Base Document
1st National Working Group Meeting

IGCP 582
TROPICAL RIVERS
HYDRO-PHYSICAL PROCESSES, IMPACTS, HAZARDS AND MANAGEMENT

Edited by
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Geological Survey of India
Central Region
Seminary Hills, Nagpur, India

FOREWORD

The 1st meeting of the International Geological Correlation Programme (IGCP) –now called, 'International Geoscience Programme' is a platform for eminent geoscientists to collaborate and exchange ideas, experiences in the field of earth sciences. IGCP is a unique collaboration between International Union of Geological Sciences (IUGS) and United Nations Educational, Scientific and Cultural Organisation (UNESCO), for last three decades working in global environment, natural resources, natural hazards etc.

IGCP activities in India is monitored by the Indian National Committee (INC). INC is headed by Director General, Geological Survey of India (GSI) as its ex-officio Chairman. INC also has members from ONGC, NGRI, AMD, WIHG, BARC, CGWB, CWC, SINP, etc.

IGCP-582 in particular is a consortium of professionals to interact on hydro-physical processes, hazards and management of Tropical Rivers. IGCP-582 consists of professionals from geoscientific organisations like NGRI, NIH, WIHG, ISM and academicians from University of Lucknow and CEPT University. This group will work on various aspects of tropical river system with special emphasis on the Holocene period of earth's history.

This compilation of work provides a glance of the experience of the distinguished experts in this subject field, who will work together for the next 4 years in the identified areas.

I take this opportunity to convey my best wishes to the newly selected NWG members and wish the IGCP-582 all success in its initiatives and endeavour.

29.09.10
Dr. K Rajaram
Deputy Director General, Op. Maharashtra,
Head Mission II, Central Region
and
Chairman IGCP 582

FROM THE DESK OF THE DEPUTY DIRECTOR GENERAL AND HOD, CENTRAL REGION

The Geological Survey of India, as the nodal agency for Indian National Committee (INC), implements IGCP Projects in India. IGCP 582 on Tropical Rivers is one such programme that is being taken up this year to continue till 2014 in India. It gives me immense pleasure to know that the 1st National Working Group (NWG) meeting for the prestigious IGCP 582 which has tremendous societal values is being organized at Geological Survey of India, Central Region, Nagpur.

I look forward to active participation of the geoscientists and brainstorming sessions from this 1st NWG meeting. I extend my best wishes to all the participants in this regard.

I extend my sincere thanks to Chairman, IGCP, INC, Chairman, IGCP 582 and Member Secretary, IGCP, INC for providing logistics and infrastructural support. I also wish to place on record, the sincere initiative on the part of Convener, IGCP 582 , NWG members and officials associated with IGCP 582 secretariat at GSI,CR for arranging the meeting and bringing out a volume within such a short time span. I am confident that the deliberations will lead to fruitful contributions to the success of IGCP 582 Project.

29.9.10

Arun Kumar Mathur

Deputy Director General & HOD,

GSI, CR, Nagpur

INTERNATIONAL GEOSCIENCE PROGRAMME– 582

TROPICAL RIVERS: HYDRO-PHYSICAL PROCESSES, IMPACTS, HAZARDS AND MANAGEMENT (2009 - 2014)

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Section I

TROPICAL RIVERS: HYDRO-PHYSICAL PROCESSES, IMPACTS, HAZARDS AND MANAGEMENT (IGCP 582)

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Introduction

River systems are considered as the economic engine in tropical regions; they have a central role in electricity production, and sustain the bulk of agricultural production and other high-value economical activities based on natural resources extraction (mining, fishing, timber). At the same time they can also be drivers of natural disasters such as floods, bank erosion and rapid channel migration. The most recent example of this is the Indus floods in Pakistan which affected 14 million people and has devastated 1/5th of the country. Another major river disaster occurred in the Kosi river basin in north Bihar and Nepal affected more than 3 million people when the river avulsed by more than 120 km in August 2008 and the new channel, ~22km wide, carried 144,000 cusecs of discharge inundating large areas (Sinha, 2009).

Tropical rivers draining the wet and wet-dry tropics with annual rainfall totals more than 700mm/year occur in a variety of geologic-geomorphologic settings: (a) orogenic mountains belts, (b) Sedimentary and basaltic plateau/platforms, (c) Cratonic areas, (d) Lowland plains in sedimentary basins and (e) Mixed terrain (Latrubesse, et al., 2005). The size of the river basins varies from 10^4 to $6x10^6$ km^2 and all of them show clear high but variable peak discharges during the rainy season and a period of low flow when rainfall decreases. Some tropical rivers show two flood peaks, a principal and a secondary one, during the year. Large tropical rivers in different parts of the world have drawn particular attention and a range of subjects have been investigated including geomorphology, sedimentological and hydro-sedimentary processes, flood and paleoflood hydrology and tectonic/ fluvial processes relationships. However, bearing in mind the large extent of the tropical regions and the size of the rivers themselves, the knowledge base of the tropical rivers is still limited.

Keeping this in view, the ongoing IGCP 582 project on tropical rivers is focused on three principal research themes: 1) analysis of past and present behavior on key hydrophysical indicators of climate change (e.g. mean discharges, flood frequency, drought occurrence, sediment transport, geomorphic processes), and within the environmental systems (soil degradation, desertification, ecotope distribution); 2) study of spatial and temporal human impacts on land use (agriculture, deforestation, river engineering, mining) and related changes to water resources, considering the countries' policy and institutional framework; and 3) establishment of a set of methods on river management to decrease hydro-physical impacts of global change, flood disasters and direct impacts by river engineering and mining. This paper presents a synthesis of the major issues related to tropical rivers and challenges of research in this area.

Challenges of tropical river research

Large populations in developing economies, chaotic growth of urban areas and a sharp increase in water and power demands are some of the common problems in all tropical countries. The resources available and management strategies adopted to tackle geomorphic disasters, however, may be entirely different from country to country. These differences eventually affect the overall economic growth of the country. For example, Brazil, with a total of 8.5 million km^2 of area and around 190 million people, is considered as one of largest agricultural producer in the world because of a widespread agricultural area and intensive water management practices. On the other hand, millions of people in India live on rather rudimentary agriculture and face scarce availability of ground and surface water. This has obviously resulted in a much lower rate of growth in the agricultural sector in India and has also affected the water and power demands in many parts of the country.

Similarly, the overall increasing trends in sediment load in river basins of Colombia such as the Madgalena River are attributed to a range of anthropogenic influences including decrease in forest cover and increase in agricultural and pasture. In Argentina and Bolivia, the impact of land use changes in historic time scale is also dramatic and has been affecting some of the most productive fluvial basins of the world in terms of sediment production such as the Pilcomayo and Bermejo rivers. The environmental disaster is repeating now with the destruction of the Chaco and the Sub Andean forest along the socially and economically underdeveloped parts of these countries where flow some of the most avulsive rivers of the world. Another major concern can be identified in flood disasters while comparing different countries and regions. In Asia, the occurrence of floods is recurrent and catastrophic and even though some of the largest rivers of the world drain through South America, floods are not as much significant as in Asia and some basins of Africa

Human interference with the river systems has affected the natural flow conditions of tropical rivers in many ways. Construction of dams and barrages on major rivers affects the entire river system manifested as aggradation or degradation in certain reaches and alteration of natural ecosystem because of changes in supply of nutrients and sediments. Water pollution, produced by the influx of large amounts of mercury in the rivers, however, was significant, particularly along the Tapajos river basin affecting mainly a few minor tributaries. At present, gold extraction by garimpeiros is scarce and declining. Today mining in tropical countries of Africa is a huge and unknown environmental disaster. As a good example we can use Angola, where a good part of the fluvial systems has been affected by mining. The tropical rivers of New Guinea such as the Fly basin have been severely affected by mining extraction for decades. The Fly is a medium sized river and its sediment load was significantly altered by mining waste, increasing from 85 to more than 100 million tons/year (Milliman et al., 1999). Other estimations suggest annual additions of ~50 million tons of sediments through mining waste, out of which ~3% is transferred to the floodplain (Dietrich et al., 1999).

The IGCP 582 project: plan of action

The overall scope of the IGCP 582 project is to provide an integrated assessment of long-term direct impacts of climate variability and human-induced change and management of tropical rivers basins by identification, quantification and modeling of key hydro-geomorphologic indicators during the past and present times. The potential impacts of global change on fluvial systems and of their socio-economic implications will also be analyzed.

Research plan

Activity 1: Multidisciplinary Data Base on tropical rivers: Reports, data and spatial information (digital maps and images) will be available trough a web site

Activity 2: Reconstruction of climates and past environment using indicators of global changes

Activity 3: Analysis of hydro-geomorphologic parameters of Global change and mechanism of sediment routes

Activity 4: Analysis and compilation of recent flood disasters, investigation of the causative factors and debate on the efficacy of the existing flood control measures

Knowledge dissemination

A series of international meetings will be organized during the project duration. At least one intercontinental meeting will be organized to involve the majority of the participant researchers. With this objective we will encourage the inclusion of our IGCP meetings inside largest international meetings. Several meetings are planned to be organized in different parts of the world and they will announced form time to time to enable the researchers to participate and interact.

Concluding remarks

The IGCP is a unique platform that facilitates the interaction among the researchers across the globe. In tropical regions, it is a fact that generalizations are frequently encountered when comparing the different developing countries or "tropical" countries. The IGCP 582 project would contribute significantly towards understanding of tropical river systems in terms of their societal relevance as this will address the issues of river management and human intervention as well as the flood disasters which are often interconnected. The IGCP would facilitate the sharing of experiences of river management among the researchers from different parts of the globe and would therefore contribute directly to the Society.

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MORPHOLOGICAL MODELING WITHIN HOOGLY ESTUARY, INDIAN SUNDERBANS: A FRAMEWORK FOR COASTAL ZONE MANAGEMENT

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Abstract

The southern sea facing islands of the Indian part of the Ganges- Brahmaputra delta is constantly under threat due to natural causes and anthropogenic interventions. This demands implementation of viable management plan backed by scientific reasoning. In this backdrop, coastal area morphological modeling of Sagar Island located within Hoogly estuary was taken up utilizing map, imagery and tide gauge computed relative sea level rise rate for the period between 1942 and 2001. Spatio-temporal correlation based model was utilized to determine continuous variation of coastal configuration with varying relative sea level rise (RSLR) scenario. Present study indicates, with higher sea level rise greater amount of erosion is evident. 2.8mm/yr. of RSLR rate could be determined within Hoogly estuary which is not on the higher side. A good match between the projected configuration of Sagar Island and map data for same year determines the effectiveness of the model at least at decadal to sub decadal scale.

Key words: Ganges Brahmaputra delta**,** relative sea level rise, spatio-temporal correlation, morphological modeling

Introduction

The West Bengal part of the Ganges-Brahmaputra delta, popularly known as the Sundarban delta, is a system where intricate estuarine and coastal processes are influenced by adjacent marine, terrestrial and meteorological systems and the dynamic interface amongst the three. Being the center of population growth, coastal sea, ponds/wetlands, estuarine islands in this area are to sustain the negative impact caused by society's commercial, recreational, and residential activities. Additionally, natural forcing like sea level rise or climate change is a prime issue of concern for this vulnerable tract. Presently, this deltaic system is facing degradation due to natural and anthropogenic causes. Degradation of this littoral tract is manifested in terms of frequent embankment failures, submergence & flooding, beach erosion, siltation within embayment, saline water intrusion in the agricultural field etc (Hazra et al. 2002).

In the above perspective, viable coastal zone management options are to be adopted based on scientific approach retaining socio-economic use of the coastal zone complying with preservation of resources and nature values. Knowledge and understanding of coastal morphodynamic behaviour as well as middle to long-term developments therein is essential in this respect. Lack of data pertaining to this coast makes the task all the more difficult than expected and restricts proper estimation of impacts to be caused by the different coastal variables.

The present study is aimed at predicting evolution of Sagar Island located at the mouth of Hoogly estuary by a set of physical mathematical model through extrapolation of observed morphological behaviour of erosion-accretion. The long term goal of this study is to identify the coupling amongst the coastal processes and mainly two dimensional evolutions (shoreline change) of the form of deltaic island system of West Bengal with special reference to sea level rise which in turn is guided by climate change. This study is carried out so that a greater degree of certainty can be achieved while applying the output as a blue print for the coastal managers and planners for this vulnerable niche.

Geological and Geomorphological setup:

Ganges-Brahmaputra delta is located at the northern apex of Bay of Bengal. Quaternary outbuilding of the fine silt to mud dominated, macrotidal, lobate (Boyd et al., 1992) Sundarban delta took place following depositional regression of the sea during Middle Holocene. With a tidal range of about 3.5 to 5m in the estuaries and complex network of estuaries, creeks and islands, this delta is a classic example of tide dominated one and harbors the largest single continuous tract of mangrove forest. The Ganges-Brahamaputra delta is represented by a low-lying flood plain covering more than 90,000 sq. km in India and Bangladesh and grades into a more extensive sub-aqueous delta and deep sea fan complex. The main sediment sources for the delta and the fan are the Ganges and Brahamaputra rivers, with a yearly discharge of 1×10^9 t, with 80% of discharge occurring during the four months of SW Indian monsoon (Coleman, 1969).

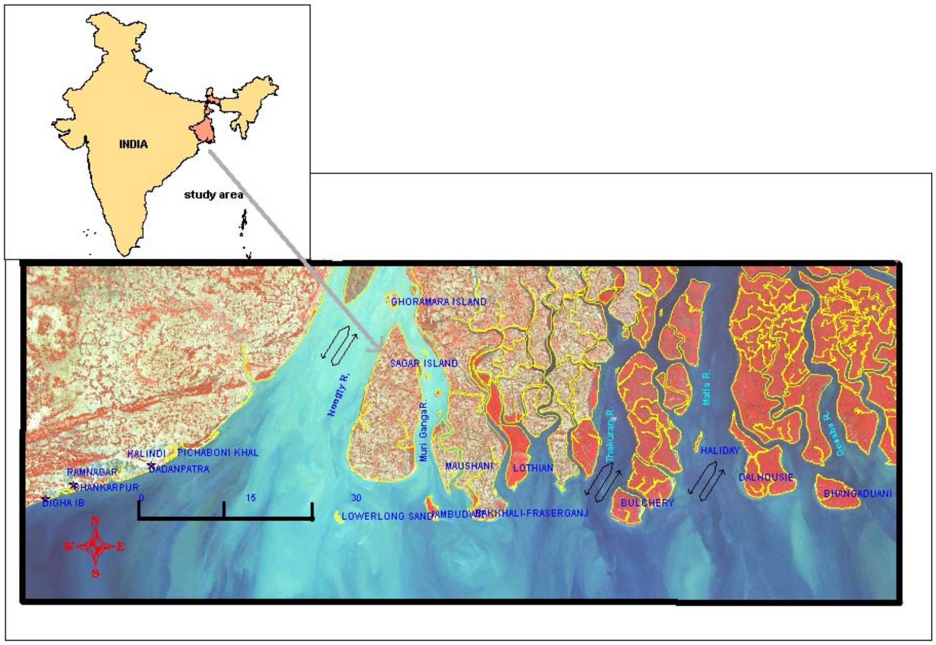

Figure 1. LISS III FCC showing the meso-tidal open coast (west of Hoogly river) and macrotidal Indian sunderbans (East of Hoogly river) and location of Sagar Island.

