Hydroinformatics 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.

GIS and remote sensing based approach for urban flood-plain mapping for Tapi catchment

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Abstract: In India, flood occurs typically during monsoon season due to heavy tropical storms downpour and unregulated urban development. The floods during August 2006 in Tapi catchment caused greater damage to personal and property resulting into 300 people being killed and US$ 4.5 billion value 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 10m as 35-years return period, more than 80% land in west and south-west zone will be under flood against 40% in central, 33% in northern and 15% in eastern zones.

Key words: Flood, Hazard mapping, Hydraulic Remote sensing, Tapi river

INTRODUCTION

There was considerable increase in the occurrence of flood and flood related damages during 2006 globally. The flood events accounted for nearly 55% of all disaster registered and approx. 72.5% of total economic losses world-over. Flooding is considered as the world's most costly type of natural disaster in terms of both human causalities and property damage (ESA 2004). The annual disaster review indicate that flood occurrence has increased almost 10-fold during last 45 years, merely 20 events in 1960 to 190 events in 2005 (Scheuren et al. 2007). These extreme flood events have caused major damage to property, agriculture productivity, industrial production, communication network, and infrastructure parallax mainly in downstream catchment. Therefore, floods are posing a great concern and challenge to design engineers, re-insurance industries, policy makers and to the government.

In India, about 40 million ha of land is flood prone which is about 12% of the total geographical area of 328 million ha of the country. The flood occurs typically during monsoon season (July to September) caused by formation of heavy tropical storms, ever decreasing channel capacity due to encroachments on river beds and sometime due to tidal backwater effect from the Sea. The India sub-continent in general and Western peninsula in particular has experienced heavy floods during August 2006 that caused greater damage to personal and property. The arid regions in Rajasthan and Gujarat to humid regions in North-East were caught with surprise. It is estimated that a single flood event in lower Tapi basin, a river strech between Ukai dam and Arabian Sea during 7-14 August 2006 resulted in 300 people being killed and approximately Rs. 20,000 Crore (US$ 4.5 billion) of property damage. The human life was stand-still for almost 2-weeks in Surat and Hazira twin cities, as well tens of rural villages along lower Tapi basin. The Tapi River in Surat has recorded highest water level during last 35-years. Therefore, it becomes prime importance to minimise the property damage, reduce infrastructure disturbances, and identify zones and building structures having greater flood hazard and flood risk.

It is at the strategic planning level that the possibility of utilising information available in cartographic forms assumes significant importance for urban flood mapping. However, a major contribution to flood mapping and planning is derived from the information made available by use of remote sensing technologies and its integration with Geographical Information system (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. The evaluation of flood risk is generally based on a two stage procedure: In first stage, the statistical probabilities of stage-discharge characteristics of river sections are calculated. Thereby bringing about the over-bank flow and river sections at which the flow exceeds the carrying capacity of the river channel. In addition, measurements for critical channel sections are undertaken to assess the hydraulically determined characteristics of the section of river course. In second stage, the inhabited areas falling in the greater or lesser flood risk zone are evaluated based on relief map and high resolution remote sensing imagery. Research on flood risk mapping (Singh et al. 2005, Miwa et al. 2003) reveals that three elements such as maximum water level, the velocity of water flow, and the amount of time flood remains in given land area are essential to evaluate possible damage. The described requirements are to be essentially considered for preparation of urban flood management and risk plan.

