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Chapter1

Introduction

1.1 General

Floods are the most common natural disasters; their frequency, magnitude and the cost of damage are on the rise all over the world. "Flooding is a general temporary condition of partial or complete inundation of normally dry areas from overflow of inland or tidal waters or from unusual and rapid accumulation or runoff" (Jeb and Aggarwal, 2008). According to European Commission (2007), a flood can be defined as "a natural phenomenon that results in the temporary submerging with water of a land that does not occur under normal conditions". They are the naturally occurring event and hence cannot be prevented and they can have serious consequences such as displacement of people and damage to the environment (IFRC,2001; Adeoye et al., 2009; Nmeribeh, 2011). Floods can also be caused by anthropogenic activities and human interventions in the natural processes such as increase in settlement areas, population growth and economic assets over low lying plains prone to flooding leading to alterations in the natural drainage and river basin patterns, deforestation and climate change (EC, 2007; Balabanova, 2008; Kwak, 2008; Kondoh, 2008; and Vassilev, 2010). Floods cause about one third of all deaths, one third of all injuries and one third of all damage from natural disasters (Askew, 1999). During a World Conference on Natural Disaster Reduction organized by the United Nations in Yokohama in May 1994, one of the 10 "principles" of the Yokohama Strategy is that "risk assessment is a required step for the adoption of adequate and successful disaster reduction policies and measures". The terms "floods", "flood hazard", and "flood risk" cover a broad range of phenomena. The terms such as "flood risk" and "flood losses" are essentially our interpretation of the negative economic losses and social consequences of natural events. Flood risk may increase due to human activity and may decrease by appropriate flood management and planning (Simonovic, 2009).

1.2 Flood Risk Concept

An attempt by the risk experts in late1970's to come up with the standard definition of risk concluded that a common definition is perhaps unachievable, and authors should continue to define the risk in their own way. As a result, the numerous definitions of risk can be found from vague and conceptual to rigid and quantitative. At conceptual level, we define risk as (i) a significant potential unwelcome effect of system performance, or (ii) the predicted or expected likelihood that a set of circumstances over some time frame will produce some harm that matters, or (iii) future issues that can be avoided or mitigated, rather than present problems that must be immediately addressed (Simonovic, 2009). Singh et al. (2007) classified risk into three categories: (i) risk for which statistics of the identified causalities are available; (ii) risk for which there may be some evidences, but where the connection between suspected cause and damage cannot be established; and (iii) estimates of the probabilities of the events that have not been occurred. Additionally, there are risks that are unforeseen.

In the last decades, methods for risk assessment have been developed in different fields, e.g. in the insurance sector and in the fields of environmental or technological risks (Molak, 1997). Here, risk is defined as the probability of suffering, harm or loss, and risk analysis is a body of knowledge that evaluates and derives the probability of the adverse effects of a natural process, technology, industrial process or an agent (chemical, physical etc).

The term 'risk' has different meanings, and therefore, it is necessary to define it and to give indicators, which allow to quantitatively describe and to map flood risks. Flood risk analysis of the German Research Network on Natural disasters (DFNK) investigated the complete flood disaster chain from the triggering event to its consequences: "hydrological load – flood routing – potential failure of flood protection structures – inundation – property damage".

Commonly, there are three components to determine flood risk:

- Hazard: the threatening natural event including its probability/magnitude of occurrence
- Exposure: the values/humans that are present at the location involved
- Vulnerability: the lack (or loose) of resistance to damaging/destructive forces.

This means that within an identified flood hazard area there may be the same exposure or risk of flooding, but a wide range of vulnerability to the hazard (Federal Emergency Management Agency / Emergency Management Institute).

As per the Flood Directive (2007), "flood risk "is the definition of risk as the product of "hazard", i.e., the physical and statistical aspects of the actual flooding (e.g. return period of the flood, extent and depth of inundation), and the "vulnerability", i.e., the exposure of people and assets to floods and the susceptibility of the elements at risk to suffer from flood damage.

Forster et al. (2007) defined flood risk as a combination of potential damage and probability of flooding. More precisely, risk is considered as the product of hazard and vulnerability of a region. Risk is an integral part of life. Indeed, the Chinese word for risk "weji-ji" combines the characters meaning "opportunity/chance" and "danger" to imply that uncertainty always involved some balance between profit and loss (Smith, 1996). Since risk cannot be completely eliminated, the only option is to manage it. Risk assessment is the first step in risk management.

Risk assessment generally comprises of three distinct steps Kates and Kasprson (1983):

a) An identification of hazards likely to result in disasters e.g. what hazards events may recur?

b) An estimation of the risks of such event e.g. what is the possibility of such event?

c) An evaluation of the social consequences of the derived risk e.g. what is the loss created by each event?

However, for sound risk management to occur there should be a fourth (d) step which addresses post-audit of all risk assessment exercises. When risk analysis is undertaken, risk (P) is taken as some product of probability (P) and loss (L)

$$R = P \times L \quad \ldots\ldots (1)$$

Flood risk assessment involves estimation of both statistical probability of an event occurring and the scale of the potential consequences (Smith, 1996). All development of land within the floodplain of a watercourse is at some risk of flooding, however, small. The degree of flood risk is calculated from historical data and expressed in terms of the expected frequency 10 year, 50 year or 100 year flood. Flood risk is a combination of flood occurring (the hazard) and of the potential adverse consequences of the flood for the human health, the environment, the cultural heritage, and the economic activity (the vulnerability) (Ologunorisa, 2001; FRM 2009).

A real flood risk level therefore requires a certain level of hazard, and for the same location, a certain level of vulnerability. A situation of risk is due to the incompatibility between hazard and vulnerability levels on the same land plot. The United Nations Commission for Human Settlements (Unchs – Habitat, 1981) has defined the hazard and vulnerability as follows:

(a) **Hazard:** It is the probability that in a given period in a given area, extreme potentially damaging natural phenomena occurs that induce air, earth movements, which affect a given zone. The magnitude of the phenomenon, the probability of its occurrence and the extent of its impact can vary and, in some cases, be determined. Table 1.1 shows hazard catagories based on The Commonwealth Scientific and Industrial Research Organization (CSIRO, 2000).

Table 1.1: Flood hazard categories based on CSIRO (2000)

HAZARD CATEGORY	**BASEFLOOD EVENTS**	**CHARACTERISTICS**
Low	100yr	Areas that are inundated in a 100yr flood, but the floodwaters are relatively shallow (typically less than 1m deep) and are not flowing with velocity, adult can wade.
High – Wading Unsafe	100yr	The depth and/or velocity are sufficiently high that wading is not possible, risk of drowning.
High - Depth	100yr	Areas where the floodwaters are deep (> 1m), but are not flowing with high velocity. Damage only to building contents, large trucks able to evacuate.
High - Floodway	100yr	Typically areas where there is deep water flowing with high velocity. Truck evacuation not possible, structural damage to light framed houses, high risk to life.
Extreme	100yr	Typically areas where the velocity is > 2m/s. All buildings likely to be destroyed, high probability of death.

(b) **Vulnerability:** Any physical, structural, or socio-economic element to a natural hazard is its probability of being damaged, destroyed or lost. Vulnerability is not static, but should be considered as a dynamic process, integrating changes and developments that alter and affect the probability of loss and damage of all exposed elements.

Vulnerability can also be defined as the measure of the capacity to weather, resist, or recover from the impacts of a hazard in the long term as well as the short term. Vulnerability depends upon many factors such as land use, extent and type of construction, contents and use, the nature of populations (mobility, age, health), and warning of an impending hazardous event and willingness and ability to take responsive actions. Vulnerability to flood has been defined as a combination of four distinctive types of vulnerabilities: physical, economic, infrastructure and social.

I. Physical vulnerability generally incorporates only those indicators susceptible to biological sensitivity. Wetlands are for example, considered regions of physical vulnerability. Wetlands are among the most productive ecosystems on earth. The richness of these transitional ecosystems relates mostly to the diversity of ecological niches created by the variability of seasonal and inter– annual cycles. Modifications in the hydrologic regime that disturb these cycles have been found to be the main stress factor threatening shoreline wetlands in all the world's major rivers . The regulation of water levels has also caused the shrinkage of wetlands, and an incidental reduction in the diversity of plant communities and the number of plant species .These regions have high biodiversity and sensitive life, which would experience higher damages, longer, slower recovery times due to flooding.

II. Economic vulnerability includes flood damage indicators which can be expressed in monetary terms.

III. Infrastructure vulnerability includes civil structure such as road networks, railways, and road bridges. Infrastructure components are important to movement of population, communications, and safety. Their inundation impedes traffic and hinders communications, increasing stress in the exposed population. Inundation may also block important emergency routes and cause physical damage to roads.

IV. Social vulnerability focuses on the reaction, response, and resistance of a population to a disastrous event. Vulnerable population may require special attention in an evacuation situation for example. The indicators are chosen based on a review of existing literature assessing vulnerability to current hazards. (Karmakar et al., 2010).

Risk can be related directly to the concept of disaster, given that it includes the total losses and damages that can be suffered after a natural hazard: death and injured people, damage to property and interruption of activities. Risk implies a future potential condition, a function of the magnitude of the natural hazard and of the vulnerability of all the exposed elements in a determined moment. Risk is a factor, element, or course involving danger or can be seen as the possibility of suffering harm or loss (Encarta, 99).It can also be mathematically calculated as the product of hazard, exposure, and vulnerability. By following this approach a large GIS database can be designed and developed in order to spatially represent the three components of risk. Flood risk may be described at different scales, ranging from the global to the local scale. Risk has become an issue that is being discussed in various fields where in varied definitions have been given (Stig, 1996). Studies of risk cover the issues such as identification and estimation of risk, risk assessment and evaluation, including monitoring and management of risk (Gerrard, 1995).

1.3 Background and Motivation

The Kosi River, with distinctive geomorphology and hydrological characteristics include a very dynamic regime and very high sediment load. It has long been considered as a problematic river due to recurrent and extensive flooding and frequent changes in its courses (Sinha, 2008). The dynamics of the Kosi river, generally described as ‘avulsive’ shifts, has been well documented by previous workers and a preferentially westward movement of 150 km in the last 200 years (Gole and Chitale, 1966; Wells and Dorr, 1987). Contrary to a dominant westward shift during the last 200 years, the Kosi river shifted by~120 km eastward in August 2008 triggered by the breach at the eastern afflux bund at Kusaha in Nepal at 12 km upstream of the Kosi barrage. The avulsed channel reoccupied the one of the paleo channel of the Kosi river and 80-85% of the flow of the river diverted into the new course. This has been termed as one of the greatest avulsion in any large river system across the world in recent years (Sinha, 2009) that inundated a large area in Nepal and north Bihar.

Since then, there have been several attempts to prevent future breach and flooding through flood protection schemes and engineering methods such as strengthening of embankments and dredging to divert the flow of the river along its central channel. Apart from a complete failure of these schemes, this has also led to controversy in nearby villages located in the Sansuri district of Nepal who protested the dredging to restore the flow of the river along its central current or pilot channel, as it would lead to the inundation of local villages if the water level rose too high, although it has been reported that the elevation of the villages would likely keep them safe from flood waters. But it’s unclear as to what consequences this would have for the river as a whole. It is important to consider that this inundation was different from the regular flooding event. When the embankments were first built they were intended to hold back rising flood water levels, but since then they have eroded severely and river bed a risen considerably.

The governments of Bihar (India) and Nepal have persistently been arguing for or against the digging of an 11.6 km pilot channel of the Kosi river. One of the main disputes arises from the political boundaries separating both countries; the eastern embankment lies on the Indian side of the Kosi and the western side in Nepal. Neither countries wants to increase the risk of raising water level on their side of the river and therefore, the conflict continues while in the meantime the threat of heavy monsoon rainfall lingers and emergency services in Bihar and Nepal are alerted every year. After the August 2008 event, even after the breach has been plugged, the eastern embankment continues to be at risk, as the conditions that led to the disaster have not changed (Sinha, 2009).

1.4 Research Questions and Objectives

In the backdrop of the persistent flooding problems in north Bihar and the August 2008 event, my thesis project was designed to address the following research questions:

1. How are river dynamics (avulsion) and flooding related in the Kosi river and what are the causal factors?
2. What are the geomorphic controls and manifestations of river migration and flooding?
3. How to integrate geomorphic, terrain and socio-economic parameters to prepare a flood hazard / risk map?

The main objective of this project is flood risk assessment of the Kosi basin based on geomorphic, topographic and hydrologic parameters in a GIS framework. Some of the important tasks of this project include:

1. To understand the causative factors (mainly geomorphic and meteorological) of dynamics and flooding (and the interrelationship) of the Kosi river.
2. To ascertain the relative importance of each of the factors for the flood risk evaluation including socio-economic factors.
3. To integrate all data in a GIS framework for flood risk assessment of the Kosi river basin and propose the first order floodplain zoning in parts of north Bihar.

1.5 Study Area

The Kosi river or Koshi also known as Saptakoshi known for its seven Himalayan tributaries, is a trans-boundary river flowing through Nepal and India. The name ‘Kosi’ came from ‘Kausiki’ after the name of a legendry ascetic who was a low cast women (Gohain and Parkash, 1990). Some of the rivers of the Kosi system, such as the Arun, the Sun Kosi and the Bhote Koshi, originate in the Tibet autonomous region of China. It is one of the largest tributaries of the Ganges. Along with its tributaries, the river drains 29,400 km^2 (11,400 sq mi) in China (mainly the upper Arun basin north of the Mount Everest region), 30,700 km^2 (11,900 sq mi) in Nepal (the eastern third of the country), and 9,200 km^2 (3,600 sq mi) in India (Virgo and Subba, 1994). The river basin is surrounded by ridges in the mountainous catchment that separate it from the Yarlung Tsangpo river in the north, the Gandaki in the west and the Mahananda in the east (Rao, 1975; Vargehese, 1993). The river is joined by major tributaries in the Mahabharata Range approximately 48 km (30 mi) north of the Indo-Nepal border. South of the Siwaliks, the river has built up a megafan some 15,000 km^2 (5,800 sq mi) in extent, breaking into more than twelve distinct channels, all with shifting courses due to flooding. The Kamla, Baghmati (Kareh) and Budhi-Gandak are the major tributaries of Kosi in India, besides minor tributaries like Bhutahi, Balan. Over the last 250 years, the Kosi river has shifted its course over 120 km (75 mi) from east to west. Its unstable nature has been attributed to the heavy silt it carries during the monsoon season and flooding in India has extreme effects.

The study window for the analysis includes the upper part of the Kosi basin upstream of the Kosi barrage and the lower part of the Bihar(India) covered between the longitudes 86°37'29.086"E to 87°8'28.983"E and latitudes 26°3'21.709"N to 26°43'32.213"N. It includes ~ 89 blocks in India and Nepal (Figure 1.1). Figure 1.1a shows the area of interest for the risk analysis. Figure 1.1b and 1.1c show the Landsat imagery of the study area of year2003 and 2009 i.e. prior and post to august 2008 avulsion respectively.

1.6 Organization of Thesis Chapters

This thesis has been organized in 7 chapters. Chapter 1 presents the introduction, basic concept of flood hazard, vulnerability and risk, and defines the major objectives of the thesis and study area. Chapter 2 presents a detailed literature review on the geomorphic control that affects floods and flooding history of the Kosi river, and also documents the different approaches for flood risk analysis. Chapter 3 presents the details of the data used, methodology and approach followed for this research. Chapter 4 documents the detailed geomorphic mapping of the study area with the consideration to the major avulsion of August, 2008. Chapter 5 contains the generation of thematic layers and results of this thesis. Chapter 6 discuss the results. Chapter 7 summarizes the thesis and presents major conclusions.

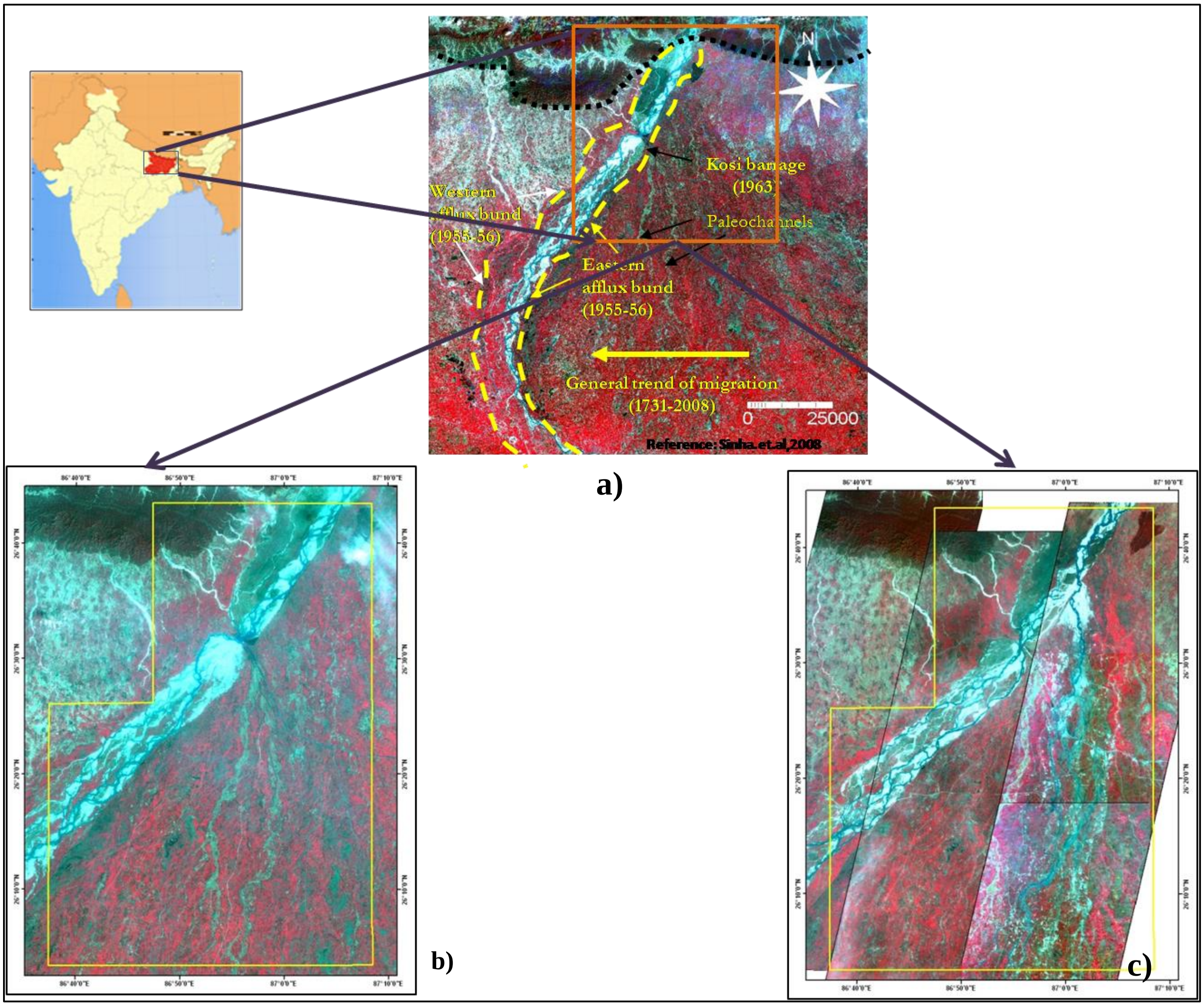


Figure 1.1: Location of the Study area, (a) FCC of the Kosi River basin (b) FCC of the Study area Pre avulsion (Landsat, 2003), (c) FCC of the study area Post avulsion (Liss-4, 2009, 2010)

Chapter2

Literature Review

2.1 General

The Kosi river in the North Bihar is one of the major tributary to the Ganga river. It is being responsible for the most devastating flood in the region of Bihar and Nepal. During last thirty years these regions have experienced the highest number of flood incidences (Kale, 1997), the plain experiences extensive loss of life and property. This is attributed by short-term changes in sedimentation load and water volume and long-term changes of climate. The dynamism of the Kosi River attributed to the westward movement of 150 km in last 200 years. On August 18, 2008, the Kusaha breach was totally unexpected and followed by avulsive shift of ~120 km towards east with an order magnitude higher than any other avulsive shift in historical times. This results in the inundation of very large area and the new channels formed which follow the new course and did not join the main Kosi river. This cause change in the geomorphology of the river, which leads to the understanding of the nature of the river to cause flood and helps in taking the proper measures to control the flood and minimize the effect.

In the same way, the geomorphology along with the other influential parameters helps to study the flood risk analysis for the Kosi which will help in timely availability of information for taking decisions and actions (Miranda et.al., 1988) for reducing the loss of lives, properties and resources. It has therefore become important to create easily readable and rapidly accessible flood hazard map, which will prioritize the mitigation effects. Several approaches were considered to study the associated risk of the river in the different parts of the world with the use of different medium to define it. The current flood mapping approaches include combination of the geomorphological, hydraulic, hydrology, the meteorological , the socio economic factors, with aid of Remote Sensing and GIS environment and their combinations, some of which has been discussed with their case studies below.

2.2 Geomorphic Controls of Floods

Geomorphology can contribute to the choice and design of flood control. It contributes to most of the cases relating to the interactions among flooding, sedimentation and channel behavior. The change of the river geomorphology occurs with the flood frequency and the propensity within an area. Measures to reduce the flood risk may be classified into two categories:

structural and non-structural. Non-structural measures refer to any measure, which involves the knowledge, practices or agreements to reduce the potential impacts of floods. It may be cost effective or traditional engineering solutions. It include emergency flood warnings, public information system, post catastrophe recovery which help to mitigate flood related problems. Whereas, structural measures refers to any physical construction to intervene, control or to mitigate the potential of flood impact. It includes the measure to increase the infiltration, reduce the runoff rate in upper catchment areas, structure to design to keep the floodwaters away from the people and property such as dam, levees, dikes, embankments.

The Flood 2010 was due to infrequent floods caused by extreme drying of embankments, cracking and rodent holes weakening the structures. Hence, the strategies for improving flood management include; establishment of new benchmarks including highest flood levels, Freeboard, etc design of embankments is to be made and the standard operating procedures have to be revised to ensure their utility/adequacy under the present conditions. SOPs (Standard Operating Procedures) for flood management have to be prepared for individual structures keeping in view the identified weak areas / hotspots. Contingency plan is to be prepared which shall indicate the infrastructures located in the flood route with special focus to low lying areas and villages / towns to be affected in the Swat, Kabul and Indus river (Haq and Zaidi., 2010).

The flood controls embankment experiences breaching since their completion and are not very effective in reducing the damage to the environment, economy and property as embankments and polders reduced floodplain storage capacity during floods, leading to an increase in water levels and discharges in many rivers (Chowdhury, 1998). A total of 5,695 km of embankments, including 3,433 km in the coastal areas, 1695 flood control/regulating structures, and 4,310 km of drainage canals have been constructed by the Bangladesh Water Development Board (Rahman and Chowdhury, 1998). It create a false sense of security among residents living within embanked areas. To mitigate flooding propensity in Bangladesh, both the government and people will have to adopt watershed–scale management practices (BMPs) which includes a series of activities designed to: (a) reduce the runoff, (b) increase the carrying capacity of drainage system, and (c) increase land elevations.

Flood protection infrastructure generally comprises river banks protections, the floodplain zoning, planned urbanization, restoration of abundant channels, dredging of rivers and streams, increased elevations of roads and village platforms, building of efficient storm sewer systems, establishment of buffer zones along rivers, conservation tillage, controlled runoff near construction sites, adjustment of life-style and crop patterns, good governance, and improvement in flood warning/preparedness systems (Khalequzzaman., 2008).

Jain and Sinha (2003) evaluated Geomorphic Instantaneous Unit hydrograph (GIUH) on the river Baghmati which provide link between hydrology and geomorphology. The analysis suggests that conventional methods for flood control such as embankment may not be the effective measure in the Baghmati river basin. The additional efforts such as catchment afforestation, upstream storage through small check dams, detection basins within flood plains and artificial drawdown of ground water has been suggested as flood control measures.

For controlling flood in Sacramento river and its tributaries, almost 980 miles of levees were constructed providing flood protection to 800,000 miles of highly productive land, their cities (US Army Corps. of Engineers and West Sacramento Area Flood Control Agency).

Rosgen. 1997, presented Integrated Geomorphological concepts to restoration of incised river. This concept describes evolutionary tendencies associated with stream adjustments leading to their most probable natural state. The range of restoration design concepts such as; returning the stream to its original elevation and re-connecting floodplains, widening the belt width to construct a new channel at the existing elevation, changing stream types, and stabilizing the existing incised channel in place has been demonstrated.

