# Vulnerability of Surat, Gujarat to Flooding from Tapi River: A Climate Change Impact Assessment

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***ABSTRACT***

*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, impact of floods on cities often become disastrous 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.*

*Urban climate resilience needs to rely on scientific data and sound analytical framework encompassing urban planning and socio-economic analysis. In this study, we have attempted to identify and analyze the immediate and medium-term impacts of flooding events in a rapidly growing urban system of Surat city (Gujarat, India). We have used HEC-RAS model to analyze inundation scenario in Surat. Two scenarios have been developed. In scenario-1, water discharge corresponding to the flood of 2006 has been modeled whereas in scenario-2 the water inflow considered is 1.5 times the volume of 2006. We have considered 50% increase in the inflow of Tapi river as the probable impact of future climate change. In addition to measuring the physical impacts of floods, we have studied the socio-economic impacts also to provide policy implications for developing adaptation capacity and city resilience plans. The analysis shows that west zone and north zone of the city are highly flood prone while south zone is least. Topographically, west zone is the lowest zone and hence it has more chances to get flooded severely. The results are particularly useful for the preparation of city development plans with a view to make cities resilient to climate change, minimize the damages and informing citizens about the risk of specific areas in the city to avoid construction there.*

***Keywords****: Climate change, Flood plains, City resilience and Inundation.*

## 1. Introduction

The impact of extreme weather and climate events on exposed and vulnerable human and natural systems manifests in the form of disasters (IPCC, 2012). Such weather and climate related disasters have social as well as physical dimensions. There has been an increase observed in the frequency and magnitude of extreme weather- and climate-events in the past decades (IPCC, 2012), which has exacerbated the disaster risks on growing human population and associated infrastructure. The risks associated with weather- and climate-related disasters can be mitigated by adopting appropriate policy measures in advance based on modeling the potential consequences of extreme events.

Various researchers have studied flooding in Surat city as well as district. Desai and Tailor (2007) analyzed the present management approach of flood moderation in Tapi basin. They found that the entire system of flood control is based on:

- Prediction of daily inflow from Central Water Commission
- Processing of data and decision making by Govt. of Gujarat.
- Rules for operation of reservoir to meet specified objectives

They concluded that the present system of flood management does not take into consideration changes in environment, flood plain, drainage (due to urbanization), economic analysis of overall public loss against benefits and hardships to 3 million people for a month. Singh and Sharma (2009) studied the flood of 2006 in Surat using high resolution remote sensing images and prepared urban flood hazard maps employing 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 GPS (Global Positioning System). Patel and Dholakia (2010) assessed 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). They also suggested feasible structural and non-structural measures in order to minimize the effect of flood, in and around Surat city. Joshi and Patel (2010) studied morphological processes in Tapi River Basin. They developed an "optimization process" for minimizing the impacts of floods. Timbadiya et al. (2011) used HEC-RAS (Hydrologic Engineering Centre-River Analysis System) model for studying the flood in the lower reaches of Tapi river. They carried out topographic assessment of river bed features (characterized as channel roughness using Manning's roughness coefficient) for simulating the floods of 1998 and 2003. Agnihotri and Patel (2011) 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 of the city. Their analysis revealed that the flood was due to the excessive outflow of 25711 $m^3/s$ (9.08 lakh cusecs) from Ukai dam. They suggested preventive remedial measures such as reservoir operation policy, warning system from upstream, water release from the dam etc. Goswami et al. (2015) studied water surface elevation of the nearly 110 km stretch of lower Tapi Basin using HEC-RAS model.

All these studies are primarily focused on the past events of floods. In the changing climatic conditions, it is also important to map all the vulnerable locations and public facilities where a large section of vulnerable population may congregate. For example, schools where children and hospitals where patients go in large number and evacuation may be difficult. And if the probability of extreme events and its magnitude is greater than normal by current standards, then additional adaptation actions might have to be planned proactively. In this context, the present work assumes significance as it provides a glimpse of potential inundation in Surat in a modeled future situation in which the water released from the Ukai dam exceeds 1.5 times the volume released in 2006 and assesses the vulnerability of schools, hospitals, slums and industries.