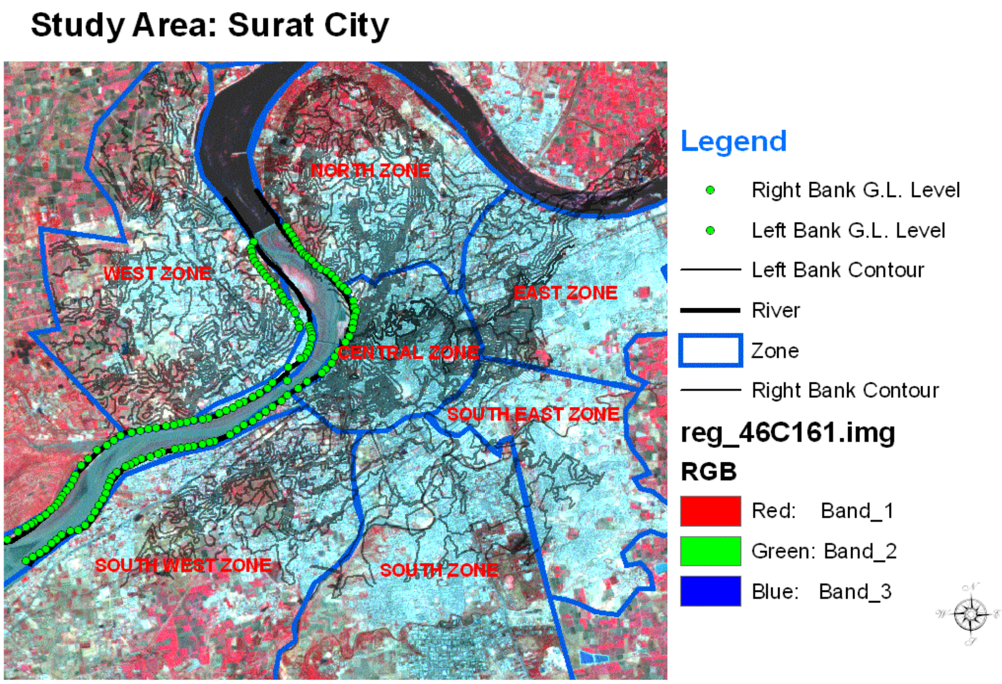
STUDY AREA

Tapi is the second largest westward draining inter-state river in India after mighty Narmada River. It covers approximately 51504 km2 (79%) in Maharashtra, 9804 km2 (15%) in Madhya Pradesh and 3837 km2 (5%) in the Gujarat state. The basin finds its outlet in the Arabian Sea that is bounded on the three sides by the hill ranges. The Tapi River and its tributaries flows over the plains of Vidharbha, Khandesh and later to Gujarat, and can be divided in three zones, viz. Upper Tapi basin, Middle Tapi Basin, and Lower Tapi Basin (LTB). The portion between Ukai Dam to Arabian Sea has been considered as LTB, mainly occupying Surat and Hazira twin city along with tens of small towns and villages along the river course. The Surat and Hazira twin cities are downstream of Ukai Dam almost 100 Km distance and are affected by recurrence floods at regular intervals.

The LTB receive an average annual rainfall of 1376mm, and these heavy downpours result into devastating floods and water loggings 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 in the LTB are cotton and maize followed by Soybean. The land use prevailing in the study area is mixed forest, agriculture land, rural and urban settlements. The topography in LTB comprises narrow valley and gently sloping ground. Figure 1 below shows the spatial location of study area Surat City along with relief and administrative zones. The main reasons for flooding in LTB depend on heavy rainfall and discharge due to high water levels from Ukai dam. Therefore, the flood problems of the river system are inundation due to over flowing of the banks, inadequate drainage capacity of the river, congestion at the point of confluence, and excessive silt load factor.
In order to assess the geographical impact of flood in the IRS-1D LISS IV with PAN satellite data at 5.8m resolution has been procured. Besides IRS-1D PAN Data, high resolution Google-earth data at sub-meter scale were downloaded. The hydraulic data on river cross-sections including channel levels, hourly gauge discharge measurements for three stations in and around Surat City have been collected from several sources. GIS analysis was conducted for all seven zones of Surat Municipal Corporation.

The data used for conducting present research work includes Geo-coded Indian Remote Sensing (IRS-1D) satellite image of April 2005, several Survey of India topo-sheets at 1:50000 scale, high resolution Google-earth images and physical measurements for river hydraulic parameters obtained during end of 2006. Contour maps for various city zones at 0.5m interval were collected from Surat Municipal Corporation (SMC). More than 200 river channel sections at a mean distance of 150 to 200m were measured by Irrigation Department for LTB between Ukai dam and Magdala weir. The water level and river discharge data from hourly to daily scales for discharge stations viz. Ghala, Mandavi, Ukai Dam, Kakarpar weir, Singanpur Weir, Hope (Nehru) Bridge were collected from Central Water Commission, State Water Data Centre (SWDC), and Irrigation Department respectively. All the data were attributed to be put into digital database management system (DBMS) using GIS software. Time series data on stage and discharge that stored as *.ASCII format have been linked with GIS software based analysis tools. In this paper high resolution remote sensing images from Google-earth and IRS-1D are combined with river hydraulic analysis and digital elevation model (DEM) to identify the flood susceptible areas.