The deltaic deposit located at the mouth of Ganges-Brahmaputra is comparatively recent in origin. Morphogenetically, this delta is a product of fluvial, fluvio-marine and marine activities that form innumerable active tidal inlets of diverse shapes and dimensions. Varied geomorphological signatures viz. sand dunes, beach ridges, inter-tidal clayey/sandy flats, tidal shoals, etc. and evolved out of the dynamic and varied interactions of marine agencies like waves, tides and littoral currents, combined with fluvial and aeolian components. Following is the four-tier morphostratigrahic classification of the fluvio-marine depositional sequence propounded by Roy and Chattopadhyay (1997).

Four basic types of landforms of form-process interaction characterize the study area i.e., the fluvio-marine landforms, tidal landforms, wave generated landforms and, wind generated landform.

Table 1. Morphostratigraphy of the study area. (Source: Roy and Chattopadhyay, 1997).

Sundarban deltaic coast		Age
Active estuarine deposit	Channel bar, intertidal flat and abandoned creek with or without mangroves, no oxidation effect of sediments	Upper Holocene
Older estuarine deposit	Interdistributary supratidal flat	
Ancient estuarine deposit	Interdistributary stabilized supra-tidal flat	Middle Holocene

Sagar Island:

Sagar Island **is** located at the mouth of the Hoogly estuary at the western extremity of the West Bengal part of Sundarban delta. Sagar Island used to be a part of the single continuous stretch of mangrove ecosystem prior to 1811. The reclamation of this fragile island was initiated thereafter as it served as a source of revenue to British colonial government. The island became almost settled within next 125 years. According to the 1991 census the population of the island was 1,49,222 with a decadal growth of 39.9%. The natural processes like sea level rise, tidal action, current, wave etc. aided by anthropogenic interventions have resulted into accelerated rate of erosion of the coastal stretch of the island. Historical records indicate submergence of the Kapil Muni Temple, a significant cultural landmark created at the southern tip of Sagar Island for couple of times in the recent past (Bandyopadhyay, 1997). Apart from these the construction of Farakka dam upstream of the river Ganges has affected the sediment budget and other physical variables for this estuary (Basu, 2001).

Materials and methods:

Data integration in time series using GIS (MapInfo) and image processing (ERDAS Imaging) methodologies for Sagar island has been carried out using multi dated maps and imagery. Two types of data sources utilized for the present work include raster data and rate of relative sea level rise data. The raster data defines the initial condition for modeling for the three islands and includes 1942-SOI toposheet, survey year: 1921-23, 1973, 1971– SOI toposheets survey year: 1967-68,1968-69, 1989-LISS II FCC, 2001-LISS III digital data. Trend of shoreline changes is determined for Sagar Island through overlay analysis of the high tide line (HTL) between the above mentioned time frames.

Quantitative change detection analysis is carried out on the vectorised data set to estimate the nature and quantum of erosion and accretion for the islands. Limited ground truth input on HTL has been incorporated after field studies for the year 2000, 2001 for Sagar Island. Field traverses pertaining to physical identification of the zones of erosion and accretion in the year 2001 corroborate well with the zones of erosion and accretion while comparing 2001 and 1988 data.

The sea level data for this study has been collected from a precursor model on relative sea level variation for the West Bengal coast. The yearly average of rate of relative sea level variation is then calculated for the said time frames for the Hoogly estuary (Table 2). These data are being used in the present model for correlation purpose. The SLR, which is being measured by tide gauge, reflects the local relative sea level (RSL) oscillations.

Table 2. Relative/ local sea level input data.

Island	Time intervals	No. of years	RSLR input data (mm/yr.)
Sagar	1942-1969	27	3.3065
	1969-1988	19	3.55
	1988-2001	13	2.8

Coastal area morphological modeling:

Coastal area morphological modeling has become a useful tool in recent years. Coastal area models are mainly developed on the basis of measurement of physical variables of the coast. These models mainly account for shoreline response to sea level rise for open beach condition. Limited number of models provides insight into the coupling between shoreline and inlet processes that govern the overall adjustment to changes in sea level. Even if available, the predictive capacity of these models is limited to sub decadal time scale. The predictive capabilities of such models are limited depending upon among other things, the selection of physical processes included in the model, the natural scales of these processes as well as the extent to which they have been schematized and accuracy with which their respective forcing can be specified. This problem is avoided to some extent by adopting a "behaviour oriented approach" i.e., modes of coastal change are mapped directly onto a mathematical model instead of computing the same via underlying sediment transport processes (Hennecke et al., 2000). Thus a simple, alternative approach to assess coastal evolution in response to the different coastal processes including the role of sea level rise is also evaluated. (Thom and Roy, 1998; IPCC, 1996; Bakkar and De Vriend, 1995).

In the present study a statistical spatio-temporal correlation based model was developed correlating sea level scenario and change of coastal configuration (Ghatak and Sen, 2004). The evolution of Sagar Island in the past years (about 60 years for Sagar i.e., 1942-2001) around a common reference point i.e., the centroid of the first base year, is estimated by considering rate of radial shifts/change in the consecutive base years (say, for Sagar island it is 1969,1988,2001) in terms of erosion and accretion. Spatial data of each intersecting data points between the radial line and each base year HTL polygons are retrieved. Statistical correlation of rate of sea level change and rate of radial change both spatially and temporally are incorporated into the GIS environment by applying a functional relationship. Here, spatial as well as temporal data of positions are considered for correlation analysis to understand the impact of one location on the dynamic process at other locations. Rationale behind this hypothesis lies in the fact that hydrodynamics of river and sea is influenced by regional as well as local constraints. As a result of this, impact is felt at adjacent regions. The degree of impact again varies with positions from the zone of influence and so does the scenario for temporal changes. The projected output reflects the configuration the island is likely to attain with a particular sea level rise in the presence of set of other variables that were effective in the said time frame. Thus indirectly a coastal form-process approach is adhered to where the dynamics of sediment transport or deposition from one point to the other over a space of years is ultimately reflected in its form. The best correlated points, best correlated sea level value and rate of change are cast under the shield of a composite algorithm for Sagar Island to arrive at the projected outputs of the island configuration of the three islands at a desired SLR scenario. Three sea level rise scenarios are initially considered for Sagar island (including the maximum and minimum possible RSLR scenario for this region). This analysis is further carried out to find out the projected configuration of the islands under most suitable relative sea level rise (RSLR) scenario for a particular time interval by determining least area or shape deviation between projected data of a year (projected from a base year) with the particular HTL of the same year as available in the map. This predicted data is either projected from the previous base year, in case of forecast situation or projected from next base year in case of hind cast situation with respect to a particular base year.

Results:

Data analysis in the GIS platform reveals that the overall area of Sagar Island has decreased between the years 1942 to 2001 with an initial decreasing trend of total area between 1942 to 1988 followed by an increasing trend between 1988 and 2001. The southern sector of Sagar Island has been under the constant threat of erosion in the said time frame. The sites and rates of erosion and accretion are not constant in different intervals of the said time frame. At the eastern half of the island, south of Chemaguri Gang accretion is active and stabilization of the shoal by mangrove growth is taking place, while at the northeastern part significant erosion has taken place. The southern sea facing part of the island near Dublat, Kapil Muni’s temple, significant erosion has taken place in the model time frame.

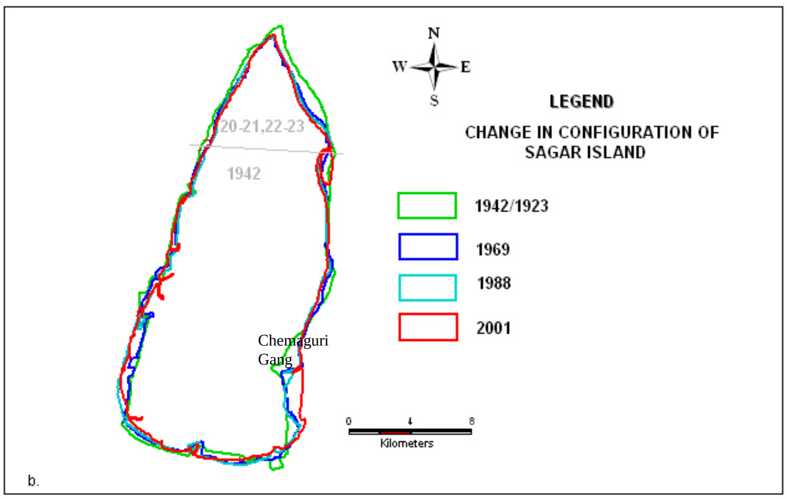

Figure 2. Area change of Sagar Island.

The initial estimate on the projected output of the island with these three different sea level rise rates (viz. 3mm/yr., 3.5mm/yr., 4mm/yr.) after five years (2006), ten years (2011) and twenty years (2021), projecting the same from 2001 shows that with increasing sea level accelerated erosion or maximum percentage area loss will occur (2.68% with RSLR of 4mm/yr.). Estimation of both shape and area change between the projected output and the original data set is carried out through GIS query using three different RSLR scenario viz. 3mm, 3.5mm, 4mm/yr. Area change is determined by measuring total area deviation between the projected year and reference year and shape change is determined by estimating total deviation in area of the projected data set in and outside the reference year. This is carried out to determine the order by which the projected configuration moves toward the dynamic equilibrium configuration for that reference year. The dynamic equilibrium configuration is achieved through continuous readjustment of the coast to the environmental changes over the geological/historical periods in the regional and environmental setting. The least deviation in total area or area deviation with respect to shape change provide comparatively accurate sea level rise rates for different time frames assuming that erosion and accretion are the effect of relative sea level rise for this region in the presence of other short-term coastal variables. Using the above mentioned RSLR it is seen that 3.5mm/yr RSLR between 1942-1969, 1969-1989 and 3mm/yr RSLR during 1989-2001 both for fore cast and hind cast situations provide least deviation in comparison to the available maps of that particular year. Further fine-tuning of data for RSLR is achieved by introducing smaller variation of the RSLR values for particular time period and calculating the least deviation between projected and observed configuration. This provides a suitable RSLR of 2.8mm/yr. for 1989-2001, 3.4mm/yr for 1969-1988 and 3.15mm/yr for 1942-1969. A good correlation between the projected and map data determines the effectiveness of the model at least at decadal scale.

Conclusions:

Use of this type of coastal area morphological model is advantageous as very restricted type of data (topographic maps and imagery, aerial photo and SLR data) can be utilized to provide modeling outcomes. Moreover, the dynamics of sediment transport or deposition from one locale to the other through space and time are indirectly considered into the model as the shoreline position reflects the dynamic equilibrium condition through continuous adjustments to the environmental changes over the geological/historical periods in the regional and environmental setting. The whole approach of the study including new type of modeling method adds a new dimension for providing the scientific background for formulating coastal zone management plans. The present knowledge base with further research in these directions is expected to open up new vistas. This work is a contribution to IGCP-582 project.

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FLOOD HAZARD MODELING AND FLOOD RISK ASSESSMENT FOR A RIVER BASIN

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Abstract

In recent years the number and scale of water related disasters, flood in particular has been increasing. The losses from floods often offset years of hard-won social and economic development. The problem is further expected to be aggravated with the phenomena of climate change. Therefore, mitigation and managing of flood hazards has become a priority for alleviating poverty, ensuring socio economic progress, preserving our eco-systems and ensuring the gains of development. The paper presents procedure for flood hazard modeling and flood risk zoning for a river basin. Floods of various return periods have been estimated using the L-moments approach. Rating curves have been developed employing the Artificial Neural Network and the least squares techniques. Depth of flooding, inundation for various return periods and risk associated with the flooding have been simulated using the HEC-RAS package. The flood inundation simulated by the HEC-RAS has been compared with the flood inundation mapped using the satellite data.

Key Words : Flood hazard, Hydrologic Modeling, L-moments, Flood risk zoning.

Introduction

Flood is the most frequent natural disaster claiming loss of life and property compared to any other natural disaster. About one-third of all losses due to nature's fury are attributed to floods. On an average floods claim a loss of more than 50 billion US dollars per year and 40000 victims per year in the last decades of the twentieth century in the world (Berga, 2000). In India also, floods are the most frequently faced natural disasters. As reported by Central Water Commission (CWC) under Ministry of Water Resources, Government of India, the annual average area affected by floods is 7.563 million ha. This observation is based on the data for the period 1953 to 2000 published in Indian Water Resources

Society (IWRS, 2001) with variability ranging from 1.26 million ha in 1965 to 17.5 million ha in 1978. On an average floods have affected about 33 million persons during 1953 to 2000 and average annual damage due to floods is about IRs. 46 billion. There is every possibility that this figure may increase in future due to rapid growth of population and increased encroachments of the flood plains for habitation, cultivation and other activities (Kumar et al., 2005).