There are many flood controls structure at work within the city of London (Peck et al, 2011) for both safety and recreation in the city. The Fans have dam is an embankment dam with concrete spillway that controls drainage area of 1450 sq.km at its outlet have extensive network of dykes (Western London Dyk**e** is the largest) designed to protect city from flood damage around north, south and main Tames river which was approx 5.5 km to bring it up to acceptable conditions and the 250 years regulatory flood levels.

The Nyack flood plain of the Middle Fork Flathead River, MT, USA is a 9-km anastomosed alluvial montane flood plain. Poole et al.,2002 combined field data with pre-existing ground penetrating RADAR (GPR) surveys, these data intimate a sinuous lattice of preferential ground-water flow paths (buried abandoned streambeds) in the upper alluvial aquifer. Using aerial photo interpretation and the identified relationships among element types, elevation, and preferential ground-water flow paths, a quantitative, three-dimensional characterization of surface and subsurface geomorphology across the entire flood plain was developed to support a heuristic modeling effort investigating the influence of flood-plain geomorphology on spatiotemporal patterns of surface and ground-water flow and exchange under dynamic hydrologic regimes .

2.3 Methods of Risk Assessment

The usage of the computer–automated models, which incorporate the hydrology, hydraulic models, digital terrain models of flood plains in conjunction with Remote Sensing and GIS are increasingly becoming the common methods for the delineation of the floods and the associated hazards and risk. The hydrology and hydraulic provide important data related to the flood hazard but is expensive and intensive. Several others means of estimation of flood risk (Benito et al; 2004) based on the past flood information based on paleo flood history and from historical information based on chronicles and documents provide information on the flood event during the period of settlement. In recent decades, Optical Remote Sensing has been used in many studies to map the inundated area characterized by different climate, morphology and landuse. It is provide large volume of information on timely basis, cost effective and helps in acquiring information for hazardous or inaccessible regions also.

2.3.1 Hydraulic and Hydrologic Approach

Flood hazard mapping and risk assessment of Bagmati river in central Nepal was done to identify the priority areas and high risk zones using Advanced Spaceborne Thermal Emission and Reflection (ASTER) image combined with hydraulic model (HEC–RAS) which was used to simulate flood flows through the river and its flood plain for discharges corresponding to various return periods using annual maximum instantaneous discharges for the period from 1965–2004. The flood hazard factors for each Village Development Committees (VDCs) were based on the total inundation area and inundation area having a flood depth of greater than 1m. The model results were verified through a field visit and data collected on flood depths corresponding to the peak flood of year 2004 that had a magnitude close to that of a 50year flood. Vulnerability was assessed based on the economic importance of land type being inundated and population density using Census Data (2001) from Central Bureau of Statistics, Nepal. Finally flood risk factor was determined using the flood hazard and vulnerability factors based on matrix multiplication method on VDC level (Kafle et al. 2006).

Karagiozi et al. (2011) implemented the hydrological models into a GIS environment (Arc Hydro model) taking into account the geomorphologic characteristics of the study area for flood hazard assessment. Digital Elevation Model (DEM) has been used to produce the hydrographic network and the hydrological basins layer, the morphologic characteristics such us area, mean slope, mean elevation, and total relief were calculated for each basin. All enhancing flood hazard factors were combined in a product (by simple multiplication) in order to produce the inherent flood hazard map for each water basin and enhance the spatial differentiation of the phenomena.The flood hazard map was published into a web GIS environment providing a friendly Graphic User Interphase (GUI) to the end users that can interact dynamically with the map.

Masood and Takeuchi (2010) has developed flood hazard map for mid-eastern Dhaka (37.16 km^2) which was carried out by 1D hydrodynamic simulation of digital elevation model (DEM) data from Shuttle Radar Topography Mission (as modified to represent the current topography of the area as topography was considerably change due to land filling) and the hydrologic field-observed data for 32 years (1972–2004), river cross–section, discharge data and water level. Finally, to assess the flood risk of that area, a risk map was prepared as the product of hazard (i.e., depth of inundation) and vulnerability (i.e., the exposure of people or assets to flood). Inundation has been assigned as hazard index and for vulnerability index, the landuse land cover with houses/living place has been considered.

Ologunorisa, (2004) undertaken flood risk assessment in the Niger Delta, Nigeria using a combination of hydrological techniques based on some measurable physical characteristics (depth of flooding (m), duration of flood (hrs/weeks), perceived frequency of flood occurrence, and relief or elevation (m) of flooding, and social-economic techniques based on vulnerability factors (proximity to hazard source, land use or dominant economic activity and adequacy of flood alleviation schemes and perceived extent of flood damage). 18 settlements randomly selected across the three ecological zones in the region were rated on the basis of the said parameters using rating scale. Three flood risk zones emerged from the analysis and these are the severe flood risk zones, moderate flood risk zones and low flood risk zones.

Thailand flood forecasts were prepared for the Huai nam Chun catchment of Pa Sak Watershed, Phetchabun province, using a hydraulic model and GIS (Okoduwa, 1999). The objective was to test what extent the integration of a hydraulic model and GIS can contribute to the quantitative assessment of effects of the upstream land use changes on downstream flood pattern. The HEC-1 hydraulic model and ILWIS (GIS) were used. The simulation result showed the effect of the land use changes on flood levels down steam.

There are several other case studies which has incorporated the combination of Hydraulic and Hydrological parameters for the analysis of flood hazard and risk assessment.

2.3.2 Remote Sensing and GIS approach

Venkata and Sinha (2008), identified risk areas and prioritize their mitigation/ response efforts in the flood-hazard areas in the Kosi river basin, North Bihar, India in a GIS environment using Analytical Hierarchy Process with the aid of the data which includes district level maps, topographic maps and census data of 1991 for the regional divisions of Bihar, obtained from the Survey of India, National Atlas and Thematic Mapping Organization (NATMO), and District Statistical Office, Saharsa respectively. Digital elevation data (GTOPO30), a global digital elevation model (DEM) from U.S. Geological Survey's EROS Data Centre, Sioux Falls, South Dakota and the DEM derived from the Toposheet of the study area and the digital remote sensing images for the study area are Liss-IV, Liss-III, were used. The primary decision factors considered in this study are geomorphic features, distance to active channels (drainage buffer), elevation, vegetation, land cover, and population density which were used to prepared flood hazard map.

Forkuo (2011), has generated efficient and cost effective methodology for preparing flood hazard maps in Ghana, particularly those regions where floods pose a recurrent danger. The level 1b ASTER imagery, topographic map covering the study area at a scale of 1:50000, the contours generated DEM, land cover and demographic data has been used to create a district level map indicating flood hazard index for district scale using an additive model which was adapted for this study (Sanyal and Lu, 2003).The hazard categories of classification was based on the Jenks scheme (natural break).

Fosu et al. (2012), has illustrated the case study of the Susan river, Ghana. The land cover data obtained from classified ASTER image, the contour generated DEM, the geometric data extracted from the DEM, topographic map and field measurements collections. HEC-RAS model (i.e., open channel flow) used as main model to calculate floodplain elevations and determine floodway encroachments. the geometric data coalesced with the topographic maps to generate the flood hazard maps that covers an approximately 2.93 km² indicating flood depth of 4.02 m was obtained as the maximum water level and high water depth occurred along the main channel and spreads gradually to the floodplains. The recent satellite images of high resolution are therefore needed so that an effective terrain models can be created since the accuracy of any hydrological model depends largely on the accuracy of the terrain model that is being used.

With the little data availability (e.g. cadastral, topographical, hydrological, and meteorological), Guarin et al., (2004) perform the basic flood risk assessment by combining aerial photo interpretation, the use of data questionnaires in a community-based field data collection, and subsequent analysis using Geographical Information Systems (GIS) in study area of San Sebastian based on traditional hydrological modeling. The cadastral base map with an attribute database was generated as key inputs for flood hazard and vulnerability assessment of the area. The vulnerability maps were combined with the cost information for the estimation of the loss. The flood vulnerability curves relating water height and speed were assessed for the three of the main elements at risk within the urban area: buildings, contents, and road network. The municipal authorities used the generated cadastral map with database containing physical and social information at the parcel level as well as detailed information on flood hazard, vulnerability and expected losses, as a valuable tool in municipal planning, including a wider range of applications in addition to risk management.

Georgakos et al., (1997) undertook an estimation of flash flood potential for large areas in United States of America. Geographical Information System (GIS) technology was used to assimilate digital spatial data, remotely sensed data, with physically-based hydrological, hydraulic models catchment response. This methodology used digital river reach data, digital terrain elevation data, , and the US Geological Survey land-use and land-cover data to produce estimates of the effective rainfall volume of a certain duration required to produce flooding in small streams.

The Village-wise flood risk index map for 267 villages was generated by Sharma et.al. 2012, using multi temporal satellite data for the study area Naogaon district, Assam, India . The final flood risk map is derived by integrating the flood hazard with land use land cover, infrastructure and population data and assigning weightage to each classes considering the village as reference unit, a method to generate the village flood risk map using GIS environment. 50 satellite datasets, including optical and microwave data acquired during the flood season for the last 10 years period (1998-2007) has been used for the flood hazard layer. The Vulnerability has been considered as function of population, infrastructure and landuse land cover for each assign value based on its significance.

2.3.3 Other conventional model approach

Evans et al. (2007), explained a case study of the Medway Estuary Strategic Flood Risk Assessment used a wide range of GIS data sets and were integrated using the TUFLOW, ESTRY, SFRA model techniques. It shows how near shore bathymetry, low level LIDAR, forward and downward looking video, LIDAR, flood defense asset data and a range of bespoke and other datasets were combined to assess flood risk for a tidal estuary. It has describes the use of GIS in land classification, data processing, creation of Digital Terrain Model (DTM) and flood risk and hazard mapping. The Environment Agency invests substantial resources collected hydrometric and topographical data using various techniques. These data is used for a wide range of purposes such as flood risk mapping, catchment flood management plans, shoreline management plans, and integrated coastal zone management that provide essential information for day to day asset management and long term flood risk management.

Using a Geographic Information System (GIS), a risk-based methodology LATIS (risk assessment tool) was created to quantitatively assess flood risk based on hydrologic models, land use information and socio-economic data to generate the final risk map at Flanders, a region of north Belgium suffered several serious riverine floods that caused substantial property damage (Deckers et al. 2010).

Zhang., (2003), presented the methodology and procedure for flood risk assessment using GIS and flood inundation model (FIM) based on the “micro-zonation concept” on an entire floodplain at Shinkawa-river floodplain around Nagoya City, Japan. The assessment was made on the availability of the spatial data that include digital elevation model (DEM), channel network, dams or floodgates, watershed boundary and buildings/properties. Nonspatial data include discharge, land/building values, weather data, and channel geometric data sets.

To determine flood risk zones in Accra and its environs, a hydrological model (modified rational model) was integrated into the GIS platform, by the arithmetic overlay operation method, using operators such as addition and division. The official data obtained from published information on flood generation factors, such as rainfall, discharge of the various rivers and human activities within the study area (Water Research Institute, Meteorological Services, Hydro-Division of Ministry of Works and Housing). The data collected from primary source included vegetation characteristics; landuse pattern, channel characteristics (cross section area) and soil characteristics that consist of extensive fieldwork, field observation and image interpretation were used (Nyarko, 2000).

2.4 Flood Scenario in India

India is the worst flood–affected country in the world after Bangladesh and accounts for one-fifth of the global death count due to floods. Twenty-three out of thirty-two states/ union territories in the country are subject to floods and 40 million hectares of land, roughly 1/8th of the countries geographical area, is prone to floods. The chronic flood-prone river basins in India are the Ganga and the Brahmaputra. These Himalayan rivers flowing down the hills cause flood problems in Uttar Pradesh, Bihar, Orissa, West Bengal, and Assam due to high discharges concentrated during monsoon months (June to September). India accounts for nearly one-fifth of global death count due to floods. About 4 lakh km^2 or nearly 1/8th of India's geographical area is flood prone. In a country like India where one part or the other was affected by flood every year, it is very important to plan flood management measures in frequently flood prone areas. On an average, the area that actually affected is of the order of 10 million hectares of which about half is cropland. Rashtriya Barh Ayog (National Flood Commission of India) identified 40 million hectares of land as flood prone in India.

The Planning commission (2011) has conducted the survey and estimated the annual damage of more than rs1800 crore beside the loss of precious human lives and cattle. Table 2.1 highlights the flood area affected and the damage caused in India within the year 1953–2010.

Table 2.1: Flood affected area and damages in India (1953- 2010)

Item	**Unit**	**Average Annual Damage**	**Maximum Damage(Year)**
Area Affected	Million Hectare	7.208	17.50 (1978)
Population Affected	Million	3.19	7.045(1978)
Human Lives Lost	Nos	1612	11316 (1977)
Cattle Lost	Nos	89345	618248 (1979)
Crop Area Affected	Million Hectare	3.679	15.18 (2005)
Value of Damaged crops	Rs. (Crore)	693.866	4246.6 (2000)

Houses Damaged	Th.No.	1194.64	3508 (1978)
Value of Damage Houses	Rs. (Crore)	275.48	1307.9 (1995)
Value of damage Public Utilities	Rs. (Crore)	814.596	5606 (2001)
Total Damage to houses, crops and public utilities	Rs. (Crore)	1804.419	8864 (2000)

Source: Planning Commission (2011).

Some of the most unusual and unprecedented floods have been recorded on different rivers of the subcontinent in the most recent decades (Kale, 2002). Remote sensing and GIS based research work has gained considerable momentum in the last few years. Flood hazards mapping is very important for our country to assess and identify the flood prone areas. There are different agencies which are frequently involved in the mapping for the whole country such as National Remote Sensing Centre (NRSC), Central Water Commission , CWC (Flood Atlas of India), Building Materials And Technology Promotion Council, BMTPC (vulnerability Atlas of India) and National Atlas and Thematic Mapping Organization, NATMO (Natural Hazards Map of India). These agencies are frequently mapping the important flood prone areas viz. Sub-Himalayan region and the Ganga plains, Brahmaputra Valley, Punjab Plains, Mahanadi-Godavari-Krishna-Kaveri Delta Plains and Lower Narmada-Tapi-Mahi Valleys.

Optical and microwave data from IRS, Landsat ERS and RADARSAT series of satellites have been used to map and monitor flood events in near real-time and operational mode. Information on inundation and damage due to floods is furnished to concerned departments so as to enable them organizing necessary relief measures and to make a reliable assessment of flood damage. Owing to large swath and high receptivity, WiFS data from IRS-1C and -1D hold great promise in regional scale floods monitoring. Based on satellite data acquired during pre-flood, flood and post-flood along with ground information, flood damage assessment is being carried out by integrating the topographical, hydrological and flood plain Land use/Land cover information in a GIS environment. In addition, space borne multi-spectral data have been used for studying the post-flood river configuration, and existing flood control structures, and identification of bank erosion-prone areas and drainage congestion, and identification of flood risk zones (Rao, 2000).

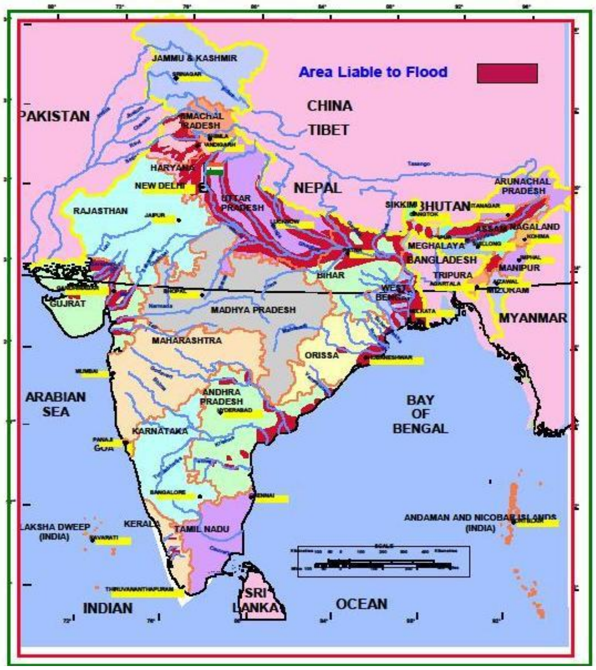


Figure 2.1: India Flood prone States

Source**: http://ndma.gov.in/ndma/floodzone.html**

In the Figure 2.1 shows the flood affected areas in India. Assam, West Bengal, Bihar and Orissa are among the high flood prone affected states of India. Apart from these, most of the rivers in the northern states like Punjab, and Uttar Pradesh are also vulnerable to occasional floods. It has been noticed that states like Rajasthan, Gujarat and Haryana and Punjab are also being inundated in recent decades due to flash floods. This is partly because of the pattern of the monson and party because of blocking of most of the streams and river channels by human activities. Sometimes, Tamil Nadu, Andhra Pradesh and Kerala experiences flooding during November- January due to the retreating monsoon (NCERT, 2006).

2.5 Kosi Basin and its flooding History (1997-2008)

The river Kosi originates at an altitude of over 7000 m above MSL in the Himalayas. The upper catchment of the river system lies in Nepal and Tibet. The highest peak in the world, the Mount Everest and the Kanchenjunga are in the Kosi catchment. It is known as Sapta Kosi in Nepal. It enters the Indian Territory near Hanuman Nagar in Nepal. It joins the Ganga river near Kursela in Katihar district. The river Kosi drains a total catchment area of 74030 sq.km in India and other countries. Out of the total catchment area of the Kosi, only 11410 sq.km lies in India and the rest 62620 sq.km lies in Tibet and Nepal.

Table 2.2: Salient Features of the Kosi Basin:

1.	Total Drainage Area	74,030 sq.km
2.	Drainage Area in Bihar	11,410 sq.km
3.	Population in Bihar	66.55 lakhs
4.	Water resources	52,219 Million cubic meter
5.	Average annual rainfall	1,456 mm
6.	Total length of main river in Bihar	260 km
7.	Cropped area in Bihar	8,694 sq.km
8.	Tributaries	Bagmati(R), Kamla Balan(R), Bhuthi Balan(R), Trijuga(R), Fariani dhar(L), Dhemama dhar(L)

Bihar is India's most flood-prone State, with 76 percent of the population, in the north Bihar living under the recurring threat of flood devastation. About 68800 sq.km out of total geographical area of 94160 sq.km, comprising 73.06 percent is flood affected.A number of rivers that have their catchments in the steep and geologically nascent Himalayas drain the plains of Bihar, adjoining Nepal. Kosi, Gandak, Burhi Gandak, Baghmati, Kamla Balan, Mahananda and Adhwara group of rivers originates in Nepal, carry high discharge and very high sediment load and drops it down in the plains of Bihar. About 65% of catchments area of these rivers falls in Nepal/Tibet and only 35% of catchments area lies in Bihar. A review by Kale (1997) indicated that the plains of north Bihar have recorded the highest number of floods during the last 30years. In the years 1978, 1987, 1998, 2004 and 2007 Bihar witnessed high magnitudes of flood. The total area affected by floods has also increased during these years. Flood of 2004 demonstrates the severity of flood problem when a vast area of 23490 sq.km was badly affected by the floods of Baghmati, Kamla and Adhwara groups of rivers causing loss of about 800 human lives, even when Ganga, the master drain was flowing low. In the year **1998** maximum discharge in the first week of July in most of the rivers in North Bihar caused excessive pressure on the embankment along the rivers resulting in damages at several places.

Embankments of Burhi Gandak, Baghmati, Adhwara and Kosi were partially damaged. Three hundred and eighty one persons died and public property worth rupees 9,284 lakhs were damaged. There was crop damage of about rupees 36,696.68 lakhs. There was unexpected heavy rains in the month of October, in the catchments in Nepal and flood level suddenly touched the 1987 HFL at Jhanjharpur Railway Bridge in Kamla Balan river and the spurs in Kosi river experienced threat throughout the flood season in the year **1999.** Crop of rupees 24,203.88 lakhs and public property of rupees 5409.99 lakhs were damaged. Kamla Balan and Bhutahi Balan catchments received heavy rainfall during first and last week of July resulting in unexpected rise of water level. In first week of August 2000, Eastern Kosi Afflux Bund was punctured. Twelve thousands three hundred and fifty one villages were affected and crop worth rupees 8303.70 lakhs were damaged. North Bihar was badly affected by flood due to heavy rain in Nepal portion of catchments of rivers in the year **2001.** Western Kosi embankment, Bhutahi Balan right embankment, Baghmati left embankment and Burhi Gandak left embankment were partially damaged. Crop of rupees 26721.79 lakhs and public property of rupees 18353.78 lakhs were damaged. During the year, **2002** North Bihar experienced serious flood and overtopping reported in Kamla Balan left embankment and right embankment at Khiroi. Four hundred and eighty nine persons died. Crop damage of rupees 51149.61 lakhs and public property damage of rupees 40892.19 lakhs were reported. The HFL at Bhagalpur surpassed the 1978 record of 34.18 m and at Gandhihat, Patna the HFL surpassed the 1994 record of 50.27 m in river Ganga and the status of flood in other rivers except Ganga and Gandak remain normal in the year **2003**. The catchment area of North Bihar rivers received heavy rainfall in the first week of July, **2004** itself, which not only broke last three years flood record but also surpassed the 1987 flood. Flood level at Dubbadhar site on river Baghmati surpassed all time high flood level by about 1.18 m. Similarly, Burhi Gandak river on July 15, 2004 and Kamla Balan river on July 10, 2004 touched all time high flood level. This itself speaks about the fury of flood in the year 2004. Many places in the embankments of north Bihar were breached, resulting in flood inundation in a vast area of North Bihar. Unprecedented flood in river Baghmati, Burhi Gandak, Kamla Balan and Bhutahi Balan and Adhwara group of rivers breached the embankments at many places and there was loss of life and property on a large scale. In river Kosi, situation was normal. There were altogether 53 number of breaches during 2004 flood season. Crop damage of rupees 52205.64 lakhs, public property damage of rupees 103049.64 lakhs and death of 885 persons were reported. Flood situation during **2005** and **2006** remain normal but in the year 2007 the flood situation was serious in north Bihar due to heavy rainfall in catchments of almost all rivers flood. There were 28 breaches at different locations of the embankments during 2007 flood season. Heavy spell of rainfall (average 82.70 mm) was observed in the beginning of flood season. In Burhi Gandak and in Baghmati river basins there has been regular rainfall in July and August, which kept the river water level continuously rising. Almost whole of north Bihar was badly affected and heavy losses of crops and public property occurred. In the year 2008 an appreciable amount of rainfall was received on very first day of monsoon season i.e. 15^{th} June (160 mm at Chanpatia, 141 mm at Sikanderpur and 92.2 mm at Khagaria). July was the wettest month having maximum rainy days followed by August. There was an unprecedented flood due to breach near 12.9 km of Eastern Kosi Afflux embankment near Kusaha village in Nepal on 18^{th} August 2008 that took a shape of a catastrophe leading to miseries to lakhs of people in Sunsari and Saptari districts of Nepal and Supaul, Madhepura, Araria, Saharsa, Katihar and Purnea districts of Bihar. River Kosi entirely changed its course from earlier one, which was again tamed to its original course by Water Resources Department after a tremendous effort keeping in line with the advice of Kosi Breach Closure Advisory Committee. The rainfall was scanty in entire Bihar in the year 2009. The situation was so aggravated that Disaster Management Department GOB declared 26 districts as draught hit. The first appreciable rainfall was recorded in late June-09 and early July-09. There were few isolated storms at few stations of some basin in September and October. Flood situation remained normal this year except few breaches such as Tilak Tajpur on right embankment of river Baghmati under Runnisaidpur block of Sitamarhi district, Gobindpur site of Labha Choukia Paharpur embankment of Mahananda river and Sallehpur.

Chapter 3

Data and Methods

3.1 General

The flood risk map of Kosi basin has been generated by considering different thematic layers of the factors controlling the flood. These thematic layers were prepared using remote sensing data (LISS-IV, Landsat-VII), Topographic maps, Block level boundary maps, population data, SRTM DEM data, and rainfall data. The different data sets were analysed for information generation like geomorphic features, population density, landuse landcover etc. The SRTM DEM was analysed for the generation of slope map. All the data / thematic layers derived from different sources were converted to grid format which will be used in GIS analysis. Finally, all data was integrated in a GIS environment using multi-criteria decision tools for preparation of flood hazard, vulnerability and flood risk maps. Details of the data used for this study and the methods employed were elaborated in below section.

3.2 Data used

An extensive use of satellite based remote sensing data for mapping and topographic analysis was made for the study of flood risk assessment in the part of Kosi basin. Table 3.1 and Table 3.2 listed below shows the details of various data sets used.