Flooding causes serious impact on people and property. The European Union (EU) Floods Directive (Directive 2007/60/EC Chapter 1 Article2. eur-lex.europa.eu. Retrieved on 14/12/2015) defines a flood as a covering by water of land not normally covered by water. This definition includes floods from rivers, mountain torrents and floods from the sea in coastal areas.

"Vulnerability" is the level of exposure of persons and property to hazards. Timmerman (1981) 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. Physical vulnerability is related to the physical location of the people and elements at risk, and their physical proximity to the hazard. Socio-economic vulnerability indicates the degree to which a population is affected by a calamity such as disruption in services like schools, hospitals etc. It will not be strictly confined to the physical components but also depends on 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 likely to aggravate floods. IPCC (2007) also noted "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. With an estimated 14% of population living within 100 km of the coast in India, the damage due to floods in coastal cities in our country could not be overemphasized. The cities have high density of population, expensive properties and high economic activities. It is therefore necessary to understand the ramifications of natural hazards like floods on urban areas to evolve appropriate policies to strengthen the resilience of our coastal cities. Against this backdrop, this paper attempts to identify and analyze the immediate and medium-term impacts of flooding in the city of Surat, which is a rapidly growing coastal city on the banks of river Tapi on the west coast of India.

Broadly the objectives of this study are to assess the vulnerability of the Surat city to flooding from Tapi river taking the scenario of 2006 flood and to model the inundation in Surat city assuming a 50 % increase of water inflow in Tapi river (considered as a probable impact of climate change) relative to 2006

## 2. Study Area

Surat city (Fig 1) is located at a latitude of 21.0° to 21.23° North and longitude of 72.38° to 74.23° East on the bank of Tapi River. The city has a tropical monsoon climate with temperatures in summer going up to 44°C. Annual precipitation ranges from 1000 to 1200 mm. 90% of this rainfall occurs between June and September. The Tapi River, which meets the sea at a distance of 16 km from the city centre. The city is located at the mouth of Gulf of Khambhat and experiences a tidal range of 5-6 m. High tides often inundate the western part of the city. The city is governed by three bodies: Surat Municipal Corporation (SMC), Surat Urban Development Agency (SUDA) and the Hazira Development Authority (HDA). HDA governs the port and industrial hub located downstream from Surat city.

Much of the city is located <10 m above mean sea level. The city has a history of flooding with the earliest record of floods being that of 1869 (Bhat et al., 2013). Before a dam (named Ukai) was built in 1972 at Ukai situated 94 km upstream of Surat for controlling the recurring floods, most of the floods in the city were caused by heavy rainfall in the catchment area of Tapi River, 6% of which lies in Gujarat. The catchment area receives 90% of the annual rainfall between June and October, and most floods occur in the month of August (Bhat et al., 2013). Heavy rainfall in the

