Discharge fro UKAI and Kakrapar Dams during Peak Flood Period in 2006



Source: Irrigation Department, Surat

Figure 6.11: Line Diagram Of Distance From Surat To Ukai



Thus, if climate change increase rainfall by 30% in the catchment area of UKAI reservoir, the inflows can increase correspondingly but once the reservoir gets filled discharges will increase by all the additional inflows. Therefore, we have taken 50% higher inflows at Surat in climate change scenario.

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PART III: SOCIO-ECONOMIC IMPACTS OF VULNERABILITY

CHAPTER 7: VULNERABILITY OF FACILITIES AND SOCIO-ECONOMIC IMPACTS ON COMMUNITIES

7.1 Introduction

Flood is a cruel and violent expression of water. It leads to human loss, loss of livestock and even has the threat of epidemic break out. The human misery and economic hardships that accompany flood is unfathomable. It ruins already impoverished economy and finance of the state. It can severely stress the finances of the state. The economic loss to homes and personal property, to business facilities and stock, utilities and transportation, and loss of lives are major elements of flood losses. There is a need for sustainable and effective management of floods which requires a holistic approach linking socio-economic development with the protection of natural ecosystems.

Surat is frequently ravaged by the fury of mighty Tapi and its tributaries causing untold human misery and devastation of indescribable nature. The city is located at a point not far from where river Tapi meets Arabian Sea and it has been a flood prone area for centuries. This city is the most flood-prone city in the state of Gujarat, with high vulnerability amongst the poor population and industries. The flood in August, 2006 resulted in huge economic and human life loss to the city. Both physical and social infrastructure of the city was damaged because of the flood. However, city has been facing several floods since 1983 but the flood that occurred in 2006 was the most devastating, it was because there was a heavy seasonal rainfall in year 2006. Whenever there is a heavy seasonal rainfall in the catchment areas there is a flood in the city. Disaster causes both direct and indirect losses. The physical destruction caused by a disaster is considered as direct loss, which includes damage to building, insfrastructure, urban spaces etc. Indirect losses are divided into social and economic effects. Social effects include interruption of communication and transportation, while economic effects are considered to be the cost of reconstruction and rehabilitation. Major flood disasters can be asoociated with disruption of infrastructure. It is virtually impossible to prevent the occurrence of floods, hence, it is imperative to concentrate on minimizing or mitigating the magnitude of their damaging effects by undertaking plausible adaption measures.

To study the problem faced by schools, hospital, slum and industries in the city due to flood we have tried to do micro level studies specific to them . The primary objective of the study is to evaluate and interpret the causes and impact of flood and to identify suitable adaptation strategies specific to the schools, hospital, slum and industries.

In the present study we are creating vulnerability index to measure the vulnerability of schools, hospital, slum and industries which will be useful to gauge the relative differentiated vulnerabilities of different geographical settlement of the city. Index is based on the probability of damages due to flood in the future and intensity of damages incurred in flood in year 2006. Vulnerability Index also takes into account problem faced immediately after floods, duration of inundation etc specific to the sector. Social and economic status of the people concerned to specific sector has also been given due consideration in the index. Vulnerability index provides an input to government machineries at different levels such as Municipal Corporation, State Government and other stakeholders dealing with natural hazards and city planning to make an informed decision and take appropriate actions when there is menace of flood. In recent years rapid growth of new slums, schools, hospitals and industry in the vulnerable zones of the city calls for reliable information at local level (at the level of city and zones within the city) for assessment of socio economic vulnerability.

7.2 Vulnerability Impact Analysis of the Key Locations in Vulnerable Zones

In the quest of knowing the socio-economic aspect of the devastating flood of 2006 in Surat, a field survey has been conducted with a variety of questions to identify the key vulnerable locations in Surat and to understand the impacts of flood in 2006. We have identified four important target groups which are most susceptible in the event of flooding. We have chosen “schools” because children get trapped in the sudden flood and schools receive unimaginable damage. “Hospitals” are naturally vulnerable to pre and post flood events. “Slums” are the most vulnerable targets because of their physical proximity to rivers and water bodies. “Industries” are important because of their economic activities. Our aim of the survey is to look into the socio-economic aspect of the damage caused by the flood to these target groups and their vulnerability to the flood.

Vulnerability is considered a function of exposure, sensitivity, and adaptive capacity of the system in the climate change literature. Exposure refers to degree to which the system is unprotected from the effects of social, political, economic, cultural, institutional and environmental conditions that define the sensitivity or ability of the system. Adaptive capacity refers to the ability to adjust to exposures in ways that limit damages, take advantage of opportunities and cope with impacts (Smit and Wandel, 2006). Adaptive capacity changed with economic wealth, knowledge and skills, social capital and institutions at the local and regional (and national) levels that are dynamic overtime and interact with broader socio-economic and political processes (Watts and Bohle, 1993). Economically disadvantaged populations are disproportionately affected by disasters. The poor are less likely to have the income or assets needed to prepare for a possible disaster or to recover after a disaster. Although the loss suffered by the poor household in monetary value are not very high but given their financial health and absence of insurance the hardship inflicted on them is very high. For the poor household lost property is more expensive to replace than the economically well-off household. Poor households are mostly self employed engaged in their own small business for their livelihood, disaster not only damage their immovable personal assets like house, household stuff and etc but also take away their employment opportunities. Vulnerability is influenced by many factors, including age, income, the strength of social networks, and neighbourhood characteristics. Impact of a disaster on the people leaving in the same area varies by their social and economic affiliation.

There is numerous definition of vulnerability in the literature by different researchers. Chamber (1983) defined that vulnerability has two sides. One is an external side of risks, shocks to which an individual or household is subject to climate change and an internal side which is defencelessness, meaning a lack of means to cope without damaging loss. Blaikie et al., (1994) defined vulnerability as the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impacts of natural hazards and states that vulnerability can be viewed along a continuum from resilience to susceptibility. According to Adger (1999) vulnerability is the extent to which a natural or social system is susceptible to sustaining damage from climate change. It is generally perceived to be a function of two components. The effect that an event may have on humans, referred to as capacity or social vulnerability and the risk that such an event may occur, often referred to as exposure. Watson et al., (1996) defined vulnerability as the extent to which climate change may damage or harm a system, depending not only on a system's sensitivity but also on its ability to adapt to new climatic conditions. Kasperson et al., (2000) defined vulnerability as the degree to which an exposure unit is susceptible to harm due to exposure to a perturbation or stress and the ability or lack of the exposure unit to cope, recover or fundamentally adapt to become a new system or to become extinct.

O'brien and Mileti (1992) examined the vulnerability to climate change and stated that in addition to economic well being and stability, being important in the resilience of populations to environmental shocks, the structure and health of the population may play a key role in determining vulnerability. Age is an important consideration as the elderly and young persons are tends to be inherently more susceptible to environmental risk and hazard exposure. Generally populations with low dependency ratio and in good health are likely to have the widest coping ranges and thus be least vulnerable in the face of hazard exposure.

Handmer et al., (1999) studied the coping mechanisms to environmental shock or hazard brought about by biophysical vulnerability. The factors like institutional stability and strength of public infrastructure are crucial importance in determining the vulnerability to climate change. A well connected population with appropriate public infrastructure will be able to deal with a hazard effectively and reduce the vulnerability. Such a society could be said to have low social vulnerability. If there is an absence of institutional capacity in terms of knowledge about the event and ability to deal with it, then such high vulnerability is likely to ensure that biophysical risk turns into an impact on the human population.

Atkins et al., (1998) studied the methodology for measurement of vulnerability and to construction of a suitable composite vulnerability index for developing countries and island states. The composite vulnerability indices were presented for a sample of 110 developing countries for which appropriate data was available. The index suggests that small states are especially prone to vulnerable when compared to large states. Among the small states, such as Cape Verde and Trinidad and Tobago are estimated to suffer relatively low levels of vulnerability and majority of the states estimated to experience relatively high vulnerability and the states like Tonga, Antigua and Barbedas being more vulnerable to external economic and environmental factors.

Chris Easter (2000) constructed a vulnerability index for the commonwealth countries, which is based on two principles. First, the impact of external shocks over which the country has affected and second the resilience of a country to withstand and recover from such shocks. The analysis used a sample of 111 developing countries of which 37 small and 74 large for which relevant data were available. The results indicated that among the 50 most vulnerable countries, 33 were small states with in this 27 are least developed countries and 23 are islands. In the least vulnerable 50 countries, only two were small states.

There are various techniques developed by researcher, policy makers and etc to measure the vulnerability of the system with the natural hazards. Vulnerability to natural hazard focused on the physical world, emphasizing infrastructure and technology. The concept of vulnerability is also changing and it now encompasses social aspect to it. The new concept of social vulnerability was introduced in the 1970s when researchers recognized that vulnerability also involves socioeconomic factors that affect community resilience (Juntunen 2005).

INCOIS (2012) calculated coastal vulnerability index for the coastal cities of India. To calculate coastal vulnerability index all the input parameters with different spatial resolutions were interpolated in to one km segments and these values were transferred to the corresponding section of the coastline. Each coastal section has risk ratings of all the seven variables under consideration. The coastal vulnerability index (CVI) is then calculated as the square root of the product mean of the seven variables. The formula used to calculate CVI is as follow

$$\textbf{CVI} = \sqrt{[(a * b * c * d * e * f * g)/7]}$$

Where a = Shore line change rate

b = Coastal Slope
c =Coastal Regional Elevation
d = Coastal Geomorphology
e = Sea-level change rate
f= Significant Wave Height

and g = Tide Range

Vulnerability is a sub component in evaluating overall risk (expectation of loss) related to the natural disaster. Disaster management researches also recognize that “Risk” is directly related to vulnerability and inversely related to resources. Higher the vulnerability of the system higher would be “risk” whereas higher the resources at disposal to society to cope up with disaster lower would be the “Risk” to the system.

Vulnerability of a locality also depends upon the planning of local response and relief organization. Local authorities are in the best position to identify vulnerable communities as they have more information about the available infrastructure, social and economic status of area. But such agencies are commonly underfunded, understaffed, and stretched thin by ongoing other responsibilities like health and social service. State or central authorities though sufficiently funded and staffed may lack the micro level knowledge about the area and lack the system in place to allocate resources based on the need.

7.3 Methodology

Surat city is divided into seven zones by the definition of SMC. Our approach in this study is to focus primarily on four most affected zones of the city for schools, hospitals, slums and industries. Primary survey with stakeholders located in the four most vulnerable (indentified through hydrological analysis) zones specific to schools, hospitals, slums and industries carried out. Primary survey was conducted to understand the intensity of damage caused due flood to hospital, slum, industry and school.

To conduct survey study has taken stratified convenient sampling method for collecting data. Stratification is the processes of dividing members of the population into homogeneous subgroups before sampling. On the other hand, convenience sampling is a non probability sampling which involves the sample being drawn from the population for their convenient accessibility and proximity to the researcher. Out of seven zones, we have selected four zones basis their level of vulnerability i.e. selection of four subgroups out of seven groups. Samples are drawn from the selected four zones for generating an appropriate data set and the analysis has been done by using elementary statistical techniques.

7.3.1 Design of questionnaire

Survey questionnaire was broadly divided in 8 sections that are: 1 Basic information about selected sector, 2 Infrastructure, 3 Water supply and sanitation, 4.Finalcial management, 5 Past flood experience, 6 Effects of flood on various parameters specific to the sector, 7 Flood warning measures and 8 Adaptation measures. All questions were significant for generating an appropriate data set.

7.3.2 Assigning weights to indicators

Assigning weights to different vulnerability indicators is a difficult task. In the analysis, it is assumed that overall vulnerability of sector depend on all the vulnerability indicators considered but the likelihood of occurrence of a particular vulnerability indicators during an event of disaster varies distinctly. Likelihood of occurrence of particular vulnerability parameters depends on the exposure and risk reduction measures taken by sector pertaining to particular vulnerability parameter. Most importantly likelihood of getting affected and the level of loss measured on a particular parameter depend on the geographical location. Low lying areas are more prone and likely to suffer higher level of damage.

To capture variation in magnitude of vulnerability of a sector we have assigned weights to different vulnerability parameters reflecting probability of damage and the intensity of damage. Weight to a parameter situated at a given geographical location is based on the probability of damages for varying levels of submergence during flood in 2006. (for details refer to the box below having vulnerability defined as per the level of flood water during flood). It is reasonable to assume that the extent of damage will be linearly related to the level of submergence hence, we have assigned a continuous increasing weight for each submergence levels. Matrix (table.7.1) shows a hypothetical example of assignment of weights to various parameters.

Table 7.1: Assignment of weights to various vulnerability parameters

	Submergence level 1Meter	**Submergence level between 1Meter to 2Meter**	**Submergence level more than 2 Meter**
Total Sample	**7**	**8**	**41**
Affected (incurred loss) sample	3	2	18
Weight specific to level of submergence during 2006 flood	1	2	3
Assigned weights to Parameter	(3/7)*1	(2/8)*2	(18/41)*3

Submergence levels

- **Low submergence**: Flood water level up to 1Meter in the area during 2006 flood
- **Moderate Submergence**: Flood water level between 1 Meter to 2 Meter in the area during 2006 flood
- **High Submergence**: Flood water level above 2 Meter n the area during 2006 flood

7.3.3 Normalization of continuous indicators

Indicators specific to the sectors are mixed of continuous and dichotomous variables. Indicators are measured in different units and scale hence there is a need to normalize the continuous indicators to make it unit free for calculation of vulnerability index. We have used the normalization methodology similar to UNDP's Human Development Index (HDI-UNDP, 2006). The variables values for an indicator are normalized so that mean is zero and range is 1. There exist direct relations between vulnerability value and indicator value i.e. if vulnerability increases the value of indicator also increases and vice versa therefore higher indicator value shows higher vulnerability. Normalisation has been made by using following formula.

$$\mathbf{Xi=} (Xi- Min \{Xi\})/(Max \{Xi\}-Min \{Xi\})$$

Where X_i is the actual numeric value of indicator "i".

7.3.4 Vulnerability Index (VI)

This study attempts to create a composite vulnerability index (VI) for industry, slum, hospital and schools from the different indentified vulnerability indicators specific to each of them. Vulnerability is the product of probability of damage and intensity of damage.

Vulnerability (VI) = ∑ (Probability of damage to a parameter) X (Intensity of damage to parameter)

7.4 Vulnerability Analysis of selected locations and targets in Surat City

7.4.1 Vulnerability Analysis of Schools

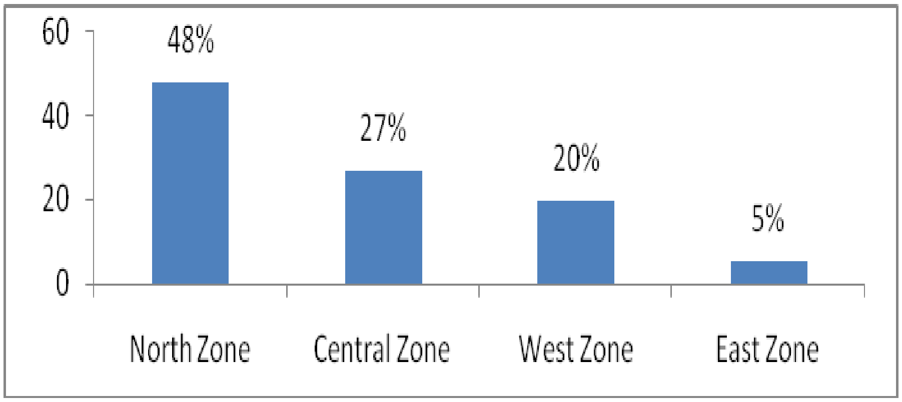
7.4.1.1 Introduction

Schools play a multiple role, it is not only used as education, and sometimes it is treated as safe shelter. Disaster has three impacts, Educational impact, physical impact and Economic impact. Educational impact implies that the damage of schools, disruption of educational rights and it also reduces quality of education and loss of time. Physical impact portrays that student loss their sense of continuity and their hopes and plans for the future are destroyed. Economic impact reveals the loss of income and reinvestment for repairing damage part of schools. Education is the basic requirement for a country's economic development. Educational infrastructure often plays a significant role in ensuring sustainable development. This section of the study delves into the flood vulnerability and adaptation measures for schools.

7.4.1.2 School Sample Composition

We have selected a total 56 sample schools from four selected zones, sample from north zones are 48 percent of total selected schools whereas a merely 5 percent samples are selected from the east zone (fig7.1).The schools were selected because it is readily available and convenient. We tried to cover schools from different cross sections and locations within the city to be able to understand the vulnerability of schools by zones.

Figure 7.1: School sample distribution by Zone



Source: Primary data collection by IRADe

Representation from the various categories of schools was tried to ensure in the sample composition. In the schools sample 48 per cent schools are higher secondary schools, 27 per cent schools are secondary 25 per cent schools are primary schools. School sample comprised 34 percent Government schools, 57percent private and the remaining 5 per cent semi-private schools.

Figure 7.2: Schools Category

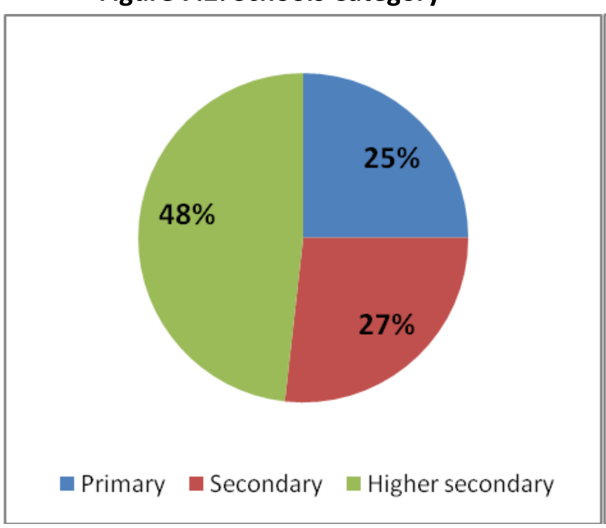
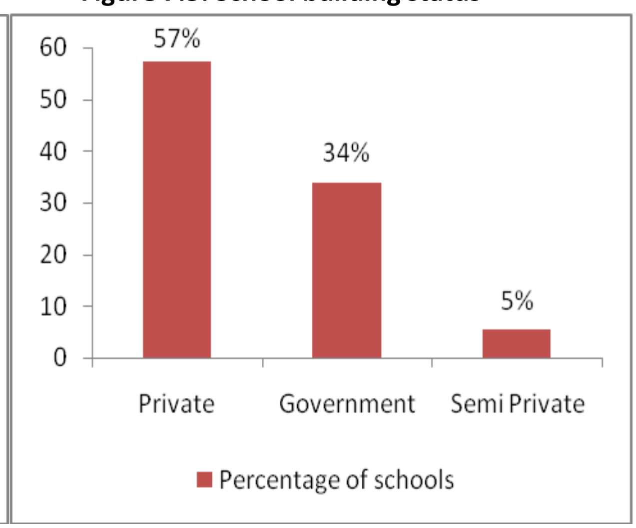
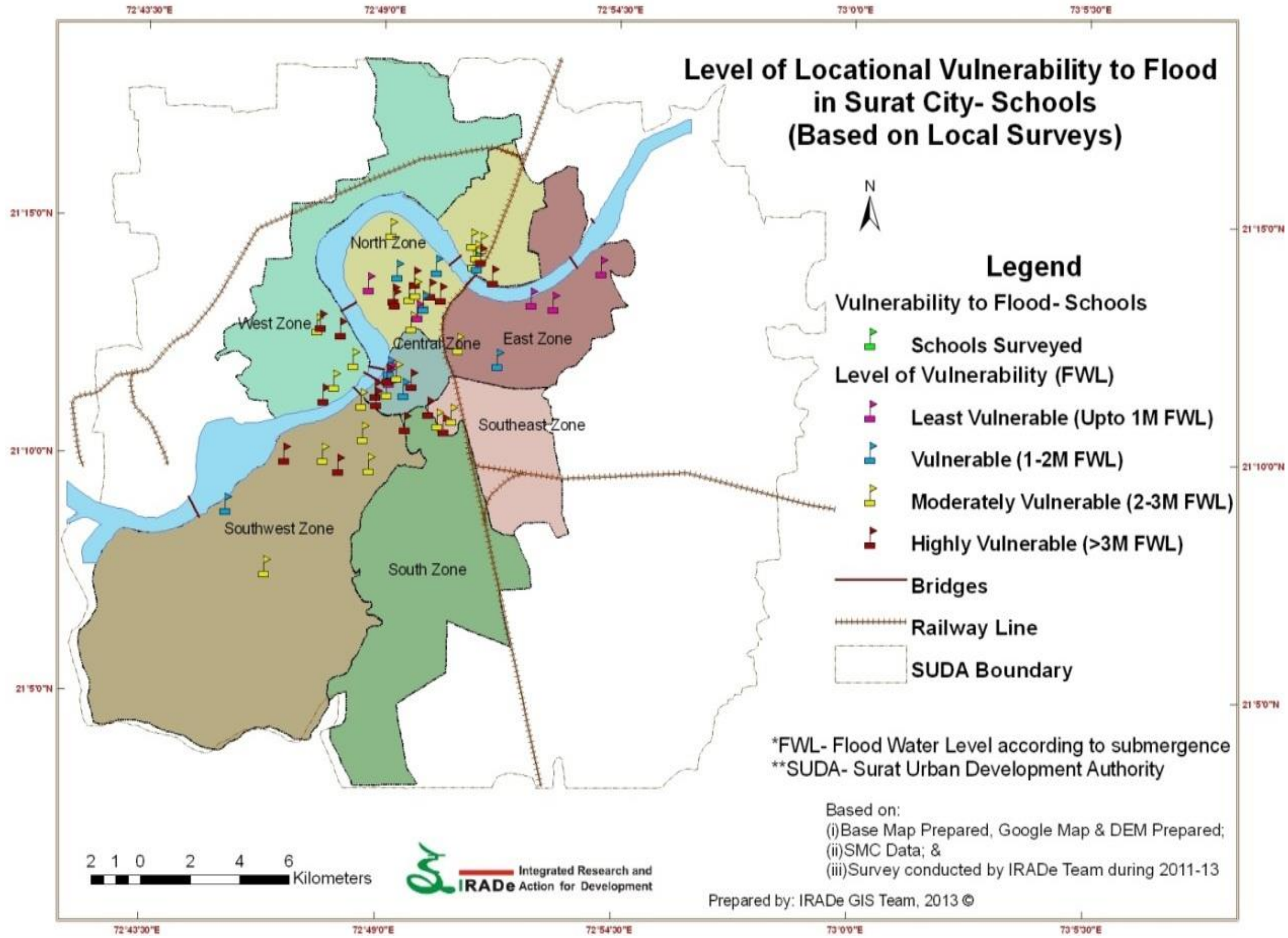


Figure 7.3: School building status



Source: Primary data collection by IRADe

Figure 7.4: Schools surveyed during IRADe primary survey and level of vulnerability based on flood water level in flood event 2006

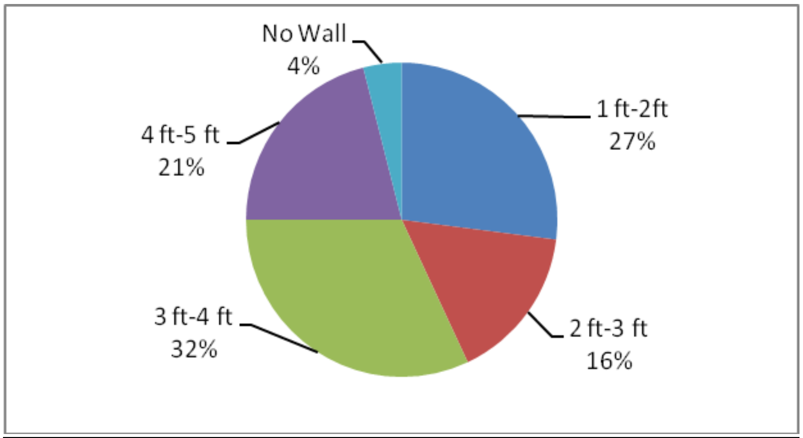


Source: Primary data collection by IRADe

7.4.1.3 School infrastructure

Boundary wall is an important infrastructure resist flood water to enter into the school building. Merely 27 percent schools surveyed have pucca boundary wall having height ranging between 1feet to 5 feet (fig 7.5). SMC used to check the sanitation and drinking water facility of schools after each flood events only after checking drinking water and sanitation by SMC then schools were permitted to reopen.

Figure 7.5: Height of Boundary Wall (Kutcha +Pucca) from the ground



Source: Primary data collection by IRADe

Flood in 2006 had affected three fourth of the schools surveyed in zones of Surat city. Schools in the west and north zones got flooded twice and thrice respectively during different flood events in the last decade (Table 7.2). Post flood students absenteeism in schools had increased dramatically. More than 60 percent of the schools surveyed had reported student absenteeism after floods. Students were unable to commute to school due to transportation problem and because their houses were also flooded. Out of 56 schools surveyed 33 schools had reported absenteeism of students post flood in 2006.

Table 7.2: Occurrences of flood in schools

Schools closed	School	% Schools
1 month	North Zone, West Zone	36
25 days	North Zone, West Zone	18
More than a week	Central Zone	14
One Week	Central Zone, East Zone	32

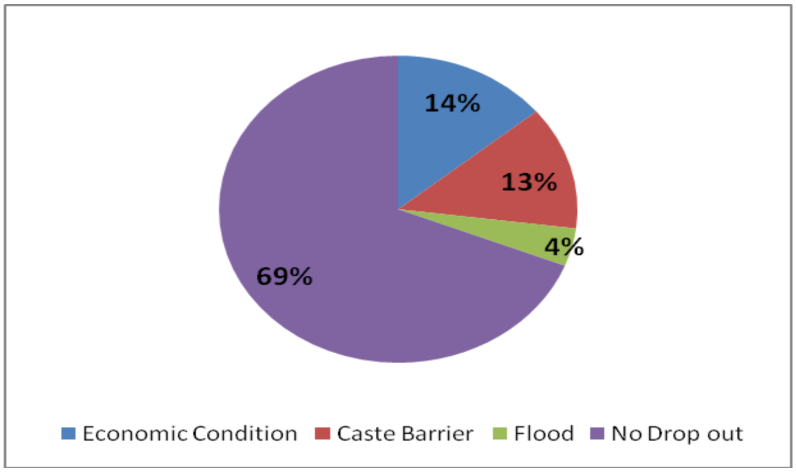
Economic condition of the parents and caste of the students did play a role in the students drop out from the school (fig 7.6).

Table 7.3: School closed due to flood

Flooded	% Schools	Zone	Year
Once	73	Central,East,North,West	2006
Twice	18	West	1998 2006
Thrice	9	North	1998 2002 2006

Source: Primary data collection by IRADe

Figure 7.6: Drop out of girl student



Source: Primary data collection by IRADe

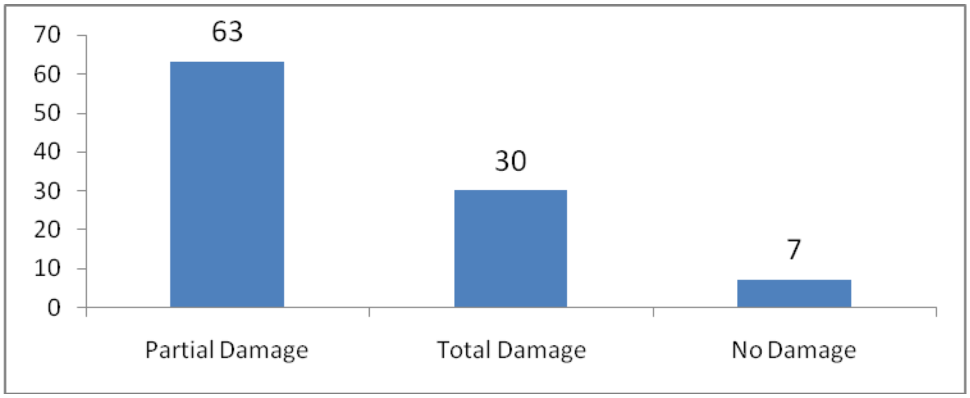
Flood had worsened the communication, transportation and had done structural damage also. Flood is a threat for structural damage which leads to school closure for a certain period and also reduces the education quality. In this survey we have seen infrastructure damaged due to flood. School building, floor, wall, boundary wall, electrical equipments, power disruption and telephone were severely affected. According to our survey data 80 per cent of the schools have faced disruption in communication and transportation.

A picture taken during flood event 2006 in Surat City

Soure:https://www.google.co.in/?gfe_rd=cr&ei=rdkEU9qPD4LC8ged**oDwDQ#q=flood+surat+2006+photo**

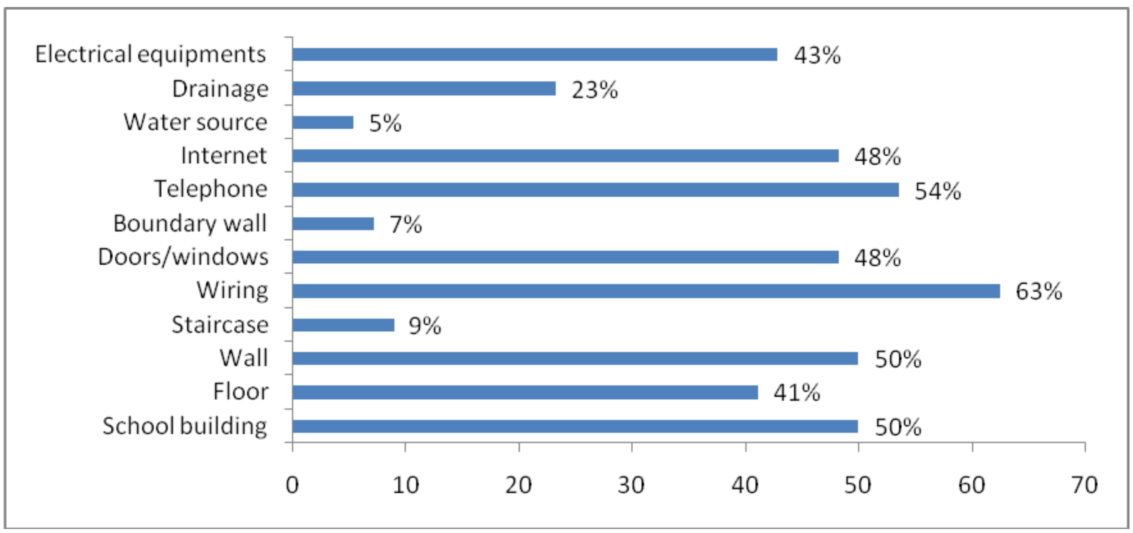
It can be observed from figure 7.7 that, 30 per cent of schools reported complete damage of furniture because of flood whereas 20 percent schools reported partial damage and another 20 percent reported moderate damage of furniture. Small percent (10 percent) of schools reported no damage of furniture due to flood. Flood has not only affected the overall infrastructure relating to school, it has also affected severely to the communication and transportation. During this survey we have found that after flood the schools faced so many problems like, damaged furniture in the class room, bad smell, wiring problem, unsafe drinking water, less vehicles on road and also lost official documents. These had created an unhealthy situation for students and formed more vulnerability to the schools.

Figure 7.7: School furniture damage due to flood



Source: Primary data collection by IRADe

Figure 7.8: Damage to infrastructure of surveyed schools

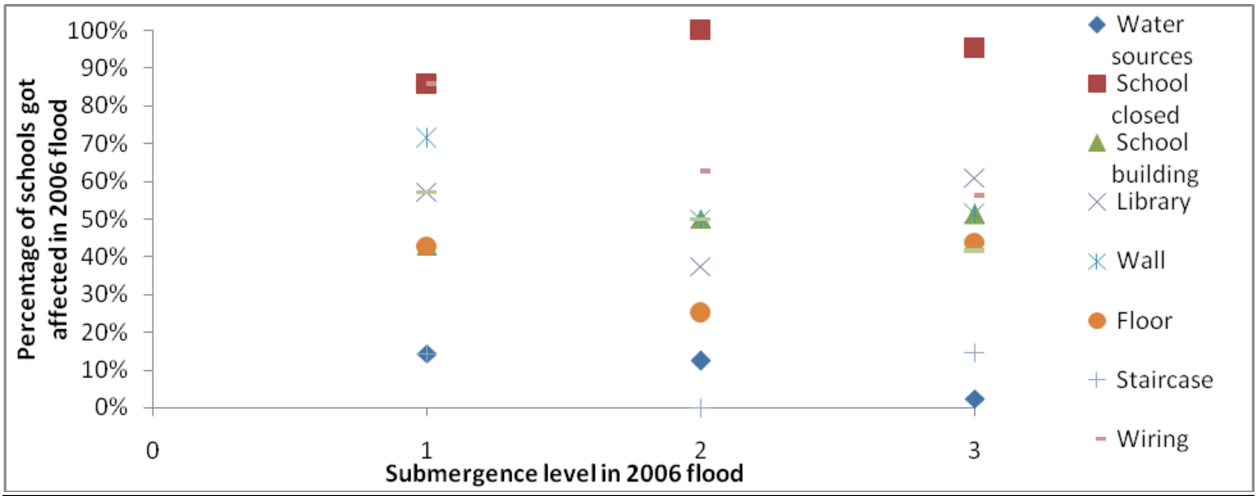


Source: Primary data collection by IRADe

7.4.1.4 Weights to Parameters

All the indicators are chosen in constructing vulnerability index have impact on vulnerability of the school to the flood events. For example, damage cause to library, damage cause to boundary wall, and damage cause to school telephone and etc all contribute to vulnerability of the school to flood. Vulnerability index constructed is a formative measurement and the indicators chosen need not have internal correlation.

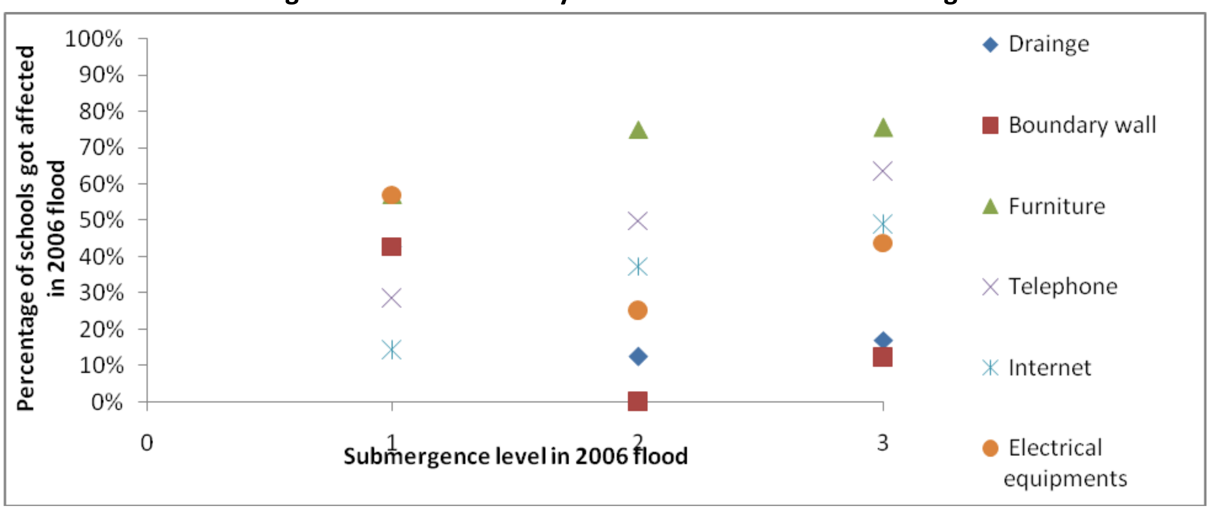
Figure: 7.9 Vulnerability of schools at different submerge level



Source: Primary data collection by IRADe

In the plot horizontal axis depicts submergence level during flood event in 2006 while vertical axis shows ratio of effected sample to the total sample for a particular attributes of schools for a given submergence level (fig 7.9 and fig 7.10- indicators are plotted in 2 charts to avoid it getting cluttered).In this analysis we have considered 3 submergence levels 1) 0 to 1 Meter 2) 1 to 2 Meter, 3) More than 2 Meter based on flood events in the city in 2006.

Figure 7.10: Vulnerability of schools at different submerge level



Source: Primary data collection by IRADe

Schools closure was reported by 100 percent of the sample school irrespective of submergence levels during the flood event in 2006. Because of proactive approach of SMC to check the sanitation and drinking water facility of each schools post flood menace of water source getting affected was reported by a very small percentage of schools. Schools were permitted to reopen only after checking the drinking water and sanitation by SMC. Flood causes damage to the library, approximately 60 percent of schools in high submergence areas above 2 meters. Schools building damage was reported by 40 to 50 percents of the schools across the submergence levels. It is a general understanding that with increasing submergence levels damage to the infrastructure of the schools should also increase i.e. schools located in the areas in 0 to 1 Meter submergence level would have lesser percentage of schools reporting damage to a particular infrastructure than the schools located in the areas of 1 to 2 Meter submergence level. But there are other factors like plinth heights, heights of boundary wall, drainage system and etc of the schools also play a significant role and decide the level of damage caused to the schools because of a particular flood event.

A small percentage approximately 15 to 20 percent in the high submergence areas reported damage to their drainage system whereas 45 percent schools in a submergence level 0 to 1 reported damage of draining due to flood. With increasing level of submergence, percentage of schools reporting damage to furniture also increases similar trend was also reported for damage to the communication system (internet and telephone).To devise weights for the different parameters in the vulnerability index we have considered percentage of effected sample to the total sample school at different submerge level.

7.4.1.5 Vulnerability Index for Schools

Social vulnerability analysis is considered as one of the most important and widely used methods for addressing the social effects and capacity to recover from the adverse effect of disaster. Since vulnerability calculated is dynamic over time hence all the indicators are relate to a particular time point only. Vulnerability index will help to identify human suffering and the economic loss related to providing social services and public assistance after an incidence of disaster.

These tables have shown the different submergence level owing to flood in 2006 and vulnerability of schools. Value of vulnerability index and level of vulnerability have linear relation i.e. higher the vulnerability index higher would be the vulnerability and vice-versa. Vulnerability constructed in this analysis for each sample depicts the level of vulnerability of each school located in different zones of the city.

Table 7.3: Flood Water Level upto 1 Meter during 2006 flood

Zone Name	School Category	Vulnerability
Central zone	Secondary	0.11
Central zone	Primary	0.17
East zone	Higher Secondary	0.46
East zone	Higher Secondary	0.46
East zone	Secondary	0.47
North zone	Higher Secondary	0.31
North zone	Primary	0.10

Source: IRADe Analysis

Average vulnerability index for the schools in the east zone of the city having inundation level between 0 to 1 meter during the 2006 flood is 0.30 and insignificant variance in vulnerability index of the selected sample school. Similarly average vulnerability index for schools in the central zone is 0.14 and have small variance. This implies that the schools located in the East zone are more likely to suffer infrastructure damage in the event of flood than other zones of the city (table 7.3).

Table 7.4 Flood Water Level from 1 Meter to 2 Meter during 2006 flood

Zone Name	School Category	Vulnerability
Central zone	Primary	0.54
Central zone	Secondary	0.20
North zone	Higher Secondary	0.48
North zone	Higher Secondary	0.46
North zone	Higher Secondary	0.43
North zone	Higher Secondary	0.57
North zone	Higher Secondary	0.45
West zone	Higher Secondary	0.75

Source: IRADe Analysis

Average vulnerability index for the schools in the North zone of the city having inundation level 1 to 2 meter during the 2006 flood is 0.48. Average vulnerability index for schools in the central zone has high variances. We can infer that schools located in the west and north zone of the city are more vulnerable to the flood (table 7.4).

Table 7.5 Flood Water Level above 2 Meter during 2006 flood in central zone

Zone Name	School Category	Vulnerability
Central zone	Secondary	0.88
Central zone	Higher Secondary	0.91
Central zone	Secondary	0.73
Central zone	Secondary	0.80
Central zone	Secondary	0.80
Central zone	Secondary	0.92
Central zone	Secondary	0.37
Central zone	Secondary	0.29
Central zone	Secondary	0.61
Central zone	Higher Secondary	0.71
Central zone	Primary	0.55

Source: IRADe Analysis

Table 7.5, 7.6 and 7.7 show the vulnerability index of schools in central, north and west zone having inundation level more than 2 meters during 2006 flood. Average vulnerability index of the sample schools located in the central zone of the city is 0.69 and having insignificant variances for the sample schools (table 7.5).

Table 7.6: Flood Water Level above 2 Meter during 2006 flood in north zone

Zone Name	School Category	Vulnerability
North zone	Higher Secondary	0.66
North zone	Higher Secondary	0.97
North zone	Primary	0.97
North zone	Primary	0.65
North zone	Higher Secondary	0.94
North zone	Primary	0.82
North zone	Secondary	0.94
North zone	Higher Secondary	0.86
North zone	Primary	0.97
North zone	Secondary	0.90
North zone	Primary	0.82
North zone	Higher Secondary	0.99
North zone	Higher Secondary	0.80
North zone	Secondary	0.91
North zone	Primary	0.81
North zone	Higher Secondary	0.90
North zone	Primary	0.72
North zone	Primary	0.81
North zone	Primary	0.89
North zone	Higher Secondary	0.94

Source: IRADe Analysis

Average vulnerability index of the sample schools located in the north zone of the city having inundation level above 2 meter during 2006 flood is 0.86 and for west zone schools average vulnerability index is 0.89 (table 7.6 and table 7.7).

Table 7.7 Flood Water Level above 2 Meter during 2006 flood in west zone

Zone Name	School Category	Vulnerability
West zone	Higher Secondary	0.88
West zone	Primary	0.87
West zone	Secondary	0.81
West zone	Higher Secondary	0.76

West zone	Higher Secondary	0.87
West zone	Higher Secondary	0.95
West zone	Higher Secondary	0.88
West zone	Higher Secondary	0.96
West zone	Higher Secondary	0.94
West zone	Higher Secondary	0.97

Source: IRADe Analysis

Fig 7.8 Pictures taken by IRADe team depicted below shows the mark of water level during 2006 flood. Maximum water level had reached up to 8ft that was shown in this picture.

The average high value for the vulnerability index shows that schools are located in high very risk areas and are likely to suffer high damages to their infrastructure in the event of flooding. Schools located in the low lying area of the west and north zones are required greater attention and preparedness by the local authority in case of flooding in the city.

7.4.1.6 Adaptation Measure Proposed for schools

Many educational institutes remain closed for long time. Some schools in north zone and west zone were closed for 1 month. During this phase of time, students have given up their valuable time and quality of education. Some students were absent due to flood. They faced the disruption like road destroyed, traffic delay and house flooded. Discontinuing of their study has a stern adverse impact on their mind. While the schools are still now in flood prone area, they have not introduced essential adaptation measures that are urgent need of the hour. They have been facing repeated flood that yielding repeated loss and damages. After a devastating flood of 2006, some Surat schools have taken few adaptations to rescue their school from flood. This is an attempt to modify the ecology, social or economic system in response for changing the conditions. Adaptation can be classified as spontaneous and planned adaptation. Spontaneous adaptation signifies immediate adaptation that is taken by individuals institute or authority of schools while planned adaptation is taken by higher authority (like state or central Government). This picture elucidates a planned adaptation of the structure of building. This has been constructed in such a way that if flood comes, it does not damage the building.

Source: IRADe

Planned Adaptation

- Disaster related curriculum would be incorporated in school syllabus.
- Disaster preparedness training must be taken place with teacher and students.
- Affected or damaged schools will be immediately repaired and reconstructed.
- Ground floor of the schools is used as play ground.
- Library and Laboratory must be situated on upstairs of the schools.
- The boundary wall must be concrete and proper height from ground that protects the flood water.
- Electrical equipments (electrical wire) must be kept in water proof case to prevent short-circuit.
- Electricity shuts down automatically when water level goes up.
- Ground floor and wall of the schools where flood water can reach must be made by tiles. (Hazards resistance building).

- All the schools in the flood prone areas will be reconstructed as shelter to facilitate safe shelter to the affected people.
- Need for constructing reservoirs down the embankments in hilly areas for water conservation.
- Network of necessary roads to solve the problem of transportation.
- Proper warning system, that people can comprehend the language of warning system.

Spontaneous Adaptation

- During flood officials documents are shifted to up stairs.
- Fire extinguisher must be available in the school premises and people should know the operation of fire extinguisher.
- Equipped with immediate relief plan.

Few schools in Surat city have taken some adaptation after 2006 devastated flood like they shifted library, lavatory and computers upstairs (2nd floor or 3rd floor) and they increased the height of the computers desks that flood water cannot reach to that level. They have introduced a hazard preventive measure by repairing the walls and floors by tiles up to that level where flood water reached.

Figure 7.9: Picture taken by IRADe during field Survey

(left side picture shows mark for level of submergence during flood in 2006 and right one show teachers meeting in a school)

Source: Picture taken during IRADe field survey

Some schools made the class rooms hazard prevents, like floor and walls made by tiles and benches and chairs made by iron instead of wood. In our survey data reveal that the schools did not get any teachers and students disaster coverage insurance.

Flood Warning Measure

Flooding is the most common of all environmental hazards. In this framework, students, teachers and staffs must know how to manage the situation, for which, they need pre disaster training to protect socio economic damages from flood. To make the school safe from disaster, the culture of safety should be developed. However, this is not possible within a day. A holistic approach needs to be taken. Government as well as non government organizations can play a vital role for achieving the culture of safety. Safety audit is an essential for making schools safer through practical review, evaluation and guidance. Table 7.10 depicts only 45 per cent schools have had safety audit. So this result depicts that there was a little initiative for making the school safe at Surat, while the city has been traditionally vulnerable to natural disaster like flood. School safety audit should guide the school authority about the process of making the school safe.

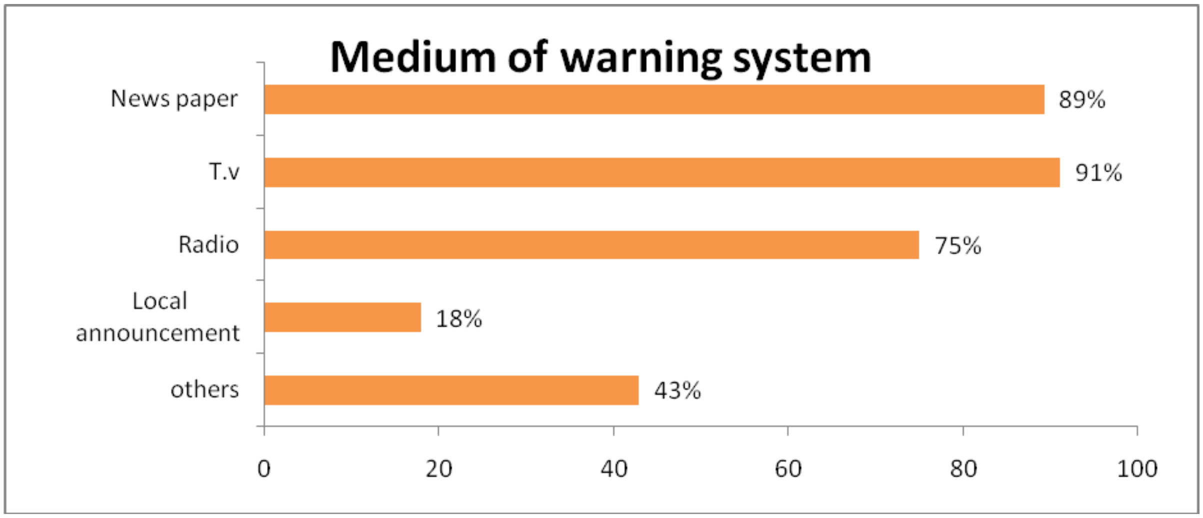
Table 7.9: Safety measures taken by the schools

Safety Measure	Percentage of schools	
	Yes	**No**
Safety audit	45	55
NDMA team arrived	13	88
Workshop with teachers and students	52	48
Flood Prevention measures after the flood	45	55

Source: Primary data collection by IRADe

National Disaster Management Authority of India has released its first guidelines on management of floods and their team had visited only 13 per cent schools at the city. Teacher and students workshop held only in 52 per cent schools at Surat city and 45 per cent schools have taken the flood prevention measures. In contrast, 38 per cent schools do not have safety materials like fire extinguisher which is very important equipment during flood because there is high possibility of short-circuit, and furthermore, it needs practical demonstration in times of installation.

Figure 7.10: Various medium of warning system



Source: Primary data collection by IRADe

Figure 7.11 shows the status of warning system for disaster. Natural disaster cannot be controlled but it can be prevented through warning system. Early warning system is the most important factor to take a safeguard from flood. It has a vital role to save a life. Through this warning system, teacher can warn the students. It can be seen from figure 6 that most of the schools do not have internet facilities while it is an important medium to know the prediction of flood. Consequently, flood forecasting system needs to be improved to overcome the vulnerability of schools.

7.4.1.7 Conclusion

This study has emphasized on the impact of flood on schools at Surat city. It has been observed that several problems have been occurring repeatedly to the schools due to flood. Some schools are situated in low-lying area which can be submerged even during heavy rains. Children are future of the nation and they are more vulnerable segment of the society as well. In such a situation, government has to step in and provide grants and required remedial measures to prevent vulnerability of the flood affected schools. Zone wise vulnerability index mapping of the selected sample schools shows that schools located in the north and west zone of the city are having high risk and suffer more damages during any flood event.

There is lack of disaster preparedness and warning system. Respondent said that they only aware through news, T.V. and radio but there is no alert or waning came from administration before water gushed. They recommended SMC should blow the siren before the danger loom. Most of the respondents in schools told that after schools reopen SMC came for checking the safe drinking water but after flood water receded they did not get any help from SMC to clean up mud, particles and dead animals. They have taken help from neighbors, school staffs, maids etc. Some schools told that they found some animals like snake, frog and they called up the snake catcher. However the role of administration was minimal in terms of relief and cleaning up the surrounding schools premises after water receded.

The vulnerability ranking profile of schools located in the different zones of the city and categorized under different level of submergence during the 2006 flood can be used to enhance disaster preparedness for the schools in the city to minimize the risk of damages to the schools in future in the event of flood.

7.4.2 Vulnerability Analysis of Slums

Slum population in Gujarat is 0.46 crore (2.6 percent of all India) as per census of India 2011. In Surat city slum population was 26% of total city population (433,496 people) by 1993 in 294 slum pockets. The annual growth rate for slum population is 7.5 percent. At present there are 351 slums in Surat city located in different zones (Please refer to the table 7.9 for the details of slums zone wise).

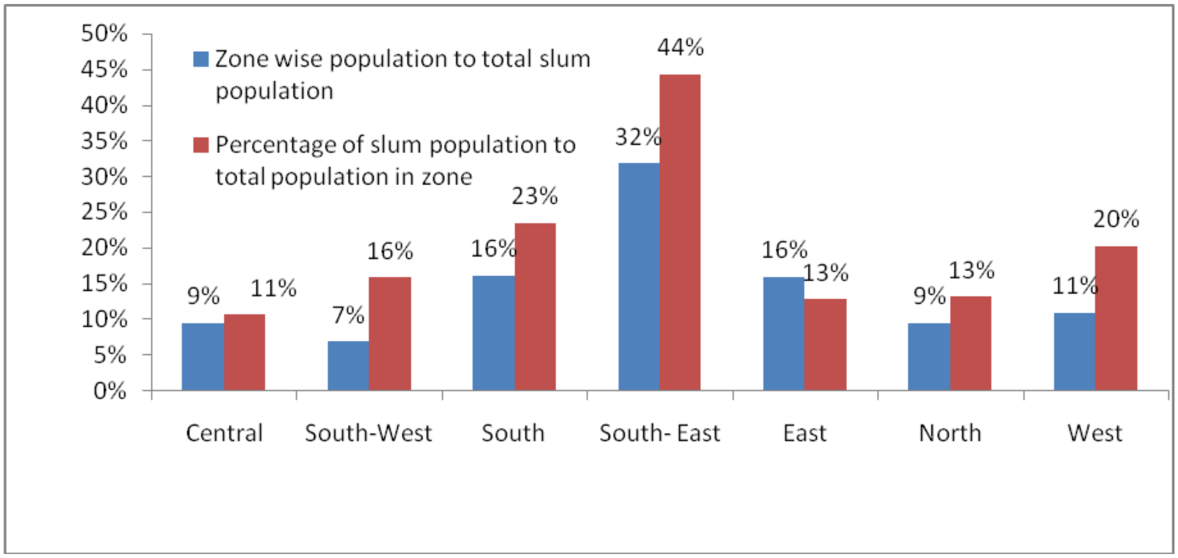
Table 7.10: Distribution of slums in Surat city

Zones	Number of Slums
Central Zone	25
East Zone	58
North Zone	47
South Zone	56
South East Zone	76
South West Zone	35
West Zone	54

Source: Surat Municipal Corporation

A larger proportion of the slum population is male (58 percent) as against 42 percent of females. This proportion however varies across different migrant groups there is predominance of males among those who have come from the states such as Uttar Pradesh and Orissa.

Figure 7.12: Slum population share to total population across zone



Data Source: Census 2011

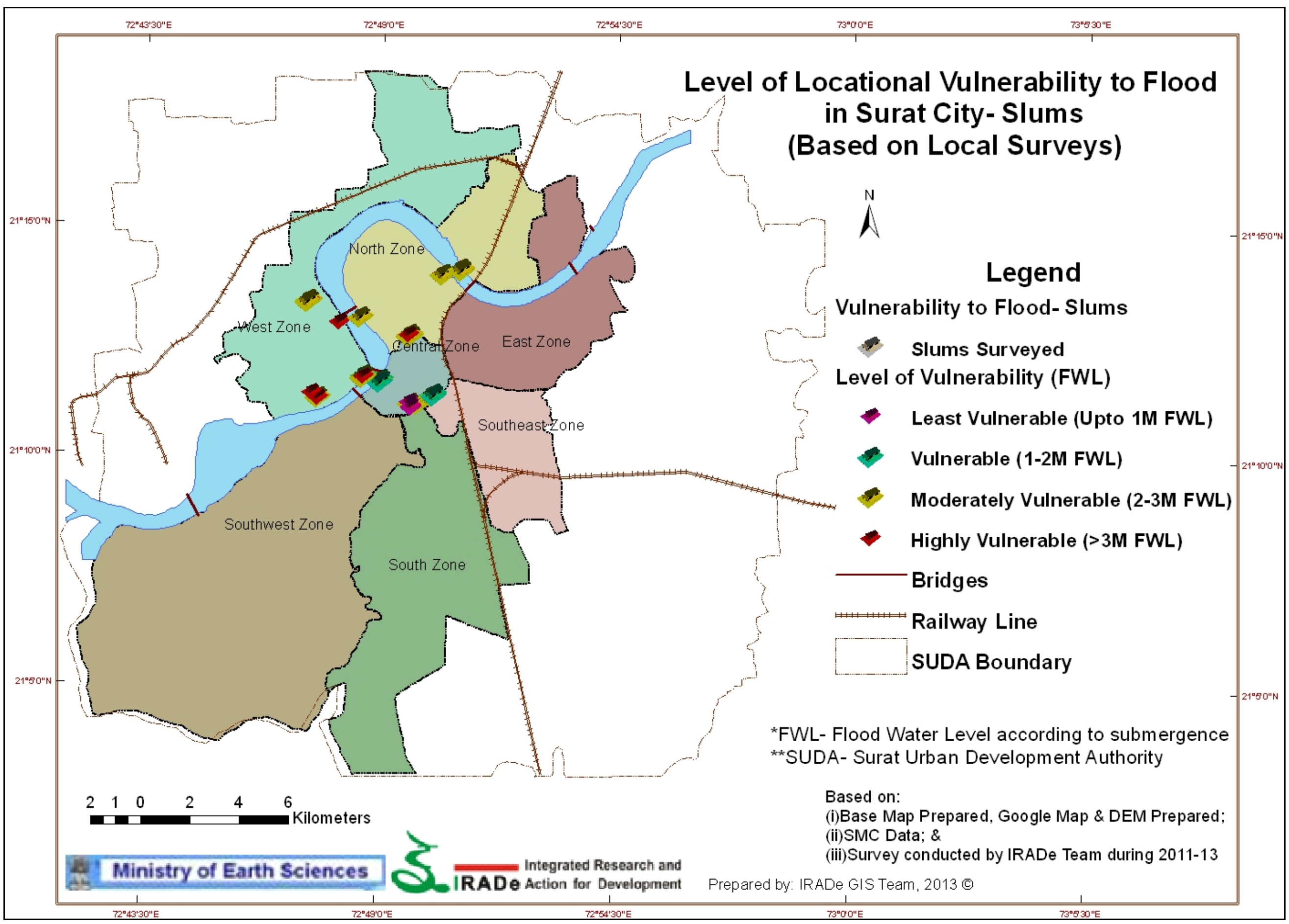
4/5th of slum population consists of migrants only of which 81% are Hindus; 18% are Muslims. Hindus live mostly in the northeast and southwest. Muslims live mostly in the northwest and east. Buddhists live mostly in 5 slum pockets in the east. Slum population are clustered around the industrial area Udhna-Pandesara industrial area accounts for 41% slum population. 11% belong to higher castes, of which 47% live in the southeast industrial area. 9% are tribal, of who as many as 75% live in the southeast and east. About 20% speak Gujarati at home; 19% speak Hindi. 33% speak 2 languages; 5% speak 3 languages. A substantial percentage of migrants to the city are from 2 major states of India 47% of are from Maharashtra; 18% are from Uttar Pradesh. Slums are spread across the zone of city. South East zone with 32 percent of total slum population of the city is the largest zone having slum population in the city, only slum population accounts for 44 percent of the total population of this zone.

Surat has experienced rapid industrial development in last two decade resulting in rapid growth in the economy, an economy dominated by labour intensive activities fuelling the growth of slums. Migrant labours from other parts of Gujarat, Maharashtra and Eastern India, have settled down mainly along the major transportation corridors, river and creek banks and in the vicinity of industrial areas. This leads to formation of informal settlements characterized by high density of population and associated public health risks. These densely populated areas resemble slums with minimal basic facilities like drinking water, roads, light, sanitation etc and lack of facilities make them susceptible to natural disaster. To delve on the issue further and explore the risk reduction options for the slum dwellers we have conducted socio economic surveys with the selected slum dwellers at the selected locations.

7.4.2.1 Sample Composition of Selected Slum Dwellers

Slum survey was focused mainly on North, Central, South and West zone of the city as these zones were identified as the most vulnerable zones by the flood water level during 2006 flood in Surat city. Most of the slum households are nuclear family and having average family size of around three members per household. Wide variations exist within and amongst slums in terms of the distribution pattern of household heads by different occupations. Slum households are employed either in the unorganized sector or self employed engaged in activities like Barber, Rikshaw Puller, hotel and etc. Employment patterns are found to be by and large same across the zones. In west zone it was observed that more number of people was employed in the organized sectors and this zone also has a significant proportion of retired people. Genders wise distribution of the respondents indicates 92% were male and 8% were female.

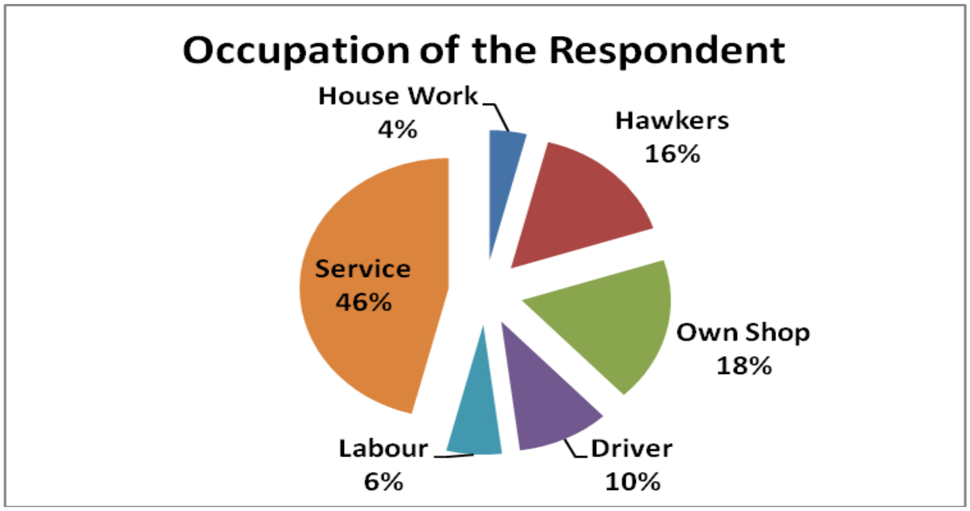
Figure 7.13: Slum surveyed during IRADe primary survey and level of vulnerability based on flood water level in flood event 2006



Data Source: SMC & *IRADe*

Occupational distribution shows a merely 42 percent male and 4 percent of female are engaged in service sector, 18 percent have their own shop, 16 percent are hawkers, 10 percent are drivers, 6 percent are labours and 4 percent female respondent are housewife. Like slums in other cities of India, Surat slum also has a high number of child participation in the labour force (below age 18). Child work force generally works in the diamond polishing and the spinning, twisting and colouring sections in the textile and activities related to petty sales and repairs.

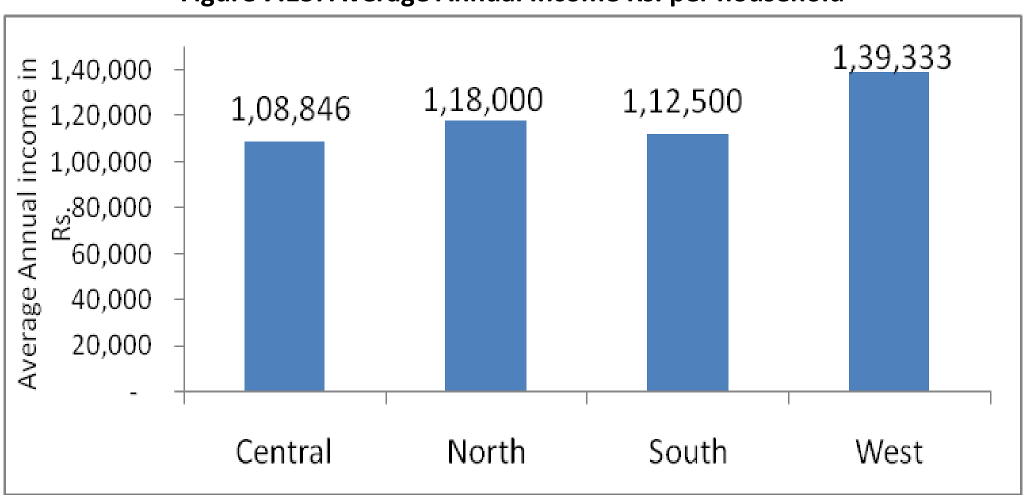
Figure 7.14: Distribution of Interviewed Households by Occupation



Data Source: Primary Survey IRADe

An economic profile of the slum household (average annual income per household) across zones for selected sample shows that incomes of the households in west zone are highest and central zone are lowest. Almost 100% of the slum household posse's household appliances like Fan, Freeze, TV and etc across regions. Maximum household uses LPG for cooking but there are a small percentage of household also uses kerosene for cooking. Almost 100% household have electricity connection and also have toilets in their house.

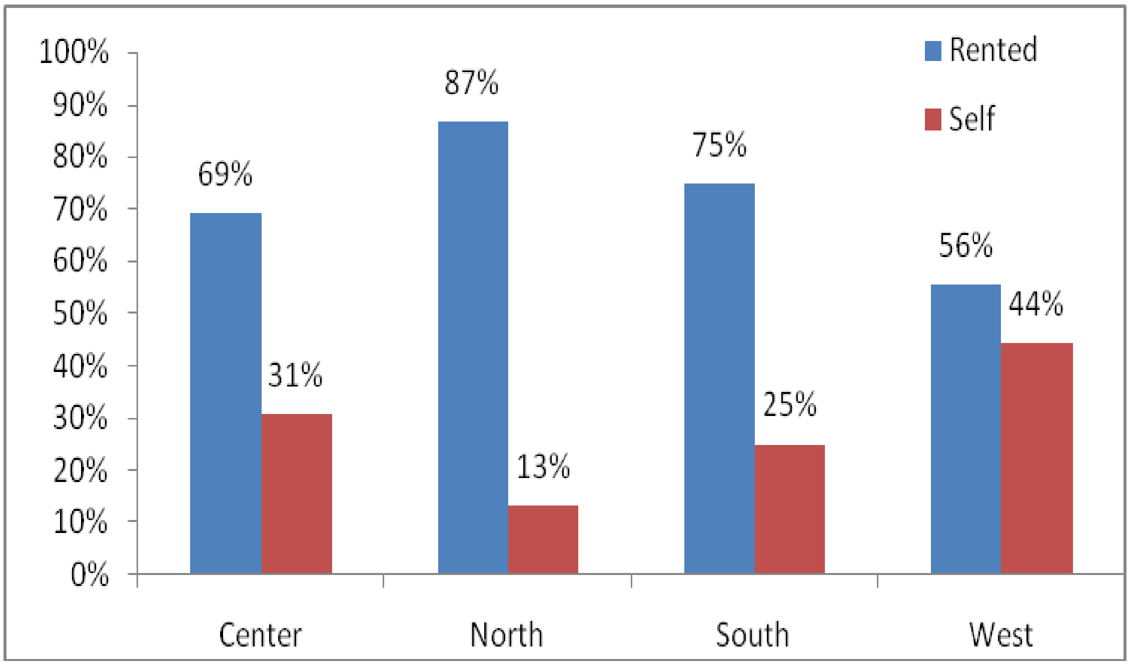
Figure 7.15: Average Annual Income Rs. per household



Data Source: Primary Survey IRADe

Slum households consists of people migrated from the rural areas to the urban areas for the livelihood and majority of them have migrated and settled there with their family permanently. But more than 50% of the households live in rented house across zones. In north and south zone proportion of rented household dwellers are more than 3/4of the total household. Almost all the slum houses are semi pucca and are not in good conditions and are of more than 10 year old, more than 50% of the houses are more than 20 year old.

Figure 7.16: Ownership of the house



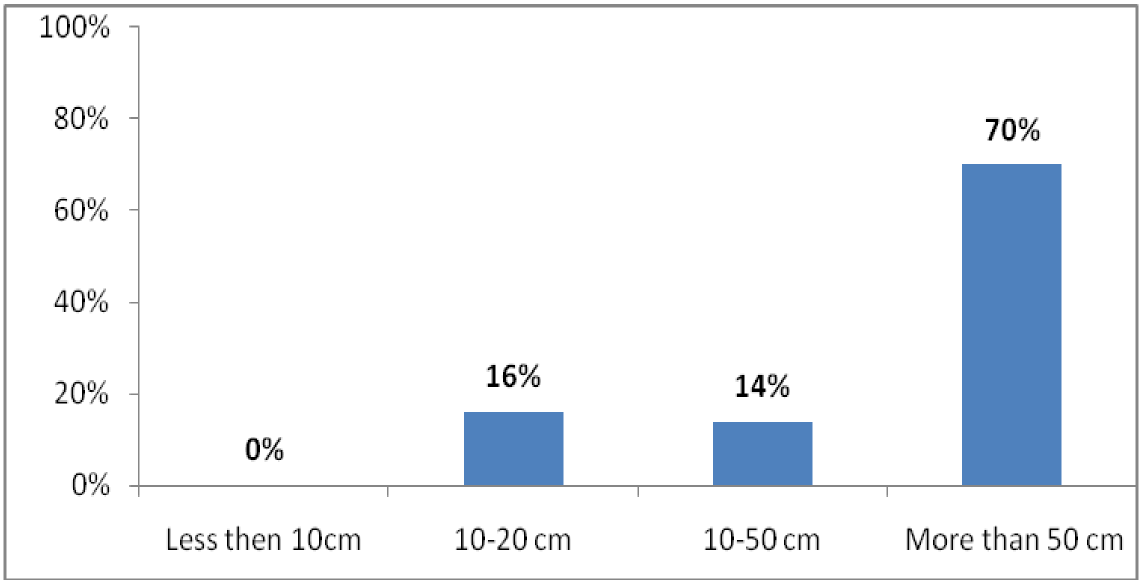
Data Source: Primary Survey IRADe

7.4.2.2 Impact of Flood on the Sample Household in Last Decade

The high rate of in-migration of labour workforce, and their dependants coupled with a lack of affordable housing, led to the growth of slums. The slums located on the bank of river Tapi and on the banks of creeks are severely affected by flood almost every year. More over the slums on the roads, canal banks and on the important reservation plots are highly vulnerable to extreme events like floods.

Flood in 2006 have severely affected the slum household across zone almost all the household covered in primary survey reported that they were affected during the flood and it also causes loss to their property. Approximately 70 percent of the household reported that the water level inside their house was more than 50cm there was not even a single slum household reported less than 10cm of water level in their house. Entry of water in the house causes damage of the wall, flooring of the house and also damaged household items. A large number of slum dwellers also reported vehicle damage.