Table 3.1: Lists of satellite data used for analysis

Data type				Month/Year of Acquisition	Ground Resolution/ Scale
Satellites	Sensors	Path/Row	Spectral Resolution (μm)		

Landsat–7	TM	140/42	B1: 0.45–0.52 B2: 0.52–0.60 B3: 0.63–0.69 B4: 0.76–0.90 B5: 1.55–1.75 B6: 10.4–12.5 B7: 2.08–2.35	December 2009	30 m for bands 1,2,3,4,5and 7 120m for band 6 resampled to 30 meters
IRS–P6	LISS–4	102/35 102/36,102/37 102/41,102/42,102/43 102/6,102/7,102/8	B1: 0.52–0.59 B2: 0.62–0.68 B3: 0.77–0.86	January 2009, February 2009 and 2010	5.8m for bands 1,2,3
Digital Elevation Map (DEM)	Surface Radar Terrain Mapper (SRTM)	Elevation in 1m pixel precision, ±7m vertical accuracy		2009	90m

Table 3.2: Lists of maps used for the analysis

Data Type	Details	Data Source
Topographic sheet	Scale = 1: 2,50,000	Survey of India, 1983
District maps with block boundary Sunsari District (Nepal) Saptari District (Nepal) Udayapur District (Nepal)	Scale = 1: 300,000,00	OCHA, Nepal 2008

. Madhepura District (Bihar) . Araria District (Bihar)	N/A	National Informatics Centre, Bihar
. Flood Inundation Map of North Bihar state, Block Level	Scale = 1:450,000	DSC, NRSC, Hyderabad 2012
. E80 N30, MODIS Flood Inundation Map		Darmouth Flood Observatory,

3.2.1 Rainfall Data

The rainfall data used for the Risk analysis is from "The Tropical Rainfall Measuring Mission (TRMM)". This is a joint mission between National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall. A combined Precipitation Radar (PR) / TRMM Microwave Imager (TMI) rain-rate product with path-integrated attenuation at 4 km horizontal and 250 m vertical resolutions. TRMM data (2b31) are available at a nearly global scale for the past 12 years (1998 to 2009). It has been designed to monitor and study tropical rainfall and the associated release of energy that helps to power the global atmospheric circulation, which is responsible for shaping both global weather and climate. The processed TRMM (2b31) rainfall data has been made available by Dr. Bodo Bookhagen, (bodo@icess.ucsb.edu) at http://www.geog.ucsb.edu/~bodo/TRMM/. These data sets are available for download in several formats (NetCDF, GeoTIFF, and Google Earth) for different analysis purposes.

3.2.2 Census Data

The Latest Census data for the year 2011 has been procured from "The LandScan global population" which has approximately 1 km resolution (30" X 30"). LandScan Global is the finest resolution global population distribution data available and represents an **ambient population** (average over 24 hours). LandScan population distribution models are matched with the data conditions and geographical nature of each individual country and region. The LandScan data for India and Nepal has been used for the purpose of risk analysis in my study area.

3.2.3 Field data

An extensive field visit for the collection of topographic points and ground validation was done during September 2012. For the geomorphologic mapping, various features has been mapped and validated with the ground during field visit. Also, the data for road river intersection points have been collected throughout the study area, which is being used as one of the supporting parameter for the analysis of the vulnerability of the area to risk, which was classified accordingly to various classes. The avulsion channel has been mapped using Differential Global Positioning System (DGPS). For river profiling the continuous topographic point were collected and for the land profile, the discrete profiling was done.

3.3 Methodology

The methodology mainly relies on analysis of the satellite images and field visit. It involved several steps such as,

(1) Study area selection using remote sensing images and GIS.

(2) Field data collection using DGPS survey.

(3) Processing and generation of different thematic layers according to the availability of the data.

(4) Integration of all data sets, preparation of final risk map for the study area, and interpretation of the results.

(5) Finally, the validation of the results generated.

The following pre-processing techniques has been applied to remote sensing images using ERDAS imagine 9.3 software.

A. Layer stacking :

LISS-IV has four spectral bands (provided by NRSC, Hyderabad) and the Landsat–7 has seven bands (downloaded from the USGS website). For any pre-processing step, it is necessary to stack all individual bands together to make a false color image and this was done by using ERDAS imagine 9.3 software. The combination of spectral bands 3, 2, and 1 has been used for false color composite from LISS-IV image and combination of spectral bands 4, (0.76–0.90 µm), 5 (1.55–1.75 µm) and 7 (2.08–2.35 µm) from Landsat–7 was used. As the incident wavelength (> 0.7 µm), get completely absorbed by water, thus very useful in identifying the palaeochannels in the study area (Shepherd et al., 2000; Gaurav et al., 2011).

B. Georeferencing and Registration:

The first step of the processing of the raw data is geo-referencing the different data sets for comparison and overlay. This was done by collection of ground control points on different data sets of comparable and identity information. The permanent structures, construction, non-movable structures were used for the GCPs stable from long time. The next step was to rotate, scale and rubber sheet different data sheet layers so that they should be overlaid each other this is called registration. The topographic maps were first to referenced and used as the reference for the other imageries for geo-referencing. The block level boundary, the satellite images has been georeferenced using the control points from the maps. LISS-4 data is already available in the georeferenced format of UTM as spheroid and WGS84 as the Datum.

C. Histogram Equalization :

An image enhancement technique was used to improve the quality of the images, which makes the data sets more informative and helps in image interpretation. The following image processing techniques was applied to the raw data to emphasize the features distinctly on the images. This method usually increases the global contrast of many images, especially when the usable data of the image is represented by close contrast values. Through this adjustment, the intensities of image can be better distributed on the histogram. This allows the lower local contrast to gain a higher contrast without affecting the global contrast of the area. Histogram equalization accomplishes image enhancement by effectively spreading out the most frequent intensity values improving the contrast of the pixel and helpful in identification of the different feature. Such type of image processing was adopted for the LandSat–7 imagery for preavulsion period for Identification of palaeochannels; water logged areas as well as flood plains.

D. Geographic Information System:

ArcGIS 9.3, ArcGIS 10 software tool, with spatial analyst and 3–D Analyst tool and model builder, developed by ESRI was used. It provides a visual environment for viewing and manipulating data. The thematic layers from the risk analysis have been prepared with the different tool extension of ArcGIS. The geomorphology map, the river map has been prepared with the help of on screen digitization. Spatial analyst tool extension, the 3-D analyst tool extension and the model builder was used for the final generation of the risk map. ArcGIS provide the platform for post processing and further analysis of the data sets.

The generation of database has been categorised into following section as stated below which has been shown in Figure 3.1

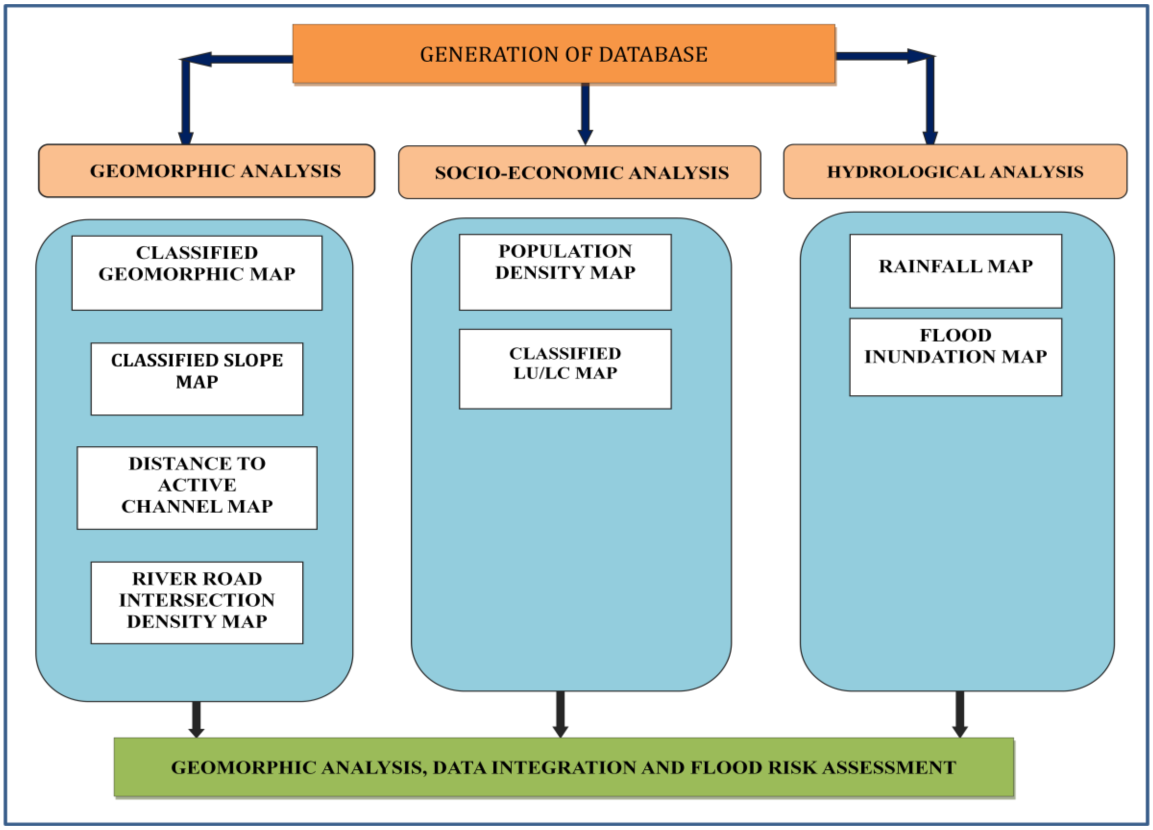


Figure 3.1: Flow chart of Methodology

The different satellite images that were used for the generation of the thematic layers are LISS-4 and LandSat–7. LISS–4 imagery was used for the generation of geomorphic map of post avulsion and LandSat–7 imagery for the geomorphic map of pre avulsion, which was done by onscreen digitization of the georeferenced satellite images. The digitization of various geomorphic features based on the visual interpretation of user. The SRTM DEM has been used to extract the slope map for the study area. Further, the field DGPS survey data of the classified points of road river intersection has been used for the generation of intersection density map on block wise basis. Detailed description of the layers generated has been discussed in the Chapter 5.

3.3.1 Socio-economic analysis

The LandScan Global data of 1km x 1km grid has been used to extract the population of the 99 developmental blocks of both Nepal and Bihar (India) and hence the generated population density map was used for calculation of the vulnerability index. The Landsat-7 (2009) data has been used for the generation of the Landuse Landcover map, which was validated with the GRBMP Landuse Landcover map at 1: 250K provided by the NRSC, Hyderabad. Detailed description of the layers generated has been discussed in the Chapter 5.

3.3.2 Hydrological analysis

The TRMM (2b31) data has been used for the generation of the rainfall map as it has very high-resolution data as compare to other rainfall grid map. The Flood Inundation map derived from DSC, NRSC, Hyderabad, was available for the north Bihar only. The flood inundation map from Dartmouth flood observatory is global based and requirement for both Nepal and Bihar parts was being compensated . Detailed description of the layers generated has been discussed in the Chapter 5.

3.3.3 The Analytic Hierarchy Process (AHP)

Multi Criteria Decision Analysis (MCDA) or often called Multi Criteria Decision Making (MCDM) (Linkov et al., 2004) is a technique that contains regulated set of methods that helps decision makers to decide or to make critical decision on the basis of several criteria orbiting that decision. The MCDA methods are very well suited when verdict makers have to take decision on numerous and disagreeing evaluations. Analytic Hierarchy Process (AHP) is the most recommended and most suited MCDM method that was developed by T. Saaty (1977, 1980, 1988, and 1995). Thomas Saaty (University of Pittsburgh) has developed the AHP based on three principles: decomposition, comparative judgment and synthesis of priorities. AHP is a mathematical method of analyzing complex decisions problem with multiple criteria.

- The decomposition principle of AHP requires the decision problem to be decomposed into hierarchy that captures the essential element of the decision problem.
- Decision factors are further decomposed into sub factors.
- Construction of pair wise comparison matrices at each decision level.
- Aggregating the different factors to calculate the relative importance of the factors and

the sub factors.

The AHP methodology starts with the goal which comes at the top of the hierarchy and that hierarchy further categorized in criteria, sub criteria and alternatives. These entities are called parent and child nodes, group of related child nodes will form assessment groups. The parents of an option from different assessment groups are called its covering criteria. The Saaty's (1980) study has been implemented in many multinational large scale government and private organizations (Grandzol, 2005; McCaffery, 2005; Ken et al., 2006; Lori, 2006; Robert, 2006; Berritella et al., 2007; Stein et al., 2007; Alghamdi, 2009; Tobias et al., 2009).

Table 3.3: The fundamental scale of Absolute number (Saaty, 1980)

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
2	Weak or Slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice

8	Very, Very Strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

To make comparisons, we need a scale of numbers that indicates how many times more; important or dominant one element is over another element with respect to the criterion or property, with respect to which they are compared. The evaluation and ranking of alternatives by MCDM techniques is based on associated criteria values, objectives and preferences of the different decision makers. Spatial multi–criteria analysis is vastly different from conventional MCDM techniques because of its additional explicit geographic component. In comparison with conventional MCDM analysis, spatial multi–criteria analysis (AHP) requires information on criterion values and the geographical distribution of alternatives in addition to the decision maker's preferences in a set of evaluation criteria. In spatial multi–criteria decision analysis, two concerns are of vital importance: (1) the GIS component (e.g., data acquisition, storage, retrieval, manipulation, and analysis capability); and (2) the MCDM analysis component (e.g., aggregation of spatial data and decision makers' preferences into discrete decision alternatives).

The strength of the AHP is that it organises the tangible and intangible factors in a systematic way and provides structured, which are relatively simple solution to the decision-making problems. AHP is very appropriate for those fields where intuition, rationality and irrationality in connection with risk and uncertainty can be found. The problem can include the social, political, economic and technical goals, criteria's, and possibilities.

The main goal of the thesis is flood risk assessment in the given study area of Kosi river basin using Spatial Analytical Hierarchy Process (SPHP) which combines the AHP and GIS to identify to the flood risk areas and rank them accordingly using knowledge based user preferences, and data contained in the GIS maps. The goal (Flood Risk Index) is related by the sets of attributes called decision factors, which are identified and then further, the sub–factors (a set of alternatives) for the concern decision factors are to be decided to better described the decision factors.

1) The top level is the goal of the hierarchy .i.e. the flood risk zonation.
2) The next level is the decision factor and sub–factors with increasing details, which are constructed according to decision makers with better understanding of problems/goal.
3) The next level is the generation of the decision matrix that comprises of decision factors like Geomorphology map, landuse landcover map, Rainfall map, Population density map, Road river intersection map, Slope map, and their sub–factors of each decision factors e.g., Geomorphology map has been further classified into geomorphic elements and units, known called sub–factors.
4) Pair wise comparison using the fundamental scale of absolute numbers (Saaty, 1980) of decision matrix and their sub–factors.
5) Calculation of Estimated Eigen Vectors for each decision factors and their sub–factors using the following equation:

$$\textbf{Estimated Eigen Vector of each element} = \sqrt[N]{a_1 * a_2 * a_3 * a_4 * a_N} \quad \text{……..(3.3.3a)}$$

6) Normalization of the Eigen Vectors was accomplished by dividing each Eigen Vector element by the Sum of the Eigen Vector elements.

$$\textbf{Normalization of Eigen Vector(RIW)} = \frac{\sqrt[N]{a_1 * a_2 * a_3 * a_4 * a_N}}{a_1 + a_2 + a_3 + a_4 + a_N} \text{…………………...…(3.3.3b)}$$

Where, a_1, a_2, a_3, a_N = values of the row elements; N= number of the row elements

7) The FRI for each parameter is calculated by aggregating RIWs at each level of the hierarchy using the equation.

$$\mathbf{FRI} = \sum_{\mathbf{i=1}}^{\mathbf{N2}} \mathbf{RIW_i^2} * \mathbf{RIW_{ij}^3} \quad \text{…………………………………………………………(3.3.3c)}$$

Where, FRI = Flood risk Index; N_2 = the number of level 2 decision factor; RIW_i^2 = relative importance weight of level 2 decision factor i; RIW_{ij}^3 = relative importance weight of level 3 sub- factor j of level 2 decision factor i (Siddique .et. al., 1996).

3.4 GIS integration of data layers and generation of Flood risk map

Finally all the generated thematic layers that have been developed by the different sets of data types will be integrated in the GIS platform. Out of seven thematic layers, four thematic layers namely Geomorphology, Slope, Rainfall and Distance to Active channel are used to generate flood hazard index. The remaining three thematic layers namely river road intersection density, the Landuse Landcover and the population density were used to generate Flood Vulnerability index. The two-flood index map were combined by simple multiplication to form the final risk index map. All the thematic layers should be brought to a common projection and datum for the integration in the grid format. ArcGIS9.3 version which was developed by the ESRI has been used with the extension of spatial analyst, 3D analyst, and model builder (Figure 3.2).

3.4.1 Model Builder: an overview and application

Model builder is part of the ArcGIS geoprocessing framework. A Spatial Analyst Extension tool helps to create spatial models of geographic areas. It is an application in which you create, edit, and manage models. In Model Builder, a spatial model is represented as a diagram that looks like a flow chart. At the highest level, models contain only three things: elements, connectors, and text labels. Elements are the data, and tools we work with. Connectors are the lines that connect data to tools. Text labels can be associated with the entire model, individual elements, or individual connectors. Models are how we automate our work. When we create a model, we are preserving a set of tasks, or a data processing workflow, that we can execute for multiple times. There are infinite numbers of tasks that can be automated by using models. We create models using Model Builder to chain together tools, using the output of one tool as the input to another tool. The model you create is added to Arc Toolbox as a model tool, which you can execute using its dialog box or the Command Line window. In Model builder, model is a collection of processes performed on the spatial data that produce information in the form of maps. These maps can be used for multi tasking purpose like decision-making, scientific study and for general information too.

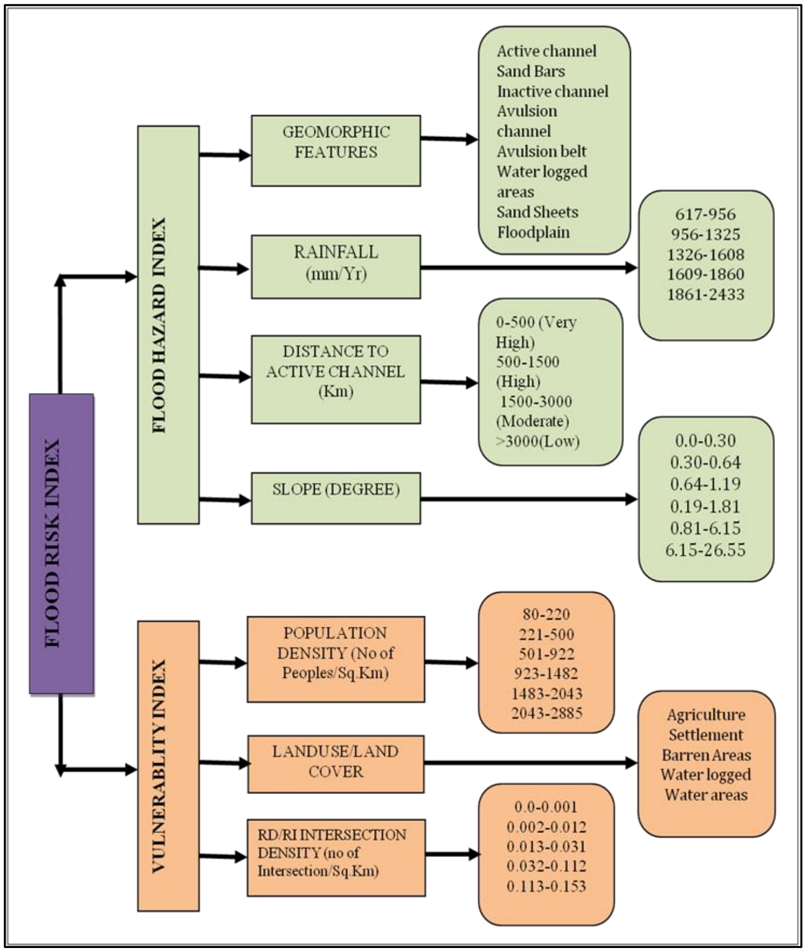


Figure 3.2: GIS frame work (Analytical Hierarchy Process)

The main advantage of using the model builder for GIS work is that your processes can be automated without using any code. Another advantage is that you can save your GIS process and rerun the model at any time. This is particularly good when you need to go back and adjust your process/analysis. Rather than redoing the entire analysis, you can simply change one parameter and rerun the model to produce new results.

In this thesis work, the Model builder was used to convert all the thematic layers of Vector format to the Grid format, to create the buffer around the active channel at specified distance, and to generate final hazard and vulnerability maps, which ultimately used for the generation of the final flood risk map as shown in Figure 3.3.

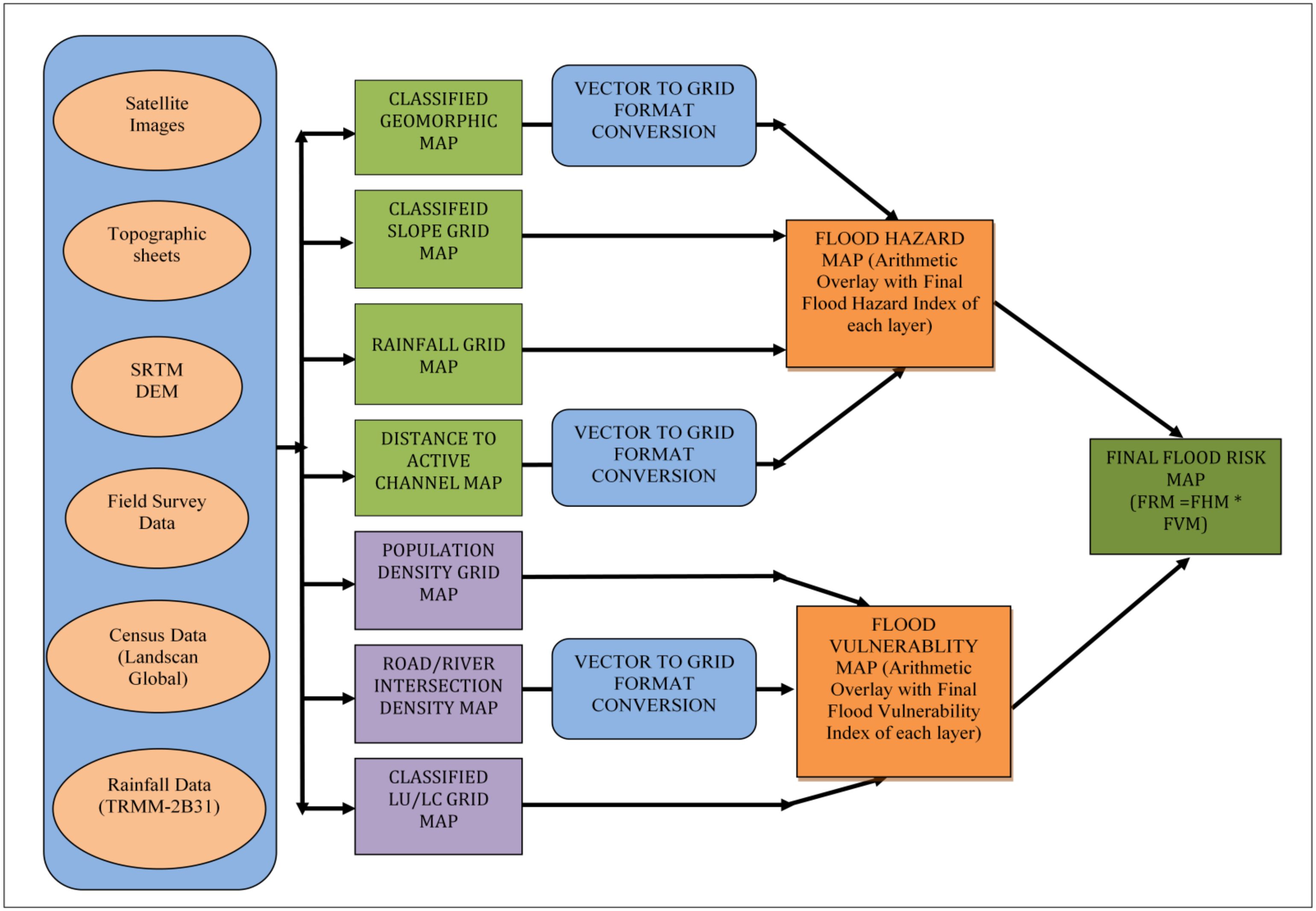


Figure 3.3: The Integration Phase (Arc-GIS Model Builder) for generation of Flood risk map

Chapter 4

Geomorphic Mapping

Geomorphology deals with the identification, interpretation and representation of the landforms according to the morphology and formational process (Hubbard and Glasser, 2005). Geomorphological mapping not only identifies the nature of the individual landforms but also the materials they comprise of i.e. the geomorphic process associated with their formation. The Kosi River has distinct hydrological and sediment transport characteristics, which are clearly manifested in morphology of the channel belt and the fan surface. One of the most distinctive processes which has been responsible for the formation of the megafan itself is the "avulsive shift" which has resulted in a number of paleochannels on the megafan surface. Synoptic view and spectral characteristics of satellite images provide a good opportunity to map the landforms. In the present work, the emphasis was to map the features related to river dynamics and flooding so as to integrate the geomorphic data in flood hazard evaluation.