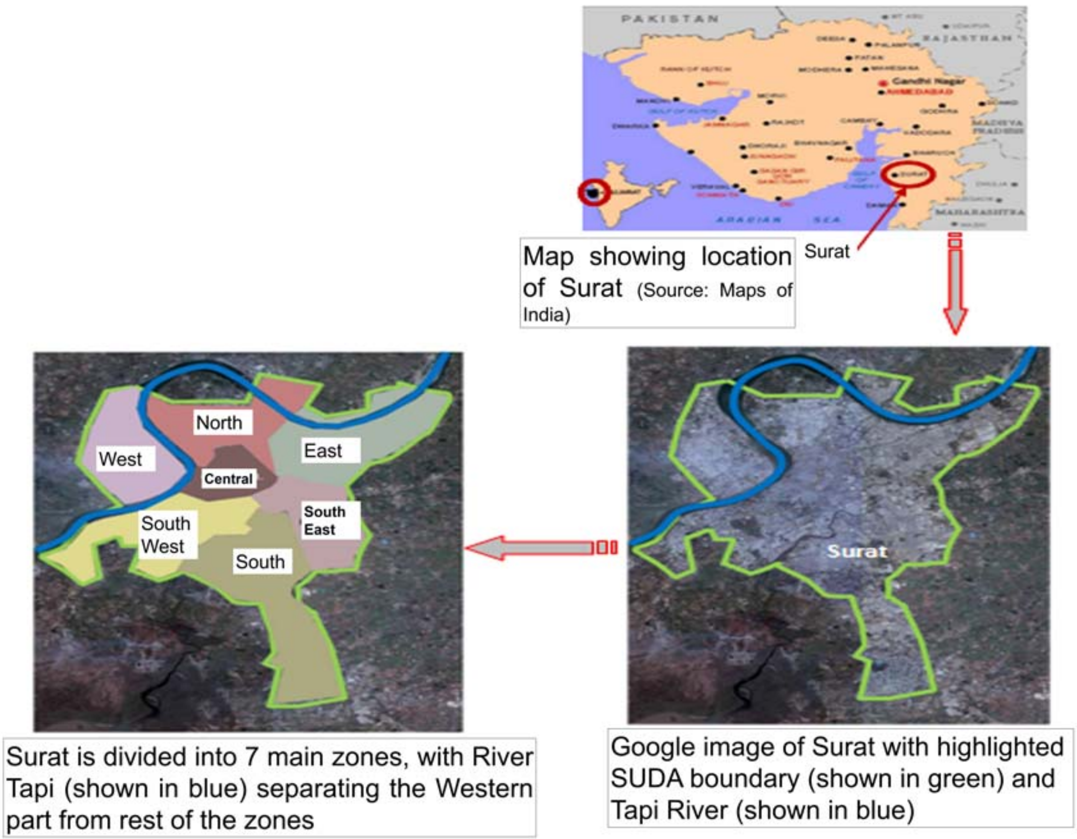


**Figure 1: Study Area**

catchment area results in heavy inflow of water into the dam's reservoir, which gets filled up often leading to heavy discharges from the reservoir, creating flood-like situation in the city.

The city has also seen dramatic expansion along both sides of the Tapi River since 1971. During the period 2001-2011, the city has recorded a decadal growth rate of 55.29% (https://www.suratmunicipal.gov.in/TheCity/Demographics). Large expansion in the built-up area, construction in floodplains, silting of riverbeds, building of bridges and weirs have reduced the capacity of the river to carry water. Encroachment in the adjoining floodplain area exacerbates flooding as the floodplain's capacity to hold the excess water gets reduced. The floods of 1968, 2004 and 2006 occurred due to heavy discharges from Ukai Dam which brought to the fore growing vulnerability of rapidly expanding population in Surat city. The 2006 flood was the most devastating of all since the construction of the Ukai Dam in 1971. It covered almost the entire city and more than 75% of the population was affected.

The catchment area of Tapi and the city may experience an increase in precipitation in the future due to climate change (Bhat et al., 2013). This may also lead to monsoons dominated by high intensity of rainfall for a shorter duration, followed by drier spell of longer duration (Bhat et al., 2013). This may lead to an increased frequency of floods in the future with potentially heavy discharges from Ukai Dam as the reservoir might get filled up faster. Thus this becomes highly important that we model the future discharge scenarios from the Ukai Dam to know the inundation level in the city in such scenarios. This information will help plan the adaptation strategies to reduce the vulnerability of the people to flooding events.

## 3. Methodology, Data and Materials Used

The approach to assess the vulnerability of the city to floods involved the following steps: develop a contour map of the city with 0.5 metre intervals; develop a hydrological model for the flows in the Tapi river to assess submergence areas and depth; simulate inundation levels and depth for two flood scenarios: one corresponding to the flood of