Figure 7.17: Level of water in house during flood



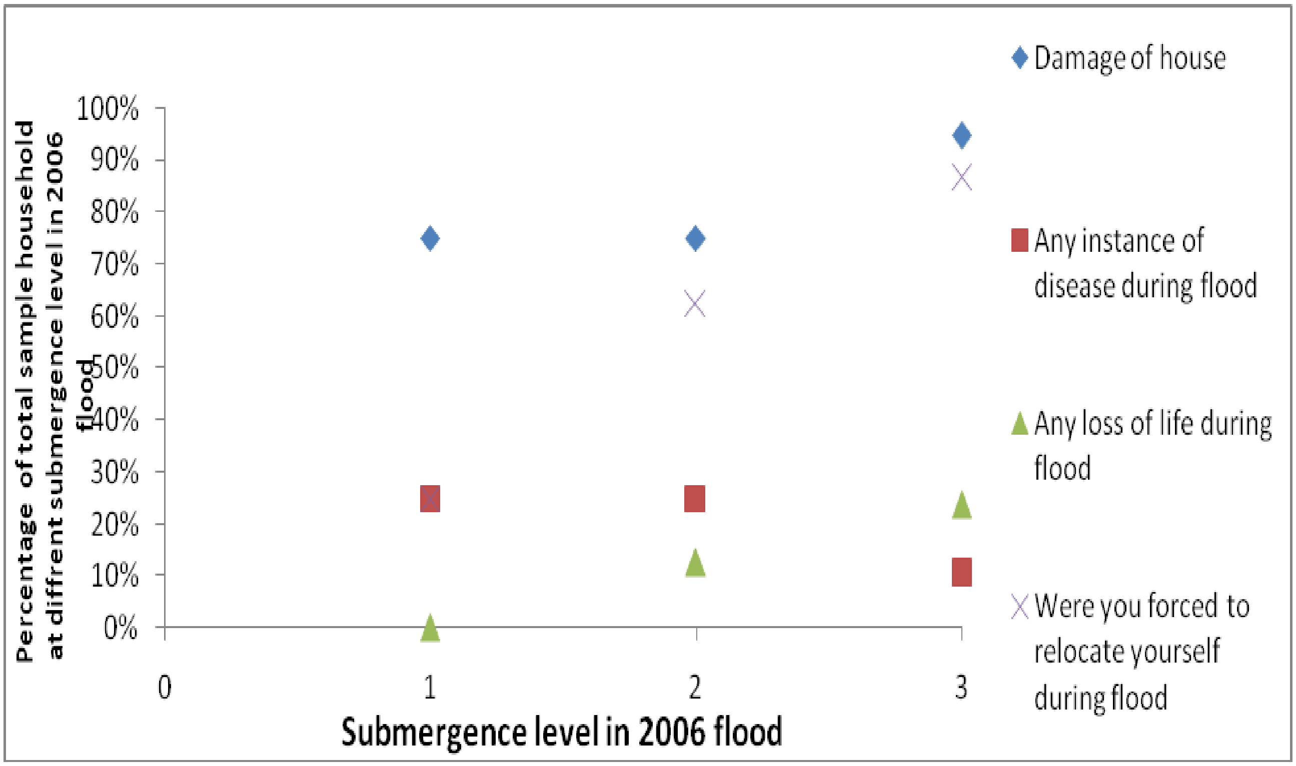
Data Source: Primary Survey IRADe

Damage caused by flood continue even post flood as household have to incur expenditure on repairing of damaged house and vehicle. Household also reported an unusual increase in their medical expenses because of spurt in disease like fever, chicken guinea, cholera and etc. Approximately 3/4th of the household said that they were forced to relocate to safer places like bridge, temple and to their relative during flood. Around 20 percent household reported loss of life. Flood causes damages to roads inside the slum and communication infrastructure.

7.4.2.3 Vulnerability Index for slums

To create a composite index we have assigned weights to the different parameters based on percentage of people getting affected and vulnerability defined by SMC based on the water level during flood. Slum houses generally do not have any plinth or have insignificant plinth heights. If the plinth of a house is at very low level then it is quite likely that household will suffer the damage even at the low water level during flood. Some time even during heavy rain in low lying areas water gets inside the house and causes damages to the household stuffs.

Figure 7.18: Vulnerability at different submerge level



Source: *IRADe*

Vulnerability index at micro level will indicate to the likely impact of natural disastrous events for a households and it also talks about the impact on the entire zone. Higher the vulnerability index high would be the likely loss for the household in the events of flood. Vulnerability to the natural disaster can be reduced by required adaptation measures. Vulnerability Index will help to identify the likely adaptation at micro and macro level.

Table 7.11: Flood Water Level upto 1 Meter during 2006 flood

Zone	Occupation	Vulnerability
Central Zone	Driver	0.25
Central Zone	Driver	0.00
Central Zone	Hawker	0.25
Central Zone	Service	0.19

Source: IRADe Analysis

Average vulnerability index for the slums submerged upto 1 meter during 2006 flood is 0.17. Loss of property, loss of life and forced relocations were not reported at 1m submergence level.

Table 7.12: Flood Water Level 1 to 2 Meter during 2006 flood

Zone	Occupation	Vulnerability
Central Zone	Barber	0.19
Central Zone	business	0.00
Central Zone	rickshaw puller	0.00
South Zone	Hawker	0.34
South Zone	Labour	0.34
South Zone	Service	0.41
West Zone	Chicken shop	0.38
West Zone	Service	0.41

Source: IRADe Analysis

Average vulnerability index for the slum dweller in the central zone having inundation level 1 to 2 meter is much smaller than the vulnerability of slum dwellers in south and west zone. In the central zone slums there were peoples said that they didn't suffer any loss in the flood in 2006. Average vulnerability of slum dweller at same inundation level in the slums located in south zone and west zone are 0.36 and 0.39 respectively. This suggests that people in the South and west zone slums are more vulnerable than the people residing in central zone slums.

Table 7.11, table 7.12 and table 7.13 represents the vulnerability index for the slum dwellers had inundation level more than 2 meters during 2006 flood located in central, north and west zones respectively. Average vulnerability index are 0.36, 0.46 and 0.46 for the central, north and west zone respectively. This explains that slums located in the central zones are relatively less vulnerable even at the higher inundation level than the slums located in north and west zone of the city. This shows that all slums are not equal when it comes to hardship they face and the loss of properties and life in the event of natural calamities like floods and thus need to be addressed differently to reduce their overall vulnerability.

Table 7.13: Flood Water Level above 2 Meter during 2006 flood in North zone

Zone	Occupation	Vulnerability
North Zone	Hawker	0.51
North Zone	Hawker	0.51
North Zone	Service	0.45
North Zone	Service	0.24
North Zone	Service	0.45
North Zone	Service	0.45
North Zone	Service	0.45
North Zone	Service	0.51
North Zone	housewife	0.45

North Zone	Driver	0.51
North Zone	Hawker	0.45
North Zone	Retierd	0.45
North Zone	Service	0.45
North Zone	housewife	0.45
North Zone	Hawker	0.51

Source: IRADe Analysis

Table 7.14: Flood Water Level above 2 Meter during 2006 flood in West zone

Zone	Occupation	Vulnerability
West Zone	Hawker	0.45
West Zone	Kirana store	0.51
West Zone	Labour	0.51
West Zone	Service	0.51
West Zone	Service	0.45
West Zone	Service	0.45
West Zone	Service	0.26
West Zone	Service	0.45
West Zone	Service	0.51
West Zone	Hawker	0.48
West Zone	Labour	0.45
West Zone	Own shop	0.45
West Zone	Service	0.45
West Zone	Service	0.48
West Zone	Service	0.45
West Zone	Service	0.45

Source: IRADe Analysis

7.4.2.4 Adaptation Measures for Slums

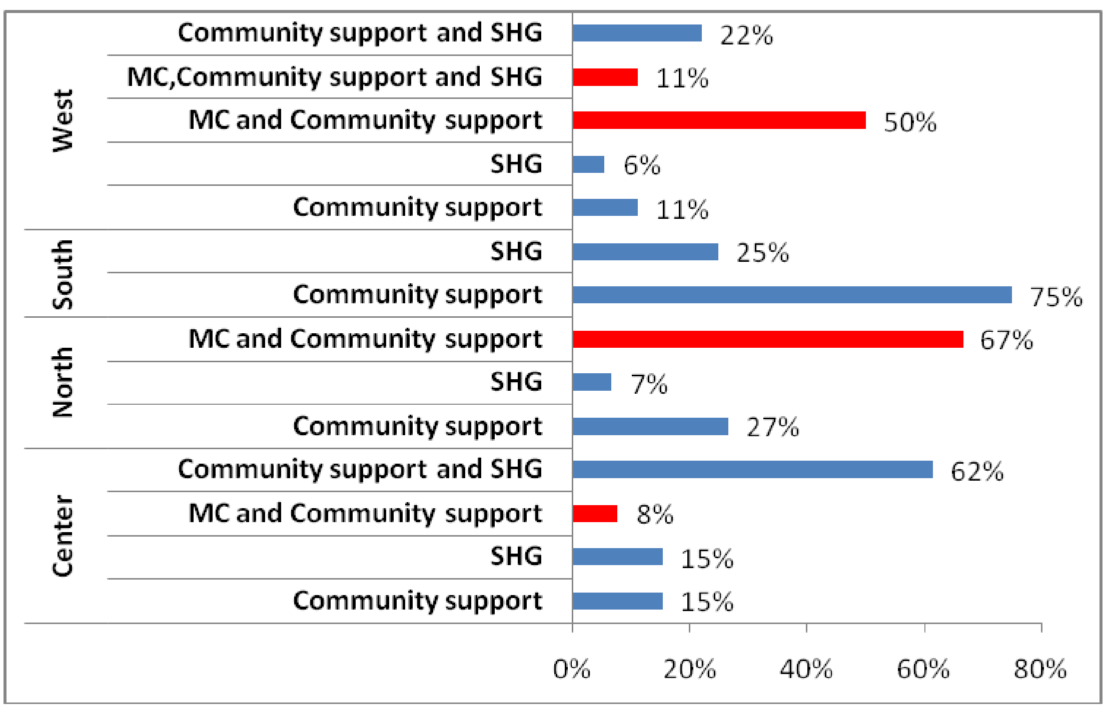
Slums situated along the west bank of river Tapi, mostly north of Nehru Bridge, including Iqbalnagar (located between the embankment and river) and Subhash Nagar, were completely devastated in the 2006 flood. Primary survey conducted by IRADe with the selected sample slum dwellers across the 4 vulnerable zones to asses risk mitigation measures taken at different levels brings out following facts

- It is a wide spread perception amongst the slum dwellers that the health facility provided to them are not sufficient to meet their needs.
- In response to the question that did slum dwellers received any early warning during the past flood event we received a response that either they were informed through neighbour or

relative but they did receive information 24 hour a priori to the flood and information received by them in the past were accurate every time.

- At least one people know swimming in ¾th of the slum household.
- In the event of flood in the past support from municipal corporation, was extended only to the slums in north and west zones community support were extended in south and central zone (fig below)
- Almost every slum household said that during flood help came too late and a small proportion of household also said that only few household got the benefits from the government help
- Support like medicine, livelihood support, clean drainage/sewerage and clean water supply was the most sought after demand by slum dwellers post flood.
- 70 percent household reported that disaster preparedness camp had never been organized in their area
- It was highlighted in the survey that in participate of female in flood awareness campaign is nil or very insignificant. Whereas female are more vulnerable to flood than their male counterparts.

Figure 7.19: Support extended by Municipal Corporation (MC), Community Support and SHG to the slum dwellers during flood events



Data Source: Primary Survey IRADe

7.4.2.5 Conclusion

This study has tried to ascertain the impact of flood on the slum settlement in Surat city and various measures taken to mitigate/minimize the loss to the slum community. The aim of the study was not so much to determine the extent but to understand differential levels of vulnerability to different slum settlements in the city. Slum dweller are nuclear family engaged primarily in unorganized sector for their livelihood having lesser means to cope with any uncalled for natural disaster like flood. Slum houses are semi pucca and located in low lying areas having poor drainage system where water logging is a regular menace.

Our study clearly indicates that recurrent flood poses several hardships to the slum dwellers. Fragile livelihood and disadvantageous living conditions makes the situation grimmer but it is observed that slum dwellers were able to cope efficiently with the flood instances in the recent past because of rich social capital which extends their supports to flood affected people at the time of crisis. Sanitation, safe drinking water, communication and transportation become a huge problem post flood. Flood destroy fixed assets of the slum dwellers and also flush out a huge proportion of their saving as post flood they need to bear expenditure to repair their damaged house and household items. Natural disaster makes the poor even poorer as they are more in needs to established their ravaged livelihood. Moreover natural disasters reinforce slum dwellers to stay in the slum.

Adaptation measures through appropriate coordination mechanism amongst the stakeholders (Surat Municipal Corporation –SMC, Slum dwellers and etc) will help substantially to reduce vulnerability of slum dwellers to natural events. Our study highlights various measures like strengthening livelihood opportunities and creating awareness amongst both male and female through disaster preparedness camp will be make the slum dwellers better equipped to face the disaster. Early warning system and preparedness for evacuation in the event of flood will reduced the losses of life and property.

Any natural disaster destroys (flood) prospects for better life by causing tremendous physical, social and economic loss to the society. A coordinated approach by different stakeholders is required to fundamentally improve the living conditions of slum dwellers and to reduce their long term vulnerability to any future disaster events. A coordinated approach by different stakeholders is required to fundamentally improve the living conditions of slum dwellers and to reduce their long term vulnerability to any future disaster events.

Snapshot of slum infrastructure population mix and their livelihood: A story of *Bapunagar, Nehru Nagar and Subash Nagar slums*

Bapunagar: slum has majority Muslim population with Vanzara families living since 40 years and incremental housing units were added to the vacant space by the new dwellers mainly on the periphery. The internal roads in the colony had been improved during the various slum improvement schemes in 1984-85 and 1994-95. The housing unit here has been provided with electricity, water connection, underground/open drains, paved Kota stone streets, streetlights, community toilets, public distribution shops, health clinic, Balwadi etc.

The housing typology found in the slums was pucca, semi pucca and those ched housing units. Floors were made from mud, kota stones, tiles in majority of housing units. The housing units were closely defined with little open space surrounding the units, the community open spaces, available in Subashnagar and Bapunagar. Roads width in these areas varies from 1meter to 6 meter width in colonies.

The community has also constructed five Masjids, of which four were big and one school. Most of the households in the Bapunagar are engaged in businesses related to household's article, auto rickshaw driving, grocery, and small merchants.

A photo of Bapunagar slum taken by IRADe team during slum survey

Nehru Nagar: is dominated by Muslims, Khandesi and Vagri community (SC), residing along the bank and above the old embankment. Majority of slum population are engaged in daily vending services in the city and are residing in slum since late 1960s.

The community has managed to attempt slum improvement with access to good roads, community toilets and streetlights under various projects of Surat Municipal Corporation.

A photo of Nehru Nagar slum taken by IRADe team during slum survey

Subash Nagar: is dominated by fishermen and sand loaders who used to make their living out of fishing and sand mining on the Tapi riverbed. The site earlier used to have functional boat club (abandoned now) by private party, fully functional sand mining business (non-functional after Ukai dam construction). Slum dwellers from these areas are now working in the old city and west zone for their livelihood as daily wagers, housemaid and small business vendors.

A photo of Subhash Nagar slum taken by IRADe team during slum survey

7.4.3 Vulnerability Analysis of Hospitals

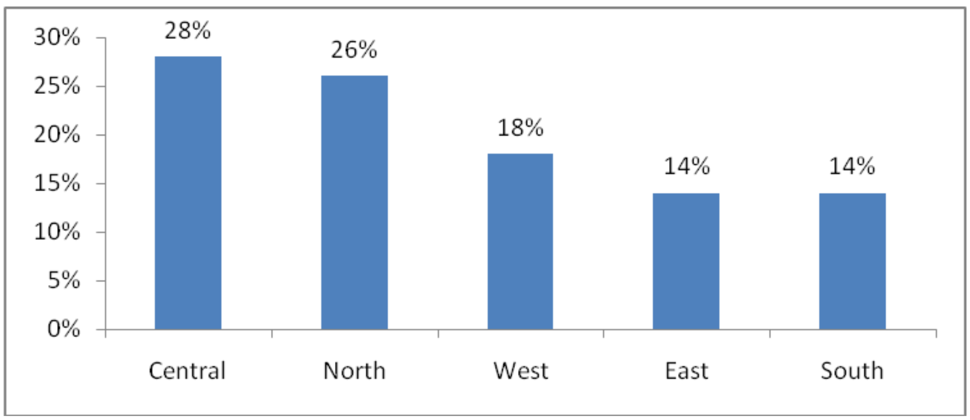
7.4.3.1 Introduction

Vulnerability of hospitals is important due to their significant role in the recovery of community after disaster. The study aimed to understand the impact of damage to hospitals, which are one of the lifeline buildings at the time of disaster as well as are considered to be particularly vulnerable as flooding can disrupt their functioning. In this study, the hospitals that were partially or fully affected by the unanticipated flood of 2006 were surveyed and analysed.

7.4.3.2 Hospital Sample Composition

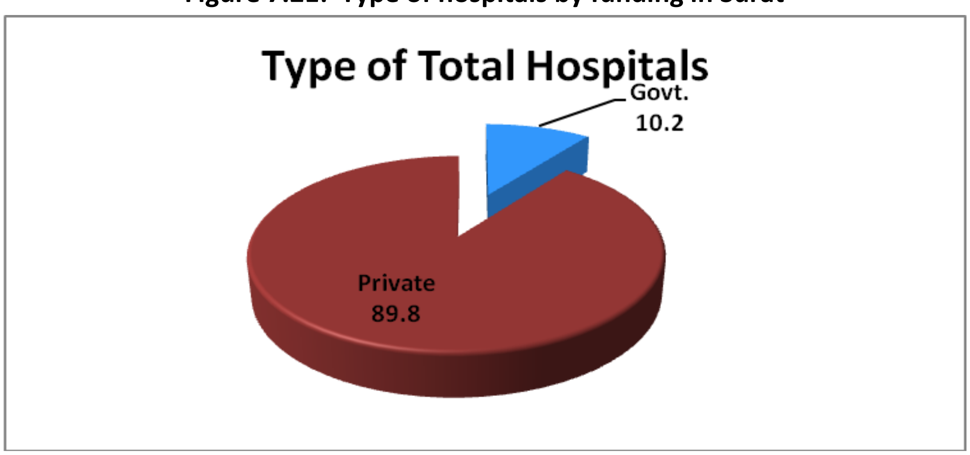
Surat city has 678 hospitals, out of which 89.8 percent are private hospitals and 10.2 percent are government hospitals. IRADe survey sample comprises both government and privately funded hospitals from the selected zones (fig7.20).

Figure 7.20: Distribution of Hospital Surveyed in each Zone



Source: Primary data collection by IRADe

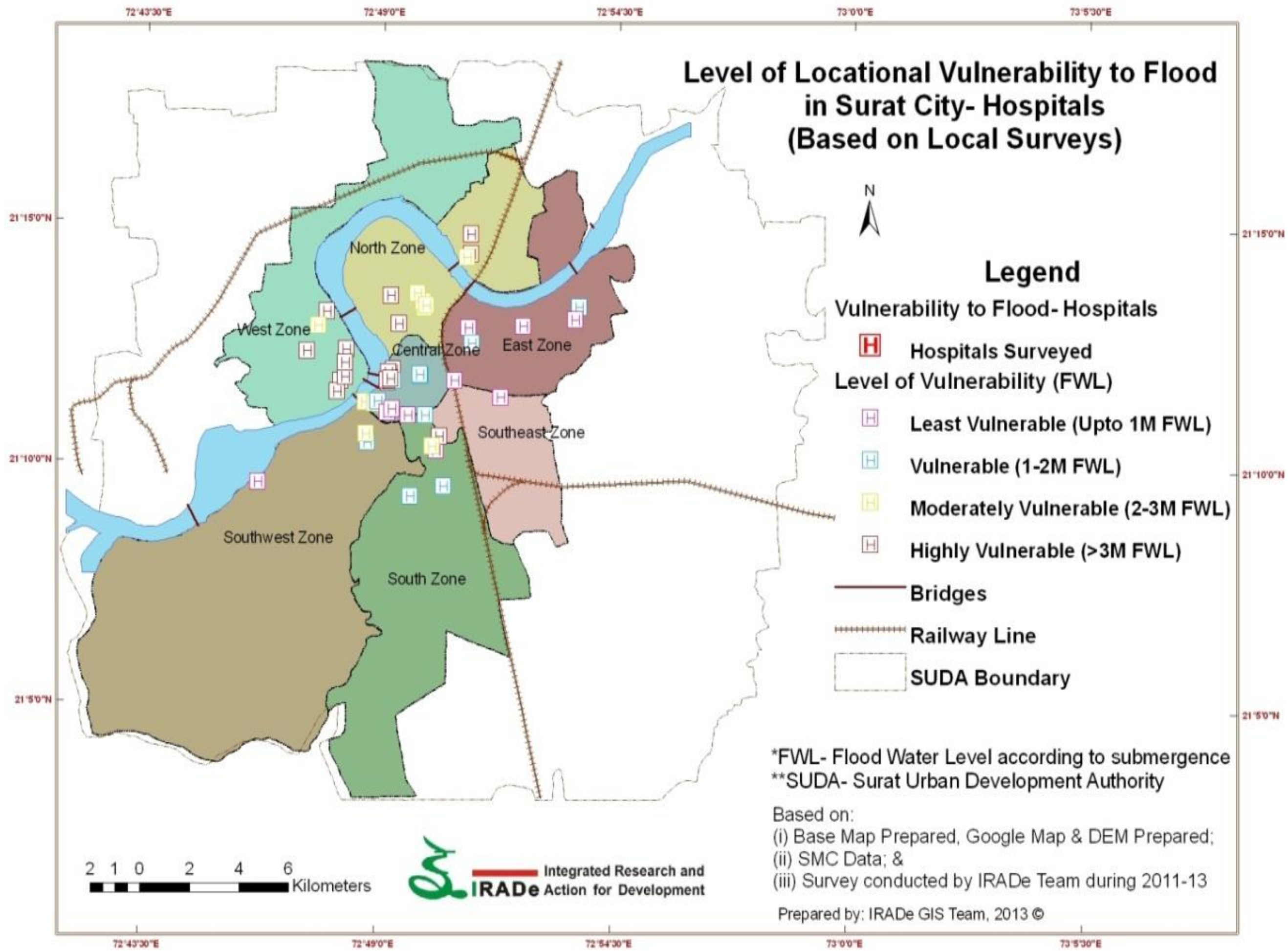
Figure 7.21: Type of hospitals by funding in Surat



Source: Primary data collection by IRADe

We have collected data from five zones. In the sample 14 percent hospitals are in the East zone, 18 percent hospitals are in the West zone, 14 percent hospitals are in the South zone, 26 percent hospitals are in the North zone and 28 percent hospitals are in the Central zone (fig7.21).

Figure 7.22: Hospitals surveyed during IRADe primary survey and level of vulnerability based on flood water level in flood event 2006

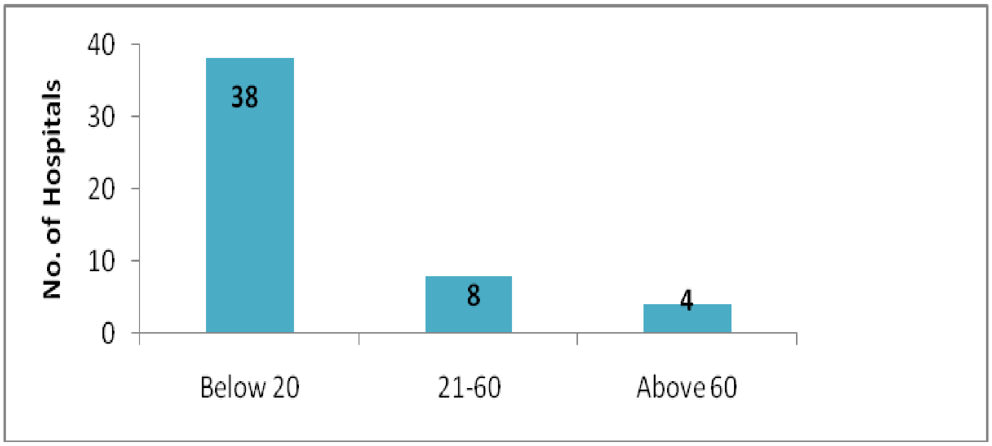


Source: IRADe

7.4.3.3 Infrastructure Status of Hospitals

Survey results exemplify that 38 percent hospitals have below 20 beds and 8 percent hospitals have a capacity of 21 beds to 60 beds. Merely 4 percent hospitals have more than 60 beds, therefore, their capacity to admit patients is quite better than those hospitals that has less number of beds. While discussing about the total strength of the doctors in the hospital, we observed that 90 percent of hospitals have a total strength of doctors around 10 whereas only 10 percent hospitals have more than 20 percent of doctors.

Figure 7.23: Distribution of Hospitals according to the number of beds



Source: Primary data collection by IRADe

During field survey, it was found that only 50 percent of the hospitals from the selected sample have only ground floor, which shows that they are the ones which are more vulnerable to flood, because in case of flood they don't have any other place except for the building's roof to rescue themselves. 10 percent hospitals reported that existing practice of building construction is not proper and safe with respect to floods.

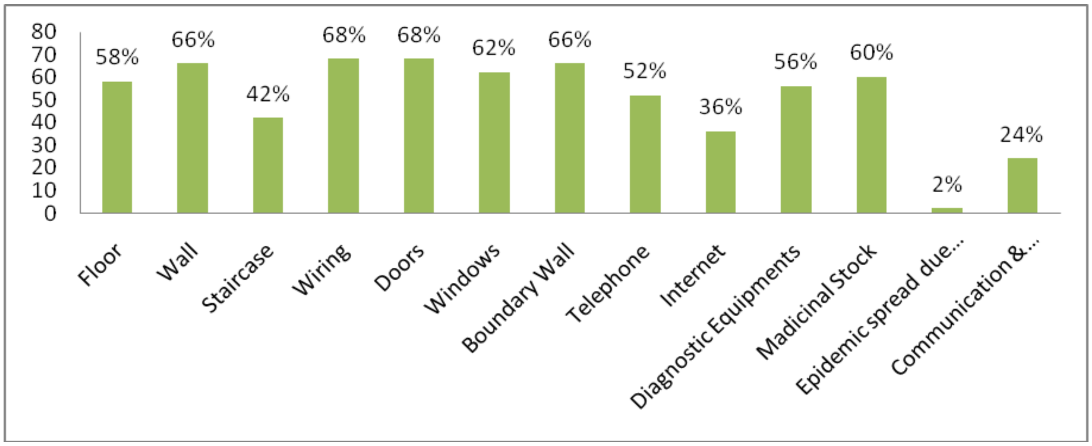
Table 7.15: Distribution of the Hospitals according to Height of Boundary Wall

Height from the ground (In feet)	Hospitals (In percentage)
1-2	38
2-3	24
3-4	14
4-5	8
5-4	16

Source: Primary data collection by IRADe

All the surveyed hospitals have boundary walls surrounding hospitals to prevent building from the direct flood stroke. 38 percent of the surveyed hospitals reported that height of the hospital bounday wall is between 1-2 feet,whereas 24 percent respondent said that their boundary wall's height is between 2-3 feet. The height of boundary wall of 38 percent of hospitals is between are above 3 feets (table 6.1).

Figure 7.24: Structural Damage of hospital

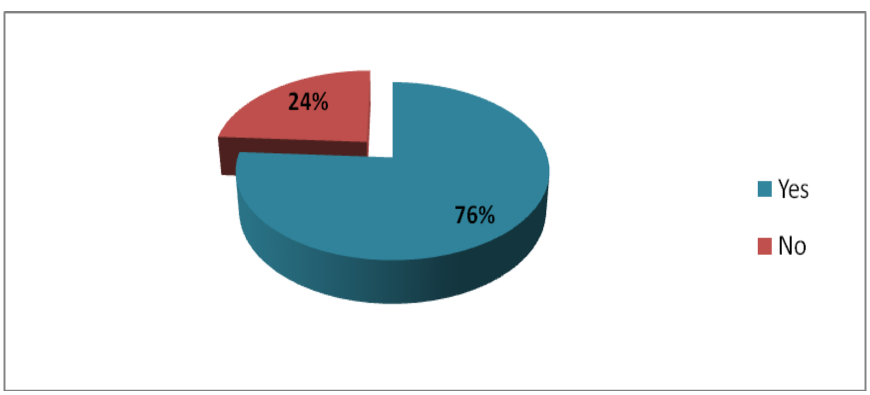


Source: Primary data collection by IRADe

7.4.3.4 Damage to Hospitals due to Flood

The major damage to hospitals occurs in the form of physical and economic damage. Our survey results show the significant damage to the boundary walls, doors, windows and wiring. Damage to wiring can result in short circuit of the electric system, often leading to fire. Damage to communication system leads to mismanagement that hampers the networking system among the hospitals. It is also found during the survey that flood interrupted in transportation system of most of the hospitals. The damage to the transportation system of the hospitals often results in much more disastrous situation, as the essential medical care could not reach the affected people at an appropriate time. The results show significant damage to the flooring of the building along with others damages to the building, the reconstruction and repair of which will become the economic damage to the hospital building.

Figure 7.25: Availability of ambulance facility in the hospital



Source: Primary data collection by IRADe

Most of the hospitals are equipped with backup power options to manage power outage during disaster despite of uniform electricity supply. It is also found in the survey that 76 per cent of the hospitals do not have ambulance facility, which is an essential service during emergency like floods, to support the evacuation and rescue operations during the disaster. Also, 56 percent of hospitals surveyed do not have emergency exit plans.

It is also found that 14 percent of the hospitals are not networked with other hospital referral system. The Internet connectivity in the hospitals is really helpful during disasters as it supports shifting of patients from one hospital to another and reduces the residual risks. As far as other safety measures, like fire extinguishers along with fire safety and evacuation plans and proper training of hospital employees of fire safety to avoid high chances of fire due to short circuits of electric wiring, 84 percent of interviewed hospitals said that their staff is trained and they know how to use fire equipments.

30 percent of hospitals do not have planned emergency exit. Most of the hospitals are found equipped with backup power options to manage power cut-off during disaster. But the adaptation measures like disaster preparedness plan, training to deal with disaster from the National Disaster Management Authority, etc. were not found in any of the surveyed hospitals. Also, no hospital is found to be equipped with immediate relief work in case of disaster like flood.

Hence, the major disruptions are found in communication and transportation services during flood, along with lack of preparedness and adaptive measures. It is almost impossible to prevent the occurrence of flood but the damage caused can be reduced and mitigated by stimulating plausible adaptation schemes. The lessons should be learned from the past experience and should strengthen the hospitals to deal with the disasters like floods. The effects of disasters can be substantially reduced if people are well informed and motivated towards a culture of disaster prevention and resilience. Only 20 per cent of total hospitals have taken preventive measures after flooding event. They have also taken a preparedness plan and Surat Municipality Corporation added one floor in hospital building as a prevention measure after flooding event.

7.4.3.5 Adaptation Measures Proposed

In order to reduce existing risk levels, adaptation measures must be considered a fundamental part of sustainable urban development. The adaptation measures can be classified as planned and autonomous. Planned adaptation is the result of deliberate policy decision, based on the awareness, and would progress from the top-down approach, through regulations, standards, and investment schemes. Autonomous adaptation refers to those actions that are taken as individual institutions, enterprises, and communities independently. Some of the adaptive measures proposed are

Table 7.16: Suggested adaptation measures

Adaptation Measures for flood	Planned or Autonomous
Equipped with Immediate Relief plan	Autonomous
Disaster Training along with Mock drills	Planned
Disaster Preparedness Plan	Planned
Effective communication solution during disasters	Planned
Evacuation plan of ground floor of hospital building in case of floods	Autonomous
Installation of Services on Upper floors	Autonomous
Fire safety System	Autonomous
Networking among the hospitals	Autonomous
Insurance of medical stock and equipments	Autonomous
Elevating Building floors/ Stilts in vulnerable areas	Autonomous
Early warning System	Planned
New Building Codes	Planned
Compensatory Payment	Planned

Source: Primary data collection by IRADe

7.4.3.6 Some Suggestions Provided by the Respondents during Survey

Following are the some suggestions provided by the respondents during the survey:

- Early warning system and preparedness plan
- Effective communication solutions during disaster.
- Disaster training
- State Government and central Government should be taken steps and prepared policy for this type of disaster.

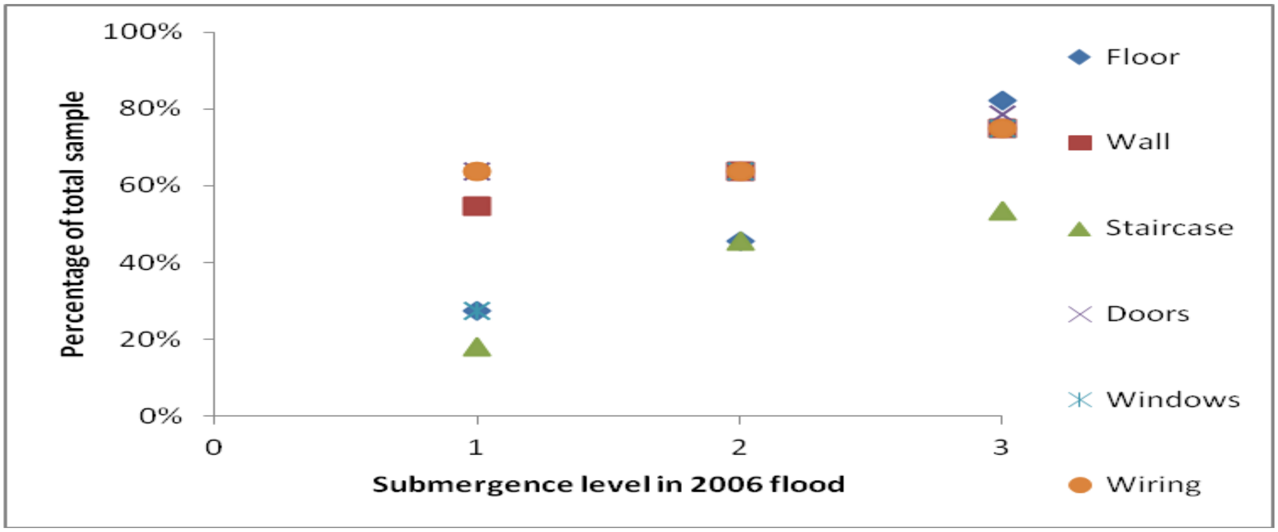
Emergency procedures are especially important in the mobilization of people, equipment and supplies.

Disaster mitigation plans must address the need for repairs in case of damage to the hospital facilities, both before and after a disaster occurs. This is necessary that committee should formulate and implement disaster mitigation measures and carry out emergency response planning.

7.4.3.7 Vulnerability Index for Hospitals

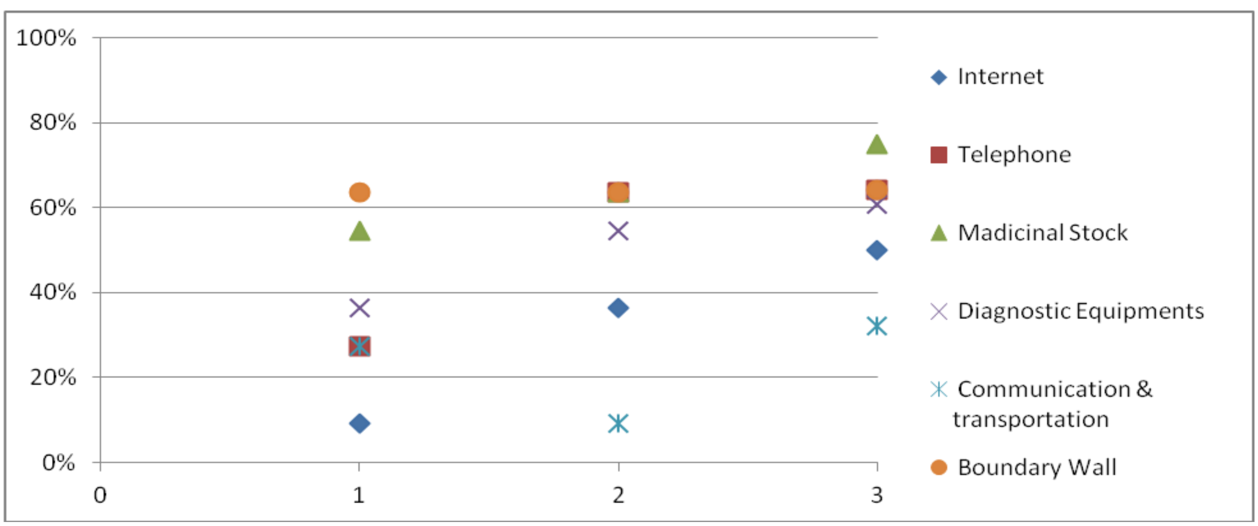
Vulnerability due to flood is influenced by many factors like submerge level, preventives measures before flood, building construction, boundary wall, etc. In the graph shown below, we have considered submergence levels as 0 to 1 Meter, 1 to 2 Meter, 2 meter above. Out of a total 50 sample hospitals, 11 hospitals are located in the area submerged 1Meter, 11 are located in area submerged 1 to 2 meter and 28 are located in area submerged more than 2 meters during flood in 2006. X-axis depicts submerge level for 2006 while Y-axis shows different attributes of hospitals at different submerge levels (figure 6a and 6b).

Figure 7.26a: Vulnerability of hospitals at different submerge level



Source: Primary data collection by IRADe

Figure 7.26b: Vulnerability of hospitals at different submerge level



Source: Primary data collection by IRADe

Higher VI value translates higher vulnerability of the hospital to any likely climate hazards. Higher vulnerability means lesser resilience of the hospital to the climate hazards and it calls for the mitigation strategy by various stakeholders to reduce the vulnerability.

Hospitals represent a type of critical facilities that require special attention during flooding. Hospitals may have patients that need special attention in the case of an emergency. To treat patient in emergency hospital equipments are critical and inundation of critical facilities in the hospital makes hospital vulnerable and incompatible to discharge its duty when it is very much needed. Average vulnerability of the hospital located in the areas having submergence level upto 1 meter during 2006 floods is 0.26. Hospital in the east zone have high vulnerability index of 0.27 over the hospital located in the central zone of the city.

Table 7.17: Flood Water Level upto 1 to 2 Meter during 2006 flood

Zone	Type of Hospital	Vulnerability
Central Zone	Private	0.68
Central Zone	Private	0.58
East Zone	Private	0.64
East Zone	Private	0.62
South Zone	Private	0.77
South Zone	Private	0.67
South Zone	Private	0.56

Source: IRADe Analysis

Average vulnerability of area inundated less than 2 Meter in 2006 flood is 0.68 and a variance of 0.005. Average vulnerability of hospitals located in the south zone of the city is comparatively higher than the hospitals in the east and central zone area of the city.

Table 7.18: Flood Water Level upto 1 to 2 Meter in central zone

Zone	Type of Hospital	Vulnerability
Central Zone	Private	0.89
Central Zone	Private	0.90

Source: IRADe Analysis

Table 7.19: Flood Water Level upto 1 to 2 Meter in north zone

Zone	Type of Hospital	Vulnerability
North Zone	Government	0.89
North Zone	Private	0.85
North Zone	Private	0.88
North Zone	Private	0.98
North Zone	Private	0.92
North Zone	Government	0.92
North Zone	Private	0.73

North Zone	Private	0.85
North Zone	Private	0.94
North Zone	Private	0.87
North Zone	Private	0.85
North Zone	Private	0.92
North Zone	Private	0.89

Source: IRADe Analysis

Table 7.18, 7.19 and 7.20 shows the vulnerability index of hospital located in the area inundated more than 2 Meter during 2006 flood in the city. The average vulnerability index for the hospitals located in central zone, north zone and west zones are 0.87, 0.88 and 0.84 respectively. Variances in vulnerability index for the hospitals located in a particular zone are not very significant. This implies hospitals located in a particular zone have equal likelihood to suffer infrastructural damages in the event of floods in future.

Table 7.20: Flood Water Level upto 1 to 2 Meter in west zone

Zone	Type of Hospital	Vulnerability
West Zone	Private	0.90
West Zone	Private	0.83
West Zone	Government	0.94
West Zone	Private	0.88
West Zone	Private	0.93
West Zone	Private	0.79
West Zone	Private	0.89
West Zone	Government	0.74
West Zone	Private	0.65

Source: IRADe Analysis

7.4.3.8 Conclusion

The ability to measure vulnerability to flood is an essential prerequisite for reducing its risk. The measurement of vulnerability in this study was aimed at identifying the infrastructure vulnerability of hospitals due to flood. This study has estimated vulnerability index for the sample hospital located in the flood vulnerable zone of the city which provides additional guidance to local planning authorities to ensure the effective implementation of the planning policy set out for development in areas at risk of flooding. This will help us to minimize the overall risk of the hospitals faced due to flood through suitable planning.

This study has emphasized on the impact of flood on hospitals as hospitals play a vital role in providing essential medical care during disaster, but they also tend to be highly vulnerable being a highly complex and infrastructure intensive facility. Local authorities need to step in and provide grants and required remedial measures to prevent vulnerability of the flood affected hospitals.

7.4.4 Vulnerability Analysis of Industries

7.4.4.1 Introduction

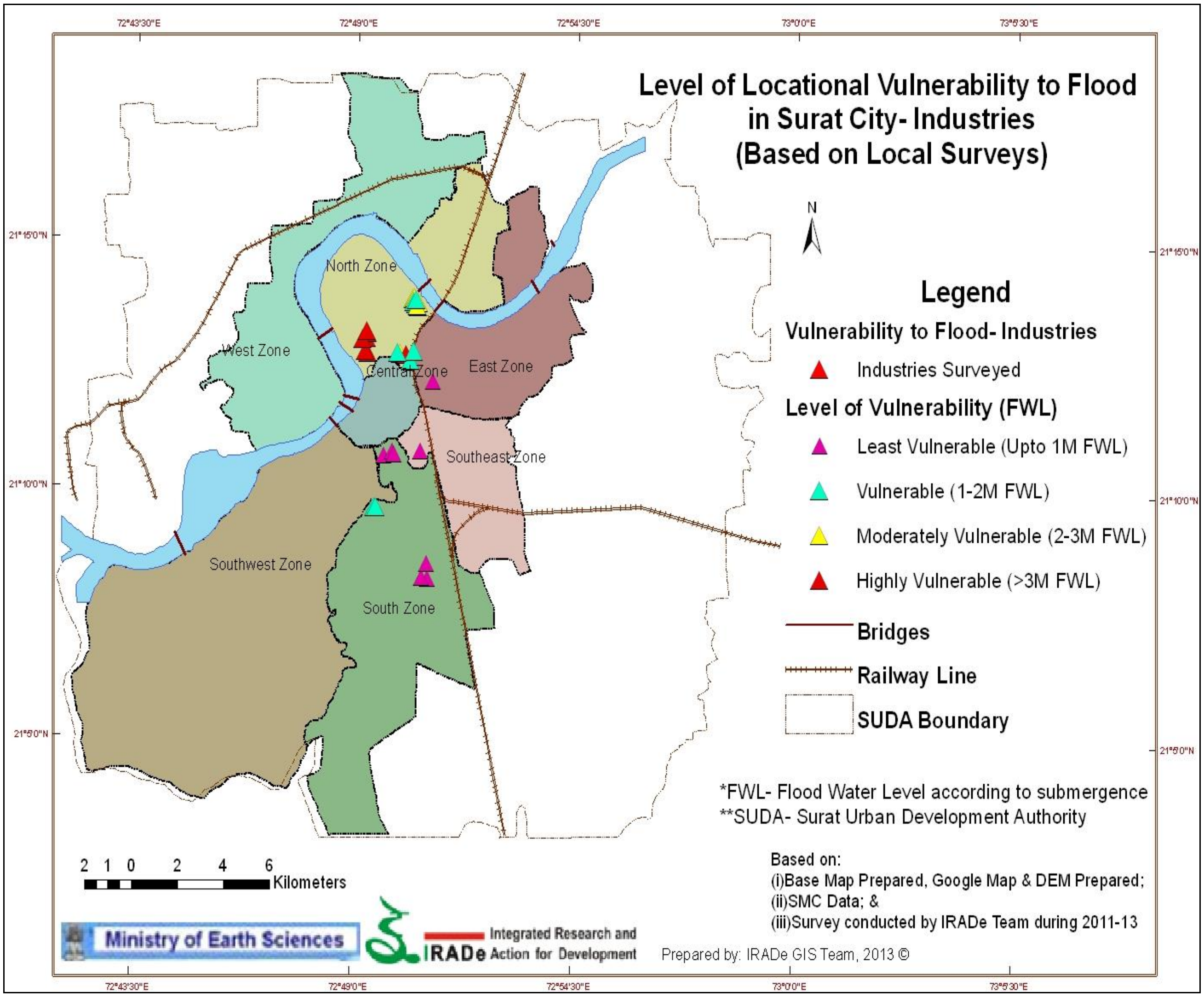
Surat has presence of a large number of diamond processing, textiles and chemical & petrochemical industries. The city is a hub of small and medium size unorganized labour intensive industries. Of the total 278656 small scale units registered (2003) in Gujarat Surat districts has 41509 units comprises 14.9 percent of total SSI units in the state. Number of SSI units in the city is increasing with a rapid pace share of city in total SSI units of the state has increased from 12.6 percent in 1980 to 15 percent in 2005. Surat has 1990 registered factories units employing about 1 lakh 35 thousands worker. Much of the industrial development in Surat district is concentrated around city area. Surat is an industrial city with more than 50 percent of the workforce employed in manufacturing activity.

Surat is a major player in the textile sector, textile processing units is back bone of city's economy. This is having a total sales value of Rs 20,000 crore. Textile units mainly depend on ground water for its processing and withdraws about 700 to 1000 cubic meter of water every day. Diamond cutting and polishing another important industry of Surat accounts for almost 80 percent of total diamond processed in India. Surat is one of the world's largest diamonds processing centres. Like textiles, diamond cutting and polishing is also a labour intensive industry employee approximately 5 lakhs worker in about 25000 units operating within the city region. Surat is one of the leading city in the country that has attached massive investment proposals. According to CMIE, as on 31st August 2006 there are 1819 projects under implementation with investment of Rs 134206 crore with an estimated employment generation of 277947. Surat accounts for 26 percent of units, 21 percent of investment and 11 percent employment being generated through this investment in the state.

7.4.4.2 Industry Sample Composition

Surat is primarily dominated by small and medium scale industries; primary survey sample comprises 30 percent medium scale industry and 70 percent small scale industries scattered across four most vulnerable zones indentified namely East zone, North zone, South-East zone and South zone for industries in Surat. To have a proper representation from various subsectors within the textile industries our survey sample considered main products of the industry also (Please see the chart below for sample composition by main product types). Small and medium enterprises employ generally less than 500 employees.

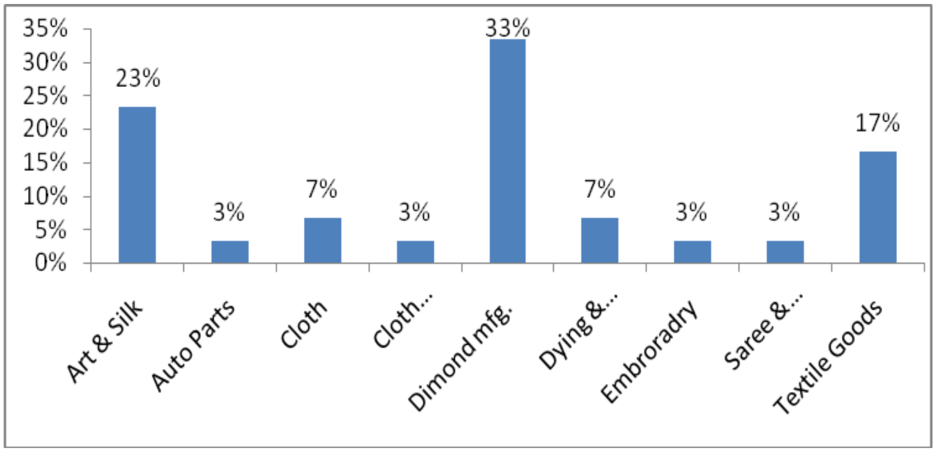
Figure 7.27: Industry units surveyed during IRADe primary survey and level of vulnerability based on flood water level in flood event 2006



Source: IRADe

In our sample there are 30 percent industries engaged less than 100 people, only 17 percent sample industries employ more than 500 workers. Enterprises having employee strength between 100 to 200 and 200 to 500 are 20 percent and 33 percent respectively of the total sample.

Figure 7.28: Sample composition by main product types of the enterprise



Source: Primary data collection by IRADe

Majority of small and medium size industries in Surat city are in the private sectors having sole proprietorship and partnership nature of holdings. Small and medium enterprises are having working days ranging between 250 to 365 days in a year. Approximately 95 percent of the industries do not pay any rents as they own the properties. All the industries covered in the survey reported that they have taken insurance coverage against any untoward incidence in future in their plants.

7.4.4.3 Vulnerability of Industries

Industries having high exposure, sensitivity to impacts and lack of /limited ability to cope or adapt to the climate change related events like flood needs to be aware about the unforeseen future disaster events. The severity of the impacts not only depends on the exposure, but also on the sensitivity of the exposure and on the capacity to cope or adapt, having a prior knowledge will help to reduce the likely severity of impacts of the events through planned adaptation measures. This section briefly evaluates the severity of impacts of flood events in 2006 on the industries in and around city.

Approximately 50 percent of the industries surveyed reported that they got affected with flood in 2006, out of which 37% said that impact of flood was severe and forced the production disruption for 5 days and more. 7 percent industries reported moderate impact of flood and production was disrupted by 3 to 5 days. Only 7 percent industries reported slight impact of flood and production was disrupted for 1 to 2 days. A small textile company having employee strength 200 to 500 said that he had to discontinue production for more than 3 months and carry out repair work to his plant because of damage caused by flood in 2006. Production day’s loss translated into loss of revenue by the companies depending upon the size of companies. Because of flood individual companies reported loss of revenue which varies from Rs 15000 to Rs 40 lakh for smaller scale enterprise suffer slight impact and medium scale enterprise suffer very high impact respectively. Impact of flood was not only limited to production disruption it also causes epidemic, 17 percent of the industry representative responded that post flood there were spread of epidemic which further impacted their production. Disruption of transportation and communication post flood also causes loss for the enterprises located in the flood affected areas. 53 percent enterprise covered in survey reported loss due to transportation and communication disruption.

During survey some respondents, who are basically workers from North India stay in industry premises and don't have shelter said that they are the one who mostly gets affected by the flood because flood can come any time and sometime at night when they used to sleep. They don't have TV or Radio access in the industry and at night time they sometimes do not listen to the SMC alarm and gets affected.

Recurring flood events in the Surat city is a threat for the industry located in the high flood prone zone of the city. Vulnerabilities also varies by zones hence, vulnerability assessment at micro level (specific to each zone) is important for suitable adaptation risk mitigation measures.

7.4.4.4 Risk Mitigation Measures by Industry

Flood in 2006 forced diamond cutting, polishing units and textile factories in Surat, considered the diamond and textile hub of India, being closed for the many days. The closure of factories has wider ramification results into loss of revenue by the factories, loss of employment for workers employed and it also has implication for India's diamond and textile trade. Primary survey by IRADe with the industries in selected zones (based on vulnerability) of Surat city tries to evaluate the risk mitigation efforts taken by various stakeholders and factories.

- Insurance cover against natural disaster is taken by all the factories covered in survey
- All the factories have generator backup in case of power disruption. Only 1/4th of the factories covered in the survey reported that they face power load shading but for small durations only.
- 80 percent factories rely on SMC (Surat Municipal Corporation), 3 percent on GIDC for their water supply whereas 17 percent factories have their own boring to meet their water requirements.
- Almost 100 percent factories said that 1) making the building flood resistant, 2) shifting important material on upper floors, 3) better communication and 4) Improve drainage system are the flood preventive measures already taken by the them.

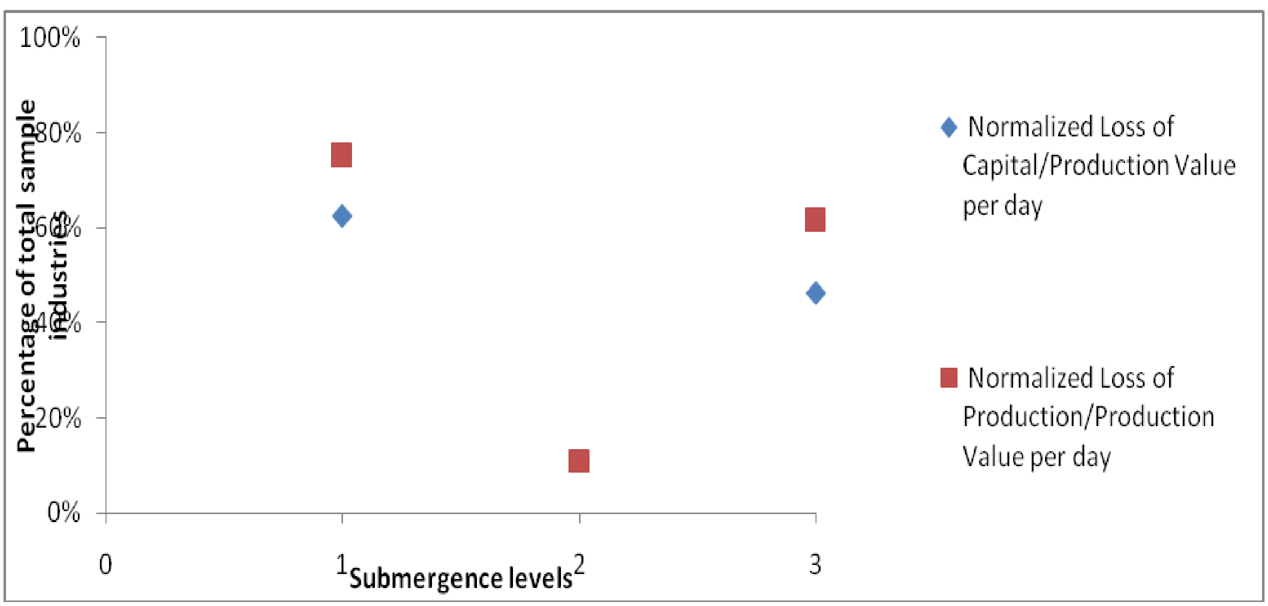
- Fire safety instrument is installed in 100 percent factories
- In case of any emergency/eventuality there is lack of back up rescue preparation. 60 percent of factories responded that they themselves are responsible for having their own rescue team. 40 percent said that they do have their own rescue team for emergency/eventuality backed by SMC

7.4.4.5 Vulnerability Index for Industry

Vulnerability Index (VI) for industry are calculated based on the primary data collected from the Industry for the parameters loss/damage of capital/stock and Loss in production during the flood events in last decade. Capital loss (Rs) and loss in production (Rs) are further normalized by production value per day (Rs per day) to adjust for the economy of scale of a particular industry getting undue advantage.

In the analysis, it is assumed that overall vulnerability of industry depend on both vulnerability indicators considered but the likelihood of occurrence of a particular vulnerability indicators during an event of disaster varies distinctly. Likelihood of occurrence of particular vulnerability parameters depends on the exposure, risk reduction measures taken by industry on those particular parameters. To capture this variation in magnitude by vulnerability parameters on overall industry we have assigned weights to different vulnerability parameters by considering economic losses reported by percentage of industry population (to the total population) during primary survey conducted by IRADe team.

Figure 7.29: Vulnerability of Industry at different submerge level



Source: Primary data collection by IRADe

To capture the vulnerability of industries located at different location we have further classified weights by the location of the industries as per the flood water level during flood event in 2006.

Surat is the second largest commercial hub in Gujarat dominated by micro, small and medium enterprises in textiles and diamond cutting & processing. Hence, majority of companies surveyed for this study are small & medium enterprises and are textiles and diamond cutting & processing units.

Table 7.21: Flood Water Level upto 1 Meter

Zone	Type of Industry	Main products	Vulnerability
East Zone	Small	Saree & Dress mat.	0.00
South East Zone	Medium	Embroradry	0.02
South Zone	Medium	Auto Parts	0.01
South Zone	Small	Cloth	0.03
South Zone	Small	Dying & Process	0.00
South Zone	Small	Dying & Process	0.04
South Zone	Small	Textile Goods	0.07
South Zone	Small	Textile Goods	0.38

Source: IRADe Analysis

Table 7.21 presents the vulnerability index of the industry based on damaged caused in 2006 flood. It can be observed that the overall vulnerability indexes for the industry are very low except a small textile goods industry located in the south zone having the vulnerability index of 0.38.

Table 7.22: Flood Water Level 1 to 2 Meter

Zone	Type of Industry	Main products	Vulnerability
East Zone	Medium	Textile Goods	0.00
East Zone	Small	Art & Silk	0.00
East Zone	Small	Art & Silk	0.00
East Zone	Small	Art & Silk	0.00
North Zone	Medium	Diamond mfg.	0.00
North Zone	Medium	Diamond mfg.	0.03
North Zone	Medium	Diamond mfg.	0.00
North Zone	Small	Diamond mfg.	0.00
North Zone	Small	Diamond mfg.	0.00

Source: IRADe Analysis

Majority of high vulnerability industries are located in the South and north zone of city. East and south east zone of the city are relatively less vulnerable. Vulnerability of industries also depends on the nature of business. Diamond cutting & processing units are relatively less vulnerable than textile industries. A significant percentage of enterprises involve in the business of textile goods, dying & processing and cloth are in high vulnerability rank. Art & silk, cloth weaving and saree & dress materials are in medium and low vulnerability rank. Vulnerability of an enterprise is a function of economy of scale also. Small scale enterprises are more vulnerable than their medium scale counterparts.

Table 7.23: Flood Water Level above 2 Meter

Zone	Type of Industry	Main products	Vulnerability
North Zone	Medium	Dimond mfg.	0.00
North Zone	Medium	Dimond mfg.	0.40
North Zone	Small	Dimond mfg.	0.00
North Zone	Small	Dimond mfg.	0.00
North Zone	Small	Textile Goods	0.74
North Zone	Medium	Dimond mfg.	0.11
North Zone	Small	Art & Silk	0.03
North Zone	Small	Art & Silk	0.05
North Zone	Small	Art & Silk	0.00
North Zone	Small	Art & Silk	0.15
North Zone	Small	Cloth	0.00
North Zone	Small	Cloth Weaving	0.04
North Zone	Small	Textile Goods	0.09

Source: IRADe Analysis

7.4.4.6 Conclusion

This study tries to delve into the vulnerability of industrial settlement mostly small and medium enterprises spread across the high flood zone. Industrial facilities of city are structurally exposed to flooding. Past events witnessed industrial vulnerability to flooding, including direct impact on structure, loss of safety measures, loss of utilities, loss of production, business interruption and etc. Industrial settlement (textile and diamond) in the city are highly labour intensive in nature and contribute substantially to India’s foreign trade, when flooded industrial facilities present direct damage to structure and indirect business interruption (especially international diamond trade of India), temporary unemployment and etc. It is therefore necessary for all the stakeholders to improve their understanding of potential impact of flooding, and develop a suitable strategy to mitigate/minimize the loss that may be caused by such natural events in future.

Vulnerability index for selected sample factory from the vulnerable zones developed based on tangible damage to which monetary values can be assigned to the consequences of flooding. The magnitude of the damage may be taken as the cost of restoration of property to its condition before the flood event, or its loss in market value if restoration is not worthwhile. Vulnerability index shows that factories in the east zone are least vulnerable whereas north and south east zone is the most vulnerable. Vulnerabilities also depend upon the industry types (main products) and scale of industry (small or medium enterprise).

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CHAPTER 8: SUMMARY OF THE CASE STUDY AND ADAPTATION STRATEGY

8.1 Introduction

The impact of climate change on urban areas can be serious. We need to take adaptive measures to strengthen resilience of our cities. This is particularly important as our urban population is expected to increase by hundreds of millions in the coming decades. Due to vagaries of climate, increased anthropogenic activities and encroachments, and unmindful constructions along the river-banks cities often face disasters like floods. These will impact socio-economic conditions, leading to loss of livelihoods, infrastructure and property damage in affected areas, and hardship for vulnerable communities. At the same time, the rapid growth of urbanization offers an opportunity to take proactive measures to adapt urban growth to make our cities more resilient to climate change.

The analysis of the projected impact of climate change in urban areas and examining a way forward towards building a climate resilient city is a complex task. It requires interdisciplinary research work involving the hydrodynamic analysis, socio-economic assessment, understanding the techno-economic constraints and urban system simulation. It also requires the integration of these various aspects in a coherent framework. Fortunately, some of the building blocks are available, but what is missing is an integrating framework. The study develops a methodology to integrate outcome of available city specific analysis and expands it to generate a procedure to introduce climate change concern in the existing framework for decision support system (DSS), for identification of adaptation options given the uncertainties of projection and scenarios to generate robust results.

In this project, analytical methods have been developed in the context of a specific case study of Surat city. As the hydrology of the region is shaped by Tapi River, Ukai Dam at upstream (~100 Km east) of Tapi River, proximity to sea-shore, and frequent rainfall especially in July and August, the findings of the project are quite relevant for Surat city as well as other cities having more or less similar conditions and which are in transition and on a development path. It is hoped that these findings are shared with the larger group of policy makers, academia and local community to initiate a meaningful dialogue on climate risks, general perceptions about the adaptive capacity and how adaptation can be mainstreamed in these policy processes. There by, the study will help further policy formulation, especially the formulation of city development plans to understand how climate risks and adaptation can be incorporated into these plans to make cities climate change resilient and minimize damage to cities' vulnerable sections.

8.2 Vulnerability Mapping

Keeping the objectives of the project in mind we have assessed the vulnerability of Surat city and its people to climate change. We have also carried out the socio-economic vulnerability surveys of the city to find out level of vulnerabilities in the city in the context of flood due to water discharge from the UKAI dam in to the Tapi river water. For identifying and assessing the hydro-meteorological vulnerability of the city, we have performed HEC RAS simulation modeling on ARC GIS platform. Tools for vulnerability mapping and assessing the impacts of climate change on the region in the study include Hydrological modeling tools (HEC RAS, HEC GeoRAS and HEC HMS), Statistical tools (MS Excel and SPSS), Remote Sensing and GIS Tools (ERDAS Imagine-LPS, ARC GIS and AutoCAD Map) and IPCC SRES models. We have also assessed the flood vulnerability of the city in various water discharge scenarios from the UKAI dam. In this project we have mainly focused on the flood analysis and flood related vulnerability of the city.

Moreover, vulnerabilities of coastal cities to climate change related risk exposure is explored in this project. With natural growth as well as push migration from rural hinterlands, most of the cities are likely to expand significantly over the next few decades and the risk profile expected to worsen. Following are the few observations with regard to growing risks in the cities:

- Improved access from new bridges and growing real estate demand, the cities have expanded from one bank to both banks of rivers, thereby constricting the flood plains. As the city expands, the demand for high value land within and periphery leads to blockage of natural drainage, encroachment of flood buffers (reservoirs and tanks) by landfills, narrowing of river channels and flood plains. These encroachments increase the flood risks of the cities.

- The haphazard peripheral growth led by the private sector and individual houses by multiple land owners further add to the complexity of the challenge. As the cities expand by multitude of land developers, natural drainage is often blocked and increase in impervious areas as well as filling of lakes have increased the pluvial flood risks. Growing gap between master plan projections and actual expansion of the cities can lead to increased risks of floods, water logging as well as water scarcities in many cities over coming decades even without any significant change in precipitation pattern. The recurrent floods and water scarcities in cities like Delhi, Ahmedabad, Vadodara, Pune, Surat, Cuttack, and Kolkata highlight this challenge. While urban planners are expected to incorporate these issues in developing expansion plans and master plans, in practice the hydrological issues are not incorporated in master plans.

As mentioned in earlier sections, Indian cities face challenges of scarcity of resources, inadequate and infrastructure and poor quality of lifeline services. A significant proportion of urban infrastructure is old and decrepit in the core city areas. These old infrastructure is still being used, since refurbishing or installing new infrastructure is nearly impossible due to very high densities and lack of space. Major changes in density and decongestion of the core to improve the services are politically unpopular and administratively challenging. Only in rare cases, the ULBs are able to decongest the old core and improve the services in the core areas.

8.3 Socio-economic Impacts on Facilities and Communities

The flood risks have increased due to the anthropogenic changes in river hydrology and coastal environment. This has increased the flood risk of many river-bank as well as coastal cities like Ahmedabad, Vadodara, Pune, Surat, Cuttack, Kolkata, Delhi, etc. Also the problems of inadequate storm water drainage and filling of traditional water storage reservoirs (which acted as buffers) within the city have increased the pluvial flood risks. The Restriction imposed by master planning process (e.g low FSI limits) has led to increased house prices and has indirectly forced the poor to settle in peripheries marginalized areas like drainage lines and differentially higher flood prone areas with little or no protection.

Most of the cities are likely to expand over the next few decades and the risk profile is likely to change towards worse, unless the land use planning is informed by the changes in hydrology and climate variability issues. As mentioned earlier, the private sector and individual household led expansion of peripheral areas without developing regional infrastructure networks are likely to increase the risk profiles. It is noteworthy that this increase in risk profile of the cities is not related with the climate change. Rather it is more due to increased anthropogenic interference and lack of clarity on policy restricting inhabitation in the most flood-prone areas of the city.

To know the socio-economic aspect of the devastating flood of 2006 in Surat, a field survey has been conducted with a variety of questions to identify the key vulnerable locations in Surat, to understand the impacts of flood in 2006 and to know and suggest various adaptation measures needed to minimize the damage due to flood in the future. We have identified four important vulnereable facilities and communities such as schools, hospitals, slums and industries becuase of the very role played by them for the society and economy, and these are most susceptible in the event of flooding. This study attempts to create a composite vulnerability index for these from the different indentified vulnerability indicators specific to each of them. Since vulnerability calculated is dynamic over time hence all the indicators are related to a particular time point only. However, the vulnerability index developed is related to depth of inundation and will help to identify human suffering and the economic loss related to providing social services and public assistance after flooding for another flood scenario.

The index is based on the probability of damages due to flood based on the intensity of damages incurred in flood in the year 2006. Vulnerability Index also takes into account problem faced immediately after floods, duration and level of inundation.

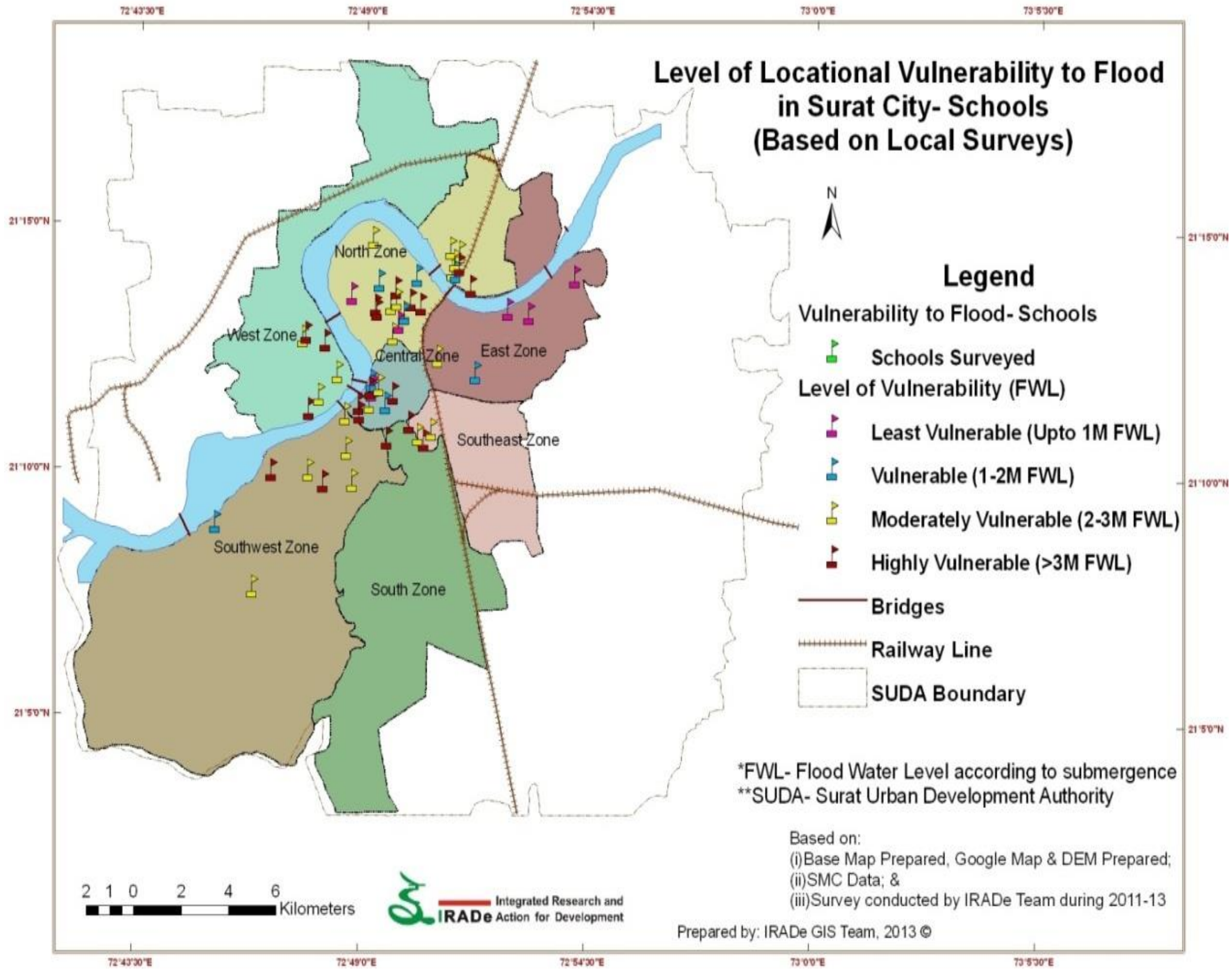
The vulnerability index provides an input to government machineries at different levels, such as Municipal Corporation, State Government and other stakeholders dealing with natural hazards and city planning to make an informed decision and take appropriate advance actions or plan for actions when there is the menace of flood.