4.1 Geomorphic Map

To understand the river avulsion and landform evolution in Kosi alluvial plain, a dynamic geomorphic mapping has been done on satellite images for pre - and post-avulsion based on elements of image interpretations i.e.

(i) Size, shape, tone, texture, association and pattern

(ii) Superimposition of features, and

(iii) Their preservation and proximity scale of the photograph.

The above factors have helped to analyze landforms in the light of their physical appearances and occurrences which, in turn, have proved useful in understanding their genesis (Baker, 1986). Image interpretation needs systematic and frequent examination of the object presents in the image. The geomorphic map comprises of different geomorphic units like those of hilly areas that comprises hard rock terrain, piedmont plain. The feature related to the river are channel bars, meander scar, avulsed channel, sand sheets, sand bars, the fan surface etc.

Each geomorphic element was coded in different colors and an ID was given in the thematic map. Table 3.4.1 describes the different geomorphic elements and units mapped for both the periods. The pre-avulsion map (Figure 4.1) based on the satellite image of the year 2003 consists of several geomorphic units namely active channel belt, active flood plain of major rivers, inactive flood plain, minor active channels and its flood plain, hard rock terrain, piedmont plain, fan surface etc. Based on the distribution of geomorphic elements and the understanding of the modern processes, major geomorphic units have been identified (discussed later). The post-avulsion map also shows similar geomorphic features except for some variation in their spatial distribution. In addition, an additional and distinctive unit, avulsion belt, has been mapped in the post-avulsion image covering a large part of the fan surface (Figure 4.2).

Table4.1: Geomorphic elements, their characteristics and elements of image interpretation

Geomorphic element	**Geomorphic characteristics**	**Identification criteria on satellite images**
Active channel	Active channel (AC): Area frequently or recently reworked by fluvial processes during high flow events. The active channel includes only channel-like features (i.e. elongated, appear to have been carved by flowing water); other water bodies are classified within the floodplain. The area in the active channel is occupied by water, bars, and exposed channel bed. This element defined as the portion of the river and flood plain inundated both ends connects to the main channel (Figure4.3).	Color: Dark Blue to light blue color. Shape/size: Elongated, narrow and appear to have been carved by flowing water.
Channel bars	Channel bars are the land forms in a river that begin to form when the discharge is low and the river is forced to take route of less resistance by means of flowing in location of lowest elevation. Vegetated bars and Moist Sand bars have been	Color/ Tone: Greenish and bright color it is identified from imagery. Vegetated bars look dark red in color in between the river channel with coarse texture. Dry bars look cyanish in

	classified separately (Figure 4.4)	color with smooth texture. Pattern: They are randomly arranged with in the River channel Association : They are associated with the Main River channel
Meander scar	Meander scar is a geological feature formed by the remnants of a meandering water channel. They are often formed during the creation of oxbow lakes. These are the remnants of the highly sinuous paleo drainage system, which were cut-off from main channel.	These are identified by crescentic arcuate shape, uniform and dark tone, isolated occurrences depressed relief characteristics. Pattern: Curvilinear pattern. An Abandoned Meander Scar often filled by vegetation and deposition, but still discernable especially from air.
Palaeochannels	Ancient drainage line of the stream of the river through which it might have flown in the past. In present it is filled with alluvium, gravels and sands or with tills.(figure4.8)	Tone: Identified from medium to dark bluish tone, Pattern: Curvilinear pattern, and uniform to continuing of older stream. Association: It generally occurs with a distinct orientation of the vegetation.
Minor active	These are the important tributaries to the	Color: These are identified

channels and associated flood plains	main stream; associated flood plains have formed by the overtopping of water on both side of river channel. (Figure4.7)	from its dark to light blue color. Flood plain appears light greenish.
Avulsion channel and avulsion channel deposit	Avulsion channels formed during the August 2008 breach has been mapped separately on the post-avulsion image; widespread sand around these channels have been mapped as avulsion deposits(Figure 4.5 & Figure 4.6)	Color: Avulsion channel is identified from imagery due to its dark green to light cyanish tone; sand sheet is identified by its very bright tone and whitish color.
Water logged area and areas of high moisture	These features are identified in the low depressed areas where stagnant water bodies have been found and the areas that have high moisture condition but water do not stagnate (Figure4.9 & Figure4.10).	Color: shades of greenish to bluish in FCC image. Tone: It is identified from its dark tone in the image.

4.2 Major geomorphic units combines several geomorphic elements

4.2.1 Unit 1: Hard rock terrain

The NW part of the window consists of exposures of hard rock with elevations ranging from 120m to 220m and the slope up to 24 degree. It has a coarse drainage pattern and covers an area of 100.50 sq km in the study window. This highly vegetated unit displays a typical dendritic drainage. Several minor channels draining from this elevated terrain join together to form a larger channel, which ultimately feeds the Kosi River.

4.2.2 Unit-2: Piedmont surface

This unit, lying in an elevation range of 100m to 120m, is characterized by a distinct topographic break close to the mountain front (Sinha et al, 2005). As a consequence, the rivers draining out of the high mountains deposit most of the coarse sediments in this region to form the piedmont plains covering an area of 86.326 sq km in the study area. This unit shows a very distinct tone on the image and is characterized by a very low vegetation cover, parallel to sub-parallel drainage pattern with a low drainage density and a few patches of water-logged areas.

As mentioned above, this unit marks the formation of larger channels at the foot of the elevated areas (Unit-2). Most of these channels appear dry on the satellite image (apparently due to thick alluvial cover below the piedmont plains) but they are active during monsoon periods. One of the larger channels is the Mahuli River which has two major tributaries and the combined flow joins the Kosi River just upstream of the barrage. It is interesting to note that they join the Kosi system at obtuse angles 120˚ which may be due to the embankment.

4.2.3 Unit 3: Active channel belt

This unit is defined by the active course of the major river Kosi and associated channel bar deposits. This unit constitutes the youngest geomorphic surface and occurs at an elevation range of 65m to 90m. Channel surface is the youngest geomorphic surface and the associated channel bars are slightly elevated surface in this zone, which are often washed out by water. Stable bars are covered by grass like vegetation hence classified as vegetated sand bars. Some are dry as the course of the river due to high sedimentation change the flow path and direction whereas others are dry due to elevation and stacking of sediment each year during high water level. Some bars are moist which are frequently inundated due to fluctuations in water level. Active channels and associated sand bars are clearly visible on the FCC of both pre-and post-avulsion period. Dark tones on the NIR band indicate the presence of deep water. Sand bars show a brighter tone on the FCC, moist bars exhibit very light blue shades and the vegetated bars show different shades of red. It covers almost 210 sq.km of area within the river area.

4.2.4 Unit 4: Active floodplain

The active floodplains, adjacent to the present-day major channel belts, define a geomorphic surface which is often flooded in monsoon period through overtopping by the river. Generally, this unit is at a higher elevation compared to the present day river but in avulsing rivers like the Kosi, this unit is at a lower elevation than the river, termed as super elevation. This unit is characterized by the presence of meander scars, minor channels, dry channels and water logged areas. Some areas having high moisture but no water logging condition can be easily seen on the satellite images and suggests recent channel activity on the floodplain. Meander scars with an arcuate shape are the remnants of a meandering water channel which were cut off from the main channel. These are low elevation regions and exhibit a darker tone. The tributaries joining the main channels are considered as the minor channels which show a darker to lighter blue tone on the FCC. In terms of topographic relationships, this unit ranges in elevation from 72m to 83m. Approximately, the area covered by the active flood plain is 349.07 sq km.

4.2.5 Unit 5: Inactive floodplain

This unit is presently beyond any major channel activity except that minor channels may sometimes remobilize sediments during heavy precipitation. This unit ranges in elevation from 76m to 85m, which is higher than the active flood plain. Covering an area of 215.306 sq km in this window, this unit is recognized by the presence of typical flood plain features such as abandoned channels, dry streams, highly vegetated area (mostly agricultural land); water logged areas and high moisture zones. The water logged patches are the low-lying areas where water gets stagnated and show distinct darker tones on the NIR band of the image. Dry streams are fairly continuous and sinuous, and show a very bright tone on the image.

4.2.6 Unit 6: Minor Active channels and associated flood plain

Active minor channel belt and floodplains of minor rivers in the study area are much narrower as compared to the active major channel belt. Therefore, minor channels and their flood plains have been combined into one geomorphic unit. The active minor channels on the satellite image appeared as a line, so they could be visualized by applying low pass filter. These channels are continuous in nature and show darker tones on the image. Evidence of shifting of channel course is insignificant in this unit, but the channels actively transport water and sediment load throughout the year. Some of these channels are nearly perennial because they are fed by spring water most of the year.

4.2.7 Unit 7: Fan surface

The remaining part of the study window to the east of the eastern embankment has been mapped as the fan surface covering an area of 1542.946 sq km in the study window. This unit is monotonously flat (elevation varies from 43m to 90m)and is primarily marked by the former channels of the Kosi river many of which are still active and flow for a large part of the year. Large patches of water-logged areas are conspicuous which probably mark low-lying back swamp areas associated with the former channels. Many of these areas have dried out but can still be picked up on the satellite images due to high moisture conditions. The paleochannels are recognized by medium to dark tone and are marked by the curvilinear orientation of vegetation along these. Adjacent to the eastern embankment widespread water logged areas probably represent the seepage through the embankment and this is confirmed in the field as well. Over the years, these seepages have combined to form several well-defined channels on the fan surface and one of them is flowing along the eastern embankment. A small patch of forested area shows up in the NE corner of the window and the remaining parts are marked by widespread agricultural fields.

4.2.8 Unit 8: Avulsion Channel and Avulsion Channel belt

This is characterized by the flow of the main Kosi river during the avulsion of 18 August, 2008which ultimately meets the Ganga River. The avulsion belt is characterized by the presence of sand deposits and the active avulsion channels covering 381.99 sq km of area on the fan surface. These features show a very distinct variation in spectral characteristics as compared to other features in the study area. Sand deposits show a brighter tone while the channels show darker tone on the image. These features are formed by the deposition of sand during the avulsion process which occurs mainly in aggrading rivers. In the field it was observed as vast stretches of sands spread over several kilometres of area with more than 1.5 meters thickness.

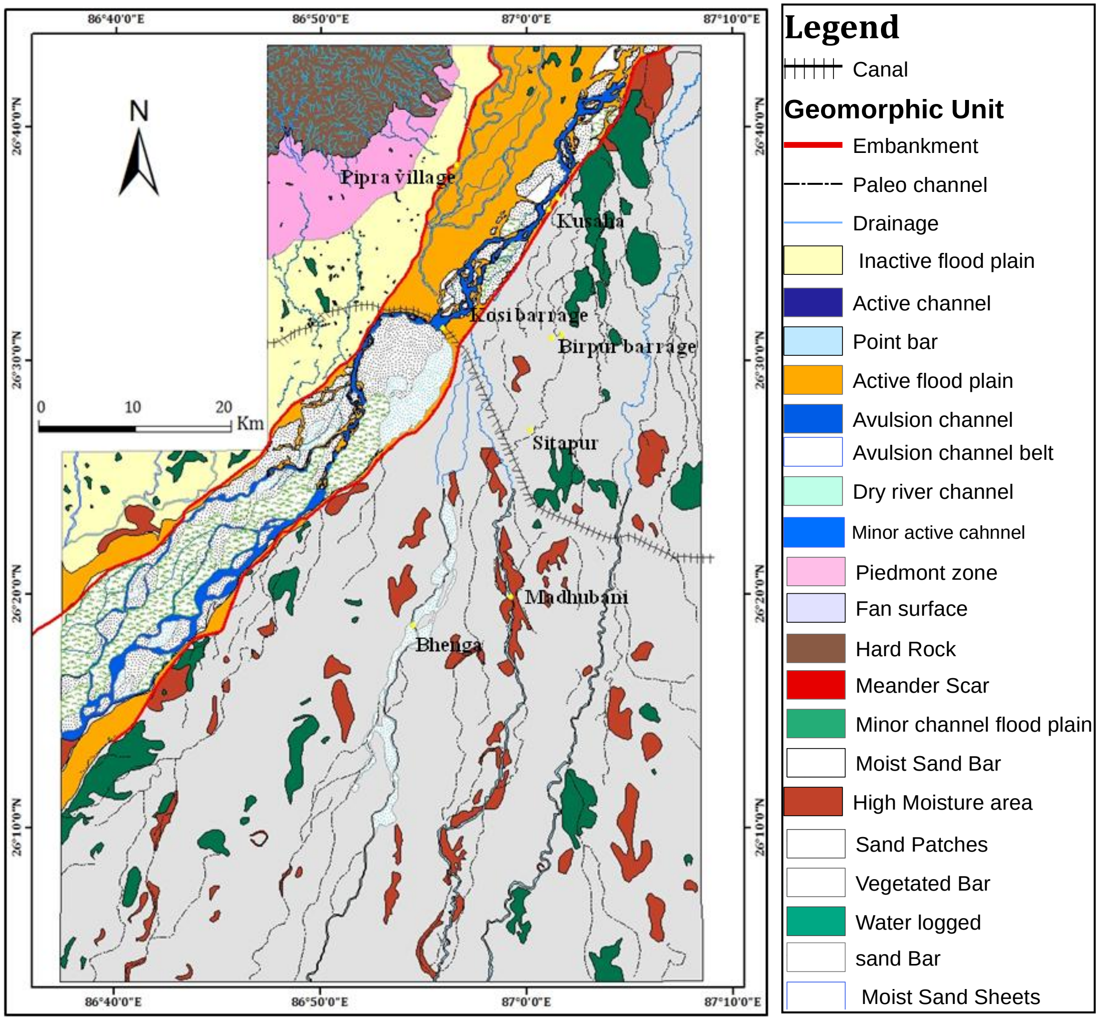


Figure 4.1: Geomorphic Map (Prior to Avulsion)

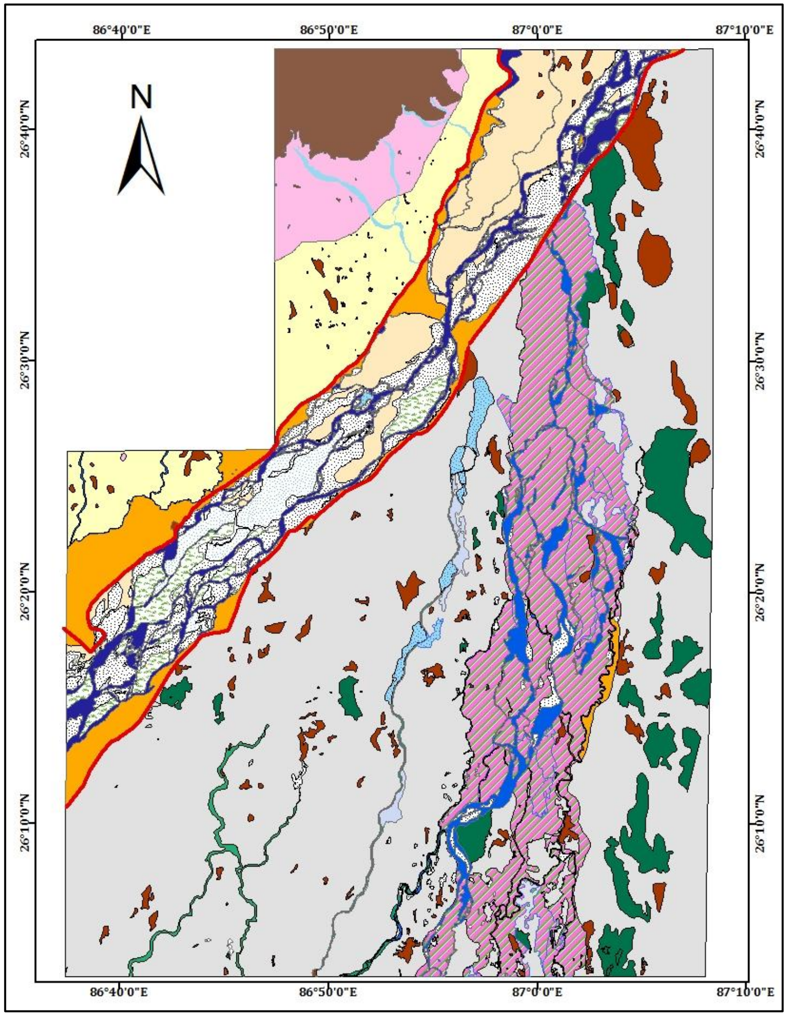


Figure 4.2: Geomorphic Map (Post Avulsion)