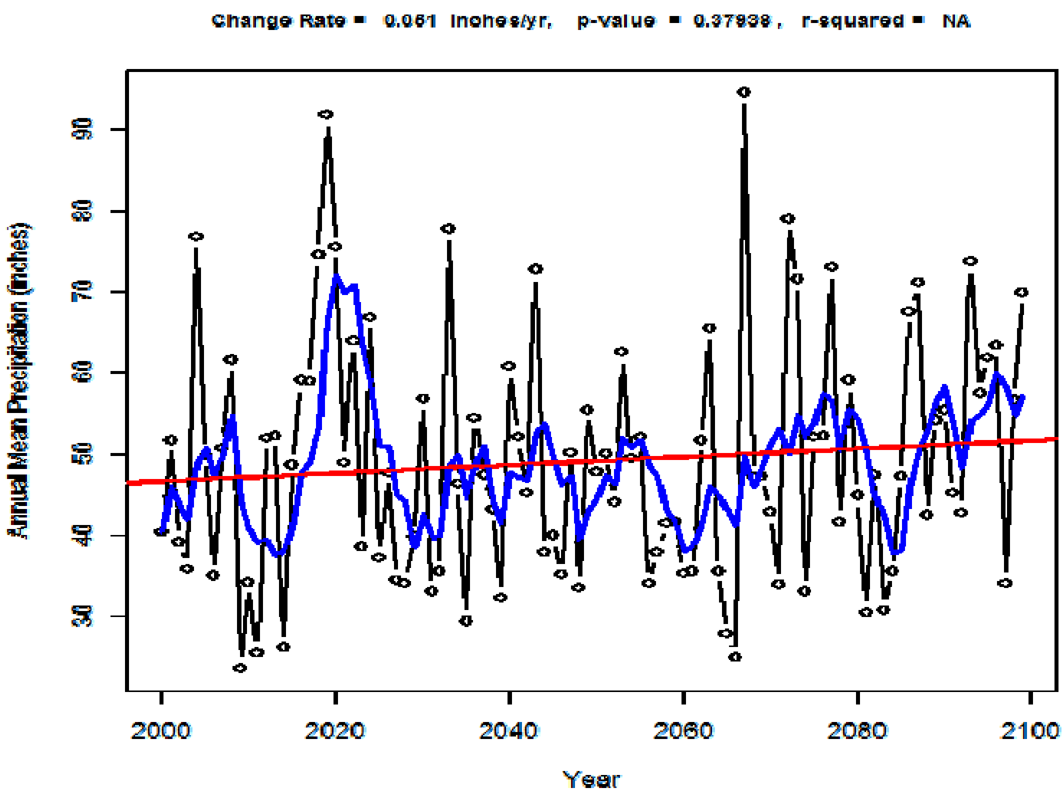


**Figure 2: Modeled average annual precipitation for Surat during 2000-2099 under SRES A2 scenario [Source: Hadley Centre (UKMO-HadCM3)]**

2006 and the other that can be expected due to climate change; locate critical infrastructure, sectors and identify their vulnerability; and draw some policy suggestions.

The methodology and data used for each of the above steps are as follows:

**i) Develop contour map of 0.5 m intervals on GIS platform:** This step involves GIS mapping of Surat city including its wards and zones. National Remote Sensing Centre's (NRSC) Geo-coded CARTOSAT-1D satellite imagery of April 2008 with spatial resolution of 2.5 m was analyzed. Contour maps for various city zones at 0.5 m interval were collected from the SMC (Surat Municipal Corporation) in Auto CAD format for the reference.

**ii) Develop a hydrological model for the Tapi River:**The water level and river discharge data from hourly to daily scales for three discharge stations: Ukai Dam, Kakrapar weir, and Hope (Nehru) Bridge were collected from the Flood Control Cell, SMC for the period from 2006 to 2010. Rainfall data were collected from IMD (Indian Meteorological Departments) stations for the period 1973-2010. All these data were fed to HEC-RAS (Hydrologic Engineering Centre-River Analysis System) hydrological model to predict extent and depth of flood. This model has the advantage (as compared to several other existing hydrological models) of requiring a limited number of parameters and thus can be easily customized to Indian conditions.

**iii) Develop inundation scenarios:** HEC-RAS model was used to simulate 2006 flow to assess submergence area and levels in Surat city. This model was used in conjunction with ESRI's ArcGIS and Leica's ERDAS IMAGINE and LPS (Leica Photogrammetric Suite) tool. Water surface elevations along the channels were computed in HEC RAS, HEC Geo RAS and the results were exported to the GIS, where the floodplain limits were delineated and flood hazard zones were mapped. In one scenario, the inundation due to discharge in 2006 was modeled. In the second scenario, inundation due to 50% higher discharge compared to 2006 was modeled. The second scenario was considered as explained later as the probable impact of climate change.