Some of the important policies on flood management have been described by Kumar et al. (2005). Various types of structural as well as non-structural measures have been envisaged to reduce the damages in the flood plains in India. Construction of embankments, levees, spurs, etc. have been implemented in some of the states. The total length of constructed embankments is 16800 km and drainage channels are of 32500 km. A total of 1040 towns and 4760 villages are currently protected against flood. Barring occasional breaches in embankments, these have provided reasonable protection to an area of about 15.07 M ha. A large number of reservoirs have been constructed and these reservoirs have resulted in reduction of intensity of floods. The non-structural measures such as flood forecasting and warning are also being adopted. The flood forecasting and flood warning in India commenced in 1958, for the Yamuna River in Delhi. It has evolved to cover most of the flood prone interstate river basins in India. The Central Water Commission has established a flood forecasting network for 70 rivers basins covering 18 States/Union Territories. The forecasts are issued at about 175 stations. Out of these 145 stations are for river stage forecasts and 28 for inflow forecasts to the reservoirs. A Working Group of National Natural Resources Management System (NNRMS, 2002) standing committee on water resources for flood risk zoning of major flood prone rivers considering remote sensing input was constituted by the Ministry of Water Resources in 1999. The working group recommended flood risk zoning using satellite based remote sensing with a view to give thrust towards implementation of flood plain zoning measures. There is a need for taking more effective structural and non-structural measures of flood management and flood damage reduction based on long term reliable data, advance analyses and modelling procedures and antecedent rainfall forecasting using information based on radar, satellite based instrumentation and high resolution Numerical Weather Prediction (NWP) models. It also necessitates capacity building for implementation of these measures and bridging the gaps between the developed advance and robust procedures and their field applications.

Definitions of Terms

The definitions of terms (i) flood inundation map, (ii) flood hazard map, (iii) flood risk zone map and (iv) flood plain zoning map used in the study are described below.

Flood inundation map

A flood inundation map provides information about the areal extent of inundation for a reach of a river during a flood event when the flood water in the river overtops its banks and leads to the flooding of adjoining areas or flood plains. The flood inundation map for a reach of river may be prepared by demarcation with physical inputs i.e. by demarcating the various locations of the flood plains which get inundated during a particular flood, by hydraulic/hydrologic modelling and using the satellite data.

Flood hazard map

A flood hazard map provides information about the return period associated with the areal 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 frequencies. These maps may serve as important tools in proper flood plain management. It is necessary that the area flooded by a particular flood is shown by suitable colour scheme or designs on the map. In addition, explanatory notes, tables and graphs may also be provided with flood hazard maps to facilitate their use.

Flood risk zone map

A flood risk zone map provides information about the risk associated with the damages caused or losses resulting from a flood event in a particular area or flood risk zone. Preparation of flood risk zone map incorporates the financial aspects and provides the actuarial inputs for flood insurance plans and for other purposes.

Flood plain zoning map

A flood plain zoning map categorizes various zones based on administrative legislations for planning and development of the flood plains for various purposes such as agricultural activities, play fields, industrial areas and residential areas etc. Preparation of flood plain zoning maps takes into consideration the inputs from flood inundation, flood hazard and flood risk zone maps.

Methodology

The methodology for flood hazard modeling and flood risk zoning for a reach of a river basin is briefly described as follows. The objective of the study are: (i) to develop L-moments based flood frequency relationships using the annual maximum peak flood series and the partial duration series for the gauging sites of the river reach, (ii) to develop rating curves for the gauging sites of the river reach, (iii) to prepare flood inundation maps for the river reach, (iv) to prepare flood hazard maps for the river reach, (v) to prepare flood risk zone maps for the river reach and (vi) to predict flood inundation and flood hazard areas for various stages of river flow.

In the study, risk is defined as the probability of occurrence of a flood at least once during successive years of design life. The return period for which a structure should be designed is computed based on the risk acceptable. Risk acceptable depends upon economic and policy considerations. If for a time invariant hydrologic system the probability of occurrence of an event, x, greater than the design event, x_o, during a period of n years is P, then the probability of non-occurrence, Q is 1-P. The probability that x will occur at least once in the n years i.e. the risk of failure, R is: $R = 1-(1-1/T)^n$; where, R is the risk, T is the return period for which the structure should be designed, and n is the design life of the structure (Robson & Read, 1999). Using the above formula, the return period T can be determined for a given R (acceptable risk) during a period of time in years (n). The flood corresponding to this T is estimated and routed through the river reach for estimation of the water surface profile and inundation mapping. The expression of risk mentioned above may be extended to incorporate other variables related to losses due to floods, which can be defined as functions of return period (T). The flow chart illustrating the general terminology of flood inundation mapping, flood hazard mapping, flood risk zone mapping and flood plain zoning is shown in Fig. 1.

Analysis and Results

In the study, flood frequency analysis has been carried out using the L-moments approach (Hosking & Wallis, 1997; Kumar & Chatterjee, 2005; Kumar et al., 2003). For identifying the robust frequency distribution for the respective gauging sites, L-moment ratio diagram and Z^{dist} statistic criteria have been adopted. Table 1 gives the Z^{dist} statistic values for seven sites of the study area. The values of the parameters of the robust identified distributions for the stream flow gauging sites are given in Table 2. Floods of various return periods viz. 2, 10, 20, 25, 50, 100, 200, 500 and 1000 return periods have been estimated for the seven stream flow gauging sites of study area, using the robust identified frequency distribution for each of the stream flow gauging sites. The Digital Elevation Model (DEM) of the study area has been prepared employing the GIS package Arc View 3.2 (Fig. 2). Rating curves have been developed using the least squares approach and the Artificial Neural (ANN) technique (Kumar et al., 2004). The mosaic of satellite data for the study area covered in three satellite scenes of IRS 1C and 1D has been prepared and flooding for some of the previous years simulated by the hydraulic modelling have been compared with the spread of flooding over the flood plain estimated from the analyses of the remote sensing data using the GIS package ERDAS. Hydraulic modeling of the river reach has been carried out using the HEC-GeoRas 3.1 and HEC-RAS 3.1.2 (Hydraulic Engineering Centre-River Analysis System) packages developed by the U.S. Army Corps of Engineers. Fig 3 shows flood plain area inundated and depth of flooding for 1000 year return period flood for the study area. Fig 4 illustrates flood plain area inundated for various return periods for the study area. Flood risk zone maps have been prepared for various risk levels and for different durations of flooding. Fig 5 shows flood risk zone map for a risk (R) of 25% over a period (n) of 25 years.

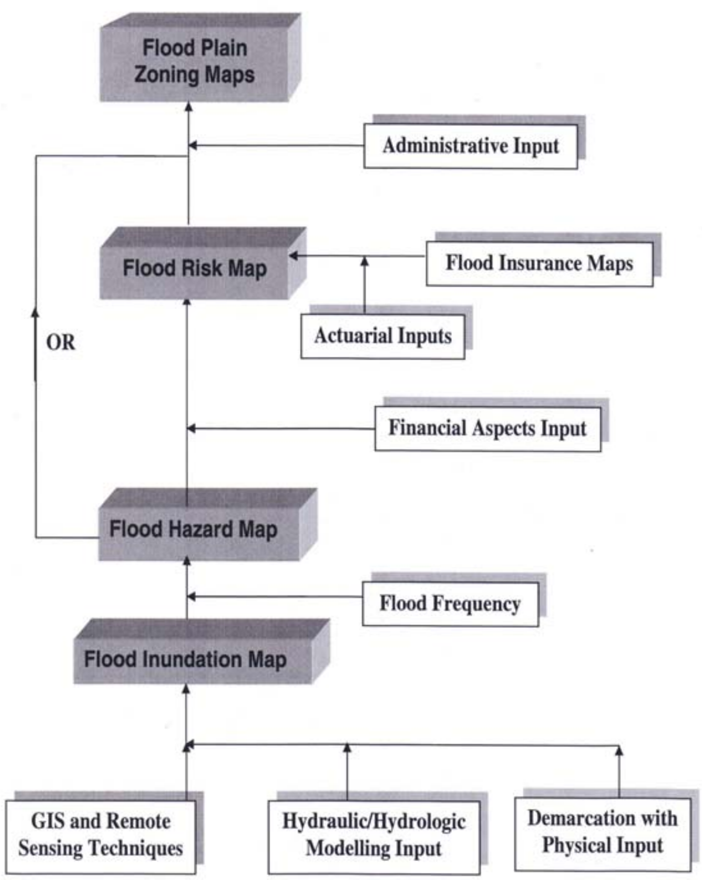

Fig. 1 Flow chart illustrating the general terminology of flood inundation mapping flood hazard mapping, flood risk zone mapping and flood plain zoning

Table 1 Z_i^{dist}-statistic for various frequency distributions

Sl. No.	Distribution	Site-1	Site-2	Site-3	Site-4	Site-5	Site-6	Site-7
1	GLO	-0.04	0.37	0.35	1.91	0.72	0.10	1.03
2	GEV	--0.66	-0.01	-0.62	1.51	-0.26	-0.12	0.42
3	GNO	-0.50	-0.08	-0.26	1.38	0.03	-0.33	0.36
4	PE(3)	-0.50	-0.24	-0.33	1.12	0.02	-0.69	0.17
5	GPA	--1.77	-0.88	-2.19	0.57	-1.97	-0.76	0.90

Table 2 Values of parameters for various distributions for seven gauging sites

Site	Distribution	Parameters of the Distribution		
Site-1	GEV	$\xi = 0.856$	$\alpha = 0.238$	k = -0.025
Site-2	GLO	$\xi = 0.999$	$\alpha = 0.174$	k = -0.002
Site-3	GNO	$\xi = 1.022$	$\alpha = 0.210$	k= 0.208
Site-4	GPA	$\xi = 0.230$	$\alpha = 0.978$	k = 0.269
Site-5	GLO	$\xi = 0.905$	$\alpha = 0.162$	k = -0.316
Site-6	PE-III	$\mu = 1.000$	$\sigma = 0.339$	$\gamma = -0.166$
Site-7	PE-III	$\mu = 1.000$	$\sigma = 0.433$	$\gamma = 1.010$

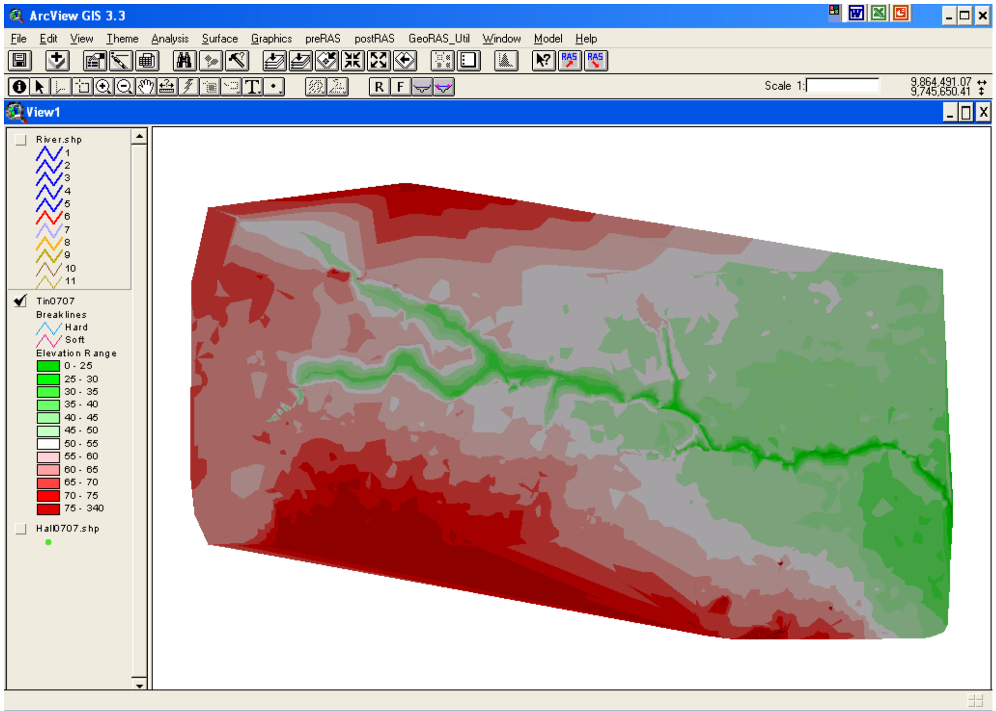

Fig. 2 Digital Elevation Model (DEM) of the Study Area

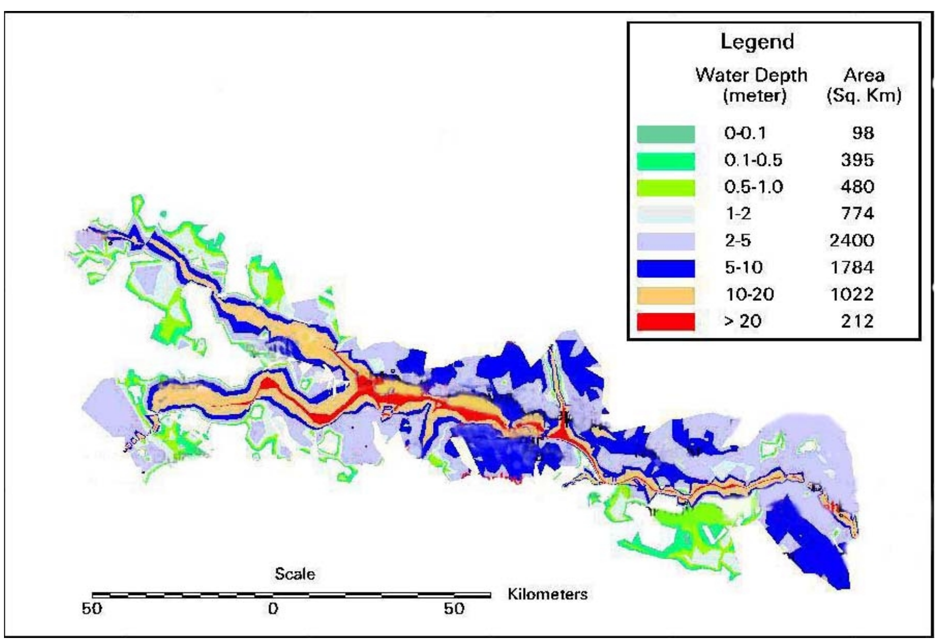

Fig. 3 Flood plain area inundated and depth of flooding for 1000 year return period flood for the study area