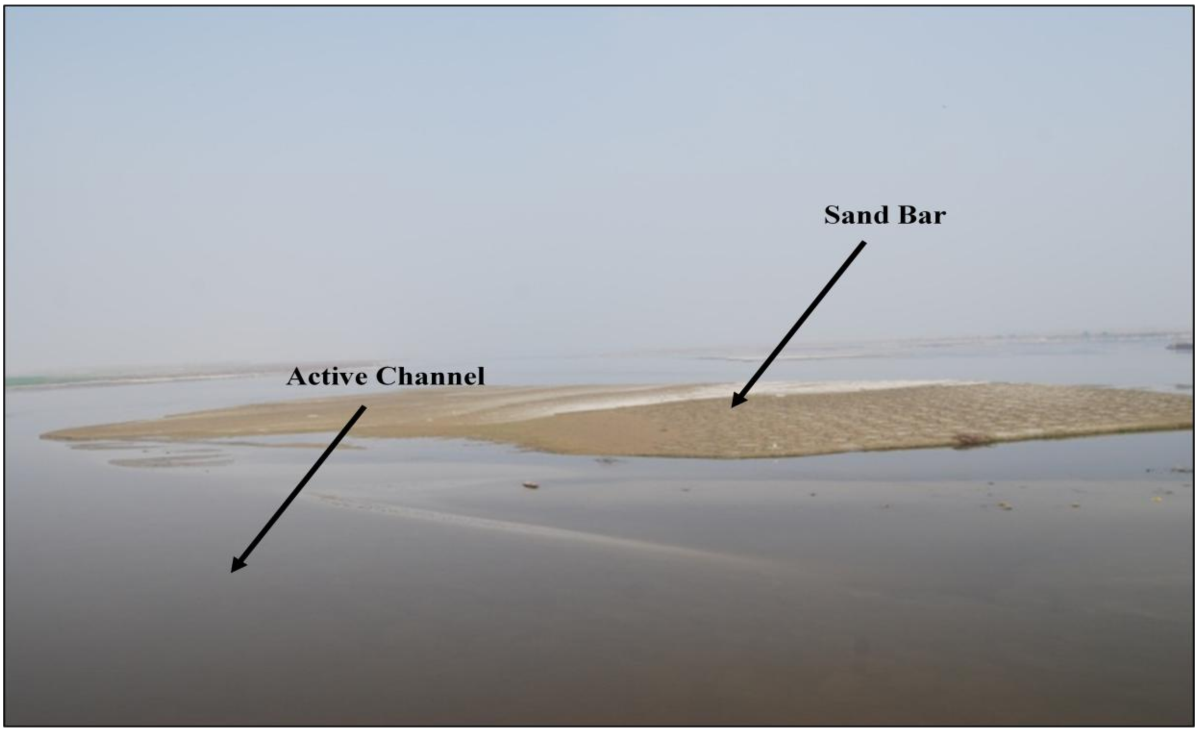


Figure 4.3: Active channel with sand bar

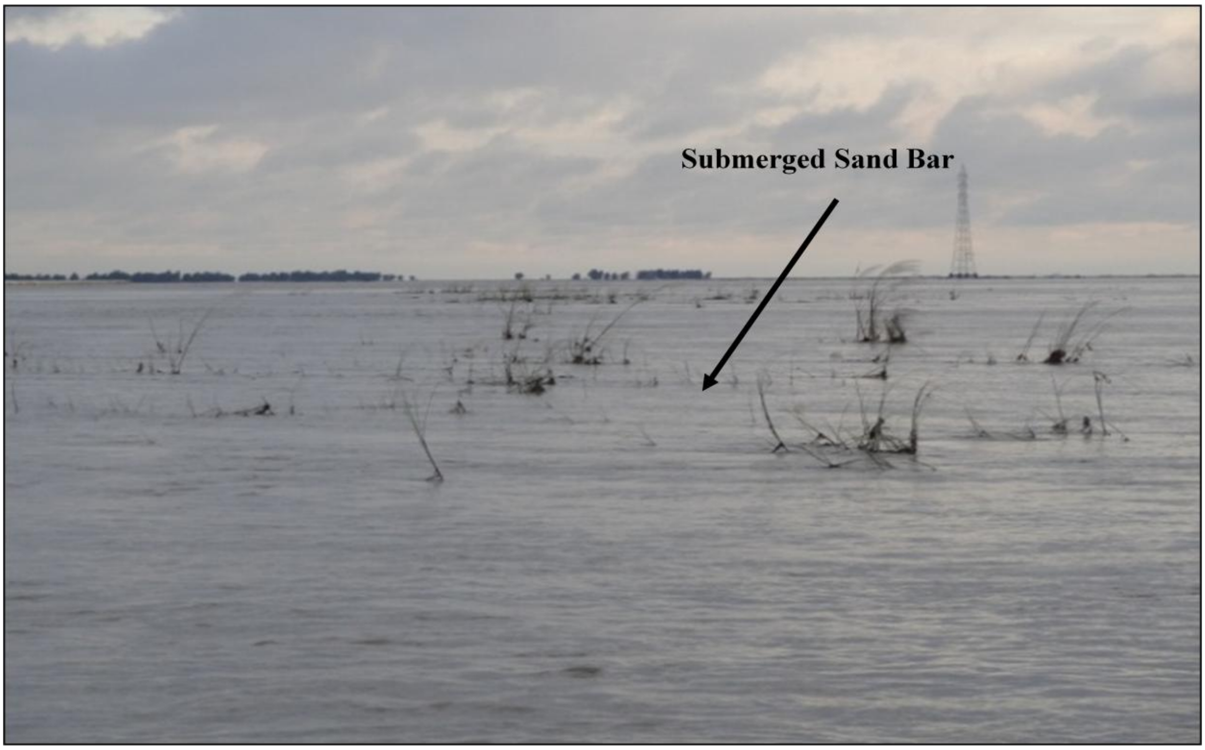


Figure 4.4: Submerged Channel Bar

Figure 4.5: Avulsion channel

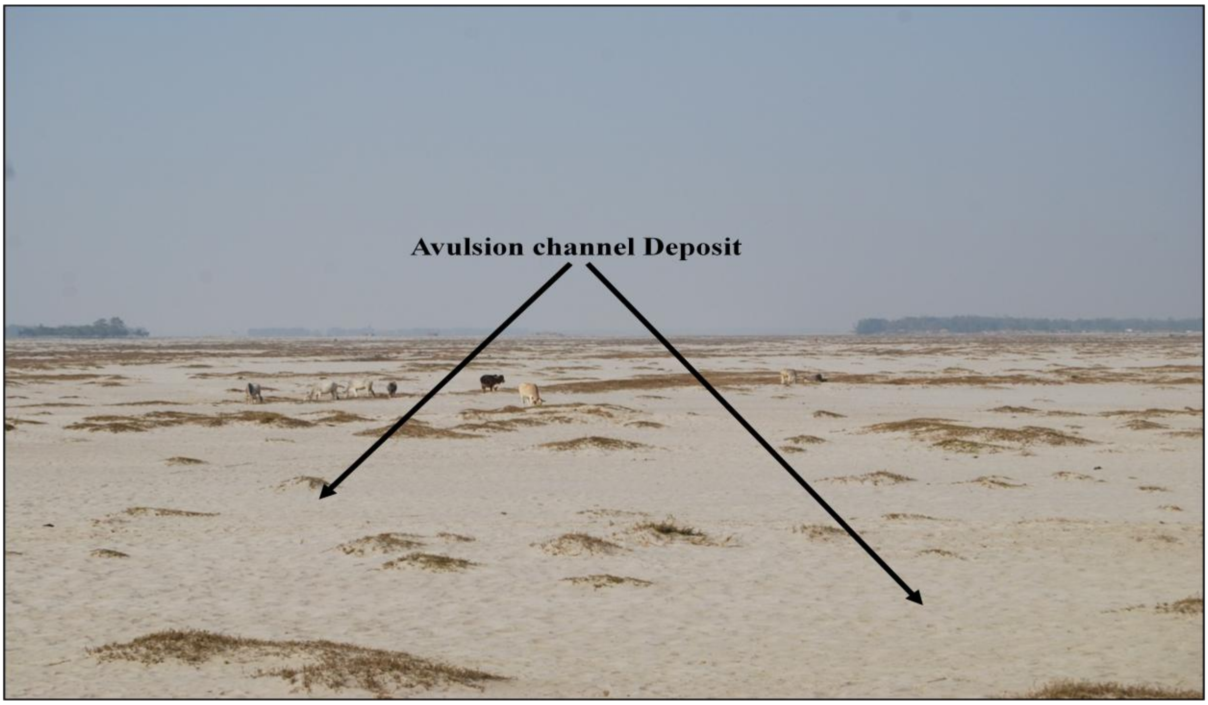


Figure 4.6: Avulsion channel Deposit

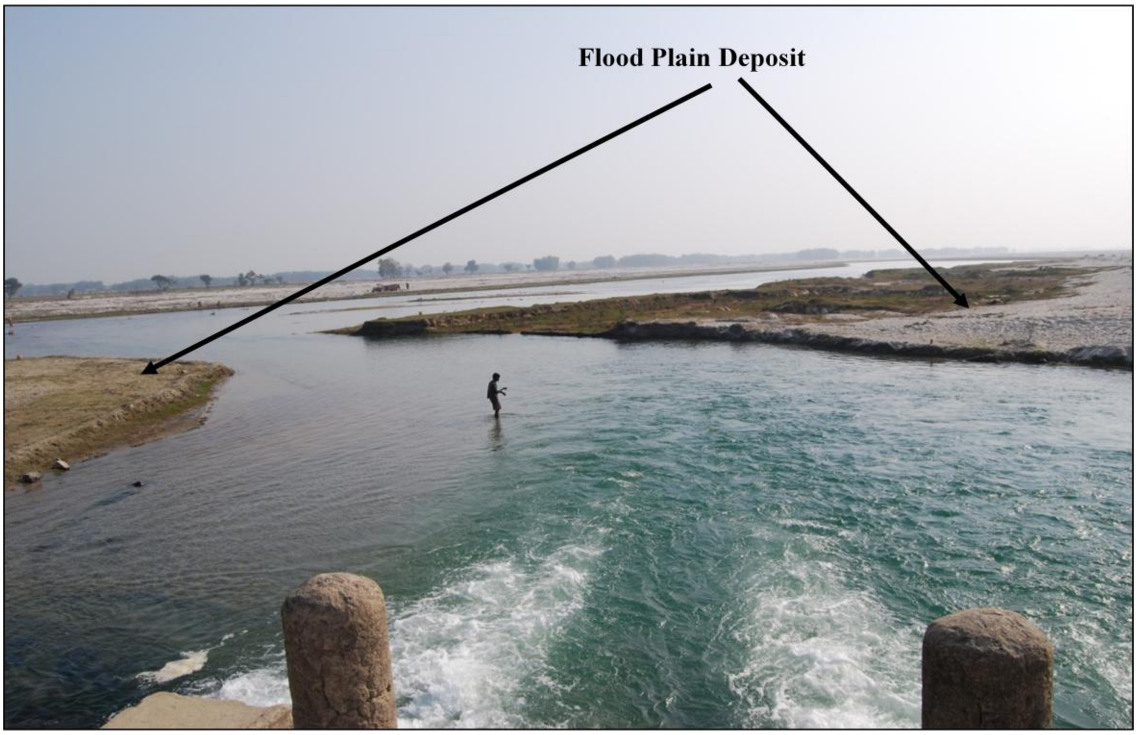


Figure 4.7: Active channel and Flood plain deposit

Figure 4.8: Seepage channel

Figure 4.9: Water logged patches

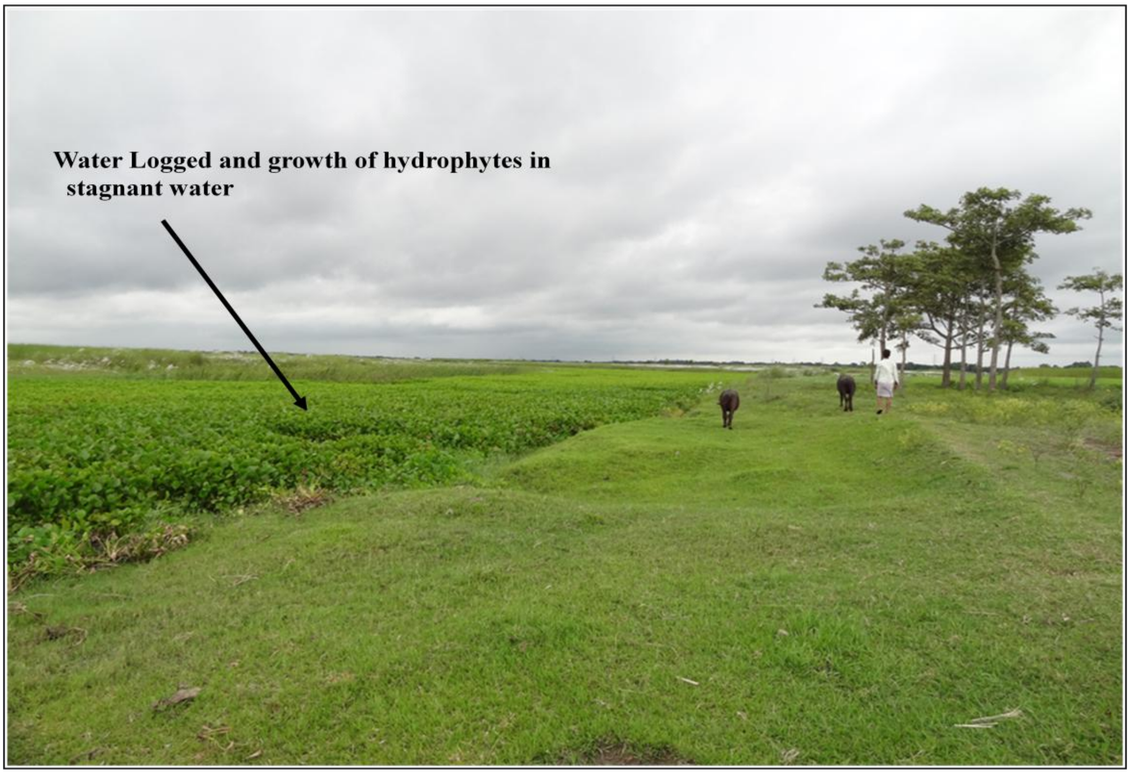


Figure 4.10: Water logged condition

4.3 Sythesis of Results

Remote sensing based geomorphic mapping of the pre- and post-avulsion images brought up many important changes of the geomorphology of the landscape due to the avulsion of the Kosi River on August 18, 2008. One of most spectacular change is the recognition of the avulsion channel beltwithin the fan surface during post avulsion period stretching from north to south marked by vast stretch of sand sheets (1 to 1.5 meters thickness).The areas with gentle or low slope are marked by waterlogged patches (permanently waterlogged areas).The main river course shifted from west to east of the embankment of the Kosi river. The flow direction upstream of the breach location had also gradually changed prior to breach, providing a more erosive angle of attack against the eastern embankment. Reactivation of the palaeochannels on the active flood plain as well as on the fan surface is observed after the avulsion due to the longitudinal connectivity during the flooding which followed the avulsion. Palaeochannels passing through Madhepura and Saharsa district formed the main conduits for the post avulsion channel of the Kosi.

Chapter 5

Results

Thematic layers have been prepared through different sources of the available data sets based on the understanding of the causative factors of floods in the study area. In the current study, block level analysis has been selected as the unit of investigation. An integration of flood 'hazard' and flood 'vulnerability' maps has been used to generate the final flood 'risk' map. The basic idea is to classify the 89 blocks of the Kosi basin in terms of flood risk based on the choice of variables considered (Table: 5.1). Seven factors have been considered namely geomorphic features, population density, slope, distance to the active channel, rainfall for the hazard analysis as according to the definition the hazard leads to the probability of damaging the physical environment of the given area and landuse/landcover, and road-river intersection density and population density of the study area for the vulnerability analysis as it to the loss of the physical , social and structural damage , destroyed or loss of ultimate user that is lives.

Table 5.1: The parameters used for the flood risk analysis.

Flood Hazard Analysis	Vulnerability Analysis
1. Geomorphology	1. Population density
2. Rainfall	2. Landuse-landcover
3. Slope	3. Road river interaction
4. Distance to active channel	

5.1 Thematic layers and their Description

5.1.1 Geomorphology

Chapter –4 has already described the various geomorphic features and units mapped in the study area. The importance of geomorphic features in flood risk assessment derives from the fact these features reflect specific processes and vicinity to the active channels. Various geomorphic features were assessed in terms of flood hazard for AHP analysis (discussed later).

5.1.2 Rainfall Map

Rainfall is one of the major factors contributing to the flooding of the Kosi river. Rainfall of the Kosi basin is anomalous in behavior, which ranges from 623mm/yr to 2433mm/yr (Figure 5.1). TRMM

(2b31) rainfall grid map has been used for the analysis and extracted for the given study area using ArcGIS 9.3. The rainfall product used for the analysis is 4km by 4km which is very coarse resolution for the hazard analysis purpose. Hence the data has been resampled to the cell size of 0.00025691 to match the requirement with the other data sets for the purpose.

Rainfall of the area decides the total water availability during the monsoon period. The histogram shows the distribution of the rainfall within the study area, which has been classified for the analysis (Figure 5.2). The map shows that the blocks such as Pipra, Nirmali, Luakahi in India and Dhodhanpur, Hadiya, Theliya and some parts of Kamalpur and Kanchanpur in Nepal have rainfall more than 623 mm/yr. The area having rainfall in the range of 1325 mm/yr to 1860 mm/yr is widespread in most parts of Bihar such as Tribeniganj, Singheshwar, Chatarpur, Pratapganj, Baptiyahi Ramnagar, Sitapur, Central part of Raghopur and Western part of Basantpur. Trikola Bardaha, Joginiya, Barsaini, Diman are some of the blocks in Nepal also show similar rainfall as shown in final classified map in Figure 5.3.

5.1.3 Slope map

The length and the steepness of the topographic slope affect the flow and inundation of the particular area. For example, low and flat topography decreases the runoff, causing high infiltration within the area thereby resulting in water logging condition. Also, the low-lying area with low slope angle will be inundated first as compared to the high slope area during flooding. Those area with steep slope show high peak discharge as compared to the low-lying area and causes the depletion of the storage in the upstream areas.

The SRTM DEM has been used for the generation of the “Slope map” of the area with the help of Arc-GIS tool called Slope, the extension tool of the Data Management Analysis. The slope map has been generated with the help of SRTM 90 m DEM version 2 available from the USGS Earth resources observation and Science (EROS) centre for the year 2009 which has been shown in figure 5.4. It can also be downloaded from National Aeronautics and Space Administration (NASA), National Geospatial- Intelligence Agency (NGA), German Space Centre (DLR), Italian Space Centre (ASI) The DEM derived in the Geotiff format with Geographic projection which was re-projected to the Universal Transverse Mercator (UTM) WGS 84, Zone 45.The USGS has provided DEMs for over 80% of the globe with a resolution of 90 meters i.e. 3 arc second. The vertical accuracy in SRTM data is reported to be less than 16 meters. The SRTM data was subjected to substantial pre-processing operations. The basic problem is the voids or missing data which affect the quality of the data.Voids are resulted from shadows and layover. This mostly occurs in the mountainous region where there are poor signal returns and smooth areas like water and sand which reflect little energy to the radar. It was processed to fill in the voids in Arc-GIS and the final processed map is used for slope conversion in degree.

On the basis of histogram distribution of the DEM shown in the figure 5.5, the slope map has been classified into six major classes. The study area is mostly dominated by the flat topography with a slope varying from 0 to 0.30 degree whereas high slopes (> 10 degree) are noted in the hilly terrain (Figure 5.6). A large part of the fan surface area is dominated by slope values of < 1 degree. Areas with slope less than 0.3 degree shows the water logging condition and moist area with patches of water bodies. Since the general trend of the slope is from northwest to southeast, the river has also changed its course during the last 150 years. The slope governs the geomorphology of that area as the high angle of slope or steepness decides that terrain geomorphology comprises of hard rocks, the piedmont zone comprises of moderate slope as it lies close to the mountain front, the fan area has low angle of slope, hence the different slope angles decides the river behaviour along with the geomorphology and directly contribute to the flood hazard. The spatial resolution of the DEM is 90 meters, which is very coarse to achieve the objective of the study and higher resolution DEM will add to the benefit of the risk analysis.

5.1.4 Distance to active channel

Active channel is the main passage for the flow of river water. Apart from the main channel of the Kosi river, there are numerous palaeochannels on the Kosi megafan surface. These channels are long and meandering in pattern as they are flowing over low gradients and have easily erodible banks. During flooding, dam break or embankment breach, they become the passage for flood water and sediments which causes the loss of life and property as well as damage to the natural environmental conditions.

The distance to the active channel has been mapped from the satellite imagery of LISS-IV. The main Kosi river channel and the palaeochannels on the fan surface (Figure 5.7) were considered for generating this thematic layer. These channels have been buffered by considering the distance up to which damage to life and property can be significant (Figure 5.9). This will also help to locate the distances from active channel for the safe evacuation of the people at risk. The distance to the active channel has been computed by buffering on at 500 m both sides of the channels with spatial analyst and 3–D analyst. After buffering, the values were divided into four classes with respect to hazard assessment namely, very high (0-500m), high (500-1500m), moderate (1500-3000m), and low (>3000m) based on our field experience. Based on the above classes, distance to active channel buffer map shows that the blocks downstream of the river Kosi (the Indian blocks of Madhepura, Araria, Tribenigunj, Pipra, Chatarpur, Sitapur are likely to be more affected by flooding by the active channels. Several of these channels have been blocked due to human interventions, which have resulted in severe water logging in these areas, thereby making the area unfit for cultivation and settlement.