Fig. 1 Satellite image of IRS-1D LISSIV [illegible] river



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 IRS-1D and Google-earth,
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 customised DBMS tools.
Step- 4 being generation of thematic maps and
Step- 5: the analysis of results and delineation of areas under various degrees of floods. The above methodology has been applied to prepare a flood potential and risk map for Surat city.

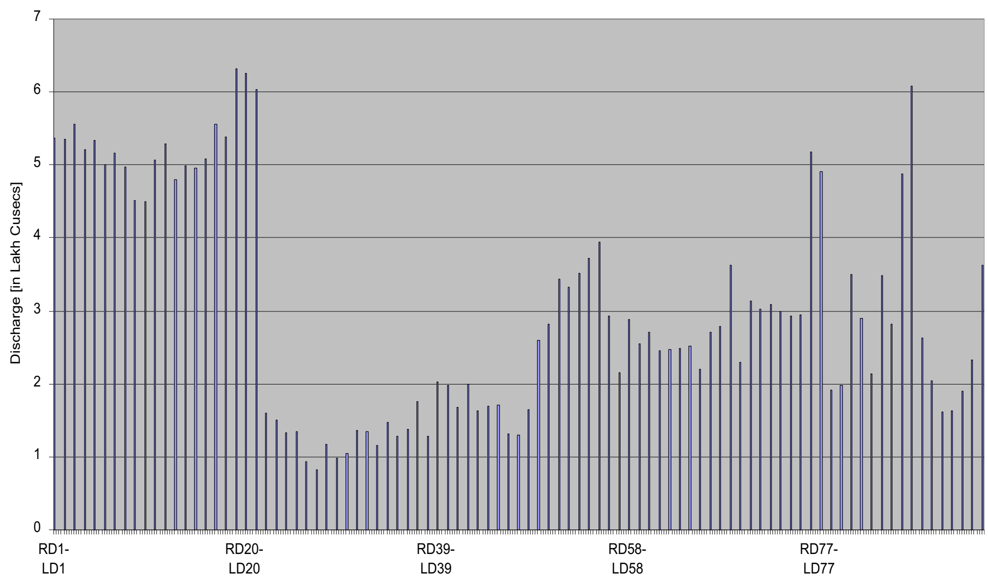
RESULTS

River discharge capacity using hydraulic data

In the study area, Ukai is a multi-purpose reservoir and is designed to cope with project flood of 49470 cumecs (17.48 Lac cusecs) and a probable maximum flood of 59880 cumecs (21.16 Lac cusecs). The provided spillway has a capacity of 16.34 Lac cusecs. On the other hand the safe carrying capacity of the river channel below Ukai dam considered to be 8.5 Lac cusecs. The river channel carrying capacities have been calculated from river section data collected after August

2006 flood using Bathymetry method in GIS environment as shown in Fig. 2 (a) and (b).

Fig. 2 Analysis of discharge carrying capacity at different river channel sections based on hydraulic model between weir to Arabian sea. Surat City falls under sections RD22-LD22 to RD54-LD54 as shown in figure below.



The field data on river cross-sections were collected immediately after the August 2006 flood event and we have calculated the river carrying capacity. Therefore, this section increases the flood risk in and around neighbouring areas. In our analysis on river channel sections it is found that the peak discharge capacity has been reduced as low as 1.2 Lac cusecs at Viveknand Bridge. Hence, the discharge in the river channel above 1.2 Lac cusecs will lead to flooding and this flood volume will lead to submergence of west zone and central zone of Surat city.

The safe water carrying capacity of the Tapi river near Surat is reported to have been significantly reduced due to, encroachment in the flood plain areas, silting in the river-bed, and afflux caused by Singanpore weir constructed on the river very close to the city. It is assessed that the river at Surat can carry only between 2 to 4 Lac cusecs without causing significant damages to urban dwellings and infrastructures.

Analysis of flood frequency at selected stations

The flood frequency analysis of water level and discharge data shows that there was a likelihood of flood hazard once in 8-yaers till 1998 that has increased during recent decade to one in five years. Fig. 3 shows the flood frequency analysis at Ghala discharge station for 5, 10, 15, 20 and 25 years return period. It is estimated that discharge will exceed or equal to 1.0 Lac cusecs each 17-years, 2.0 Lac cusecs each 21 years and 4.0 Lac cusecs each 25-years. The 25-years flood will results into several area being under flood risk and river bank breach at several locations. For quantification of flood prone area thematic map based on Google-earth and IRS-1D data and reveals that more than 80% of the urban area in Surat city can be under flood for an event of 50-years return period.