8.3.1 Vulnerability of Schools

Schools play a multiple role, be it for education or for safe shelter to the flood affected people. Schools face three types of impacts- educational impact, physical impact and economic impact. Educational impact includes the damage to the school infrastructure, disruption in educational activities, reduced quality of education due to loss of time, etc. Physical impact portrays that students lose their sense of continuity and their hopes and plans for the future are disturbed. Economic impact reveals the loss of income and reinvestment for repairing damaged parts of the school. Educational infrastructure often plays a significant role in ensuring sustainable development. Chapter seven of the report delves into the flood vulnerability and adaptation measures for schools.

Vulnerability Index for the schools are based on the primary data collected from 56 sample schools surveyed from North, East, West and Central zones of the city. These sample schools are spread across different inundation levels during the 2006 flood in the city (Fig 8.1). The sample composition tried to represent the various categories of schools such as government funded, privately funded. Sample composition also consists of primary, secondary and higher secondary schools.

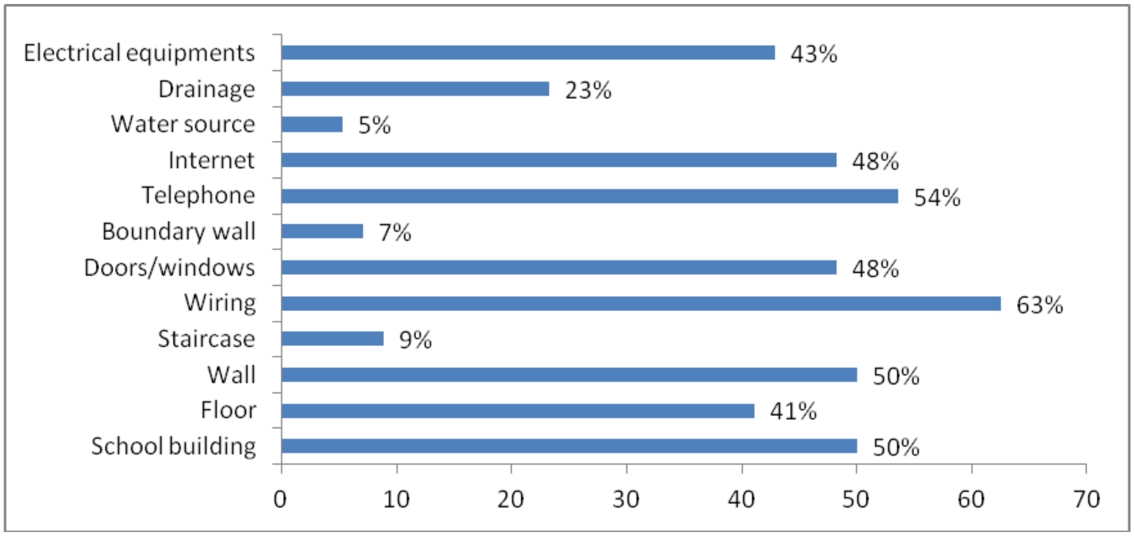
Figure 8.1: Schools surveyed during IRADe primary survey and level of vulnerability based on flood water level in flood event 2006



Source data: Primary Survey, IRADe

Flood is a threat for structural damage which leads to school closure for a certain period. In this survey we have seen infrastructure damaged due to flood. School building, floor, wall, boundary wall, electrical equipments, power disruption and telephone were severely affected (Fig 8.2). It has been observed that several problems have been occurring repeatedly in the schools due to flood. Some schools are situated in low-lying area which can be submerged even during heavy rains. In such a situation, the government has to step in and provide grants and required remedial measures to prevent vulnerability of the flood affected schools.

Figure 8.2: Damage to infrastructure of surveyed schools



Source data: Primary Survey, IRADe

The vulnerability ranking profile of schools located in the different zones of the city and categorized under different level of submergence during the 2006 flood can be used to enhance disaster preparedness for the schools in the city to minimize the risk of damages to the schools in the future in the event of a flood.

The vulnerability index analysis of the schools shows that with increasing levels of inundation during flood vulnerability of schools are also increasing. Schools located in the low lying area are highly vulnerable to floods (Table 8.1 and 8.2). Zone wise vulnerability mapping of the selected sample schools shows that schools located in the East zone of the city have a relatively high risk and suffer more damages during flood events (Table 8.1).

Table 8.1 Flood Water Level upto 1 meter during 2006 flood

Zone Name	School Category	Vulnerability
Central zone	Secondary	0.11
Central zone	Primary	0.17
East zone	Higher Secondary	0.46
East zone	Higher Secondary	0.46
East zone	Secondary	0.47
North zone	Higher Secondary	0.31
North zone	Primary	0.10

Table 8.2 Flood Water Level from 1 Meter to 2 meters during 2006 flood

Zone Name	School Category	Vulnerability
Central zone	Primary	0.54
Central zone	Secondary	0.20
North zone	Higher Secondary	0.48
North zone	Higher Secondary	0.46
North zone	Higher Secondary	0.43
North zone	Higher Secondary	0.57
North zone	Higher Secondary	0.45
West zone	Higher Secondary	0.75

Source: IRADe Analysis

There is a lack of disaster preparedness and warning system. Respondents during the survey said that they get awareness through the electronic and print media such as news, T.V. and radio, but no alert or warning came from administration before water gushed in. Most of the respondents in schools told that after schools reopened, SMC came for checking the safe drinking water, but after flood water receded, they did not get any help from SMC to clean up the mud and the dead animals. They have taken help from neighbours, school staff, maids etc. Role of administration was minimal in terms of relief and cleaning up the premises surrounding the school after the water receded.

Considering the vulnerability of schools to floods there is a need for adaptation measures that can be taken up by schools and administration to reduce the impacts of floods to schools in the future. Following are some of the planned and spontaneous adaptation measures that can be taken up.

8.3.1.1 Planned and spontaneous adaptation measures

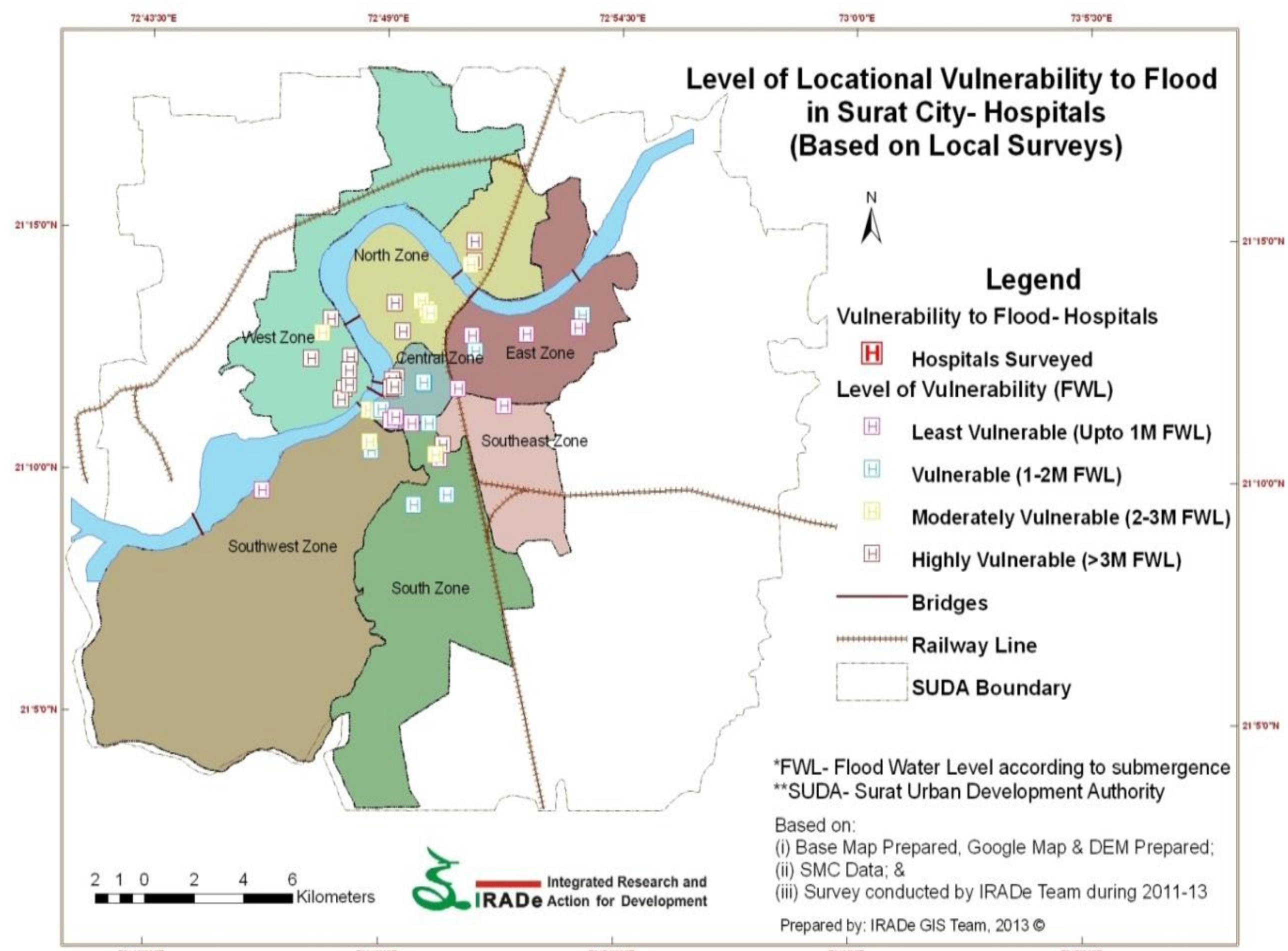
- How to act during a disaster should be incorporated in the school syllabus.
- The boundary wall must be pucca with provision to block the gate opening with a movable waterproof barrier to keep out the flood water.
- Electrical equipments (electrical wire) must be kept in waterproof case to prevent short-circuit.
- Electricity shut down should be automatic when water level rises.
- Ground floor and wall of the schools where flood water can reach must be made up of tiles. (Hazards resistance building).
- All the schools in the flood prone areas should have safe places to provide safe shelter to the affected people.
- Network of necessary roads should be constructed to solve the problem of transportation.
- Proper warning in a language that the people can comprehend should be given in time.
- Important documents should be kept up stairs.
- Fire extinguisher must be available in the school premises and people should be trained for operating them.

8.3.2 Vulnerability of Hospitals

Vulnerability of hospitals is important due to the significance of their role in the recovery of community after disaster. In this study, the hospitals that were partially or fully affected by the unanticipated flood of 2006 were surveyed and analysed. This study has emphasized the impact of flood on hospitals as hospitals play a vital role in providing essential medical care during disaster, but they also tend to be highly vulnerable being a highly complex and infrastructure intensive facility. Local authorities need to step in and provide grants and required remedial measures to prevent vulnerability of the flood affected hospitals.

The vulnerability index for the hospitals are based on the data collected through primary survey conducted by IRADe from 50 sample hospitals spread across five zones, namely North, East, West, South and Central zone of the city. Sample comprises both government and privately funded hospitals from the selected zones (Fig 8.3). During the field survey, it was found that only 50 percent of the hospitals from the selected sample have only the ground floor, which shows that they are the ones which are more vulnerable to flooding, because in case of flood they don't have any other place except for the building's roof to rescue themselves. 10 percent hospitals reported that existing practice of building construction is not proper and safe with respect to floods.

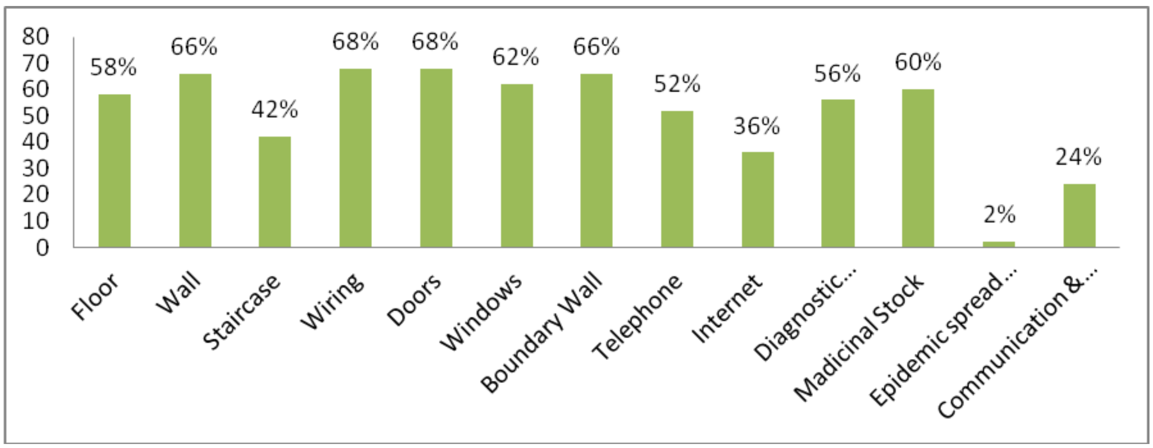
Figure 8.3: Hospitals surveyed during IRADe's primary survey and level of vulnerability based on flood water level in flood event 2006



Source data: Primary Survey, IRADe

The major damage to hospitals occurs in the form of physical and economic damage. Our survey results show the significant damage to the boundary walls, doors, windows and wiring. Damage to wiring can result in short circuit of the electric system, often leading to fire. Damage to communication system leads to mismanagement that hampers the networking system among the hospitals. It is also found during the survey that flood interrupted the transportation system of most of the hospitals. The damage to the transportation system of the hospitals often results in much more disastrous situation, as patient care gets disrupted and the essential medical care could not reach the affected people at an appropriate time. The results show significant damage to the flooring of the building along with others damages to the building, the reconstruction and repairing will put another economic burden (Fig 8.4).

Figure 8.4: Structural Damage to hospitals during 2006 flood



Source data: Primary Survey IRADe

The ability to assess vulnerability to flood is an essential prerequisite for taking advance action. The measurement of vulnerability in this study is aimed at identifying the vulnerability of hospitals due to flood and provide an index that can help assess it different flood scenarios. Types of management of hospitals, government or private do not play any role to the vulnerability of the hospitals. Zone wise vulnerability mapping of the hospitals shows that the location of the hospital in a particular zone does not affect its level of vulnerability. Whereas hospitals located in the low lying areas are more vulnerable to flood events (Table 8.3 and 8.4).

Table 8.3: Flood Water Level upto 1 meter during 2006 flood

Zone	Type of Hospital	Vulnerability
Central Zone	Private	0.27
Central Zone	Private	0.23

Table 8.4: Flood Water Level upto 1 to 2 meter during 2006 flood

Zone	Type of Hospital	Vulnerability
Central Zone	Private	0.68
Central Zone	Private	0.58

Central Zone	Private	0.27
Central Zone	Private	0.27
East Zone	Private	0.30
East Zone	Government	0.27
East Zone	Government	0.30
East Zone	Private	0.18
East Zone	Private	0.64
East Zone	Private	0.62
South Zone	Private	0.77
South Zone	Private	0.67
South Zone	Private	0.56

Source: IRADe Analysis

Adaptation measures such as early warning systems and preparedness plans and effective communication solutions during disasters will help to reduce the vulnerability of hospitals to flood.

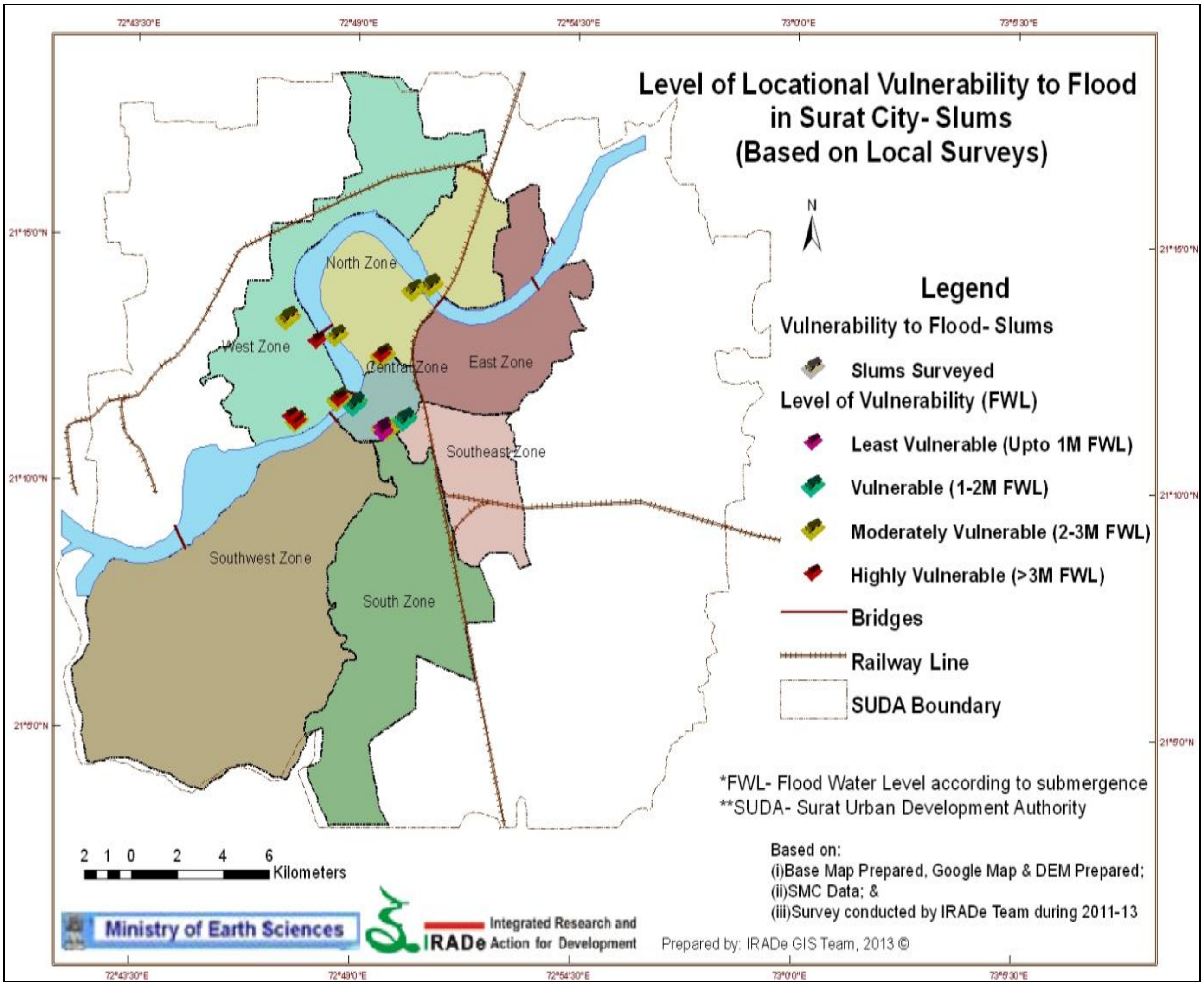
8.3.3 Vulnerability of Slums

Rapid the growth of labour intensive industries such as textile and diamond industry in India is happening in Surat, which is attracting labourers from the rural areas of Gujarat as well as from other states of the country. Despite the growth of housing and expansion of the city area, a number of slum settlements are there in the city. Slum populations are clustered around the industrial area Udhna-Pandesara, which accounts for 41% of total slum populations.

Most slum dwellers are nuclear family engaged primarily in unorganized sector for their livelihood, having lesser means to cope with any uncalled for natural disasters like a flood. Slum houses are semi Pucca and located in low lying areas having a poor drainage system where water logging is a regular menace. The slums located on the bank of river Tapi and on the banks of creeks are severely affected by flood almost every year. Moreover, the slums on the roads, canal banks and on the important reserved plots are highly vulnerable to extreme events like floods.

To delve on the socio-economic issues further and explore the flood risk reduction for the slum dwellers, we have created vulnerability index for the slum settlements in different zones of the city. The vulnerability indices for the slums are based on the primary data collected from the 50 sample slum dwellers from the slums located in North, Central, South and West zone of the city.

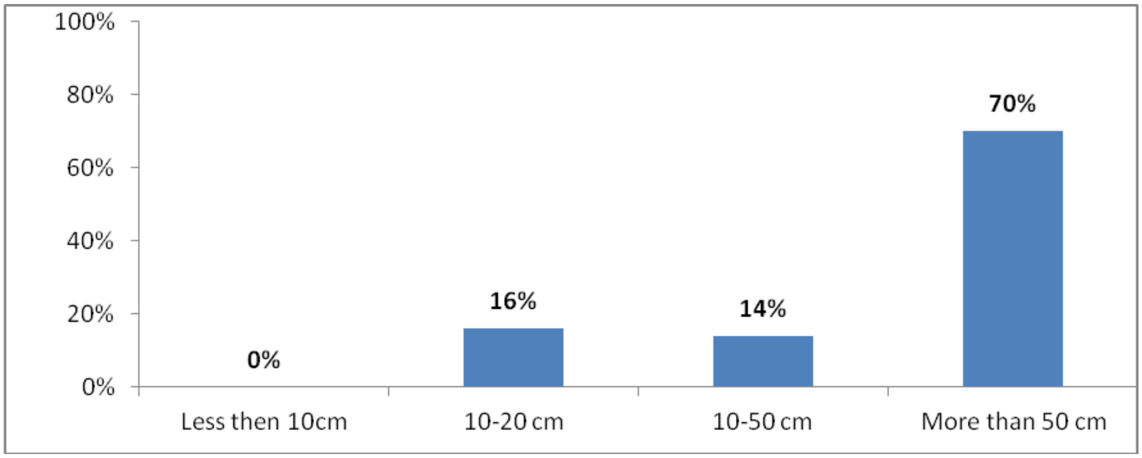
Figure 8.5: Slum surveyed during IRADe primary survey and level of vulnerability based on flood water level in flood event 2006



Source data: Primary Survey, IRADe

Flood in 2006 severely affected the slum households across all the zones, almost all the households covered in the primary survey reported that they were affected during the flood and faced property losses. Approximately 70 percent of the households reported that the water level inside their houses was more than 50cm and the rest of the respondents reported that the level of water was at least 10 cm in their houses during the flood (Fig 8.6). The entry of water inside the houses causes damage to the walls and the flooring. A large number of slum dwellers also reported vehicle damage.

Figure 8.6: Level of water in house during flood



Data Source: Primary Survey IRADe

Our study clearly indicates that recurrent floods pose several hardships to the slum dwellers. Fragile livelihood and disadvantageous living conditions make the situation grimmer. The vulnerability index analysis of slum shows that South and West zones are relatively more vulnerable at the same inundation levels than Central zone.

Table 8.5: Flood Water Level 1 to 2 Meter during 2006 flood

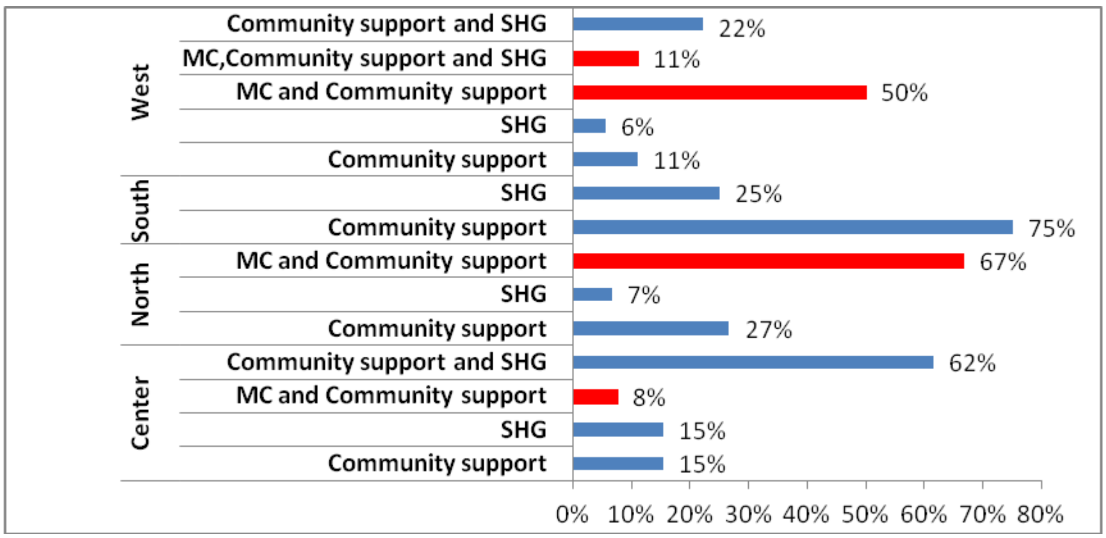
Zone	Occupation	Vulnerability
Central Zone	Barber	0.19
Central Zone	Business	0.00
Central Zone	Rickshaw puller	0.00
South Zone	Hawker	0.34
South Zone	Labor	0.34
South Zone	Service	0.41
West Zone	Chicken shop	0.38
West Zone	Service	0.41

Data Source: Primary Survey IRADe

Floods make the poor even poorer as many depend on daily earnings and that get disrupted. Also a flood forces the slum dwellers to stay in the slum. As floods destroy fixed assets of the slum dwellers and also flush out a huge proportion of their savings and post flood they need to bear extra expenditure to repair their damaged house and replace household items. Vulnerability to floods can be reduced by prudent adaptation measures. Vulnerability Index will also help in identifying the likely adaptation strategy for the slums. Following are some of the adaptation measures that emerged from the survey.

- 70 percent households reported that disaster preparedness camp had never been organized in their areas. Local government bodies should organize disaster preparedness camp, which will enhance the flood adaptive capacity of the slum dwellers.
- It was highlighted in the survey that the participation of the females in the flood awareness campaign was nil or almost negligible. Whereas females are more vulnerable to floods than their male counterparts. Females should be encouraged to take part in the awareness camp.
- Almost every slum household reported in the survey that during the flood in 2006, help came too late and only a few households got the benefits from the government.

Figure 8.7: Support extended by Municipal Corporation (MC), Community Support and SHG to the slum dwellers during flood events



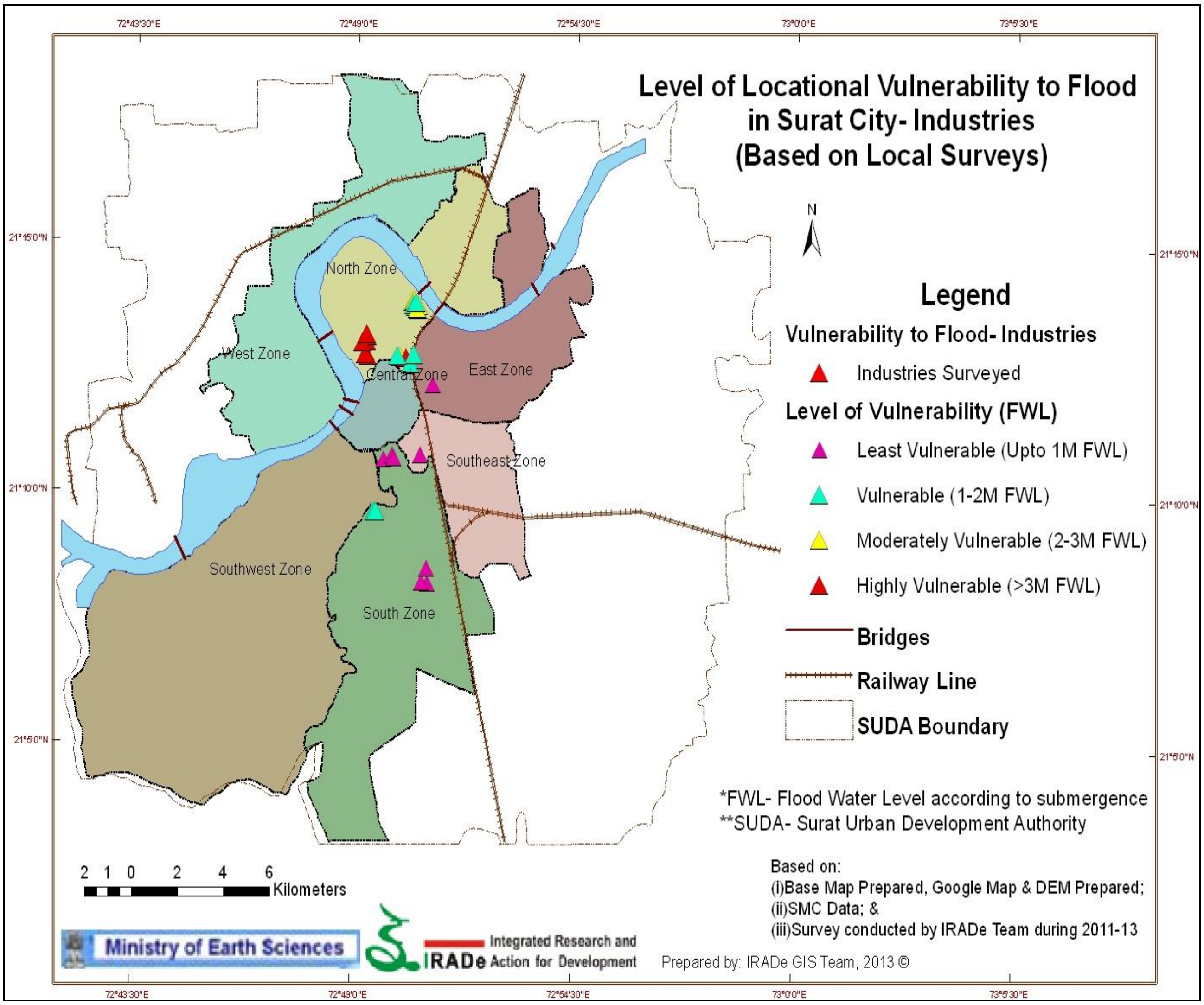
Source data: Primary Survey, IRADe

8.3.4 Vulnerability of Industries

Surat is primarily dominated by small and medium scale industries. Industries having high exposure, sensitivity to the impacts and lack of limited ability to cope or adapt to the floods need to be aware of the possible future disaster events. The severity of the impacts not only depends on the exposure, but also on the sensitivity of the exposed and on the capacity to cope or adapt. Having a prior knowledge will help to reduce the likely severity of the impacts of the events through planned adaptation measures.

Industrial facilities of Surat city are structurally exposed to flooding. The vulnerability index for the industries are based on the data collected through a primary survey from the industry about the tangible damage to industry due to flooding to which monetary values can be assigned. The magnitude of the damage may be taken as the cost of restoration of the property to its condition before the flood event, or its loss in market value if restoration is not worthwhile. To construct the vulnerability index 30 sample industries spread across North, East and South zones of the city were surveyed to collect data about the loss of capital and loss of working days during the 2006 flood in the city (Fig 8.8).

Figure 8.8: Industry units surveyed during IRADe primary survey and level of vulnerability based on flood water level in flood event 2006



Source data: Primary Survey, IRADe

Vulnerability analysis shows that the vulnerability of the industries to floods in the city is moderate. Vulnerability index shows that industries in the east zone are least vulnerable whereas industries in the North and South zones are the moderately vulnerable to floods. Vulnerabilities also depend upon the industry types (main products) (Table 8.6 and 8.7).

Table 8.6: Flood Water Level upto 1 Meter

Zone	Main products	Vulnerability
East Zone	Saree & Dress mat.	0.00
South Zone	Embroradry	0.02
South Zone	Auto Parts	0.01
South Zone	Cloth	0.03
South Zone	Dying & Process	0.00
South Zone	Dying & Process	0.04
South Zone	Textile Goods	0.07
South Zone	Textile Goods	0.38

Table 8.7: Flood Water Level 1 to 2 Meter

Zone	Main products	Vulnerability
East Zone	Textile Goods	0.00
East Zone	Art & Silk	0.00
East Zone	Art & Silk	0.00
East Zone	Art & Silk	0.00
North Zone	Diamond mfg.	0.00
North Zone	Diamond mfg.	0.03
North Zone	Diamond mfg.	0.00
North Zone	Diamond mfg.	0.00
North Zone	Diamond mfg.	0.00

Data Source: Primary Survey IRADe

Impact of the flood of 2006 was limited not only to production disruption, but it also caused an epidemic. 17 percent of the industry reported that in the post flood scenario, there was spread of epidemic which further impacted their production. Post-flood disruption in transportation and communication also caused loss for the enterprises located in the flood affected areas. 53 percent of the enterprise covered in the survey reported loss due to transportation and communication disruption. It is, therefore, necessary for all the stakeholders to improve their understanding of potential impact of flooding on overall system, and develop a suitable strategy to mitigate/minimize the loss that may be caused by such natural events in the future. Some of the risk mitigation measures taken by industries in Surat which are the primary reason for low flood vulnerability of the industries are the followings:

- Insurance cover against natural disasters is taken by all the factories covered in the survey.
- All the factories have generator backup in case of power disruption. Only 1/4th of the factories covered in the survey reported that they face power load shading that too for small durations only.
- Almost 100 percent factories, said that 1) making the building flood resistant, 2) shifting important material on upper floors, 3) better communication and 4) Improved drainage system are some of the flood prevention measures already taken by the team. There is awareness among the industries about the risks associated with the floods and they have taken some or other measures.
- Fire safety instruments are installed in 100 percent factories.

It is, therefore, necessary for all the stakeholders to improve their understanding of potential impact of flooding, and develop a suitable strategy to mitigate/minimize the loss that may be caused by such natural events in future.

8.4 *Flood Inundation Scenarios in Surat city*

Floodplain mapping results are shown using the flood inundation map. Surat is highly vulnerable to flooding as much of it is in low lying areas. To know the flood vulnerability due to river flow and peak water discharge from the UKAI dam, the analysis of inundation of the Surat city has been done and floodplain-mapping results are shown using the flood inundation map. Two scenarios are developed, scenario-1 with the inflow corresponding to the 2006 flood and scenario-2 where that inflow is raised by 50%. Due to large uncertainty, as explained earlier we take 50% increase in Tapi inflows as reflecting the impact of climate change. Preliminary observations of these two scenarios of Tapi river water discharge show the submergence zones. When we compare the two discharge scenarios we find that with the change in river water discharge from Ukai dam at 2006 level to 50% level higher level, more areas get submerged.

The inflow in Tapi at Surat is largely determined by discharges from the UKAI dam. The extent to which the reservoir can be used is limited by its capacity. It is seen that inflow increased from 1, 00,000 cusecs (2900 cumecs) to 4, 00,000 cusecs in six hours and to 12, 00,000 cusecs (35,000 cumecs) in 30 hours. It remained above 4, 00,000 cusecs for more than 4 days. The reservoir got filled up in two days even though discharge level was raised to 8, 00,000 cusecs (23,000 cumecs) and remained above that for 2 days.

Figure 8.9: Zonewise Area submerged in Inundation scenarios of Surat City

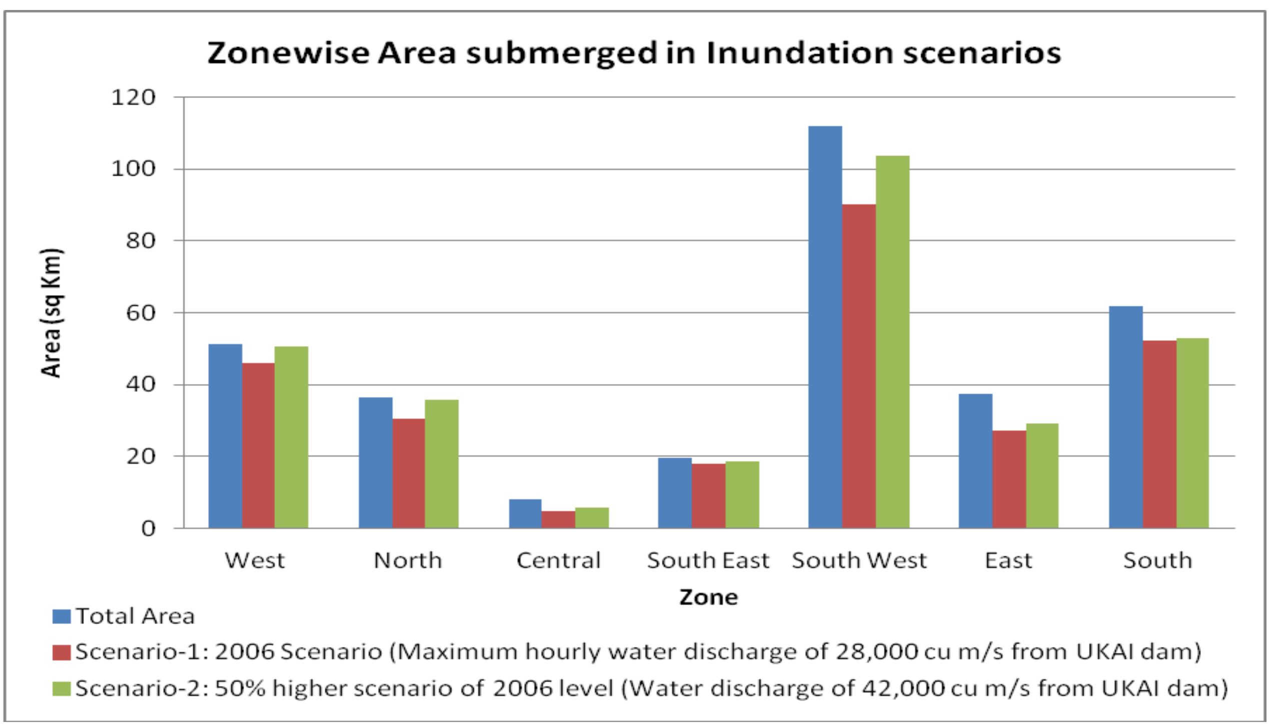
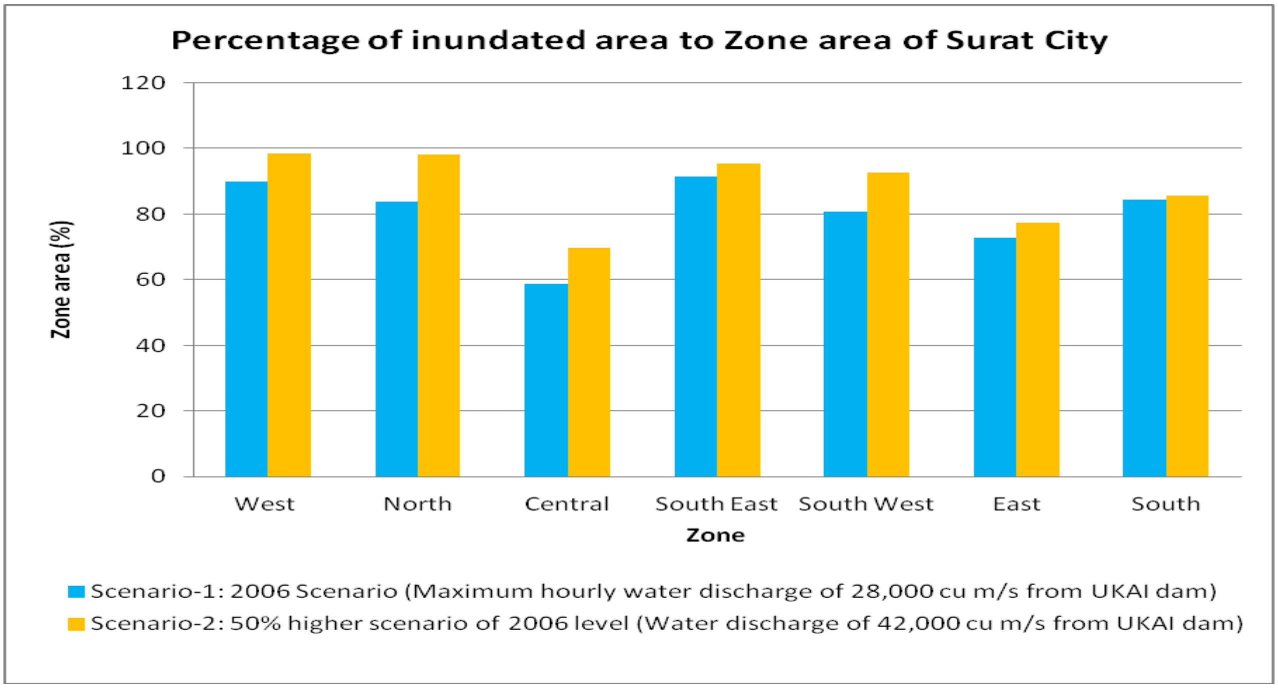


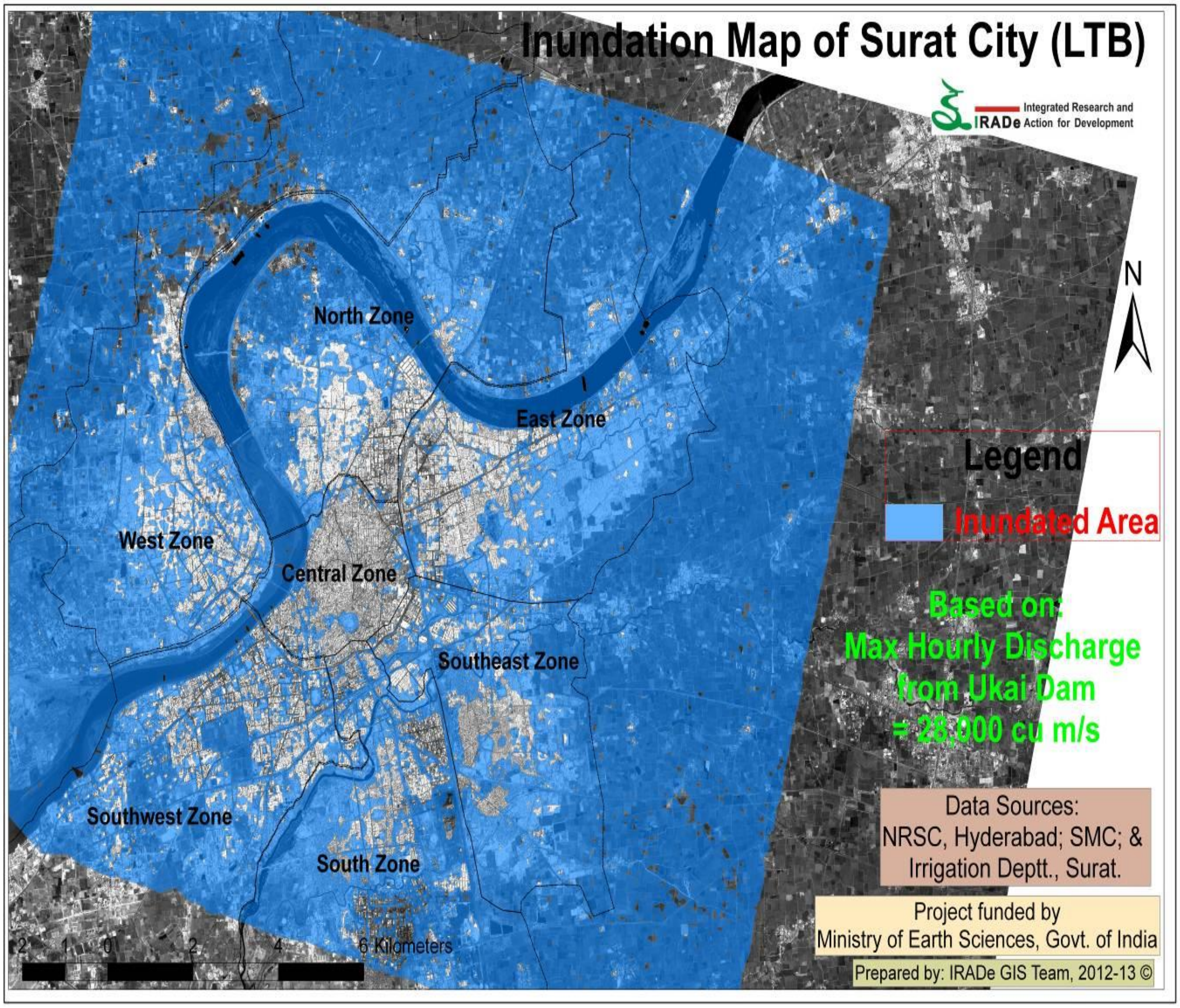
Figure 8.10: Zonewise percentage of area submerged in Inundation scenarios of Surat City



Figures 8.9 and 8.10 show area submerged of diffeerent zones. A sbstantial part of all zones get submerged even in scenarios 1 and more in scenario 2.

- In **scenario 1** (Figure 8.11), when 28,000 cu m per sec water is discharged from Ukai dam, then almost 270 sq km area out of a total area of 320 sq km would get submerged affecting mainly the west, north, central and southeast zones of Surat city. Even in the central zone, which is the least vulnerable, nearly 60% of the area is submerged. After studying the inundation map closely, the following zones and important locations have been identified as vulnerable to floods. West and North zones have been identified as highly affected with more than 90% area under water, whereas Central and Southeast zones are moderately affected to inundation. Some areas of Southwest and East zones are vulnerable to inundation due to discharge of 28,000 cu m per second.

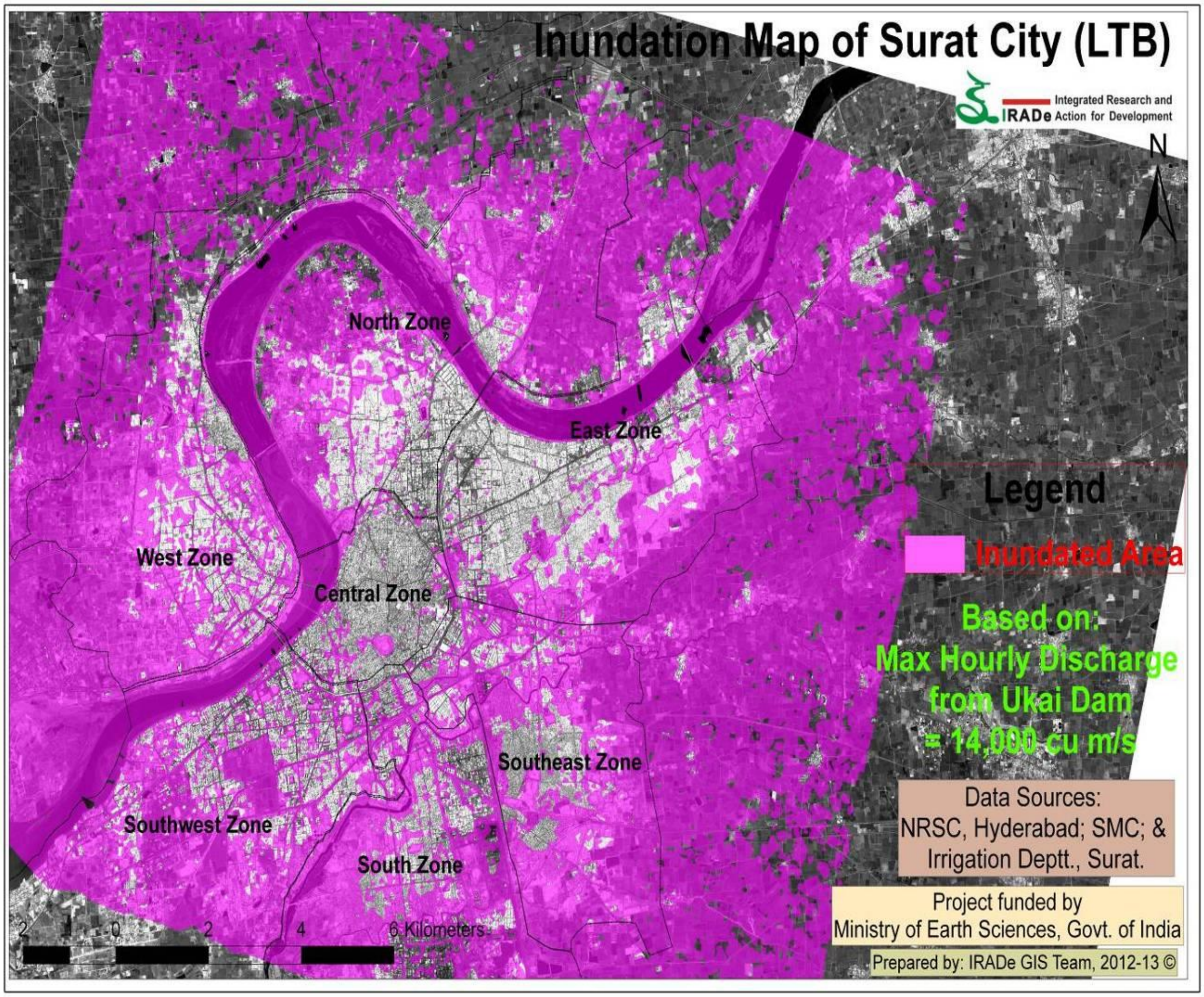
Figure 8.11: Scenario 1: 28,000 cu m/s Water Discharge from Ukai dam (Year 2006 level)



- In **scenario 2** (Figure 8.12), when 50% higher i.e. 42,000 cu m per sec water is discharged from Ukai dam, then almost 295 sq km area would get submerged, an increase of 9.25% than that of 2006 level. The choropleth clearly depicts most of the parts of west and north zones will get submerged with the increase of 50% in discharge. East and Southeast zones will also be at great risk of flooding.

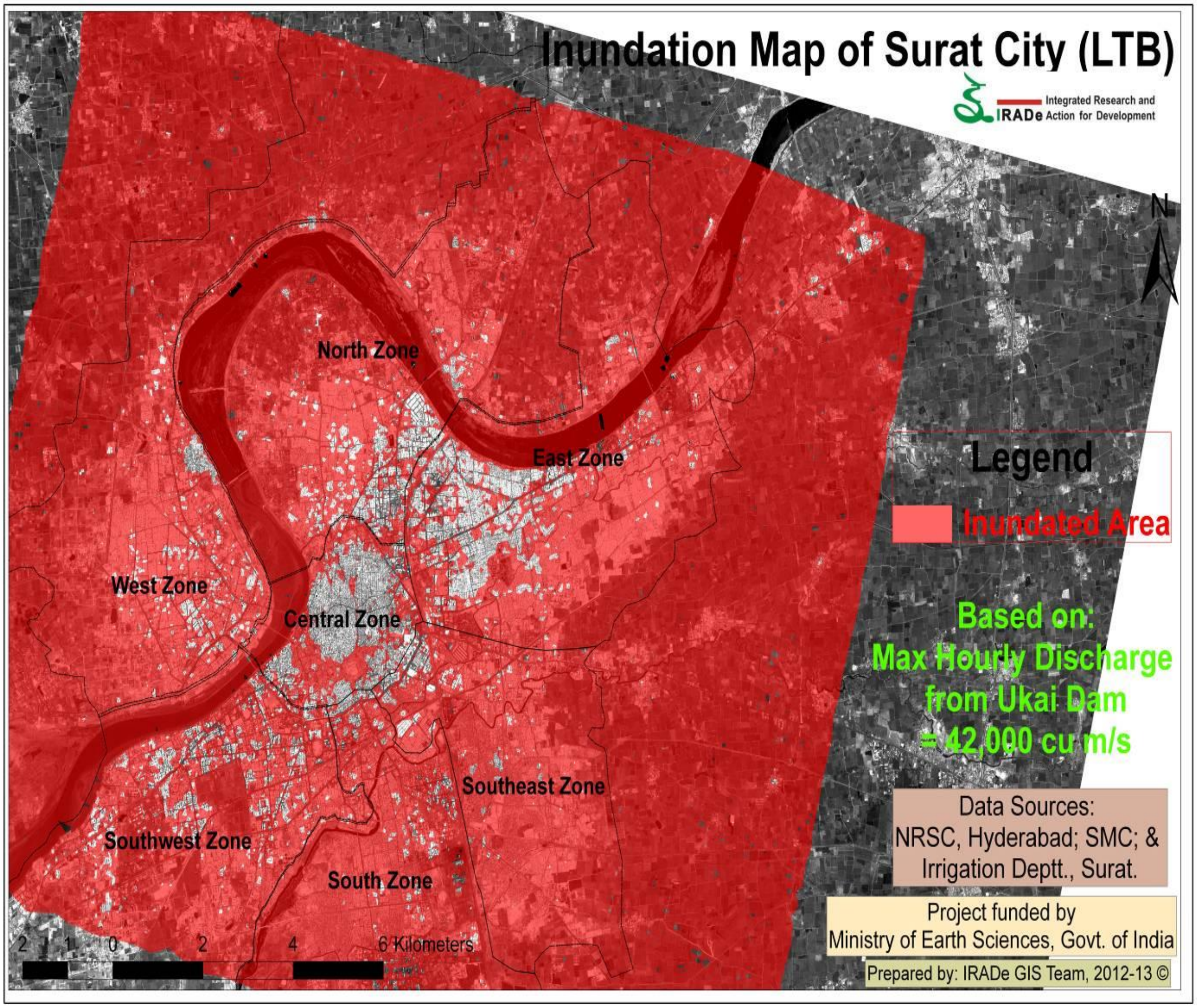
The Hope Bridge has a bank level of 4.1 m; therefore there will be about 3–4 m water over the right-bank area. Hence, the major parts of the Adajan area would get inundated. The Rander area, having experienced fury of 2006 flood, will also be inundated by 1–2 m depth of water in scenario-2.

Figure 8.12: Scenario 2: 50% less Water Discharge from Ukai dam of Year 2006 level (14,000 cu m/s)



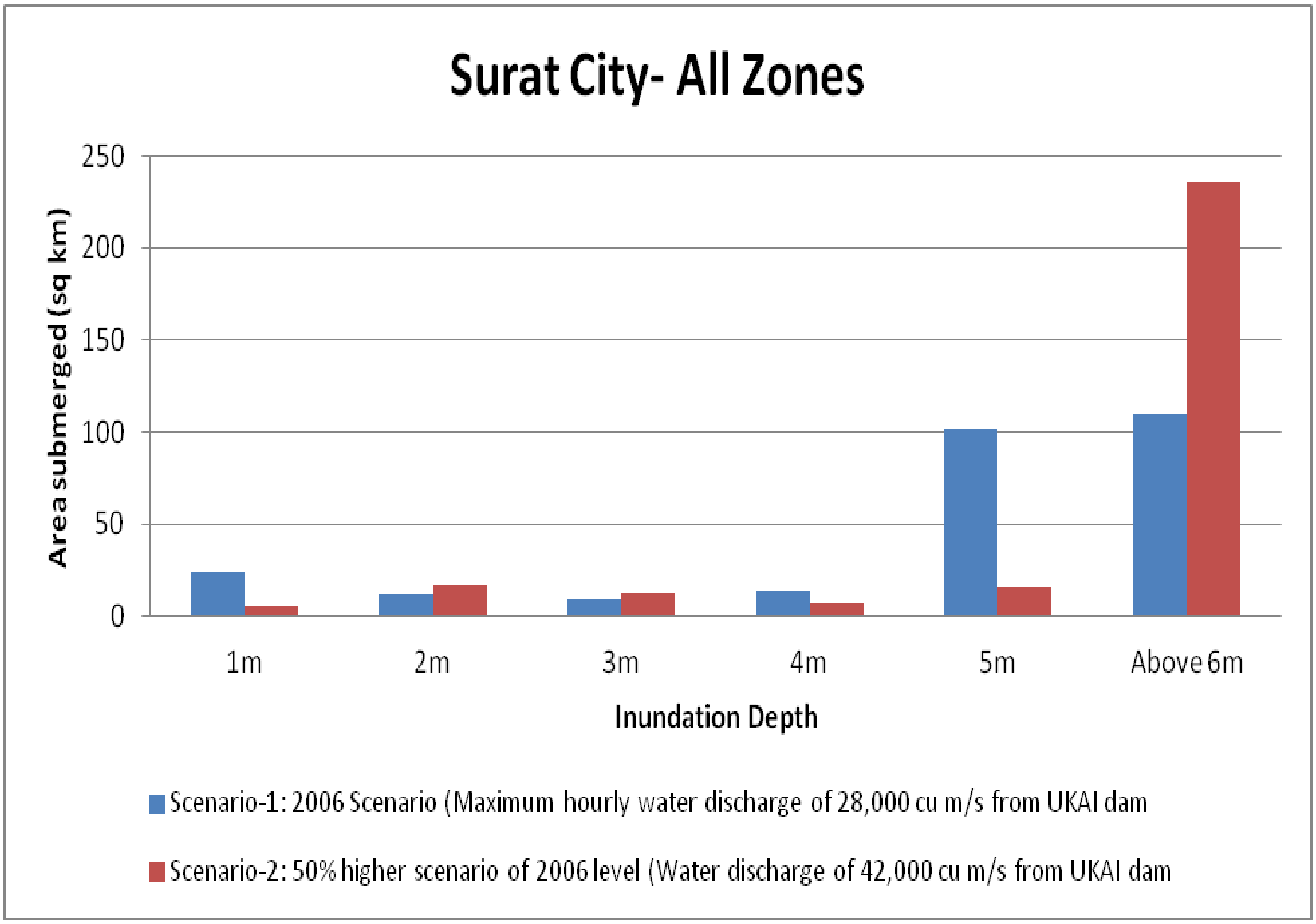
- In **scenario 3** (Figure 8.13), when 50% less i.e. 14,000 cu m per sec water is discharged from Ukai dam, even then almost 228 sq km area would get submerged largely affecting the west, north, some areas of central and southeast zones of Surat city. There is only 15.5% decrease in submerged areas if the discharge is 50% less than that of 2006 level.

Figure 8.13: Scenario 3: 50% higher Water Discharge from Ukai dam of Year 2006 level (42,000 cu m/s)



It is not just area submerged that paints a grim picture for Surat, but the depth of water shows a grimmer picture. Figure 8.14 shows areas submerged by depth of water.

Figure 8.14: Area submerged in Inundation scenarios of Surat City-All Zones



It is found that under climate change and the distribution of area submerged by depth of water in the two scenarios, 230 sq km of Surat city would be under more than 6 meter of water, compared to only 100 sq km in 2006 flood. Even in 2006 floods around 210 sq km was under 5 feet or more water.

Important highlights of the submerged regions are:

- Low lying areas like Ved Road, Katargam, Singhanpore, Kadar Shah naal, etc
- Adjoining regions of Weir-cum-Causeway due to overflow
- Adjoining regions of Nehru Bridge at Chowk Bazaar
- Areas along the bridges and the river ghats always at threats with rising water level due to discharge from UKAI dam

- Creeks like Kakra, Bhedwad, Mithi, Bhatena and Simada overflow due to excessive water discharge from Ukai dam and heavy rainfall in the catchment areas

8.5 Adaptation Measures for Flood Risks

In order to reduce existing risk levels, adaptation measures must be considered a fundamental part of sustainable urban development. The adaptation measures can be classified as planned and autonomous. Planned adaptation is the result of deliberate policy decision, based on the awareness, and would progress from the top-down approach, through regulations, standards, and investment schemes. Autonomous adaptation refers to those actions that are taken as individual institutions, enterprises, and communities independently.

8.5.1 Adaptation Measures to Schools

Many schools are in flood prone areas. Many of them have not introduced essential adaptation measures that are required to be disaster resilient. They have been facing flood repeatedly yielding huge loss and damages. After the devastating flood of 2006, some Surat schools have taken few adaptation measures to face the challenges of flood. Adaptation can be classified as spontaneous and planned. Spontaneous adaptation signifies immediate adaptation that is taken by individuals, institutes or authority of schools while planned adaptation measures are taken by higher authority (like local, state or central Government). They have to be such that if flood comes, either it does not damage the building or the intensity of damage is lower.

From the case study, following adaptation measures are emerging:

(A) Planned adaptation measures:

- Disaster related curriculum would be incorporated in school syllabus.
- Disaster preparedness training must be taken place with teachers and students.
- Affected or damaged schools should be repaired and reconstructed with high priority.
- Ground floor of the schools should be used as play ground.
- Library and Laboratory must be situated on upstairs of the schools.
- The boundary wall must be concrete and of proper height with a portable seal to prevent flooding through gate.
- Electrical equipments and wiring must be kept in water proof case to prevent short-circuit.

- Electricity should shut down automatically when water level goes up.
- Ground floor and wall of the schools where flood water can reach must be made with tiles. (Hazards resistance building).
- All the schools in the flood prone areas should be reconstructed as shelter to facilitate safe shelter to the affected people.
- Need for constructing reservoirs down the embankments in hilly areas for water conservation.
- Network of necessary roads to solve the problem of transportation.
- Proper warning system, that people can comprehend the language of warning system.

(B) Spontaneous Adaptation Measures:

- During flood official documents are shifted to upper floors.
- Fire extinguishers must be available in the school premises and people should know the operation of fire extinguishers.
- Equipped with immediate relief plan.

Few schools in Surat city have taken some adaptation measures after 2006 flood. They shifted library, lavatory and computers upstairs (2nd floor or 3rd floor) and they increased the height of the computer desks so that flood water cannot reach to that level. They have introduced a hazard preventive measure by repairing the walls and floors by tiles up to that level where flood water reached. Some schools made the classrooms hazard proof, with floor and walls made by tiles and benches and chairs made by iron instead of wood. Our survey data revealed that no school got any disaster coverage insurance for teachers and students.

8.5.2 Adaptation Measures for Hospitals and Industries

Some of the adaptation measures proposed for the hospitals as well as industries are as follows:

Table 8.8: Suggested adaptation measures for Hospitals

Adaptation Measures for flood	Planned or Autonomous
Equipped with Immediate Relief plan	Autonomous
Disaster Training along with Mock drills	Planned
Disaster Preparedness Plan	Planned

Effective communication solution during disasters	Planned
Evacuation plan of ground floor of hospital building in case of floods	Autonomous
Installation of Services on Upper floors	Autonomous
Fire safety System	Autonomous
Networking among the hospitals	Autonomous
Insurance of medical stock and equipments	Autonomous
Elevating Building floors/ Stilts in vulnerable areas	Autonomous
Early warning System	Planned
New Building Codes	Planned
Compensatory Payment	Planned

Source: Primary data collection by IRADe

Early warning systems, disaster preparedness plan including capacity building and training for disasters, and effective communication solutions during disaster are some of the important measures need to be taken care of. Short term and long term plans are of utmost importance to be disaster resilient. Moreover, emergency procedures are especially important in the mobilization of people, equipment and supplies. Disaster mitigation plans must address the need for repairs in case of damage to the hospital facilities, both before and after a disaster occurs. This is necessary that a committee is set up to formulate and implement disaster mitigation measures and carry out emergency response planning.

8.5.3 Adaptation Measures for Slums

Slums situated along the west bank of river Tapi, mostly north of Nehru Bridge, including Iqbalnagar (located between the embankment and river) and Subhash Nagar, were completely devastated in the 2006 flood. The primary survey conducted by IRADe with the selected sample slum dwellers across the vulnerable zones to asses risk mitigation measures taken at different levels brings out the following facts

- It is a wide spread perception amongst the slum dwellers that the health facility provided to them are not sufficient to meet their needs. It should be provided.
- In response to the question that did slum dwellers receive any early warning during the past flood event, we received a response that they were informed through a neighbour or a relative but they did not receive information 24 hours ahead. Information received by them in the past was not accurate every time. Early warning should be communicated in time and effectively.
- At least one people knew swimming in three fourth of the slum households. Makeshift floating devise such as a number of plastic bottles tied together should be kept handy.
- In the event of flood in the past support from Municipal Corporation was extended only to the slums in north and west zones. Only community support was extended in south and central zone. Municipal corporation needs to have wider coverage.

- Almost every slum household said that during flood, help came too late. A small proportion of households also said that only few households got the benefits from the government measures. Flood preparedness programme should be geared to provide timely help.
- Support like medicines, livelihood support, clean drainage/sewerage and clean water supply was the most sought after demand by slum dwellers post flood. Supplies of these critical items should be ensured.
- 70 percent of the households reported that disaster preparedness camp had never been organized in their area. Camps should be organized.
- It was highlighted in the survey that the participation of females in flood awareness campaign is nil or very insignificant, whereas female are more vulnerable to flood than their male counterparts. Females should be encouraged and required to attend the camps.

8.6 Adaptation Strategy

The project findings in the case study of Surat city highlight its vulnerability to climate risks due to its geographic location, flood prone topography, large population with a major percentage living a life of poverty in informal settlements, changing land use pattern, rapid infrastructure development often by reclaiming land from sea (as in case of Surat) and inadequate civic amenities. The study has examined the physical, economic and social impacts of selected extreme weather events leading to flood in Surat city. An important finding is that the huge monetary costs of these impacts are the uninsured losses borne by households belonging to poor strata of society and the private sector mostly engaged in informal activities. The study also examines the responses of local government institutions as well as people to cope with flooding. There are a number of public and private adaptation strategies that have been identified in this study. A significant finding is that all private initiatives and responses are a direct out-of-pocket expense for the concerned individuals or establishments. There is virtually no insurance cover that helps them to deal with the adverse impacts of floods and bring about changes or improvements in the existing infrastructure. Some of the public and private responses have the potential to enhance the medium to long-term adaptation capacity of the city to cope with future floods. However, there is a need to address the larger issues of climate risks and adaptation in the long-term development planning for the cities.

The importance of the vulnerability of natural and human system to climatic changes and their adaptation to such changes has taken much prominence in the present context. However, climate change has remained a marginal issue in the immediate agenda of policy making in the light of more pressing concerns of the country such as poverty, food security, and access to health and education services, infrastructure facilities, etc. These factors contribute to the vulnerability of the society and thus, require a higher need of adaptation strategy.

Among the various adaptation strategies to face the flood hazard is to develop a common framework at the national level, which should be used towards implementing the integrated watershed management strategy starting right from the lower level to river basin level in a unified manner to reduce the threat of floods. Integrated watershed management does not merely imply the amalgamation of different activities to be undertaken within a hydrological unit. This framework will need regular maintenance and updating to reflect fully the most accurate ground truth data. Local-level planning and management strategies have to be evolved and validated through the proposed framework so as to generate and evaluate various coping up options suitable for the local conditions.

8.6.1 Measures of Adaptation option and Economic Implications:

Following scientific analysis appropriate response strategies to potential threats, risks, and hazards called adaptation can be developed. The task of designing long term measures for adaptation includes the following:

(i). Optimal land use planning for moderation of events such as floods;

(ii). Management of quality water availability; and

(iii). Climate proofing measures for existing industrial, commercial, and social infrastructure etc.

Adaptation scenario is the location specific requirement. Most of the systems, whether human or natural, automatically adapt to accommodate some deviations from the normal climatic conditions. But when the impacts of climate change and climate variability are expected to fall outside the coping range of a particular system, then "planned adaptation" response is required.[33]

Climate change and climate variability, together with other stresses on coastal environment produce actual impacts and can be shown to have future potential impacts. These impacts trigger efforts of mitigation, to remove the cause of impacts, and/or adaptation to modify the impacts.

These can be viewed in the larger perspective taking cue from the experience of the case study of Surat in this project. The adaptation scenario is conceptualized as:

a. Baseline scenario – Predictions with the current climate pattern and demand analysis of essential commodities based on demographic change;

b. City protection scheme for city located at the confluence of river and sea or city few kilometers inland;

[33] Anand Patwardhan, et al.: Impacts of Climate Change on Coastal Zones

c. Retreating from the flood prone area;

d. Flood-proofing critical infrastructure, and provide a time frame to shift to flood proof infrastructure.

Impact analysis with separate permutations and combinations of climate change and adaptation scenario is carried out evaluating their influence on flood control measures, drainage system, socio-economic state of the region, etc.

8.6.2 The important adaptation measures

What can cities do to minimize damage from flooding? What adaptation measures cities can take to minimize the damage from flooding? These are the few questions that pose challenges to find out various adaptation options.

Among the various options that one might consider are

A. Reducing level of inflows by creating flood plains
B. Raising embankments
C. Early warning to evacuate people to minimize loss
D. Control future expansion of areas that are not flood prone
E. Flood proof infrastructure facilities

1) **Reducing inflows:** Scope to increase the capacity of UKAI reservoir should be explored. Also models to forecast inflows in UKAI in advance should be made so that capacity to absorb inflows can be increased. Between UKAI and Surat large flood plains can be developed. This may be difficult as the areas required may be large. If one metre depth of water is to be permitted, a flood plain of some 2000 sq km would be needed. Similar kind of strategy can be adopted for other coastal cities or cities having reservoir nearby to them.

2) **Raising embankment:** The cost may be huge as the length and height of needed embankments need to be worked out.

3) **Early warning for evacuation:** As releases from UKAI reach Surat in about 8 hours, thus, a system of early warning and shelters could be created. The submergence level of the scenario suggests the nature of shelters required in different zones.