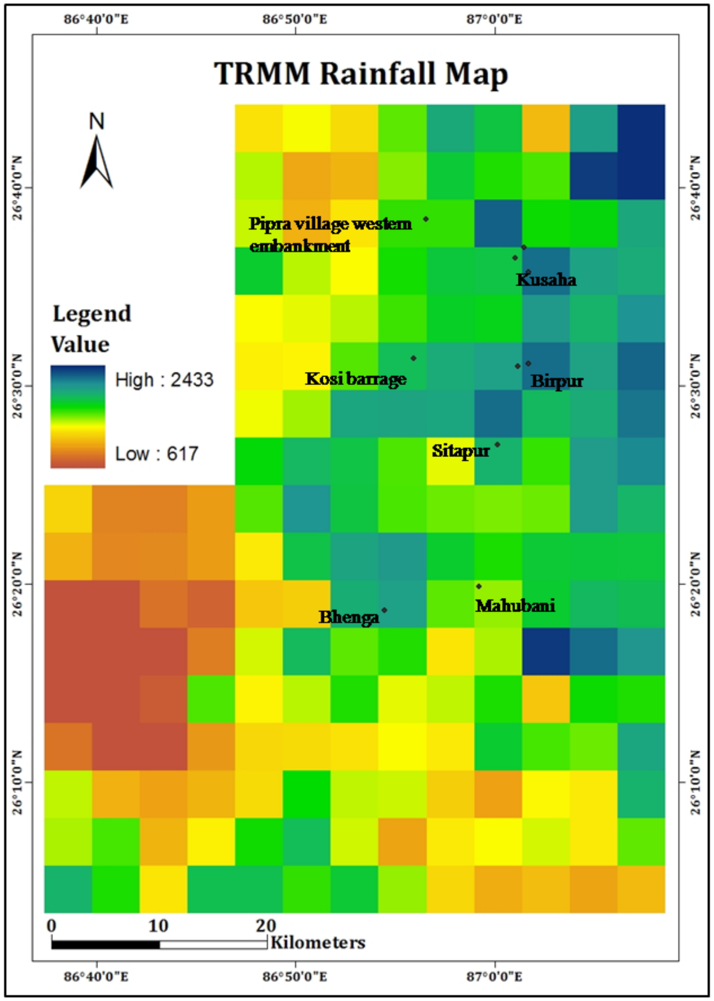


Figure 5.1: TRMM DEM Map

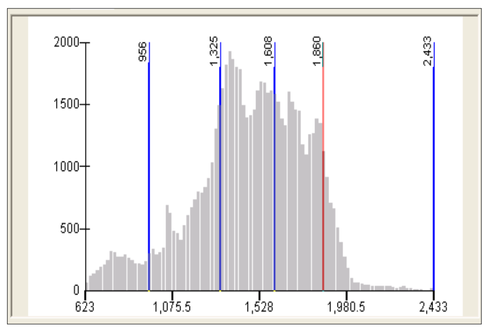


Figure 5.2: Histogram of Rainfall Map

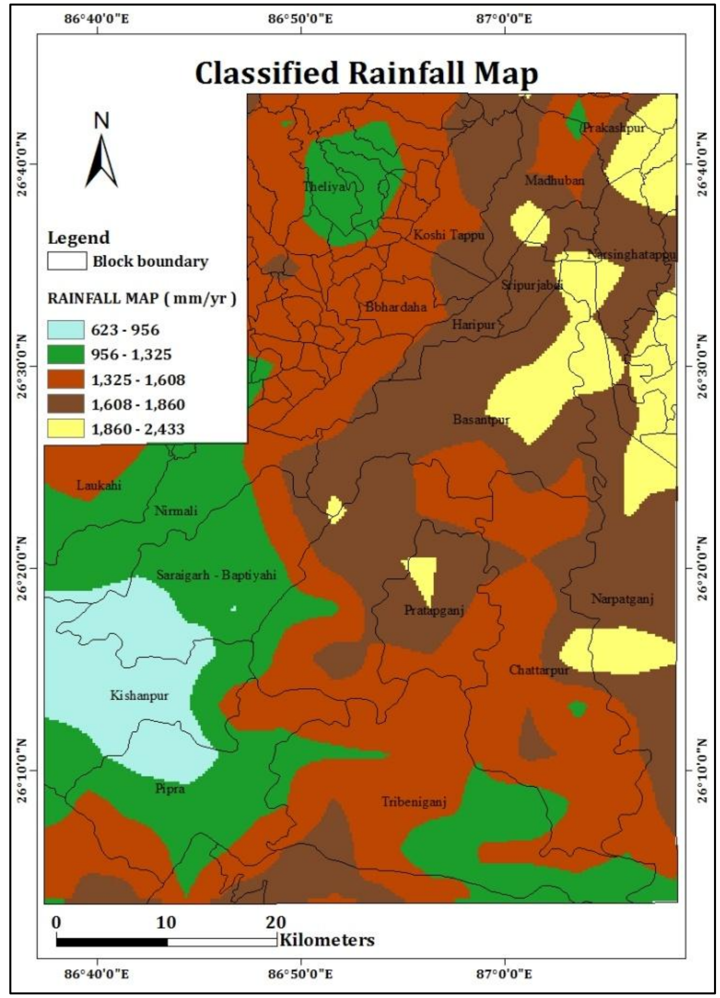


Figure 5.3: Classified Rainfall Map

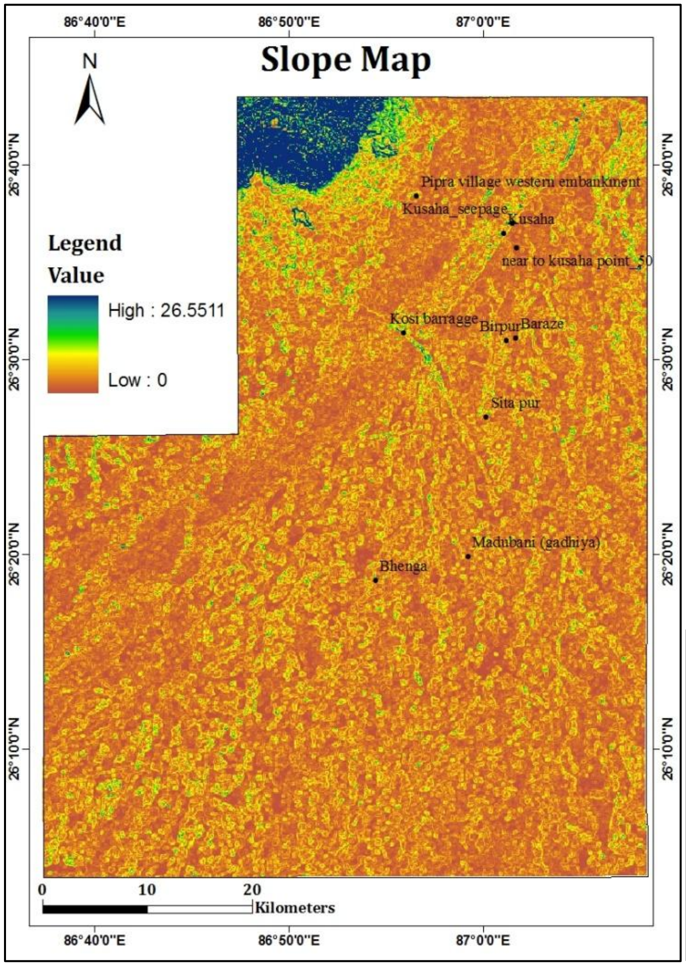


Figure 5.4: SRTM DEM Map

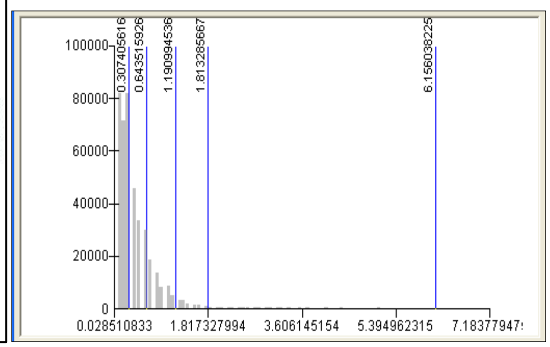


Figure 5.5: Histogram of Slope Map

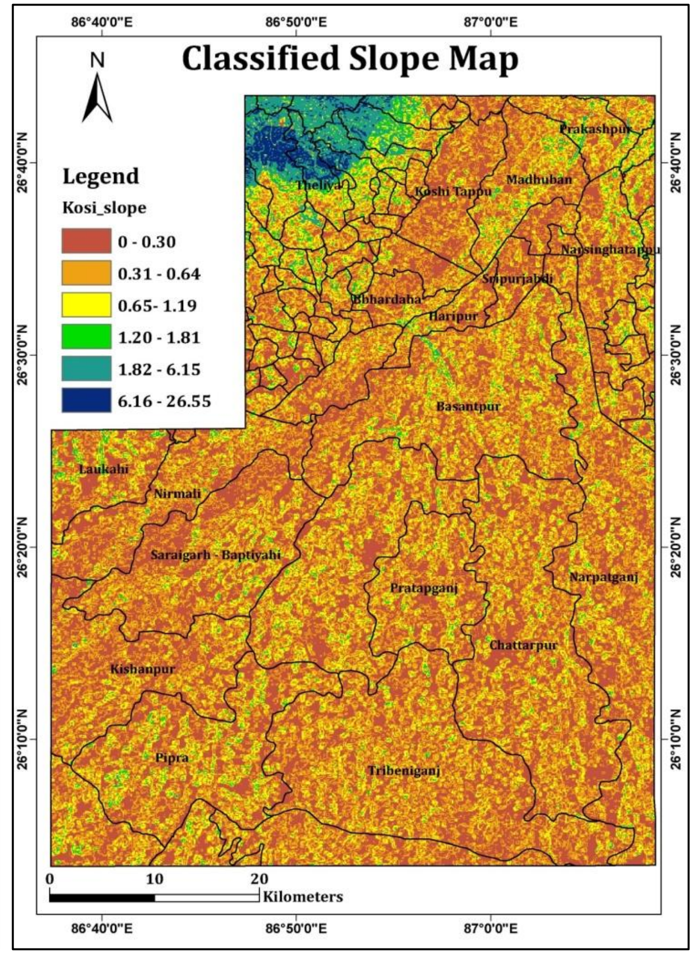


Figure 5.6: Classified Slope Map

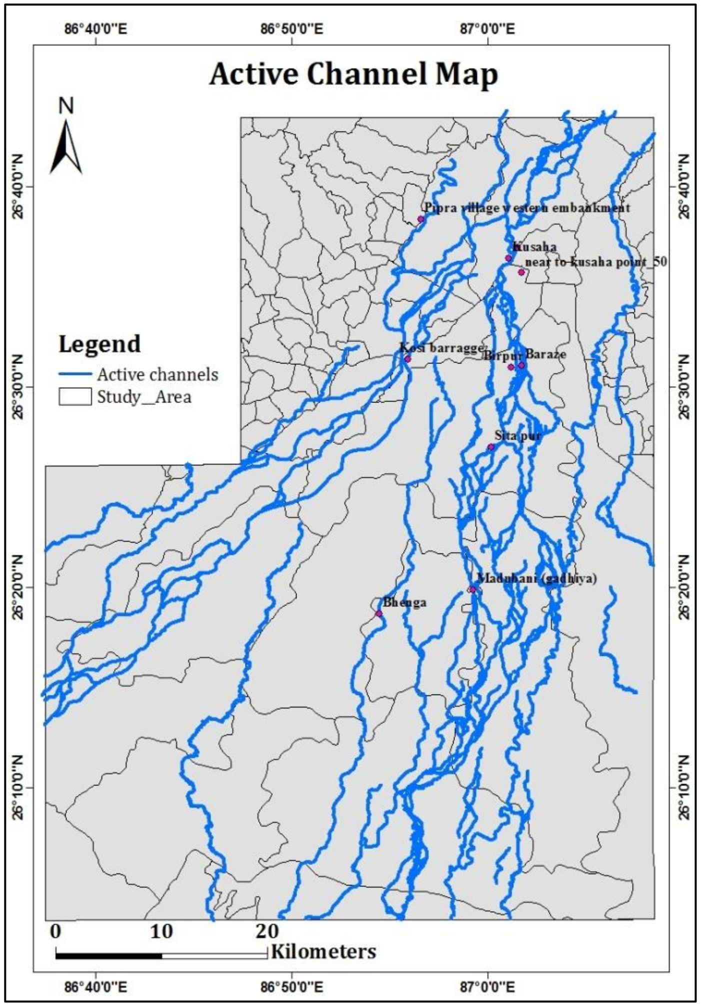


Figure 5.7: Active Channel Map

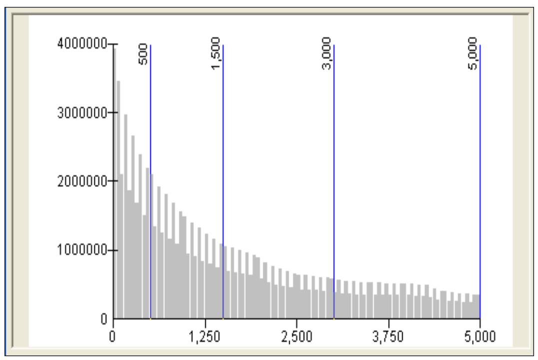


Figure 5.8: Histogram of Active channel map

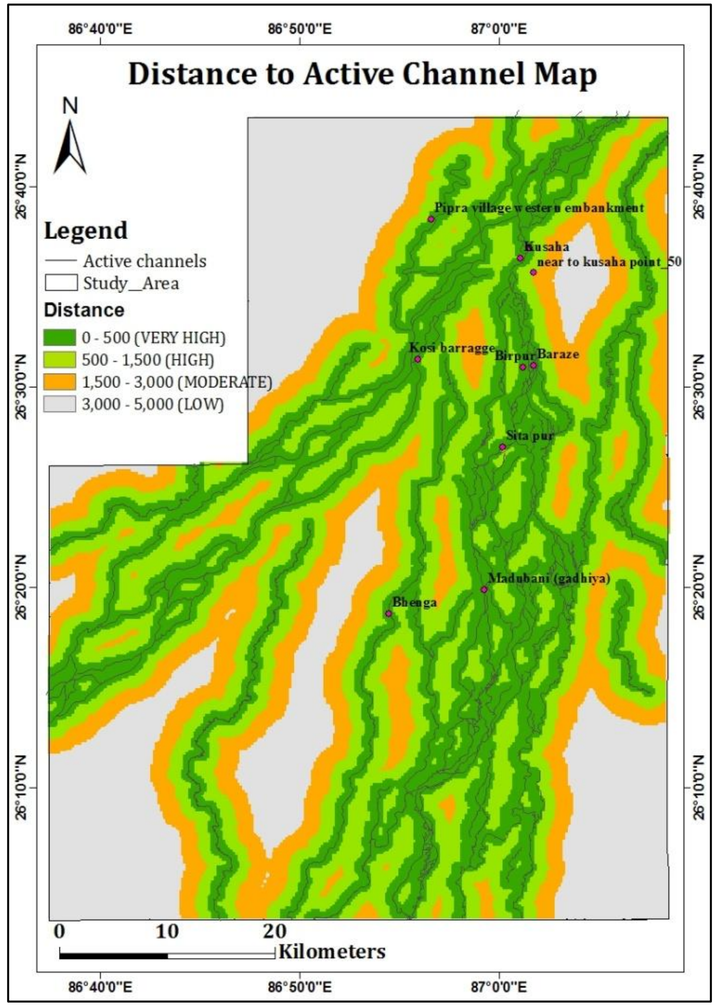


Figure 5.9: Distance to Active channel Map

5.1.5 Landuse/Landcover (LULC) map

The World Meteorological Organization (WMO, 2009), promoted the principle of Integrated Flood Management (IFM) as the integration of "the land and water resources development in the river basins and aims in maximizing the net benefits from use of flood plains and minimising the loss of life from the flooding". The nature and the extent of the landuse and landcover have a strong control over the runoff characteristics of the river and its catchment areas. Areas with low forest cover, settlement are more vulnerable to damage as river draining the plain, increases the runoff rate and its quantity and shortens the time of concentration and vice versa.

Supervised Classification using maximum likelihood classifier (MLC) was carried out for Landsat-7 TM image for the year 2009 (post avulsion period). MLC classifies the image based on the information contained in the samples collected. The layer assigned with name "Landuse Landcover". The available LULC include six different categories namely: agriculture, forests, moist sand areas, dry sand areas, water bodies and settlements (Figure 5.10). The landcover classes represent feature on the land surface while landuse represents the activities within which the landcover is being used. This is the classification scheme of selecting the representative areas with the help of the spectral characteristic of the feature in the image. The accurate and complete classes to be defined in the supervised classification is critical in case of coarse resolution image, because not all data fit into a particular class because of fuzzy or mixed areas within the image as that of settlement and moist sand areas in case my study area.

The error matrix of the image classification was computed to determine the accuracy based on 250 random sample points. The overall accuracy was 85.59 % and KHAT statistics, a measure of the difference between the actual agreement between the reference data and automated classifier and the chance of agreement between the reference data and random classifier (Lilisand and Kiefer, 2000) is 0.7959. Classification results are good for the major classes but there is confusion between settlement areas and moist sand areas in this context. Hence the settlement areas have been extracted from LISS-4 post-avulsion period image which was masked with the landcover (Landsat-7 TM) to generate the final LULC map.

The LULC statistics (Table 5.4) show that the major part of the study area is dominated by agriculture land (1109 sq.km) which is 33% of the total area. This is followed by moist sand areas (1613sq..km), which is 48 % of the total area which include the small water patches, waterlogged areas. The dry sand areas which was the outcome of the sand sheets that has been widespread after the 18/8 avulsion contributes to 294 Sq.km to the total area with 9% of the study window. The study area is almost flat with gentle slope mostly suitable for agriculture. The area of forest cover is very less which is estimated to be around 2% of total area. The settlement cover is 5% of the total area mapped from post avulsion image, which is very less due to recurrent flooding; the permanent settlement area gets disturbed and for rehabilitation it needs proper mitigation strategy along with the proper time span.

5.1.6 Population density map

The population at risk is one of main factor that needs to be considered to evaluate the loss caused due to the flooding in an affected area. To quantify the economic assets under potential threat, the block wise population density has been chosen as an important variable. The layer has been assigned with the name “Population Density Map”. The classified population density map (Figure 5.11) has been generated with the 2011 census data of the Bihar, India and Nepal which has been purchased from the “LandScan Global East View. The population data is a secondary data and it has already been processed. The spatial resolution of the data is 1km x 1km, (grid 30" X 30") for the year 2011. The format used is ESRI grid format with projection of Geographic, WGS 84(mandatory to be used), it will incorrect the population count if projection or coordinate system is changed. The LandScan algorithm uses the spatial data and imagery technology and the most update census data within the administrative boundary which are modified to match the data condition and the geographic extent of the individual country and region. The LandScan provide easy, quick assessment and estimation of the population at risk. It also integrates the age, sex, race and socioeconomic characteristics for the impact of risk assessment.

The population for the study area has been extracted with the help of LandScan tool provided with the dataset, which works with the ArcGIS–10 versions. The LandScan add-in provided with the feature extraction tool, Graphic population tools, Age sex-calculation polygons, Lasso tool, Buffer tool. According to the requirement of the analysis, the feature extraction tool has been used for the purpose, by taking the polygon of the blocks for which the population is to be extracted and the population grid of the Nepal and India was taken to extract the population of each of the blocks polygons. There is one option called Nested plume in the Feature extraction tool which counts the cumulative totals from outside in and the inside out population and were extracted and added to the output. The net population calculated from this tool was further processed to generate the population density at block wise basis.

On the basis of the histogram shown in figure 5.12 the following classes of the population density has been mapped and accordingly the area and the name of the blocks has been estimated.

Table 5.2: Population density with the name of the blocks and area estimated

Population Density Classespersons/sq km	Area Covered sq km	Name of the Blocks
80–220	264	Gobargada, Dhodhanpur, Madhuban, Koshi Tappu, Bishariya, Joginiya-2, Bhardaha, Dharampur, Joginiya-1.
221–500	1031	Jogidaha, Kamalpur, Saraigarh, Bairwa, Hadiya, Bakdhanwa, Babiya, Badgama, Mahendranagar, Nirmali, Mainakude, Baisain (Ko), Prakashpur, Koshi tappu, Sunserpur, Bathmaha, Diman, Jandaul,Basantpur, Fatepur, Hariharpur, Rampuramathaniya, Lalapati, Tapeshwori, Shankarpur, Dharampur, Pakari, Sripurjabdi, Singiya, dewaganj, Pashim Kusaha, Goithi, Bhagwatpur, Pipra(puraba), Chinnmasta, Gautampur
501–922	1895	Inarwa, Odraha, Jalpapur, Rupnagar, Sunsari(Dumaraha), Narshingatappu, Theliya, Haripur,Kaptanganj, Mahadeva, Duskee, Singheshwar, Kishanpur, Lohajara, Prasabani, Dadha,Koiladi, Pratapganj, Bathanaha, Ramnagar Butaha, Jagatpur, Tribeniganj, Kanchanpur, Madhepura
923–1482	1923	Harinagar, Supaul, Narpatganj, Lockahi, Dharampur, Chattarpur, Trikola
1483–2043	260	Pipra, (Ko)Madhepura, Madhawpur, Portaha,

		Hanumannagar,
2044–2885	35	Deurimania, Baramjhiya, Rajbaraj, Buarwa

The population density map for the study area has been classified into six major classes shown in the Table 5.3 and the population varies from 80 persons/sq. km to 2885 persons/sq. km. The population density of 80–220 persons/sq. km covers Gobargada, Bardaha, Dharampur, Joginiya, Bisariya, Mahuban blocks etc. There are some blocks in Nepal like Bharamjhiya, Portaha, Buarwa, Rajbaraj whose areal extent is very less but feed a high population of more than 2000 persons/sq. km.

The majority of the blocks of Bihar are highly populated with a range of 923-1482 persons/sq. km (Figure 5.13) which includes Raghopur, Basantpur, Chatarpur, and Narpatganj, Theliya, and Loharaj blocks. These are the blocks through which the river flows. The avulsion due to breaching at Kusaha and consequently the new path of the river channel also affected.

5.1.7 Road River Intersection (RI/RD)

The road network is considered to be a critical element of a community's infrastructure in a region. Damage to infrastructure is one of the most significant problems caused by flooding often results in the isolation of towns and villages from aid and facilities (IFRC, 2002).The impact of inundation of road and back water logging makes it one of the important parameter for vulnerability analysis which has been modeled by considering number of roads/ river interaction per unit area. Initially road river intersection points were mapped during the field visit (July, 2012) with the help of the DGPS survey (Figure 5.14).Then these classified points were validated with the satellite imagery of LISS-IV post avulsion period which also indicated that several of these points were created after the channel avulsion at Kusaha and reactivation of palaeochannels. These points (RI/RD) converted to the point shapefile and with the help of SQL (Sequential Query Language) the number of intersection points have been called out for each of the blocks and finally the (RI/RD) intersection density of each of the blocks (Area extracted before for each blocks) has been estimated. All these steps are carried out using ARC-GIS 9.3.

The RI/RD intersection density map has been classified into five major classes'. Table 5.4 below shows the intersection point density classes and the number of blocks within the particular class.

Table 5.3: RI/RD intersection Density with the name of the blocks and area estimated

RI/RD intersection density(no of points/ sq.km)	Area (Sq.km)	Name of the blocks
0.00-0.001	667	Dharampur, Bishariya, Mahadeva, Joginiya, Bathmaha, Bharwatpur, Dadha,Bahtnaha, pakari, hariharpur, bairwa, jagatpur, Pipra(purva), dharampur, Kanchanpur, Jogidaha, Tapeshwori, Ordaha, Theliya, Bakdhanwa, Madhuban, Fatepur, Koshi Tappu wildlife, Dhodhanpur, Kamalpur, Rupnagar, Sunderpur, KosiTappu, Lalapati, Channmasta
0.002-0.012	1207	Madhepura, Kishanpur, Narpatganj
0.013-0.031	948	Supaul, Singheashwar, Saraigarh-Baptiyahi
0.032-0.112	1071	Pratapganj, Pratapganj, Pipra,Chattarpur, Raghopur,
0.113-0.153	333	Tribeniganj

The thematic layer shows that the number of intersection occurring per sq.km of area ranges from 0.00 to 0.153.Most of the areas in the given map (Figure 5.16) have the values ranging from 0.00-0.001 which includes blocks that lies in Nepal (Figure 5.15). These are the blocks of Nepal that are least affected as the intersection road river intersects are less distributed. The prominent classes of road river intersection point density lie in the lower part of the study area i.e. southern part of the Kosi basin. Some of the blocks have higher risk to damage as the classified points (RI/RD intersection points) follow the trend of the slope i.e. from NW to SE in the Kosi fan of Bihar region and lead to the inundation and backwater logging in these areas (Figure 5.16) making the area vulnerable. The (RI/RD) intersection density map graphs show the spatial distribution of points and form the basis of classification of the classes required for the analysis. According to Figure 5.16, Tribenigunj shows the higher RI/RD density values of 0.113-0.153, hence more vulnerable to risk. This is followed by Madhubani, Raghopur, Basantpur, and Pipra blocks with the moderate values of 0.032 to 0.112/sq.km.

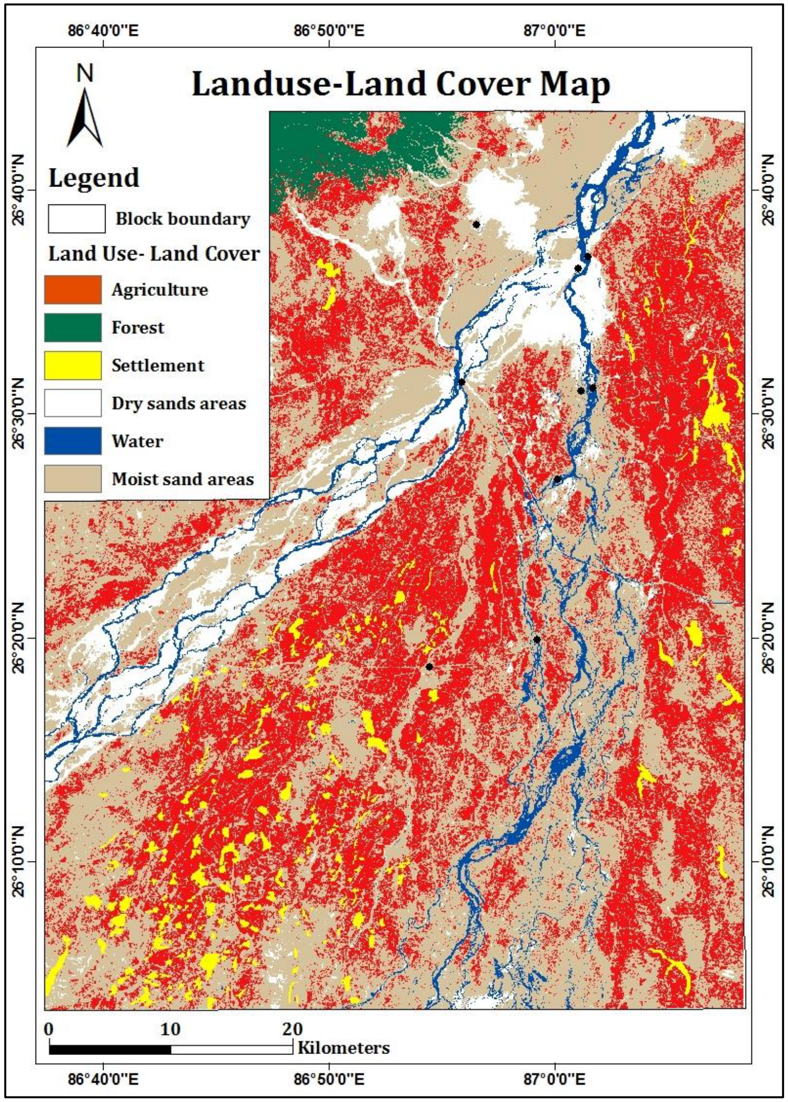
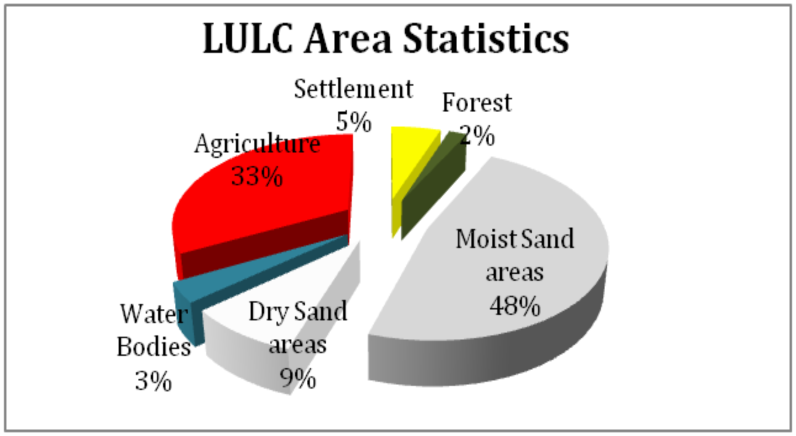


Figure 5.10: Classified Landuse Landcover Map

Table 5.4: LULC Statistics

Description	**Area (sq.km)**
Settlement	182.35
Forest	67.06
Moist Sand areas	1613.44
Dry Sand areas	294.41
Water Bodies	117.489
Agriculture	1109.38