**iv) Critical infrastructure and sectors vulnerability analysis:** This has been done by ground surveys of the exposure and susceptibility of basic infrastructure services and their facilities, e.g. schools, hospitals, buildings (public and private), slums, industries, etc. Interviews of persons covering households, administrators, professionals, slum dwellers, etc. in selected locations of the city to identify and assess the different vulnerabilities of various infrastructure and social groups to floods.

## 4. Flood Scenarios in Tapi River

Surat is highly vulnerable to flooding because much of the city is in the low lying areas. The city receives an annual rainfall ranging between 950-1200 mm. About 90% of the rainfall occurs during July to September. An analysis of climate modeling results indicates a higher probability of increased precipitation in the future (Fig. 2). The modeled average annual rainfall for Surat for the period 2000-2099 is shown in Fig 2. In the year 2006, the rainfall was around 50 inches. As per the modeled results (Fig 2), the highest rainfall projected is 70 inches for 2022-24 period, which is 40% higher than 2006 rainfall. One can thus expect 40% higher rainfall in the catchment area of the Tapi River due to climate change.

The inflow in Tapi at Surat is largely determined by discharges from the Ukai dam. The extent to which the reservoir can be used to store water is limited by its capacity. Fig 3 shows the inflow, discharges and reservoir level during the 2006 flood. It can be seen from the figure that the inflow increased from 1,00,000 cusecs to 4, 00, 000 cusecs in six hours and to 12,00,000 cusecs in 30 hours (Fig 3). It remained above 4, 00, 000 cusecs for more than 4 days. The reservoir got filled up in two days even though the discharge level was raised to 8,00,000 cusecs and remained above that for two days. Given that the capacity of the reservoir is fixed, once the reservoir is full, discharges will reflect rainfall. Considering all the above arguments, we have taken 50% higher discharge inflows from Ukai Dam relative to 2006 discharge as the probable impact of climate change.

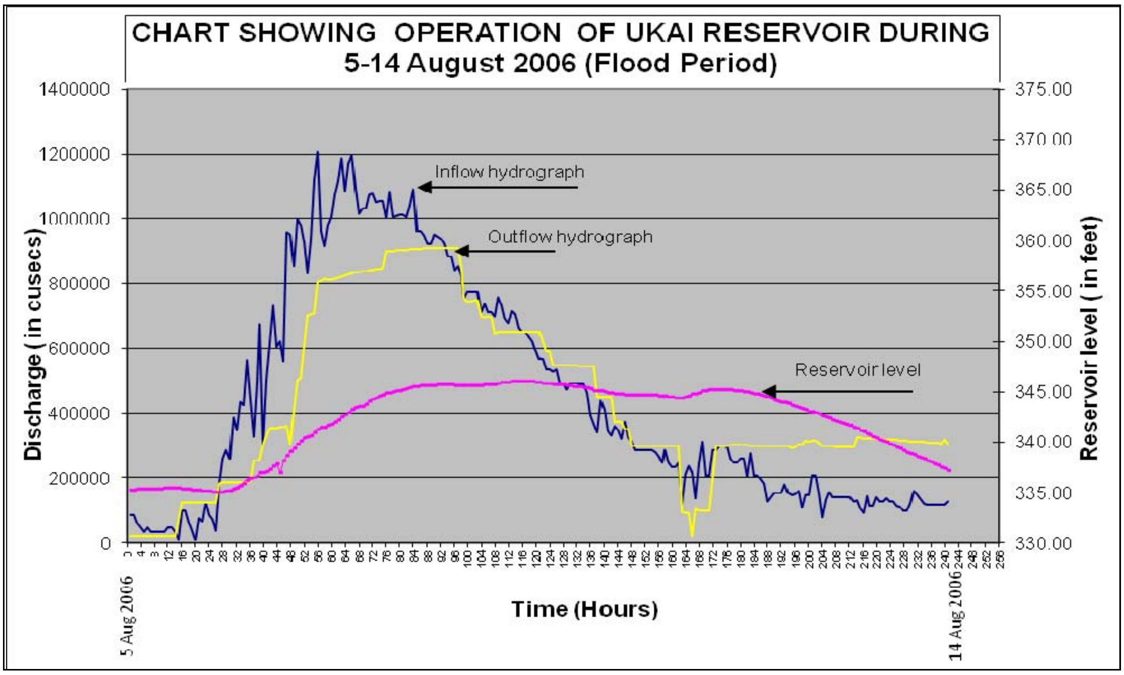


**Figure 3: Chart showing operation of Ukai reservoir during 5-14 August 2006 (*Source*: Irrigation Department, Surat)**

## 5. Vulnerability of Surat

Two scenarios analyzed to assess the vulnerability of the city to flood are:

**Scenario 1**: This scenario corresponds to km upstream of the city. This led to submergence of 270 sq km area out of a total city area of approx. 320 sq km. Most of the west, north, central and southeast zones of the city got submerged (Fig. 4). In particular,

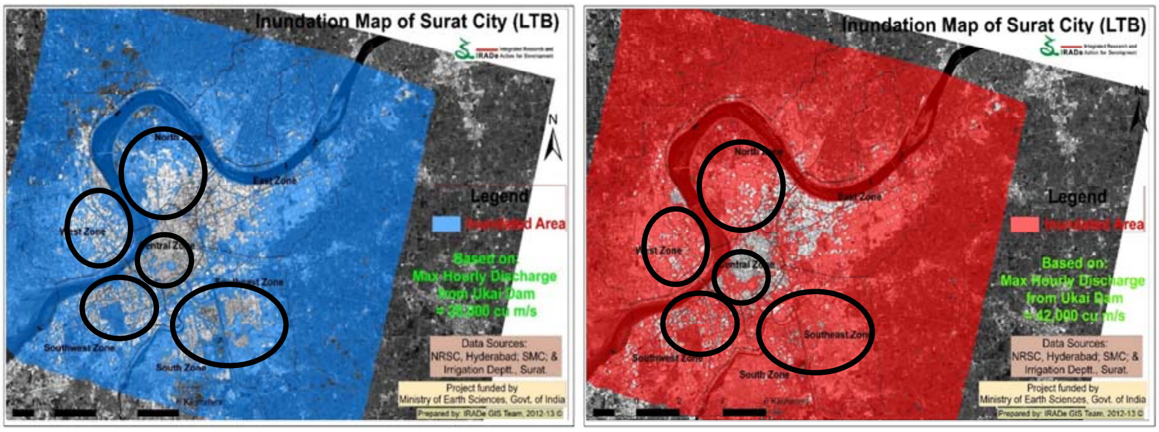


**Figure 4: Area inundated in Surat in the two scenarios (black circles highlight areas with potentially more inundation in second scenario)**

2006 flood when a volume of 28000 cubic meter (cu m) water was discharged per second from Ukai dam which is situated 94 more than 90% of the west and north zones was covered by water.

**Scenario 2:** In scenario 2, when 50% higher (i.e. 42,000 cu m per sec) water is discharged, then almost 295 sq km area would get submerged, an increase of 9.25% over that of 2006 level. Fig 4 clearly depicts that 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