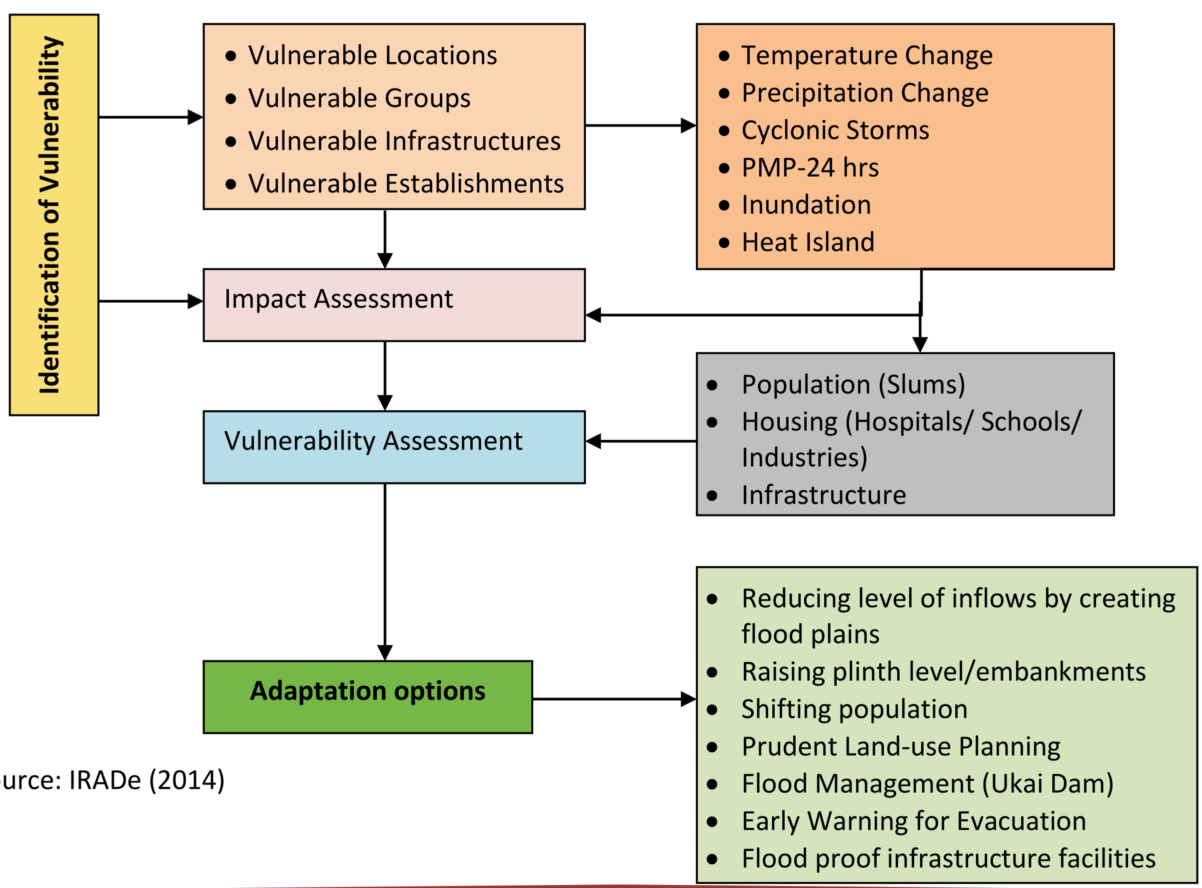
4) **Control future expansion:** Optimal land use planning to protect vulnerable population and commerce can be promoted. Wide public distribution of the risk and extent of flooding will

make buyers aware and builders would be required to build in flood risk free areas. Of course, regulatory authorities should play a role in directing development.

5) **Flood proofing infrastructure facilities:** Knowing the risk and extent of possible flooding can help in their task. Plan for infrastructure and facilities needed for countering and protection against adverse natural event depending on (i) probability and likelihood; and (ii) techno-economic analysis. Flood proofing of infrastructure for water supply, power and energy, storm water drainage and storage, heat stress; sea-level rise, etc can be developed in flood prone cities.

Apart from the above adaptation measures, water storage and ground water recharging facilitations can be considered and promoted. Administrative procedures and strategies, incompliance with status of climate sensitive resources can also be taken into consideration. Development of contingency plans for abnormal natural situation to support the livelihood structure and ability of the people to function in adversity can also be strategized. Hence, an holistic approach together with the economic implication analysis is needed for selected adaptation options in consultation with stakeholders. Stakeholders at various stage of decision making should be consulted to select adaptive measures and priority of action required for the particular city.

Figure 8.15: Framework for Adaptation Strategy



Source: IRADe (2014)

8.7 Conclusion

This research is anchored on applying appropriate models and tools that connect climate change, hydrology, land use, infrastructure related to basic services for vulnerability mapping/ assessment. The output and analysis of appropriate solutions to manage hazards suggest measures to enhance resilience to climate change. In the process we have augmented analytical capability of the stakeholders that helps them to foresee climate variability and change and to assess socio-economic vulnerability to climate change. These suggest ways to develop climate resilient city and update the “Decision Support System” framework also for initiating action at local, state, and national level involving stakeholders. This may facilitate designing of a resilient development plan that provides proactive safeguards to Climate Change.

The methodology developed and used in the project to identify and analyze the immediate to medium-term impacts and responses of flooding events is expected to improve the understanding of adaptation interventions coming from the government as well as communities. The project will help in enhancing the ministry’s initiative in identifying and developing effective methodologies in different areas of global change research and transferring the knowledge base to the scientific community and policy makers. Better characterization of post-event impacts and the recovery process would further help in improving the disaster management interventions. The findings of this project will also help inform the authorities of other Indian coastal cities and other climate networks.

The study measures the hydro-meteorological and socio-economic impacts of selected extreme weather events and inflows scenarios of flooding. It will help identify the public and private responses in the short to medium-term and explores their policy implications for long-term adaptation capacity, city resilience and development plans. The case study of Surat also identifies the immediate to medium-term post disaster responses of the civic administrations, concerned authorities as well as the citizens to cope with future floods.

To assess the impacts and adaptation needs, it would require integrated assessment that involves various set of data and analytical approaches. Data on urban structure, land use, roads and transport infrastructures, basin and channel, drainage systems, settlement pattern, vulnerability profiles have been collected, organized and analyzed to evaluate capacity and assess vulnerability. Such an integrated assessment considers the interaction between climate change and other change processes to assess the social, economic and environmental impacts of climate change. It requires a wide understanding of natural and human systems. This is important because demographic profile, economic development and land use and land cover of a region have a significant influence on how changes in climate are likely to impact and the capacity to adapt to any such future changes. It is also necessary to take into account the concerns of various stakeholders and priorities of the concerned authorities because the extent of impacts and scope of adaptation are strongly influenced by their actions.

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CHAPTER 9: RAPID VULNERABILITY ASSESSMENT STRATEGY FOR OTHER CITIES

9.1 Introduction

Many other large cities in India are facing challenges of various types of risks. To face these challenges we need to develop a better knowledge of the interrelations and social dynamics of flood risk perception, preparedness, vulnerability, flood damage, and flood management. Currently vulnerability assessment of cities is lacking and consequently are missing are prudent policies and long-term strategies; appropriate legal framework; adequate institutional arrangements; effective flood forecasting and warning systems; community participation; effective mechanisms for information/data collection and exchange; and adequate emphasis on environmental concerns. It is imperative to understand the type and intensity of vulnerability of cities including identifying the impact of climate change, adaptation options to enhance resilience, mitigation measures to contribute to its solution, and some ways forward.

The case study of Surat gives an insight to vulnerability to flood risk. The supporting analysis of climate change impacts and adaptation options in cooperation with the relevant government agencies enable us to better understand the economic, social, and environmental impacts of climate variability and change, and associated vulnerabilities of the urban community, especially the poor, to such impacts; and the need to adapt urban infrastructure to mitigate these impacts and protect urban population.

The main concept used in this chapter is the relationship among hazard, vulnerabilities to that hazard, and capacities to cope with that hazard in order to reduce the vulnerabilities and enhance the adaptation capacities. Reducing the risk to disaster requires a clear identification of hazard and its potential consequences; measures to reduce the vulnerability; and actions to increase the capacity to adapt and adjust to the impacts of hazard:

Disaster Risk (DR) = Hazard (H) X Vulnerability (V)/Capacity (C)

Besides, vulnerability-capacity assessment (VCA) (Benson and Twigg, 2007) and adaptation policy assessment framework (United Nations Framework Convention on Climate Change, 2005) are key components of disaster risk analysis since it helps in identifying vulnerable groups and factors that make them vulnerable and how they are affected; as well as assessing their needs and capacities, therefore, used for developing adaptation strategies. According to this, the exposure and sensitivity of any hazard should be identified to determine its impacts. Based on the identified impacts and understanding of current adaptive capacity, the vulnerability to risks can be determined and assessed. Moreover, after assessing the vulnerability and adaptive capacity to a particular hazard related to climate change, the results can be used to assess the risk to that hazard in order to develop appropriate adaptation measures and strategies to cope with adverse consequences.

Rapid expansion of Indian cities and climate induced risks to them pose several challenges to resource management and infrastructure planning. And it is a matter of paramount concern for the country. It also displays an urgency of the need to adapt city level operations to both current climate variability and future climate change. Since overall risk in Indian cities typically is associated more with vulnerability than hazard exposure. It is, therefore important to understand a number of processes that are rapidly changing the Indian urban landscape, making cities more prone to the natural disasters, altering the course of development, that as result affect the vulnerability of many communities. Due to geographical diversity of the country, vulnerability to climate change would vary from city to city. Some cities would be more prone to flooding and other would be more affected by sea level rise and so on so forth. Impacts of variation in precipitation would also not have uniformity. Therefore, there is an urgent need to assess the vulnerability to climate change of major Indian cities in order to facilitate the adaptation at the city level.

Nowadays, cities are growing very fast, so are their risks. To make cities climate resilient we need to assess their vulnerabilities in a rapid mode. Every city is different. No two cities are same. A formal strategy for rapid vulnerability assessment is needed which would support the decision makers for prudent policy measures to make cities sustainable and climate resilient. As part of the adaptation development process objective, this project research has studied the impacts of flood disaster under the changing discharge scenarios in Surat city. There is a limitation in using tools for vulnerability assessment and adaptation evaluation, therefore, the simplest tools and strategies for rapid vulnerability assessment (RVA) has been developed by IRADe.

9.2 Rapid Vulnerability Assessment Strategy (RVAS) Framework

9.2.1 Why Assess Vulnerability to Disasters?

A vulnerability assessment can serve as the basis for developing strategies for reducing the risks from disasters. The assessment helps in:

- Estimating the area and number of people at risk, including people with special needs;
- Identifying the number and location of buildings/infrastructures at risk, including critical facilities such as hospitals and schools; and
- Examining the communication links and networks that are vulnerable to disruption during and after a disaster.

This rapid vulnerability assessment strategy (RVAS) framework incorporates the project methodology and lessons learnt during the study. It is designed to help assess rapid vulnerability of a city by identifying vulnerable populations and locations; and anticipate how they will be affected by likely hazards and develop strategies for reducing its vulnerability. This RVAS framework provides a step-by-step process for preparing an assessment of a city's physical and social vulnerability to disasters, both natural and technological, and includes detailed instructions for conducting an assessment, a list of information that is needed to complete the assessment, and worksheets for compiling and organizing data collected.

It can be used by the central and state government ministries; various stakeholders such as city administration, city planners, etc seeking to understand and reduce a city's vulnerability to disasters, as well as by central, state, and local emergency preparedness or hazard mitigation offices to help cities become better prepared for disasters. It can be used, for example, in preparing a local hazard mitigation plan.

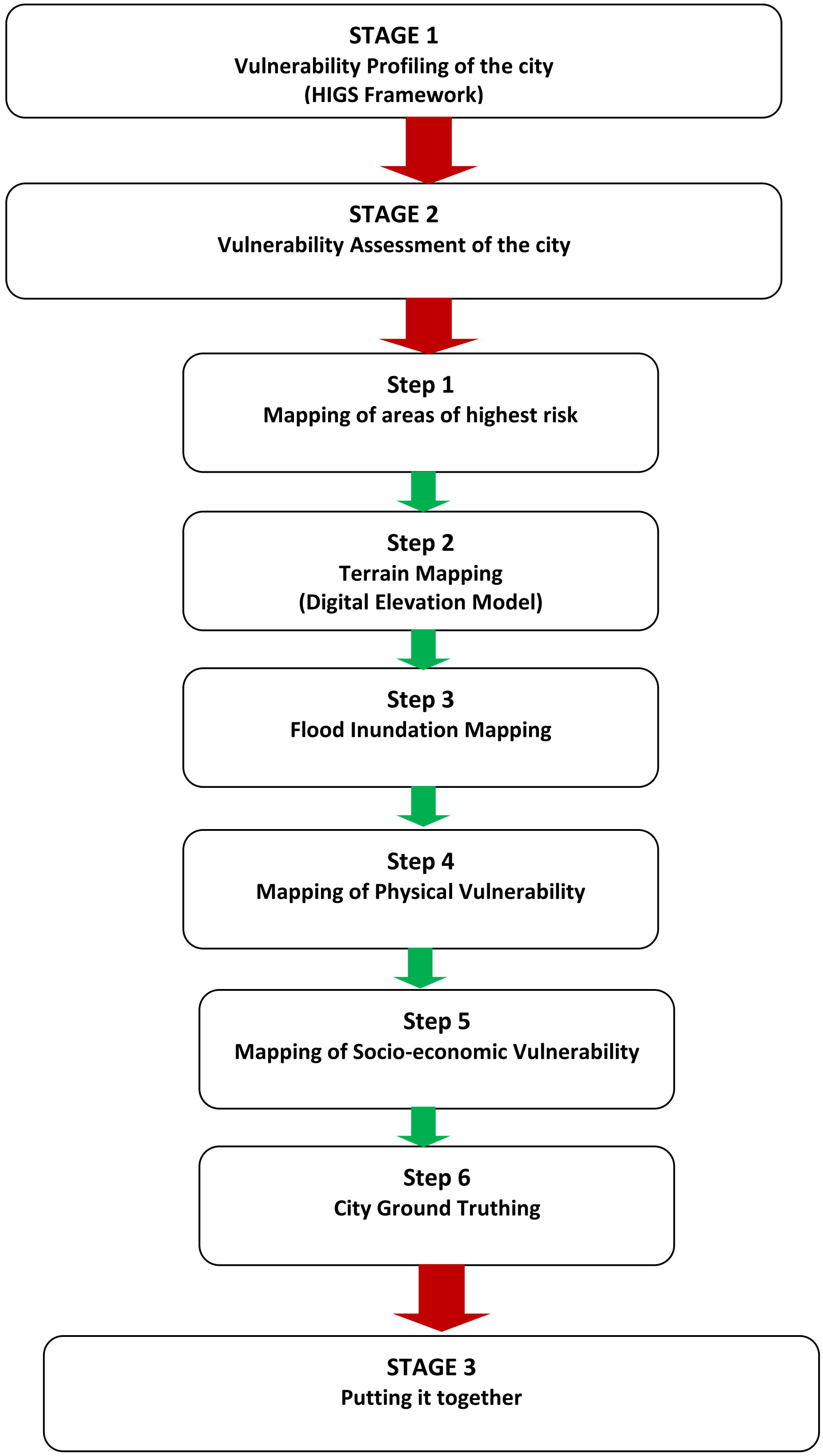
We recognize, however, that not all local governments have the same level of resources and expertise to carry out the vulnerability assessment. Similarly, most cities do not have the staff or equipment to conduct a highly technical assessment. We have designed this RVAS framework so that a vulnerability assessment can be conducted using information and maps that are readily available, e.g., from government agencies and from the web. In some cases, a city administration may choose to conduct a more sophisticated analysis, using in-house GIS capabilities to generate original maps and more detailed and up-to-date analysis of vulnerable populations and locations as the case with the Surat Municipal Corporation.

9.2.2 The Key Stages for RVAS Framework

To assess the vulnerability of the cities, IRADe has developed its own approach and methods. Its approach and methodological framework include generating baseline data pertaining to urban development in socio-economic and infrastructure aspects; simulation of flood pertaining to hydro-meteorological scenarios; and prudent adaptation strategies which help in efficient urban policies and programmes.

This framework describes in two stages, which comprise a rapid vulnerability assessment. Each of these stages is described in more detail in the following sections. The assessment is best carried out through a process of meaningful and sustained city engagement to help ensure that the needs, capabilities and concerns of all groups, particularly those who are often under-represented, are addressed. The key is to conduct the assessment in a way that works best for the city with input from a diverse cross-section of the community, reaching out and engaging those who often do not participate in such activities.

Figure 9.1: Rapid Vulnerability Assessment Strategy Frameworks



9.2.3 STAGE 1: VULNERABILITY PROFILING OF THE CITY: IDENTIFY AND RANK HAZARDS

In this stage, identification and ranking of the hazards of the city based on threat level, and their frequency and severity. A detailed list of disasters that have occurred in the city, including earthquakes, floods, droughts, landslides, heat waves etc. has been prepared. These hazards are, then, ranked in terms of their frequency of occurrences and the severity of impact. In order to get a more complete understanding of likely hazards and their impacts, not only the formal sources, such as state and local agencies are utilized, but also review archival information and interview long-time residents about past events and their impacts on the city. At the end of this stage, a detailed list of hazards that have struck the city, and a ranking of these hazards in terms of their frequency of occurrence and the severity of impact are prepared.

Some hazards are more likely to occur than others. Some occur infrequently, but their impacts can be widespread and severe. Thus, a city can decide to focus its efforts on preparing for such type of disaster, given the potential damage that may occur, rather than on disaster itself.

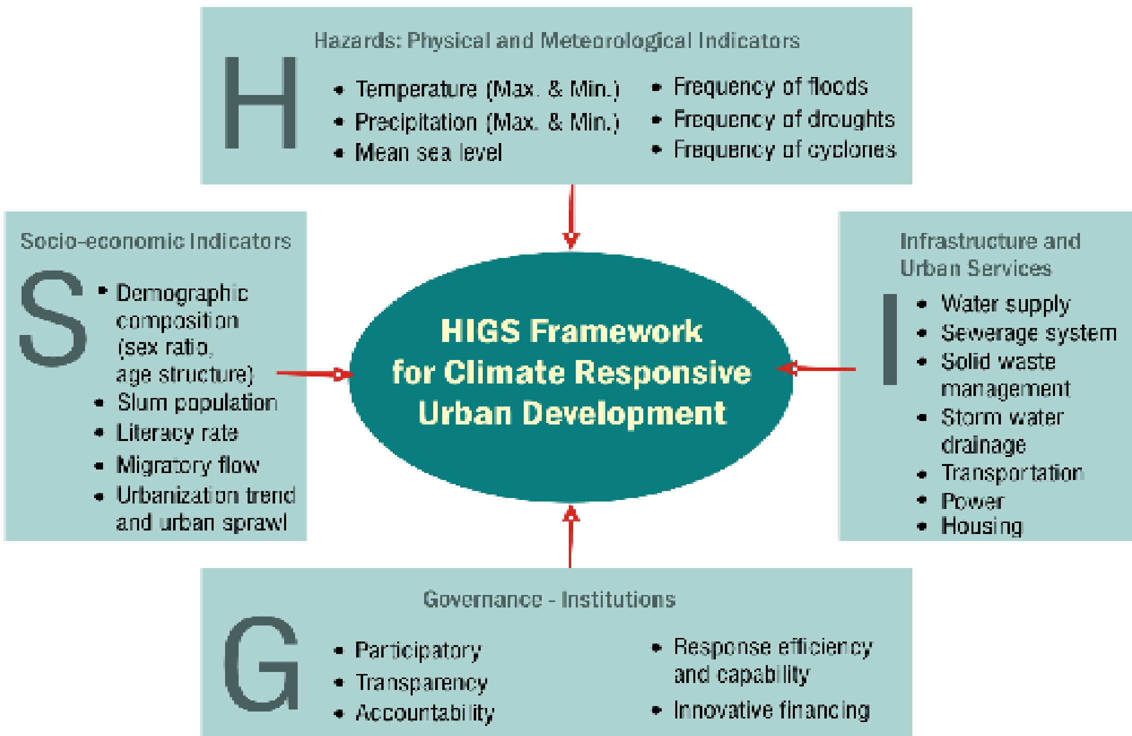
The methodology developed by IRADe for vulnerability profiling of the cities aimed to explore various aspects influencing the vulnerability of the cities like considering variability in the maximum and minimum temperature and precipitation over the decades and socio economic factors, infrastructure availability and efficiency. It also considers the impact of efficient governance on building resilience of the cities. With the changing scale of urbanization and characteristics of the small towns and cities, there is a need for rapid analysis of their vulnerability, so that quick decisions can be made by officials to overcome unforeseen catastrophes. Adaptation also needs city specific knowledge of vulnerability and impacts, which is resource intensive and requires an updated and comprehensive database. It also needs a downscaling of climate change impacts for specific urban locations in order to plan location specific adaptation strategies.

9.2.3.1 Methodological Framework

A framework is developed to address and to understand the current scenario of cities that features many of the impacts of climate change as well as the adaptive capacity of the cities.

Sets of variables are identified to assess the exposure, vulnerability and adaptive capacity/responsiveness of the cities for example geographical location and physiographic characteristics, disaster frequency (considering hydro-metrological disasters) and intensity (Max. & Min. temperature, rainfall) , mean sea level etc to determine the exposure of the cities to natural hazards and the nature and degree to which the city is exposed to climatic variations, availability of services and infrastructure like water, sanitation, solid waste management system transportation, housing, power etc, trend of urbanization, urban sprawl, demographic composition and characteristics to determine the impact and institutional framework and governance to assess the vulnerability and adaptive capacity of the city. All the variables are then grouped in four major sections and named as "**HIGS**" where **'H'** denotes Hazards and extreme events, **'I'** is for the Infrastructure and services, **'G'** for Governance and **'S'** for Socio-economic characteristics. The interplay of the four variables is of importance to understand priorities and proximate causes of increased climate risks in Indian cities

Figure 9.2: HIGS framework for climate responsive urban development



9.2.3.2 *Data collection and Preparation of the Template*

The methodology provides flexibility to converge data within these four variables - hazards and extreme events, infrastructure services, governance and socio-economic characteristics. The interplay of the four variables is of importance to understand priorities and proximate causes of increased climate risks in Indian cities. A vulnerability template is developed to collected data on each variable. The data for the variables is collected from the authentic secondary sources like Indian Metrological department, City Development Authorities, national reports and Published papers. For preparing disaster timelines data from city disaster management plans, Maps prepared by NATMO and BMPTC, disaster report and News settlers etc.

During the course of this study it becomes evident that data and information on these cities are inadequate. Across all these cities, on several indicators of urban poverty, education and health are found missing or not reliable. Due to lack of data, the methodology has to be very simple as comparative analysis, regressions or mathematical models are not applicable, when uniform data availability across sample cities is unavailable.

Table 9.1: Description of HIGS variables

Variable	Description	Data Source
H- Hazards and extreme events	Exposure to hydro-metrological stresses/ hazards due to location and frequency and intensity of the hazard events. 1. **Geographical Location:** Geographical locations like location of flood proneness (proximity to coast or river), land area, elevation. 2. **Frequency and intensity of hazards:** Disaster timelines to determine the number of occurrence of an hazardous events like- • **Floods:** The occurrences of floods over the last 50 years due to heavy rainfall or other weather events like storm surges and cyclones. Besides that, incidents of urban floods due to sudden release or failure to release water from dams, the inefficient storm water drainage system or lack of natural drainage/water logging are also considered. • **Droughts:** Drought: due to significantly less rainfall in an area than the climatology means of that area, depletion of surface water, ground water table are considered. • **Cyclones:** Incidents of cyclonic events over the past 50 years • **Sea level rise:** SLR simulations, proximity to coast and information from different studies • **Landslides:** Occurrences of the landslide events during the last few decades due to rainfall, landfall, and hill slides due to construction activities were included • **Extreme events:** Occurrences of extreme temperatures events (exceeding mean monthly maximum temperature) over the last 50 years) and extreme rainfall events (exceeding mean monthly rainfall over the last 50 years.) • **Temperature:** occurrences of extreme temperature events (exceeding mean monthly maximum temperature) over the last 50 years. • **Precipitation:** occurrences of extreme rainfall events	• Indian Meteorological Department Data set (1950-2000): Maximum/Minimum Temperature and Maximum and Minimum Precipitation Data. • City Disaster Management Plan, • BMPTC, NATMO • Government news settlers,

	(exceeding mean monthly rainfall) over the last 50 years.	
I- Infrastructure status	The availability and status of basic services and stress on infrastructure. The key issues in the sector are the adverse effect of inadequate services on the vulnerability of the city. They include: • **Water supply:** Per capita water availability in the cities, water supply coverage and water resources (surface water and ground water).Water scarcity and potential threats of climate change. • **Sewerage:** Sewerage generated and treated in MLD, coverage, sanitation status. Key problems in the sector. • **Solid waste:** Per capita MSW kg/day. The techniques to collect the waste. Issues in this sector. • **Strom water drainage:** Status of the sector issues. • **Transportation:** Road length, coverage and issues • **Power:** Sector wise consumption, Electricity use (million KwH) • **Housing:** Number of household, type of houses (on the basis of material used in walls) in 2001 and 2011	• Service level benchmarking data, 2010-11, Ministry of urban development. • NIUA, Urban handbook for Statistics, 2000. • City Development Plans • ICLEI Energy and Carbon Emissions Profiles of 54 South Asian Cities, 2009 • Census of India 2001, 2011
G- Governance	**The institutional framework**. Preparedness for disasters, guidelines or action plans for climate change. Immediate responsiveness. **Willingness of City leadership to address climate change** is determined through the current initiatives and programs implemented or perused by the city , state governments	• City Development Plans • Climate change action Plans • State environment report
S- Socioeconomic characteristics	**Demographic compositions:** Includes population trends, decadal growth rate. Population structure (age group 0-6 year), population Density, sex ratio and literacy rate in the city, urban poor and slum population, urbanization trend in the city.	• Census of India 2001 and 2011 • Slum population data 2001 • India Urban Poverty Report, 2009 • City Development Plan

9.2.3.3 Vulnerability Matrix:

The vulnerability matrix is prepared for a detailed analysis of the types of the vulnerabilities that selected cities in the country are subjected to and the issues or the infrastructure failure and socio economic status that extent the impact of the hazards is considered. The cities have been categorized according to the physiology and location, which are mountainous, coastal, riverine and mixed cities. Each variable is then divided into

1) Hazards, denoting the risk to the hazards

2) Infrastructure, considering the infrastructure services.

Each city is then categories into “Y” denoting the exposure and risk and N denoting that the city is not critical.

Table 9.2: Analysis for Vulnerability Matrix

Category	Hazards	Infrastructure
Y	Has experienced hazard events more than 20 times in past 50 years. In case of urban flooding more than 50 water logging events in one year.	Below the standard benchmark assigned to cities and Infrastructure services failure leading to hazardous events 1-Water supply below 135 lpcd 2-Sewer network less than 50% of coverage 3-Solid waste management - collection efficiency of MSW is below 30% and house hold coverage is below 50% 4-Strom water drainage system – below 50 % of coverage 5-Electricity
N	No occurrence of events	Coverage more than 50%, collection efficiency of MSW more than 30%

To analyse the exposure and risk of the cities, the number of natural disaster events in the last 50 years are considered if the is above 20 events then the city is considered as prone to that hazard and put in **“Y”** category. If the occurrences of the disasters are accompanied by the inefficiency of the infrastructure services then the hazard exposure is put into **Y** category. **For example** if a city provide water supply of 135-150 lpcd (Indian standard for a city) but the population of the city is more than 10 million than the city is considered as exposed to water scarcity. The impact assessment is not done as the concrete data on socio economic loss during the hazardous events is either not available or not maintained at city level.

Cities with a population of more than 4 million is in the **A** category, those between 1 and 4 million persons are in the **B** category and cities with a population of less than 1 million is in category **C**. Socio economic factors are also considered whiling profiling the cities exposure to climate change impacts.

9.2.3.4 HIGS Framework:

The existing methodologies for multi-hazard assessment are diverse in nature and generally require large datasets, specific software, digital maps, satellite imageries and also skilled professional expertise to analyze and assess the scenarios. By comparison, IRADe's HIGS framework requires pooling of data from available secondary sources, and from published reports from different government departments at national, sub-national and city levels. While data availability does remain a concern at the level of Indian urban centres, the Census of India, National Social Survey Organisation (NSSO) state and national statistical reports and atlases do provide a range of data sets across time scales and administrative boundaries. To prepare a HIGS vulnerability profile, the collected data can be compared to the city level benchmarks provided by the national authorities in term of infrastructure services coverage and availability, in order to understand where gaps remain in service provision, hence exposing city residents to further risk.

The HIGS framework has been conceptualized to assess climate vulnerability in cities, which is an important step towards enabling planned adaptation. The key issue in climate adaptation practice is to make effective use of available climate information, despite large uncertainties and unfamiliar or unhelpful data formats. There is a lack of probabilistic data regarding climate impacts, the present condition and coverage of infrastructure and ongoing plans, which government authorities had hoped to use to design infrastructure standards. While this framework does not address the climate data problem, it helps in understanding the current status of the services and condition of the city infrastructure as well as its management, providing a systematic way to collect the necessary data for analysing the capacity and ability of a city to cope with climate change induced hazards. The outputs from applying the HIGS framework would also support broader comparative analysis among cities. The application of the HIGS framework highlights the scope for, and strengthens the implementation of, an urban climate resilience program.

9.2.4 STAGE 2: HAZARD VULNERABILITY ASSESSMENT OF THE CITY

9.2.4.1 Step 1: Map Areas of Highest Risk

In this stage, we carry forward our study from stage 1 in which vulnerability profile of the city has been prepared. The purpose is to do in-depth analysis and mapping of locations in the city that are at highest risk from hazards identified in Stage 1. This enables the rapid vulnerability assessment through the process of producing a map that shows the locations of hazard areas and its impacts. The outcome is a map with associated overlays that clearly depict areas and populations that is likely to be affected by the hazards such as flood, droughts, etc. The key features (Land use/ Infrastructures) of the city are placed on a base map, which is in digital form (GIS format). Using RS/GIS techniques a base map that includes major roads, rivers, and municipal boundaries is to be generated. This map will be used as a sample base map throughout the assessment process. A good base map with accurate overlays depicting hazard areas and vulnerable populations is fundamental to completing the remaining steps in the assessment.

TASKS:

A. Prepare a base map for use throughout the vulnerability assessment.

B. Identify and map specific areas in the city that are vulnerable to disasters, such as floodplains, storm surge areas, landslides, droughts, earthquake-prone areas, etc.

TASK A: Select or prepare a base map for use throughout assessment process.

GIS maps can incorporate different layers showing the extent of the floodplain, areas where earthquakes, cyclones, etc have occurred, and other hazards as well. Other layers could include critical facilities, roads, bridges, and the location of vulnerable populations. If the city does not have GIS capability, they can develop a manual map system—a paper base map with layers or features (e.g., floodplains, critical facilities) depicted on a separate layer or transparency— to display the base map with desired layers of information.

TASK B: Identify and map specific areas in the city that are vulnerable to disasters

For selection of a base map, there are numerous types of maps that might be available. Political maps (like above) depict road networks, infrastructure and boundaries well and are usually most preferred. In mountainous areas, where landslides and flash-floods are prevalent, contour maps (produced from satellite imagery) depicting terrain and slopes might be useful as well.

Create a base map and identify vulnerable areas. Subsequent maps will add layers for environmental hazards, schools, hospitals, and fire stations. The layers included on the map depend on the particular features and circumstances of the city for which we are conducting the vulnerability assessment.

9.2.4.2 Step-2: Terrain Mapping (Digital Elevation Model)

Terrain mapping of a city is done by using Digital Elevation Model (DEM). A DEM is a gridded array (raster) of elevations. Rasters represent the world as regular arrangements of pixels (cells). In a DEM, each cell has a value corresponding to its elevation. The fact that locations are arranged regularly permits the raster GIS to infer many interesting associations among locations: Which cells are upstream from other cells? Which locations are visible from a given point? Where are the steep slopes?

It is indispensable for many analyses such as topographic feature extraction, run off analysis, and flood susceptibility analysis and so on. Before hand such analyses, accuracy of DEM must be discussed. The accuracy of DEM is usually represented by spatial resolution and height. Digital representations of landscape topography as DEMs incorporate series of reduced level values so that terrain features can be evaluated using specialized numerical algorithms and the GIS visualizations rendered. The major issues with DEM-derived hydrographic data are related to the resolution and quality of the DEM and to the derivation of surface drainage. Here, ERDAS Imagine-LPS (Leica Photogrammetic Suit) and ARC GIS software have been used for various feature extraction from DEM.

Floods, one of the major geo hazards, always cause a major problem by killing hundreds of people every year besides damaging the properties and blocking the communication links. Most of the terrain in mountainous area is dissected rugged topography with highly complicated land use. The most useful direct indicators of flood susceptibility are considered to be evidence of past floods as well as tension cracks and other detectable earth movement. Therefore, the simplest type of flood hazard assessment comprises an inventory of previous floods and signs of mass movement, based on the premise that an area with past floods is flood prone and has a high probability of new floods.

9.2.4.2.1 Methodology

The step-wise methodology adopted for the generation of flood mapping and zone-level flood hazard assessment is described below:

Step-1: Collection of high resolution remote sensing images

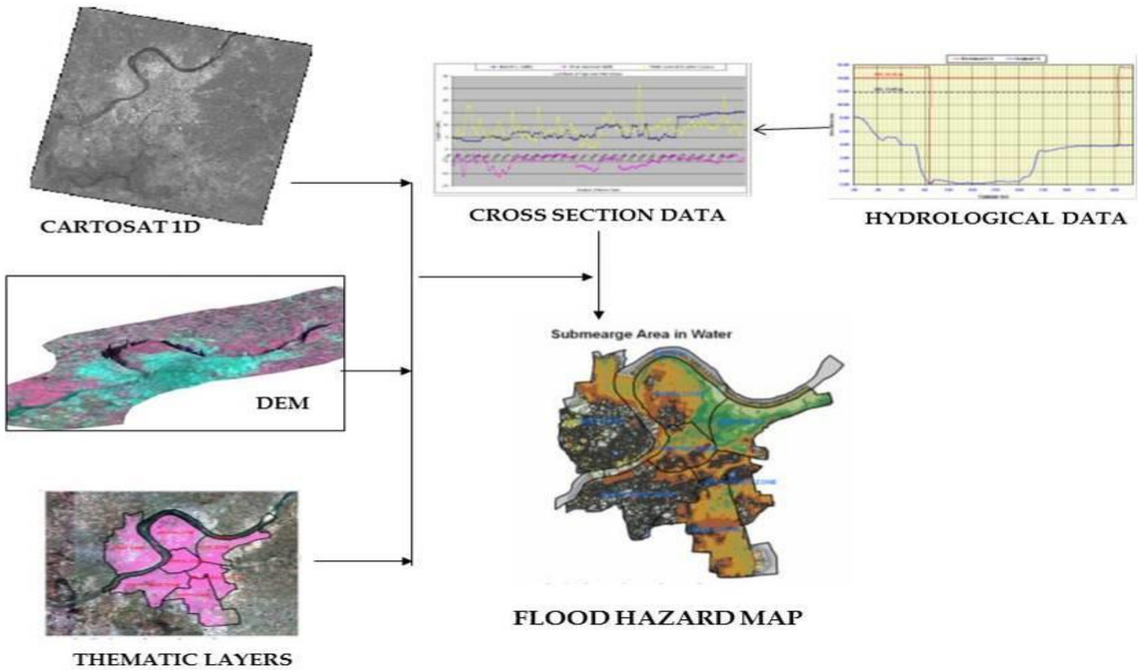
Step- 2: Collation of topographical features such as contours, river channel sections, and water level and discharge data,

Step- 3: Inter-linking of spatial and temporal data using GIS software and customized DBMS tools for DEM creation

Step- 4 Generation of thematic maps and

Step- 5: Analysis of results and delineation of areas under various degrees of floods.

Figure 9.3: Methodology for Flood Hazard Map of Surat City (for example)



This methodology has been applied, for example, to prepare a flood vulnerability map for Surat city.

9.2.4.3 Step-3: Inundation Mapping of a City for Various Inflow Scenarios:

In this step a hydrological assessment of people and infrastructure of a city is done. The elements of infrastructure under consideration include- buildings (schools, hospitals, slums, industries, etc) within and adjacent to the flood plains, roads, bridges, etc. A systematic procedure is followed to gather and examine available data in order to develop an understanding of the relevant climatic effects and their interactions with infrastructure. The purpose of this is to provide the assessment procedure with the extent of inundation and water depths for various discharge scenarios under consideration. The integrated hydraulic modelling system and spatial analysis software have been used in this process.

Moreover, climate change is invariably considered in the development of any floodplain map of a city. Such floodplain maps can be generated by using satellite imageries. Inundation depths that are required for an assessment of infrastructure vulnerability can be developed by using the satellite imagery and river discharge data. Geometric data have been developed by using the GIS and Hydrological computer software for spatial analyses.

A set of tools and utilities provided with the ArcGIS computer package can be utilized in the preparation of spatial data for the hydraulic analyses. HEC-GeoRAS is an extension of ArcGIS, which is used for the preparation of spatial data for input into hydraulic model HEC-RAS and the generation of GIS data from the output of HEC-RAS software.

The methodological details of the steps followed under this are described here.

9.2.4.3.1 Methodology

The process of flood inundation mapping is based on the hydraulic calculations of water surface elevations extracted from the satellite imagery of the city of high resolutions. The main objective is to bring the process into digital format for use of software tools for spatial analyses.

Hydrological profiles and flood inundation scenarios of a city method involve:

(i). Review of existing hydrological analysis of river basin in Surat city

(ii). GIS mapping of a city including wards and zones

(iii). Contour map of 0.5m/ 1m/ 5m intervals based on satellite imagery used

(iv). Creation of Digital Elevation Model of the city

(v). Hourly basis river discharge data for a 5/10/15 years period

(vi). Rainfall gauge station data of IMD of selected stations for 30 years period

(vii). Inundation/ submergence scenarios with tools like ARC GIS, HEC-GeoRAS, HEC RAS, ERDAS Imagine-Leica Photogrammetric Suit, Auto CAD

(viii). Various scenarios of submergence:

The methodology for Inundation mapping using HEC and ARC GIS tools consists of three steps:

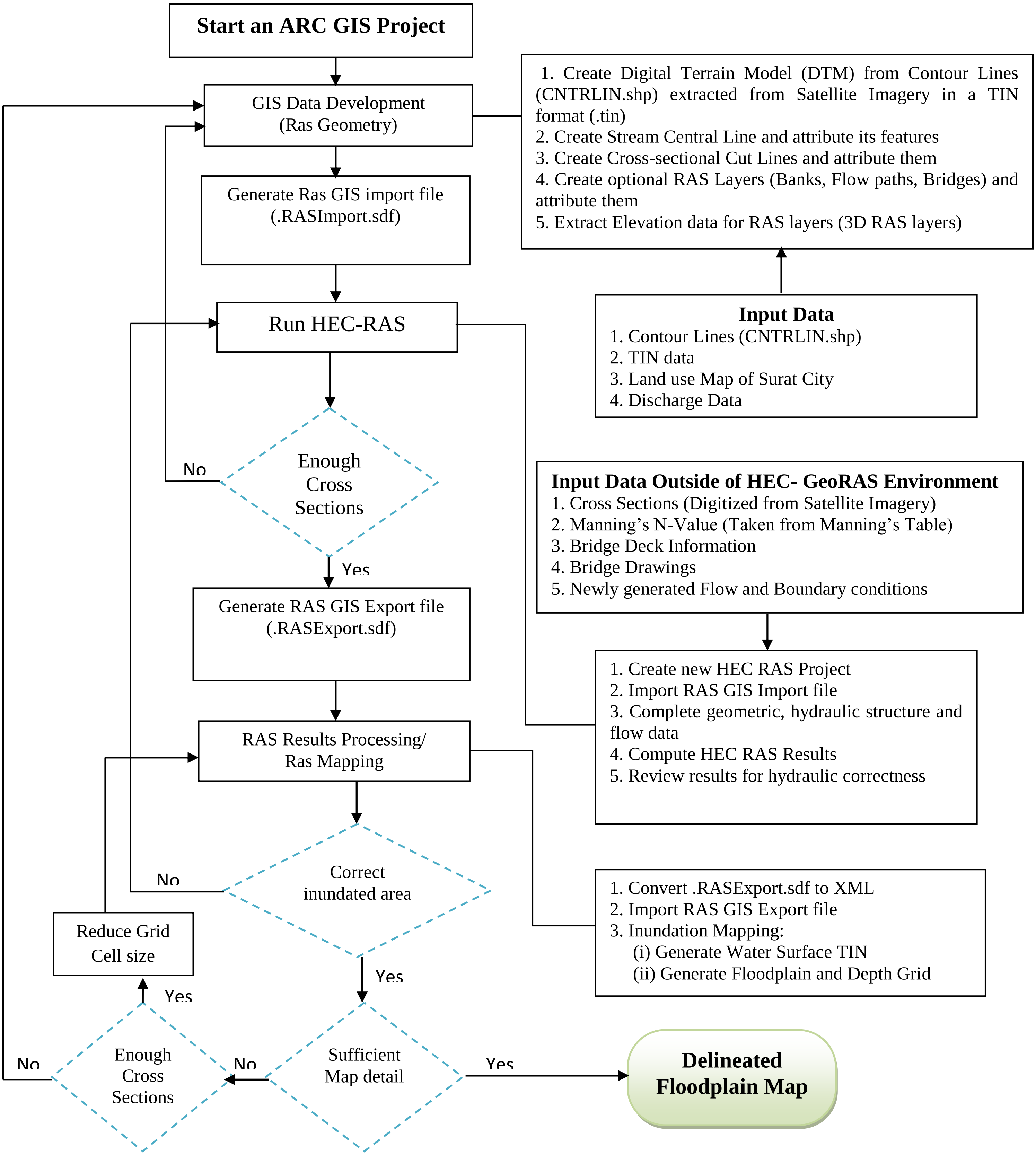
a) Pre-processing of geometric data for HEC-RAS, using HEC-GeoRAS;

b) Hydraulic analysis in HEC-RAS; and

c) Post-processing of HEC-RAS results and inundation mapping, using HEC-GeoRAS.

Process diagram for using HEC-GeoRAS is shown in Figure 9.4:

Figure 9.4: Schematic Diagram of Methodology for Inundation Mapping using HEC RAS and HEC-GeoRAS Framework



9.2.4.4 Step 4: Map Physical Vulnerability

In this step, physical vulnerability of the city is determined. The idea is to assess how many people and structures, including critical facilities, lie within the hazard areas of the city. Critical facilities include, but are not limited to, schools, hospitals, police/fire stations, nursing homes, slums, sewage treatment plants, water treatment facilities, and power plants. The analysis includes current conditions (people and property currently at risk) as well as potential future conditions (people and property likely to be at risk in the future, given current development trends) based on the data collected from the city and concerned authorities. All such analyses can be represented on a map (using an overlay).

9.2.4.5 Step 5: Map Socio-Economic Vulnerability

Some people in the city are more vulnerable than others. Socially vulnerable populations, including low-income households, elderly or those with disabilities, may lack the resources and ability to prepare for and recover from disasters. In addition, some residents may suffer indirectly from the effects of a disaster, for example if their house wasn't flooded, but they were cut off from work, or the local pharmacy due to flooding of roads, etc. Physical impairments may make it difficult to seek shelter or evacuate during an emergency or to seek help afterward. Similarly, language or cultural barriers, cognitive difficulties or physical isolation, (e.g., an elderly person who lives in an isolated part of a rural community), may cause people to be cut off from crucial information, services or supplies in the event of a disaster. The purpose of this step is to identify disadvantaged people in the city who may be especially vulnerable, directly or indirectly, to the impacts of disasters. The vulnerability assessment team will catalogue and map the location of socially vulnerable members of the city.

In this process a city wise survey can be conducted to know the socio-economic vulnerability of the city.

There are various techniques developed by researcher, policy makers and etc to measure the vulnerability of the system with the natural hazards. Vulnerability to natural hazard focused on the physical world, emphasizing infrastructure and technology. INCOIS (2012) calculated coastal vulnerability index for the coastal cities of India. To calculate coastal vulnerability index all the input parameters with different spatial resolutions were interpolated in to one km segments and these values were transferred to the corresponding section of the coastline. Each coastal section has risk ratings of all the seven variables under consideration. The coastal vulnerability index (CVI) is then calculated as the square root of the product mean of the seven variables. The formula used to calculate CVI is as follow

$$\text{CVI} = \sqrt{[(a * b * c * d * e * f * g)/7]}$$

Where a = Shore line change rate
b = Coastal Slope
c =Coastal Regional Elevation
d = Coastal Geomorphology
e = Sea-level change rate
f= Significant Wave Height and
g = Tide Range

Vulnerability is a sub component in evaluating overall risk (expectation of loss) related to the natural disaster. Disaster management researches also recognize that “Risk” is directly related to vulnerability and inversely related to resources. Higher the vulnerability of the system higher would be “risk” whereas higher the resources at disposal to society to cope up with disaster lower would be the “Risk” to the system.

Vulnerability of a locality also depends upon the planning of local response and relief organization. Local authorities are in the best position to identify vulnerable communities as they have more information about the available infrastructure, social and economic status of area. But such agencies are commonly underfunded, understaffed, and stretched thin by ongoing other responsibilities like health and social service. State or central authorities though sufficiently funded and staffed may lack the micro level knowledge about the area and lack the system in place to allocate resources based on the need.

9.2.4.5.1 Methodology

Our approach in this study is to focus primarily on the most affected wards/zones of the city for infrastructure and facilities such as schools, hospitals, slums, industries, etc. Primary survey with stakeholders located in the most vulnerable (indentified through hydrological analysis) zones specific to the infrastructures and facilities is to be carried out. Primary survey is to be conducted to understand the intensity of damage caused due flood to the city.

To conduct survey a suitable sampling method can be selected for collecting data. Samples are drawn from the selected zones/wards of the city for generating an appropriate data set and the analysis is to be done by using statistical techniques.

9.2.4.5.2 Design of Questionnaire

Designing of suitable questionnaire of the survey is an important task which would broadly gather information such as:

(i). Basic information about selected sector, (ii). Infrastructure,

(iii). Water supply and sanitation,

(iv). Financial management,

(v). Past flood experience,

(vi). Effects of flood on various parameters specific to the sector,

(vii). Flood warning measures, and

(viii). Adaptation measures.

All questions are significant for generating an appropriate data set.

9.2.4.5.3 Assigning weights to indicators

Assigning weights to different vulnerability indicators is also an important task. In the analysis, it can be assumed that overall vulnerability of sector depend on all the vulnerability indicators considered but the likelihood of occurrence of a particular vulnerability indicators during an event of disaster varies distinctly. Likelihood of occurrence of particular vulnerability parameters depends on the exposure and risk reduction measures taken by sector pertaining to particular vulnerability parameter. Most importantly likelihood of getting affected and the level of loss measured on a particular parameter depend on the geographical location. Low lying areas are more prone and likely to suffer higher level of damage.

To capture variation in magnitude of vulnerability of a sector weights can be assigned to different vulnerability parameters reflecting probability of damage and the intensity of damage. Weight to a parameter situated at a given geographical location is based on the probability of damages for varying levels of submergence during the flooding period (for details refer to the box below having vulnerability defined as per the level of flood water during flood). It is reasonable to assume that the extent of damage will be linearly related to the level of submergence hence, we have assigned a continuous increasing weight for each submergence levels.

Submergence levels

- **Low submergence**: Flood water level up to 1Meter in the area during the flood
- **Moderate Submergence**: Flood water level between 1 Meter to 2 Meter in the area during the flood
- **High Submergence**: Flood water level above 2 Meter n the area during the flood

9.2.4.5.4 Normalization of continuous indicators

Indicators specific to the sectors are mixed of continuous and dichotomous variables. Indicators are measured in different units and scale hence there is a need to normalize the continuous indicators to make it unit free for calculation of vulnerability index. We have used the normalization methodology similar to UNDP's Human Development Index (HDI-UNDP, 2006). The variables values for an indicator are normalized so that mean is zero and range is 1. There exist direct relations between vulnerability value and indicator value i.e. if vulnerability increases the value of indicator also increases and vice versa therefore higher indicator value shows higher vulnerability. Normalisation has been made by using following formula.

$$X_i = (X_i - \text{Min } \{X_i\})/(\text{ Max } \{X_i\} - \text{Min } \{X_i\})$$

Where X_i is the actual numeric value of indicator "i".

9.2.4.5.5 Vulnerability Index (VI)

A composite vulnerability index (VI) can be prepared for the infrastructure and facilities such as industry, slum, hospital, schools, etc from the different indentified vulnerability indicators specific to each of them. Vulnerability is the product of probability of damage and intensity of damage.

Vulnerability (VI) = ∑ (Probability of damage to a parameter) X (Intensity of damage to parameter)

9.2.4.6 Step 6: City Groundtruthing

This step involves working with local residents and organizations, particularly those who have lived or worked in the city for many years, in a process of ground-truthing the information collected in previous steps. Ground-truthing refers to a method of validating data with input from members of the city to ensure outcomes accurately reflect conditions in the city. The goal is to produce a dataset and maps that incorporate resident's and service provider's knowledge, insights and experiences. Information about areas susceptible to hazards is often outdated and might not accurately reflect current conditions. In this step, city authorities are encouraged to verify the accuracy of the maps and to provide additional information based on personal experience or knowledge. Thus, during the ground-truthing process, maps are double-checked for accuracy and appended with information that may aid in the assessment process.

9.2.5 STAGE 3: PUTTING IT TOGETHER

The purpose of this step is to combine, analyze, interpret and discuss the information collected from the previous stages. It involves identifying the areas of greatest risk, as well as the most critical facilities, vulnerable populations, at-risk commercial centres, etc that pose the greatest risk to the city today and in the future. Each of these risks can be ranked in terms of the severity and extent of the threat and the likelihood of occurrence. This ranking may be used to develop and prioritize strategies and investments to reduce risks.

As a result of putting together a vulnerability assessment, the city should have a greater awareness of the different threats posed by different hazards, an inventory of the different plans, policies and actions in place to reduce vulnerability to hazards, improved communication networks among those groups that typically respond to disasters, and a greater understanding of why and how to include socially vulnerable populations in the planning and implementation process.

Finally, the vulnerability assessment can be link closely with the city's hazard mitigation plan and can establish a baseline of information for planning and for evaluating the success of plans or strategies to reduce vulnerability. Pulling together and making sense of the information collected and organized in the previous steps will likely involve several meetings with the city both to validate the information collected and to develop and prioritize strategies to reduce the city's vulnerability to hazards.

The rapid vulnerability assessment serves as the basis for developing strategies for action: for prioritizing steps to reduce a city's vulnerability, including social and physical vulnerability. The strategies, which should reflect the city's capabilities and in particular the needs and challenges of its most vulnerable people, could include raising awareness about the need to prepare for disasters, identifying policies and plans that facilitate development in hazard-prone areas, and improving communication and coordination between agencies that are responsible for disaster management and organizations that serve or represent the poor, minorities, immigrants, or those with disabilities. The goal is to reduce the entire city's vulnerability in order to make it more resilient to future disasters.

TASKS:

A. Consolidate ground-truthed information into accessible data base

B. Produce a final report that identifies the city's hazards, socially and physically vulnerable populations, and possible strategies for mitigating risks.

C. Present final result to the city administration.

D. Incorporate into comprehensive plans, land use plan, disaster management plans.

9.2.5.1 TASK A: Consolidate ground-truthed information into an accessible database

One of the final tasks in putting together a rapid vulnerability assessment is to assemble the information collected as part of the process into a database that will be readily accessible to disaster managers, concerned departments and officials, and others who may want to use it. The database, which represents information that has been collected, analyzed and validated by the city, should be updated, revised and revisited regularly. It represents the most up-to-date information on people and places that are vulnerable to disasters and the strategies to reduce that vulnerability.

9.2.5.2 TASK B: Produce a final report

A report should be produced that can be used by state and city disaster managers. The final report should include all information, maps, photographs, and datasheets/worksheets collected or prepared as part of the rapid vulnerability assessment. The purposes of the report are to identify and describe the city's hazard risks, socially and physically vulnerable populations, and possible strategies for reducing risk, as well as to identify priorities for action, outline a strategy for implementation and provide a schedule for revisions as new conditions or circumstances change and new information becomes available. Finally, the report should describe the process of conducting the assessment, the lessons learnt, and the key departments/organizations involved, both to give legitimacy to the city-based nature of the document and also for the benefit of other cities that may want to prepare a rapid vulnerability assessment.

9.2.5.3 TASK C: Present the final results to the city at a public meeting

Upon completion of the city-based vulnerability assessment, the taskforce should hold a final public meeting to inform the city about the findings and results of the process. At this meeting, it is important to acknowledge the contributions of the city institutions and individuals who have helped develop the final document, and to look toward the future by highlighting the report's recommendations and opportunities to make the city safer. This meeting represents the closure of the information-gathering phase and marks the beginning of the implementation phase of the process. In addition, it will be a useful forum for building momentum toward implementing the recommendations of the report. It is also a good way to help maintain the involvement of people who have participated in earlier steps and help them see how their efforts will help shape the future of their cities.

9.2.5.4 TASK D: Incorporate findings and strategies into relevant plans and policies

Now that city possesses this wealth of information on hazard vulnerability, the document is ready to be used to inform local policy making authority. The results should be incorporated into the local comprehensive or general plan, capital improvement plan, disaster management plans, CDPs, and other relevant documents. This will help ensure that the agencies responsible for implementing plans are working in concert with one another and not at cross purposes. Successful preparation, mitigation, and recovery from disasters require coordinated planning and action among agencies and between agencies. Dissemination of the findings of the vulnerability assessment among these agencies can strengthen networks within the city and between the city and outside organizations.

9.3 Rapid Vulnerability Assessment Strategy for Bhubaneswar city (Based on IRADe's Methodologies)

9.3.1 Stage-1: Vulnerability Profiling of Bhubaneswar city

9.3.1.1 City Profile

Located in the Khorda district, Bhubneswar the largest city in Odisha lies at an elevation of about 45 meters above sea level in the eastern coastal plains of India. Bhubaneswar city area is characterized by undulating upland topography in western and central part while eastern part shows more or less flat topography with gentle slope towards east or south east.

9.3.1.1.1 Physiographic Characteristics

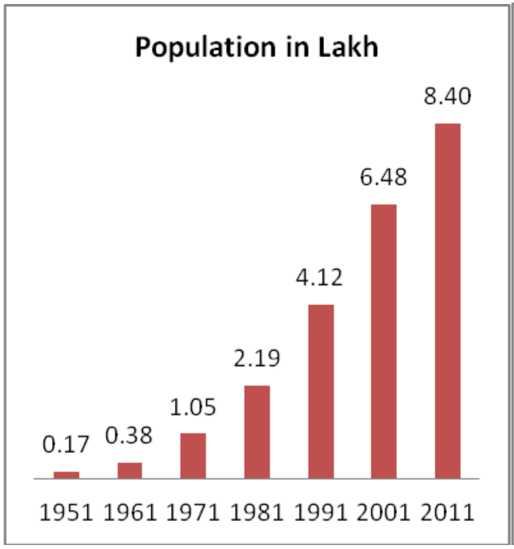
The city lies on the Mahanadi delta and on the west bank of river Kuakhai, which is a tributary of river Mahanadi, 30km south east of Cuttack. The city is bounded by the Daya River to the south and the Kuakhai River to the east

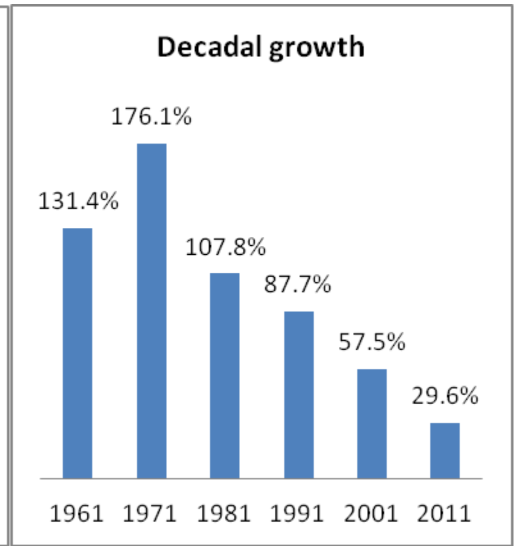
9.3.1.1.2 Socio-economic Characteristics

With a population of around 8.4 lakh in Municipal Corporation, Bhubaneswar is the largest city of Odisha. A total geographic area of 135 sq km falls under the administrative jurisdiction of the Bhubaneswar Municipal Corporation and the entire municipal area is divided into 47 wards. An extended area of 1110 sq km inclusive of BMC area falls under the jurisdiction of Bhubaneswar Urban Development Authority.

The total population for the Bhubaneswar Municipal Corporation (BMC) region in 2011 was 8,37,737 showing a decadal growth rate of 27%. The year 1961 witnessed a high decadal growth of 131.4 % and in 1971 a higher growth rate of 176% which is the highest in India. However, from 1981 a decline in the decadal growth was witnessed with 107% in 1981, 87.7% in 1991 and 57.5% in 2001. The municipal area also increased from 26.09 sq. km to 124.70 sq. km in a period of 40 years (1951-1991) and to 135 sq km in the year 2008.

Figure 9.5: Population growth in Bhubaneswar Municipal Corporation region





Source: (BMC) (Census, 2011,2001)

The BMC region has a slum population of around 3.08 lakh with 436 slum settlements (Slum Survey 2008) i.e. approximately 37% of the population lives in slums

Table 9.4: Profile of Bhubaneswar City

Particulars	Details
City	Bhubaneswar (85°44' E to 85°44' 'E longitude and 20° 12' to 20˚25' N latitudes)
Total Population BMC	8.4 lakh
Decadal Growth rate (2001-2011)	29.6%
Total Slum population(AMC)	3.08 lakh (currently 37% of total population)
Total area AUDA (including AMC)	1110 sq.kms; AMC- 135 sq.kms
Density(AMC region)	6222 persons per sq.kms
Literacy rate	93.15%
Population Below Poverty Line (BPL)	% of Population
Height from mean sea level	45 m above Mean sea Level (MSL)

9.3.1.2 Natural Hazard Profile

Bhubaneswar has predominately a tropical climate. As per the Koppen classification Bhubaneswar falls under the tropical savanna climate zone. Bhubaneswar is a multi hazard city prone to cyclones, heat waves, earth quakes and water logging. According to the wind and cyclone zoning United Nations Development Programme (UNDP) report Bhubaneswar lies in the "very high damage risk".

The average temperatures in summers is 32°C, monsoon is 22°C and winter’s 20°C. The average annual rainfall of the area is 1260 mm.

The inferences from the analysis are discussed as following:

9.3.1.2.1 Climatic Data:

Bhubaneswar city lies in south of tropic of cancer and in coastal plains of Odisha. It shows a moderating maritime influence of Bay of Bengal and has monsoon type of climate with little variations. With around 86.5% of annual rainfall concentrating over a period of 5 months, the city faces problem of water logging and urban flooding. High Population density, encroachment over natural drainage system, weak infrastructure in terms of drainage and sewerage and high number of poor socio economic groups further increases the vulnerability of the city.

Table 9.5: Climatic Data for 49 years period 1952-2000

Month	Mean Maximum Temperature in ˚C	Mean Minimum Temperature in ˚C	Mean Rainfall in mm
January	28.5	15.5	13.1
February	31.6	18.6	25.5
March	35.1	22.3	25.2
April	37.2	25.1	30.8
May	37.5	26.5	68.2
June	35.2	26.1	204.9
July	32.0	25.2	326.2
August	31.6	25.1	366.8
September	31.9	24.8	256.3
October	31.7	23.0	190.7
November	30.2	18.8	41.7
December	28.3	15.2	4.9

Source: IMD Data, Pune

Figure 9.6: Mean Minimum and Maximum Temperature for period 1952-2000

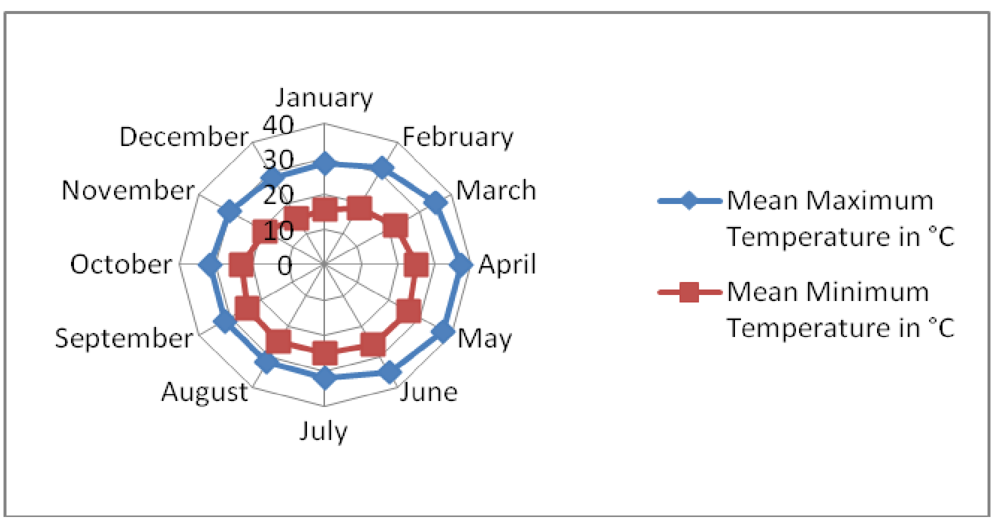


Figure 9.7: Mean Rainfall for period 1952-2000

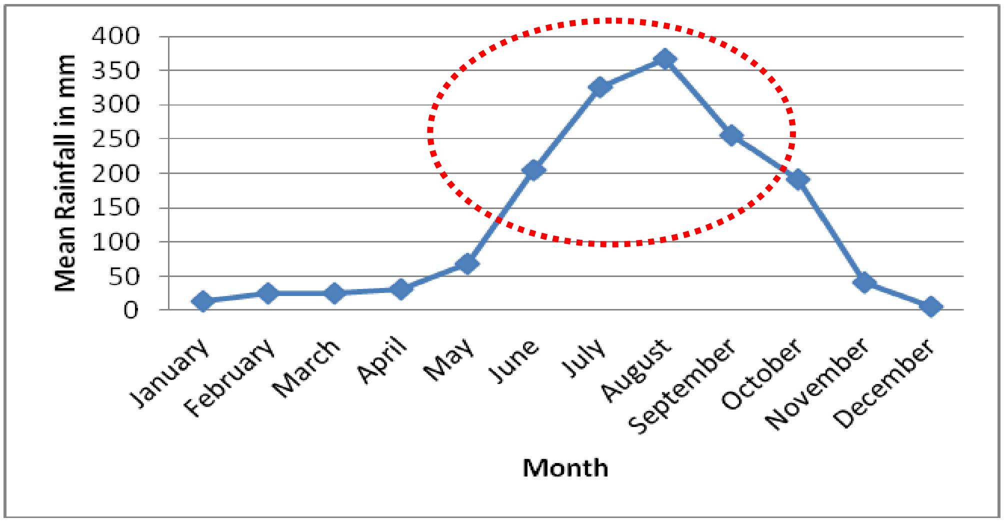


Table 9.6 shows the months in which the different hazards have struck the city of Bhubaneswar. From the table it is evident that Bhubaneswar is prone to a number of disasters and that too spread from May to October. The occurrences of the past disasters have been further elaborated in the sections that follow.

Table 9.6: Time line of hazards for Bhubaneswar city

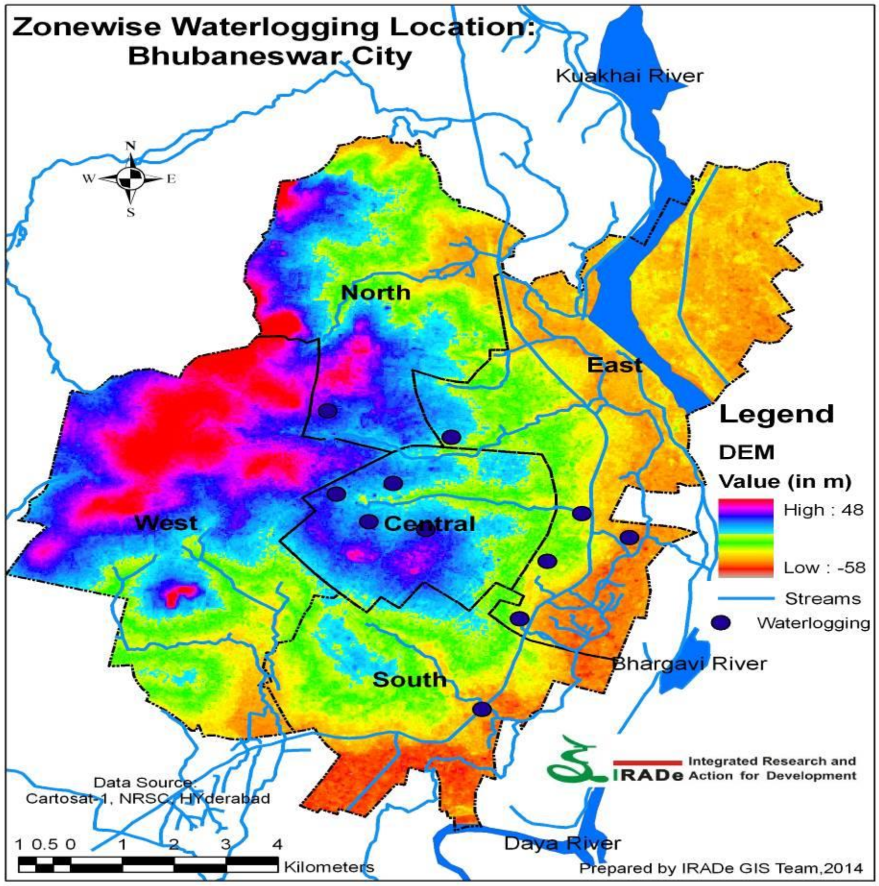
Disaster	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Urban Floods												
Heat waves												
Cyclone												
Earthquakes												

In this study we have focused only on floods.

9.3.1.3 Water and Climate Related Disasters: Urban Floods

The normal annual rainfall of the city is 1470 mm with 80% of the annual rains concentrated over five months thus making this city highly vulnerable to water logging and flooding. The probability for flooding in the city is due to the rivers Kuakhai and Daya. Further, high population density, encroachment of natural drainage systems, weak infrastructure and poor socio economic conditions increases the vulnerability of the city towards urban flooding. The unusual heavy torrential rain from May to July in 2001 caused heavy floods in all major rivers of Odisha. Bhubaneswar was heavily affected by the floods. People were just recovering from the impacts of the 1999 super cyclone when they were hit by the floods. The floods forced people to camp on highways, roads river and canal embankments.

Figure 9.8: Waterlogging areas of Bhuwaneswar city (2012-13)

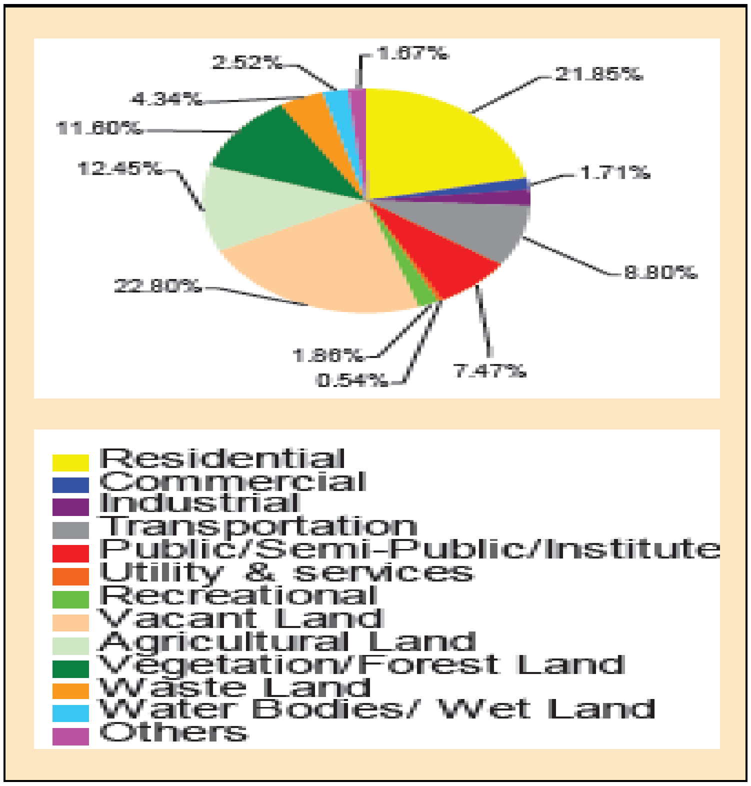


9.3.1.4 Infrastructure Status and Land use

9.3.1.4.1 Land use & Land cover

Error! Reference source not found.9.9 shows the land use pattern of BMC area in 2008. 21.8% of the total area is under residential use. Industries cover about 2.4 % of the area and large tracts of land, around 22.8% are lying vacant. Only 8.8 % of the total area is under transportation network as against the norm of 15%-18% as specified by UDPFI norms back then. 24.05% of total area lying in the north-west region is under agriculture, forest and vegetation because of the undulating and hilly topography and water body is seen to be taking a share of 2.52%

Figure 9.9: Existing Land use for BMC (2008)



9.3.1.4.2 Water supply

The water supply to the state is managed by the State Public Health and Engineering Department-(PHED). Water supply to most parts of the City is being maintained by the State P.H.E.D. At present about 220 ML of water is being supplied to the City daily through piped water supply system by PHED. Kuakhai, Daya and Mahanadi rivers are the raw water sources for water supply to Bhubaneshwar city. No ground water source is presently in use for organised drinking water supply. The present water supply distribution system of the city covers only 32.8 % of the households and the per capita water supply being 218.39 lpcd. (SLBs 2012-13).

9.3.1.4.3 Sewerage

The city sewerage system is presently under the state Public Health Department (PHD). As per the Service Level Benchmarks (2012-2013) only 47 % of the city is covered by the city sewerage system and rest of the city faces major health and environmental issues due to the absence of a proper sewerage system in place. In most part of the city the waste water flows into open fields/natural nallahs creating unhygienic and unsanitary living conditions.