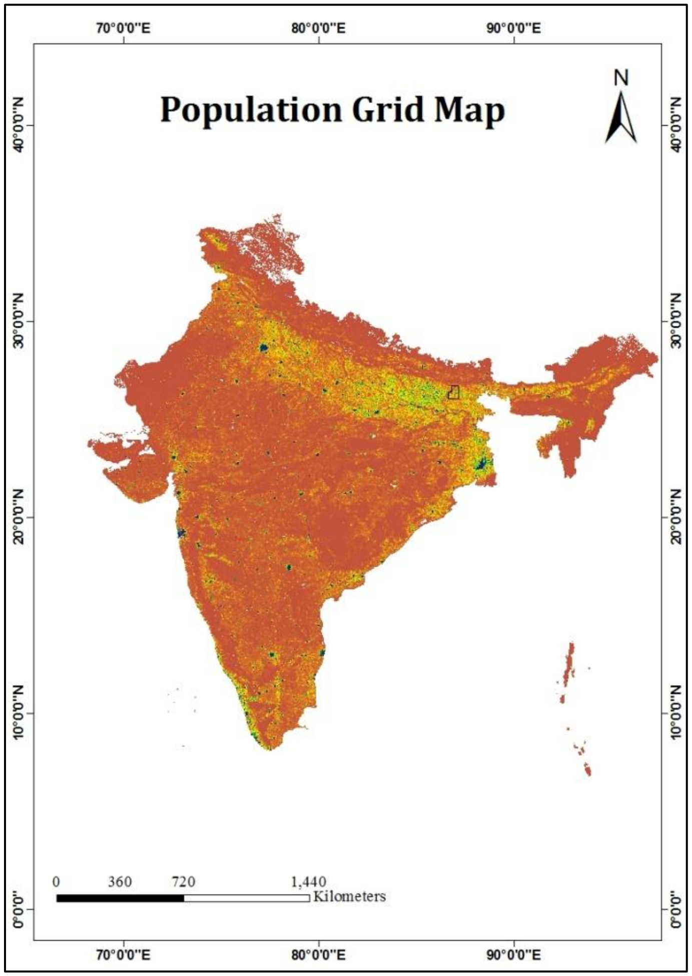


Figure 5.11: Population Grid Map

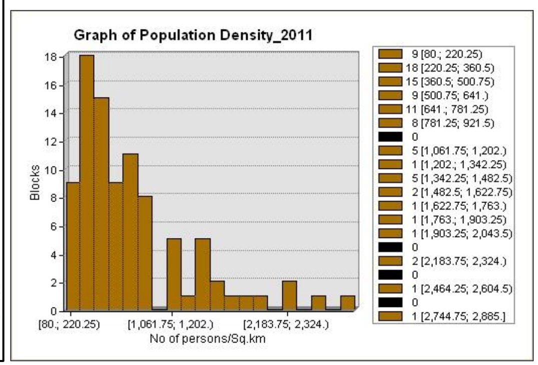


Figure 5.12: Histogram of Population Density

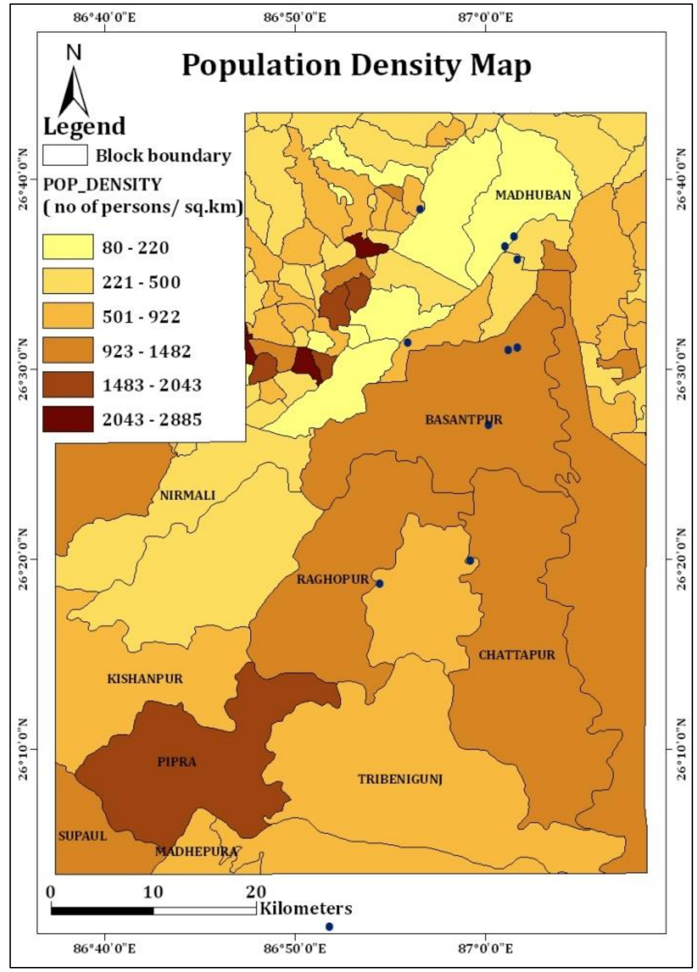


Figure 5.13: Classified Population Density Map

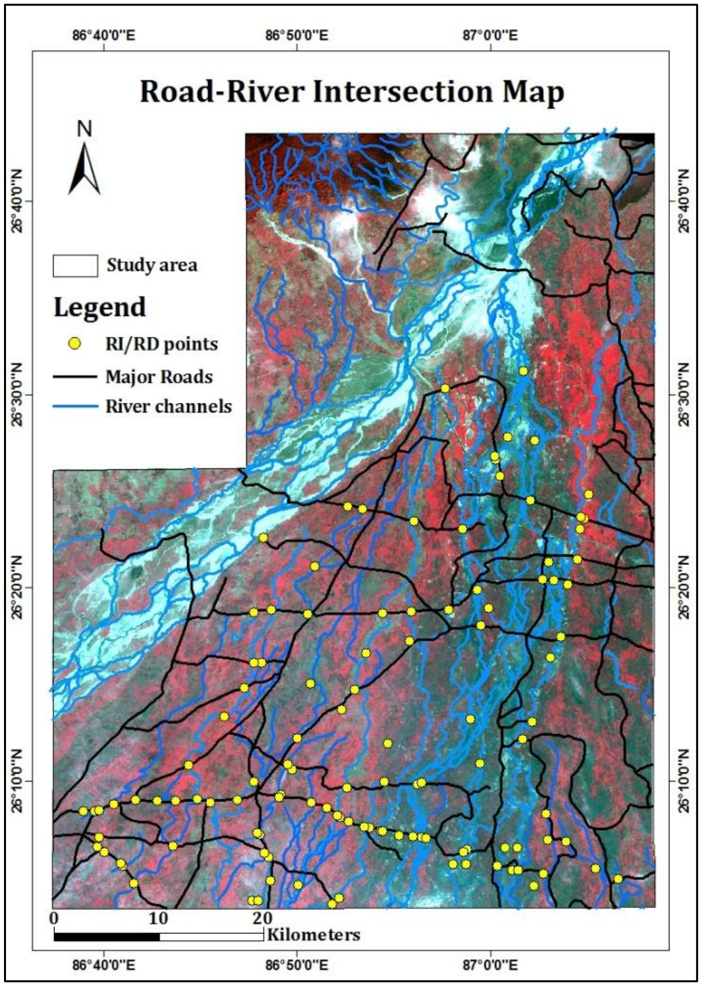


Figure 5.14: RI/RD Point Map

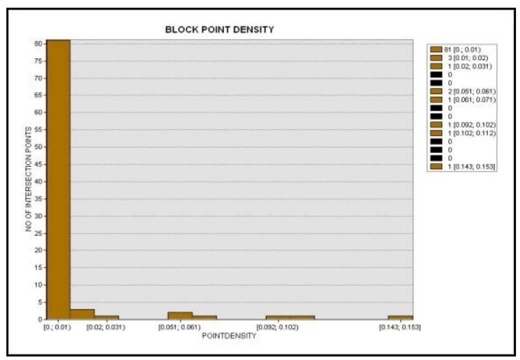


Figure 5.15: Histogram of the RI/RD Map

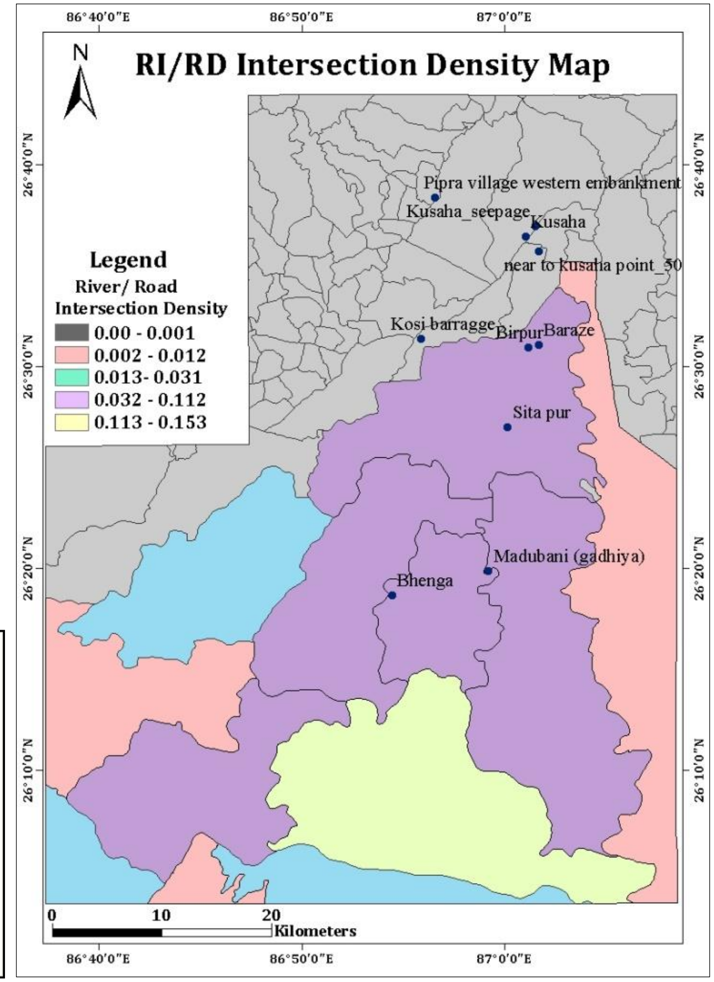


Figure 5.16: Classified RI/RD Intersection Density Map

5.2 AHP analysis for flood risk assessment

As explained earlier, flood risk has been assessed as a function of flood hazard and vulnerability. The first step in both flood hazard and vulnerability analysis using AHP is to build the hierarchy. I have used understanding of the various physical and socio-economic factors discussed above for developing the hierarchy and have then produced the hazard and vulnerability maps separately. Finally, both these maps have been integrated for flood risk assessment.

5.2.1 Building the hierarchy for flood hazard assessment

Rainfall in north Bihar region is anomalous and one of the governing factors to flood. Due to high rainfall there is recurrent flooding in the region and this also causes the high sediment flux from the catchment areas. Hence, it has been given a higher weightage with respect to the other factors in hazard index (Table 5.5). The factors for the level 3 subfactor has given high weightage to the rainfall area with rainfall 1325-1608 mm/yr which is predominant over a large number of blocks followed by 1860-2433 mm/yr the calculation of relative importance weightage for rainfall (Level 3 sub factors) in Table 5.6. The less rainfall has been given low weightage as it is influencing a small area of extent.

Table 5.5: Calculation of Relative Importance Weightage for Level 2 decision Factors

Hazard Factors					**Estimated Eigen Element**	**Relative Importance Weightage**
Decision Factors	**Rainfall**	**Slope**	**Distance to active Channel**	**Geomorphology**	**EEE**	**RIW**
Rainfall	1	9	5	3	3.409	0.592
Slope	1/9	1	4	6	1.278	0.222
Distance to	1/5	1/4	1	7	0.7698	0.134

active Channel						
Geomorphology	1/3	1/6	1/7	1	0.2988	0.052

Table 5.6: Calculation of Relative Importance Weightage for Rainfall (Level 3 sub factors)

Rainfall(mm/year)						**Estimated Eigen Element**	**Relative Importance Weightage**
Decision Factor	**623-956**	**956-1325**	**1325-1608**	**1608-1860**	**1860-2433**	**EEE***	**RIW**
623-956	1	4	8	5	6	3.949	0.531
956-1325	1/4	1	5	4	3	1.719	0.231
1325-1608	1/8	1/5	1	7	5	0.974	0.131
1608-1860	1/5	1/4	1/7	1	4	0.491	0.066
1860-2433	1/6	1/3	1/5	1/4	1	0.308	0.041

Further, the Kosi basin has a flat topography and the slope variation is very less (0.05°–26.55°) as derived from the SRTM DEM slope map. This will cause the slowing down of the river channel flow and the sedimentation will be high along the river course which follows the trend of the slope. Low slope angle indicates the areas with the flat topography will get inundated easily as compared to the moderate slope and high slope areas and hence given higher weightage. Higher slope will lead to high runoff and hence the effect due to flood will be less. Table: 5.7 shows the calculation of the relative importance of the level 3 sub factors.

Table 5.7: Calculation of Relative Importance Weightage for Slope (Level 3 sub factors)

Slope(in degree)							**Estimated Eigen Element**	**Relative Importance Weightage**
Decision Factors	**0.0-0.30**	**0.30-0.64**	**0.64-1.19**	**0.19-1.81**	**0.81-6.15**	**6.15-26.55**	**EEE***	**RIW**
0.0-0.30	1	8	7	4	3	3	3.554	0.459
0.30-0.64	1/8	1	7	3	2	2	1.479	0.191
0.64-1.19	1/7	1/7	1	3	2	4	0.888	0.115
0.19-1.81	1/4	1/3	1/3	1	3	2	0.742	0.096
0.81-6.15	1/3	1/2	1/2	1/3	1	2	0.618	0.080
6.15-26.55	1/3	1/2	1/4	1/2	1/2	1	0.4678	0.0600

The distance to active channel will be important over the geomorphology as the hazard to the flooding will be based on or to be decided on the distance that is covered by the river during flooding. Hence the distance to active channel in hazard index has to be given a high importance. The weightage of level 3 subfactors has been decided accordingly, greater is the distance from the main channel lesser the risk and lesser is the distance, higher is the risk. Table 5.8 which shows the calculation of the relative importance of the level 3 sub factors.

Table 5.8: Calculation of Relative Importance Weightage for Distance to Active channel (Level 3 sub factors)

Distance to Active channel map (mts)					Estimated Eigen Element	Relative Importance Weightage
Decision Factor	**0-500 (Very High)**	**500-1500 (High)**	**1500-3000 (Moderate rate)**	**>3000 (Low)**	**EEE**	**RIW**
0-500 (Very High)	1	5	7	8	4.091	0.647
500-1500 (High)	1/5	1	3	5	1.316	0.208
1500-3000 (Moderate)	1/7	1/3	1	3	0.615	0.097
>3000 (Low)	1/8	1/5	1/3	1	0.302	0.048

Geomorphology of the study area will be affected least during flooding as the change in the geomorphology is long term process. Hence this factor has been given the least weightage in level 2 factor index when comparing to the other hazard factors. But due to the flat topography, the avulsion channel belt, the water logging condition and many remnants river channels fed by the water seepages, increases the chances for the flooding in during monsoon period. Hence the weightage for the different geomorphic classes for level 3 sub factors defined accordingly and the avulsion channel has been given high weightage followed by the Avulsion channel, active channel, sand bars, fan surface. Table 5.9 shows the calculation of relative importance weightage for Geomorphology of level 3 sub factors.

Table 5.9: Calculation of Relative Importance Weightage for Geomorphology (Level 3 sub factors)

Geomorphology									**Estimated Eigen Element**	**Relative Importance Weightage**
Decision Factor	**Active Channel**	**Sand Bars**	**Inactive Channel**	**Avulsion channel**	**Avulsion belt**	**Water logged areas**	**Sand sheets**	**Fan surface**	**EEE***	**RIW**
Active Channel	1	3	5	7	4	5	4	7	3.946	0.349
Sand Bars	1/3	1	4	3	2	2	5	6	2.163	0.191
Inactive channel	1/5	1/4	1	5	4	5	3	5	1.715	0.152
Avulsion Channel	1/7	1/3	1/5	1	9	7	6	8	1.396	0.123
Avulsion belt	1/4	1/2	1/4	1/9	1	5	8	3	0.896	0.079
Water	1/5	1/2	1/5	1/7	1/5	1	5	3	0.552	0.049

logged areas									
Sand Sheets	1/4	1/5	1/3	1/6	1/8	1/5	1	4	0.359	0.032
Flood plain	1/7	1/6	1/5	1/4	1/3	1/3	1/4	1	0.275	0.0242

Table 5.5 of Hazard factor show a matrix for the level 2 decision factors, which include the Estimated Eigen Element (EEE) and Relative Importance Weightage (RIW) to each of the thematic layers by pair wise comparison using Saaty's 9 point scale (discussed in chapter 3). In the decision matrix, the values along the row suggest the relative importance of the factors with respect to other decision factors in the level 2. The diagonal matrix assigned with the value 1 indicates the equal preference relative to itself. The upper diagonal matrix contains different values depending upon the preference of decision factors in comparison to the other factors. The lower diagonal of the matrix contains the reciprocal of the upper diagonal matrix according to the values given to the same parameters in upper decision matrix.

After assigning the values to the level 2 and level 3 factors, the relative importance of each of the factors was

determined by normalizing the Eigen vector of the decision matrix. Finally the flood hazard map was generated in the model builder by arithmetic overlay of the different hazard parameters along with their weightage factors.

5.2.2 Generation of flood hazard map

The final flood hazard map shows a continuous value ranging from 0.0 – 4.786 (Figure 5.17). The map has been classified on the basis of histogram developed from the AHP analysis of the hazard parameters into five major classes namely, very high, high, moderate, low, and very low (Figure 5.18). The map shows the area with high rainfall, with low degree of slope includes mostly the blocks of Narpatganj, Basantpur, some parts of Raghopur of Bihar region have very high to high Flood Hazard Index (FHI) with classified value range of 3.20–4.78. Some blocks in Nepal such as Sunderpur, Jogidaha, Bakdhanwa, Andhaul, Fatepur also have high FHI but the reason is due to high intensity of rainfall cause hazard. Most of blocks with moderate hazard index range has been classified with the values as 2.4–3.2 which includes

Kanchanpur, Portaha, Thelia, Baramjhiya, Mahadeva, Batamaha etc and the blocks which are close to the active palaeochannels those of Chatarpur, Pratapgaunj, Tribeniganj, Singheshwar, Basantpur (Bihar) are hazard prone as they become the conduits for the flow of flood water during heavy rain, or flooding and hence cause the maximum damage to life and property without giving time to get alert or save from the damage caused, has the Moderate to Very High FHI. The blocks which are down to the eastern embankment e.g Kishanpur, Pipra, Saraigarh Baptiyahi, Laukahi, Lalapati shows low to very low FHI with classified value range of 0.939 to 2.4 shows less hazard as they are at safe distance from the active channel, the slope also helps to flow the river toward the trend of the movement, the rainfall is also very less. The blocks covering avulsion zone includes blocks of Pratapganj, Chattapur, Tribeniganj, Basantpur shows high hazard with moderate to high value of Flood hazard index which is likely due to nearness to the active river channel, the slope also favours the activation of palaeochannels, the rainfall also high as shown in figure 5.19.

5.2.3 Building the hierarchy for flood vulnerability assessment

Population of an area helps us to estimate the cost of life and property in an area and hence, it directly contributes to vulnerability. The socioeconomic interventions such as road, village, buildings etc., are the outcome of the population growth which contributes to the risk after effect of the flood. Higher is the population density, higher is the damage in terms of life and property. But in the study area, the blocks with moderate population density are higher and are more prone to vulnerability as it lies in the avulsion zone as shown in figure 5.13 Hence,population density has been given high weightage as compare to other factors. Table 5.11 show the relative importance weightage for population density (Level 3 sub factors).

Table 5.10: Calculation of Relative Importance Weightage for Level 2 decision Factors

VULNERABILITY FACTORS				**Estimated Eigen Element**	**Relative Importance Weightage**
Decision Factors	**Population Density**	**LULC**	**River Road Intersection**	**EEE***	**RIW**

Population Density	1	9	4	3.302	0.726
LULC	1/9	1	7	0.920	0.202
River Road Intersection	1/4	1/7	1	0.329	0.072

Table 5.11: Calculation of Relative Importance Weightage for Population Density (Level 3 sub factors)

Population Density(No of Persons /Sq.km)							**Estimated Eigen Element**	**Relative Importance Weightage**
Decision Factor	**80-220**	**221-500**	**501-922**	**923-1482**	**1483-2043**	**2043-2885**	**EEE***	**RIW**
80-220	1	4	5	8	5	4	3.839	0.444
221-500	1/4	1	5	7	3	4	2.172	0.251
501-922	1/5	1/5	1	7	6	2	1.223	0.142
923-1482	1/8	1/7	1/7	1	7	3	0.614	0.071
1483-2043	1/5	1/3	1/6	1/7	1	2	0.383	0.044
2043-2885	1/4	1/4	1/2	1/3	1/2	1	0.416	0.048

Natural or agricultural land such as forests, woodland, pastures or crop fields, is normally able to absorb a considerable proportion of rain that falls onto it. Covering such land with buildings, roads or other impermeable materials significantly reduces the ability to absorb rainfall and will lead to increased land runoff. As a result, large developments, including those away from major rivers, can increase river flows and simultaneously increase the risk of flooding to land and property. A number of smaller developments built up

over a period of time can have the same effect**.** Table 5.12 show the relative importance weightage for Landuse Landcover (Level 3 sub factors).

Table 5.12: Calculation of Relative Importance Weightage for Landuse-Landcover (Level 3 sub factors)

Landuse-Landcover classes							**Estimated Eigen Element**	**Relative Importance Weightage**
Decision Factor	**Agriculture**	**Settlement**	**Dry sand areas**	**Moist sand areas**	**Water**	**Forest cover**	**EEE***	**RIW**
Agriculture	1	9	5	7	8	5	4.824	0.511
Settlement	1/9	1	3	8	7	7	2.253	0.239
Dry sand areas	1/5	1/3	1	3	2	2	0.963	0.102
Moist sand areas	1/7	1/8	1/3	1	3	2	0.574	0.061
Water	1/8	1/7	1/2	1/3	1	3	0.455	0.048
Forest cover	1/5	1/7	1/2	1/2	1/3	1	0.365	0.039

The intersection between the road and river is contributing to the congestion condition as it obstructs the passage of flow of the water in its actual way, but at the same time it provides the access to the movement during the flood. Hence it has the moderate impact on the risk of flooding. Table 5.12 shows the Relative importance weightage for RI/RD intersection (Level 3 sub factors).

Table 5.13: Calculation of Relative Importance Weightage for Road-River Intersection (Level 3 sub factors)

River -Road intersection density (no of intersection per sq.km)						**Estimated Eigen Element**	**Relative Importance Weightage**
Decision Factor	**0.0-0.001**	**0.002-0.012**	**0.013-0.031**	**0.032-0.112**	**0.113-0.153**	**EEE**	**RIW**
0.0-0.001	1	2	4	7	9	3.471	0.455
0.002-0.012	1/2	1	3	8	5	2.268	0.298
0.013-0.031	1/4	1/3	1	7	4	1.185	0.155
0.032-0.112	1/7	1/8	1/7	1	9	0.470	0.062
0.113-0.153	1/9	1/5	1/4	1/9	1	0.228	0.030

5.2.4 Generation of flood vulnerability map

Although maps of individual components of vulnerability can be useful, but it will be easy to assess the vulnerability throughout the study area if multidimensional components can be integrated into a single measure. In the present study, the method used to combine the components is analytical hierarchy process. The final vulnerable map output has been

Table 5.14: FVI range and associated blocks

Flood vulnerability Index	**Associated Blocks**
Very High	Baramjhiya, Buarwa, Deurimaniwa
High	Chatarpur, Pipra, Raghopur, Laukahi, Trikola, Porthaha, Madhawapur, Ramangamakatti, Ko.Madhepura
Moderate	Supaul, Narpatganj, Basantpur, Lokhahi, Harinagar, Tribeniganj
Moderate to Low	Pratapganj, Singheshwar, Kishanpur, Haripur, Narshingatappu, Gautampur, Ramnagar, Inarwa,Sunsari, Jalpapur, Dhuskee, Kaptanganj, Ordaha, Rupnagar, Dharampur, Kanchanpur, Theliya, Lohajara, Bhagwatpur, Prasabani, Mahadeva, Bathnaha, Koiladi, Dadha, Bhagwatpur,
Low to very low	Saraigarh Baptiyahi, Madhepura, Mahadeva, Bathnaha, Basantpur, Fatepur, Jogidhaniya, Lalapatti, Kamalpur, Dhodhanpur, Prakashpur, Mahendranagar, Prakashpur, Sunderpur, Bakdhanwa,Jhandaul, Pakari, Mainkuder, Diman, Badgama, Bairwa, Basain(Ko), Ramapuramthaniya, sankarpura, Nirmali, Lalapati,Tapeswori, Babiya
Very low	Sripurjabdi, Singhiya, Jogidaha, Dhodhanpur, , Goithi, and Hadiya. Joginiya(1&2)

represented with graduated scale of color map indicating the flood vulnerable index (FVI) range 0.798 – 5.236 (Figure 5.20). There is no clear-cut boundary for classifying the vulnerability index hence the classification is based on the histogram of the generated vulnerable map. The final vulnerability map (Figure 5.22) has been classified on into five different classes viz. very high, high, moderate, low, very low and the associated values have been shown in the histogram (Figure 5.21). According to the classification every blocks has a range of FVI which cannot be categorized on single value hence it has been given a range which has been shown in the table below.

The regions with very high to high FVI has population density in the range of 1483–2043 persons per sq.km, these are the areas affected avulsion from which the Kosi diverges and taken up the path of palaeochannels which follows the area of Birpur, Sitapur, Bhenga, Mahuban, the area with settlement (post avulsion period) . The region that includes the Moderate FVI range have population density of 923-1482 persons with most of the area associated with agricultural land which has been converted to moist area due to water seepage from the avulsion channel, RI/RD intersection points are mostly located in these areas which has increase the vulnerability of the area e.g. Tribeniganj has the most RI/RD intersection Some of the blocks in the study area have low to very low FVI index as the population density is in range of 80-500 persons, there is least road river intersection which lead to the water congestion.