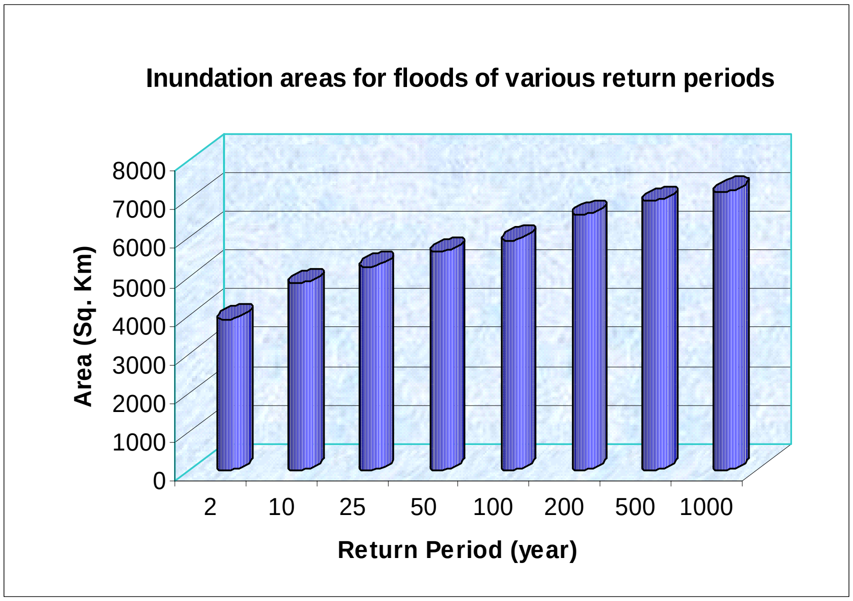

Fig. 4. Flood plain area inundated for various return periods for the study area

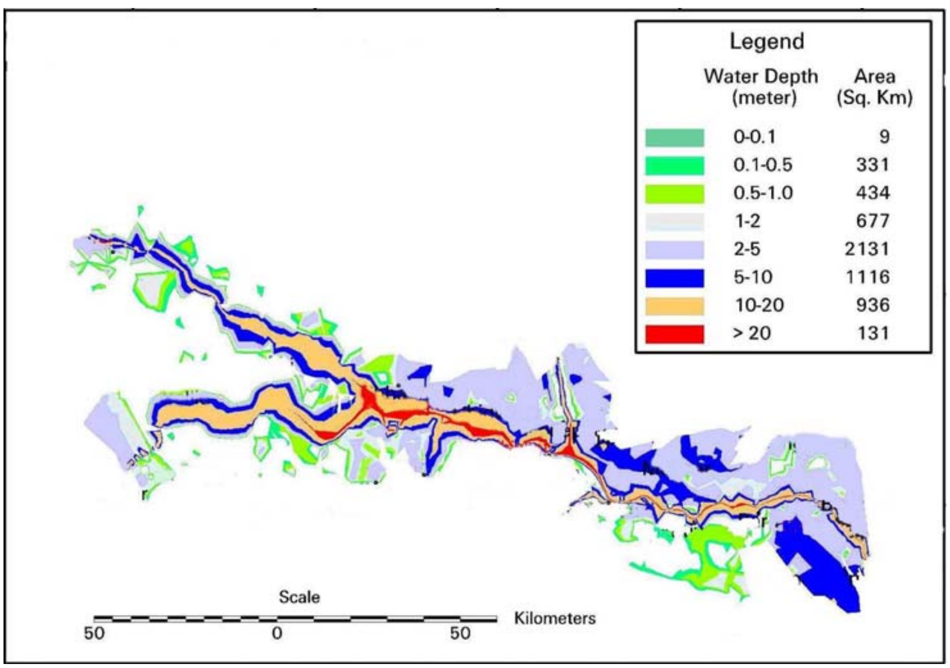

Fig. 5 Flood risk zone map for a risk (R) of 25% over a period (n) of 25 years

CONCLUSIONS

In this study flood inundation maps, flood hazard maps and flood risk zone maps have been developed for a river reach of a basin. The flooded areas for some of the years for the study area simulated by the

HEC-RAS package have been compared with the flooding mapped using the satellite data employing the GIS package ERDAS. These maps may be used for land use planning, flood insurance purposes and flood damage reduction. The calibrated and validated hydrologic model, as described in the study may be coupled with a distributed rainfall-runoff model using the antecedent rainfall forecasts based on radar, satellite based instrumentation and high resolution Numerical Weather Prediction (NWP) models and may be used for simulation of flood inundation, depth of flooding and risk associated with the flooding in real time for flood mitigation and management. Presently, there are many uncertainties in forecasting heavy rainfall and the uncertainty should be minimised, quantified and presented as an integral part of the forecast. It would help in providing improved flood hazard warning and lead to better flood management and flood damage reduction.

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ASSESSMENT OF URBAN FLOOD IN LIGHT OF A RIVER FRONT DEVELOPMENT PROJECT

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Abstract:

In this research the impacts of human intervention on flood situation for a river section in an urban area has been assessed. Sabarmati river had undergone a face-lift with AMC[1] sponsored SRFDP[2], which had reduced the river section. The purpose of SRFD project was to reclaim land for residential (21%), slum rehabilitation (10%) and recreational purpose. Flood simulation was carried out using SOBEK for different return periods for two scenarios – pre and post SRFDP. Return periods of 10, 25 and 50 years are considered based on the meteorological data and the site conditions. As predicted, the project eliminates the risk of 10year RP flood, but the 25 and 50 year RP floods still continue to happen. The study does not present the risk scenarios and flood vulnerability statistics, which were dealt separately.

Key words: Flood simulation, SOBEK, river encroachment, river front development, urban risk mitigation

Introduction

Flood in an urban area is defined as inundation due to rise in river water level. In the Indian city of Ahmedabad, flooding happens periodically, though the local authority down rate it as a local inundation. Many marginalised people live in these flood zones, which were not marked even in the development plan. First hand observation of the first author for 4 successive years reveals that annually, many parts of the river banks get inundated for duration longer than a day.

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[1] AMC – Ahmedabad Municipal Corporation
[2] SRFDP - Sabarmati River Front Development project

In a human made disaster in a near by city, Surat, there was a flood for almost 2 weeks, which killed about 300 people and cost the Govt., a US $ 4.5 billion (Singh, 2008). The Economic and Social Loss given by the Chief Minister of Gujarat is as follow:

▪ Industrial loss	INR 143 billion
▪ Crop loss	INR 40 billion
▪ Damages pertaining to infrastructure	INR 35.7 billion
▪ Total economic loss	INR 218.75 billion

This event had happened because of an human error at the dam site in estimating the run off reaching the dam site and the amount of outflow to be discharged. When the mistake was realised, much larger amount of water had to be released from the dam in order to keep the dam safe, which resulted in a massive flood wave approaching down stream, combined with the ongoing rainfall in the city and surrounding areas. This has resulted in a historic flood event in Surat city, which is every disaster manager's worst nightmare.

Ahmedabad also faced a similar event in 1998, when 100s of million INR worth goods and services were damaged. So this study aims to understand the change in the flood hazard before and after the implementation of the SRFDP.

Study area

Ahmedabad city lies 22^o 55' and 23^o 08' North Latitude and 72^{o}30' and 72^o 42' East Longitude. Ahmedabad city has an area of 194[3] Sq. Km. and more than 3.5 million (currently 5.5 million) people call Ahmedabad a Home (CEPTUniversity 2007). It is estimated to be housing more than 6.5 million people by the year 2011(CEPTUniversity 2007). Out of the total 3.5 million people in the city, 439,843 people live in slums (Census 2001). These slums also have about 65,509 kids less than 6 years of age. Mainly these slums are located in areas along the water ways and railway tracks.

As shown in the map Figure 1, much of the city is flat and lies between 46.63 to 50.92 meters height from MSL. The average elevation of the city is 48.77meters (NIH, National Institute of Hydrology 2007). River Sabarmati cuts through the centre of the city flowing from north to south. There are 7

[3] This is the area at the time of the study. Currently the city area is increased to 400Sq. Km. Source: CEPTUniversity (2007). CDS, City Development Plan. Ahmedabad, India.

man-made structures on the river in the city area (within a stretch of 11km), one railways bridge and 6 road bridges. There is a (Vasna) barrage at the southern end of the city, which is used to store water in the river for irrigation purposes. There is a small tributary, called Chandra Bhaga near Gandhi Ashram area, which drains into the river. Other than this, there are no major streams emptying into the River.

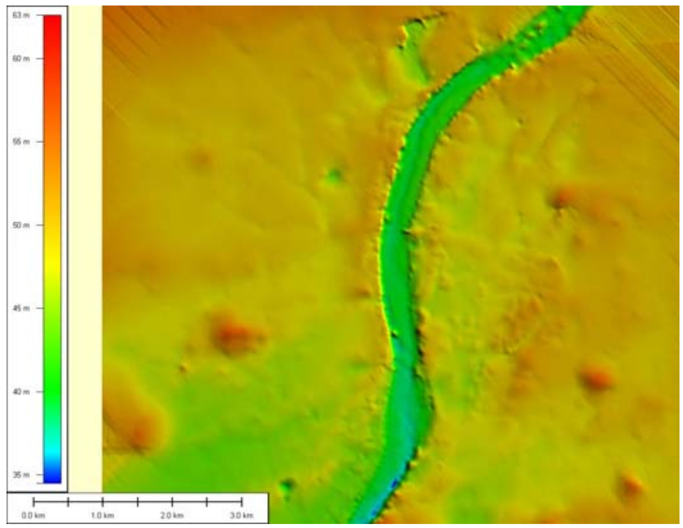

Figure 1 Topographic map of Ahmedabad

Prepared from a total station survey using ArcMap by the authors.

The River Sabarmati originates in the Aravali range in the state of Rajasthan and flows to Gulf of Khambhat to the mouth at apprx. 81 Kms in South. Overall length of the river is 371km out of which 323 km is in the state of Gujarat. Annual average rainfall in this catchment is about 575mm which mainly happens during the monsoon months of June-September.

1. Digital Terrain Model

Digital Terrain Model was prepared from total station survey points. These points were geo-referenced and used for DTM generation. 95% of the points were considered as the training data set and 5% of the data set was considered as test data set. As a part of this study, we interpolated these points into a DTM, viz., Kriging, Triangular Inverted Network (TIN), Inverse Distance Weighted method (IDW) and Spline. A pixel size of 5mteres was used for all the interpolations. Accuracy of DEM is another important aspect in this process. Accuracy is the closeness of the simulated DEM to the reality. Common methods used to express the errors are Root Mean Square Error (RMSE) and standard deviation. These two methods only present the error as a single value, which according to some authors

(Burrough, PA 1986), induces stationarity. Other ways of depicting the error is spatial variation error (Wood, J 1994).

(Wilson, J. P. editor and Gallant, J. editor 2000; Maune, DF 2007) discussed causes, detection, visualisation and correction of DEM errors. Quantitative measures of estimating the errors used topographic map elements, field measurements or hypothetical DEMs as reference values. For our case, we have a total station survey points and the DEM generated is checked for reliability and accuracy. Magnitude of error is terrain dependent. It is lower in less complex terrains (Gao, J 1997) like Ahmedabad, where the terrain is almost flat except the river and its surroundings. This data might have a slight systemic error, accumulated during the process of data collection and propagation of the same from one point to another. So above mentioned methods were applied and the method resulting least error was adapted as the model input.

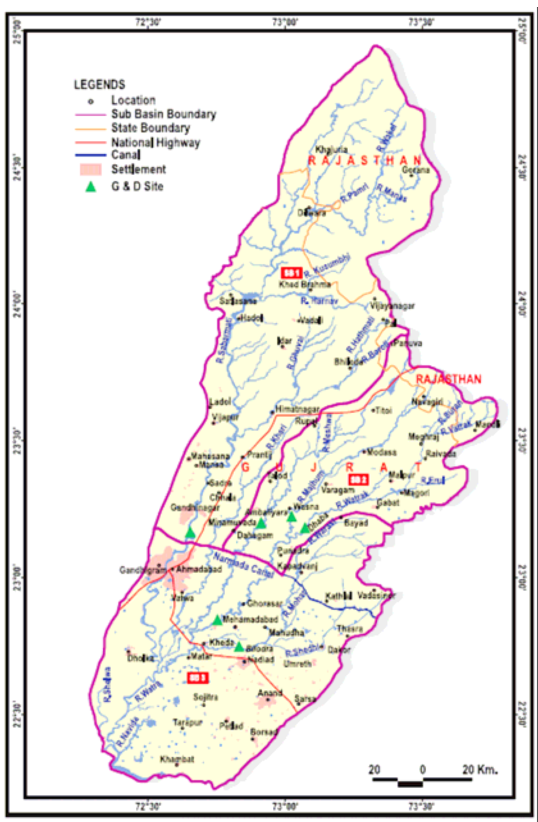

Figure 2 Sabarmati River basin

Source: (Gopalakrishnan, M 2006)

Surface output of point data for the different interpolation methods is shown below:

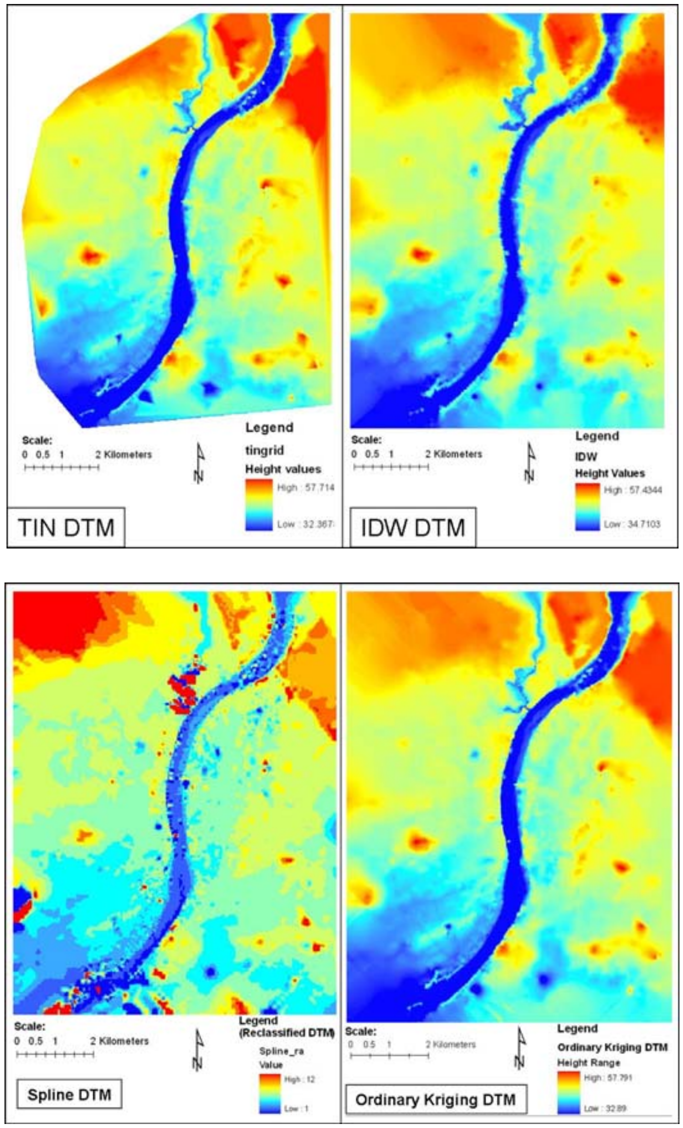

Figure 3 Various techniques used to interpolate surfaces

Vertical and horizontal accuracy of the total station data is shown in the following table:

Table 1 Comparison of horizontal and vertical accuracies of different surfaces obtained by TS data interpolation techniques

S No.	Interpolation technique	RMSE	Horizontal accuracy (meters)	Vertical Accuracy (meters)
1	TIN	0.8541	1.48	1.67
2	Inverse Distance Weighting	0.7778	1.35	1.52
3	Spline	1.088	1.88	2.13
4	Ordinary Kriging	0.6017	1.04	1.18
5	Simple Kriging	0.7705	1.33	1.51
6	Universal Kriging	0.7677	1.33	1.50

3.1 Generation of Digital Surface model

Digital surface model (DSM) was generated by adding the man made structures like residential, commercial, institutional and other buildings, roads from (Katuri, A. K., Sharifi, M. A. and van Westen, C. J. 2006). Same exercise was repeated for the post-SRFDP scenario. These two surface models were used to simulate the flood viz. both pre and post project scenarios.