In absence of comprehensive sewerage system, untreated/partially treated sewage of the densely populated areas of Bhubaneswar city discharge into open unprotected natural drainage channels, which join to form Gangua Nallah which meets river Daya. Another major drain namely Drain No 1 (Patia) carrying the sewage of Chandrasekharpur & adjoining areas flows directly into Kuakhai river that too on the upstream of drinking water intake point. Deterioration of water quality of the rivers Kuakhai & Daya not only have adverse effect on the health & hygiene of end users but also endangers aquatic life. Open flow of sewage in unprotected storm water channels always carries the risk of pollution of ground water. At present only the main city area has a proper sewerage system in place. Several areas in the city remain uncovered by sewerage system and these areas are severely affected due to stagnation of sewage, which pose severe threat to health in addition to causing nuisance of bad odour and over flow during monsoons.

9.3.1.4.4 Solid waste management

Bhubaneswar Municipal Corporation (BMC) is the waste managing authority of the city.

The departments of BMC that are involved in Solid Waste Management are:

1. Health & Sanitation department: Solid waste management comes under the purview of this department.

2. Engineering department: This section deals with the repair and maintenance of roads, drains, vehicles etc.

The formal municipal solid waste management in Bhubaneswar city includes mainly primary and secondary collection, transportation and final disposal of collected waste. The MSW generation rate in Bhubaneswar is about 360 g per capita per day (gpcd) and the total generation is about 3,00 t/d. However as per the Service Level Benchmarks (2012-2013) only 33% of the households are covered under Municipal Solid Waste Management. Not even half of the households in the city are properly covered under the Municipal Solid Waste Management.

There is no sanitary landfill in Bhubaneswar city. The city does not have even controlled dumps. Waste is simply dumped at two designated sites (Tulasadeipur and Salia Sahi) without compaction where no soil cover is used. No visual or environmental barriers and no provision for leachate checking are available. Besides the above official dump sites, it is observed that the city also has few unofficial dumpsites. Burning of waste in containers, on roadsides and small dumps is often practised by the residents and also by the municipal sweepers. Therefore as no landfills exist, more dangerous and polluting open dumps are seen to grow in Bhubaneswar. The current practices of open dumping is leading to a number of problems like air, water and ground pollution, spread of diseases through rodents and other vector carriers, increased risk of respiratory diseases, increased emission of greenhouse gases. In the city, solid waste management falls short of the desired level as the systems adopted are out-dated and inefficient. Further institutional weakness, shortage of human and financial resources, improper choice of technology, inadequate coverage and lack of short and long term planning are responsible for the poor state of affairs. All these problems pertaining to inefficient solid waste management observed in the city are definitely more pronounced when any disaster strikes the city and thus making the city more vulnerable to disasters.

9.3.1.4.5 Storm water drainage

The general elevation of Bhubaneswar is approx. 45 m above MSL and the overall topography provides a natural north-to-south advantage of drainage and the natural drains are aligned accordingly. Bhubaneswar has a network of 10 major (natural) drains maintained by the Water Resources Department; they are primarily catchment drains that receive storm water (from minor drains) and convey the same from inhabited areas to Gangua Nallah and onwards to Daya river. The minor drains (secondary and tertiary) are maintained by BMC.

However the land drainage in Bhubaneswar city is relatively poor and, incessant rains during the months of monsoon leads to flooding of low lying areas and disrupts normal lives. The total road length in Bhubaneswar is approximately 18, 00 kilometers, while the total length of pucca covered drains is only 150 kilometers which is just mere 8.3% coverage. On top of that the functioning of the existing storm water drains is hindered by blockages due to solid wastes dumped in drains. Narrow drains, drains with improper slopes or non-existence of drains in some areas cause flooding and water logging thus increasing the risk of diseases like malaria etc. Currently there are 6 flood prone points in the city. For a city like Bhubaneswar which experiences heavy monsoons and is very prone to cyclones, it is important to have a proper storm water drainage in place with optimum coverage. It is essential that improvements of existing major and minor drains and channels, improvements in channel sections of major drains and reconstruction/widening of major drains be done.

Table 9.7: Data Source and its Relevance

Layer of Information	Source of Data	Data Relevance
BMC DEM	NRSC 2010 data	▪ Topography of the city ▪ Natural slope of the city
BMC Contours	NRSC 2010 data	▪ Low lying areas susceptible to water logging
Flood hazard Zonation Layer	NRSC vulnerability assessment map based on	▪ Areas lying in moderate to high flood zones ▪ Frequency of occurrence of flooding incidents

	12 year period (2001-2013)	
BMC Land Use and transportation routes	Existing Land use of BMC (Map 3.2 in CDP of BDPA Vision 2030 Draft Proposal by Department of ARP, IIT Kharagpur)	▪ Distribution of dominant Urban Functions in the BMC area ▪ Overlap of hazard prone areas and current progress of developmental activities ▪ Assessing need for additions and modification in urban developmental policies
Population Density	Ward Map with details and ward wise population	▪ Vulnerable population in various areas prone to urban flooding
Urban Slums	Existing Slums in BDPA Area (Map 7.3 in CDP of BDPA Vision 2030 Draft Proposal by Department of ARP, IIT Kharagpur)	▪ Marginal social groups which are vulnerable to natural hazards ▪ Impact on natural city drainage pattern
Critical Support Services	Ward Map (official website of BMC)	▪ Support lifeline services to be strengthened ▪ Areas where health care centers and public services are lying in problematic areas

9.3.2 Stage-2: Hazard Vulnerability Assessment of Bhubaneswar city

9.3.2.1 Step 1: Vulnerability Profile of City

The unique geo-climatic conditions of the city make it vulnerable to several natural hazards. Natural hazards like wind, flood, heat wave and cyclone are regularly experienced by the city. Past experiences of super cyclone of 1999, Super Cyclone Phailin of 2013 and frequent heavy floods have led to formulation of Odisha state disaster management plan and action guidelines for disaster adaptation and mitigation. All the disaster prone districts prepared detail contingency plans at various administrative levels whereby measures required to be taken before floods, during floods and post floods are specified. Also, the analysis of vulnerability and classification of areas with reference of risks faced by the flood prone areas led to vulnerability atlas (Figure 9.10) for various hazards. As shown in Figure 4, Bhubaneswar is prone to multiple hazards varying in their magnitude of risk. The city lies in very high damage risk zone B with of wind and cyclone hazards with wind speed of more than 50 m/s. Wind hazards have been regular feature in comparison to cyclones. (Figures 9.10(a) & (b))

Figure 9.10 (a): State Vulnerability Assessment Maps

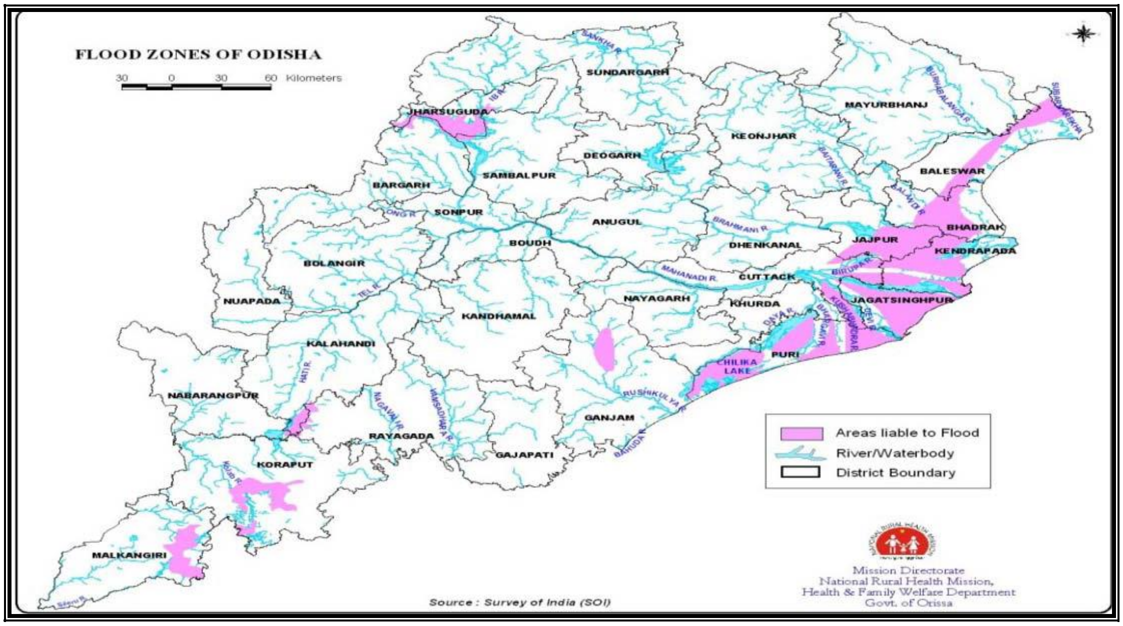


Figure 9.10 (b): State Vulnerability Assessment Maps

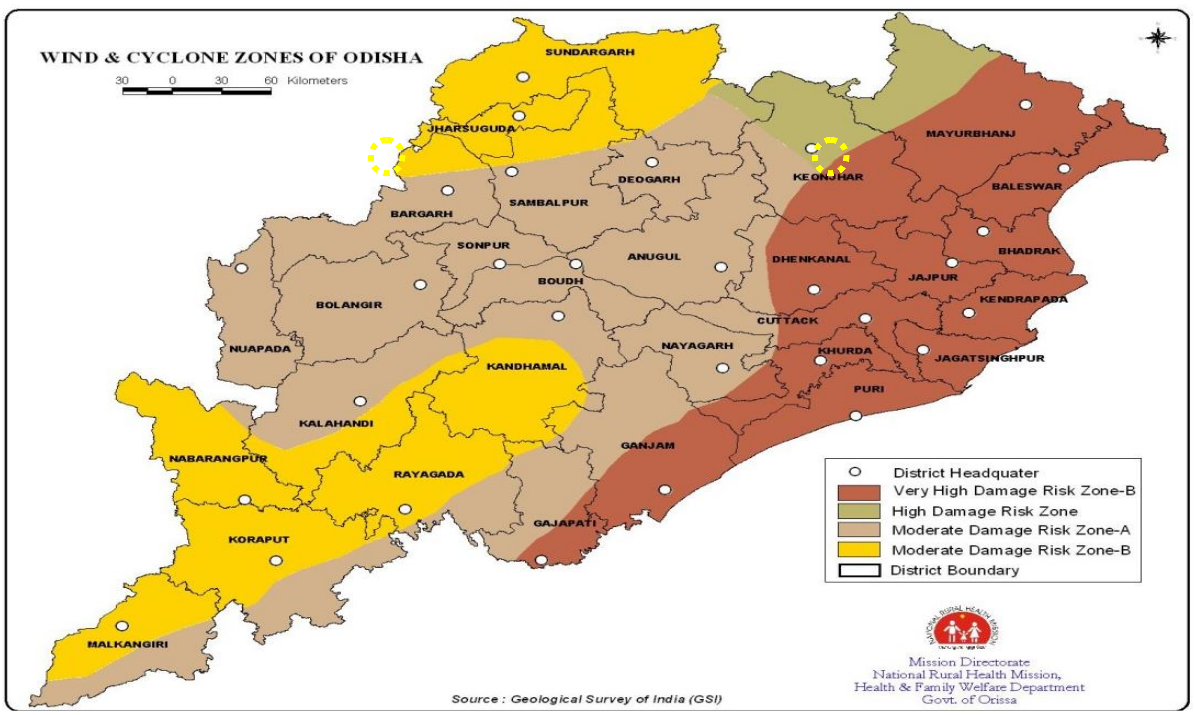
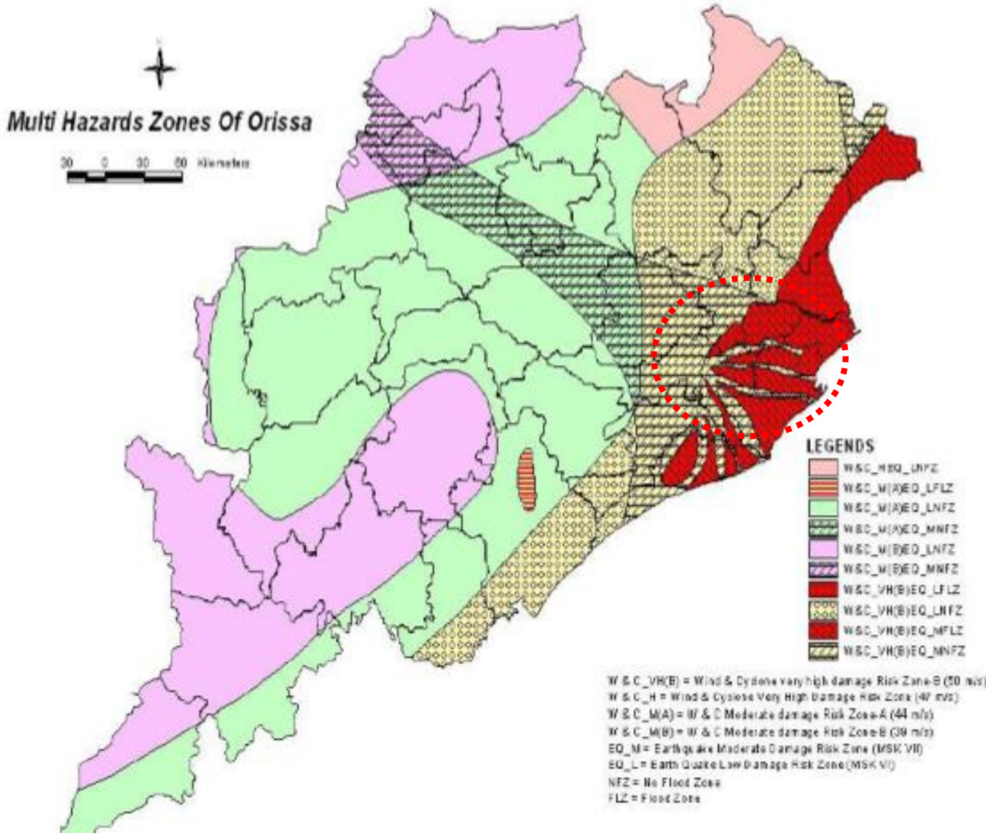


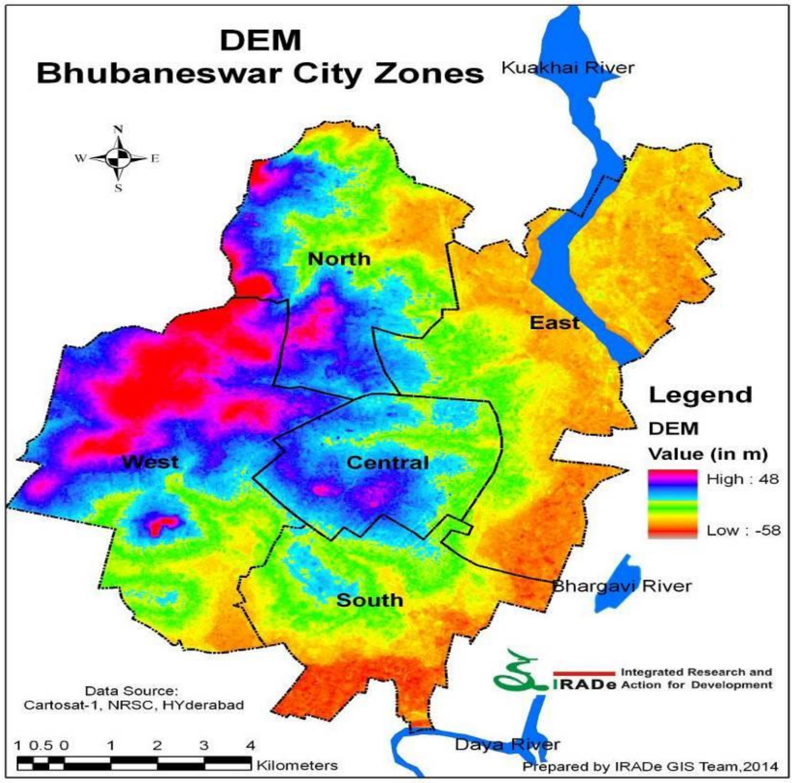
Figure 9.11: Multi Hazard Zone Map of Odisha



9.3.2.2 Step 2: Terrain Mapping of the city

The city lies in the eastern lowlands of the state and the natural slope is from west to east. This gives an advantage to align storm water drains towards natural slope. Area near Kukhai-Daya, flood plan is mostly alluvial in nature and is unsuitable for large construction activities. In North-West and South-West part of the city, lies Bharatpur reserve forest and protected forests of Chandaka. Within the city, almost all areas are affected by heat waves, earthquake and fire. There are 10 drains aligned from west to east in the city. According to the CDP for BDPA Draft Proposal Vision 2030 prepared by IIT Kharagpur, the areas where urban flooding has been an issue are along drain 4 (Nayapalli, Acharya Vihar, Jayadev Vihar and Shastri nagar), drain 5 (Laxmisagar Square and DWBC Crossing), drain 7 (encroached road along Bhubaneswar Puri road in Gouri nagar and Garage Square localities, major drain aligned parallel to Daya west branch canal and drain 10 (Jharapada, Bomikhal, Govindprasad, Shantinagar). The urban flooding is majorly due to blocked passage to storm water because of encroachment of natural drainage system and regular flooding during monsoon.

Figure 9.11: Digital Elevation Model (DEM) Map of zones of Bhubaneswar city

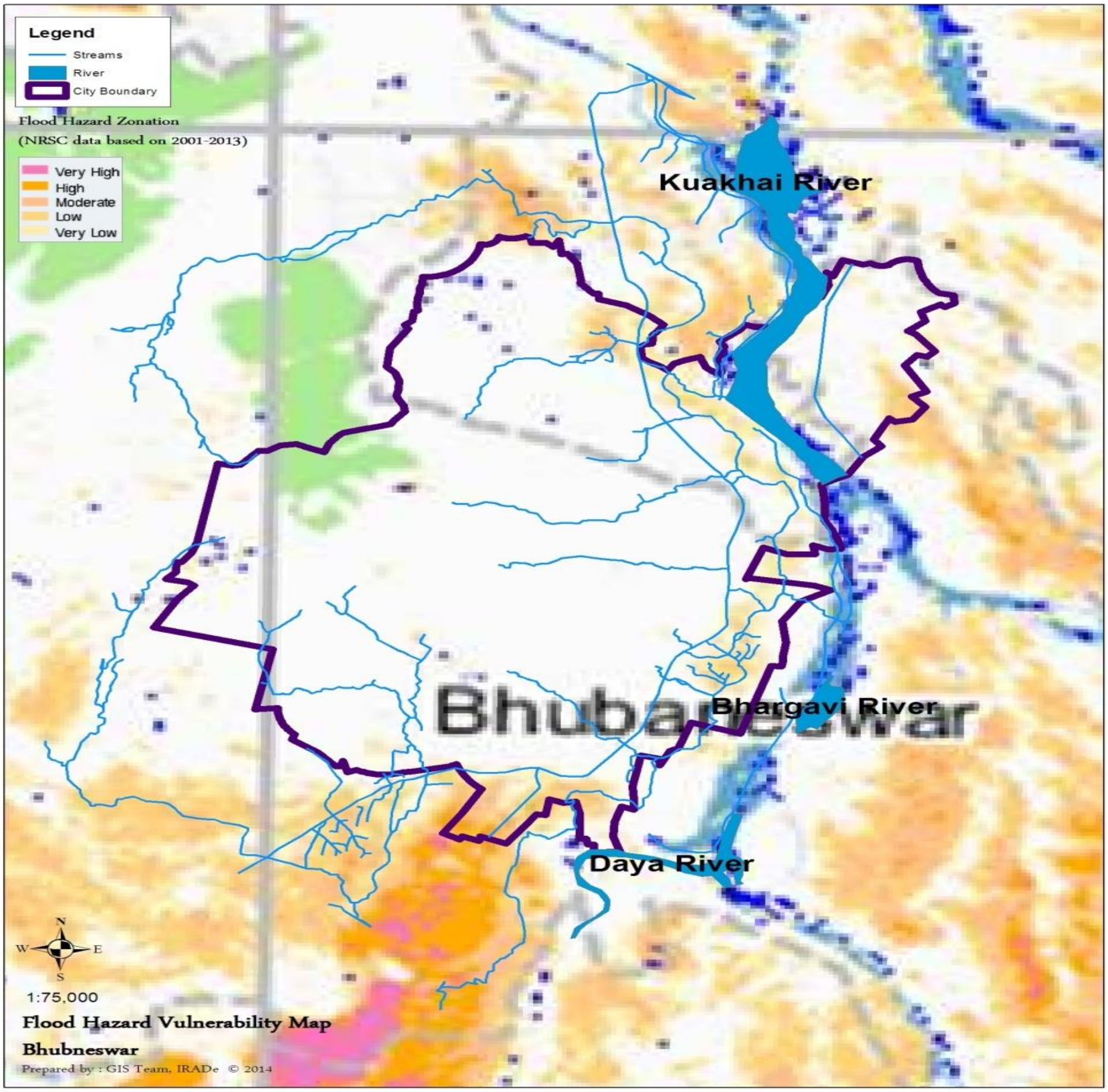


The light shaded (yellowish colour) areas in Figure 9.13 shows locations which lie on low elevation. Most of the East zone of the city lies in this low lying elevation. These locations include Jadupur, Sundarapada, Nuagaon, Kapileswar, Haripur Patna, Rajarani, Baragada, Meherpalli, Jharpada, Govindprasad, Pandara, Mancheswar, Joypur, Pahala, Johal, Bangauri, Haridaspur, Rudrapur etc. Northern part of the West zone lies in the high elevation (around 48m amsl) region.

9.3.2.3 Step 3: Flood Inundation Mapping of the city

Bhubaneswar city lies in Central Administrative division of state in Khurda district and it is the capital of the state with important administrative, institutional and educational services. The spatial analysis for Bhubaneswar city is initiated keeping in mind the disaster propensity of the region. The unique geo climatic conditions in the eastern coastal plains of the state capital city make it more vulnerable to multiple natural hazards like earthquake, heavy winds, cyclones, floods etc. The vulnerability assessment maps for the state, flood Zonation layer generated by NRSC based on 12 year period (2001-2013) and water stagnation locations in the city are superimposed spatially using GIS tool on vulnerable urban components which are at prominent risk. This includes land use, slums, traffic and transportation, critical support services etc. An essential need to remove encroached portions of natural drainage lines, slum rehabilitation and urban development controls in flood prone areas is identified. The various layers of information prepared using GIS tool are shown in figures 9.14 to 9.16.

Figure 9.13: Flood Hazard Vulnerability Map



Data Source: Bhuwan, NRSC, 2014

NRSC has prepared flood hazard zonation layer for Odisha state using annual flood inundation layers derived from 12 years of multi temporal satellite data (2001-2013). Based on the frequency and extent of inundation, the flood hazard is categorized into 5 classes namely very high, high, moderate, low and very low as shown in Figure 9.13. The eastern lower plains of city along the river line show low vulnerability. However, the southern part of the city is prone to moderate to very high flooding.

9.3.2.4 Step 4: Physical Vulnerability of the city

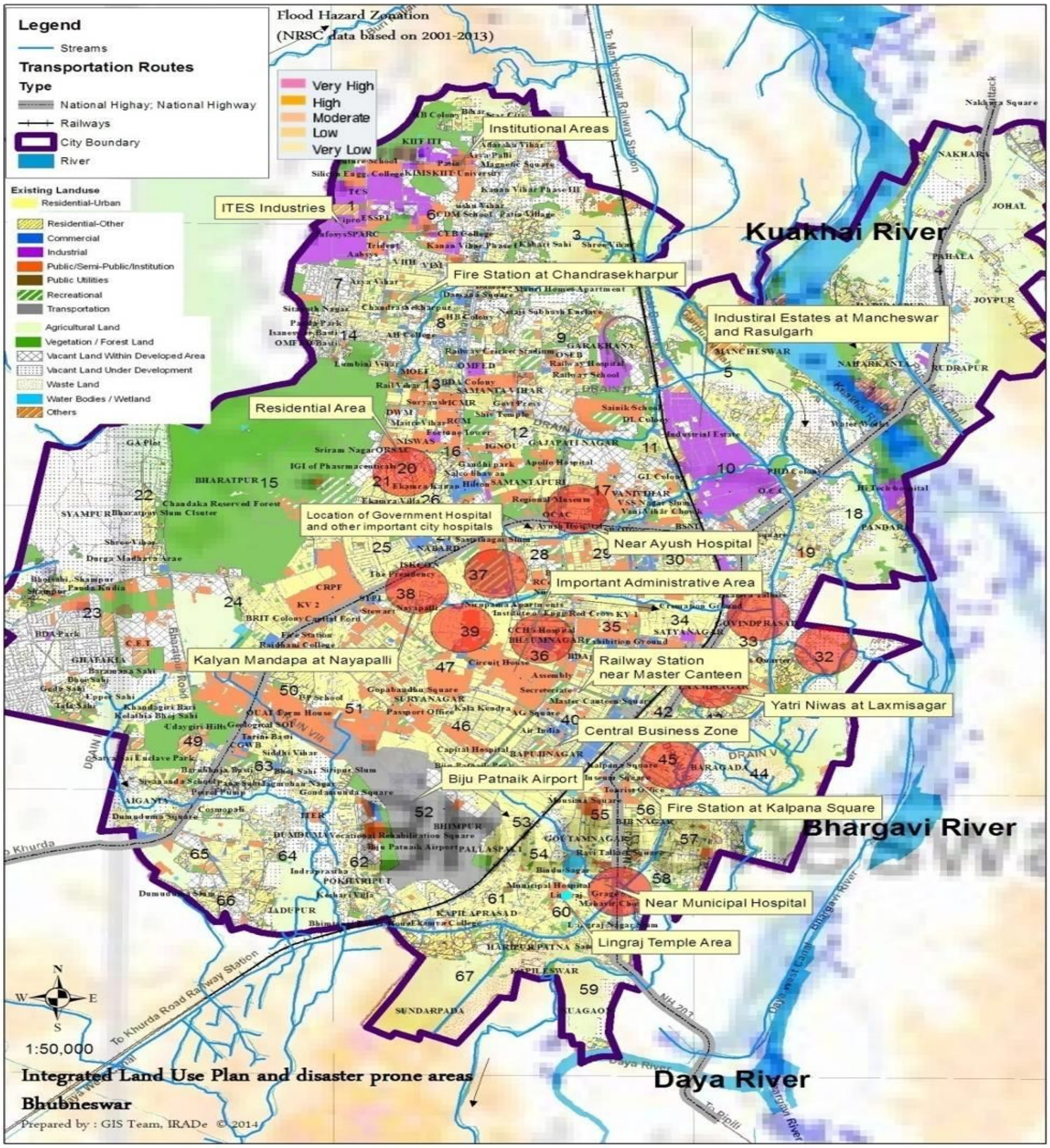
9.3.2.4.1 Urban Economy:

The state capital has realized the necessity for dynamic growth of economy. Beside wholesale warehouses in Rasulgarh, there are 4 major industrial estates namely Rasulgarh Industrial Estate, Mancheswar Industrial Estate, Chandaka Industrial Estate and Bhagabanpur Industrial Estate. However, the city is dominated by tertiary sector. Administrative, institutional, ITES, real estate development and Tourism. Also, the city is major centre for trade and commercial activities. The Central business zones are located near Rajmahal and Bapuji Nagar, Unit1 and 2 Markets. Several polycentric spatial development of retail activities have started around various residential areas.

9.3.2.4.2 Land Use:

There is mixed land use prominent in east of railways i.e. in Old town. Also, new residential areas have come up in west of NH-5. The North West part of the city is sparsely developed residential area encroached by non residential activities. The total municipal area is 35% of actual development area. Around 62.46% area is found to be agricultural, marshy land, hills, vacant land, farm houses, orchards etc. This barren land is more prone to high wind hazards because of no natural wind barrier. There is market area in Unit 1 and 2. Some commercial ribbon like development has also taken place along Janpath and Cuttack Puri road. The city is welcoming boom in construction sector and this necessitates incorporating development controls with appropriate construction technologies for hazard prone area like Bhubaneswar. Map 7 shows integrated land use plan with disaster vulnerability map of the city.

Figure 9.14: Integrated Land Use and disaster prone areas

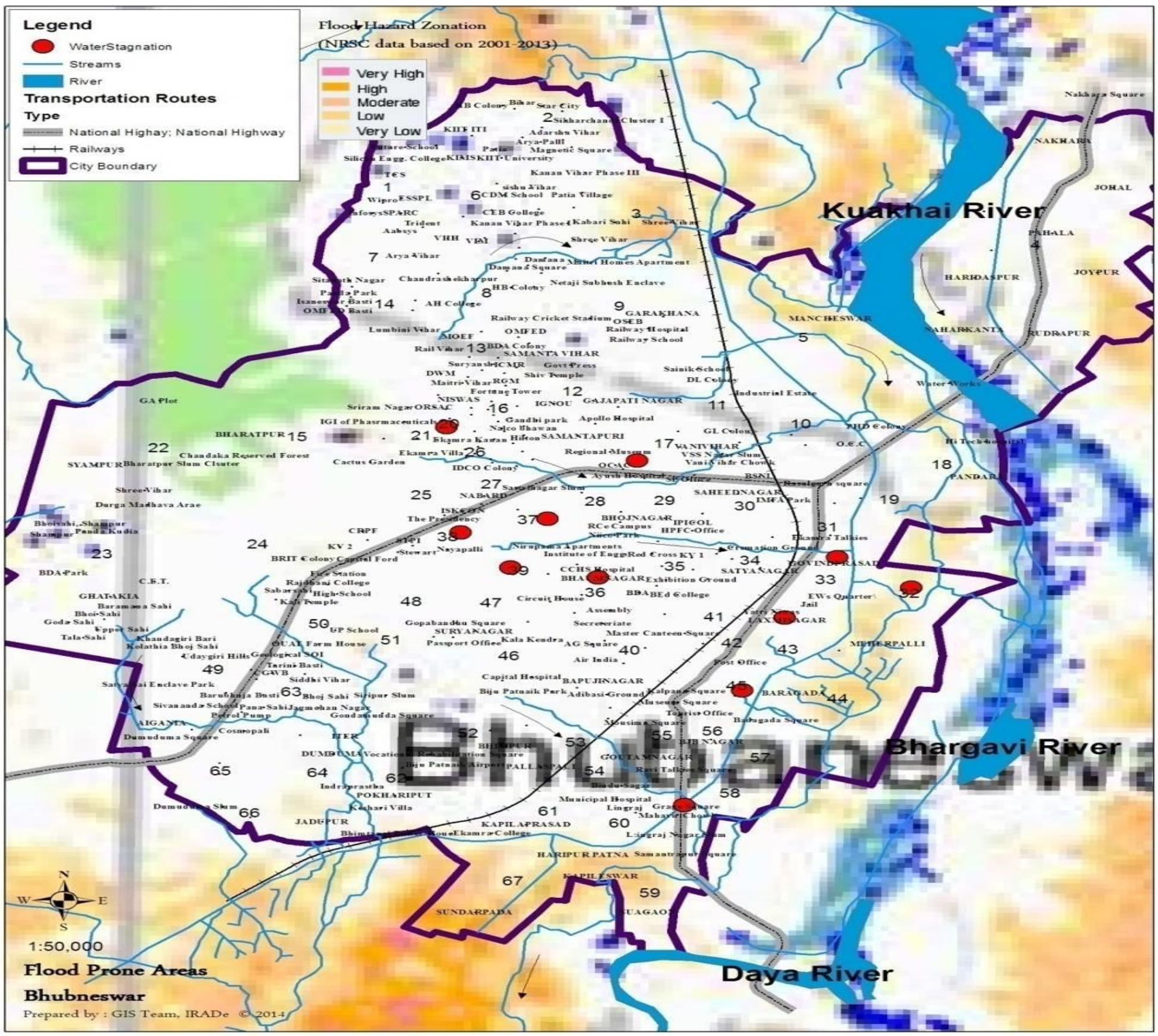


Data Source: Bhuwan, NRSC, 2014

9.3.2.4.3 Transportation and Connectivity:

Bhubaneswar is connected to the rest of the country by NH 5, which is a part of the Kolkata-Chennai prong of the Golden Quadrilateral, NH 203, SH 13 and SH 27. Biju Patnaik Airport provides sole air connectivity to various cities in the country. The East Coast Railway has its headquarters in Bhubaneswar. Bhubaneswar railway station is one of the main stations of the Indian railway network. Bhubaneswar has five railway stations within its city limits; namely (from north to south) Patia Halt, Mancheswar, Vani Vihar, Bhubaneswar station (near Master Canteen) and Lingaraj Temple Road.

Figure 9.15: Transportation Routes in Bhubaneswar city

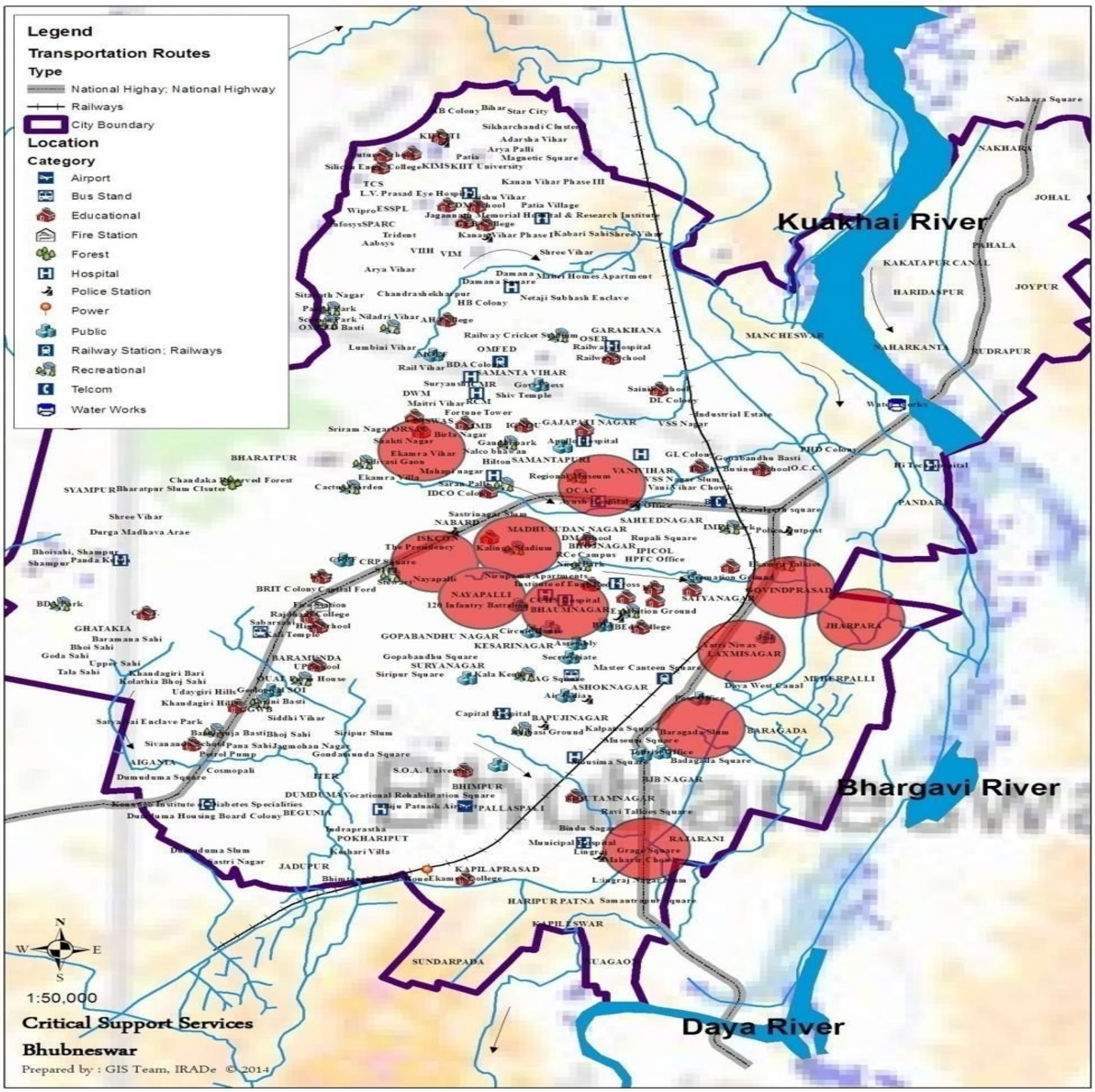


Data Source: Bhuwan, NRSC, 2014 & Google

9.3.2.4.4 Critical Support Services:

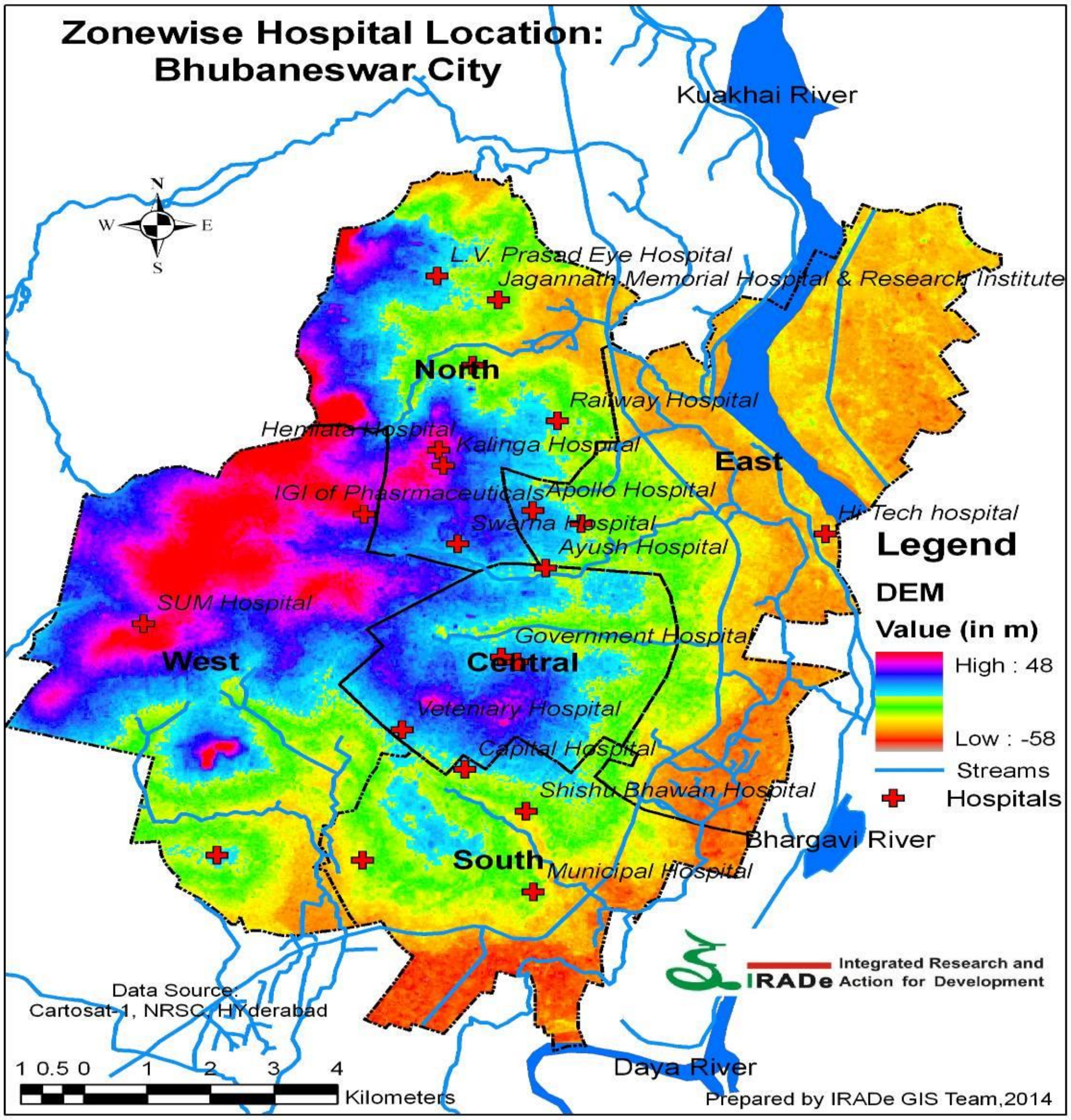
Many areas which are affected by urban flooding shows concentration of many hospitals, public buildings and educational institutions. Map shows that these areas contain important lifeline infrastructure during the time of disaster and needs strengthening of infrastructure and construction quality to respond at the time of disaster.

Figure 9.16: Critical Support Services



Data Source: Bhuwan, NRSC, 2014; Google; CDP, Bhubaneswar

Figure 9.17: Zone wise Hospital Location



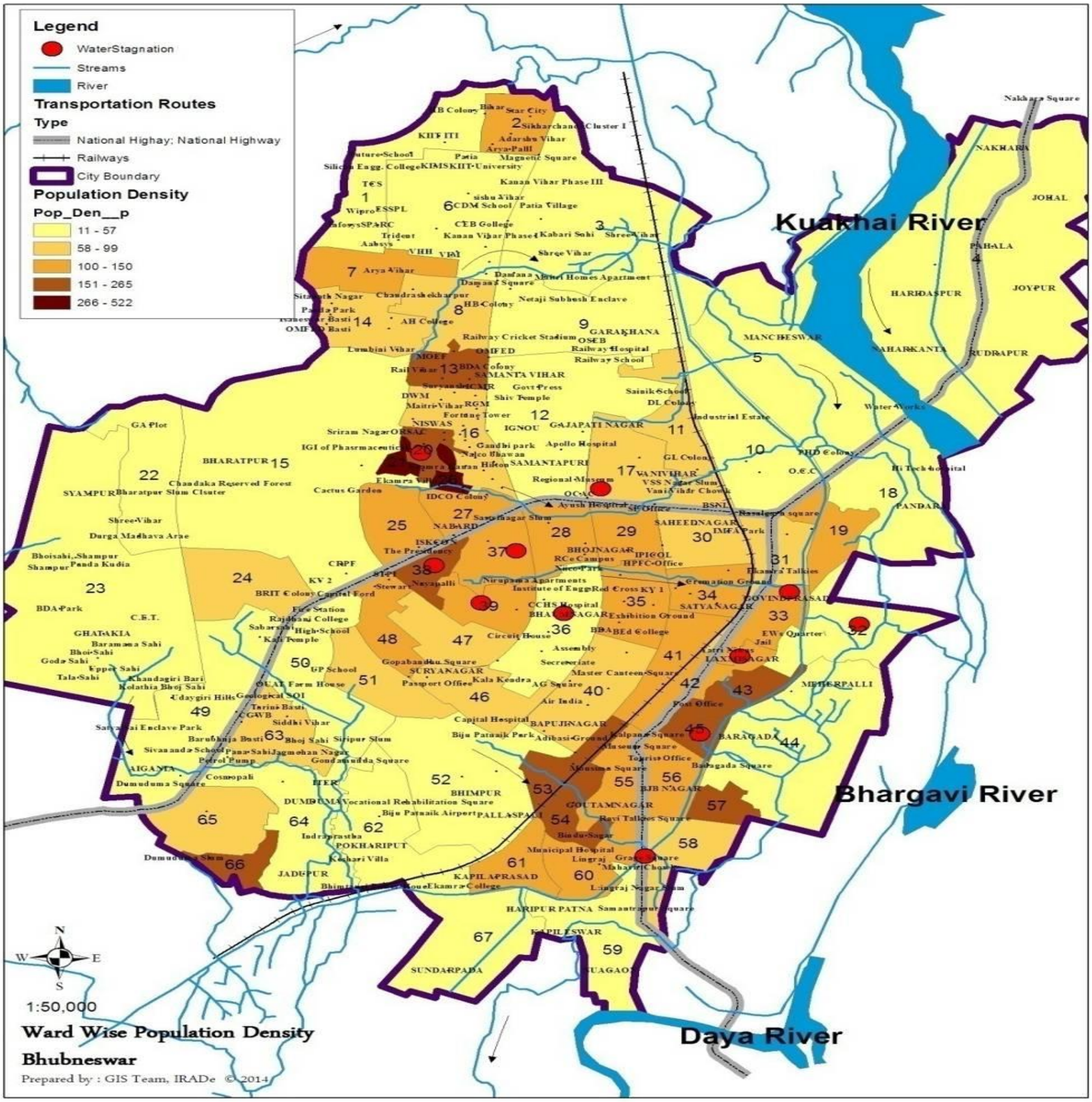
Data Source: Bhuwan, NRSC, 2014 & BMC

9.3.2.5 Step 5: Socio-economic Vulnerability of the city

9.3.2.5.1 Impact on population:

The total city population recorded in 2011 is 8,37,737 with population density 4,800 persons/km2. Map 4 shows that Ward numbers 17, 20, 32, 33, 36, 37, 38, 39, 42, 45 and 58 have problems of water logging reported. 20, 38 and 45 are the wards where population density is very high followed by ward numbers 33, 39 and 42. 37 have medium density, 58 with low density followed by 17, 32 and 36. Map 5 shows that Wards which are found to be in flood zone are 2, 3, 4, 5, 18, 19, 32, 34, 59, 64, 66 and 67. (Refer annexure 1 & 2)

Figure 9.18: Ward wise Population Density

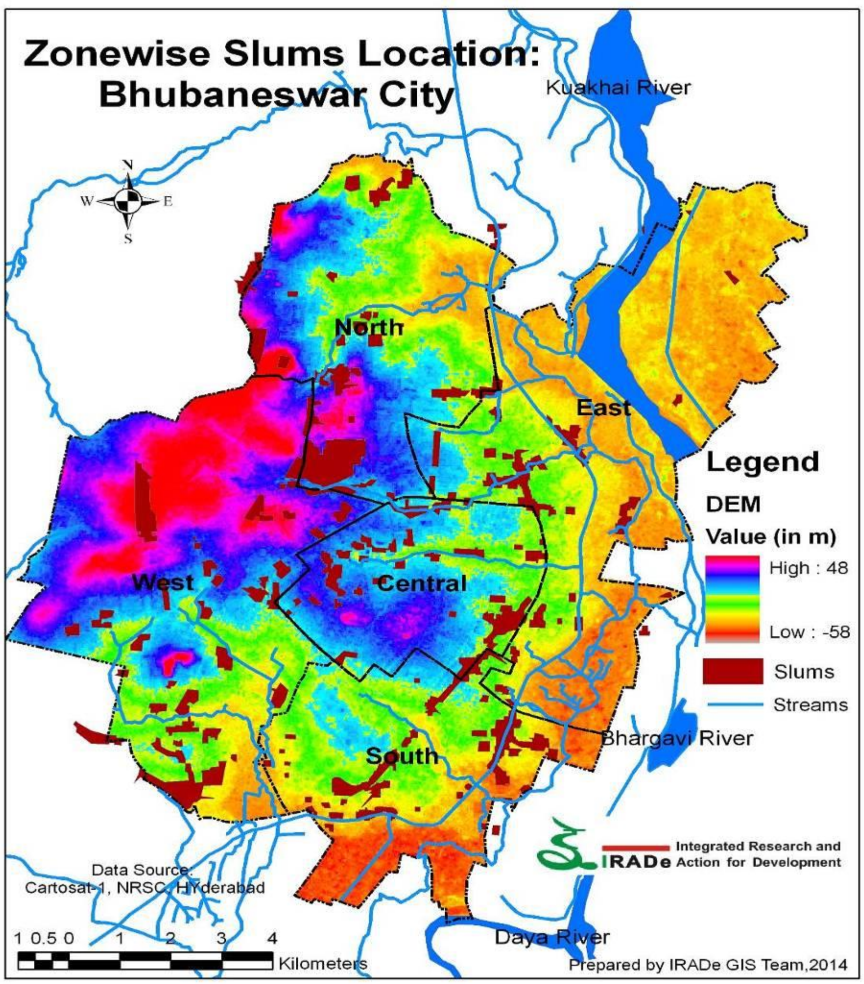


Data Source: Bhuwan, NRSC, 2014; CDP, Bhubaneswar; BMC

9.3.2.5.2 Vulnerable Social Groups:

According to the slum profile made by BMC in 2008, 377 slum pockets have been identified out of which 99 are authorized and rest 278 slums are unauthorized dwellings on government land. These are more prone to disastrous effects of cyclones. These areas generally have houses which are built with mud or brick-mud walls and located in clusters. They are characterized with polythene sheets and thatched roofs made out timber, bamboo and straw which makes them more vulnerable to heavy winds, cyclones, urban fires, earthquake etc. Map 6 shows the majority of slums lying along railway line, national highway and natural streams. Most of the water logging problem are also reported in these areas especially where the natural drainage system has been disturbed by human activities.

Figure 9.19: Vulnerable Social Groups (e.g Slums)



9.3.2.6 Step 6: City Groundtruthing

In this step we adopt a method of validating the information collected in the previous steps to ensure an accurate outcome. During the groundtruthing process maps and data are double-checked for accuracy to aid the assessment process. Since we have used only secondary data for Bhubaneswar city, the Groundtruthing process has not been taken into account.

9.3.3 Stage-3: Putting it together

9.3.3.1 Disaster Mitigation Services:

The city disaster management plan mentions availability of ample skilled and labor manpower in the time of exigency. Bhubaneswar Municipal Corporation has seven Kalyan Mandap at Sahid Nagar, Badagada, Nayapally, Chandrasekharpur, VSS Nagar, Dakhshinchandi and Badagada in addition to one Yatri Niwas at Laxmisagar, Community Centres at Unit-VIII, Shastrinagar, Bhimatangi, 111 Angan Wadi Centers, one Working Women's Hostel at Mancheswar which would be helpful during the time of emergency for relief purposes to cater the need of the affected people. Also, there are 176 Fair Price Shops and 4 storage godowns covering all the wards of BMC. The three fire stations identified are at Kalpana Square, Chandrasekharpur and State fire training institute. Also, there are many resources and equipments including trucks, generators, search lights, recovery cranes etc available with Odisha Disaster Rapid Action Force (ODRAF) unit which have been mentioned under CDMP.

9.3.3.2 Resilience Assessment and analysis

Based on the updated data of city and its assessment, the following matrix has been developed on city governance, ULB's performance, preparedness, financial indicators and SLB data. Using the data we made followings table to analyse the city by developing resilience and sustainability matrix.

Table 9.8: Resilience and Sustainability Assessment Matrix for Bhubaneswar

Sl. No	Variables	Low	Medium	High	Index Details and Remarks
1	**Exposure to hazards**				
1.1	Earthquakes		✓		
1.2	Landslides				
1.3	Urban Floods	✓			
1.4	Cyclones	✓			
1.5	Water scarcity				

1.6	Heat Waves	✓			
1.7	Industrial Hazards/Fire				
2	**Socio economic conditions**				
2.1	Population Growth	✓			Decadal growth of 29.6% in 2001-2011
2.2	Percentage of slum population	✓			37% of population is slum population
3	**Infrastructure condition (basic services)**				
3.1	Water supply (lpcd)			✓	
3.2	Sewerage system coverage	✓			Less than 50% coverage-47%
3.3	Solid waste management system coverage	✓			Less than 50% coverage-33%
3.4	Drainage (coverage & water logging incidences)	✓			Extremely low coverage-8%
4	**Governance and Institutional Framework**				
4.1	Disaster response system			✓	A Control Room which maintains a register of complaints, viz. water logging, choking of drains, fallen trees, road culvert damages
4.2	City Disaster Management department			✓	City Disaster Management committee in place
4.3	Dedicated persons to handle and update DRR data			✓	
4.4	DRR in urban planning			✓	City Disaster Management Plan recommends integrating DRR with development plans
4.5	Approach top down or Bottom up approach				
5	**Adaptation strategies in the cities**				
6.1	Human Resource-Trained workforce to community interaction, community awareness initiative etc			✓	
6.2	Early warning system			✓	
6.3	Updated previous disaster data base		✓		

6	**Mitigation Actions by Category**				
6.1	Emergency Services- like Dedicated control room for information dispensation and coordination and Necessary equipments in place and functioning			✓	
6.2	Building codes for current and future construction			✓	

9.4 Conclusion

9.4.1 Recommendations and Priorities for action and strategies

Based on the resilience and sustainability assessment matrix made on the basis of the data collected and literature study the following priorities, actions and strategies can be recommended:

- **Exposure to Hazards:** Bhubaneswar city has high exposure to a number of disasters with the highest proneness being to cyclones, floods, heat waves and earthquakes. It is imperative that disaster management and resilience be the key focus area for interventions.
- **Infrastructure Conditions:** The storm water drain coverage and sewerage system coverage is really poor and the regular incidences of urban floods suggest that it is only imperative that the shortage of storm water drains be addressed. Efforts should be directed towards making water supply 24X7 and with 100% coverage. Not even half of the households in the city are properly covered under the Municipal Solid Waste Management. Efforts should be directed towards improving the solid waste management. Also infrastructure must be developed to improve the quality of basic service for the urban poor.
- **Government and Institutional Framework:** The City Disaster Management plan recommends the integration of disaster risk reduction and building resilience is into city. The city administration is directed to take different convergence programme with other line departments and make them aware about the hazard proneness of the city.
- **Socio Economic Conditions:** The urban poor populations are the most vulnerable section in the city. The 37% slum population lives mostly on the river banks, low lying areas and in poor housing conditions thus being most exposed to the risks of floods and heat waves. Measures should be directed towards improving the resilience of the urban poor.

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CHAPTER 10: CONCLUSIONS AND RCOMMENDATIONS

10.1 Introduction

Climate change has emerged as an important global as well as regional environmental concern. Several key development sectors could be adversely impacted by the climate change. While the development process is addressing many barriers and helping the country's socio-economic and natural systems to become more resilient to adversities, there are several areas of vulnerabilities where climate change can lead to adverse impacts and welfare losses. Development and climate thus appear in adverse relationship to each other. A key challenge for country like India is to make development the principal instrument for adaptation vis-à-vis the adverse impacts of climate change and therefore make development more climate friendly.[34]

Although the level of exposure to hazard in India is high, vulnerability typically contributes more to overall risks in cities of India. Reducing such vulnerability will mean a shift in public policy towards mitigation and adaptation. This needs to focus on the most vulnerable aspects through a mix of policy, regulatory, fiscal and financial, institutional, socio-cultural and political instruments. Flood is a major and frequent problem for Surat. However, Surat particularly, has the advantage of efficient city administration, strong political consensus and fairly healthy municipal finances. Surat is one of the few cities with higher credit rating, which enables it to raise funds for infrastructure development. The city has also demonstrated its capacity to build resilience by improving the quality of the lifeline services like water supply, sewerage, solid waste disposal and health. The future target is to strengthen the existing infrastructure to withstand flood risk, to build redundancies and improve resilience.

10.2 Vulnerability and Adaptation: Concerns and Challenges

Surat city experiences floods frequently. During flood events 1998 and 2006, there was considerable destruction of the city and most of the area of the city was under water. In order to reduce the intensity of unfavorable conditions and to reduce flood effect certain measures are recommended. Because of increasing industrialization in the peripheral area of Surat, it is experiencing rapid growth of population. Due to industrialization, migrant population has also

[34] P.R.Shukla & S.K.Sharma et al

increased rapidly. A study on migrants in Surat reveals that almost every second family of the city is an outsider settled here. It is noteworthy that, in year 1974, north zone had only two villages and west zone was almost half of what it is today. But with the increasing population pressure and to accommodate the pace of development in the city, all the new settlements are found around the river, riverbanks and the banks near west zone. In the last decade the migrant population increased rapidly. The poor migrants often reside in slums generating illegal settlements. Pal Patiya, New Haveli Temple, Bhulka Vihar School, Hanuman Temple, RTO building are some of the settlements which are undesirable and make the river narrower. Rehabilitation or resettlement of these slums to reclaim the riverbank could be a promising option for decreasing the death toll in future floods (Mankodi 1992).

Some natural drainages carrying rain water which were used to meet the Arabian sea some years before are facing serious threat from the rampant construction to facilitate urban development. The airport, constructed few years ago, is an obstacle for the drainage, which is passing under it. Same way, a shipyard constructed near the mouth of the river is a barrier for one of the major natural drainages. Such infrastructures should be avoided and if they are necessary then feasible alternative arrangement for the rainwater discharges must be made before constructing them.

Parallel to the left bank of river Tapi, is Mithi-Khadi River, which ultimately meets the Arabian Sea. An existing waterway between Tapi and Mithi-Khadi River could be a possible option to absorb large amount of water at least cost by dredging the waterway, maintaining the slope, and constructing suitable structures where needed on the way. Kim and Sena Creek are the two rivers on right bank of the river Tapi, which lead the runoff of the surrounding area. As origins of these two Creeks are nearby the right bank of the river Tapi, they can be easily interlinked by excavating a channel at comparatively small cost. For irrigation purpose, Kakrapar canal network is already there on both sides of the river Tapi. Parallel to sub branch canal of Kakrapar, one moderate river leads the water and meets the sea. By providing the canal escape at suitable location as well as excavating channel between the escape and this river, an inter-linkage can be provided. Such planning can be helpful to run the canal at FSL in order to reduce water level at Kakrapar, which increases rapidly due to discharge from Ukai during heavy rain fall in the upstream. As discussed earlier, Mithi-Khadi river is flowing parallel to the left bank of river Tapi. It is proposed to construct some water storage structure in the form of reservoir and polder dams. In order to reduce water level of Tapi during peak discharge, considerable amount of water can be diverted and stored into reservoir no. 1 to 5.[35]

10.3 Response Strategies: Climate Resilient Urban Development Strategies

Evidently, climate change would pose considerable and varied challenges to the sectoral and regional development in India. India is particularly vulnerable to climate change, having limited energy resources, long coastline, snow-fed rivers, and majority of the population dependent on weather based agriculture sector. Disruptions, droughts, and floods induced by the climate change can, therefore, cause great hardships to the vast population of the country and can impose high costs. The capacity to adapt to climate change varies considerably among regions and socio-economic groups and will vary over time. Groups and regions with adaptive capacity that is limited along any of these dimensions are more vulnerable to climate change damages, just as they are more vulnerable to other stresses. Enhancing adaptive capacity, therefore, is a necessary condition for reducing vulnerability, especially of most vulnerable regions, targets, and socio-economic groups in India’s cities. These groups are already under pressure due to population growth, resource depletion, and socio-economic inequalities. Climate change is an added stress, making them more vulnerable and therefore increasing their risks due to their low adaptive capacity.

Sustainable development is an important consideration in Indian policy making, as reflected in the Twelfth Five Year Plan (Planning Commission). Various policies and strategies have historically been framed to integrate economic and social objectives with environmental integrity. The climate resilient urban development strategy has been developed based on a set of principles starting from anticipating and forecasting of risks across various time scales giving priority to avoidance, risk reduction and management of residual risks in the same order. This approach is undertaken mainly due to large uncertainties in population growth and economy as well in climate change. Considering these limitations, resilience strategy should consider current risks from models and

[35] Dhruvesh P. Patel & Prashant K. Srivastava: Flood Hazards Mitigation Analysis Using Remote Sensing and GIS: Correspondence with Town Planning Scheme, 2013.

observations. It should be an adaptive strategy that provides scope for improvement over time. Surat city stakeholders are already aware of current risks, and have taken several measures to reduce risks and improve resilience. Also the city has been implementing several infrastructure development programmes as well as basic services for urban poor under the JNNURM. The suggested strategy builds upon the ongoing efforts, existing infrastructure and established institutions.

The ULB has proved its capacity to deal with emergencies and take up proactive initiatives in urban development, community health and disaster management working closely with industry and citizens. Surat is considered as a model for good governance as well as for very effective service delivery in comparison with many Indian cities. Therefore, any progress in this city will be keenly observed and can set a model for urban resilience across other Indian cities. A multi-stakeholder "Surat Climate Change Trust" led by the SMC is addressing issues not only at city level but also attempts to influence policy at state/central levels.

The field studies conducted in this project indicate that hydro-meteorological risks, inundation risks, socio-economic risks and their inter-linkages are the most critical issues facing the city of Surat. High population growth and physical expansion of the city may aggravate these risks significantly. Anthropogenic intrusion on river hydrology and climate variability will add risks as the city is already experiencing reduced carrying capacity of the river.[36]

10.4 Towards an Integrated Approach: Linking Science and Society

Science can provide objective scientific and technical advice to the society and policy makers, especially for a complex processes like climate change and the socio-economic vulnerability of the region. Beyond the sectoral and disciplinary assessments of climate change, an urgent need is to integrate the diverse scientific assessments and link them with policy-making. While some experience of using integrated assessment models does exist in India, the capacity building in this area still remains a priority in two respects:

Firstly, it is to provide policy orientation to the scientific assessments; and

[36] ACCCRN-Surat Report "Climate Resilience Strategy", 2011-12.

Secondly, it is to provide robust scientific foundation to policy making.

The development of assessment tools taking into consideration various parameters related to hydro-meteorology, socio-economic conditions, hazard-risks vulnerability, urban morphology and infrastructures, institutional set up, etc. would need commitment of sustained resources and institutionalization of multi-disciplinary and networking efforts within the scientific and policy-making establishments.

The status and key vulnerability concerns in India, more specifically the coastal cities, response strategies, and assessment challenges for diverse sectors and regions require integrated approach for climate change vulnerability assessment and adaptation challenges. Integrated approach refers to considering the full range of stresses that affect a resource or system, including climate variability and change, land use change, and many other natural and human impacts (NAST, 2000).[37] For example, in deciding policy for flood hazard management in a particular place, integrated scientific advice should include the direct and indirect effect of urban development, agricultural run-offs, and climate change-induced increase in heavy precipitation events, along with many other related factors. Integrated approach also refers to integration over regions, sectors, and time-scales. For example, the analysis of water availability may be first integrated at individual sub-basin levels, further integrated into individual river basin levels, and finally integrated into national level. Such integration across both multiple stresses and multiple scales is needed to provide the type of comprehensive analysis that policy makers need.

Integrated assessment attempts to present the full range of consequences of a given policy- economic or environmental, prompt or delayed- in order to determine whether the action will make the society better or worse-off, resilient or non-resilient to climate change. A more progressive adaptation framework for integrated assessment of climate change and vulnerability at national, state and local levels has to be compulsorily included in policy/ strategy towards climate resilient urban development. Networking is a critical requirement for integrated

[37] NAST, 2000. Climate Change Impacts on the United States: The potential Consequences of climate variability and change. A Report on the National Assessment Synthesis Team. US Global Change Research Programme, Washington D.C.

assessment. The NATCOM project has made a beginning where more than a hundred inter-disciplinary research teams spread across the country have been networked together for a shared vision on climate change related research (Shukla et al., 2002). Such initiatives have to be strengthened.

10.5 Key Conclusions

- The existing Central Water Commission (CWC) flood forecasting system seems inadequate because the agency has limited information in terms of rainfall record and not enough inflow data. Modern technology for flood forecasting is developed day by day. It is not clear if the CWC uses recent techniques useful for river monitoring and forecasting system. Moreover, rapid population growth in the region, intensification of agriculture, climate change induced events, changes in land use and river morphology and rapid technology development make it essential to keep upgrading the forecasting system. In the existing system, river is gauged at Kakrapar weir, Mandavi, Ghala , Kathor-Singanpur weir and at Hope bridge. It is suggested to establish more rain gauge stations at Amlidam, Godadha dam, Godsamba village and at Luharpur. All these stations should be interlinked with each other and real time data during critical period should be monitored.
- The analysis under this study shows that west zone and south-west zone are highly flood prone while east zone is least. Topographically, west zone is the lowest zone and hence it has more chances to get flooded severely. As per Town Planning, Rander-Adajan is low rise area in the west zone,. Illegal and unauthorized settlements on the bank of river Tapi are constructed in river flood plains, which can be affected by even a low intensity flood event.
- Due to urbanization, some natural drainage is blocked by constructions. If such constructions are a must, then alternate routes must be provided for natural drainages to flow. Data shows that town growth is observed in the area (mostly sprawling inside the flood plains) and if preventive measures are not taken into account, the death toll due to flood will be increased in future flood events.
- Peak discharge can be reduced in Tapi by diverting some water into other rivers or reservoirs. Hydrological information as presented in this report will be beneficial for policy makers and

modelers in designing strategies for controlling flood hazards. It will be helpful for development of advance flood forecasting system and preparedness of disaster relief packages and therefore should be integrated with the current system, which will in turn reduce flood damages and loss of human lives.

The key conclusions that emerge from the study are as follows:

Firstly, downstream flood inundation models considering the meteorological aspect need to be regularly updated with the changing environmental parameters including land use, urban development and UKAI dam conditions. Detailed modeling of future flood inundation under various hydro-climatic scenarios needs to be explored to assess impacts of climate change on the people and resources.

Secondly, UKAI dam management and its regular situation and forecast reports should be available to all concerned decision makers. A multi stakeholder body should take appropriate action based on the real-time model results.

Thirdly, there should be a risk-based infrastructure and building use planning to minimize the damage cost.

Fourthly, there should be various levels of flood danger mark at the visible places of the city to make the people of the city aware of the impending threat, if any.

Lastly, Surat city has ward level Disaster Management Plan. This plan needs to be taken down to the lowest strata of the society through various means such as drills, education, community involvement, school curriculum, hospital catalogue, etc.

10.6 Way Forward

10.6.1 Urban growth and Climate Change Scenarios for City Development Plan (CDP) and Master Plan:

The urban populations as well as their incomes are expected to grow rapidly over coming decades. The average income of 112 largest cities across India was estimated to be about 66,252 Rs/capita in 2008-09 (Indicus Analytics, 2011). Most of the cities face severe capacity constraints to generate city development scenarios under a rapidly transforming urban economy in the globalized world. This limits more systematic approach to master planning process informed by future growth scenarios. The current master planning process for each area is no longer valid in the current and future urban contexts. Paradigm shift from the conventional population growth rate calculations and archaic (single use) land use planning based master planning process to integrated infrastructure and land use planning optimizing water, energy and land resources as well as services like transportation in the resources, demographic and economic context. Development of such scenarios and exploration of alternate futures would necessitate multi-stakeholder engagement starting from city levels to national level. Enabling environment for such dialogue is slowly emerging with increased focus on urban rejuvenation efforts and investments.

10.6.2 Location and differential exposure:

Since the poor cannot afford to buy land or houses due to high costs, they settle mostly in uncontested areas like river and gully banks, adjacent to railway lines and other unoccupied government/public lands. These are generally higher risk areas and often unsuitable for permanent housing.

More than 40% the slums are located along Nallahs/ drains, along railway lines, on river banks, river beds, and other areas. An estimated 24% of all slums were located along Nallahs and drains and 12% along railway lines. About 22% of slums were located on the fringe or border area of towns and 78% in other areas (NSSO 2009b).

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ANNEXURES:

Annexure-I :

Chapter3: Surat City Profile

Table 3.5: Population and Decadal Growth of Population in Surat City

Year	Population of Surat District	% Decadal variation in Population
1901	6,18,537	6.94
1911	6,61,491	0.38
1921	6,64,032	9.94
1931	7,30,007	20.64
1941	8,80,684	18.66
1951	10,45,005	25.8
1961	13,13,823	35.01
1971	17,86,924	47.83
1981	24,93,211	41
1991	33,97,900	54.3
2001	49,95,174	42.19
2011	60,79,231	42.19

Source: http://www.suratmunicipal.org/content/city/stmt9.shtml; http://censusindia.gov.in/2011-prov-results/prov_data_products_gujarat.html

Table 3.6: Land-use in Surat

S. No	Type of Zone	Area in 1978 (sq km)	%	Area in 1995 (sq km)	%	Area in 2004 (sq km)	%
1.	Residential	26.96	39.96	61.89	46.77	98.06	57.54
2.	Commercial	1.41	2.09	2.56	1.93	4.16	2.44
3.	Industrial	10.06	14.92	27.84	21.04	30.23	17.74
4.	Educational Public Purpose	5.40	8.00	7.35	5.55	5.80	3.40
5.	Recreation, garden and open space	0.22	0.33	0.58	0.44	1.07	0.63
6.	Transport & Communication	7.91	11.72	16.61	12.55	15.61	9.16
7.	Agriculture	15.50	22.98	15.50	11.71	15.50	9.09
Urbanized area		**67.46**	**100.00**	**132.33**	**100.00**	**170.43**	**100.00**
Non-urbanized area		**654.54**		**589.67**		**551.57**	
Total		**722.00**		**722.00**		**722.00**	

Source: City Development Plan (2006-2012, p.17)

Table 3.7: Flood history of Surat City

S.No	Flood Events	Water Level at Hope Bridge (in meters): Danger level 9.5 m	Period
1.	1883	11.05	July
2.	1884	10.05	September
3.	1894	10.33	July
4.	1942	10.56	August
5.	1944	11.32	August
6.	1945	11.09	August
7.	1949	10.49	September
8.	1959	11.55	September
9.	1968	12.08	August
10.	1994	10.10	August-September
11.	1998	11.40	September
12.	2006	12.40	August

Source: Agnihotri & Patel (2008, 117)

Annexure-II

Chapter4: Carrying Capacity of River Tapi at Surat

4.2.1 Theodolite Method

Theodolite is an instrument being used for measurement of horizontal and vertical angles. It in turn helps in locating positions of various points (x,y plane) as well as elevation (z-plane). Therefore, it can be used for finding out river-cross sections; however major limitation being that it is not possible to carry out survey when water is there in the river. The description on measurements has been given below;

Horizontal measurements:

For measuring the horizontal reading of the cross section one theodolite (for width up to 300m) or twin theodolite intersection (for width up to 1200m) methods is generally used. And vertical reading is taken from the staff reading. For the whole survey two theodolites should be set on the both the shores and the ray of the theodolite should be intersected. The angle of the theodolite gives the horizontal reading of the river.