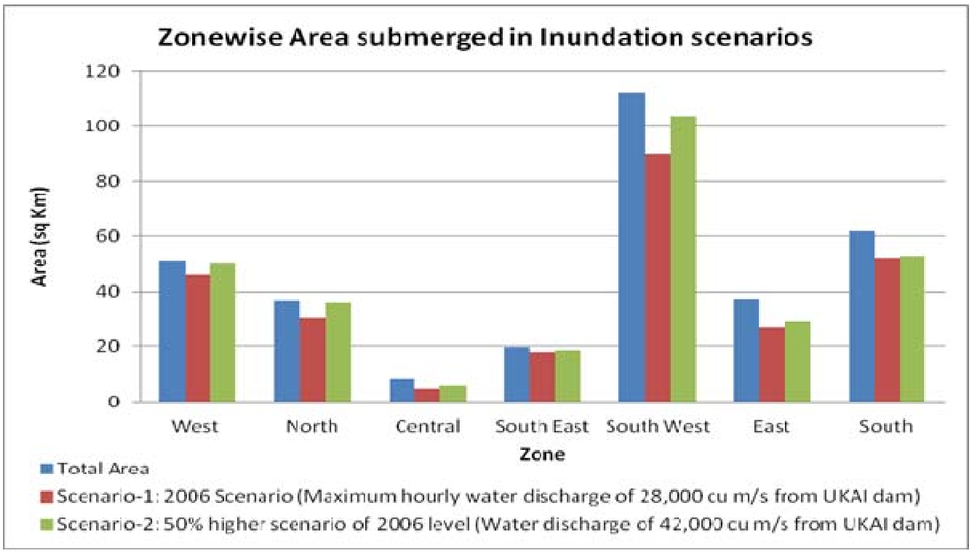


**Figure 5: Zonewise area submerged in Inundation scenarios of Surat City**

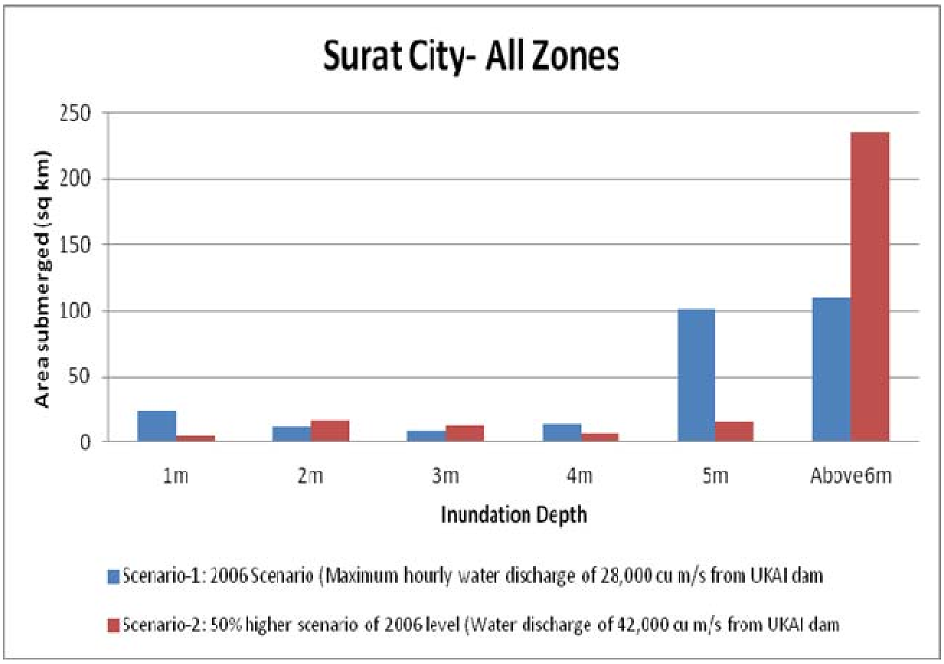


**Figure 6: Area submerged to different depths in Surat city in the two inundation scenarios**

Though the differences in area covered in the two scenarios are relatively small, the difference in the area submerged during higher depth of submergence (when inundation depth is above 6m) in the two scenarios is striking. In the second scenario, 230 sq km area gets submerged under 6 meters of water level whereas in the first scenario about 100 sq km area was found under water level of 6 m. Figures 5 and 6 show this.

### 5.1. Socio-economic vulnerability of Surat

Socio-economic vulnerability was assessed by measuring the vulnerability of different sections of the society to floods in different parts of the city. To understand the impacts of flood of 2006, a field survey was conducted which included a variety of questions targeted at four sectors of the civil society, *viz.*, schools, hospitals, slums and industries. Stratified sampling method was used to collect the data from survey. The questionnaire was divided into 8 sections:

- Basic information about the selected area
- Infrastructure
- Water supply and sanitation
- Financial Management
- Past flood experience
- Effect of flood on various parameters specific to sector
- Flood warning measures
- Adaptation measures

### 5.2. Vulnerability analysis of schools

During the event of flood, schools experience three types of impacts: educational, physical and economic. Educational impacts include disruption in studying curricula, delaying of session and reduced quality of education as teachers and students have to rush through the studies to complete the remaining syllabus. Physical impacts include loss of touch with the studies and enhanced uncertainty regarding future plans. Economic impacts include the loss of income and additional expenditure for repairing damaged parts of the schools.