Meteorological information

The weather graph of Ahmedabad can be distinctly divided into three seasons, namely, the cold dry winters, the hot dry summers and the monsoon season. The mercury starts soaring in Ahmedabad from early spring (March), reaching its peak in the month of May (43.40 Celsius). The temperature remains high until June, then falls drastically during July and again rises rapidly in the month of October (as high as 39.40 Celsius). January is the coldest month of the year with mercury dipping down to 4.90 Celsius.

Like most parts of the country, Ahmedabad receives its maximum precipitation from the southwest monsoons during the months of July and August. As is observed from the graph, the total precipitation for the year 2000 is 72.71 cm. Out of this 59.0 cm is received in the months of July and August alone.

Some pre-monsoon showers bring relief during May and June while rest of the months remains dry throughout the year.

Correspondingly, the Relative Humidity is also high during the rainy season reaching its peak in the months of July (98%) and August (90%) respectively.

For the current study, we have just considered the riverine flooding. So the rainfall data has not been analysed. Discharge data from the year 1979 to 2006 is collected from the Gujarat Water Resources Development Corporation (GWRDC). This data is analysed and used for the modelling.

4.1 Magnitude-frequency analysis

This was carried out to find out the relation between probability of the occurrence of a certain flood event, its return period and its magnitude. For this, we used two methods: Gumbel's method and Log Pearson type III method.

Gumbel's method:

Gumbel's probability was plotted to obtain the return periods using the following equations.

$$P_L = \frac{R}{N+1} \text{ .... } \quad \text{Equation 1}$$

Where: P_L is the Left sided probability (probability of having less values in the series)

N = number of observation

R = Rank

Now return period for each observation is determined using equation 2

$$T = \frac{1}{P_R} = \frac{1}{1-P_L} \text{ .... Equation 2}$$

Where T = Return Period

P_R = Right sided probability

The plotting positions 'y' are determined using the third equation

$$y = -\ln(-\ln P_L) \text{ .... } \quad \text{Equation 3}$$

The return periods obtained from the Gumbel's plots are shown in Figure 4 below.

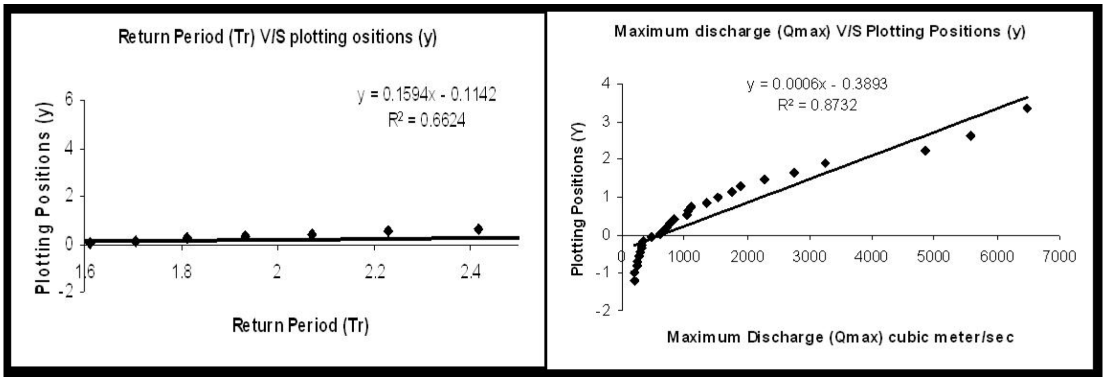

Figure 4. Gumbel's plots for the probability distribution of return periods

In the maximum discharge, we have some smaller outliers at the origin, indicating a possibility of two trends instead of the one depicted above. Using this frequency analysis the design hydrographs were obtained for the return periods of 10, 25, and 50 years based on 2006 year flood wave.

4.2 Correction for Outliers

Outliers are the data values which deviate from the general trend of the data. In our case, the lower outliers are located at the origin. Based on the coefficient of skew, the check for outliers is performed for structural break. If the skew is higher than + 0.4, the data is tested for the higher outliers. If the skew is less than -0.4, then a test for lower outliers need to be performed. Similarly, if the skew lies between +0.4 and -0.4, then test for both outliers is performed. In this case, skew was less then -0.4 (0.039), so the low outliers were detected using the using equation from(Chow, Maidment, DR and Mays, LW 1988):

$y_L = \bar{y} - K_n s_y$ ……………………………………..Equation 4

Where: y_L = Low outlier threshold in log units

K_n = One-sided 10 % significance level for the normal distribution

s_y = Standard deviation of y

$\bar{y}$ = Mean of y

y = Log x (Log of yearly maximum flow rates)

The low outlier threshold obtained was 684 m3/sec. All the values below this were eliminated from calculation of magnitudes using Gumbel's method. After removing the outliers the remaining data was limited to 16 years instead of total 28 years. The new lower outlier adjusted Gumbel's plots are shown in Figure 5. The design hydrograph for different return periods after the outlier adjustment are shown in Figure 6.

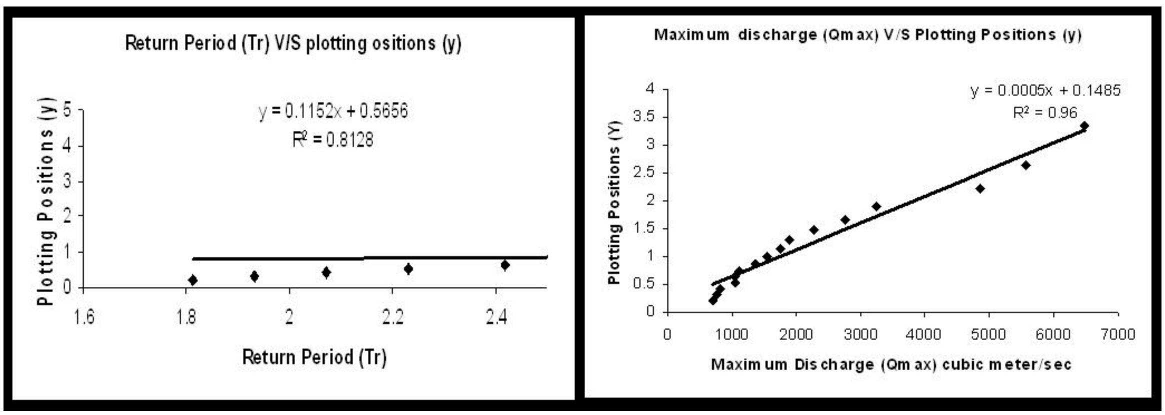

Figure 5: Gumbel's plots for the probability distribution of return periods after adjusting lower outliers

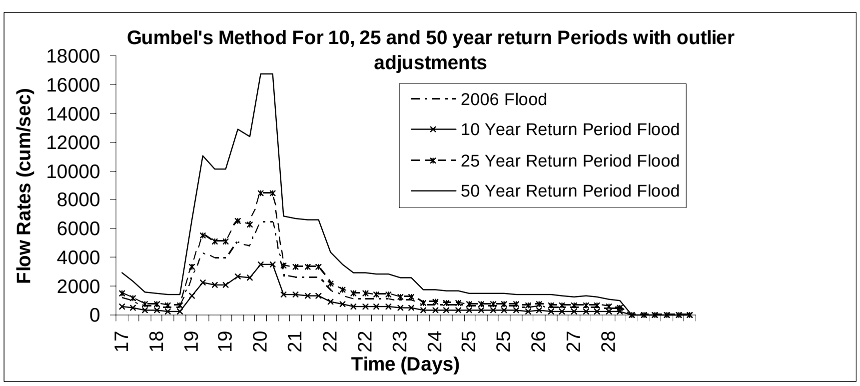

Figure 6 Gumbel's Method of flood Magnitude – frequency analysis for 10, 25 and 50 years of return period after adjusting the lower outliers

Log Pearson type III

Here, the variate is first transformed into logarithmic form (base10) and transformed data is then analysed. According to (Chow et al. 1988), the magnitude x_T of a hydrologic event may be represented as the mean μ plus the departure Δx_T of the variate from the mean.

$x_T = \mu + \Delta x_T$ **………………………………**Equation 5

The departure may be taken as equal to the standard deviation σ and a frequency factor K_T; that is,

$\Delta x_T = K_T \sigma$ **……………………**Equation 6

The departure Δx_T and the frequency factor K_T are functions of the return period and the type of probability distribution to be used in the analysis. Thus the equation 1 can be expressed as:

$x_T = \mu + K_T \sigma$ **……………………………**Equation 7

Or it can be approximated by

$x_T = \bar{x} + K_T s$ **…………………………..**Equation 8

When the variable analyzed is y = log x, then the using the equation for applying the statistics for the logarithms of the data, then the equation 4 becomes

$y_T = \bar{y} + K_T s_y$ **………………………**Equation 9

Once the value of y is obtained, then the frequency factor K_T is calculated using the equation

$K_T = z + (z^2 - 1)k + \frac{1}{3}(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + \frac{1}{3}k^5$ **…..**Equation 10

Where: K_T = Frequency factor

$K = C_s/6$

C_s = coefficient of skewness

$$C_S = \frac{n\sum_{i=1}^{n}(y_i - \bar{y})^3}{(n-1)(n-2)s_y^3}$$

n = Total number of years for data available

y_i = y for a particular year

$\bar{y}$ = Mean of y or Log x

s_y = Standard deviation of y

$$s_y = \left(\frac{1}{n-1} \sum_{i=1}^{n} (y_i - \bar{y})^2 \right)^{1/2}$$ **……………………..** Equation 11

z = standard normal variate

Finally, the frequency factor K_T is calculated using the equation

$$K_T = z + (z^2 - 1)k + \frac{1}{3}(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + \frac{1}{3}k^5$$ **……….**Equation 12

Where: K_T = Frequency factor

$K = C_s/6$

The required value of Return Period x_T is calculated by taking the antilog of y_T using the equation 9. For detailed information on this method please refer (Chow et al. 1988). Then use the value of K_T and S_y were used in equation 9 and calculated the value of yr. The return period was calculated by taking the antilog of yr.

The design hydrographs obtained by this method for different return periods of 10, 25, and 50 years along with year 2006 are presented in the following diagram..

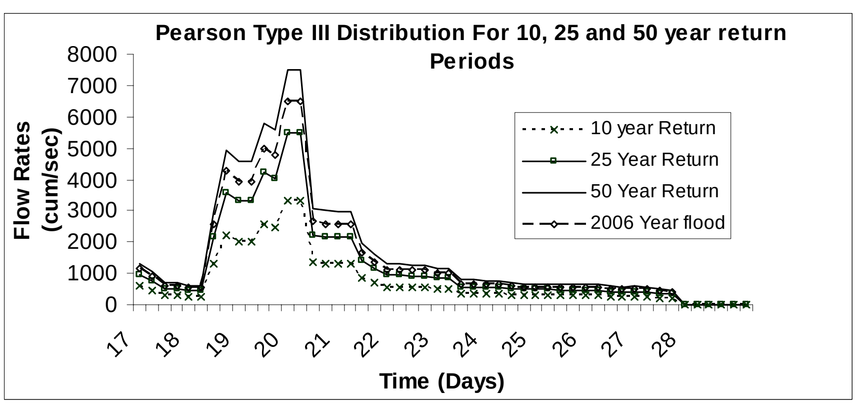

Figure 7 Log Person Type – III Flood Magnitude – frequency analysis for 10, 25 and 50 years of return period with year 2006 data

4.3 Reliability of predictions

The reliability of both Gumbel's and Pearson Type III methods was estimated at 90% confidence limits for 50 year discharge in Sabarmati river based on 28 years data. The maximum flow rates predicted by Guumbel's method with and without lower outlier adjustment and the Pearson Type III are shown in Table 2.

For $\beta = 0.9$, $\alpha = 0.05$ and the required Standard Normal Variate Z has the exceedence probability 0.05. The upper and lower limits were calculated for testing the reliability of prediction of 50 year return period and the predicted values of 50 year return period, for both methods were assessed within these estimated limits. The value for Qmax for 50 year return period at 90% confidence limits by Gunbel's and Pearson Type III method must fall within the intervals of $15524 > x > 4573$. The value produced by Gumbel's method (without outlier adjustment) and Perarson Type III, lies perfectly within the limit, but the Gumbel's (with outlier adjustment) predicted the value overshoots the 90% confidence limits.

Table 2 Comparison of the flood frequency analysis methods

Return Period (Tr)	Gumbel (No outlier adjustment) Q_{max} (m^3/s)	Gumbel (with outlier adjustment) Q_{max} (m^3/s)	Pearson Type III Q_{max} (m^3/s)
10 year	960.1436	3480.127	3331.331
25 year	2511.504	8448.343	5461.631
50 year	5097.105	16728.700	7516.807

Although, 90% confidence limits supported both Gumbel's and Pearson Type III methods but it suffers a bias introduced by the lower outliers. Due this lower outlier effect the predicted value for 50 year return period were much lower than that of 2006 year flood event, the maximum in last 28 years (Figure 6). The results obtained by Gumbel's method after removing the lower outliers overshoot the 90% confidence limits of the reliability test. The Pearson Type III suffered from no such problems and was based on entire dataset available for frequency analysis. Thus, Pearson Type III was preferred over Gumbel's method for simulating flood modelling for the return periods of 10, 25 and 50 years.