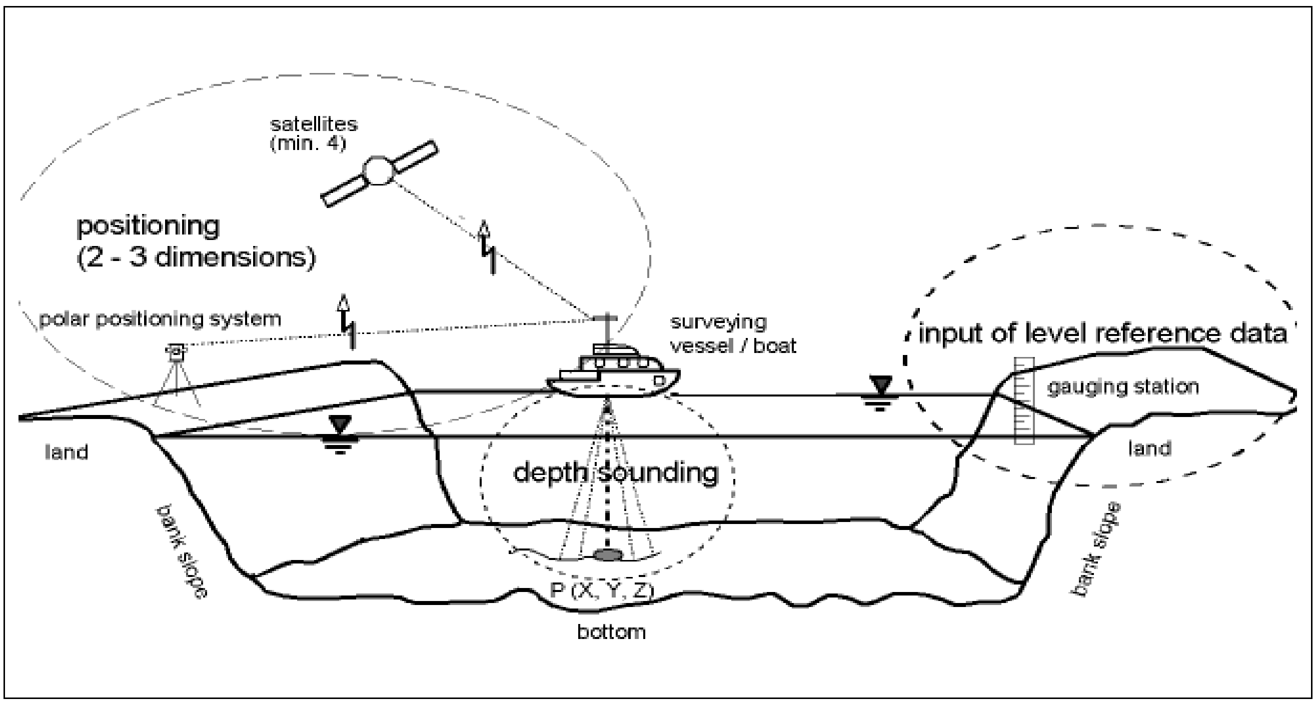
Vertical measurements:

For the vertical readings boats should be used for the staff holding. In the boat staff should be placed at regular interval of in the river and the reading should be noted by theodolite set on the shores. These gives the cross profile of the river at particular point. This method should be repeated at all the selected points.

4.2.2 DGPS and Sounding Method

Differential GPS (DGPS) together with sounding method for hydrographic survey can be an useful tool for carrying out cross-section survey for a river stretch. DGPS is being preferred due to very high accuracy (in mm) which in turn can be useful for accurate computation of discharge. Fig 2.2 shows the procedure consists of setting 2-GPS antenna (one at river bank and other on the boat) and 1-GPS rover (at boat) to start with measurements. The entire set-up works on the principle of triangulation for finding (x,y) coordinates as location while sounding device provides depth of river bed. Boat can be moved in longitudinal or lateral direction and can record depth vis-à-vis river cross section. However expensive, but sounding and DGPS method is very accurate and useful.

Fig4.2: DGPS survey for river cross section



(Source: Behrens, 2001)

Annexure-III

Chapter 5: Mapping of Flood Vulnerable Zones in Surat: Step-1 Terrain Mapping

Terrain Mapping (Digital Elevation Model):

Digital elevation model (DEM) is indispensable for many analyses such as topographic feature extraction, run off analysis, and flood susceptibility analysis and so on. Before hand such analyses, accuracy of DEM must be discussed. The accuracy of DEM is usually represented by spatial resolution and height.

The DEM file also does not contain civil information such as roads or buildings. It is not a scanned image of the paper map (graphic). It is not a bitmap. The DEM does not contain elevation contours, only the specific elevation values at specific grid point locations and delineation of terrain parameters, such as slope, drainage network, watershed boundaries etc. These parameters are often required in the preparation of development and conservation plan for natural resources, infrastructure development, town planning, etc. DEM generated from stereo data has been validated using ground control points (GCPs).

Floods, one of the major geo hazards, always cause a major problem by killing hundreds of people every year besides damaging the properties and blocking the communication links. Most of the terrain in mountainous area dissected rugged topography with highly complicated land use. The most useful direct indicators of flood susceptibility are considered to be evidence of past floods as well as tension cracks and other detectable earth movement. Therefore, the simplest type of flood hazard assessment comprises an inventory of previous floods and signs of mass movement, based on the premise that an area with past floods is flood prone and has a high probability of new floods.

5.2.1 Methodology

The step-wise methodology adopted for the generation of flood simulation, flood mapping and zone-level flood hazard assessment is described below:

Step-1: Collection of high resolution remote sensing images for CARTOSAT 1D

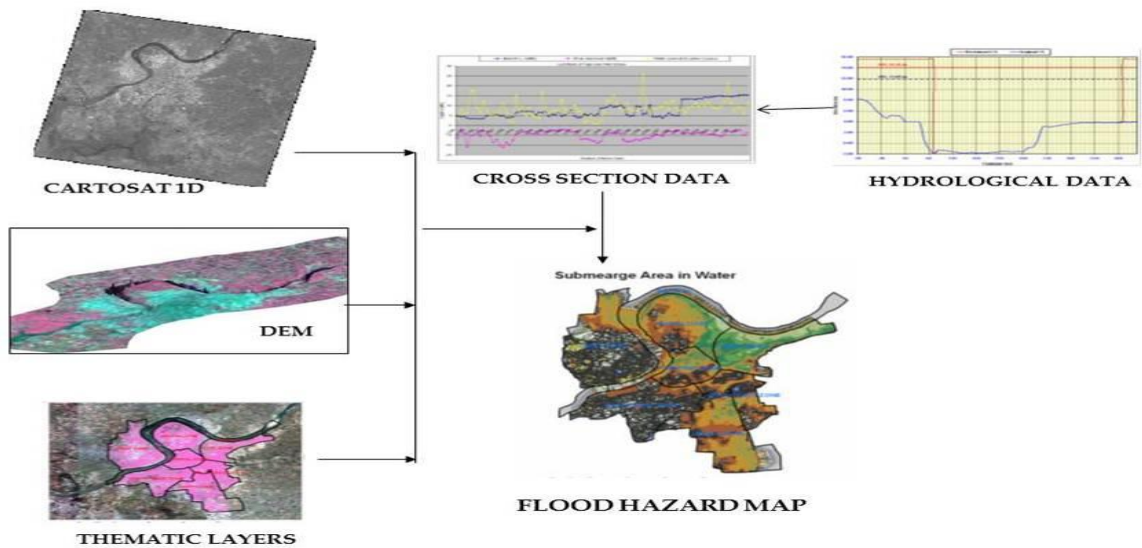
Step- 2: Collation of topographical features such as contours, river channel sections, and water level and discharge data,

Step- 3: Inter-linking of spatial and temporal data using GIS software and customized DBMS tools for DEM creation

Step- 4 Generation of thematic maps and

Step- 5: Analysis of results and delineation of areas under various degrees of floods.

Figure 5.2: Methodology for Flood Hazard Map of Surat City



This methodology has been applied to prepare a flood vulnerability map for Surat city.

5.2.2 DEM Processing

The Digital Elevation Model (DEM) provides a basic spatial reference to the GIS spatial datasets. Images or vector information can automatically be draped over and integrated with the DEM for more advanced analysis. DEMs can be used together with other spatial data, image data in GIS. A GIS is an information system designed to acquire, store, process, manipulate and display data referenced by spatial or geographical coordinates. Based on the Cartosat-1 data of 2.5m resolution supplied by the NRSC, a digital elevation model (DEM) for Surat city has been developed.

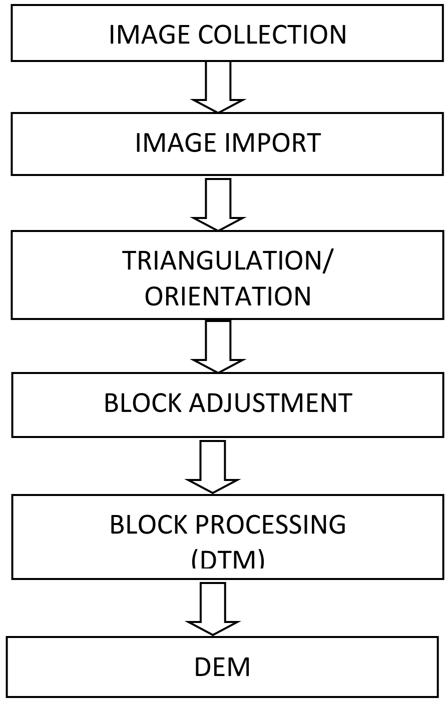


Figure 5.3: Process of DEM Generation (Source: IRADe)

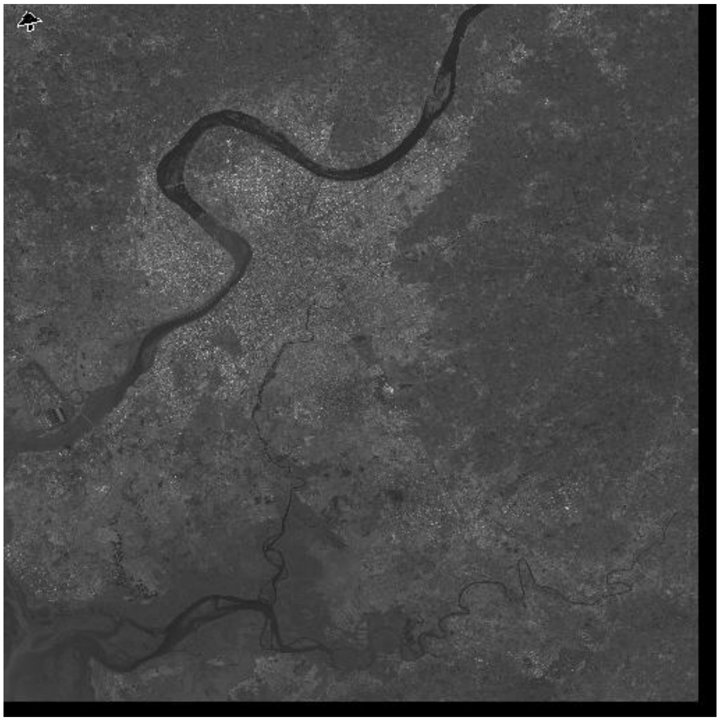
5.2.2.1 DEM Extraction

The DEM has been extracted from the full overlap area available from the Cartosat-1 stereo pairs (Table 1) using the model built from the RPC approach using 6 GCPs per image pair, in the LPS software. The grid size for the DEM generation has been 5m, and is generated for the full overlap of the image pairs. However, the assessment presented here is only for the area for which a reference DEM is available (Figure 5.2).

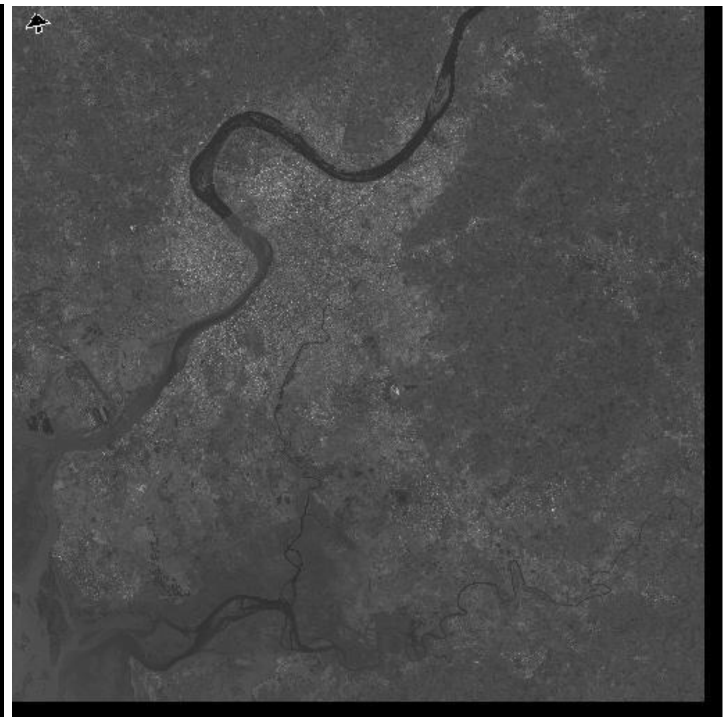
Table 5.1: Details of Cartosat stereo pair used for DEM generation

S. No.	Aft Scenes	Fore Scenes
1.	Satellite ID = CARTOSAT-1	Satellite ID = CARTOSAT-1
2.	Date of Pass = 10APR2008	Date of Pass = 10APR2008
3.	Sensor = PAN_AFT	Sensor = PAN_FORE
4.	Path = 0511	Path = 0511
5.	Row = 0299	Row = 0299
6.	Resolution along = 2.5 m	Resolution along = 2.5 m
7.	Resolution across = 2.5 m	Resolution across = 2.5 m
8.	No. of scans = 12000	No. of scans = 12000
9.	No. of Pixels = 12000	No. of Pixels = 12000

PAN-A

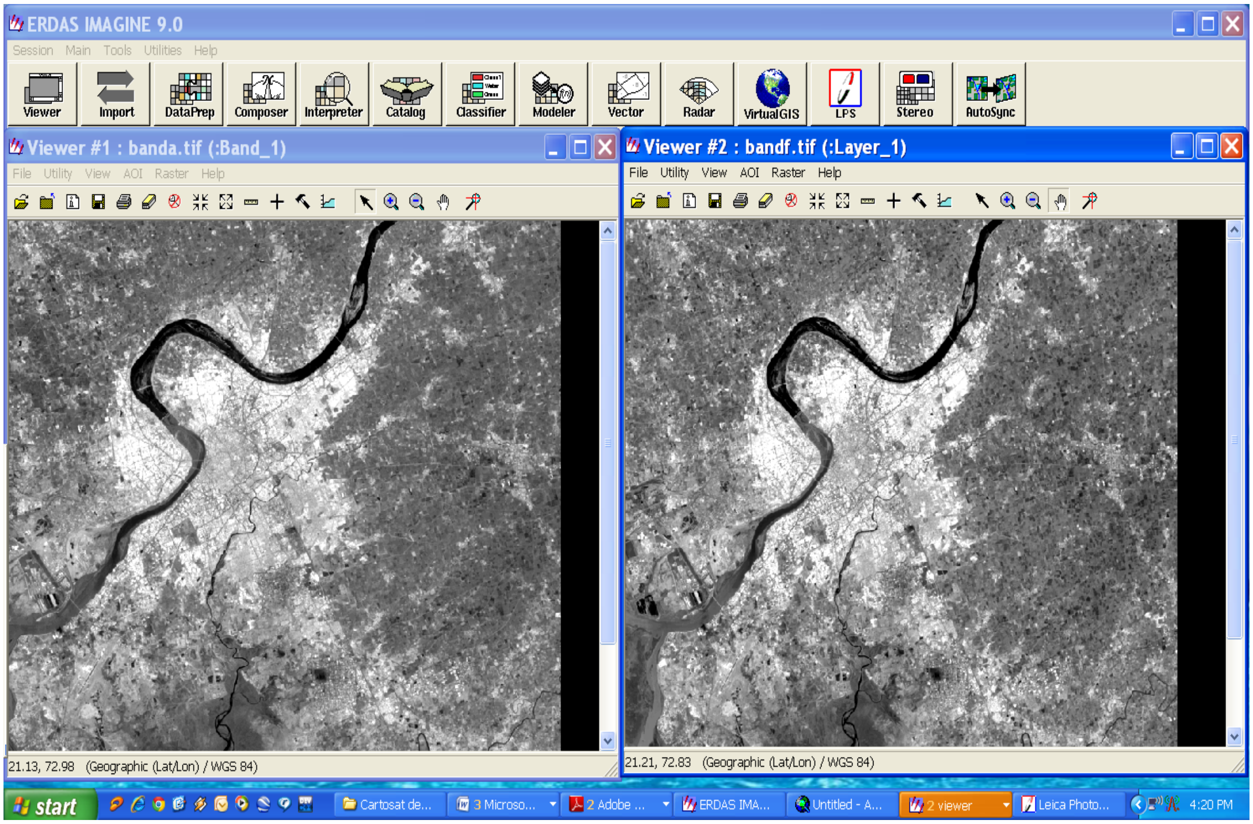


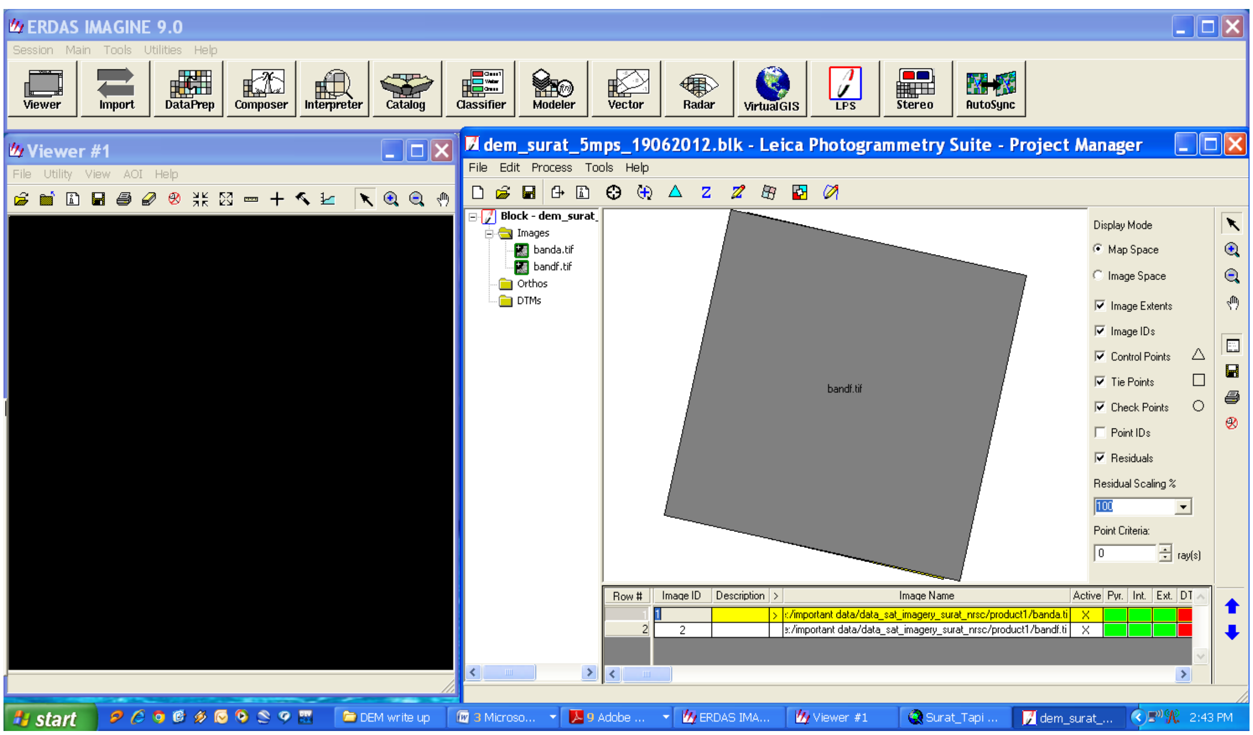
PAN-F



For both image pairs, during the creation of the DEM, all six GCPs and tie points (15 for each image pair) are used as seed vertices. This input enhances the relative position of the DEM generated and improved results. Moreover, all parameters have been carefully set for the stereo-pair images equally (e.g. search area, correlation size, coefficient limit, pixel size, etc.) to avoid that any additional factors influence processing results. Furthermore, no filtering or post-processing of the DEM to change the result of the automatic extraction is applied.

Following are the steps followed during the extraction of DEM through Remote Sensing software ERDAS Imagine with Leica's Photogrammatic Suite (LPS) v9.0 and ESRI's ARCGIS v9.3.


ERDAS IMAGINE 9.0
Session Main Tools Utilities Help
Viewer
Import
DataPrep
Composer
Interpreter
Catalog
Classifier
Modeler
Vector
Radar
VirtualGIS
LPS
Stereo
AutoSync
Viewer #1 : banda.tif (:Band_1)
File Utility View AOI Raster Help
21.13, 72.98 (Geographic (Lat/Lon) / WGS 84)
Viewer #2 : bandf.tif (:Layer_1)
File Utility View AOI Raster Help
21.21, 72.83 (Geographic (Lat/Lon) / WGS 84)
start
4:20 PM


ERDAS IMAGINE 9.0
Session Main Tools Utilities Help
Viewer
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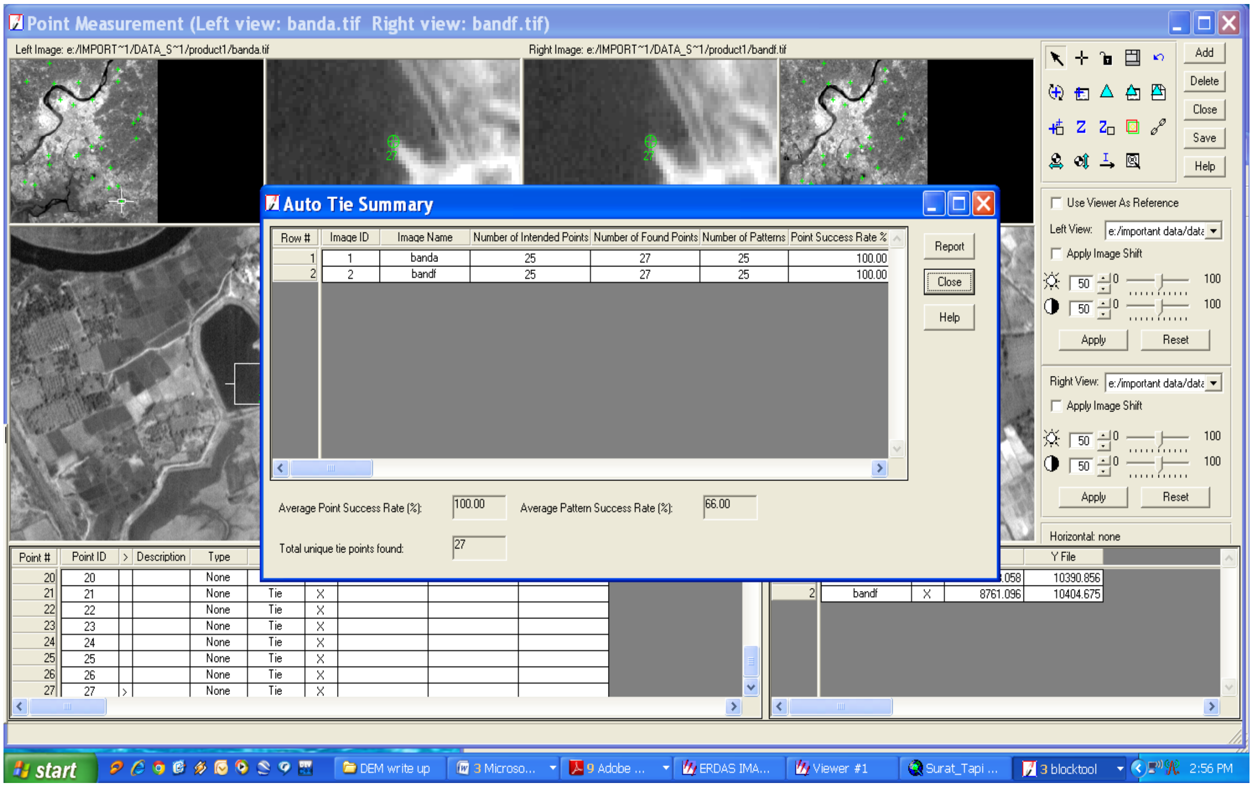
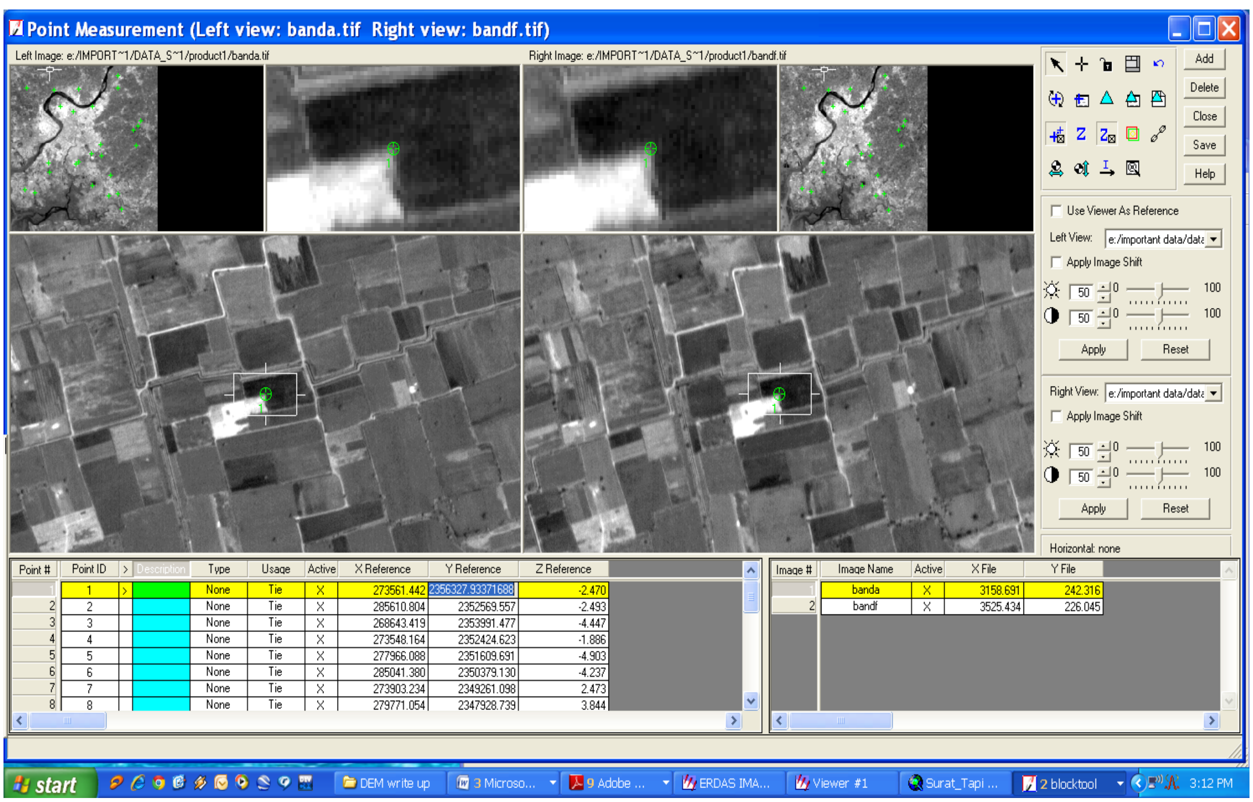
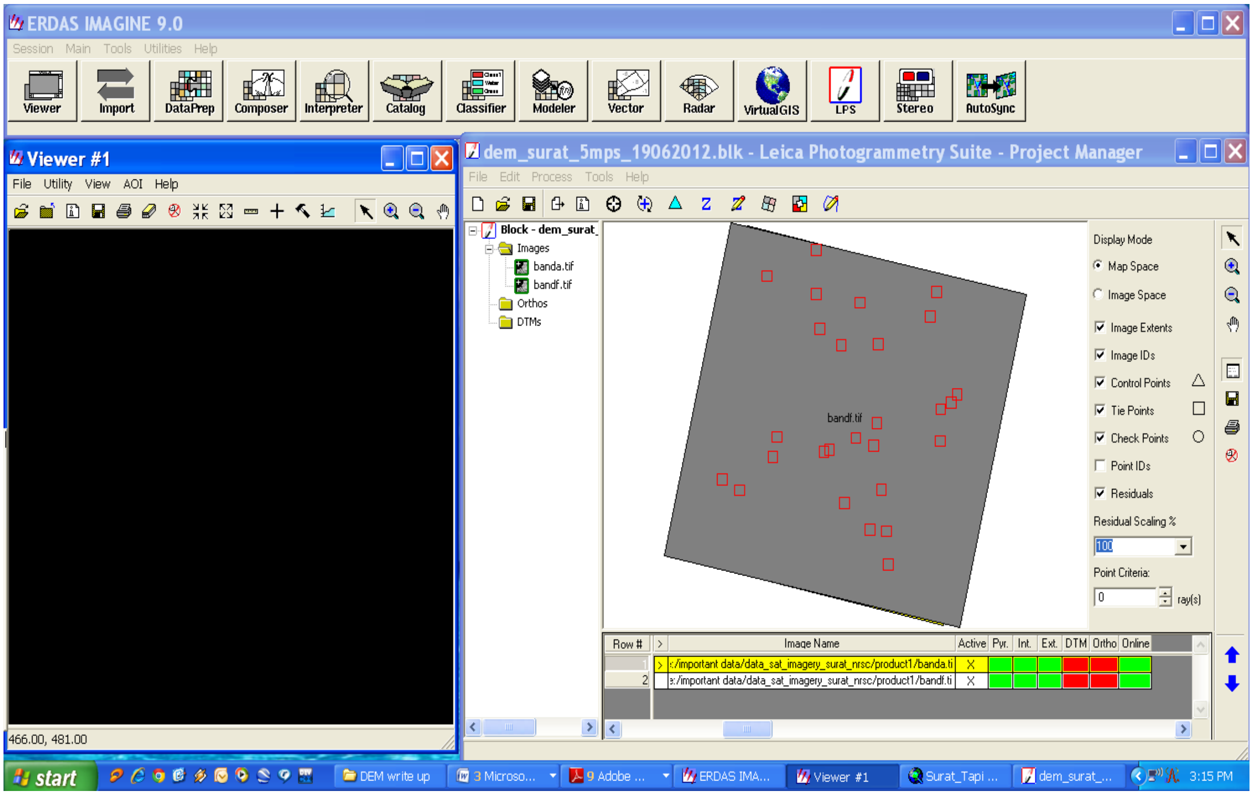
Composer
Interpreter
Catalog
Classifier
Modeler
Vector
Radar
VirtualGIS
LPS
Stereo
AutoSync
Viewer #1
File Utility View AOI Help
dem_surat_5mps_19062012.blk - Leica Photogrammetry Suite - Project Manager
File Edit Process Tools Help
Block - dem_surat_
Images
banda.tif
bandf.tif
Orthos
DTMs
bandf.tif
Display Mode
Map Space
Image Space
Image Extents
Image IDs
Control Points
Tie Points
Check Points
Point IDs
Residuals
Residual Scaling %
Point Criteria:
ray(s)
Row # Image ID Description Image Name Active Pyr. Int. Ext. DT
start
2:43 PM


Point Measurement (Left view: banda.tif Right view: bandf.tif)
Auto Tie Summary
Average Point Success Rate (%): 100.00
Average Pattern Success Rate (%): 66.00
Total unique tie points found: 27


Point Measurement (Left view: banda.tif Right view: bandf.tif)


ERDAS IMAGINE 9.0
Session Main Tools Utilities Help
Viewer Import DataPrep Composer Interpreter Catalog Classifier Modeler Vector Radar VirtualGIS LPS Stereo AutoSync
Viewer #1
File Utility View AOI Help
466.00, 481.00
dem_surat_5mps_19062012.blk - Leica Photogrammetry Suite - Project Manager
File Edit Process Tools Help
Block - dem_surat_
Images
banda.tif
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Orthos
DTMs
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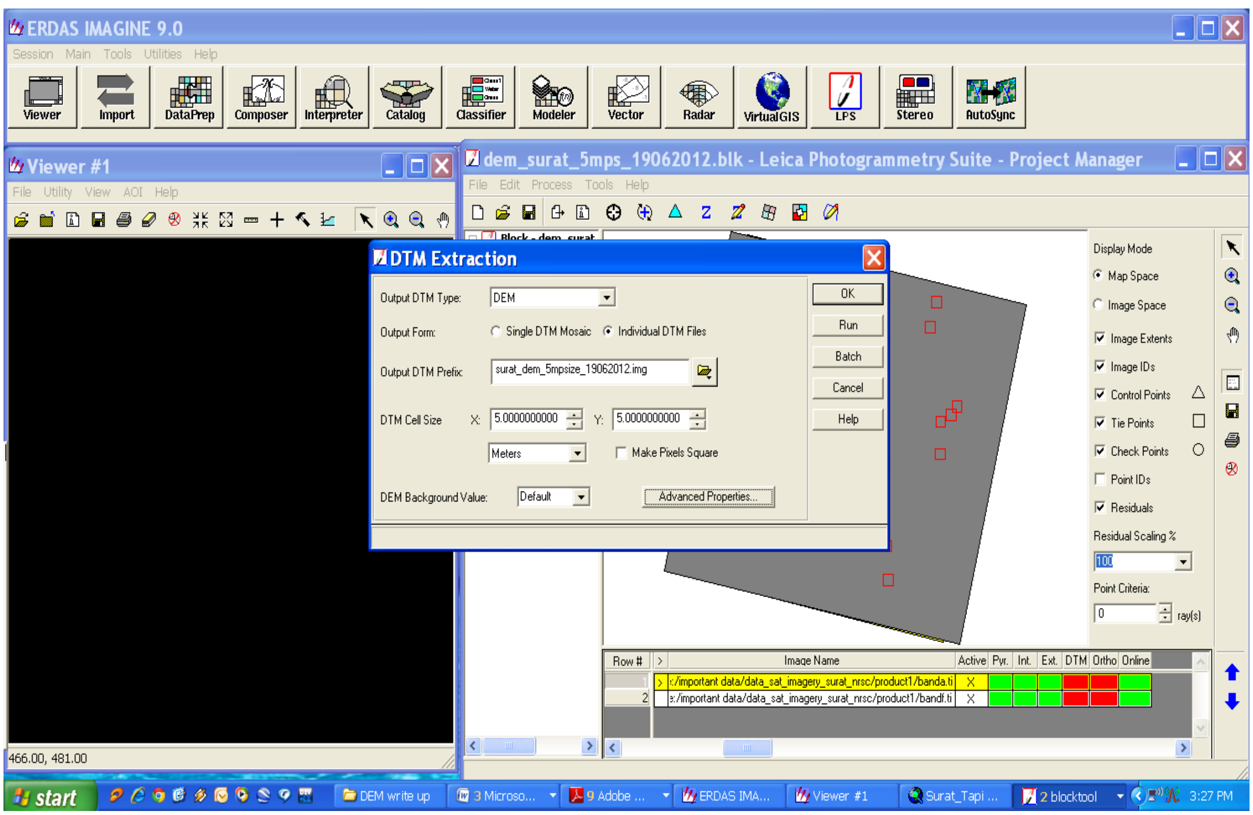
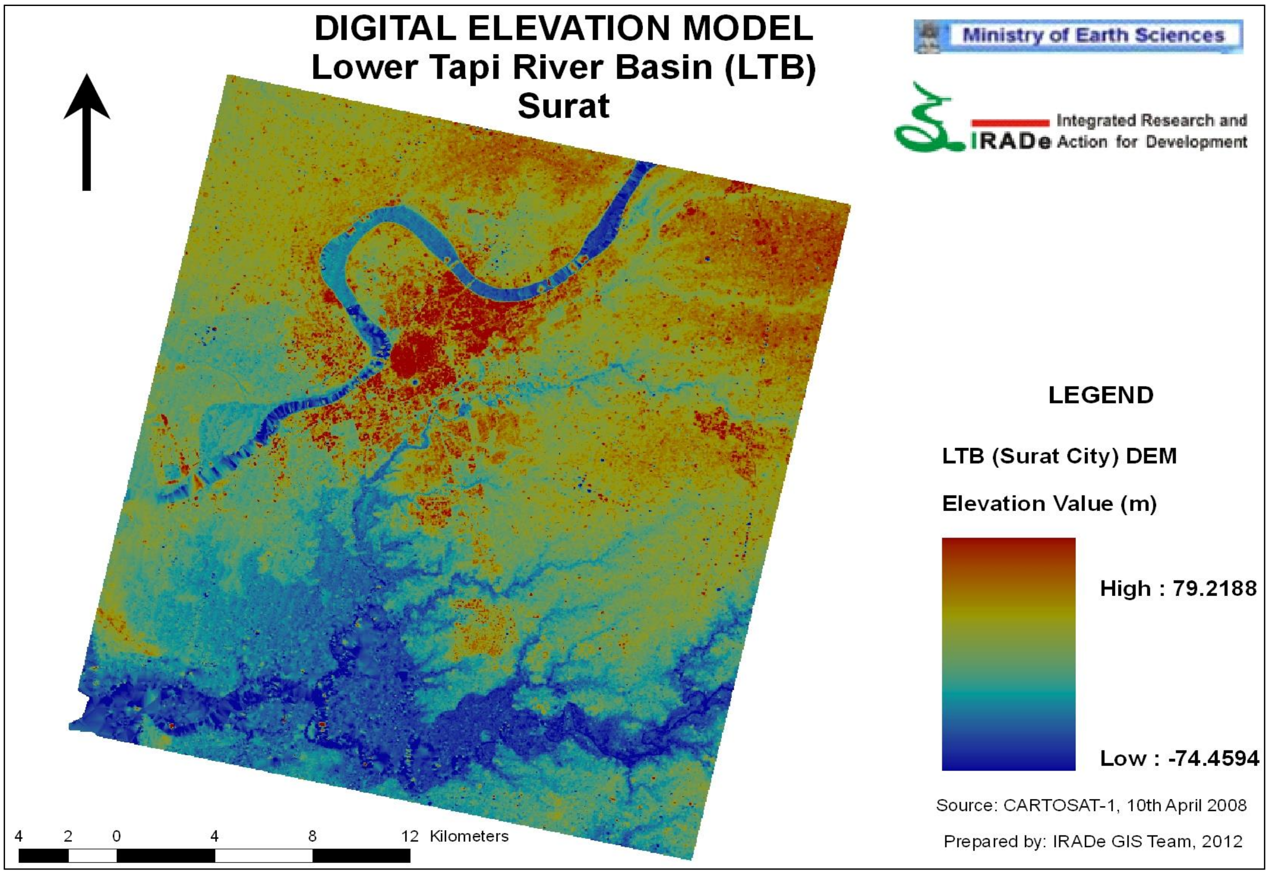
Display Mode
Map Space
Image Space
Image Extents
Image IDs
Control Points
Tie Points
Check Points
Point IDs
Residuals
Residual Scaling %
Point Criteria:
ray(s)
Row # Image Name Active Pyr. Int. Ext. DTM Ortho Online
start
DEM write up
3:15 PM


ERDAS IMAGINE 9.0
Session Main Tools Utilities Help
Viewer Import DataPrep Composer Interpreter Catalog Classifier Modeler Vector Radar VirtualGIS LPS Stereo AutoSync
Viewer #1
dem_surat_5mps_19062012.blk - Leica Photogrammetry Suite - Project Manager
DTM Extraction
Output DTM Type: DEM
Output Form: Single DTM Mosaic Individual DTM Files
Output DTM Prefix: surat_dem_5mpsize_19062012.img
DTM Cell Size X: 5.0000000000 Y: 5.0000000000
Meters
Make Pixels Square
DEM Background Value: Default
Advanced Properties...
OK
Run
Batch
Cancel
Help
Display Mode
Map Space
Image Space
Residual Scaling %
Point Criteria:
466.00, 481.00
start
3:27 PM

5.2.2.2 DEM Assessment

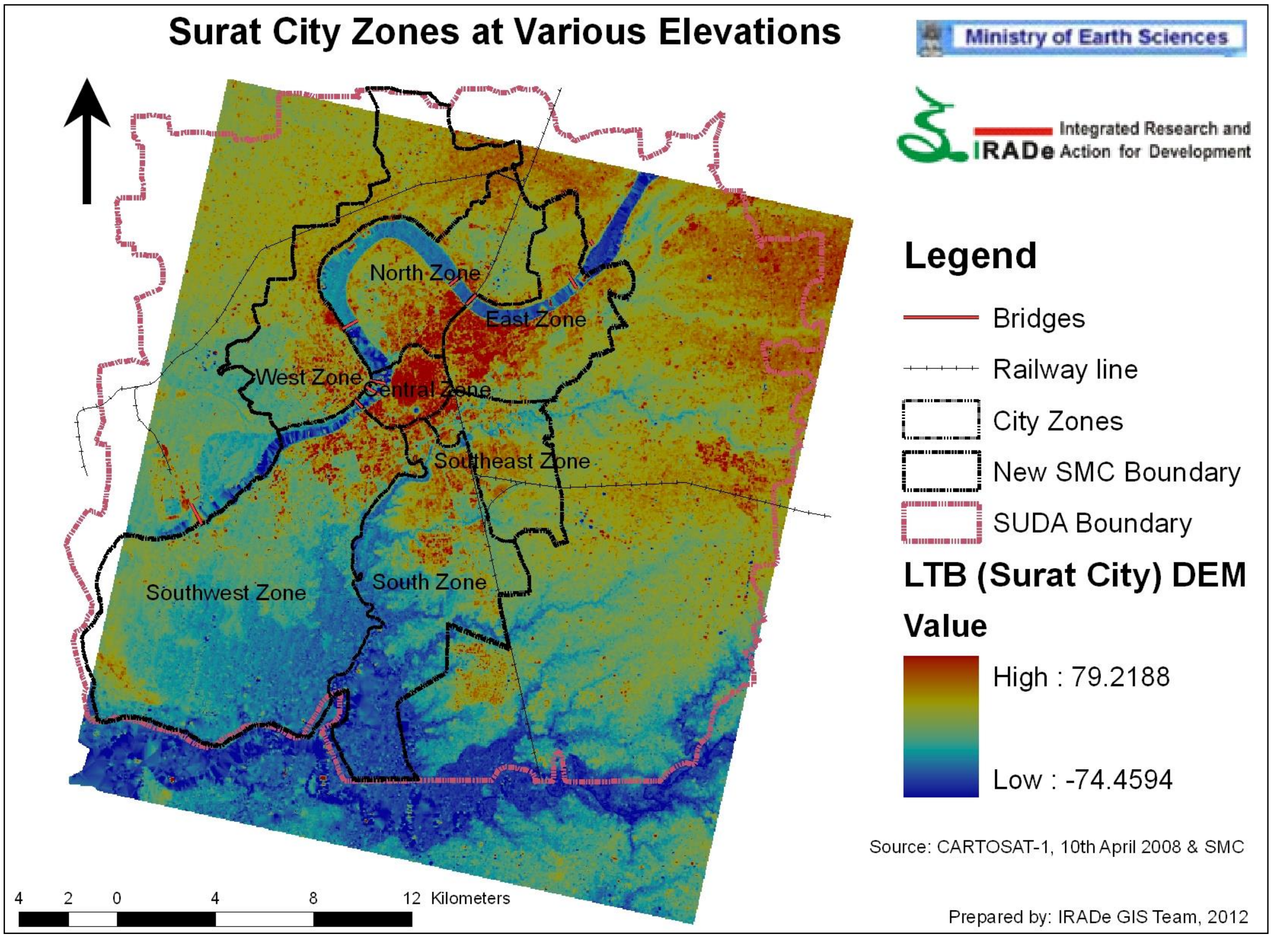
This chapter presents the overall results of the comparison with the higher-grade reference DEM. An automatic “raster to vector” approach (Kay et al, 2005) was applied using bilinear interpolation to determine the elevation of each Cartosat-1 DEM 8x8m cell position in the reference data set. The processing chain delivers the standard deviation and mean of the elevation differences (between the Cartosat-1 DEM point and corresponding interpolated vertex) and stores the raster results for further analysis. (Fig.5.4)

Figure 5.4: DEM of Lower Tapi Basin



As can be seen in Fig.5.4, the DEMs generated from Cartosat-1 image pairs gives clear picture of the topography of the region. As seen in DEM, West zone is low lying area of the city with compared to East zone. There is a significant slope direction found in the city and that is from east to west. DEM shows that west zone is low lying area and its topography varies from 2m to 15m. Major parts of Adajan region lie in the west zone and the region had experienced 2m to 4m water submergence during 2006 floods.

Fig.5.5: DEM of Lower Tapi Basin



Digital representations of landscape topography as digital elevation models (DEMs) incorporate series of reduced level values so that terrain features can be evaluated using specialized numerical algorithms and the GIS visualizations rendered. Landscape features such as slope, aspect, flow length, contributing areas, drainage divides, and channel network can be rapidly and reliably determined from DEMs even for large watersheds (Garbrecht and Martz 1999). Automated extraction of surface drainage, channel networks, drainage divides drainage networks and associated topologic information, and other hydrography data from DEMs has advanced considerably over the past decade and is now routinely a part of most GIS software packages. The automated techniques are faster and provide more precise and reproducible measurements than traditional manual techniques applied to topographic maps. The major issues with DEM-derived hydrographic data are related to the resolution and quality of the DEM and to the derivation of surface drainage. Here, ERDAS Imagine-LPS (Leica Photogrammetic Suit) and ARC GIS software have been used for various feature extraction from DEM.

Step-2 Inundation Mapping of Surat city of three inflow scenarios:

5.3.2 Hydrological Input

Meteorological input is used with the hydrologic model of the lower Tapi basin mainly comprising of Surat city to generate flow input data for hydraulic modelling. Three water discharge scenarios are selected to represent the range of potential impact that varying discharge will have on the basin. The historic scenario, i.e. 2006 conditions, is representing the lower bound of potential change and the other two scenarios i.e. 50% lesser and 50% higher level of 2006 discharge represents the upper bound of potential change.

5.3.3 Preparation of Spatial Data for hydraulic analysis:

A set of tools and utilities provided with the ArcGIS computer package is utilized in the preparation of spatial data for the hydraulic analyses. HEC-GeoRAS is an extension of ArcGIS, which is used for the preparation of spatial data for input into hydraulic model HEC-RAS and the generation of GIS data from the output of HEC-RAS software. These tasks are divided into RAS (River Analysis System) pre-processing and RAS post-processing. The pre-processing starts with the development of a Digital Terrain Model (DTM) in Triangulated Irregular Network (TIN) format. It is followed with the preparation of the following GIS layers: river center line, banks lines, flow paths, cross sections, and bridges. The pre-processing ends with the preparation of the RAS GIS import file for the use with HEC-RAS computer program.

The main post-processing task is automatic delineation of floodplains based on the data contained in the RAS GIS output file and the original terrain TIN layer. The final step involves overlaying the water surface TIN with the terrain TIN to calculate the inundation depths and visualise the floodplain boundaries.

5.3.4 Hydraulic Modelling:

The Hydrologic Engineering Centre River Analysis System, shorter HEC-RAS, (USACE, 2006) is an integrated software system designed to perform one-dimensional water surface calculations. HEC-RAS system is comprised of a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, and graphing and reporting facilities (USACE, 2002 b). HEC-RAS is able to take into consideration hydraulic effects of bridges, culverts, weirs, and other structures in the river and floodplain on water surface calculations.

HEC-RAS takes most of the data through the RAS GIS import file in order to complete the geometric data, hydraulic structure data and flow data input. In the study reported here, the Manning's roughness coefficient values and bridge data are used from the Manning's "N"-value table and

Surat Municipal Corporation (SMC) map data in Auto CAD. Three sets of generated flow data are used for the three. The HEC-RAS computed water surface elevations stored in the RAS GIS export file are used in the floodplain mapping through the post-processing done with the assistance of HEC-GeoRAS.

5.3.5 Project Boundaries:

The spatial extension of the assessment of the project is limited to city of Surat. The study area is determined based on the population and infrastructure threat perception due to the floods. The lower Tapi river enters the city from the eastern side and exits to western side tapering through the northern part of the city. The river finally meets the ocean at the western side of the city. The Tapi river model starts at the downstream cross section, which is located 142.19 m away from the starting of the river to be modelled and the last downstream cross section is located 540.14 m away from the preceding cross section. Almost 34 km length of the lower reach of the river is taken into consideration for the hydraulic modelling study which covers the entire city.

The methodology used in this research work is explained in the part 5.4 of Methodology. The usage of ARC GIS for mapping, HEC GeoRAS for pre-processing and post-processing of data and the HEC RAS for hydraulic modelling are presented stepwise. Some basic concepts and derivations are also presented in this chapter. The results of surface profile of calculations and floodplain mapping are presented further in this chapter. The HEC RAS results have been presented in the tabular format as HEC RAS Report generated by the HEC RAS software. Moreover, the floodplain mapping results are presented as (i) illustrative maps of selected areas, and (ii) maps of locations of special concerns.

5.3.7 Methodology

This chapter explains in detail the methodology applied in floodplain mapping. The process of floodplain mapping is based on the hydraulic calculations of water surface elevations extracted from the CARTOSAT Imagery of the region of 2.5m resolutions. The main objective is to bring the process into digital format for use of software tools for spatial analyses.

Hydrological profiles and flood inundation scenarios of Surat city methods involve:

(i). Review of existing hydrological analysis of Tapi river basin in Surat city

(ii). GIS mapping of Surat including wards and zones

(iii). Contour map of 0.5m and 5m interval based on Cartosat

(iv). Digital Elevation Model (a topographical map of regularly spaced grid of elevation points) (v). Hourly basis Tapi river discharge data from 2006 to 2010

(vi). Rainfall gauge station data of IMD of selected stations from 1973 to 2010

(vii). Inundation/ submergence scenarios with tools like ARC GIS, HEC-GeoRAS, HEC RAS, ERDAS Imagine-Leica Photogrammetric Suit, Auto CAD

(viii). 3 scenarios of submergence:

(A). 2006 Discharge Level (28,000 cu m/s)

(B). 50% lower Discharge of 2006 level

(C). 50% higher Discharge of 2006 level

The methodology used in this research work consists of three steps:

(i) Pre-processing of geometric data for HEC-RAS, using HEC-GeoRAS;

(ii) Hydraulic analysis in HEC-RAS; and

(iii) Post-processing of HEC-RAS results and floodplain mapping, using HEC-GeoRAS.

5.3.7.1 Pre-processing of geometric data:

Further moving towards the pre-processing of geometric data, a framework of ARC GIS and HEC-GeoRAS software is necessitated to be developed for the study. For efficient use of multiple software packages, a very rigorous data preparation procedure is implemented in the study.

5.3.7.2 Generation of Digital Terrain Model (DTM)

The first step in the pre-processing stage is to create a Digital Terrain Model (DTM) of the river system in a Triangulated Irregular Network (TIN) format. The TIN must be constructed with a special care in order to provide for accurate analyses. Elevation data for each cross section is extracted from the TIN. The TIN also serves for determining floodplain boundaries and calculation of inundation depths.

The Digital Terrain Model (DTM) is a representation of the topographical surface in terms of regularly spaced x, y, z, coordinates. The DTM can be developed from a number of sources including ground survey, photogrammetry, surface sensing and cartography. The TIN-based model has a vector-based data structure, but it can be converted into grid cells. In the TIN model, each point has defined x, y, and z coordinates. The coordinate z represents the height. These points are connected by their edges to form a network of overlapping triangles (finite surfaces) that represent the terrain surface (Lo and Yeung, 2005). The basis of TIN-based DTM is that a large series of these finite surfaces, sharing common horizontal edges, can be linked together and used to interpolate the XYZ coordinate of any point, even though actual measurements have not been obtained at that point. The contour lines at an interval of 5m (CNTRLIN.shp) in digital format shape file are used in TIN development. The data source of CNTRLIN.shp is: the CARTOSAT-1 Satellite Imagery of 2.5m resolution. The TIN development process starts by opening a new project in the ArcMap.

The CNTRLIN.shp is added to the map, and Interactive Selection Method “Add to Current Selection” is chosen from the Selection main window in order to create the desired size of the TIN. 3D Analyst Extension (Create/Modify TIN) is then used to complete TIN.

A typical problem in TIN development at a bridge location arises. Such a problem causes inaccurate cross section extraction in that area, as well as a break in floodplain mapping. The TIN Editor Extension is used for a manual TIN editing.

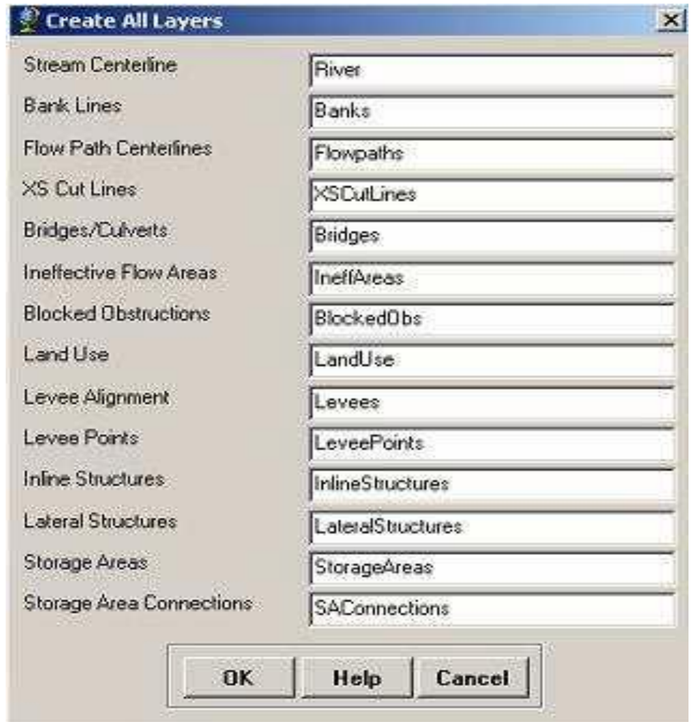
5.3.7.3 Creating of geometric data layers

The empty ArcMap is saved in the working directory and the TIN is added. As a result of this step, the appropriate coordinate system is automatically assigned in the ArcMap for the city of Surat (AOI of Imagery): WGS_1984_UTM_Zone_43N. The main task of the pre-processing is to create the geometry data file for the use with HEC-RAS. The geometry data file contains important information about cross-sections, hydraulic structures, river bank points and other physical attributes of river channels (Merwade, 2006). The pre-processing is done using the HECGeoRAS for creating physical attributes in GIS, and then exporting them to the HEC-RAS geometry file. In HEC-GeoRAS, each attribute is stored in a separate feature class referred to as a RAS Layer (Merwade, 2006). Before creating river attributes in GIS, it is necessary to create empty GIS layers using the RAS Geometry menu on the HEC-GeoRAS toolbar. The RAS layers are created in one step and stored collectively in a GeoDatabase, which HEC-GeoRAS creates automatically. By default, this GeoDatabase is saved under the same name and at the same location as the ArcMap project. The RAS layers are created by selecting from the HECGeoRAS toolbar: “RAS Geometry”→“Create RAS Layers”→“All”.

Figure 5.7 shows all available RAS layers. The following RAS layers are used in this project:

river, banks, flow paths, Xs Cut Lines, and bridges. The following sections explain how each individual RAS layer is created or digitized.

Figure 5.7 Window for selecting RAS layers



Creating river center line: The river center line layer is very important, because it represents the river network for HEC-RAS. Digitizing of the stream center line starts with selecting the sketch tool from the Editor Toolbar, and digitization proceeds in the direction of river flow. Therefore, the process begins at the uppermost end of the stream (defined by the project extent), and ends at the confluence with the coast (or the Surat City boundary). Another rule for creating the river center line is that the stream center line must follow the path of lowest elevation. Therefore, the process of digitizing the river center line cannot rely only on the Imagery only. The elevation from the TIN must be checked, too. Figures 5.8 and 5.9 illustrate

Figure 5.8 Digitizing of river center line using Satellite Imagery

Figure 5.9 Digitizing of river center line using TIN

the process of creating center line at the same location, using satellite imagery and TIN, respectively.

After digitizing all of the reaches, the next task is to name them. Each river in HEC-RAS, as well as each reach within a river, is assigned a unique name. This is accomplished by the selection of Assign RiverCode/ReachCode menu item and assigning appropriate names. The next step is to check that the created reaches are connected (though here we have only one reach), and then to populate the remaining attributes of the river layer. This is accomplished by selecting RAS "Geometry"→"Stream Centerline Attributes"→"Topology". This function is populated by the FromNode and ToNode attribute of the River layer. The Length/Stations fields are populated in a similar way.

Figure 5.10 shows an attribute table for river GIS layer (Lower Tapi). The meaning of each attribute is explained below.

Attributes of River

Shape *	OBJECTID *	Shape_Length	HydroID	River	Reach	FromNode	ToNode	ArcLength	FromSta	ToSta
Polyline	5	33669.413412	5	Tapi River	Lower Reach	1	2	33669.414	0	33669.4

Record: 1 Show: All Selected Records (0 out of 1 Selected) Options

Figure 5.10 Attributes of the river (River Centerline) layer

HydroID is a unique number for a given feature in a geodatabase. The River and Reach attributes contain unique names for rivers and reaches, respectively. The FromNode and ToNode attributes define the connectivity between reaches. ArcLength is the actual length of the reach in map units, and is equal to Shape_Length. In HEC-RAS, distances are represented using station numbers measured from downstream to upstream. For example, each river has a station number of zero at the downstream end, and it is equal to the length of the river at the upstream end. Since the Figure 5.10 shows only one reach for the LTB, the FromSta attribute is zero and the ToSta attribute is equal to the ArcLength.

Creating River Banks: The bank lines layer is used to define river channel from the overbank areas. This definition is important because Manning's n values are different for channel and for floodplain areas. Usually, the overbank areas have higher values of Manning's n due to vegetation or presence of residential areas. Since Manning's n values influence the accuracy of HEC-RAS modeling, this task is very important. The bank lines are created in similar fashion as the river centerline. On the Edit toolbar, select "Editor"→"Start Editing". The task window of the Edit toolbar is set to "Create New Feature" and the target is set to "Banks".

The digitizing of bank lines starts from the upstream end, with the left bank (looking in downstream direction) being digitized first. Since the TIN DTM is used in digitizing of banks lines, river water surface elevation at the moment of taking the satellite imagery may influence the banks line definition.

Creating Flow paths: The flow path layer is a set of lines that follows the center of mass of the water flowing down the river, during the flood event (Meyer and Olivera, 2007). The flow path layer contains three types of lines: centerline, left overbank, and right over bank. For the main channel, the flow path centerline is defined to be the same as the stream centerline. For floodplains, the flow path centerlines are digitized to represent assumed water flow within the

floodplain. The flow path layer is used to determine the length between two neighbouring cross sections (required by HEC-RAS). Flowpath centerlines are also created in the upstream to downstream direction. To create left and right flowpaths, it is necessary to start Editing, and then choose Create New Feature as the Task, followed by Flowpaths as the Target.

By using the Assign LineType button , the Flowpath is labelled Right, Channel, Right looking in downstream direction.

Creating Cross-sections: Cross-sections are one of the most important inputs to HEC-RAS. Cross section cutlines are used to extract the elevation data from the terrain and to create a ground profile across the flow. The intersection of cutlines with other RAS layers such as centerline and flow path lines are used to compute HEC-RAS attributes such as bank stations (locations that separate main channel from the floodplain), and downstream reach lengths (distance between cross- sections).

A significant amount of cross section cut lines are drawn, which show location, shape and length of the cross sections. A few important rules have been followed during the process of drawing cross section cut lines (Meyer and Olivera, 2007):

- Cut lines are drawn perpendicular to the direction of flow. At some locations, “dog-leg” shapes of cross-section are used.
- Cut lines are drawn directionally from left to right bank, looking at downstream direction.
- Cut lines are extended far enough on either side of the channel to encompass the entire portion of the floodplain. Where it is possible, they end at the same elevation at both ends.
- Cut lines do not intersect each other.
- Cut lines are spaced close enough to account for notable changes in the hydraulics or geometry of the stream, such as changes in discharge, slope, cross section shape, roughness or presence of hydraulic structures (bridges, levees, weirs).

- Each bridge intersection requires 4 cut lines, 2 upstream of the bridge and 2 downstream of the bridge. In Figure 5.11, Lc represents the contraction reach length and Le is the expansion reach length (typically, Lc < Le). These distances can be determined with a high degree of accuracy by conducting field investigation during high flows. Since there was no field investigation data, distances between cross-sections 1 and 2 and cross-sections 3 and 4, are determined by examining the TIN to locate the points in the channel where the flow is fully expanded or contracted. Then, cross sections 1 and 4 are located at these points. Cross-sections 2 and 3 are placed within a short distance of the upstream and downstream ends of the bridge. The purpose of placing these cross-sections near the bridge is to capture the natural ground elevations directly next to the bridge. Usually, cross-sections 2 and 3 are drawn at the toe of the bridge embankment on their respective sides of the bridge.

To draw cross sections, it is necessary to start an editing session and select Create New Feature from the Task menu and XSCutLines from the Target menu. The next important step is to populate the attribute table of the XSCutLines feature class, which is digitized.

From the HEC-Geo RAS toolbar, “RAS Geometry” → “XS Cut Line Attributes” → “All” is selected. The pop-up window for populating the attribute table. The drop-down menu is used to select the correct layer name for each item on the list and to populate the attribute table of the XSCutLines feature class. The XS Cut Lines Profiles is a new feature class that is created in the following way: The 2D feature class XSCutLines is intersected with the TIN to create a feature class with 3D cross section. After that, the attribute table and cross sections are examined in order to check their correctness.

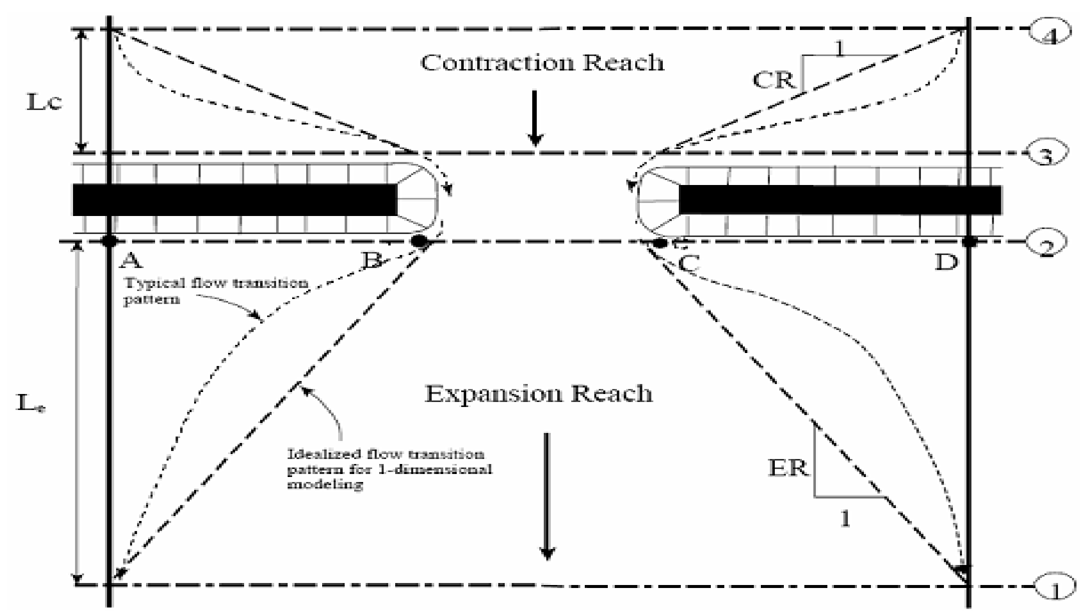


Figure 5.11 Location of bridge cross-sections (after USACE, 2002 b)

Creating Bridges and Culverts: After creating cross-sections, the next step is to define bridges, culverts and other structures along the river. Bridges and culverts are created in a similar way to the cross section layer. From the Editor Toolbar select Create New Feature for the Task and Bridges as the Target. Bridge lines are digitized from the left overbank to the right overbank, looking in the downstream direction. TINs and Satellite Imagery are used to locate each bridge and draw a line along the centerline of the bridge without intersecting the cross sections. The Bridge line is drawn with a high degree of accuracy to ensure that the sectional topography is well represented.

The next step after digitizing the bridges is to label them with the terms as River/Reach, as well as to provide a station number for these features. This is accomplished using the following procedure: "RAS Geometry"→"Bridges" →"River/Reach Names" to assign river/reach names.

The next step is as follows: "RAS Geometry"→ "Bridge/Culverts"→ "Stationing" to assign station numbers. Similar to cross-sections, the Bridges feature class stores 2D polylines, which are converted to 3D by selecting "RAS Geometry"→"Bridge/Culverts"→"Elevations" to create a new 3DBridges feature class. It is necessary to provide deck data for bridges.

5.3.7.4 Exporting GIS Data to HEC-RAS

The last step is to create a GIS import file for HEC-RAS so that it could import the GIS data to create the geometry file. Firstly, it is necessary to define which layers would be exported to HEC-RAS. The tabs "RAS Geometry" →"Layer Setup" are selected from the HEC-GeoRAS toolbar. The Layer Setup window has four tabs: Required Surface, Required Layers, Optional Layers and Optional Tables. The Required Surface option is used for choosing TIN for export.

The Required Layers option is used for entering the River Layer, XSCutLines Layer and XSCutLines 3D Layer. The Optional Layers option is used for entering other RAS layers.

Figure 5.12 shows a typical RAS Layers definition at Optional Layers tab. Other RAS Layers, which are not used in the project, show a Null value. Export of GIS Data is performed in the following way:

The menu item "RAS Geometry"→"Extract GIS DATA" is selected from the HECGeoRas toolbar. The default name GIS2RAS is accepted and saved in Maps folder.

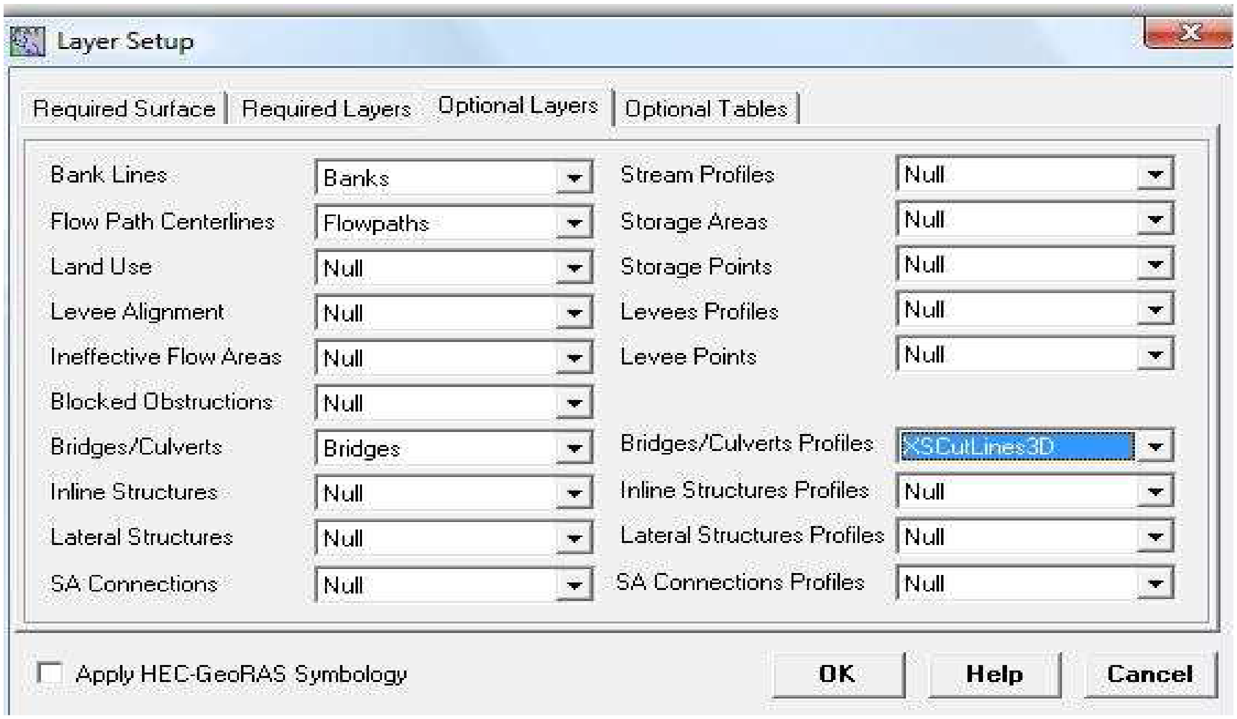


Figure 5.12 Optional Layers definition

5.3.8 Hydraulic analysis:

5.3.8.1 HEC-RAS basic concepts and equations:

HEC-RAS is an integrated software system, designed for interactive use in a multi-tasking environment and used to perform one-dimensional water surface calculations. HEC-RAS system is comprised of a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, and graphing and reporting facilities (USACE, 2002 b). The most recent version of HEC-RAS supports steady and unsteady flow water surface profile calculations, sediment transport computations, and water temperature analysis (USACE, 2002 b).