A total of 56 schools were surveyed from different parts of the city. 68% of the schools surveyed were located in north and west zones of the city which are more prone to impacts of floods. 30% of schools reported complete damage to furniture whereas 20% reported partial damage. The infrastructure damage also includes non-availability of safe drinking water, wiring problems, loss of books and documents and paralyzed/semi-paralyzed communication and transportation facilities.

### 5.3. Vulnerability analysis of slums

Surat has experienced rapid industrial development in last two decades resulting in rapid growth in the economy, an economy dominated by labour intensive activities fuelling the growth of slums. The city has 351 slums located in different zones of the city. The South East zone (76) has maximum number of slums followed by East zone (58), South zone (56), west zone (54), North zone (47), South West zone (35) and Central zone (25). Slums are characterized by high population density with minimum provisions of basic facilities like drinking water, roads, lights, sanitation etc. This makes this group highly susceptible to the impacts of disasters like floods. The slums surveyed are located in north, west, central and south zones of the city as these zones were identified as most vulnerable to floods. Almost all the households covered in the survey reported that they were affected during the floods and it caused loss to their property. Approx. 70% of the households reported that the water level inside the house was more than 50 cm. Entry of water in the house caused damage to the wall, floors and household items. After the water recedes, the people have to incur expenditure in repairing the damaged houses. People also reported an unusual increase in their medical expenses because of spurt in diseases like fever, chicken guinea, etc. Sanitation was the pressing concern.

### 5.4. Vulnerability analysis of hospitals

Surat has 678 hospitals, out of which 89.8% are private hospitals and 10.2% are government hospitals. A total of 50 hospitals were surveyed. Out of these 50, 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. It was found that 50 percent of the hospitals from the selected sample have only ground floor. They are the ones, which are more vulnerable to floods, because in case of flood they do not have any other place except for the building’s roof to rescue themselves. Vulnerability due to flood is influenced by many factors: level of submergence, preventive measures before flood, building construction, boundary wall, etc. During the flood in 2006, out of a total sample of 50 hospitals, 11 hospitals were located in the area submerged up to 1 meter, 11 were located in the area submerged up to 1 to 2 meter and 28 were located in the area submerged by more than 2 meters. 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.

### 5.5. Vulnerability analysis of industries

Surat has the 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 industries (SSI) registered (2003) in Gujarat, Surat districts have 41509 units comprising of 14.9 percent of total SSI units in the state. The 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 thousand workers. 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 sector.

The primary survey sample comprises 30 industries, 30 percent of which are medium scale industry and 70 percent small scale industries, scattered across four most vulnerable zones identified, namely East zone, North zone, South-East zone and South zone. Impact of the flood of 2006 was limited not only to production disruption, but it also caused an epidemic. Spread of epidemic was reported by 17 percent of the industries surveyed, in the post flood scenario. Post-flood disruption in transportation and communication also caused losses for the enterprises located in the flood affected areas. Losses due to transportation and communication disruption were reported by 53 percent of the enterprises covered in the survey.

## 6. Conclusions

In this study a hydrological model for the Tapi River was developed to predict extent and depth of flood in Surat city under two alternative scenarios of flows in the river Tapi. In the first scenario, we modeled the inundation in the city by considering the flow rate in Tapi River, which caused flood in 2006. Then we modeled the inundation for a hypothesized situation in which 50% increase of water inflow in Tapi River was considered. The second scenario was considered as a probable impact of climate change. The results show that more area will be inundated under high water depth if the flow in Tapi gets increased by 50 % with west zone and north zone found to be the highly flood prone zones while south zone being the least. Topographically also, west zone is the lowest zone and hence it has more chances of getting flooded severely. With the increasing population pressure and to accommodate the pace of development in the city, all new settlements have been established around the river width, riverbanks and the banks near west zone. Pal Patiya, New Haveli Temple, Bhulka Vihar School, Hanuman Temple, RTO building are some of such settlements, which make the river narrower. Rehabilitation or resettlement from riverbanks could be a promising option for decreasing the death toll in future floods

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