Fig. 3 Probability analysis of flood frequency and flood occurrence at Ghala river section upstream Surat City

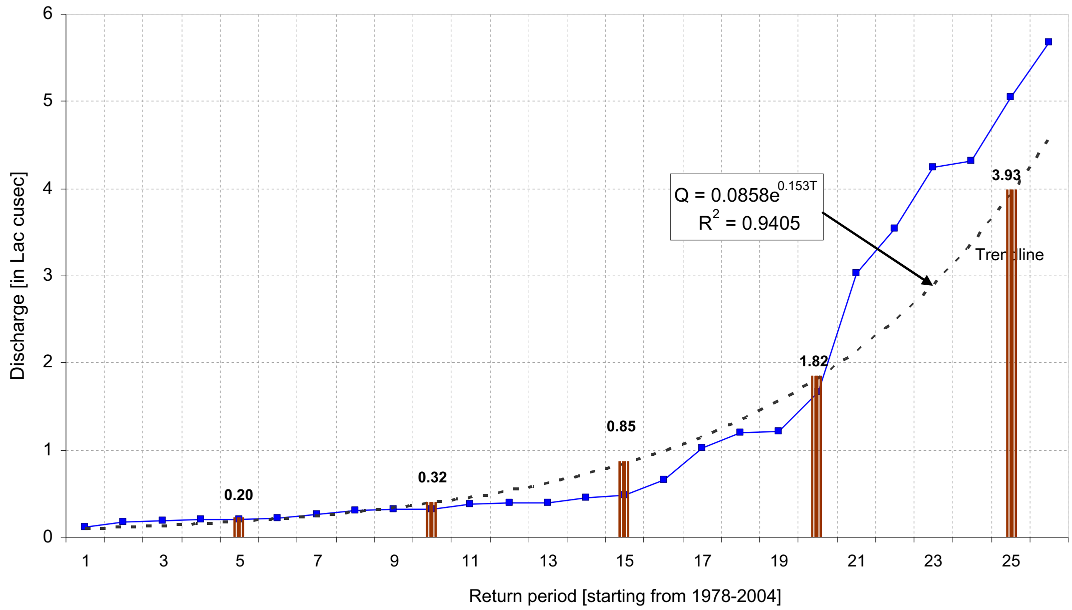
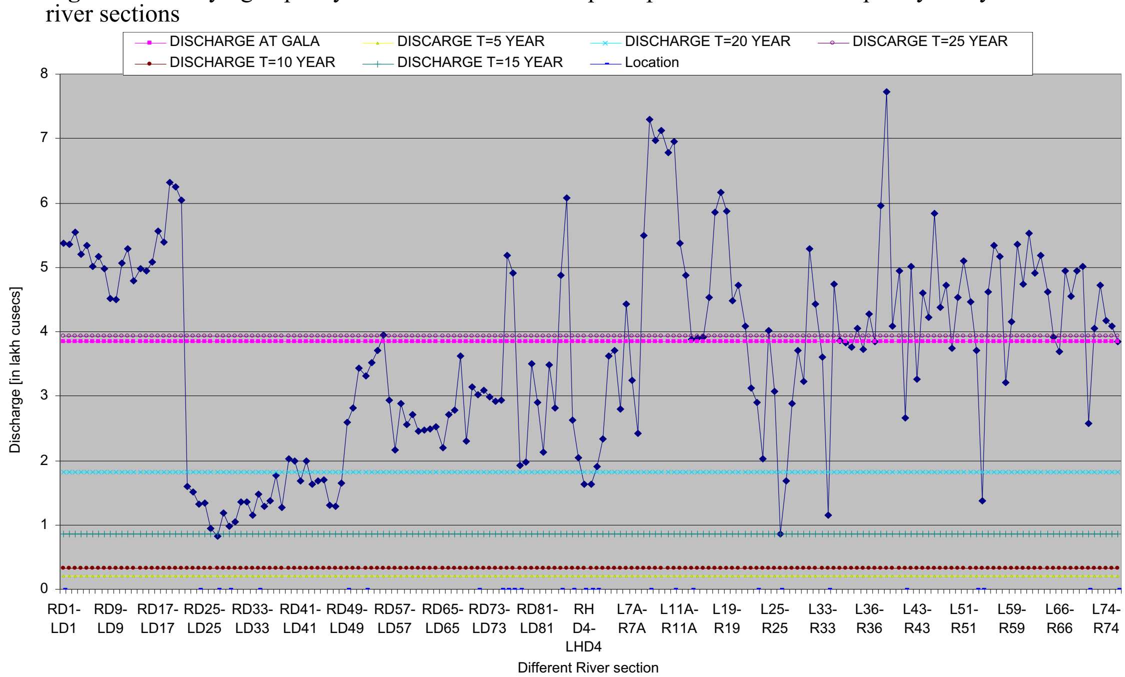