HEC-RAS is currently capable of performing one–dimensional water surface profile calculations for steady gradually varied flow in natural or constructed channels. It can handle a full network of channels or single river reach. Within steady flow it can be modelled subcritical, supercritical or mixed flow regime. Computation engine of HEC-RAS is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's formula), contraction, and expansion. In cases where the water surface profile is rapidly varied, use of the momentum equitation is necessary. These cases include: mixed flow regime calculations, bridge hydraulic calculations and evaluation of profiles at river confluence. HEC-RAS is capable of calculating effects of bridges, culverts, weirs, and other structures in the river and floodplain. The brief introduction of main concepts and equations used in the study are as follows:

Steady and Unsteady Flow: Flow in an open channel is steady if the depth, discharge, and mean velocity of flow at a particular location does not change with time, or if it can be assumed constant during the time period under consideration. If the depth, discharge and velocity of flow at some point changes with time, the flow is unsteady. A time factor is taken into account explicitly in the case of unsteady flow analysis, while steady flow analysis neglect time factors altogether.

Uniform and Non Uniform Flow: We say that channel flow is uniform if the depth, the discharge and the mean velocity do not change in space. This implies that the energy grade line, water surface elevation and channel bottom are all parallel for uniform flow. This type of flow rarely occurs in reality. Non-uniform flow is sometimes designated as varied flow and can be further classified as gradually varied and rapidly varied. The flow is rapidly varied if the spatial changes to the flow occur rapidly and the pressure distribution is not hydrostatic, otherwise it is gradually varied. Based on these classifications the steady flow can be uniform or varied. The unsteady flow is usually varied, as the unsteady uniform flow is practically impossible, because it would require that the water surface fluctuates from time to time while remaining parallel to the channel bottom (Chow, 1959). The basic assumption of the gradually varied flow computation is that the streamlines are practically parallel and hydrostatic pressure distribution prevails over the channel section. The head loss at a section is the same as with a uniform flow that has the same hydraulic radius of the section. Accordingly, the uniform flow equation may be used to evaluate the energy slope of a gradually varied flow, while the corresponding coefficient of roughness developed primarily for uniform flow is applicable to the gradually varied flow (Chow, 1959). These assumptions are valid for most river flows including flood flows. The assumption of hydrostatic pressure distribution requires the stream to have a small slope of 1:10 or less. Most floodplain studies are performed on streams which meet this requirement (USACE, 2002 b).

Subcritical and Supercritical Flow: The effect of gravity upon the state of flow is defined by a ratio of inertial force to gravitational force as the dimensionless Froude Number.

$$F = \frac{V}{\sqrt{gL}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

where,

F = Froude number (dimensionless)
V = mean channel flow velocity (m/s)
g = acceleration due to gravity (m/s^2) and
L = characteristic length (m).

In open channel flow, the characteristic length is often taken as the hydraulic depth D, which is defined as the cross sectional area channel normal to the direction of flow divided by the width of the free surface. The flow is classified as subcritical, critical or supercritical, depending on the Froude number. When the Froude number is less than 1, the effect of gravitational force is less than the inertial force and the state of flow is referred to as subcritical flow. When inertial and the gravitational forces are equal, the Froude number is equal to unity and the flow is said to be at the critical stage. When the inertial forces exceed the gravitational force, the Froude number is greater than 1, and the flow is referred to as supercritical flow. The flow regime is an important criterion for the calculation of water surface profiles. When the state of flow is subcritical, the state of flow is controlled by channel characteristics at the downstream end of the river reach. In the case of supercritical flow, the flow is governed by the upstream end of the river reach.

Continuity Equation: In the steady open channel flow analysis, the continuity equation states that flow remain constant between adjacent cross-sections.

$$Q = A_1 V_1 = A_2 V_2 \qquad \text{……………………………… (2.2)}$$

Where:

Q = flow rate/discharge (m^3/s)
V_1, V_2 = mean flow velocity (m/s) and
A_1, A_2 = cross-sectional flow area (m^2).
This equation allows tracing of changes in a cross-sectional area and velocity from location to location.

Energy Equation: Gradually varied water surface profiles are based on the principle of the conservation of energy, which states that the sum of the kinetic energy and potential energy at a particular cross section is equal to the sum of the potential and kinetic energy at any other cross section plus or minus energy loss or gains between the sections (Figure 5.13). Water surface is calculated from one cross section to the next by solving the energy equation written as:

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \qquad \text{…………………………………………… (2.3)}$$

where,

Y_1, Y_2 = depth of water at cross sections (m)
Z_1, Z_2 = elevation of main channel inverts (m)
V_1, V_2 = average velocities (total discharge/total flow area)
g = gravitational acceleration
α_1, α_2 = velocity weighting coefficients (dimensionless) and

h_e= energy head loss (m).

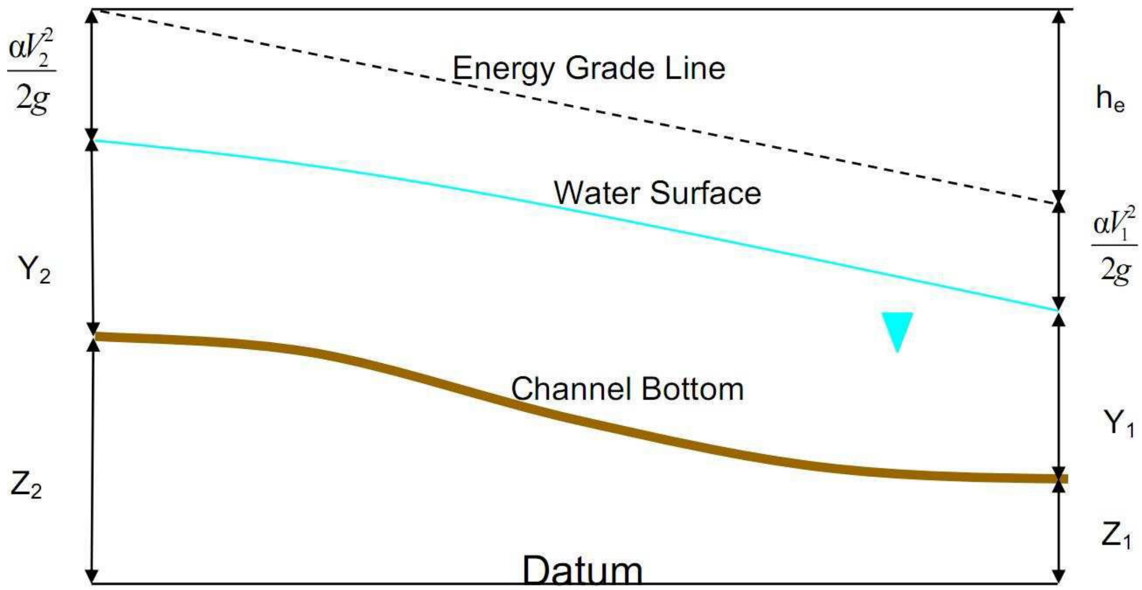


Figure 5.13 Representation of terms in the energy equation (after USACE, 2002 b)

Based on the energy equation, the energy head loss is the sum of friction losses and expansion, or contraction of coefficient.

$$h_e = L\bar{S}_f + C \left| \frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g} \right| \quad \text{………………… (2.4)}$$

where,

L = reach length between the adjacent cross sections
Sf = friction slope between the two sections and
C = expansion or contraction loss coefficient (dimensionless).
The magnitude of α depends upon the channel characteristics. Typical values of α, is shown in Table 5.3.

Table 5.3 Magnitude of α (after Debo and Reese, 2002)

Channel	**Value of α**		
	Min.	Avg.	Max.
Regular Channel	1.1	1.15	1.2
Natural Channel	1.15	1.3	1.5
Natural Channel- flooded overbanks	1.5	1.75	2

Manning's Loss Coefficient. The energy losses due to the roughness of the river bed are usually evaluated in terms of Manning's Equation:

$$Q = KS_f^{1/2} \quad \text{................(2.5)}$$

$$K = \frac{1}{n}AR^{2/3} \quad \text{............................(2.6)}$$

where:

K = conveyance of the section ($m_3 s^{-1}$)
n = Manning's roughness coefficient ($m^{-1/3}s$) and
R = hydraulic radius (m).
Selecting the appropriate Manning's *n* value is very important for accurate computation of water surface profiles. The value of Manning's *n* is highly variable and depends upon a number of factors including: surface roughness, channel irregularities, channel alignment, size and shape of channel, scour and deposition, vegetation, obstructions, stage and discharge, seasonal change, temperature, suspended materials and bed load (USACE,2002 b). The *n* value decreases with increases in stage and discharge. When the water depth is shallow, irregularities of the channel bottom are exposed and their effect may become pronounced. However, the *n* value may be large at high stages if the banks are rough and grassy (Chow, 1959).

If there is observed water surface data (high water marks, gagged data), Manning's *n* values should be calibrated. If there is no observed data (like in this study), then values of *n* obtained from another stream with similar conditions should be used. There are several references available listing the typical *n* values. Excerpts of the n value from Chow (1959) for natural streams are given in the Table 5.4.

Table 5.4 Manning's *n* values (Chow's)

Type of Channel and Description	Minimum	Normal	Maximum
A. *Natural Streams*			
1. **Main Channels**			
a. Clean, straight, full, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as "d" but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.070	0.100	0.150
2. **Flood Plains**			
a. Pasture no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
2. Same as above, but heavy sprouts	0.050	0.060	0.080
3. Heavy stand of timber, few down trees, little undergrowth, flow below branches	0.080	0.100	0.120
4. Same as above, but with flow into branches	0.100	0.120	0.160
5. Dense willows, summer, straight	0.110	0.150	0.200
3. **Mountain Streams, no vegetation in channel, banks usually steep, with trees and brush on banks submerged**			
a. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. Bottom: cobbles with large boulders	0.040	0.050	0.070

Table 5.4 Manning's *n* values-continued

Type of Channel and Description	Minimum	Normal	Maximum
B. *Lined or Built-Up Channels*			
1. **Concrete**			
a. Trowel finish	0.011	0.013	
b. Float Finish	0.013	0.015	0.015
c. Finished, with gravel bottom	0.015	0.017	0.016
d. Unfinished	0.014	0.017	0.020
e. Gunite, good section	0.016	0.019	0.020
f. Gunite, wavy section	0.018	0.022	0.023
g. On good excavated rock	0.017	0.020	0.025
h. On irregular excavated rock	0.022	0.027	
2. **Concrete bottom float finished with sides of:**			
a. Dressed stone in mortar	0.015	0.017	0.020
b. Random stone in mortar	0.017	0.020	0.024
c. Cement rubble masonry, plastered	0.016	0.020	0.024
d. Cement rubble masonry	0.020	0.025	0.030
e. Dry rubble on riprap	0.020	0.030	0.035
3. **Gravel bottom with sides of:**			
a. Formed concrete	0.017	0.020	0.025
b. Random stone in mortar	0.020	0.023	0.026
c. Dry rubble or riprap	0.023	0.033	0.036
4. **Brick**			
a. Glazed	0.011	0.013	0.015
b. In cement mortar	0.012	0.015	0.018
5. **Metal**			
a. Smooth steel surfaces	0.011	0.012	0.014
b. Corrugated metal	0.021	0.025	0.030
6. **Asphalt**			
a. Smooth	0.013	0.013	
b. Rough	0.016	0.016	
7. **Vegetal lining**	0.030		0.500

Table 5.4 Manning's *n* values-continued

Type of Channel and Description	Minimum	Normal	Maximum
C. *Excavated or Dredged Channels*			
1. **Earth, straight and uniform**			
a. Clean, recently completed	0.016	0.018	0.020
b. Clean, after weathering	0.018	0.022	0.025
c. Gravel, uniform section, clean	0.022	0.025	0.030
d. With short grass, few weeds	0.022	0.027	0.033
2. **Earth, winding and sluggish**			
a. No vegetation	0.023	0.025	0.030
b. Grass, some weeds	0.025	0.030	0.033
c. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
d. Earth bottom and rubble side	0.028	0.030	0.035
e. Stony bottom and weedy banks	0.025	0.035	0.040
f. Cobble bottom and clean sides	0.030	0.040	0.050
3. **Dragline-excavated or dredged**			
a. No vegetation	0.025	0.028	0.033
b. Light brush on banks	0.035	0.050	0.060
4. **Rock cuts**			
a. Smooth and uniform	0.025	0.035	0.040
b. Jagged and irregular	0.035	0.040	0.050
5. **Channels not maintained, weeds and brush**			
a. Clean bottom, brush on sides	0.040	0.050	0.080
b. Same as above, highest stage of flow	0.045	0.070	0.110
c. Dense weeds, high as flow depth	0.050	0.080	0.120
d. Dense brush, high stage	0.080	0.100	0.140

There are various methods and empirical formulae available for the estimation of the Manning's *n* value. Cowen (1956) developed a procedure for the estimation of formula for *n* as a function of type and size of the bed materials and channel properties. In Cowen's procedure, the *n* value is determined by the following equation:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)\, m \quad \ldots\ldots\ldots\ldots\ldots(2.7)$$

where,

n_b = base value of *n* for straight uniform & smooth channel in natural materials

n_1 = value added to correct surface irregularities

n_2 = value for variation in size and shape of channel

n_3 = value for obstructions

n_4 = value for vegetation and flow conditions and

m = correcting factor to take account of the meandering of channel.

Limerinos (1970) related the *n* related value as the function of bed materials and hydraulic radius:

$$n = \frac{0.0926R^{-0.16}}{1.16 + 2\log\left(\frac{R}{d_{e4}}\right)} \qquad \text{..................(2.8)}$$

where,

R = hydraulic radius (feet) and

d_{e4}= particle size diameter that is equal to or exceeds 84% of particle (feet).

Limerinos selected the reaches that had a minimum amount of roughness that were caused by factors other than the bed materials, and so these base *n* values should be increased to take account of other factors as shown in Cowen's method (USACE, 2002 b).

Expansion and Contraction Coefficients: The following equation is used for the determination of contraction and expansion losses.

$$h_{ce} = C\left|\frac{\alpha_1 V_1^2}{2g} - \frac{\alpha_2 V_2^2}{2g}\right| \qquad \text{....................... (2.9)}$$

where: C= the contraction or expansion coefficient.

The coefficient of expansion and the coefficient of contraction are introduced to take into account losses due to the expansion or contraction of flow caused by changes in the cross sections. The losses due to these fluctuations are significant, particularly at points where there is an abrupt change in the cross section viz, at bridges. Typical values of expansion and contraction coefficients for subcritical flow are given in Table 5.5.

Table 5.5 Subcritical Flow Expansion and Contraction Coefficient (USACE, 2002 b)

Type of Channel	Contraction	Expansion
No transition	0.00	0.00
Gradual transition	0.10	0.30
Typical bridge sections	0.30	0.50
Abrupt transition	0.60	0.80

Friction Loss Evaluation: Manning's equation is used for the calculation of energy slope as follows:

$$S_f = \left(\frac{Q}{K}\right)^2 \qquad \text{................... (2.10)}$$

There are also a few other alternative expressions for the representation of reach friction slope in HEC-RAS computer program.

5.3.8.2 Computation method:

The method of computation of water surface profiles for gradually varied flow is based on the assumption that the slope of the energy grade line at a section is equal to the energy slope for a uniform flow with the velocity and hydraulic radius of the section (Chow, 1959). Some of the basic steps in the computation of water surface profiles in HEC-RAS are explained below.

Cross Section Subdivision for Conveyance Calculations. The determination of the conveyance coefficient in HEC-RAS involves subdivision of flow into units based on Manning's coefficient *n* (Figure 2.9). The conveyance for each subdivision is calculated by using Equation (2.6). The total conveyance for the cross section is obtained by adding the three subdivision conveyances (left, channel, and right).

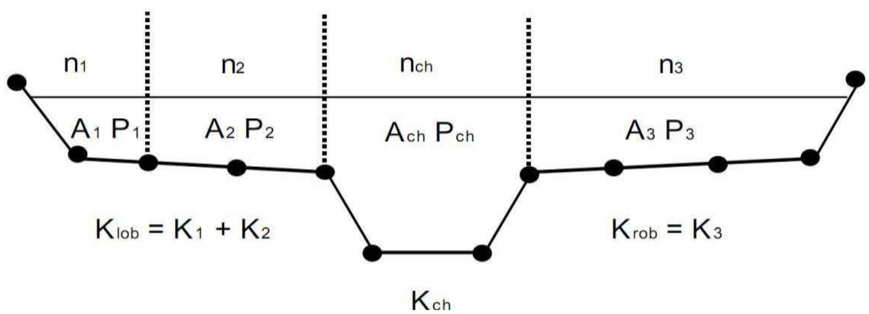


Figure 5.14 Conveyance Subdivision Method (after USACE, 2002 b)

Mean Kinetic Energy Head Calculation: Mean kinetic energy head for each cross section is obtained by computing the flow weighted kinetic energy heads for three subsections of the cross sections (main channel, right and left overbank). Figure 2.10 illustrates the mean kinetic energy calculation process for the cross section with the main channel and the right overbank.

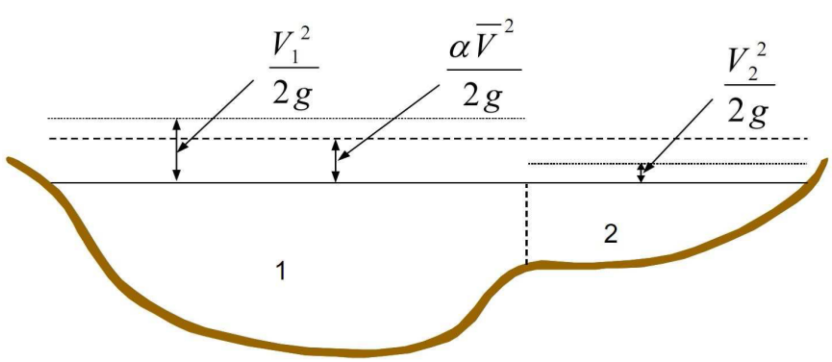


Figure 5.15 Example of Mean Energy calculations (after USACE, 2002 b)

V_1 is mean velocity for the main channel and V_2 is mean velocity for the right overbank. The calculation of the mean energy head requires the velocity weighing coefficient α.

Standard Step Method: The Standard Step Method can be used for both prismatic and non-prismatic channels, including the adjacent floodplain. This method can be applied to compute steady, gradually varied flow, and can also be used for both subcritical and supercritical flow. The computation for this method is based on the energy Equation (2.4) by steps from station to station. Depending upon the conditions of flow (subcritical or supercritical), the computations must be made in different directions. For subcritical flow that is under downstream control, the computation starts from downstream and proceeds upstream. For supercritical flow that is under upstream control, the computation starts from upstream and proceeds downstream. The computation steps used in this procedure for the subcritical flow are as follows (USACE, 2002 b):

1. Assume the water surface elevation at the upstream cross section.

2. Based on the assumed water surface elevation, determine the corresponding total conveyance and velocity head.

3. With values from step 2, calculate the frictional slope *Sf* and solve Equation (2.4) for energy head loss (*he*)

4. With values from steps 2 and 3, solve Equation (2.3) for water surface elevation WS2.

5. The computed value of WS2 is compared with the assumed value in step 1, and steps 1 through 5 are repeated until the values agree with the predefined tolerance (.003 m).

5.3.8.3 Step by step modelling using HEC-RAS:

The following section presents brief methodology adopted for the use of HEC-RAS program for computation of water surface profiles. The main objective of this step by step modeling discussion here is to provide assistance to those who may not be familiar with the HESC-RAS modelling.

Creating HEC-RAS project and importing geometry: The initial step for using this program involves opening of the main HEC-RAS interface window and entering the title and file name.

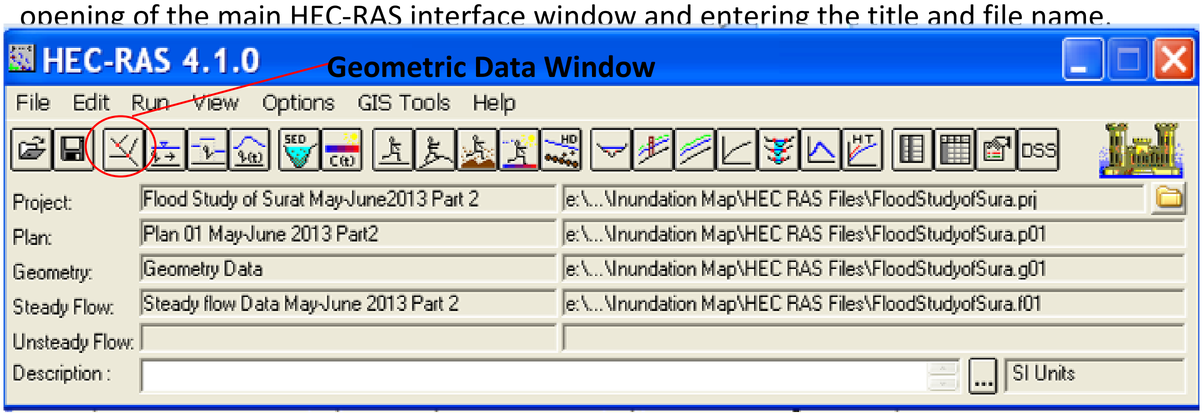
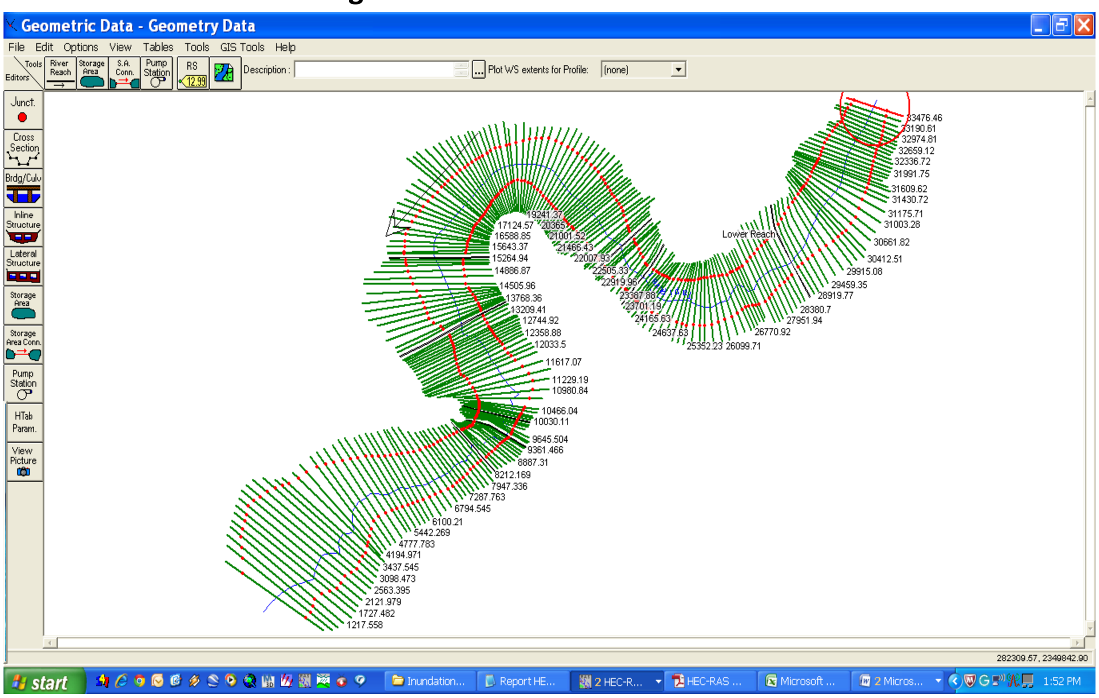


Figure 5.16 The main HEC-RAS window with the title and file name

The Geometric Data Window opens from the main HEC-RAS user window. To enter the geometry select: “File” → “Import Geometry Data” → “GIS Format” → “Browse for Desired RAS GIS Import File (GIS2RAS.RASImpor.sdf)”. Firstly, from the Import Options window, SI (metric) units are selected. Then, “River and Reach Stream Lines” are selected. Cross sections and bridges for importing are checked by selecting tab “Cross Sections and IB Nodes” (Figure 5.16). The Geometry Data are saved in the Geometric Data window. Figure 5.17 shows the Geometric Data window with the geo-referenced river system.

The next step involves the use of Cross Section Points Filter, because some cross-sections may have duplicate points or a high number of points (over 500). “Tools” and then the “Cross Section Points Filter” are selected from the Geometric Data window. For all rivers and tributaries, cross sections were filtered to 250 points.

Figure 5.17 Geometric data window



The following sections describe steps and adjustments performed for geometric data completion.

Manning’s n values: Manning’s n values are part of the Geometry data required for HECRAS modelling. In some cases, a horizontal variation in *n* values is used to increase accuracy for Manning’s value. For this study, Manning’s *n* values are adopted based on Chow (1959). For residential areas, n = 0.08 - 0.12 is used, for open water bodies, n= 0.035, for commercial areas, n=0.12, for urban areas, n=0.05, for open space, n=0.04, and for industrial areas, n = 0.1.

Bridge data: The main source for Bridge Data (Deck/Roadway Data) is the data from Surat Municipal Corporation (SMC) and Google Earth. The appropriate placing of bridge cross-sections (four for each bridge) is explained in the pre-processing section. The bridge bounding cross-sections 2 and 3 are shown in Figure 2.13, below.

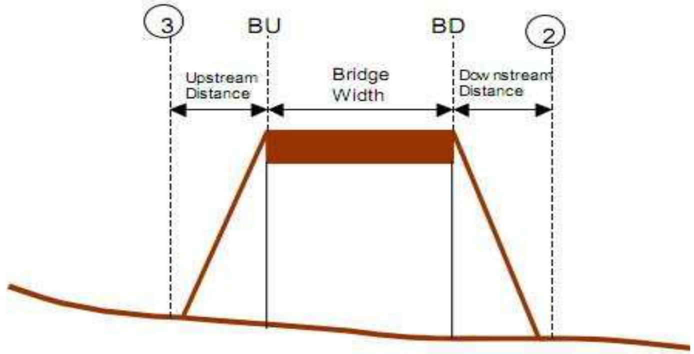


Figure 5.18 Bridge bounding cross sections (after USACE 2006)

HEC-RAS automatically adds two more cross sections, immediately inside the upstream (BU for bridge upstream) and downstream (BD for bridge downstream) bridge faces.

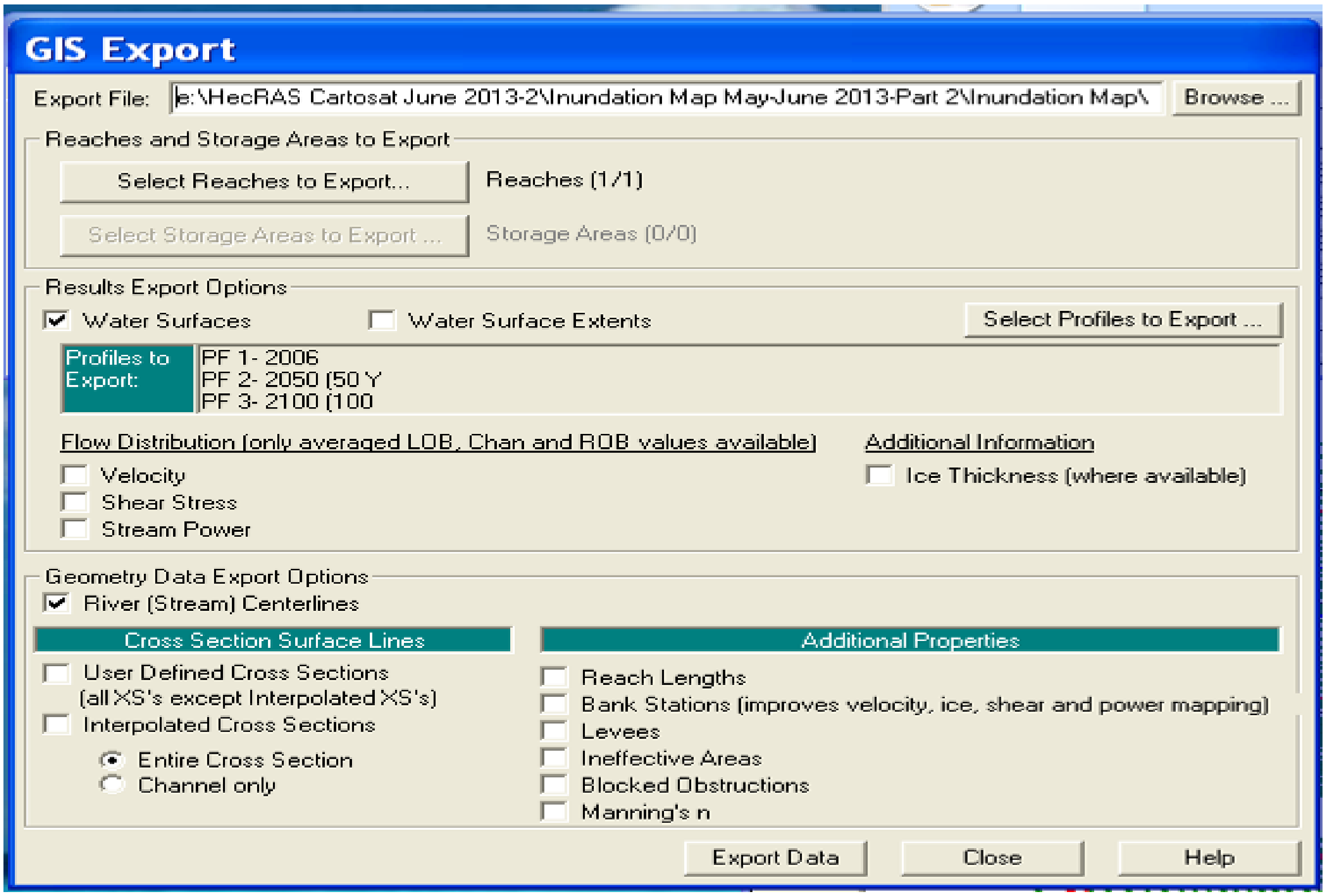
Flow data and boundary conditions: The hydraulic analysis is performed using flow data for three discharge scenarios. For all three scenarios, steady flow data are entered for the three flow scenarios.

The highest most discharge in a year at UKAI dam has been taken into consideration for this study as the Surat city gets water flow in Tapi River mainly from this dam. Discharge water in the river for the city is closely monitored here at the UKAI dam. For this particular study, flow changes (Discharge) are entered at the locations from where our study starts for HEC-RAS modelling.

Since very limited observed flow data (Known Water Surface) is available, it is very important to choose appropriate Steady Flow Boundary Conditions. Usually, if there is no observed data, the normal depth is used. In this study we have used "Normal Depth" approach for setting the boundary conditions. For this type of boundary conditions, where the energy slope is unknown, the approximate value has been taken into consideration by entering either the slope of the water surface or the slope of the channel bottom. Here, we have entered 0.001 for Normal Depth 'S' for all the profiles. The HEC-RAS model for Surat city is long enough (about 35 km) so the influence of boundary conditions at the first cross section do not affect the upstream results.

HEC-RAS computation and data export: After the geometric data is completed and the steady flow data and new boundary conditions are entered, the HEC-RAS system is executed for the subcritical flow profile. The output results are checked for hydraulic correctness. The final step involves export of the computation results (water surface elevation) back to GIS. The following computational steps are used from the main HEC-RAS window: "File" → "Export GIS Data". In the GIS export window, all three profile results (for the three flow scenarios) are selected and exported using the default format "RASexport.sdf". Figure 5.19 shows the GIS Export window and the selected profiles used for export.

Figure 5.19 GIS export window in the HEC-RAS



5.3.9 Post-processing of hydraulic results and floodplain mapping:

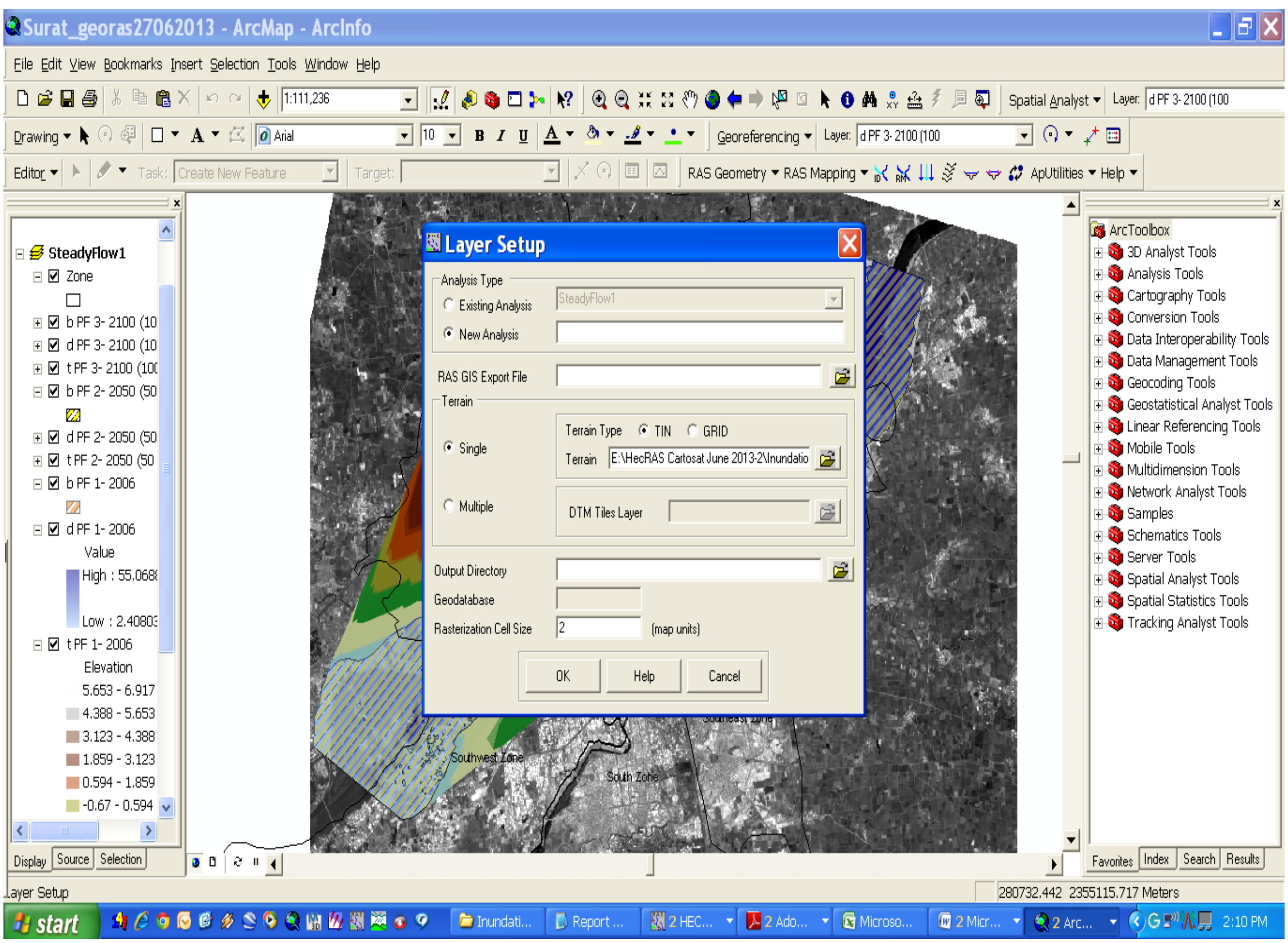
The post-processing of computation results is performed using the same maps which are used for the pre-processing of geometry data. The only additions to these maps are new map layers. Due to the large area covered by the Lower Tapi River (within the city), its post-processing is quite complicated and requires the creation of a very large TIN. Hardware limitations (when using resolution of 2 map units) required floodplain mapping of the Lower Tapi River to be done using two maps. Detailed explanation of the data post-processing is being discussed in the following paragraphs.

5.3.9.1 Data import from HEC-RAS:

Formatting: The process starts with opening a desired ArcMap (which has been used earlier) for post-processing. Since the HEC-GeoRAS cannot read the proprietary spatial data format (.RASExport.sdf) file created in the HEC-RAS, it is necessary to convert it into the XML file format, supported by HEC-GeoRAS. This is achieved by selecting the "Import RAS SDF File" option from the HEC-Geo RAS Toolbar.

Layer setup: Establishing the Layer Setup is a necessary step for processing the HEC-RAS results. In the Layer Setup window, the type of analysis and the input and output data are identified. Figure 5.20 shows a typical Layer Setup window from the data post-processing. For the post-processing analyses, the rasterization cell size is set to 2 map units. Basically, a smaller number of map units results in a better representation of the resulting floodplain boundary during the floodplain delineation. However, the program is not able to handle higher resolution, and thus, two map units are used as the best possible rasterization cell size.

Figure 5.20 Layer setup Window



Reading RAS GIS export file: After input data is entered in the layer setup, the HEC-RAS results have to be imported into the GIS in order to continue with the post-processing. The following computational steps are selected from the HEC-GeoRAS toolbar: "RAS Mapping" → "Read RAS GIS Export File". This selection introduces a new data frame with the following feature classes: River2D, XS Cut Lines, and Bounding Polygon.

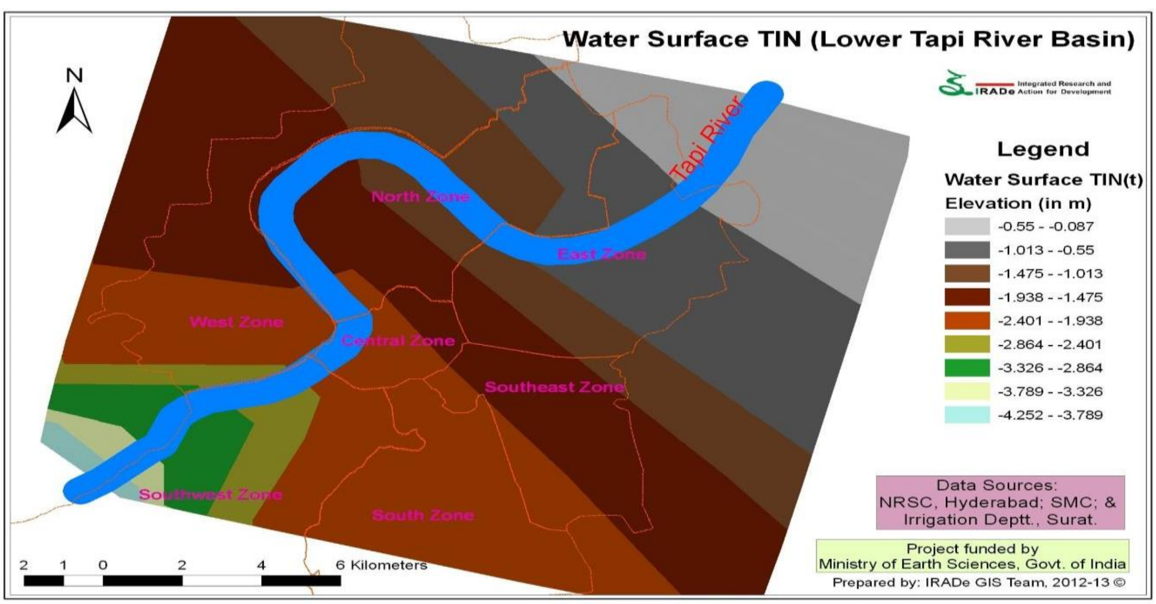
5.3.9.2 Floodplain mapping:

Floodplain mapping is performed using the water surface elevations on the XS cut lines, within the limits of the bounding polygon. Floodplain mapping is completed in two steps, which are explained in following paragraphs.

Water surface TIN: The first step is to create a water surface TIN from the cross section water surface elevations. The following computational steps are selected from the HEC-GeoRAS toolbar: "RAS Mapping" → "Inundation Mapping" → "Water Surface Generation".

For each selected water surface profile, a water surface TIN is created without consideration of the terrain model. The TIN is created using the ArcGIS triangulation method. This allowed for the creation of a surface using cut lines as hard break lines with constant elevation. Also, areas which are of little interest are still included in the water surface TIN. These areas are removed in the process of delineation with the bounding polygon. Figure 2.16 shows the water surface TIN.

Figure 5.21 Water Surface TIN (the Lower Tapi River)



Floodplain delineation: The following computational procedure is used from the HEC-GeoRAS toolbar: "RAS Mapping" → "Inundation Mapping" → "Floodplain Delineation" → "GRID Intersection". Again, all three water surface profiles are selected from the window, Figure 5.21. The water surface TIN is converted into a grid based on the rasterization cell size. Then, it is compared with the TIN terrain model, which is also in grid format, allowing the elevation difference to be calculated within the bounding polygon. The areas with positive results (where water surface is higher than the terrain elevation) are included in the floodplain area (inundation depth grid), and the areas with negative results are considered as dry. The depth grid has prefix "d" ("d" is for depth) before the profile name, e.g. d PF1. Then, the floodplain boundary feature class is created based on the depth grid. The flood boundary has prefix "b" ("b" is for boundary), before the profile name, e.g. b PF1. The floodplain boundary and the depth grid are added to the analysis map. The feature classes named b PF1, b PF1, and b PF1 represent the floodplain boundary feature classes on the analysis map. The grids d PF1, d PF1, and d PF1 represent the water inundation depths within the delineated floodplains.

Figure 5.22 Water Inundation Depth Grids

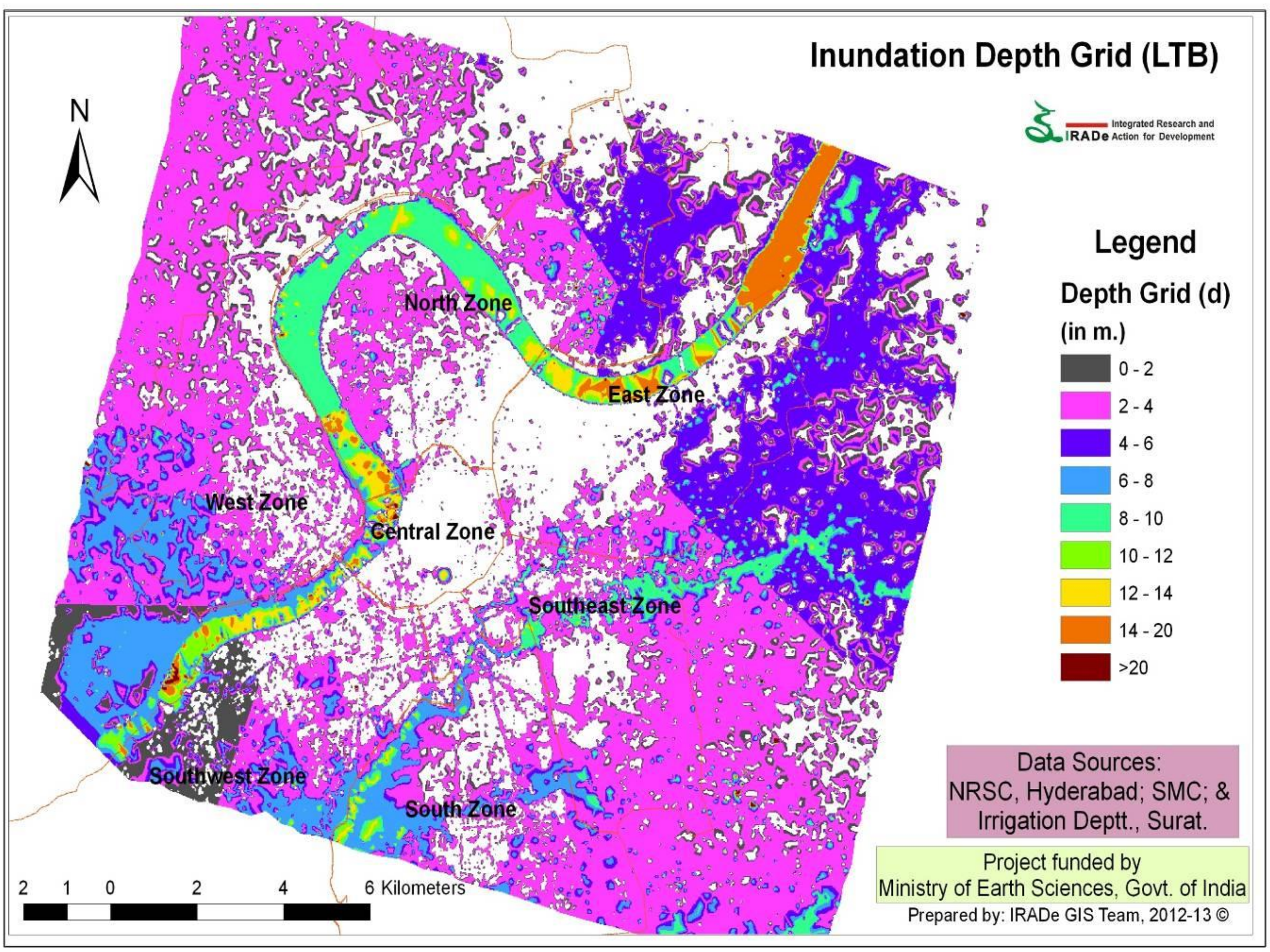
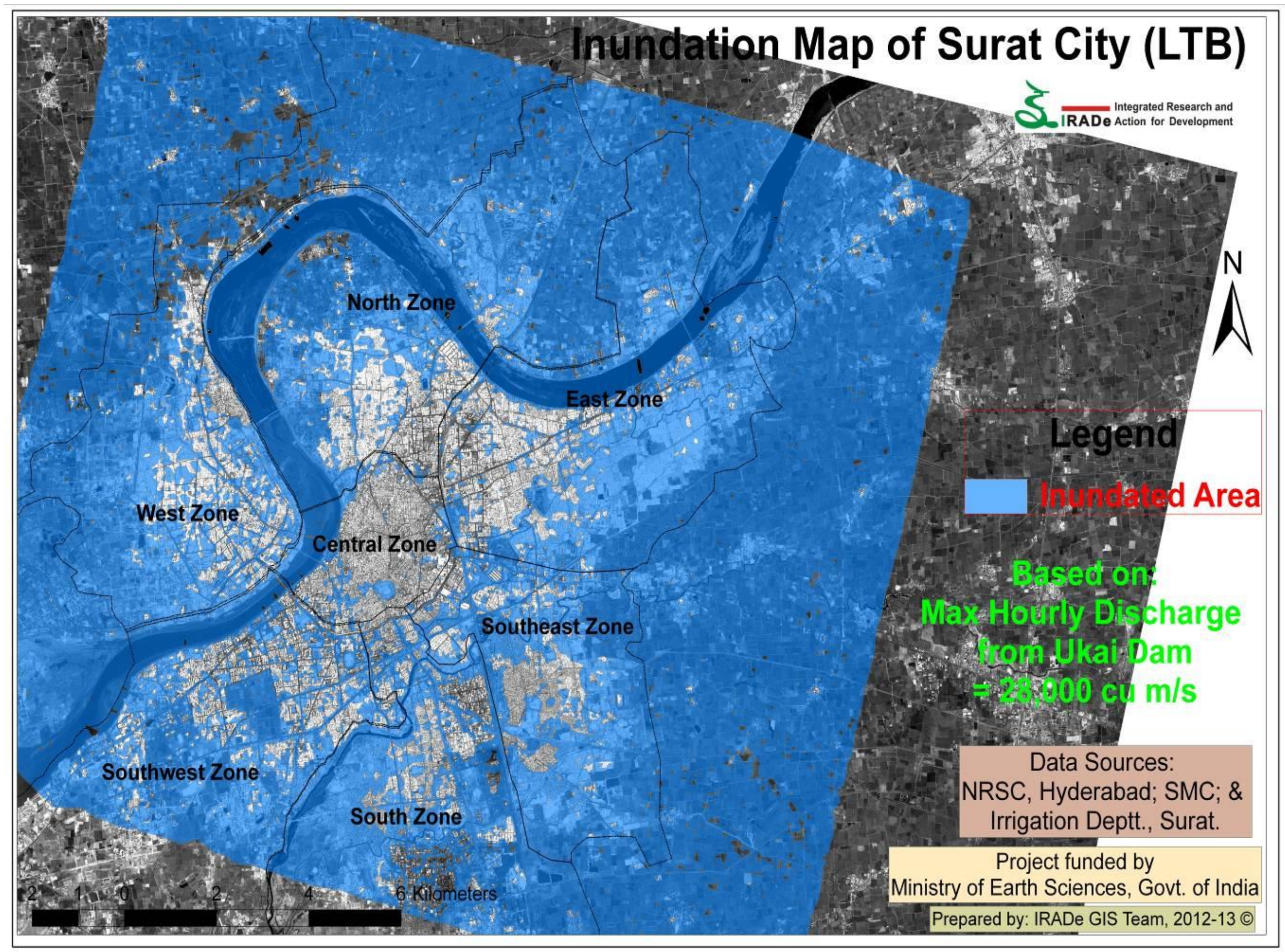


Figure 5.22 shows floodplain results from the HEC-GeoRas model at one section of the Lower Tapi River. The floodplain boundary (b PF1) is represented by a yellow line. The inundation depth grid is represented with different hues of blue (here in varying Choropleths). The largest value of water depth is represented by a dark Red, and the smallest value of water depth is represented by a grey. By using the “identify tool” button, water depth at any point can be easily identified.

Figure 5.23 Floodplain results for one section of the Lower Tapi River (Main Channel)



5.3.10 Review and editing the floodplain results:

The first review step is to verify that the cross sections are wide enough to allow for the proper floodplain delineation. In the verification process it is noticed that at some location further extension of the cross sections is required. This has ended up in the repetition of all steps for modified cross sections: assignment of new attributes, export of a new RAS GIS file to HECRAS, running HEC-RAS, export of HEC-RAS results to Arc GIS, and the floodplain mapping. Consequently, it is necessary to manually edit the flood plain results at some locations.

Another problem in the floodplain mapping is observed when the water surface elevations of two neighbouring cross sections are not within the same contour line. The floodplain line at some of these areas followed a straight line instead of following the more accurate contour line. These areas are carefully analyzed. As a result, some of them are manually edited while others, particularly those areas that fall within residential zones, are left unedited as areas of special concern.

5.3.11Results of the Analyses

In this chapter, results obtained using the HEC-RAS and GIS process are analysed and presented.

5.3.11.1 Results of hydraulic analyses:

HEC-RAS results consist of cross section water surface elevations for flows of 2006, 50% lesser and 50% higher scenarios. In addition to water surface elevations, values of other hydraulic parameters are available for each cross section from HEC-RAS outputs. These parameters include: flows, minimal channel elevation, channel velocity, flow area, and critical water surface. HEC-RAS outputs are available in both, graphical and tabular form. In graphical form, HEC-RAS output can be viewed as water surface profiles, general profiles, rating curves, and X-Y-Z perspective plots.

HEC-RAS results are presented in this Chapter in tabular form (Tables 3.1) for the river, including selected cross sections (at the beginning, in the middle, and at the end of the model) as illustration of modeling results. HEC-RAS results are also presented for selected locations discussed in the floodplain mapping results.

<u>HEC-RAS Report generated after the completion of the work:</u>

HEC-RAS Version 4.1.0 Jan 2010
U.S. Army Corps of Engineers
Hydrologic Engineering Center
609 Second Street , Davis, California
****

PROJECT DATA
Project Title: Flood Study of Surat
Project File : FloodStudySurat.prj
Run Date and Time: 8/26/2013 5:59:50 PM
Project in SI units
****

PLAN DATA
Plan Title: Steady Flow analysis Plan 1

Plan File: e:\HecRAS Cartosat June2013-2_Revised_Aug\HEC RAS File\FloodStudySurat.p01
Geometry Title: Geometry_Data_FloodStudySurat_rev_aug13
Geometry File: e:\HecRAS Cartosat June2013-2_Revised_Aug\HEC RAS File\FloodStudySurat.g01
Flow Title: Steady Flow data
Flow File: e:\HecRAS Cartosat June2013-2_Revised_Aug\HEC RAS File\FloodStudySurat.f01

Plan Summary Information:

Number of: Cross Sections = 116 Multiple Openings = 0
Culverts = 0 Inline Structures = 0
Bridges = 9 Lateral Structures = 0

Computational Information

Water surface calculation tolerance = 0.003
Critical depth calculation tolerance = 0.003
Maximum number of iterations = 20
Maximum difference tolerance = 0.1
Flow tolerance factor = 0.001

Computation Options

Critical depth computed only where necessary
Conveyance Calculation Method: At breaks in n values only
Friction Slope Method: Average Conveyance
Computational Flow Regime: Subcritical Flow

****

FLOW DATA

Flow Title: Steady Flow data
Flow File: e:\HecRAS Cartosat June2013-2_Revised_Aug\HEC RAS File\FloodStudySurat.f01

Flow Data (m3/s)

****

* River	Reach	RS	*	PF 1	PF 2	PF 3 *
* Tapi River	Lower Tapi Basin	30864.32	*	14000	28000	42000 *

****

Boundary Conditions

****

* River	Reach	Profile	*	Upstream	Downstream *
* Tapi River	Lower Tapi Basin	PF 1	*		Normal S = 0.001 *
* Tapi River	Lower Tapi Basin	PF 2	*		Normal S = 0.001 *
* Tapi River	Lower Tapi Basin	PF 3	*		Normal S = 0.001 *

****

GEOMETRY DATA

Geometry Title: Geometry_Data_FloodStudySurat_rev_aug13

Geometry File: e:\HecRAS Cartosat June2013-2_Revised_Aug\HEC RAS File\FloodStudySurat.g01

CROSS SECTION

RIVER: Tapi River

REACH: Lower Tapi Basin   RS: 30864.32

INPUT

Description:

Station Elevation Data   num=   250

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
**									
0	0	92.59	0	94.95	-.16	142.53	-3.3	142.85	-3.32
143.04	-3.34	143.32	-3.36	161.66	-4.67	165.87	-5	168.06	-5
175.71	-4.12	228.44	0	923.7	0	950.66	-2.75	951.37	-2.76
953.13	-2.77	954.23	-2.77	954.5	-2.79	956.7	-2.81	957.98	-2.82
961.68	-2.83	964.99	-2.77	965.44	-2.8	970.7	-3.19	971.29	-3.18
972.21	-3.17	973.67	-3.14	974.91	-3.13	977.55	-3.28	979.17	-3.27
979.59	-3.27	981.93	-3.26	987.46	-3.04	989.59	-3.06	990.73	-2.98
1021.15	0	1074.13	0	1085.94	-.07	1096.54	-.07	1100.14	-.17
1107.27	-.39	1108.63	-.43	1111.24	-.43	1157.78	-1.41	1159.19	-1.41
1161.42	-1.42	1162.35	-1.43	1170.1	-1.49	1170.44	-1.5	1210.88	-2.71
1256.14	-5	1396.85	-5	1411.98	-2.74	1439.31	-2.61	1440.52	-2.74
1452.59	-4.23	1458.23	-5	1486.96	-5	1493.19	-3.99	1494.4	-3.9
1495.3	-3.81	1496.03	-3.78	1497.46	-3.58	1498.02	-3.56	1507.97	-2.68
1509.8	-2.67	1510.76	-2.67	1512.97	-2.49	1515.28	-2.5	1520.97	-2.11
1528.56	-2.14	1530.89	-2.26	1534.11	-2.38	1537.28	-2.51	1538.24	-2.57
1540.44	-2.67	1542.79	-2.77	1559.86	-5	1668.09	-5	1784.55	-.84
1786.07	-.79	1787.09	-.76	1788.14	-.72	1788.76	-.7	1797.19	-.46
1797.5	-.46	1804.11	0	1812.36	0	1831.66	-1.08	1837.34	-1.37
1853.7	-2.32	1908.71	-4.56	1908.84	-4.55	1911.15	-4.61	1911.28	-4.6
1912.38	-4.54	1915.53	-4.34	1966.89	-4.17	1967.1	-4.18	1968.06	-4.23
1970.11	-4.19	1974.95	-4.09	1975.44	-4.12	1975.78	-4.11	1976.18	-4.1
1986.52	-5	2040.75	-5	2061.36	-4.02	2068.24	-3.77	2110.14	-2.2
2114.91	-2.09	2199.65	-.23	2208.85	0	2482.43	0	2526.3	-2.59
2529.42	-2.7	2539.66	-3.02	2544.96	-3.19	2551.04	-3.38	2558.29	-3.61
2568.12	-3.91	2572.8	-4.06	2585.86	-4.47	2587.82	-4.54	2602.62	-4.97
2602.7	-4.98	2603	-4.99	2603.59	-5	2814.22	-5	2816.65	-4.82
2819.58	-4.89	2824.1	-4.66	2828.94	-4.42	2831.61	-5	3375.29	-5

3434.13 -3.25 3436.32 -3.25 3443.26 -3.23 3443.78 -3.24 3443.91 -3.24
3446.68 -3.25 3447.5 -3.25 3522.36 -4.62 3522.62 -4.63 3524.1 -4.68
3524.94 -4.71 3525.43 -4.72 3527.25 -4.78 3533.69 -5 3560.3 -5
3610.09 -5 3615.79 -5.62 3620.63 -6.15 3631.56 -7.36 3638.55 -8.14
3643.69 -8.74 3654.6 -10 3654.62 -10 3678.59 -12.14 3703.54 -14.28
3711.81 -14.83 3714.02 -15 3944.95 -15 4024.46 -10.83 4027.1 -10.8
4028.48 -10.79 4031.2 -10.78 4032.28 -10.79 4034.81 -10.79 4035.81 -10.8
4036.29 -10.81 4037.46 -10.81 4038.01 -10.82 4038.23 -10.82 4044.56 -10.54
4045.37 -10.54 4045.58 -10.55 4046.13 -10.55 4047.52 -10.53 4048.39 -10.54
4049.83 -10.54 4050.09 -10.55 4050.94 -10.55 4051.44 -10.56 4063.73 -11
4064.39 -11.01 4065.79 -11.05 4067.37 -11.06 4081.78 -11.25 4081.91 -11.25
4082.89 -11.24 4083.44 -11.24 4085.26 -11.25 4086.12 -11.26 4088.36 -11.27
4088.94 -11.28 4099.34 -11.55 4100.21 -11.55 4101.99 -11.56 4102.78 -11.57
4104.68 -11.63 4106.39 -11.64 4118.16 -11.82 4147.9 -10.12 4148.04 -10.12
4149.14 -10 4160.55 -10 4162.65 -9.59 4163.03 -9.54 4163.19 -9.51
4163.72 -9.36 4178.5 -5 4183.85 -5 4190.62 -4.7 4222.29 -3.13
4285.14 0 4348.85 0 4426.41 -3.98 4428.74 -4.04 4429.51 -4.06
4429.76 -4.07 4430.5 -4.1 4431.69 -4.15 4452.52 -5 4524.18 -5
4525.55 -5 4531.37 -5 4533.18 -5 4533.97 -5 4536 -5
4537.05 -5 4539.66 -5 4543.16 -5 4544.97 -5 4548.04 -5
4556.74 -5 4571.31 -5 4582.04 -5 4633.45 -5 4643.18 -3.99
4643.22 -3.97 4643.29 -3.95 4646.1 -4.16 4648.4 -4.44 4648.44 -4.43
4659.22 -5 4662.1 -5 4662.31 -5 4672.45 -5 4677.55 -5

Manning's n Values **num**= 4

Sta n Val Sta n Val Sta n Val Sta n Val
****

0 .04 3643.69 .035 4163.72 .08 4582.04 .04

Bank Sta: Left Right Lengths: Left Channel Right Coeff Contr. Expan.
3560.3 4222.29 206.86 177.26 153.94 .1 .3

CROSS SECTION OUTPUT Profile #PF 1

****

* E.G. Elev (m) * 0.12 * Element * Left OB * Channel * Right OB *
* Vel Head (m) * 0.21 * Wt. n-Val. * 0.040 * 0.036 * 0.059 *
* W.S. Elev (m) * -0.09 * Reach Len. (m) * 206.86 * 177.26 * 153.94 *
* Crit W.S. (m) * * Flow Area (m2) * 8990.41 * 7577.55 * 1448.23 *
* E.G. Slope (m/m) *0.000257 * Area (m2) * 8990.41 * 7577.55 * 1448.23 *
* Q Total (m3/s) *14000.00 * Flow (m3/s) * 4898.12 *7130.26 * 971.62 *
* Top Width (m) * 3452.82 * Top Width (m) * 2402.72 * 661.99 * 388.11 *

* Vel Total (m/s)   *   1.55 * Avg. Vel. (m/s)   *   0.99 *   2.39 *   0.67 *
* Max Chl Dpth (m)   *   14.91 * Hydr. Depth (m)   *   3.74 *   11.45 *   3.73 *
* Conv. Total (m3/s) *1746253.0 * Conv. (m3/s)   *554941.8 *1130714.0 * 60596.4
* Length Wtd. (m)   * 184.52 * Wetted Per. (m)   * 2404.71 * 663.41 * 393.32 *
* Min Ch El (m)   * -15.00 * Shear (N/m2)   *   9.43 *   28.80 *   9.28 *
* Alpha   *   1.67 * Stream Power (N/m s) *223951.10 *   0.00 *   0.00 *
* Frctn Loss (m)   *   0.04 * Cum Volume (1000 m3) *636684.90 *226187.00 *404357.80 *
* C & E Loss (m)   *   0.00 * Cum SA (1000 m2)   *172951.70 *23911.33 *113665.30
****

CROSS SECTION OUTPUT Profile #PF 2

****
* E.G. Elev (m)   *   1.72 * Element   * Left OB * Channel * Right OB *
* Vel Head (m)   *   0.26 * Wt. n-Val.   *   0.040 *   0.036 *   0.060 *
* W.S. Elev (m)   *   1.46 * Reach Len. (m)   * 206.86 * 177.26 * 153.94 *
* Crit W.S. (m)   *   * Flow Area (m2)   *14405.80 * 8602.88 * 2147.67 *
* E.G. Slope (m/m)   *0.000309 * Area (m2)   *14405.80 * 8602.88 * 2147.67 *
* Q Total (m3/s)   *28000.00 * Flow (m3/s)   *8053.51 *14182.90 * 1763.58 *
* Top Width (m)   * 4677.55 * Top Width (m)   * 3560.30 * 661.99 * 455.26 *
* Vel Total (m/s)   *   1.67 * Avg. Vel. (m/s)   *   1.11 *   2.81 *   0.82 *
* Max Chl Dpth (m)   *   16.46 * Hydr. Depth (m)   *   4.05 *   13.00 *   4.72 *
* Conv. Total (m3/s) *2390974.0 * Conv. (m3/s)   *913893.8 *1376684.0 *100397.1
* Length Wtd. (m)   * 186.21 * Wetted Per. (m)   * 3563.77 * 663.41 * 462.02 *
* Min Ch El (m)   * -15.00 * Shear (N/m2)   *   12.23 *   39.24 *   14.07 *
* Alpha   *   1.81 * Stream Power (N/m s) *223951.10 *   0.00 *   0.00 *
* Frctn Loss (m)   *   0.05 * Cum Volume (1000 m3) *913425.70 *261970.00 *595069.70 *
* C & E Loss (m)   *   0.00 * Cum SA (1000 m2)   *208041.80 *24365.54 *146098.00
****

CROSS SECTION OUTPUT Profile #PF 3

****
* E.G. Elev (m)   *   2.90 * Element   * Left OB * Channel * Right OB *
* Vel Head (m)   *   0.28 * Wt. n-Val.   *   0.040 *   0.036 *   0.062 *
* W.S. Elev (m)   *   2.62 * Reach Len. (m)   * 206.86 * 177.26 * 153.94 *
* Crit W.S. (m)   *   * Flow Area (m2)   *18521.73 * 9368.19 * 2673.98 *
* E.G. Slope (m/m)   *0.000326 * Area (m2)   *18521.73 * 9368.19 * 2673.98 *
* Q Total (m3/s)   *42000.00 * Flow (m3/s)   *16066.35 *21393.99 * 2539.65 *
* Top Width (m)   * 4677.55 * Top Width (m)   * 3560.30 * 661.99 * 455.26 *
* Vel Total (m/s)   *   1.83 * Avg. Vel. (m/s)   *   1.35 *   3.03 *   0.95 *
* Max Chl Dpth (m)   *   17.62 * Hydr. Depth (m)   *   5.20 *   14.15 *   5.87 *

* Conv. Total (m3/s) *3103171.0 * Conv. (m3/s) *1389021.0 *1573418.0 *140731.4
* Length Wtd. (m) * 187.79 * Wetted Per. (m) * 3564.93 * 663.41 * 463.18 *
* Min Ch El (m) * -15.00 * Shear (N/m2) * 16.59 * 45.10 * 18.44 *
* Alpha * 1.64 * Stream Power (N/m s) *223951.10 * 0.00 * 0.00 *
* Frctn Loss (m) * 0.06 * Cum Volume (1000 m3) *1198509.00 *292806.40 *784479.70 *
* C & E Loss (m) * 0.00 * Cum SA (1000 m2) *233921.60 *24527.50 *153054.10
****

The table headings, not indicated by full names, are as follows: "River Sta" - river station of each cross section; "Q Total" - flow used for each climate scenario; "W.S. Elev" – water surface elevations; "Vel Chnl" - velocity in the channel; "Froude # Chl" - Froude number.

Table-3.1: HEC-RAS results for the Tapi River (at selected cross-section)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Froude # Chl
Lower Tapi Basin (LTB)	**Cross Section**	**Profiles**	**(m^3/s)**	**(m)**	**(m)**	**(m/s)**	**(m^2)**	
LTB	30864.32	PF 1	14000	-15	-0.09	2.39	18016.19	0.23
LTB	30864.32	PF 2	28000	-15	1.46	2.81	25156.36	0.25
LTB	30864.32	PF 3	42000	-15	2.62	3.03	30563.9	0.26
LTB	30687.06	PF 1	14000	-20	-0.15	2.41	17815.33	0.22
LTB	30687.06	PF 2	28000	-20	1.4	2.8	24247.52	0.24
LTB	30687.06	PF 3	42000	-20	2.52	3.11	29315.91	0.26

Annexure-IV

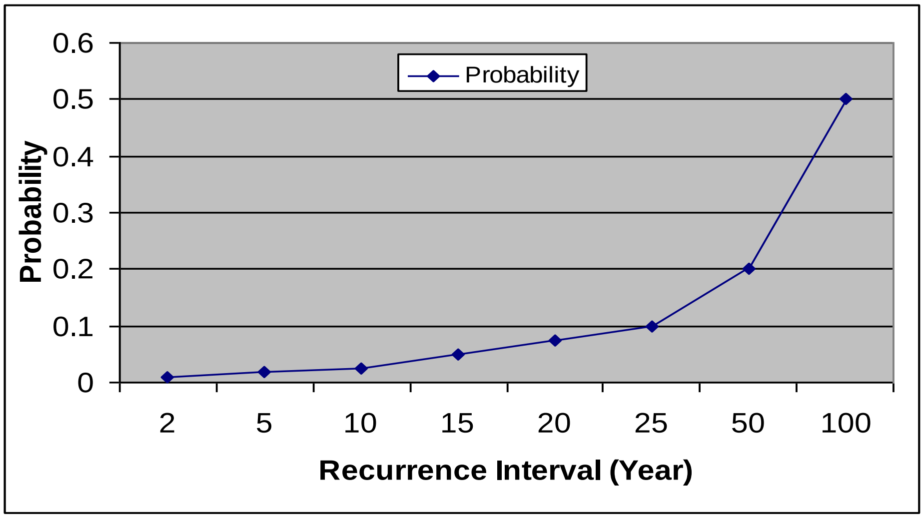
Chapter 5: Mapping of Flood Vulnerable Zones: Step-3: Climate change Scenarios

5.1 Regional Flood Frequency Analysis Of Annual Discharge Data For Surat City Using Gumbel's Mathematical Model

Flood frequency is the concept of the probable frequency of occurrence of a given flood. This study used the annual and daily flood data to determine the flood frequency analysis and flood prediction for next 100 years using Gumbel's distribution method. This analysis is used to predict design flood for site along a river. The technique used involves observed annual peak flow discharge data to calculate statistical information such as mean value, standard deviation, coefficient of variation and recurrence intervals. These data are used to calculate frequency distribution.

According to Gumbel's probability distribution, figure 5.26 depicts that the probability of flood of a given magnitudes or greater occurring in any year. The probability of flood is decreasing with recurrence interval. It is predicted that next two year flood probability percent is 0.01% and maximum probability (i.e. 50%) at 100 year return period.