Flood hazard assessment

Flood in Ahmedabad city is assessed using the above meteorological data for two different situations. One is as is situation and the other one is with complete implementation of the ongoing River Front Development Project. The DSM is conditioned for the new river sections after the implementation of the project.

The data available after the removal of outliers is only for 16 years. Using this data, flood scenarios for three return periods were simulated

5.1 SOBEK model

We used SOBEK 1D and 2D models for simulating river flow and overland flow respectively. Both ends of the river in the city (Sardar Bridge on north and Vasna barrage in south) were considered as boundary conditions. The flow rates at the Vasna barrage were used to calibrate the model results. Because of the limitation of the software to handle not more than 100,000 pixels, we have to loose the resolution of the DSM from 5 meter to 20 meters.

5.2 Surface roughness

Surface roughness was expressed using Manning's coefficients. Manning's coefficients were taken from the National Institute of Hydrology's report, "Hydrologic Studies for Sabarmati Riverfront Development Project" for the Ahmedabad Municipal Corporation. Table below show the Manning's coefficients used in the simulation.Table 3 Manning's roughness coefficients adapted for the model.

Land use category	Manning's value
Natural River section	0.25
Modified River section	0.30
Agricultural land	0.040
Industrial /Commercial	0.032
Open area	0.025
Residential	0.035

The schematisation of the network is a crucial step in the simulation. First, the river network in 1D (centreline of the river) was imported from ArcGIS into the netter in SOBEK environment. For defining the representing system, river shape, location, river cross-sections, calculation points, boundary nodes, 2D grid, connection nodes, measurement stations, and hydraulic structure like orifice etc. were defined. Then, the terrain information was imported to SOBEK in ASCII format. This DEM plays an important role in modelling flood in SOBEK. As discussed earlier, the pixel resolution, SOBEK can handle depends on the number of pixels. He computation time in SOBEK goes up enormously if the number of pixels is higher. Care was taken to restrict the total number of pixels (less than 100,000 pixels) for efficient functioning of the model. In the 2D schematization history nodes were placed at selected areas to record detailed time series of water depths and velocities.

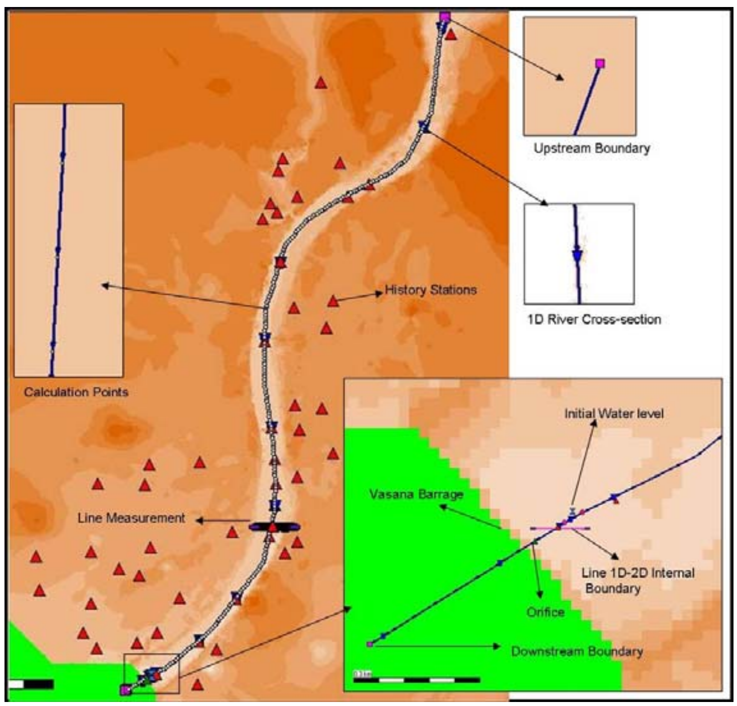

Figure 8 SOBEK Schemetisation in 1D2D with details

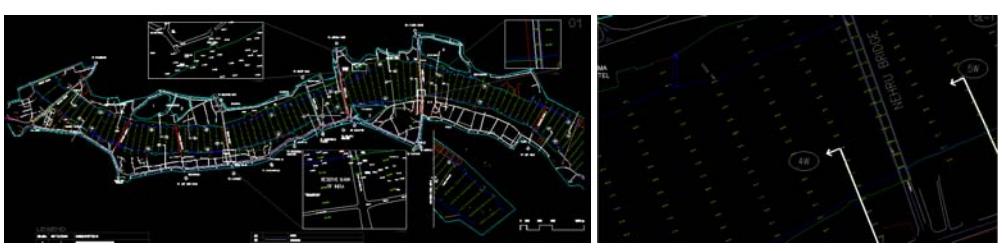

Figure 9 River sections after implementation of SRFDP

In order to assess the impact of flood hazard after the completion of the SRFDP, the digital surface model was modified to incorporate the new river sections as shown in **Error! Reference source not found.**. the cross sections were added at an interval of 200 mt. SOBEK interpolates the surface between these cross sections.

Output from SOBEK is exported into .asci format. Using various techniques, these input are converted into ArcGIS environment to visualise and assess the associated risk.

Results of flooding scenarios

After successful simulation of the 2006 event, the calibrated model was applied to both natural and modified river sections that represented the new river front known as Sabarmati River Front (SRF). The flood simulation results for both Pre and Post SRFDP situation for the return periods of 10, 25 and 50 year, are presented in next sub-section.

6.1 Flood depth maps for 10, 25 and 50 year return period

The flood depth maps for a 10 year return period for Pre and Post SRFDP are presented in figure 4-6. It can be seen that after SRFDP implementation there is no chance of occurrence of flood once in 10 years. On the other hand, the natural state of the river still produces some flood inundating an area of 1.6 meter square. Although there will be flood, but the only people who will be affected are those staying near the river bank. This includes a large number of slum dwellers. For the floods that have a chance of occurrence once in 25 years, the SRFDP again proves to be efficient in restricting the flood from spreading to larger areas as compared to that of the natural river section. This is evident from Figure 11, that the there is a 75% reduction of inundated areas with the SRFDP in place. But with a severe flood of high magnitude, having a change of occurrence once in 50 years, SRFDP no longer proves effective and the flood inundates almost equal areas - Figure 12. For actual quantification of flood hazard please refer Figure 13. The visual examination of all the flood depth maps provides a clear indication of the potentials of SRFDP towards mitigation of this disaster.

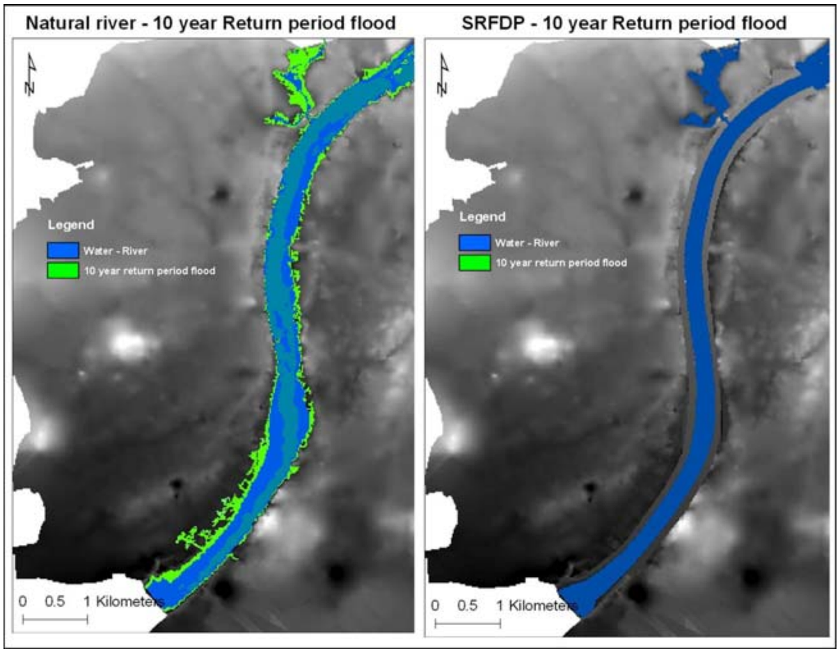

Figure 10 Flood inundation Depths maps for 10 year return period

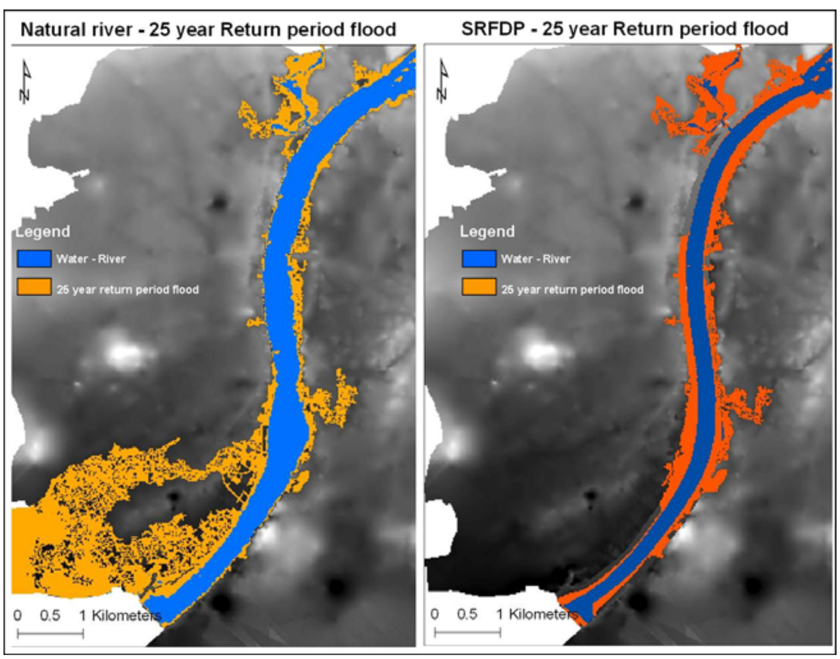

Figure 11 Flood inundation Depths maps for 25 year return period

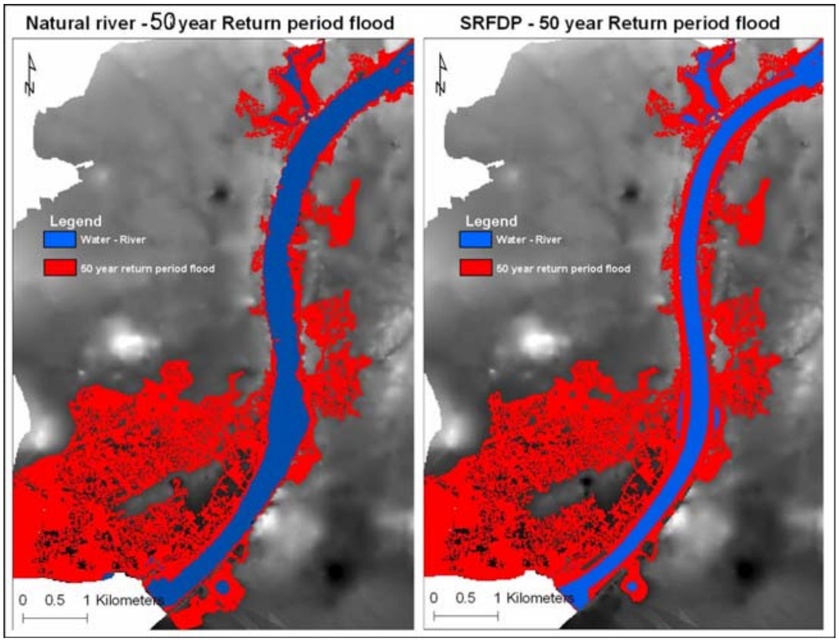

Figure 12 Flood inundation Depths maps for 50 year return period

Flood hazard assessment is conducted in two different ways. First, the hazard is presented in the form of flood spatial extents. This is done with respect to different return period flood and the increase or decreased is quantified in terms of inundated area.

The second assessment expresses the hazard in terms of severity, based on inundation depths and flow velocity. In the last section the suitability of SRFDP in combating the flood situation is compared in Pre and Post SRFDP states of Sabarmati River.

6.2 Flood hazard – spatial extents

The visual assessments in the previous chapter demand the importance of quantification of flood hazards and a comparison of the two situations. In this section, the flood hazard is quantified and compared in terms of its spatial context. The inundation depth maps produced by model were colour coded and overlaid. The river was kept separate to assess the correct measurements. The area obtained from all the flood extents maps were presented in table 5-1, and the Pre- and Post SRFDP situations were compared.

Table 4 Comparison of the inundated areas for Pre (Natural) and Post SRFDP state

Return Periods (years)	Pre – SRFDP inundated area (km^2)	Post – SRFDP inundated area (km^2)	Change in inundated area (km^2)
10	1.60	0.00	1.60
25	7.22	3.14	4.08
50	12.11	12.90	-0.79

The figure indicating the change in area column in

Table 4 shows that Post SRFDP flood are much smaller in spatial extents in comparison to the natural section of the river. The only exception to the decrease in extents is a flood of very high magnitude with a probability of occurrence of one in 50 years. While simulating the results, it was evident that the river overtops the banks at a very late stage. However the flood occurs at northern end of SRF where the river width is much higher that the constricted conditions.

The study shows that the intervention in the river course by this project does alter the flood extent in the lower return period events. In the higher return period events, i.e. 50yrs event, the project is negatively impacting the flood extent. With the change in the rainfall pattern (Das, Saurabh, Shukla, Ashish K. and Maitra, Animesh 2010) there is a need for more detailed analyses to be carried out before finalising a project which changes the river course.