Fig. 4 Safe carrying capacity at river sections are superimposed with flood frequency analysis for all river sections

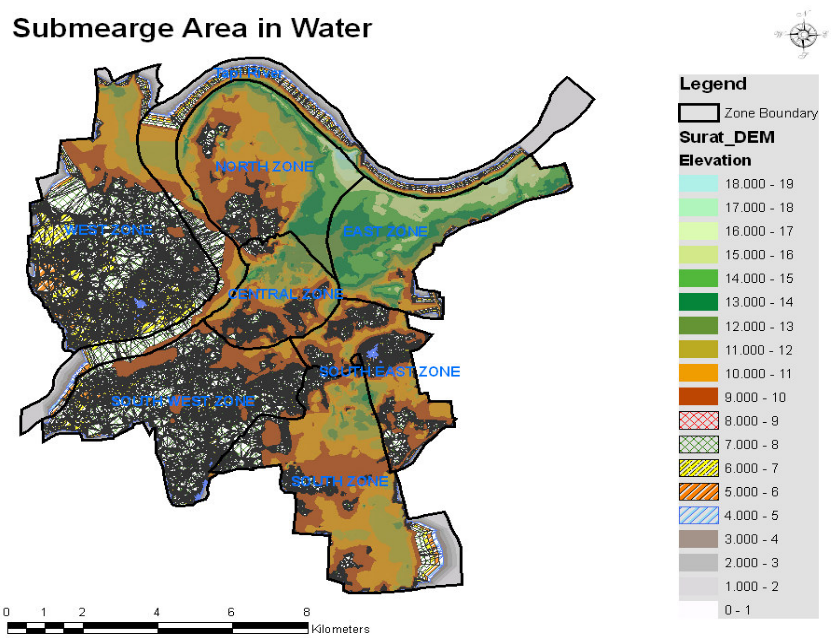


Flood hazard mapping using remote sensing data

Based on the contour levels supplied by SMC a digital elevation model (DEM) for west zone was developed. After combining the DEM with river bank levels a flood risk map for various water level scenarios at 0.5m intervals are prepared as shown in Fig. 5. The sample flood mapping potential areas for the west zone has been demarcated. The possible areas under each water level heights are depicted with variable colour as flood hazard map. After generating the flood risk map, the water levels of 2006 flood have been compared with Hope (Nehru) Bridge. It is found that Hope Bridge has a bank level of 4.1m, therefore there will be between 3-4m water in the right bank area. Hence the major parts of Adajan area will be under water submergence. The Rander area will also get submerged in water between 1-2m as was experienced during August 2006 flood. This shows the accuracy of our hydraulic and GIS model for flood mapping.

In addition to flood mapping, the flood hazard map can also be prepared. This can be done by multiplying a priori probability map which indicate the degree of danger to the map derived from the analysis of historical events. The field data for August 2006 and September 1998 are under progress and we expect to get good results in few months to come.

Fig. 5 Estimated flood hazard map of Surat City showing various zones and probable flooding potential



CONCLUSION

The research study demonstrates the utility of high resolution remote sensing images combined with field data on river hydraulics in delineating the flood prone area. The quantification of area vulnerable to flood under different frequency of occurrence has been studied. The future scope lies in applying the methodology for preparing the flood risk for the entire Surat city under varying scenarios.

Acknowledgements This research work is being carried out under ISRO-RESPOND research grant sanctioned to Dr. Anupam K Singh. We are thankful to Mr. M K Dixit, State Water Data Centre Gandhinagar; Mr M K Singh, Narmada-Tapi Basin Organisation Gandhinagar; Mr. K B Rabadia, Water Resources Investigation Circle Surat for supplying hydrological and hydraulic data. The research assistant and field support provided by Mr. D P Patel is appreciable.

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