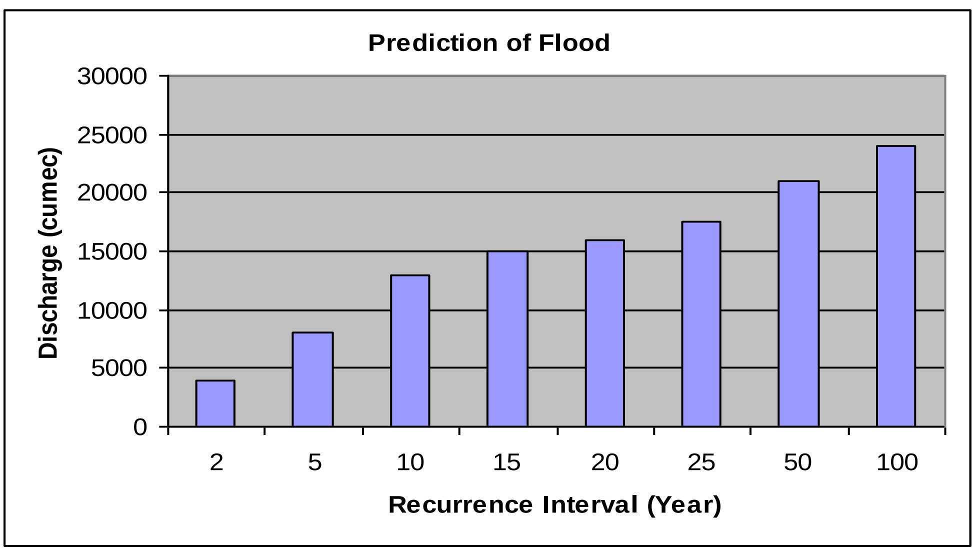
Figure 5.26: Probability distribution and its relation with recurrence interval



Source: Singh AK, 2011, Urban flood modeling and hazard management using remote sensing and GIS, Technical Note No.7, Department of Civil Engineering, Nirma University Ahmedabad, March 2011

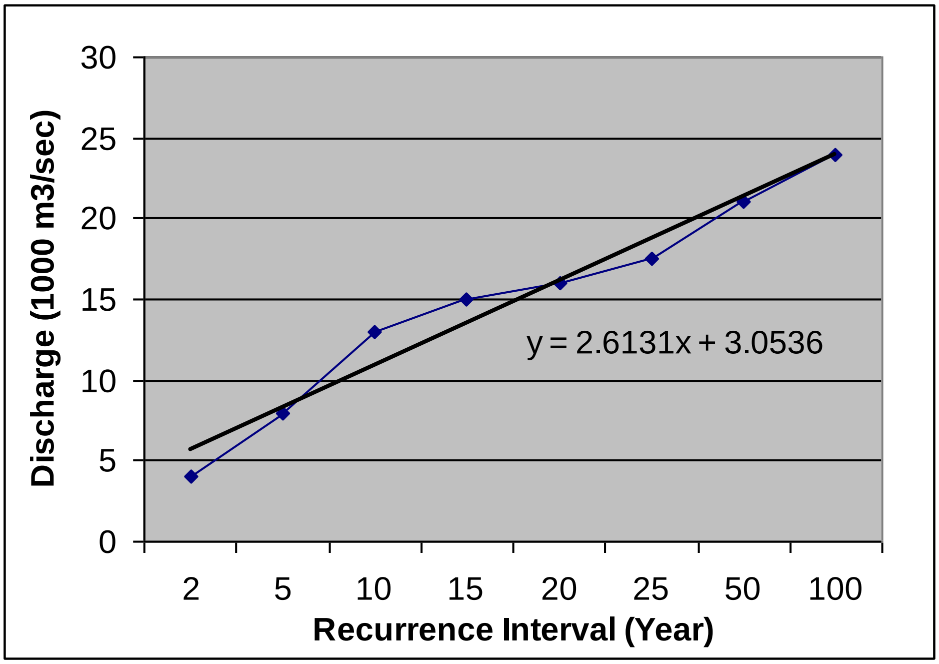
Figure 5.27 shows predicted 100 years flood frequency at Ghala station. It is found that mean flood 4,500 m^3/sec is represented at recurrence interval 2.33 year. A high flood 22,500 m^3/sec has occurred in a record of 20 years, where Q100 value predicted by Gumbel's method is 23,900 m^3/sec which is similar to the recorded flood.

Figure 5.27: Predicted 100 years flood frequency at Ghala station



Source: Singh AK, 2011, Urban flood modeling and hazard management using remote sensing and GIS, Technical Note No.7, Department of Civil Engineering, Nirma University Ahmedabad, March 2011

Figure 5.28: Distribution of maximum annual flood discharge at Ghala station



Source: Singh AK, 2011, Urban flood modeling and hazard management using remote sensing and GIS, Technical Note No.7, Department of Civil Engineering, Nirma University Ahmedabad, March 2011

On the annual it has been observed that there is an increase in the annual flood, yet there is marginal increase in the annual water yield as shown in figure 5.28. However this might be attributed to an increase in actual precipitation. The frequency results for positive annual high flow series during monsoon season and large variability of high flow system in study area.

5.5 Climate Change Scenarios

5.5.1 Introduction

In order to assess the submergence levels in different parts of Surat city under the impact of climate change. We first look at climate change scenarios of a widely used global model (GCM) of Hadley Centre in UK and the regional climate model (RCM) of the Indian Institute of Tropical Meteorology (IITM), Pune. Their model scenarios also provide at small regional scale projections. Based on the region that contains Surat, we assess the likely increase in inflows in Tapi.

From 1869 up to 1884, on an average, the city was flooded every two and half years followed by a fall in its frequency by 1914. During 1949 to 1979, the average natural flood occurrence was once in every four years followed by their occurrence in post Ukai dam (1970) at lesser and variable frequency. The 1968 flood had been the biggest flood witnessed so far and had a highest flow of about 42,475 cumecs (1.5 million cusecs). Water level at Hope Bridge, Surat had reached 12.01 m.

The Ukai dam, located about 100 km upstream of Surat, was completed in 1972. The major purposes of the dam were essentially irrigation, power generation, domestic water supply and flood protection to Surat city. As there was limited demand for use of water for irrigation in the initial stages, the situation permitted flood absorption by the dam for the first 15 to 20 years. Since 1970, changes in the intensity of rainfall in catchment, increase in demand/utilization of water by industries, land use change at catchment, change in flood plain downstream, change in river regime, change in land cover especially on the banks of river within city, variations in tidal conditions and change in water allocation to the neighboring state of Maharashtra have changed the situation. The Tapi valley winds, temperature and humidity have also changed during this period. These changes have direct influence on the number of days of rainfall and their intensity (25-200 mm in a single day). The SW monsoons are currently being over taken by SE storms. These changes are contributing to the higher flood levels and therefore increased flood risk to the City.

Apart from the above, the changing climate, the temperature gradient (TG) between Indian landmass and Arabian Sea/Bay of Bengal is decreasing in lower troposphere with a maxima around 850 hPa, from 1948-2007. This estimate was made on the basis of sixty years of daily temperature and wind data. Pre monsoon (March-May) TG pertaining to Arabian Sea is currently reducing at a significant rate of 0.036°/year. ERA-40 data confirms this decreasing trend. As TG is not governed by any significant oscillation, there is a possibility of TG tending to zero. This may have severe impacts including decrease in rainfall during in July and August months, increase in cyclonic storms and increase in the number of break days during monsoon over India. Some of these impacts are slowly being realized.[38]

According to Prof. Nikhil Desai, another possibility for the change in rainfall could be the construction of Ukai-Narmada Reservoirs i.e. "*reservoir-induced change in rainfall*". He explains that the reservoir and canals irrigating the vast command area will have impact on the climate of Surat, South Gujarat, and Saurashtra. The rise in sea level is resulting in increased tidal levels and contributing to the erosion along the coast of South Gujarat. Further, in Surat, increasing tidal levels and increased use of ground water for industrial needs has resulted in ground water depletion (around 10 m per decade) and saline ingress in the estuaries of river Tapi and Mindhola.

The projections of various climate models indicate that precipitation is likely to increase in the region along with increase in frequency of extreme events. The city lies towards northern most part of the western coastal humid zone, and arid zone is only few hundred km towards north. Slightest deviation in climate either ways is likely to impact Surat, which already falls under flood risk prone zone. Surat lies in a flat terrain at an altitude about 10 m above the mean sea level. Sea level rise of even couple of meters will shift the tidal zone towards the city, which can worsen the flood situation.

[38] Asian Cities Climate Change Resilience Network (ACCCRN) Synthesis Report, Surat

5.5 Climate Variability And Climate Change

Observed Climate

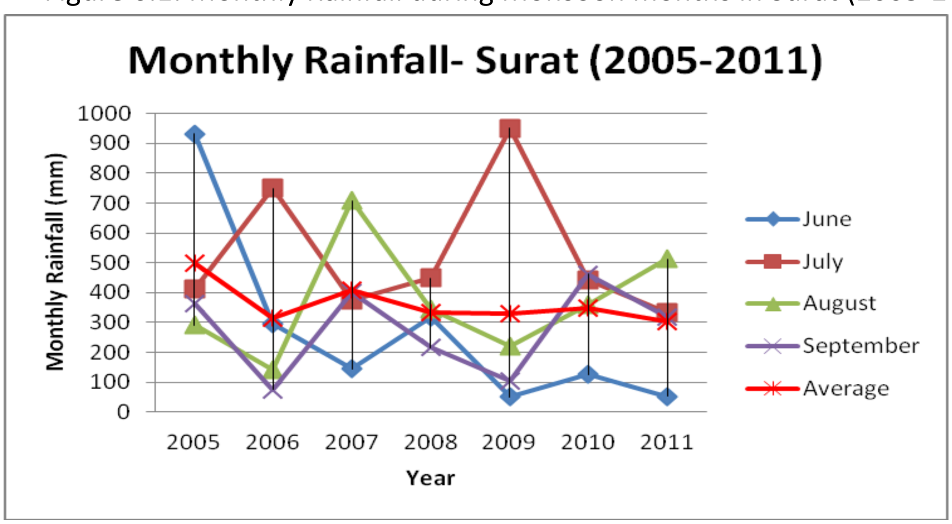
Located near the coast, Surat experiences moderate climate. The summers are hot with extreme day temperatures ranging from 37.8°C to 44.4°C. The climate is pleasant during the monsoon. The winters are pleasant with night temperatures in January drop to around 15.5°C. The average annual rainfall of the city is around 1,222 mm (IMD). Most of the rainfall occurs between June and September. Surat has a history of both droughts as well as floods. The floods occur in July and August. Monthly rainfall during the monsoon months over the past few years are given in table 6.1 and also shown in figure 6.1.

Table 6.1: Monthly Rainfall during Monsoon months in Surat (2005-2011)

Monthly RF Data Surat-2005-2011- (in mm)							
Monsoon months	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
June	932.6	296	143.4	319	50.9	125	52.8
July	413.7	748.9	374.8	448.6	950.1	441.3	332.6
August	290.1	140.2	708.8	343.9	221.4	358.8	512.6
September	362.7	73.9	399.6	216.2	102.2	461.9	318.7
Total (of 4 months)	**1999.1**	**1259**	**1626.6**	**1327.7**	**1324.6**	**1387**	**1216.7**
Average (of 4 months)	*499.775*	*314.75*	*406.65*	*331.925*	*331.15*	*346.75*	*304.175*

Source: Data provided by IMD, Pune on CD

Figure 6.1: Monthly Rainfall during Monsoon months in Surat (2005-2011)



Source: Data provided by IMD, Pune on CD

Methodology

Global Climate Model (GCM) results procured from Climate System Analysis Group (CSAG) and downscaled Regional Climate Model (RCM) results procured from Hadley Centre and Indian Institute of Tropical Meteorology (IITM) have been analyzed for Surat City. Since the city is located in the lower most part of Tapi river basin, and is also flood prone, climate change scenarios of different models vary widely on precipitation. Moreover, it is also important to mention that RCM results are not easy to downscale with confidence to city scale. However we can get some idea of the magnitude of change that may occur. Hence, we have taken 3 IPCC scenarios and their projection of average precipitation in July, August and September months (the months of most floods) for the Surat region.

The three scenarios correspond to

a) A2 Scenario (High),

b) A1B Scenario (Medium) and

c) B2 Scenario (Low).

They represent total global GHG emissions over the period from 2000 to 2100.

Table 6.2: A brief explanation of the scenarios considered in the study.

Name of IPCC scenarios	Data set	Description	Duration
SRES B1	550 ppm CO_2 maximum (SRES B1)	Atmospheric CO_2 concentrations reached 550 ppm in the year 2100 in a world characterized by low population growth, high GDP growth, low energy use, high land-use changes, low resource availability and medium introduction of new and efficient technologies.	2001–2100
SRES A1B	720 ppm CO_2 maximum (SRES A1B)	Atmospheric CO_2 concentrations reach 720 ppm in the year 2100 in a world characterized by low population growth, very high GDP growth, very high energy use, low land-use changes, medium resource availability and rapid introduction of new and efficient technologies.	2001–2100
SRES A2	850 ppm CO_2 maximum (SRES A2)	Atmospheric CO_2 concentrations reach 850 ppm in the year 2100 in a world characterized by high population growth, medium GDP growth, high energy use, medium/high land-use changes, low resource availability and slow introduction of new and efficient technologies.	2001–2100

Source: IPCC-Model Information of Potential Use to the IPCC Lead Authors and the AR4;UKMO-HadCM3

Precipitation Scenario

Surat receives an annual rainfall ranging between 950-1200 mm. About 90% of the rainfall occurs in period between July to September. The GCM and RCM results indicate a higher probability of increased precipitation in the future. This increase ranges from 200 mm (GCM) to 450 mm (RCM) annually. Total annual rainfall is expected to increase in Gujarat and adjoining western Indian plateau by 250 to 500 mm as per most of the climate models under A2 and B1 Scenarios. This has significant bearing on Khadi floods. The HadCM3 and CCCMA model also indicated higher precipitation over Tapi basin, the climate analysis of the last Century also indicates the increasing frequency of heavy rainfall events separated by long dry spells. The number of days accounting for more than 200 mm of rainfall is expected to increase in the predicted future climate scenarios (CCCMA). The events in which the precipitation will be more than 350 mm also are likely.

Figure 6.2 Average Annual Precipitation 2000 – 2099- Surat City

Model: UKMO-HadCM3, SRES emission scenarios

High (A2 Scenario):

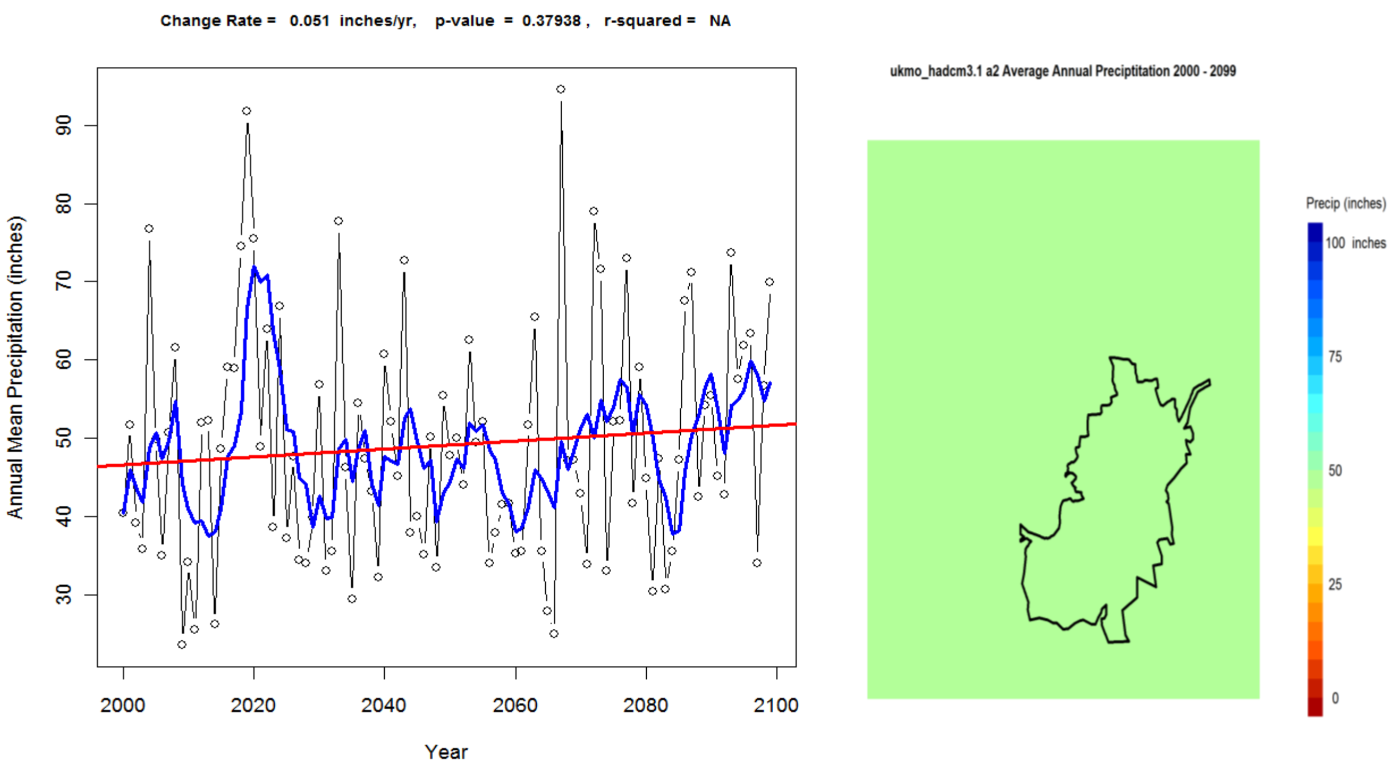
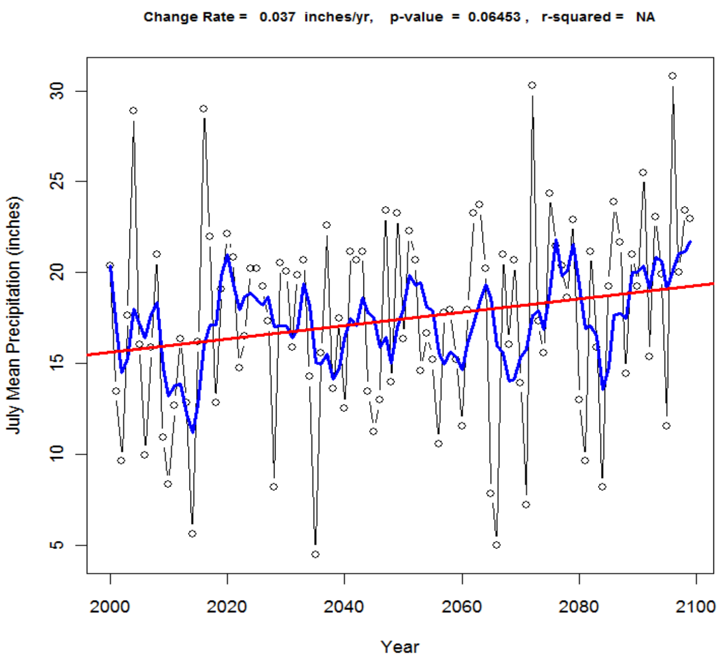


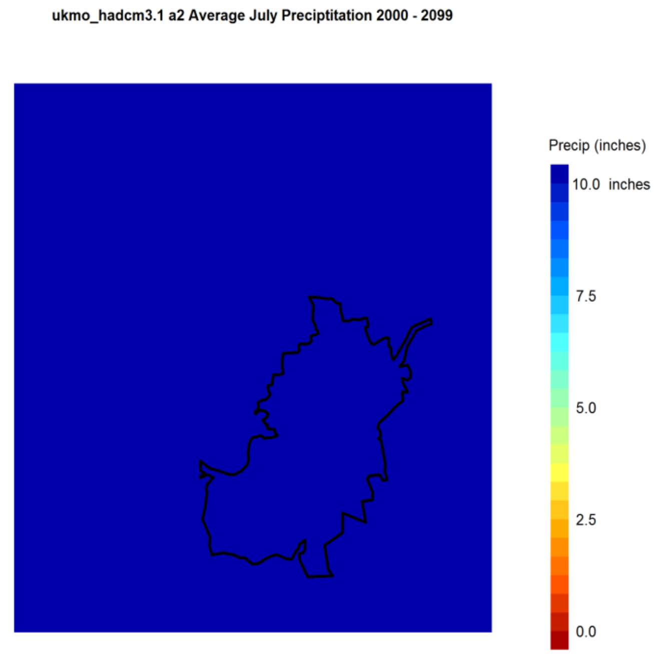
Figure 6.3 Average Monthly Precipitation 2000 – 2099- Surat City

Model: UKMO-HadCM3, SRES emission scenarios

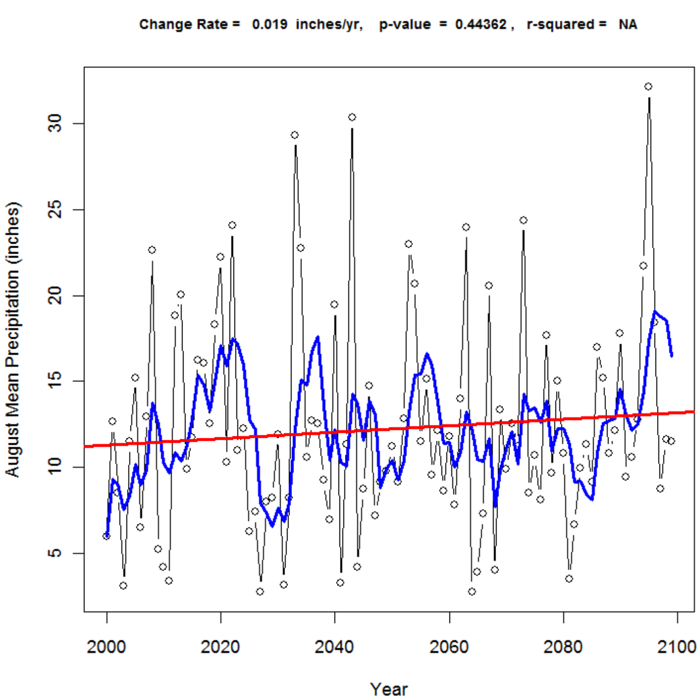
High (A2 Scenario):

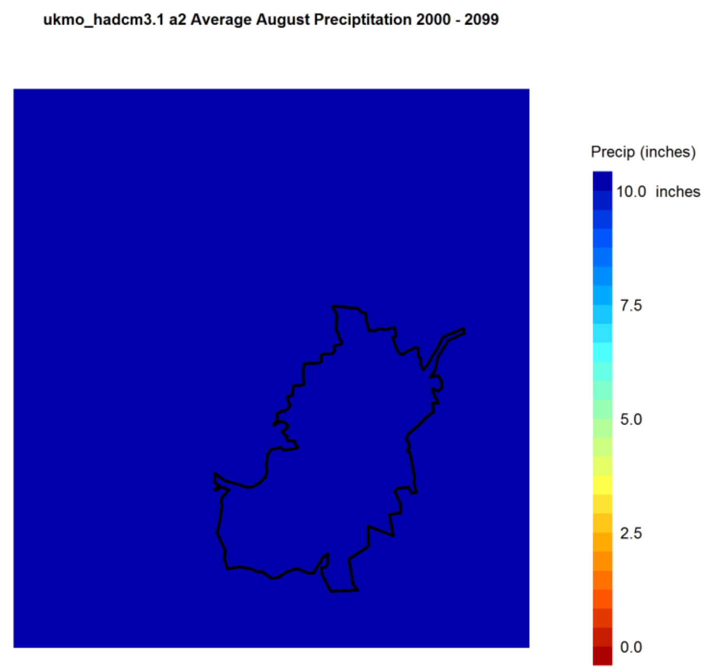
July month





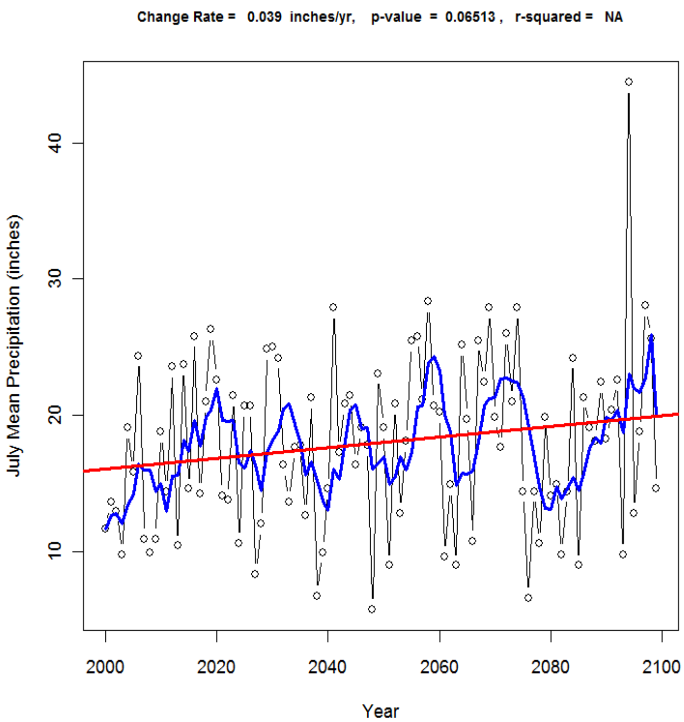
August month

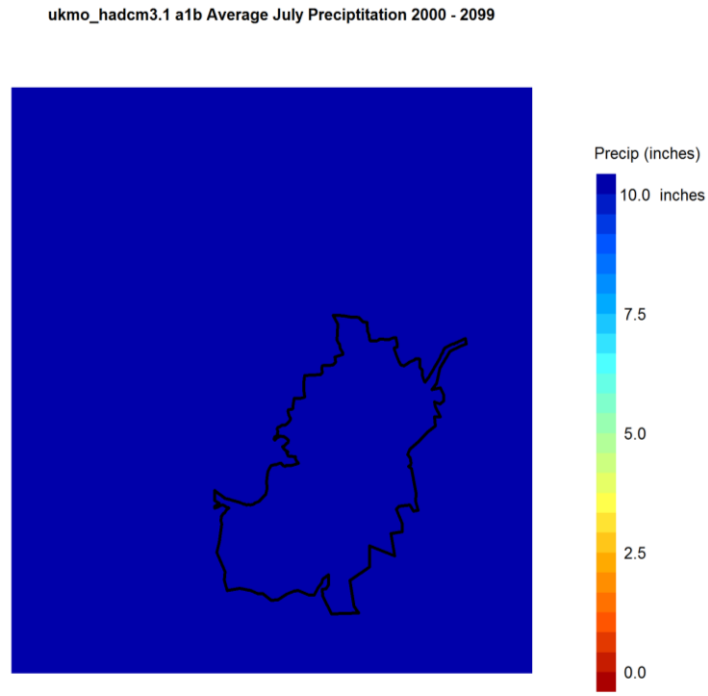




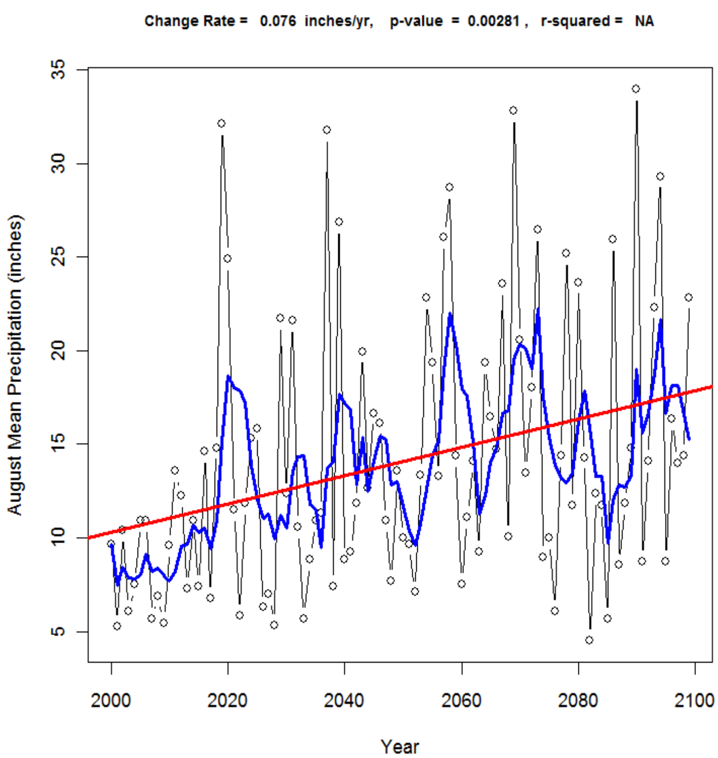
Medium (A1B Scenario):

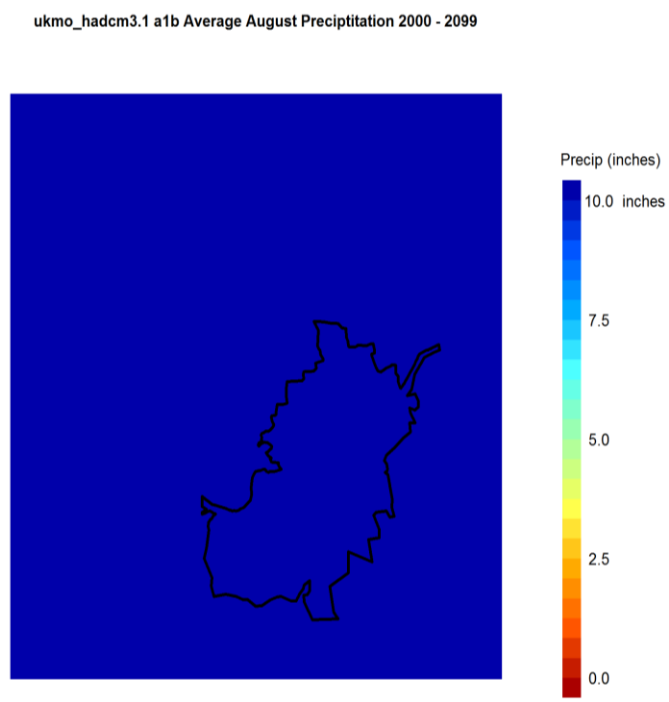
July month





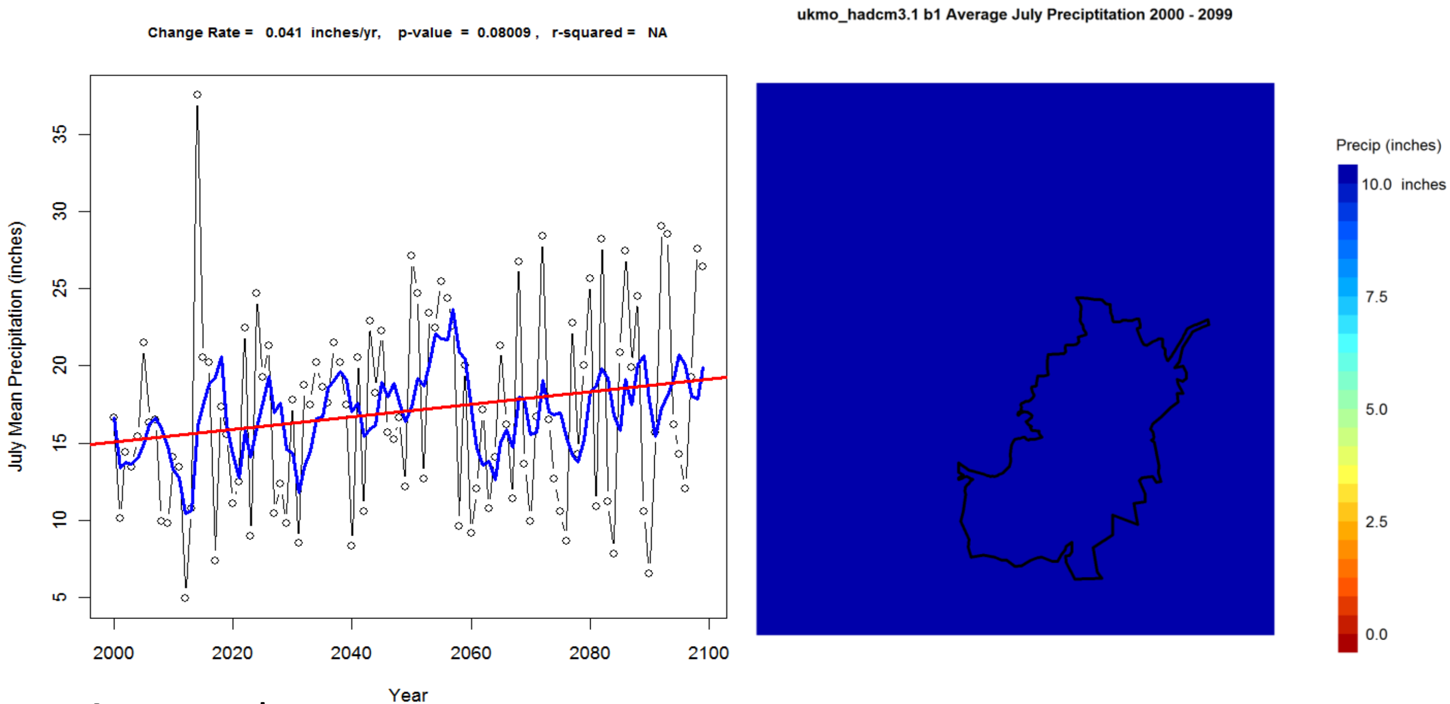
August month



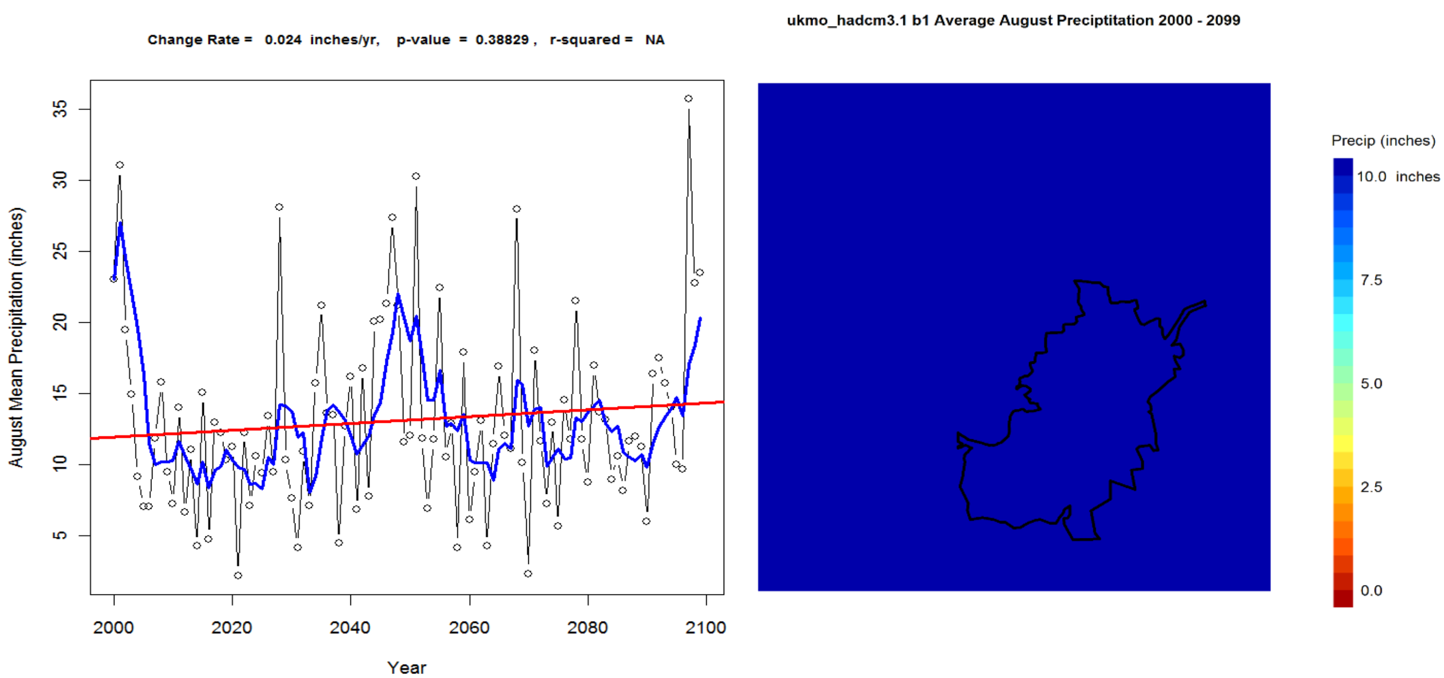


Low (B1 Scenario):

July month



August month



Source: Hadley Centre (UKMO-HadCM3)

Note: In the figure the blue line depicts downscaled precipitation and black line depicts weighted precipitation computed using precipitation.

Figure 6.2 shows the precipitation of Surat region and the Surat city and Figure 6.3 shows projected precipitation for July and August for the three scenarios.

Based on these we have taken an increase of 50% in inflows above the 2006 peak as a climate change scenario. In figure Annex. 5.3.2 the projected annual average rainfall is given for the extreme scenario A2. It is seen that in year 2006 the rainfall was around 50 inches. The highest rainfall is projected to be 70 inches in 2022-24 period, which is 40% higher than 2006 rainfall. Even when we look at figure Annex 5.3.3 for months of July and August, the highest rainfall is seen to be 21 inches in July around 2022 and 17 inches in August around 2022. The 2006 precipitations were shown to be around 18 inches in July and 10 inches in August. The percentage increases are 17% and 70% respectively.

Analysis of the Indian monsoon over past century indicates decrease in number of rainy days as well as more intense precipitation events across the country (Goswami & Ramesh, 2007)[39]. The instances of extreme point rainfall events (EPRE) have mainly affected the regions on NW, NE, central India, the coastal zones and the hill stations (Khaladkar et al., 2009)[40]. Considering the physiographic setting of Surat, the increase in rainfall with increasing EPREs may add on to the existing risks of pluvial flooding.

Annexure-VI

Chapter 8: Summary of Case Study

At the global level IPCC 2007 identified five major aspects of climate related risks to the cities.

(i). ***Heat waves*** are likely to increase over most of the land areas;
(ii). The frequencies of ***heavy precipitation*** events are very likely to increase over most of the areas, leads to the condition of ***flash flood***;
(iii). With the ***Increased Temperature***, ***Sea level*** likely to be rising;
(iv). The area affected by ***drought*** is likely to increase; and
(v). Intense ***tropical cyclone*** activity will increase.

These climate related vulnerability can amplify the risks that cities face from non-climatic sources like large slum population (which is still growing) living in the environmentally risky zones, poor infrastructures such as housing and low access to public infrastructure services. However, almost all the coastal cities including megacities of India are equally vulnerable to the impacts of climate

[39] P. Goswami & K.V. Ramesh 2007. Extreme Rainfall Events: Vulnerability Analysis for Disaster Management and Observation System Design, Centre for Mathematical modeling and Computer Simulation, Bangalore
[40] Khaladkar R.M, Mahajan P.M & Kulkarni J.R, 2009: Alarming Rise in the Number and Intensity of Extreme point rainfall events over the Indian Region under Climate change Scenario. ISSN 0252-1075 Contribution from IITM Research Report No. RR-123, IITM Pune

change depending upon the geographic factors of the cities such as nearness to the coast, socio-economic factors, etc.

Climate change is likely to increase the risks these cities are facing. It is important to understand the different pathways through which climate change can impact the urban residents and increase their vulnerability to climate related risks. The cities are particularly vulnerable to the impacts of climate change for following reasons:

(i). A large proportion of people live near and along the river banks and coasts making them vulnerable to floods including storm surge.

(ii). Urban centers in India are considered as the engines of growth. National economies to become successful depend on the well functioning and resilient urban centers. This provides an important economic rationale for addressing the current urban vulnerabilities to extreme weathers and expanding protection from likely future changes.

(iii). Very little attention has been given to the vulnerabilities associated with the low income population in urban centers in India. For example populations living in the slum areas are the most vulnerable to the impact of climate change.

Tools for vulnerability mapping and assessing the impacts of climate change on the region in the study include

- Hydrological modeling tools (HEC RAS, HEC GeoRAS and HEC HMS),
- Remote Sensing and GIS Tools (ERDAS Imagine-LPS, ARC GIS and AutoCAD Map)
- Statistical tools (MS Excel and SPSS), and
- Climate Models (IPCC SRES models).

The other assessments are based on simplistic empirical relationships between cause and effect or by correlating impact parameters with GIS based maps.

The findings from the analysis of the climate model studied under the project indicate following aspects:

- **Precipitation** is likely to increase in the region along with increase in frequency of extreme events. The city lies towards northern most part of the western coastal humid zone, and arid zone which is only few hundred km towards north. Slightest deviation in climate either ways is likely to impact Surat, which already falls under flood risk zone.
- Another aspect of city vulnerability is **sea-level rise** which raises the water level in Tapi downstream of Surat increasing the risks of flooding. That will have an impact on overflow and submergence. We have not assessed likely extent of sea level rise. However, in the

hydrological simulation the downstream water level has been taken as the maximum observed water level during the 2006 flood.

Surat lies in a flat terrain at an altitude about 10 m above the mean sea level. Sea-level rise of even couple of meters will shift the tidal zone towards the city which can worsen the flood situation. Surat is a coastal city and lies near the estuary of Tapi River. Several tidal creeks cut across the city. Surat lies at an altitude of about 10 m above mean sea level with a tidal range of about 5.8m. During rainy months, the sea wave action often causes the sea water to inundate the slums located along the creeks, making the city vulnerable to flood.

During the last five years, the slums are being evacuated during mid-July period due to above normal tidal inundation. According to the recent study of the sea level changes in Arabian Sea by Unnikrishnan (2007)[41], during the last century, there has been an increase in sea level along the Gulf of Cambay by around 0.67 m. If such increase prolongs into the future, they may have a major impact on the city.

- **Cyclones** are not common and only two events of cyclones passing through Gulf of Khambhat are reported over the last 140 years, the recent being 1976. Surat has been reporting rising highest high tide levels during July, with some of the Khadi areas are evacuated during July high tide days as a precaution. The highest tide of 2007 had inundated some of the coastal areas that had never before submerged during tides. The sea level rise is also likely to impact coastal aquifers and also erode parts of Dumas beach, which already has been reporting coastal erosion.

Climate change risks are expected to increase the frequency and intensity of current hazards, an increased probability of extreme events, spur the emergence of new hazards and vulnerabilities with differential spatial and socio-economic impacts. Surat city is, thus, facing the flood risk among other risks most. In this project, we have studied flood risks of Surat city in detail.

Annexure-VII

Discussion of Project results with the experts and stakeholders

We started off the project with the thorough analysis of relevant literatures available and identified knowledge gaps. After gaining knowledge about the actual conditions and factors prevailing at the time of disaster event (e.g. floods) in Surat, we started multi-layered work simultaneously. Work started with the collection of data on Tapi River cross-sections right from UKAI Dam to Coast and doing analysis on Carrying capacity of Tapi River. Simultaneously we also started work on mapping out flood vulnerability zones in Surat, pilot survey and full-fledged survey of vulnerable targets like schools, hospitals, industries and slums in Surat city. We started work on doing hydrological analysis of various water discharge scenarios from UKAI dam in Lower Tapi River Basin**.**

[41] Unnikrishnan 2007, Observed Sea level rise in the North India Ocean coasts in the past Century, Physical Science 91-92

Challenges faced so far for achieving the results described in the proposal

1. **Data Collection:** We have faced huge problems in data collection with respect to rainfall data at the selected stations of the required period. Tapi River Discharge data is also not available according to the need of the project. Overall data acquisition according to the need of the project has posed a great challenge to us.

2. **Local survey:** To conduct local survey in Surat City has been a daunting task as getting time and access to Schools, hospital, industries and slums has been challenging.

3. **Meeting with Stakeholders:** Having a meeting with various stakeholders has been also a time consuming and patiently waiting exercise. We have met with many officials of Surat Municipal Corporation; Professors at SVNIT, Surat; officials in Irrigation Department, Surat; officials of CWC, SWDC Gandhinagar; and various other local stakeholders, NGOs and Govt. Officials.

1) Collaborator Meeting and compilation of Information on their researches (Between 22nd -24th August 2011 and 29th March- 2nd April 2012) :

We have made many stakeholder consultations and have few meetings with regard to project. We have discussed in detail about the actual problem the city is facing due to flood. Following are the briefs:

1) Surat Municipal Corporation (SMC)- City Engineer(Mr. Jatin Shah) , Flood Control Cell(Mr. Ghariyali),
2) Dr. Mahesh D. Desai (Visiting Professor, SVNIT and Freelance Consultant)
3) Sardar Vallabhbhai Patel National Institute of Technology (SVNIT), Surat- Dr. P L Patel, Deptt of Civil engineering, SVNIT.
4) Mr. Kamlesh Yagnik, Micro Information Pvt. Ltd. (MIPL), Surat
5) Irrigation Department, (Mr. Kamlesh B Rabaria, Supttd. Engineer, UKAI Dam In-charge)
6) Centre for Environment Education (Mr. Praveen Prakash & others)

2) Dr. Mahesh D. Desai (Visiting Professor, SVNIT and Freelance Consultant): (Date: 24th August, 2011)

Dr. Desai has started discussion by introducing about the characteristics of Surat city and its adjoining regions:

- Proximity to sea
- Leveled Topography

- Unprecedented urban growth with industrial expansion in last two decades.
- City faces water scarcity in spite of 1000 mm/year rainfall.

He has also communicated that what needs to be done for the city in light of climate change concerns-

- Needs to mainstream climate concerns in city development planning process
- Provide city administration the climate change inputs for urban planning, land use and land cover planning to find out alternatives to enhance capacity to city resilience.
- Tapi river front development can be planned with flood detention reservoir by providing spillway on riverbank for excess water to divert in Sena/Tena Creek or Kim River. It reduces the flood water impacts in downstream.

Dr. Desai, furthering his conversation, had raised various issues concerning city.

Issue 1: Need to Change T.P. (Town Planning) Scheme Act:

SMC in 1963 resolved intension to prepare comprehensive development plan for old & extended city areas. T.P. schemes as per 1954 Bombay T.P. act (Existing Gujarat Town Planning and Urban Development Act, 1976) shows three stages – Draft, Preliminary & final approval by Government. The general trend shows 10 years or more time to finalize a T.P. scheme after declaration of intension and more than 30 years to implement it.

The schemes even if completed as per T.P. after 40 years do not serve useful purpose as fast growth of urbanization has changed the category, originally considered namely, predominantly residential, commercial, industrial etc. When it is stated T.P. scheme is implemented in Nanpura in 1995 as predominantly residential zone has not satisfied objectives. The area by another decade has a different use. The T.P. schemes provision of all amenities & infrastructure including population statistics have put sector in unplanned zone for the today's users.

The total T.P. scheme system, time function and unprecedented growth, unless continuously monitored and modified, has been a useless exercise. The question of review of T.P. scheme completed, for 2008 infrastructural needs, uses and density, is literally uneconomical infeasible and impracticable. This is unavoidable issue which has to be resolved. Therefore there is need to scrap existing practice and evolve new strategies to accommodate unprecedented growth. Socio-economical, political planning will must evolve better planning with review of it acknowledging the changing pattern of needs.

Issue 2: Evolving Master Plan by pasting Isolated T.P. Schemes (Micro to Macro):

The planning of area, by the time it is partly implemented, expansion of city boundary is observed in all urban centres. Surat city for example grew from 7.4 sq.km area and 5 Lakh populations in 1971 to 334 sq.km area and 30 Lakh populations in 2007.

Hence to prepare City Plan pieces of T.P. schemes are joined together. This type of evaluation of city will have perpetual problems of services like communication, water source & supply distribution, drainage & final disposal of treated effluents for each T.P. scheme, management of disaster hazards like fire, flood, etc. Also T.P. Schemes do not take in to account impact of flood, fire etc.

Issue 3: Need for Bhruhad City Master Plan to guide T.P.S. (Macro to Micro):

Unless there is overall Master Plan with telescopic projections of *traffic, water supply, drainage, storm water, flood* with ultimate disposal station planned, for projected probable outermost city limits, are defined, there will be only piecemeal solutions as per existing practice. Such solutions create side effects and unending chain of problems. Even temporary partial solutions are very expensive.

There must be overall imaginary extreme limits of expanded city and projected ultimate population. Then essential services, communication, sources of water and network of distribution, drainage mains and branches, disaster management for floods, fire etc. and sewage - partial & ultimate treatment as well as final disposal, could be planned with telescopic projections (macro) for guiding micro level T.P. Schemes. This will drastically reduce cost of urbanization and poses less problems & least side effects.To illustrate point, Surat city has ring road, outer ring road and recently proposed outer most ring road. *The Ring Road, Udhna-Magadalla Road - Hajira roads are naturally planned above the flood level.* Each has raised level from River bank at RL (+)10m, Pala RL (+)13m, Road cum Rail banks at RL (+)14m and probable outer ring road now proposed will have severe side effect of constraining flood drainage and add afflux in flood for city. Questions are raised- Has outer ring road 2008 proposal been checked for flood aspect by SUDA?

In existing practice, the sewage treated has to be drained by number of treatment plants to Khadis & Kotar e.g. Kakara khadi to Mindhola River and sea. Now for bigger city, river is polluted by storm & sewage drains affecting the sources of water.

A Master Plan for city with sea on West, Kim on North, Mindhola River on South and Kadodara NH 8 on East as boundary must envisage, level drop of 15 m to 4 m is available

a) From East to West,

b) North & South zones along Tapti banks drains with tidal river level has slope of RL (+) 8m to (+) 4 m.

18 storm drains & 28 sewerage pumps pass polluted water only by receding tide to the sea via river in micro plan ignoring the facts. Now spending hundreds of crores for connecting drains to dispose of storm (rain) & sewage water to sea at Dumas or Hazira will pose problems & sides effects. A master plan with trunk drains increasing telescopically from East-West with branches & sub-branches from each T.P. scheme was feasible, economical & efficient solution taking less time to implement. (Macro to Micro) It could have planned road cum drains and river front development incorporated with it.

Issue 4: Drainage and Disaster Management

City drains storm water to River Tapti & Mindhola. Even treated effluent of sewage treatment plant covering piecemeal job for zones or T.P.S. have been drained mostly to Tapti River by numerous outfalls.

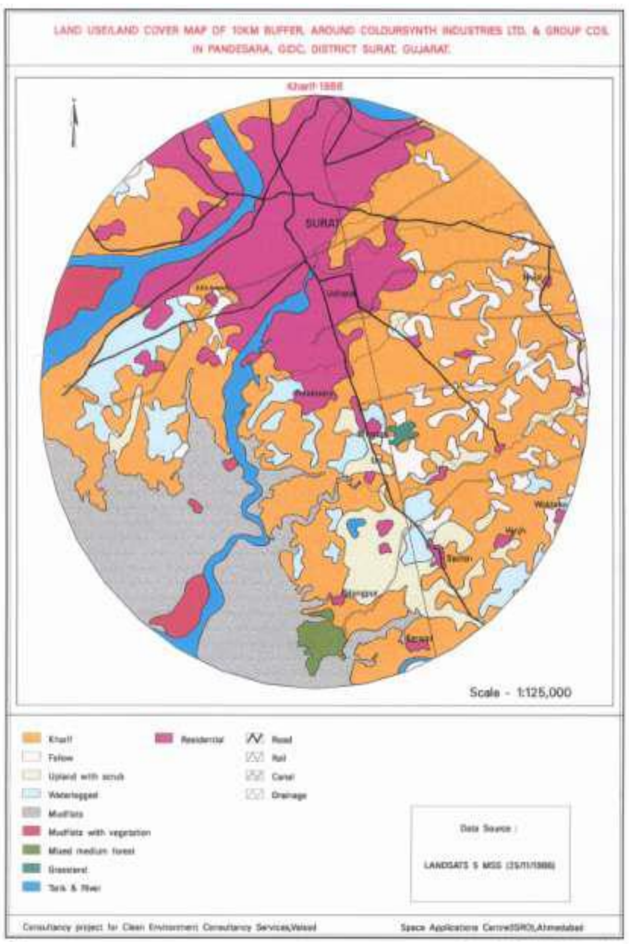


Fig. 2 - Satellite image showing Sea boundary at Surat in Year 1986.

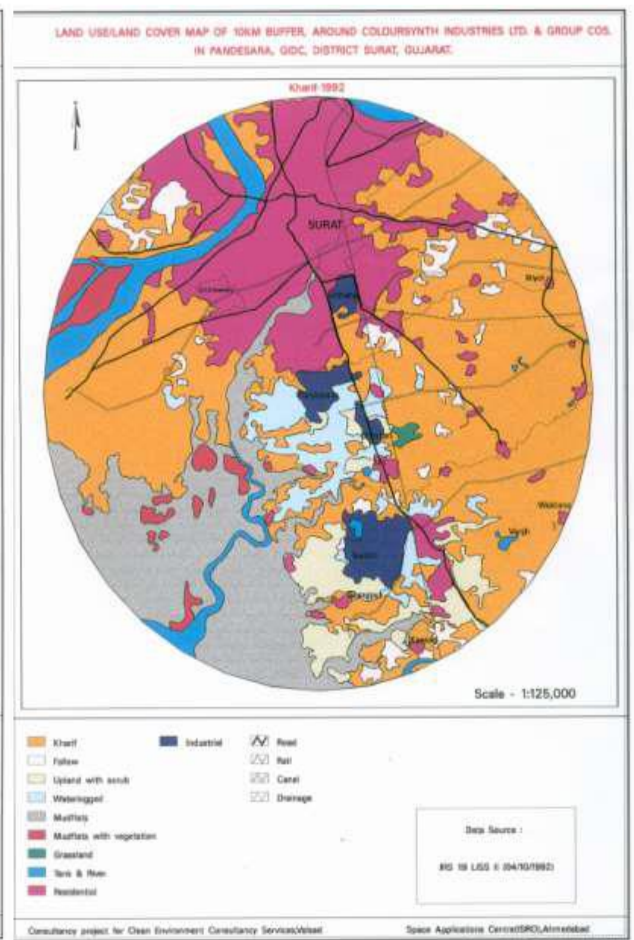


Fig. 3 - Satellite image showing Sea boundary at Surat in Year 1992.

This has posed environmental problems in water reservoir, Balloon dam as well as tidal reach downstream. High tide stagnate such effluents till low tide drain it to sea. Even urban centers like Surat, Bombay etc., by spending crores, cannot be efficiently interconnected to drain into sea near extended city boundary.

Surat city has perpetual problems of floods and as per the Global warming hypothesis the sea level will be rising considerably. This will submerge all present outfall drains in tidal estuary & coastal belt of Dumas - Hajira. The alarming erosion of coast line is seen by satellite pictures from Fig. 2, 3 and 4 and damages to Udawada, Tithal, Dandi are expected to be accelerated by sea level rise. The expanded khar land area near Surat is shown in Fig. 5.

To prevent loss of land and prevent flood from sea in addition to river a Town Planning, by act, has to assess the planning and projects from, angle not considered till day.

The afflux sensitivity of city for rise of flood level by schemes planned. (Township like Vesu, expansion of HADA, etc) should be critically considered by Town Planner. Detailed flood atlas of city is must. Unfortunately, even in 2008 there is no contour map of city & flood contours for the probable floods for present situations – use of land.

To make planning a useful exercise macro level plan of drainage, storm and sewage, disaster like flood and fire in HADA must guide the T.P. schemes for new areas added (almost 3 times old area). To conceive idea, city limits to sea on West, Kim river on North, NH-8 on East and Purna on South is imagined & frozen. For this area contours & flood drainage will be derived to evolve,

a) Trunk Roads cum drains, storm sewage North – East to South - West with major link roads & drains say North – South (RL 20 to RL 0)

b) The location shall consider natural drainage of city to Tapti, Mindhola & Kim.

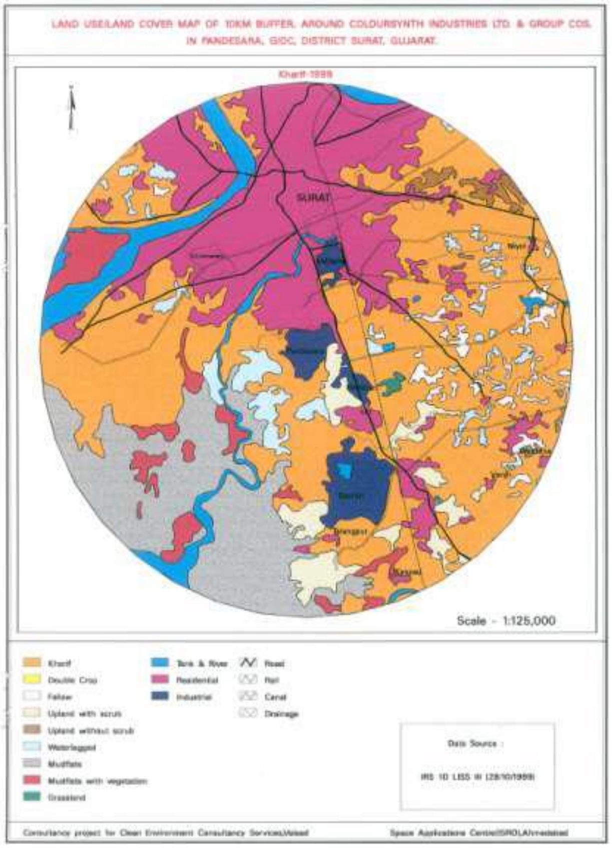


Fig. 4 - Satellite image showing Sea boundary at Surat in Year 1999

Fig. 5 - Map showing the khar land area for Surat

Issue 5: Water Resources Availability:

Unfortunately, planning and indication of water resources for growing urban centers in master plan has been vague or absent for all cities – Surat, Bombay, Delhi, Chennai etc. Even at huge cost, patches of T.P. distribution system cannot effectively avert chaos. Cities without own source of water could face crisis if sources are outside city boundary.

Surat has riparian source from Ukai reservoir to cater average 600 MLD. If down-stream (d/s) of Ukai to Surat is mismanaged by users of villages, industry such as sand mining this source could create crisis. For city of 2020 with projected 45 lakhs census population and 8-10 lakhs floating population and surrounding no source villages, 1200 MLD needs requires extra source. The ground water is saline and sea water, rain water harvesting are birds in bush. Even with all water works up-stream (u/s) of weir have perpetual problems every summer and cannot provide economical reliable quality distribution to added areas 30–40 km away from Water works.

Macro level plan even now is inevitable. Only source is flood water. For its economy and planning, integrated development plan needs to consider other problems of development,

4 NATIONAL NETWORK

The Indian EXPRESS
VADODARA ■ WEDNESDAY ■ JUNE 23, 2004

1 m rise in sea level will displace 1.7 million Indians, says report

EXPRESS NEWS SERVICE
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THIS is not from the film *Day after Tomorrow*, but the Government of India's report to the United Nations on climate change.

Parts of it read like a weather-horror story: The sea levels in India are rising and even a further one metre increase in sea levels is estimated to displace about 1.7 million people in the country, wash away 4,200 kms of roads and destroy 5,764 sq.kms of land.

The Gulf of Kutch and the West Bengal coast have recorded the highest rise in sea levels in the present climatic conditions, ranging between 0.4 and 2 mm per year.

According to the initial national communication to the United Nations Framework Convention on Climate Change (UNFCC) released by the Environment Minister, A. Raja, at a national workshop here, "Future climate change in coastal zones is likely to be manifested through worsening of some of the existing coastal zone problems."

The report containing climatic projections, with 1994 as base year, will be presented this week to the U N Convention, which aims to stabilise greenhouse gas concentrations in the atmosphere.

Gulf of Kutch and West Bengal coast have recorded the highest rise in sea levels

India's coastline stretches over 7,500 sq km and the population density in coastal areas is 455 persons per sq km — 1.5 times more than the national average of 324 persons per sq km.

The report indicates increases in both the minimum and maximum temperatures by 2-4 degree Celsius in the 2050s. In the north, the increase in maximum temperature may exceed 4 degrees, which may further rise in southern parts. There is also a possibility of overall decrease in the rainfall days.

This decrease is greater in the western and central parts by 15 days, while closer to Himalayas; it may increase by 5-10 days.

The report predicts more water scarcity in river basins. Especially, the river basins of Sabarmati and Lunei, which occupy about a quarter of Gujarat and 60 per cent of Rajasthan. The Cauvery, Ganga, Narmada and Krishna River basins are likely to experience seasonal or regular water-stressed conditions.

Consequently, the food security of India "may be at risk in future", says the report. "Food securtity of India may be at risk in future due to the threat of climate change leading to increase in frequency and intensity of droughts and floods."

The positive side to the report states: Greenhouse gas emission by India is "very low" — per capita emission is 0.87 tonnes of carbon dioxide equivalent per annum and aggregate emissions are about 3 per cent of the global total.

Addressing the workshop on Coastal Regulation Zone (CRZ) in Chennai, the Environment Minister said a CRZ management system that balances both conservation and development aspects has to be evolved.

An expert committee headed by scientist, Dr. M.S. Swamination, has been set up to consider the entire gamut of issues, which will submit its report in three months.

1). As shown in Fig. 6, **water detention reservoir** along the coast line Hajira, Bhimpore on mud – khar lands, 2 – 3 nos. of 200 MCM or so capacities to detain & download extra flood into sea by Balloon dam tidal structures. This is huge raw water source above tidal level.

2). **Floods control d/s of Singanpore weir.** (Diversion of floods from spills, natural & designed to detention reservoirs along coastline)

3). **Beautification & development of river front by Road (100 m) cum storm drain barrel along river intercepting:** Present 18 or so drains, spills system to spread flood so as to decrease depth, drain it through shortcut direct drains redesigned. The flood spills and planned spills on riverfront will drain water via coastal reservoirs to sea.

4). **Coastal protection:** The erosion of coast control is ensured by the dykes for detention ponds. That can be seen from Udawada, Tithal, Dandi & Dumas (Sultanabad). This will protect city from rise of sea water due to global warming & ice melting.

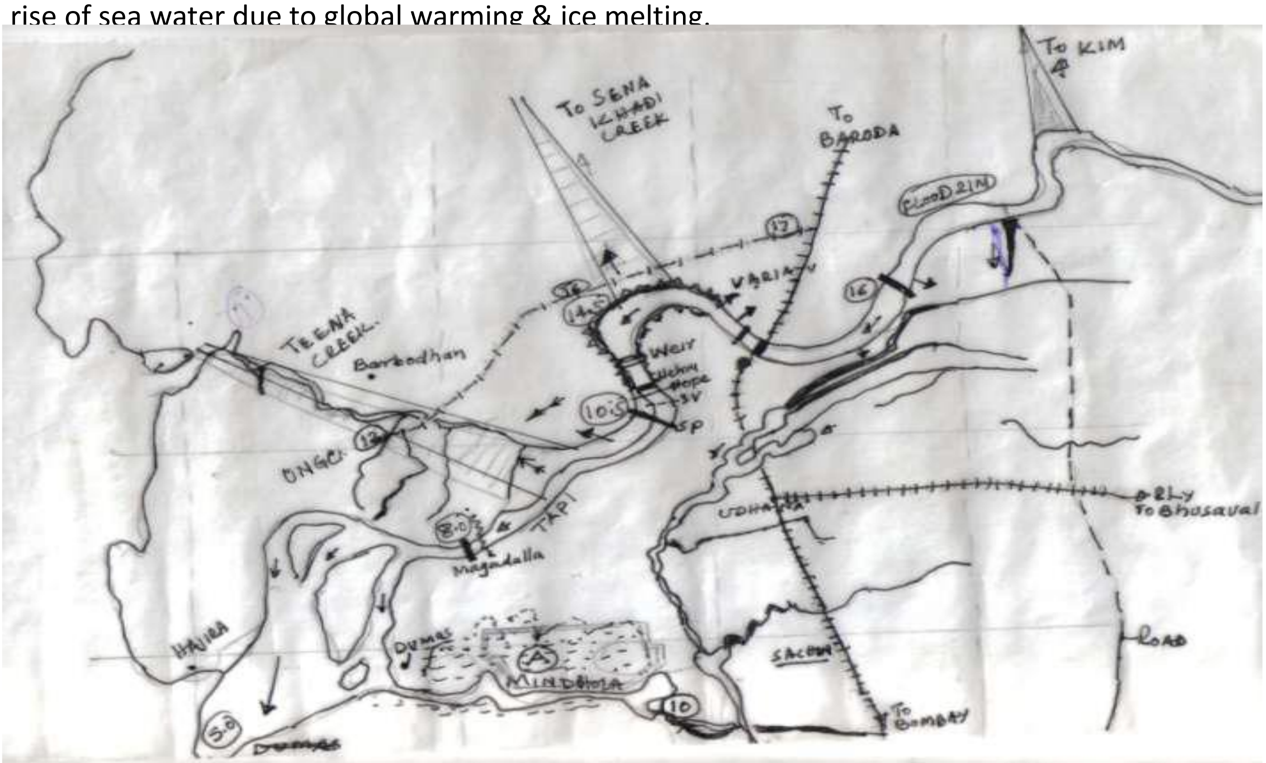

Fig. 6 - Map showing proposed flood detention reservoir with integrated planning

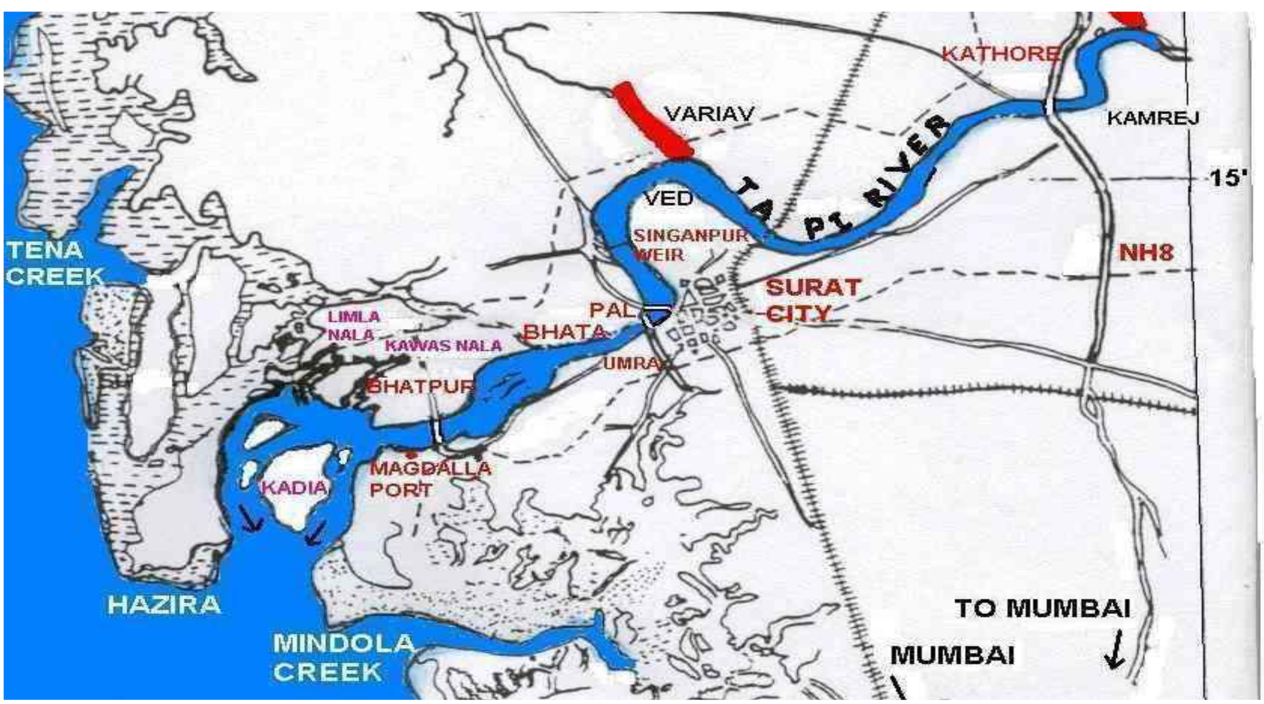

Fig. 6(a) - Map showing proposed flood detention reservoir on khar land

5). **Communication:** A coastal highway along dyke Hajira – Hansot, Dumas, Umbharat linked to NH – 8 could provide outer ring road without adding afflux to city.

6). **Recharge,** khar land development by leaching and control of salinity ingress to city area are obvious side benefits.

7). Raw water source for dry 74 or so coastal villages ponds in mostly no source areas.

8). Long term recharge will revive old aquifer after 2 – 3 decades as ground water source.

9). Disaster management plans for Hajira via coastal road to jetties – sea or NH-8.

10). Development of coast line beaches, gardens & entertainment areas for city of Surat.

11). Diversion of drains will make conservation of the surplus water from Singanpore weir by Balloon dam at Umra & water works near Gavier.

After a long thought-provoking and knowledge–enriching conversation, he finally gave few concluding suggestions that need to be taken care of by all the stakeholders of the city.

i) Master Plan evolved by cutting pasting of T.P.S. planned and completed cannot deliver services. (Micro to Macro)

ii) Correct approach of Macro plan for Bhruhad city (maximum expected boundary) for services should guide T.P.S. for zones and added new villages. The need to evaluate every project for disaster management of flood, erosion and fire like earthquake has been established.

iii) Lastly importance of multipurpose mega planning can only justify cost / benefit ratio. This is illustrated by illustration of feasibility of use of flood water as source for Surat.

10.2.2.2 Collaborators and Stakeholders Meeting (Since Oct 2012):

We made stakeholder consultations and discussed with them about the ongoing project and their interventions in Surat city with regard to flood and UKAI dam water management. We had few meetings with regard to project with other collaborators. We discussed in detail about the actual problem the city is facing due to flood. Following stakeholders to whom we had discussed with the study under the project:

1) Surat Municipal Corporation (SMC)- City Engineer(Mr. Jatin Shah) , Flood Control Cell(Mr. Ghariyali),
2) Irrigation Department, (Mr. Kamlesh B Rabaria, and new Supttd. Engineer, UKAI Dam In-charge, and other officials of the deptt)

3) Slum Development Cell (SMC)
4) Flood Control Cell (SMC)
5) Southern Gujarat Chamber of Commerce and Industries, Surat
6) Mr. Kamlesh Yagnik, Micro Information Pvt. Ltd. (MIPL), Surat
7) Surat Climate Change Group, Surat
8) Sardar Vallabhbhai Patel National Institute of Technology (SVNIT), Surat- Prof. P L Patel, Deptt of Civil engineering, SVNIT.
9) Centre for Environment Education (Mr. Praveen Prakash & others)

Annexure-VIII

Chapter-7 Vulnerability of Facilities and Socio-economic Impacts on Communties: Questionnaires for Local Survey

1) **Schools**
2) **Hospitals**
3) **Slums, and**
4) **Industries**