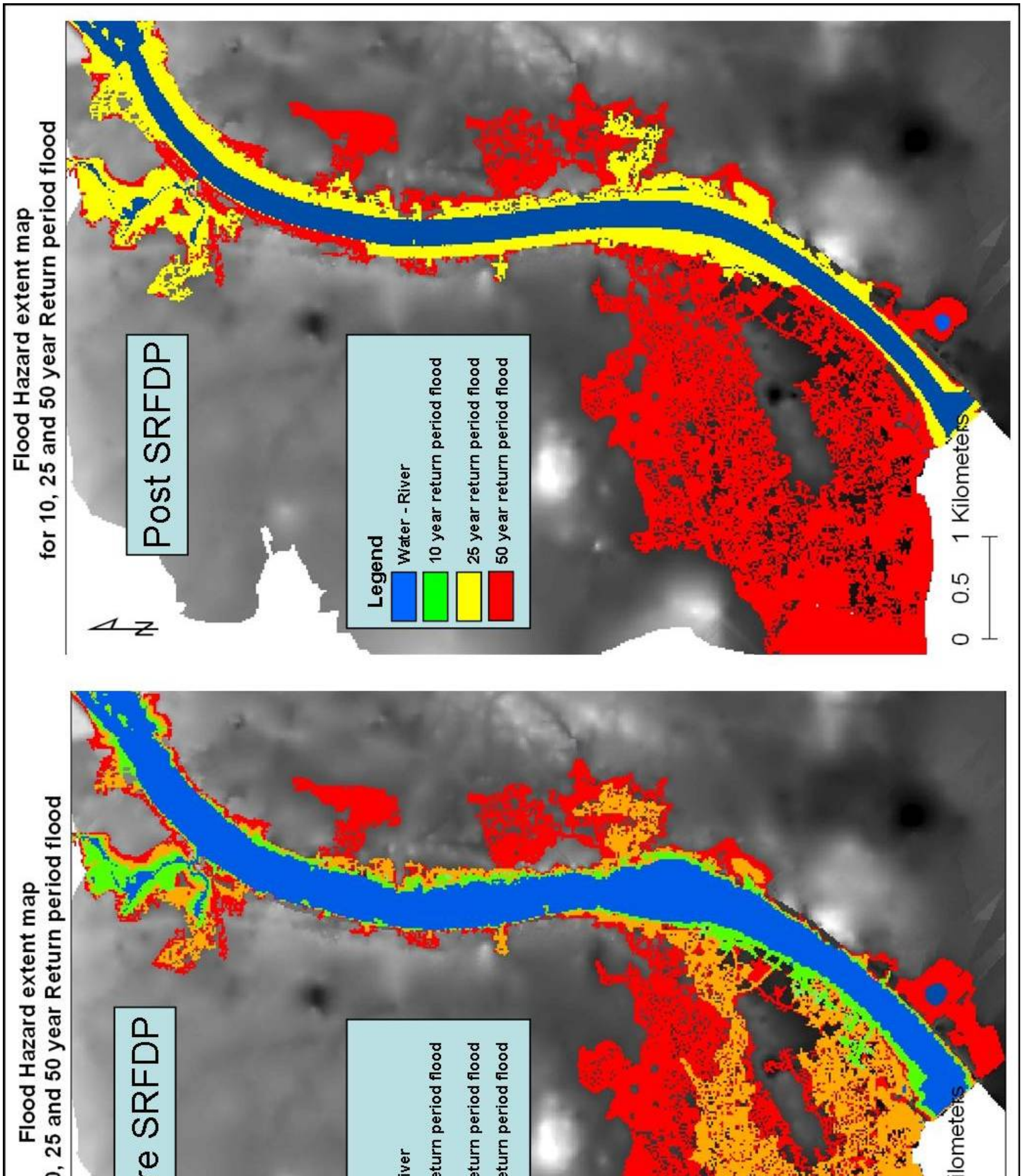

Figure 13 Comparison of Pre and Post SRFDP flood hazard extents

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STUDY OF DRAINAGE PATTERNS AS OBSERVED ON REMOTE SENSING IMAGES OVER JHARIA- RANIGANJ COAL FIELD OF EASTERN INDIA

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Study of drainage pattern as observed on remote sensing images has been carried out covering Jharia -Raniganj coal fields of Gondawna terrain of Damodar Valley of eastern India (see fig 1) from the point of view of surface water resources management, and is briefly presented here.

A. The Jharia coal field which lies in Dhanabd Dt of Jharkahnd and is the only source of prime cocking coal of the country shows coarse subdendiritic pattern with general flow direction to south and south east. on a gentle rolling topographic surface (see fig 2 and 4). The streams are effluents in nature and show characteristics of a hilly river ie they swell with sort spell of rain and drain quickly as the rain stop. The river Damodar which is the trunk river is of perennial in nature and flows approximately in a faulted southern margin of the coal field. The important tributaries of this trunk river are Jamunia , Katri , Khudia , Ekra and Kari Jhors which are seasonal in nature and are flowing in south and south easterly directions. .Drainage dissection has been also observed along Jamunia and Katri rivers. These drainage lines cut across the whole sedimentary section and the interfluve region in between shows very little variations in relief. Drainage density varies from 0.5 to 1.5 over with basin of sizes ranging from 8 to 170 sq km .and of average stream lengths from 10 to 120 km. The valley sections of these channels are flat and shallow and water flow in these streams are sluggish and slow reflecting "old age" streams in matured eroded surface of gentle slope(1 to 3 degree). The commonly observed zig- zag drainage lines of the tributaries suggest that the flow lines are controlled by criss cross joints , fractures and cross faults of sedimentary formations in the basin and of post Gondwana age.

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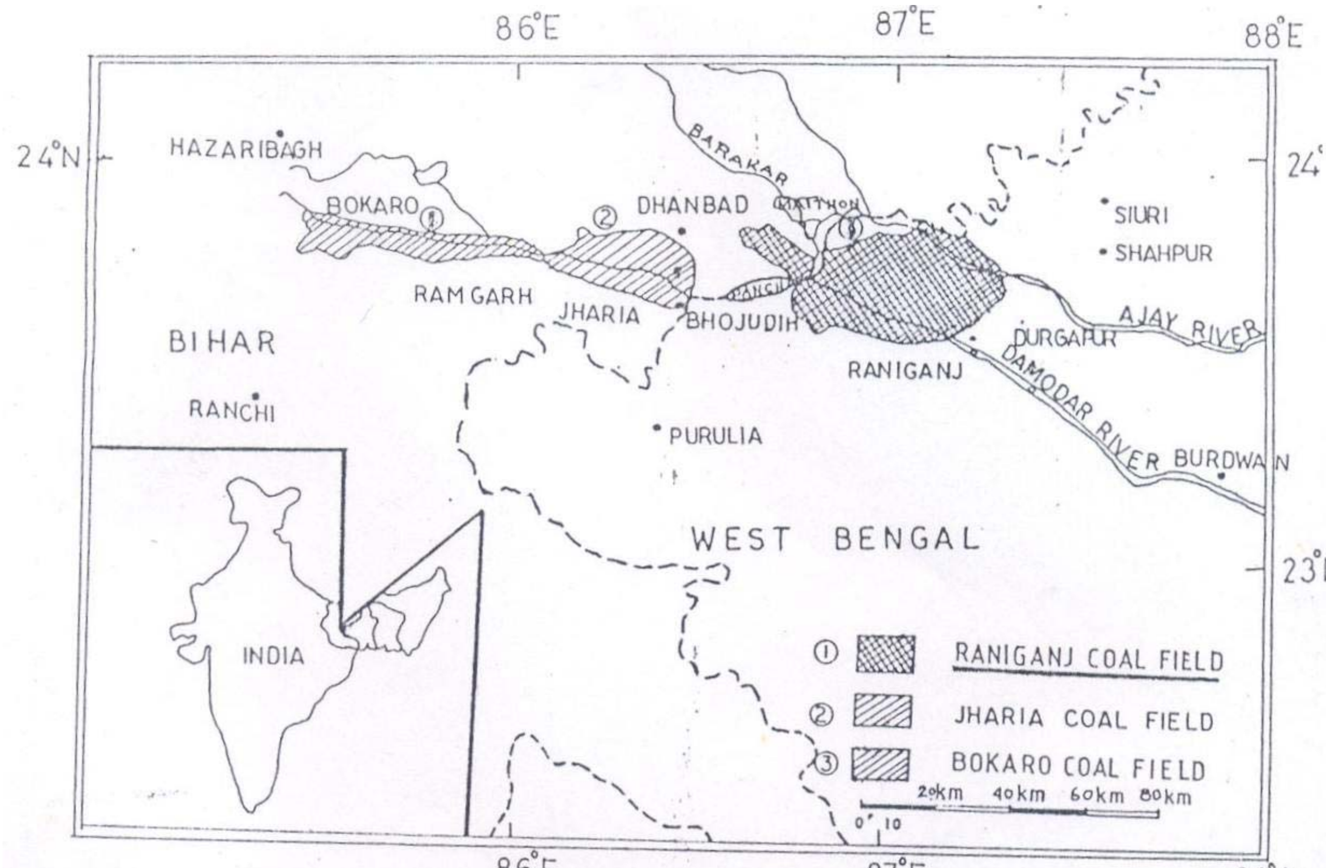
B. The Raniganj Coal field is approximately SSE above described Jharia coal field and lies in the Burdwan district of West Bengal9 see ffgi 4 and 5). The basin is drained by three perennial rivers viz,; Damodar , Barakar and Ajay having and the two group of tributaries are observed one joining

Damodar flowing mostly over Gondwana terrain and other joining Ajay river flowing mostly over archaen terrain . Structure of the basin is like half graben with mild slope of 3 to 5 degree.

The Damodar river enters the coal field near Somaliya village (86 40 E, 23 40 N) and flows in a south - south easterly direction forming approximately the southern faulted margin of this coal field and finally leaves the region to the north of Jalanpur village (87 E 23 45 N). The river Ajay enters the region from Chitranjan and partly form the northern depositional margin of this basin. The Barakar river after entering the area near Sijua settlement ie north of Karma tanr (86 12 E 23 53 N) joins the main river Damodar to the west of Dishergarh..

Besides these 3-perennial rivers, the region is drained by 15 nalas and jors and the prominent one are Barajouri ,Choupahri, Harial jhor , Khol , Machkanda ,Nonia, Paunta and Sigaran nala with stream length varying from 10 to 20 km and having basin size ranging from 15 to 120 Sq km and drainage density from 0.5 to 2.0. The general drainage pattern in the region is dendiritic to sub dendiritic flowing over a eroded plain of gentle slope(5 to 8 degree) . These seasonal water channels remain dry or contain little water during most of the months of the year except during the rainy season. Drainage section is again shallow and flat which is filled with sediments generated by sheet erosion of gently sloping surrounding terrain. It is observed that the drainage lines within the basin are controlled by criss cross joints and fractures and cross faults within sedimentary formations and also at places they are controlled by the out cropping iron stone shale and dolerite dykes.



FIG;1: LOCATION MAP OF AREA UNDER RANIGANJ COALFIELD.

Fig 2 SATELLITE OVER VIEW OF JHARIA COAL FIELD
(LANDSAT-TM F.C.C.)

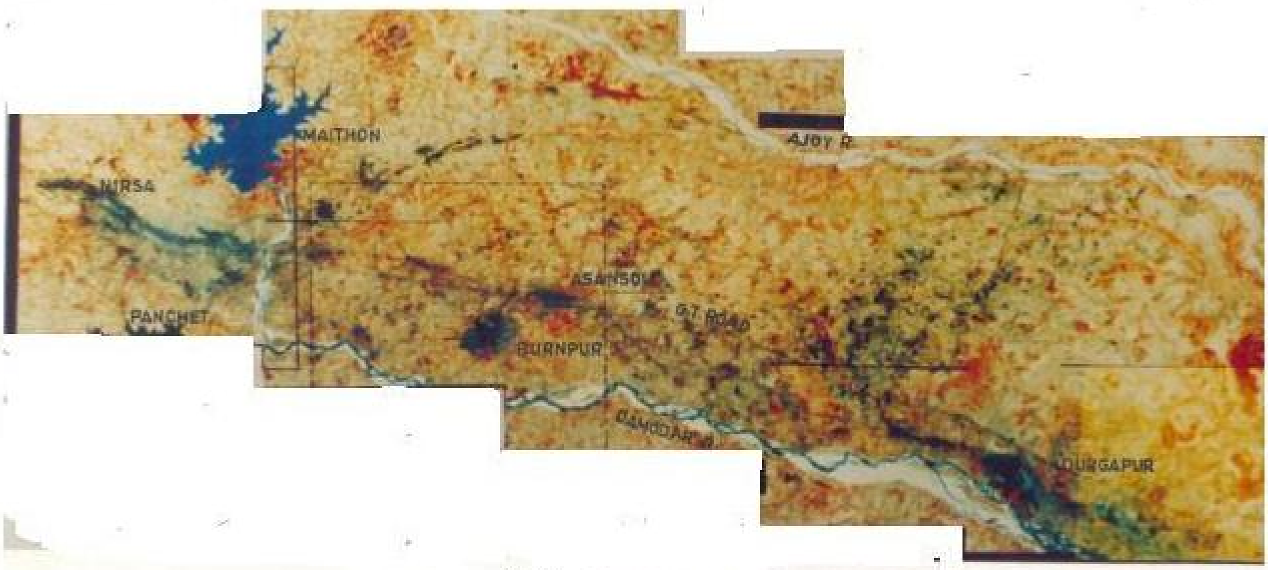


Fig 3 SATELLITE OVER VIEW OF RANIGANJ COAL FIELD
(LANDSAT-TM F.C.C.)

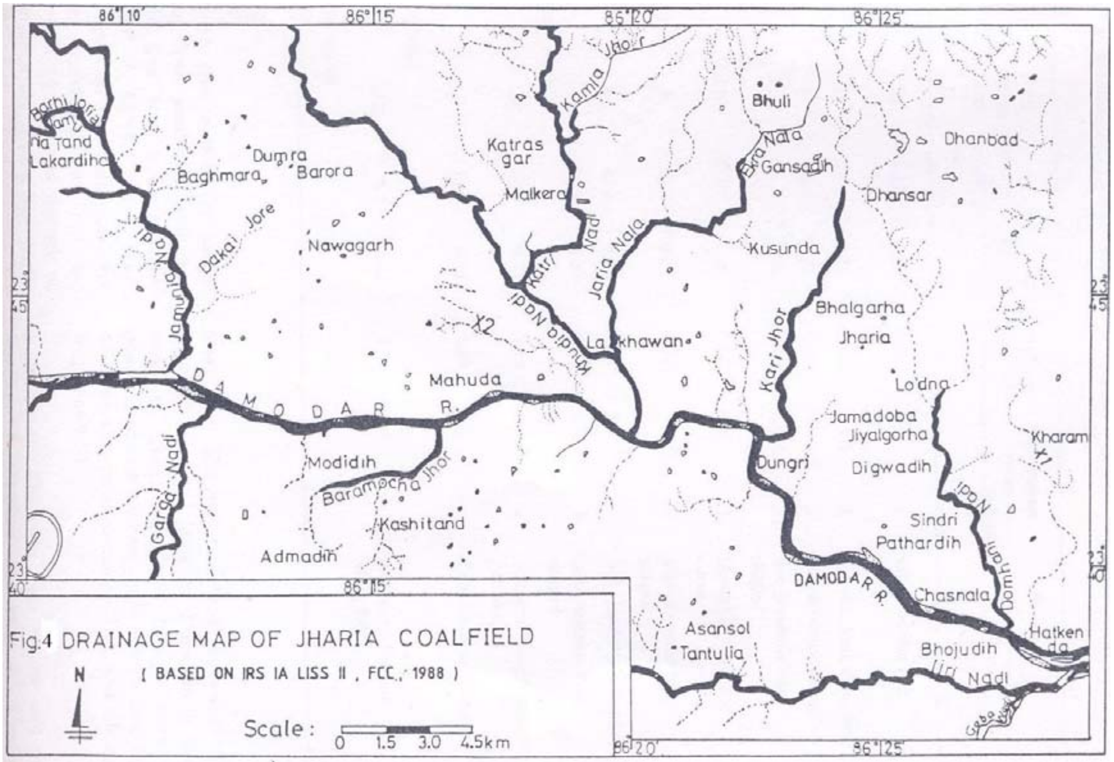


Fig.4 DRAINAGE MAP OF JHARIA COALFIELD
(BASED ON IRS IA LISS II , FCC , 1988)

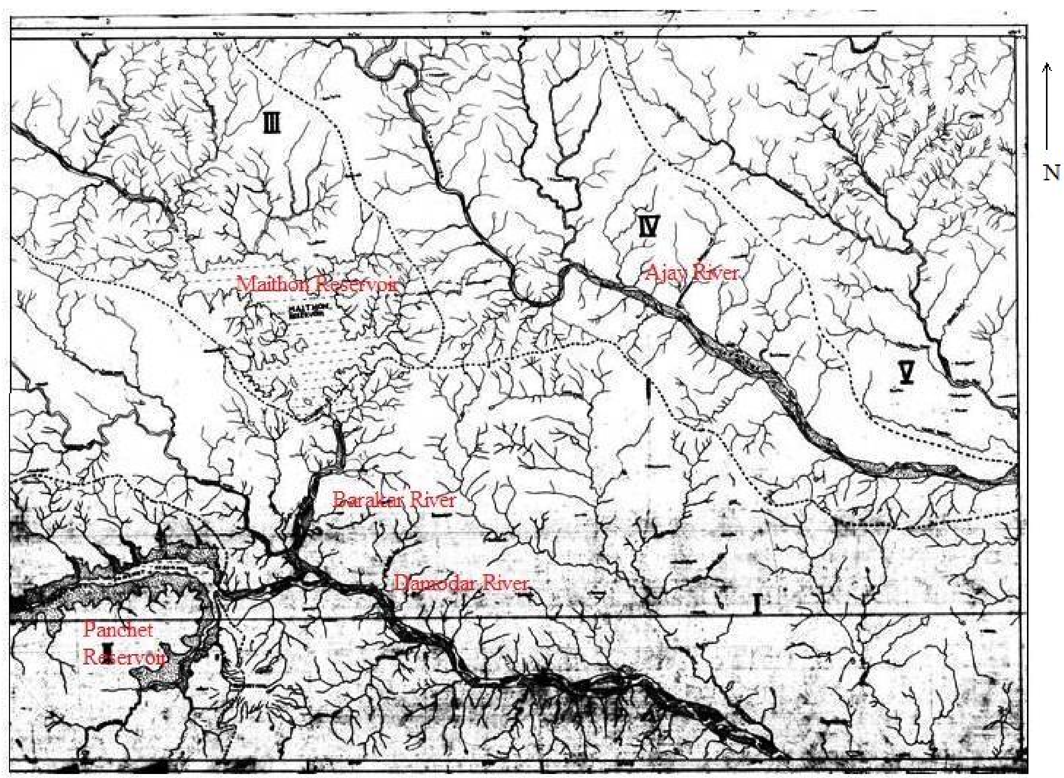


Fig 5. Drainage Pattern over Raniganj Coal Field as observed on LANDSAT TM (Scale 1:50,000)

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Section II

SOILS AND THEIR MINERAL FORMATION AS TOOLS IN PROVENANCE, CLIMATE CHANGE AND GEOMORPHOLOGICAL RESEARCH

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Abstract

Secondary minerals at a less advanced stage of weathering may adjust to subsequent environmental changes. Therefore, they may lose their interpretative value. However, pedogenic minerals like di- and trioctahedral smectite, smectite-kaolin interstratified mineral, hydroxy inter-layered vermiculite and smectite and pedogenic calcium carbonate have been found to be useful as paleo-environmental indicators because these pedogenic minerals in three major soil types (red, black and alluvial soils) and drill cores of the Ganga Plains of semi-arid parts of India, could be preserved unchanged amidst climate change from humid to semi-arid climate. Studies on the genesis of these pedogenic minerals so far conducted at the NBSS&LUP (ICAR), Nagpur, Geosciences Laboratory, Civil Engineering Department, IIT, Kanpur and Department of Geology, Delhi University, Delhi, India for the last two and a half decades have helped the pedologists and geoscientists not only to unravel the past geomorphic processes in the formation of spatially associated red (Alfisols) and black (Vertisols) soils of the Peninsular India and the existence of Vertisols amidst micaceous Indo-Gangetic alluvial Plain, but also to infer the provenance and climate change in the Himalayan Foreland and polygenesis in the major soil types of the Indian subcontinent.

The review on the research results obtained by these national institutes indicate that the X-ray diffraction analysis of the soil clay fractions and also the micromorphological thin section studies specially of carbonate minerals and plasmic fabrics have become formidable analytical tools in provenance and climate change research.

Keywords: Climate change, mineral formations, soil and earth science research

IMPACT AND HAZARDS OF FLOODING IN MUMBAI

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Abstract

Mumbai metropolitan region and Suburban areas received heavy rains on 26th and 27th July 2005which was struck with a heavy storm that resulted in the flooding of many parts of the Mumbai City and Suburbs. The entire city had to face multiple hardships, due to disruption of power supply, stoppage of road and rail communication network and other essential commodities. The above disaster was an eye opener to all major cities in India to study the effects of urban conditions on rainfall–runoff relationships. Changes in the physical characteristics of urban areas due to the developmental works, involve physical and topographical changes, thus altering the natural processes in the area. In depth basin analysis, study of the catchment area is necessary to understand the process of inundation and flooding. The soil type, the vegetative cover, topographical features of the land surface and the physical structure in the catchment play a key role in influencing the runoff process. Urban areas tend to reduce the natural vegetative cover due to developmental structures such as roads, pavements, buildings (residential and non-residential), paved parking lots and sidewalks, driveways that collectively increase the impervious surfaces in the catchments. Areas are reclaimed by dumping constructional waste/weathered Deccan trap material over the mudflat and leveled and compressed by rollers thereby reducing the ground porosity, clogging the natural drainage and increasing the surface runoff, which other wise would have been natural soak pits during precipitation. Major causes for flooding in Mumbai are due to the very low gradient, the mudflat areas have a gradient of less than 2^o and are affected due to tidal changes in sea .Also, the monsoon pattern has changed. But the drainage system has only not lived up to its capacity. For Water Management, topographic map play a very important role. These Maps gives us the basic information regarding ground slopes, which enables us to establish floodplain zones and delineate the areas subject to flooding. The most ignored system in Mumbai is its natural drainage, its rivers and rivulets. Of these, river Mithi is the most important, drainage of Suburban Mumbai. Others rivers have almost disappeared; the Mithi still flows as a stinking choked *nullah* The River originates in the Sanjay Gandhi National Park — thus, it is rain-fed. It flows to the Tulsi Lake, and then to Vihar and Powai lakes. From Powai Lake it starts an

approximately 15 km journey that ends in the Arabian Sea at Mahim creek. It is pathetic that many of the Mumbai citizens and even the civic administration are not aware of the presence of a river in heart of Mumbai.

The field observations indicate that all the rivers in Mumbai are suffering from the following five assaults:

• Open, dangling cable and pipe crossings on the sides of the bridges and culverts,

• Debris dumping (from construction activities as well as industrial wastes) on banks and into rivers,

• Sedimentation in river beds and dumping of urban solid wastes into rivers coupled with nil to inadequate annual desilting efforts,

• Ingress encroachments from the banks (building, industries, and slums); and modification of river courses and local diversion of streams.

Recommendations towards maintaining ecological balance, we have to first restore the existing degraded rivers and river-banks to initiate recovery of the urban ecosystem, provide river flushing system to initiate rejuvenation of river channels. Restore the Mangrove-Ecosystem and rejuvenate the coastal zones and construct detention basins and infiltration zones for flood control and provide broad roads near toll tax areas for people to escape in case of disasters and calamities.

Remove encroachments and facilitate flow in all the Creek System and strictly adhere to the Development Plan. Implementation of India's environmental policy in a proactive manner and ensure compliance of environmental regulations by the Municipal Corporation.

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PROCESS AND FORMS OF MOUNTAINOUS TROPICAL RIVER SYSTEMS - EXAMPLE FROM KERALA STATE, SOUTH INDIA

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Abstract

The south western part of Indian peninsula is unique with respect to climate physiographic and drainage conditions. Presence of Western Ghats running roughly parallel to the western shoreline of India plays a significant role in determining the uniqueness of this morphogenetic region. The entire state of Kerala fall in this typical morphogenetic region is characterized by number of short and swift west flowing rivers and tributary system. Out of the 44 rivers originating from the Western Ghats 41 flows in the west direction draining the Kerala state which has a total area of 38,590 km^2. Maximum transect width of this country is only 124 km which clearly vouch for the short run of even the largest river of this region. The entire region experience a typical tropical climate which comes exactly within the Tropical Am and Tropical Aw regions of Koppen (1939). By considering the classification of Indian rivers according to Gupta (1984) only five rivers can be grouped under medium river (catchment area between 2000-20000 km^2) and the rest can be classified as minor rivers (i.e., catchment area < 2000 km^2). Geologically the area is occupied by Precambrian crystalline rocks, viz., Khondalite and charnockite. This region is conspicuous by absence of any major sedimentary basin except for a fringe of Tertiary formation along the coastal margin. The regional structural grain of Precambrian rocks as evident from the satellite imagery has NW-SE or NNW-SSE direction.

Because of the archetypal climatic, geologic and physiographic milieu, the region enjoys a unique geomorphic process. The dominant fluvial process operates in this region with its full sequence right from weathering through all progression of mass wasting. The ubiquitous laterite, a residual product of chemical weathering of tropical climate gives sufficient stability to the slopes of this region. However, partly weathered portion is susceptible for slide or slump in the highland and steep slopes. Channel forms of almost all rivers are more or less uniform for minor and for medium rivers. The most notable channel form features from upstream to downstream direction of majority of mountainous rivers of Kerala are bedrock channel floors with rapids and falls, boulder - pebble bedded channel floor with unstable banks, sandy bar- pool sequence with more or less stable banks (laterite?) and wide and deeper channel with unstable banks (floodplain). The tectonic and climatic implications of the varied channel form features are explored in this study.

Key words: Tropical Rivers, process and forms, morphogenetic landforms

QUATERNARY GEOLOGY OF CENTRAL INDIA

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Nagpur

Abstract

In central India, Quaternary sediments occur as thick deposits of deep, structural riparian basins and thin deposits of shallow river valleys. Quaternary sequences from Lower Pleistocene to Holocene are seen in structural basins, whereas shallow river valley deposits show upper Pleistocene to Holocene sequence. Formal Quaternary lithostratigraphic formations have been described only in the Narmada valley and it is proposed that nomenclature and succession of the Narmada valley may be adopted in other river valleys of the central India. Quaternary stratigraphic succession, proposed for Central India comprises; 1. Ramnagar formation, 2. Hirdepur formation, 3. Baneta formation, 4, Surajkund formation, 5. Dhansi formation and 6. Pilikarar formation. Each formation has characteristic soiI/palaeosol at its top. Soils on the older formations, are ferruginous while soils on the younger formations are calcic. Tephra beds are seen at two levels; as insitu tephra below the brown soil developed on the Baneta Formation and as reworked tephra associated with coarse basal units of the Hirdepur Formation. Geochemistry and fission track dates relate the tephra beds of the Narmada, Son, Purna and Kukdi valleys with the Youngest Toba Tephra of 75 ka. Radiocarbon dates suggests that: 1. The Ramnagar formation is younger than 4.5 ka and 2. Hirdepur formation comprises sediments deposited during 25 to 13 ka Last glacial maximum). The Baneta formation with insitu tephra represents the early last glacial (Early Upper Pleistocene). Hirdepur and Baneta formations comprise mammalian fossils of Upper Pleistocene affinity and the underlying Surajkund formation comprises fossils of Middle Pleistocene affinity. The fossil of Homo erectus was recovered from the Surajkund formation. The boundary between the Surajkund formation and the underlying Dhansi formation also marks the boundary between Brunhes Normal magnetic polarity epoch and Matuyama reverse polarity epoch.

LATE QUATERNARY FLUVIAL HISTORY OF THE UPPER BRAHMAPUTRA VALLEY, NORTHEASTERN INDIA

By

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Abstract

Systematic geological mapping and allied researches in the Brahmaputra valley in parts of Assam and adjoining Arunachal Pradesh have provided evidences of Late Quaternary changes in the river regimes, possibly in response to global climatic changes and mild neotectonic movements. Recently, evidences of river metamorphosis, unilateral migration, severe bank erosion and flood hazards are also reported from parts of Upper Assam and foothill plains of Arunachal Pradesh. Building up of morphostratigraphic sequence in the alluvial plains combined with radiocarbon dates has enabled the identification of major episodes of erosion and deposition in the region. The surficial study of Quaternary formations in and around the Bengal Basin has broadly indicated the presence of four-tier sequence of Upper Pleistocene to modern sediments. A comparative study of the data from the Brahmaputra valley and adjacent isolated narrow basins brings out two distinct ages of these sediments, namely the Pleistocene and Holocene. The form and content of the terrace deposits and misfit river reveal that the rivers have progressively shrunk in size since the late Pleistocene time. Supporting evidences from the Indo-Gangetic valley, Deccan region and Arabian Sea demonstrate that the successive phases of aggradations and incision are possibly linked to late Quaternary climatic changes and local tectonic movements.