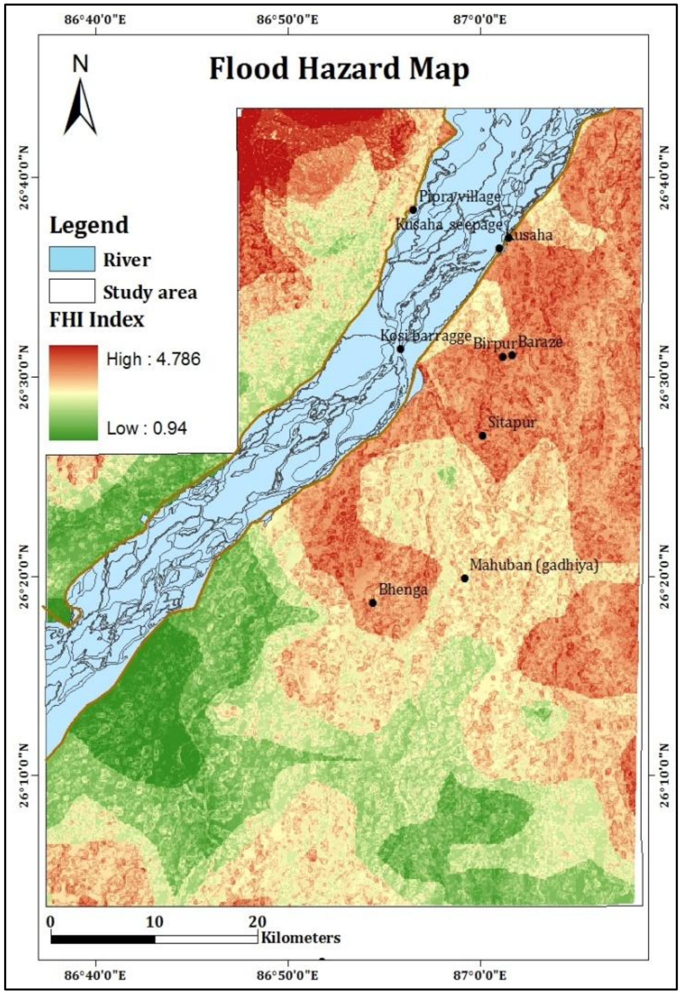


Figure 5.17: Flood hazard map

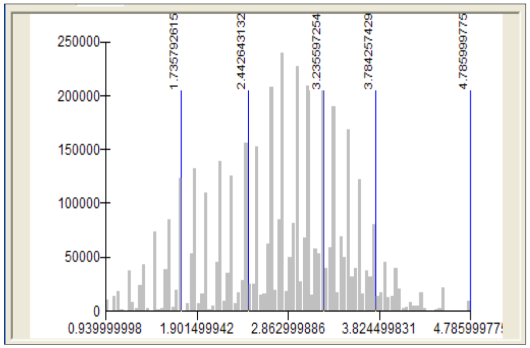


Figure 5.18: Histogram classifying FHI

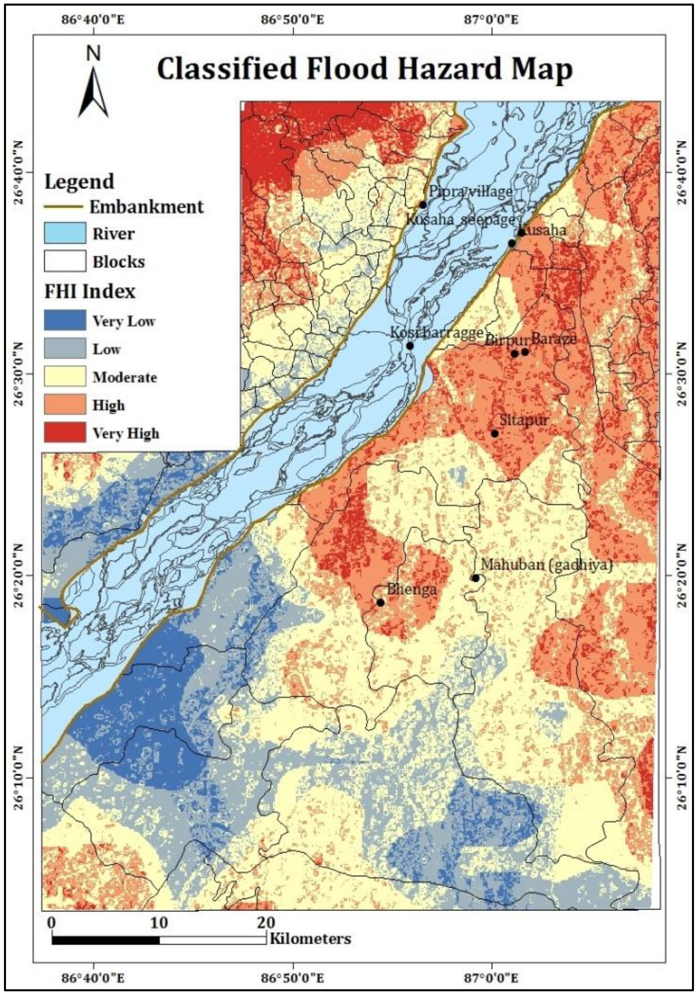
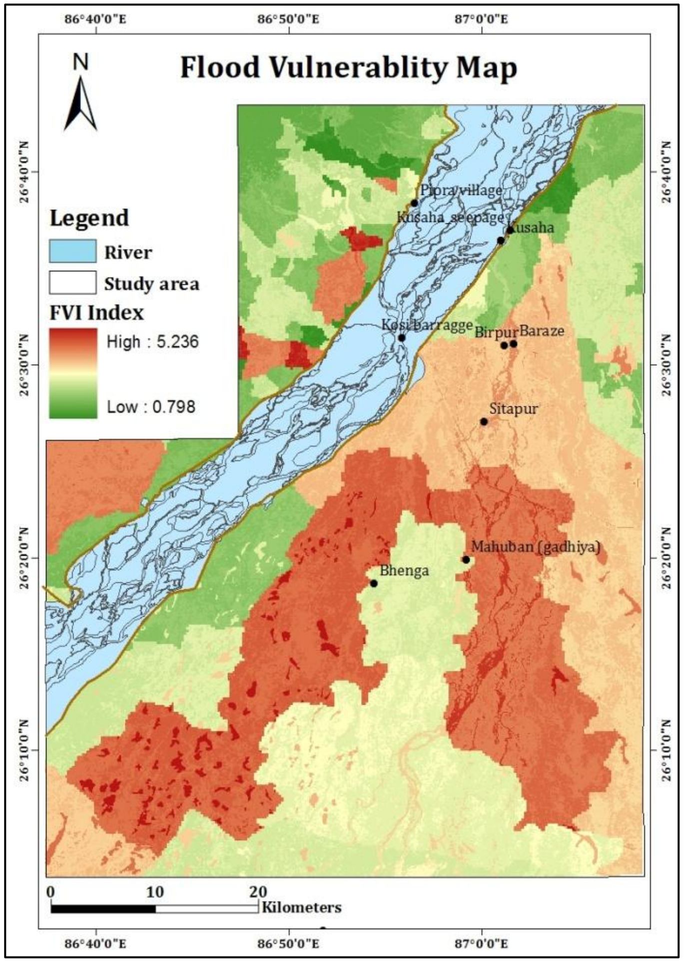
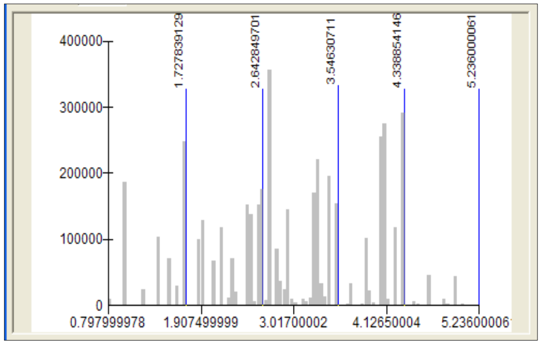


Figure 5.19: Classified Hazard Map





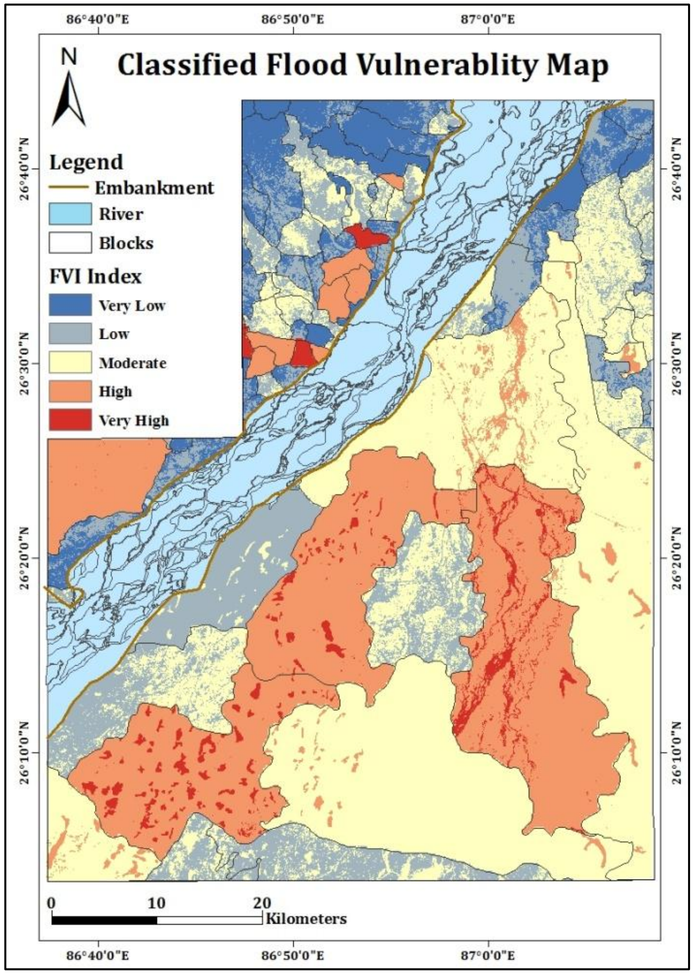


Figure 5.20: Flood vulnerability Map

Figure 5.21: Histogram Showing FVI

Figure 5.22: Classified Flood vulnerability map

5.2.5 Generation of flood risk map

Flood hazard map and the vulnerability map were multiplied to generate the final risk map of the study area in the model builder. The risk analysis was carried out block wise basis. The final Flood risk map is showing the FRI range from 1.584 to 21.1707, which has been shown in the figure 5.14. For the classification of the Flood Risk Index (FRI) we need to have a range to define the risk, for different categories such as very low, low, moderate, high , very high, thus histogram has been used to classify risk map into five major classes which are shown in the table below.

Table 5.15: Flood Risk Index with their value range

Range	Flood risk Index(FRI)
1.589 – 2.791	Very Low Risk
2.792–5.524	Low Risk
2.525–8.798	Moderate Risk
8.790–12.346	High Risk
12.347–21.170	Very High Risk

Final flood risk map can be classified accordingly with the blocks shown in Figure 5.28. No blocks in the study area is totally dominated with particular risk index and hence a range has been given as shown in the table below in Table 21. The reasons for high risk index indicates the high population density, high rainfall within the area, the avulsion affected zone, the area has very flat topography, includes the area of Chatarpur, Narpatganj, Basantpur as whole. Because of less population density and less road river intersection, less river channels and as the area lies inside the embankment, blocks such as Kishanpur, Saraigarh-Baptiyahi, Gobargadha, Nirmali, Bardaha, Bairwa, Kosi tappu, Mahuban have low FRI. The areas with intermediate values have the moderate population density, dominated with agricultural land and moist areas but the nearness to river channel increases the risk.

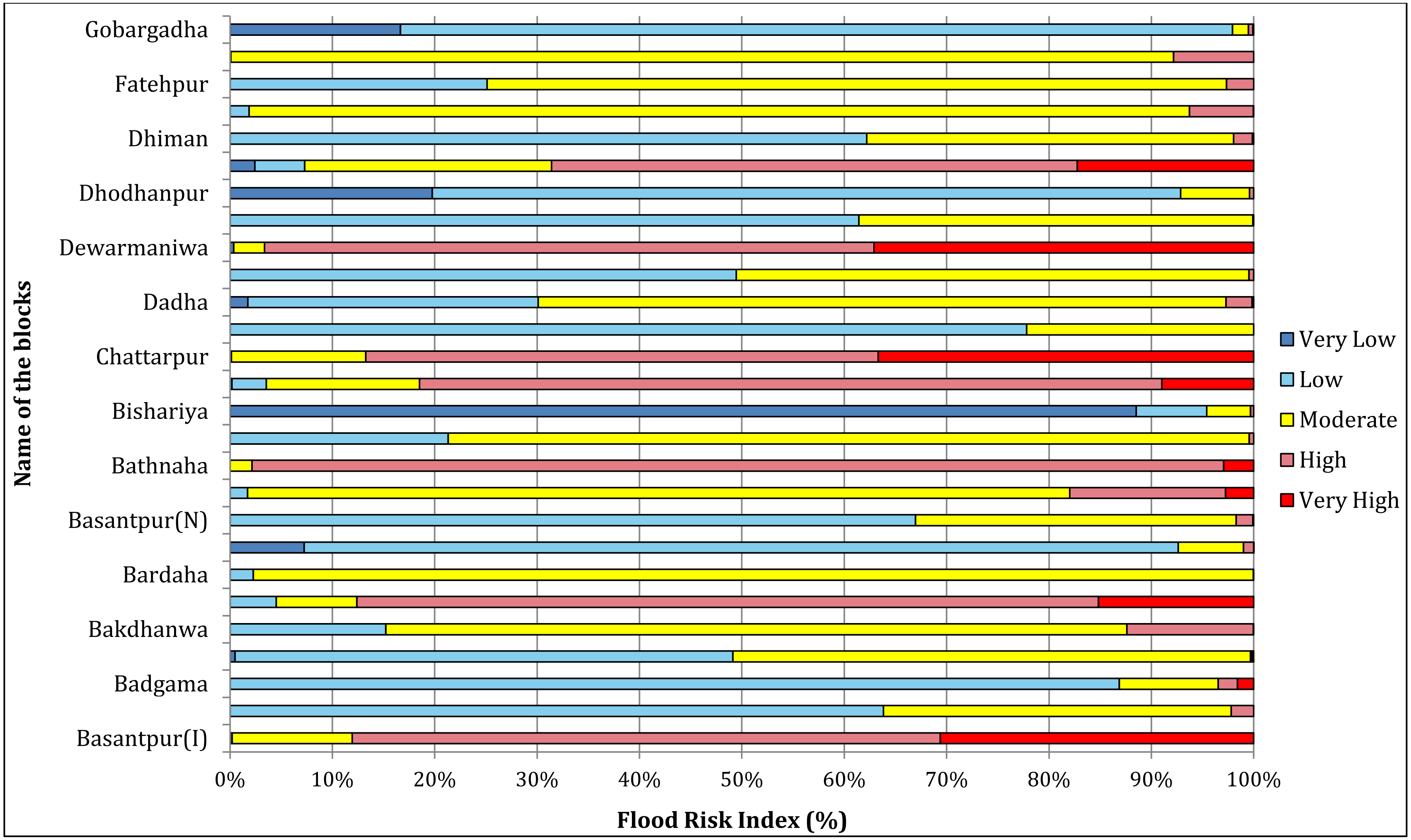


Figure 5.23: Bar diagram showing FRI values of 89 blocks

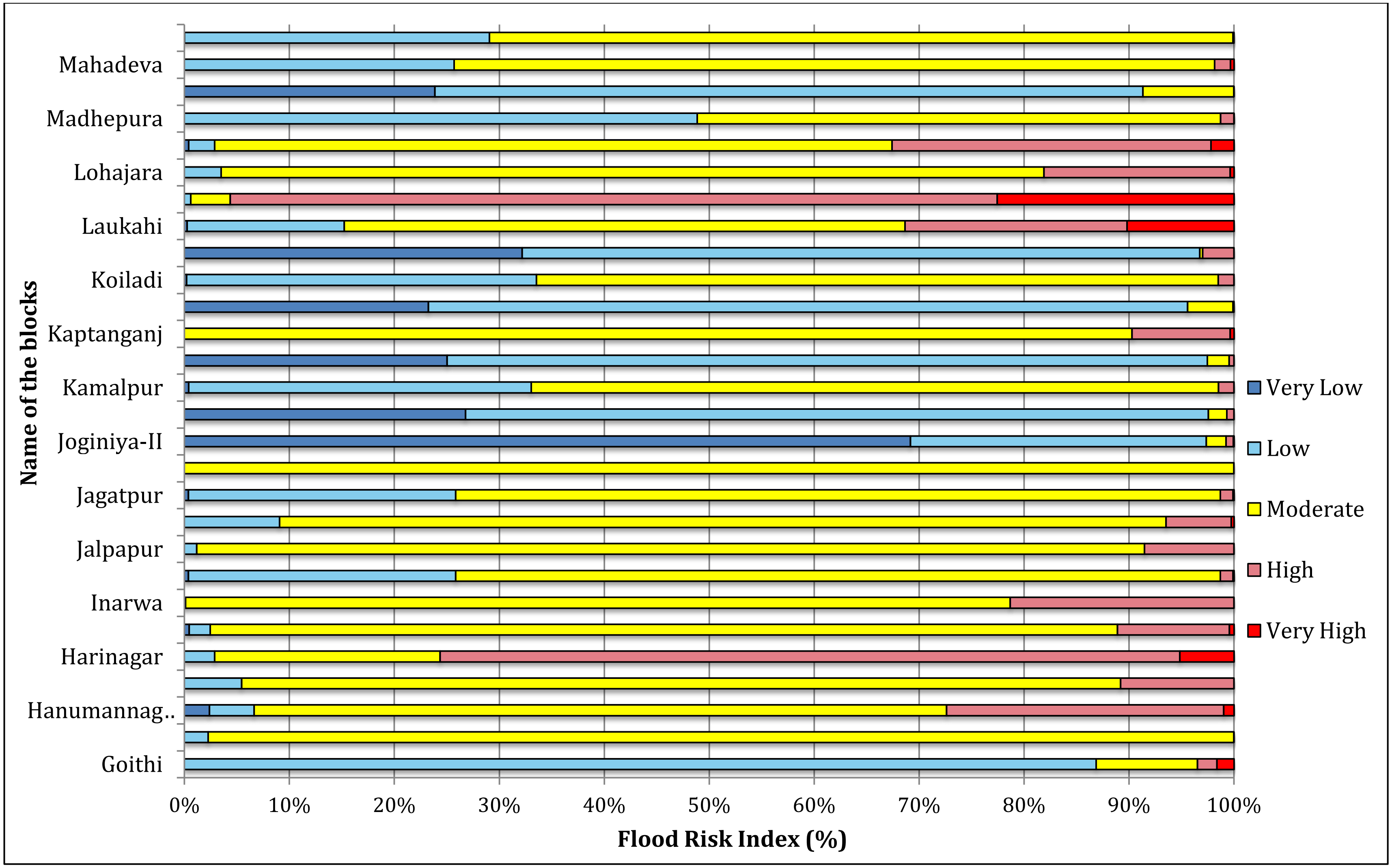


Figure 5.24: Bar diagram showing FRI values of 89 blocks

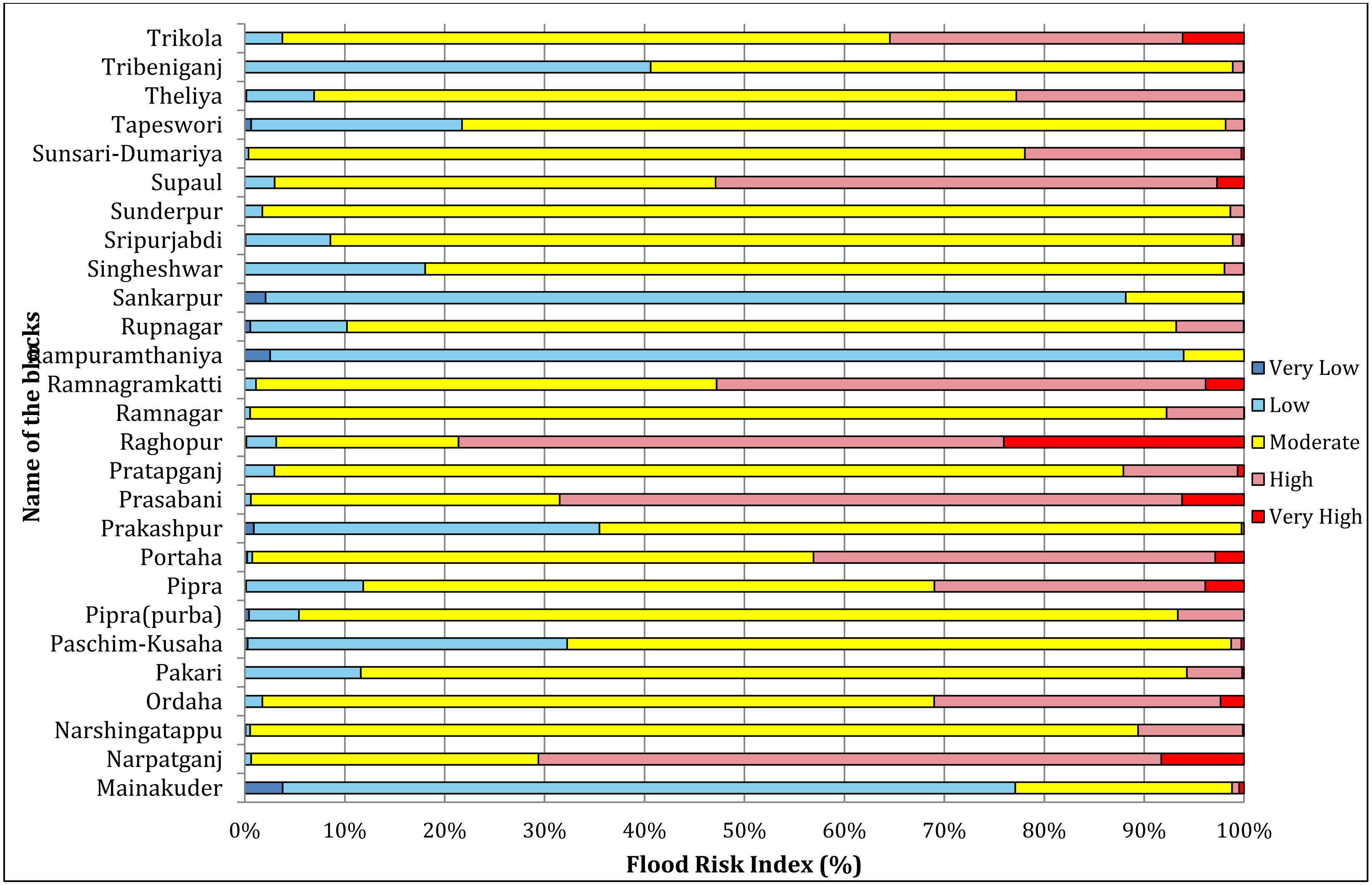


Figure 5.25: Bar diagram showing FRI values of 89 blocks

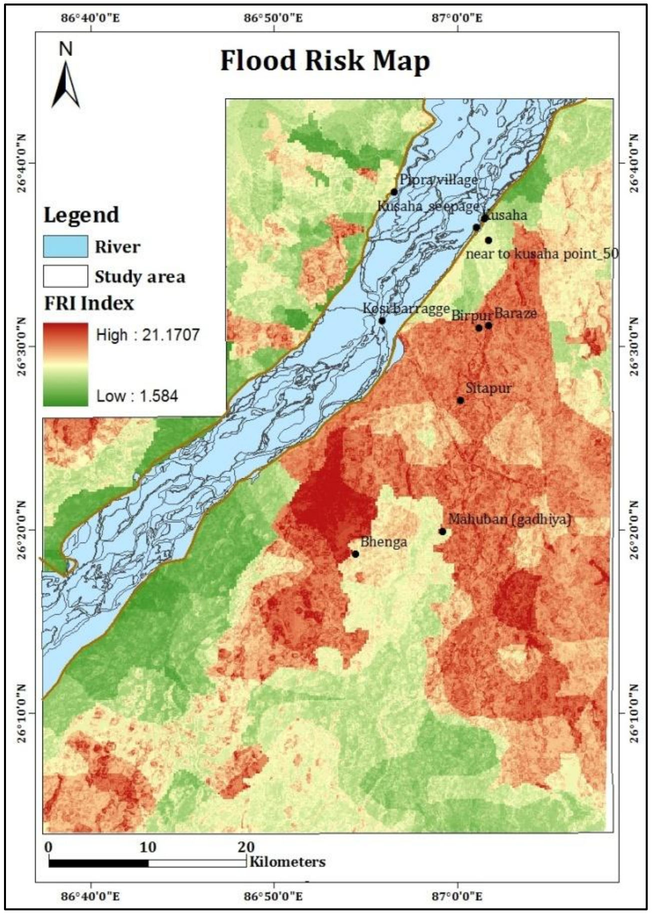


Figure 5.26: Flood Risk Map

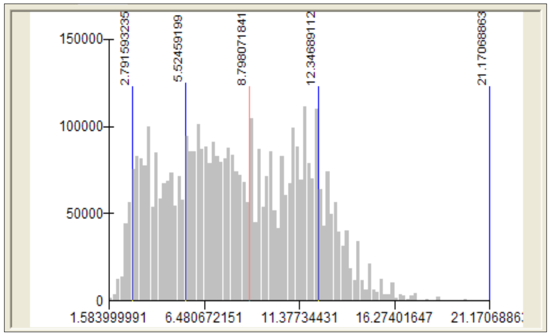


Figure 5.27: Histogram showing FRI values

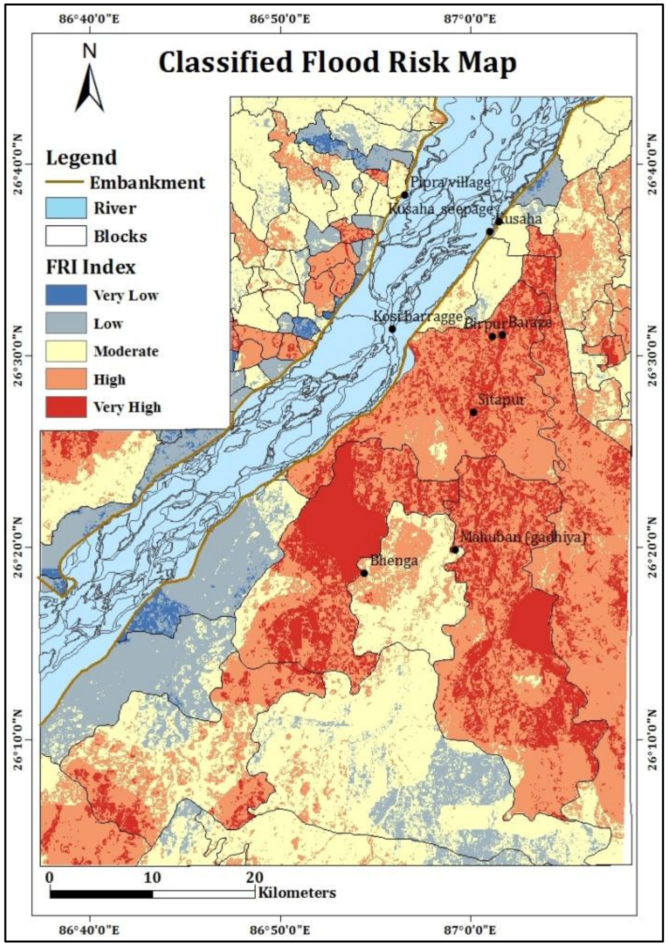


Figure 5.28: Classified Flood risk Map

The given bar diagram has been plotted for each of the blocks that has been considered for the risk analysis. Since none of the blocks has absolute values for the risk, Hence the bar diagram **(Figure 5.23, 5.24, 5.25)** is showing the value range in percentage for each blocks within different risk index . **Table 23** shows such classification of blocks on the basis of bar diagram classification.

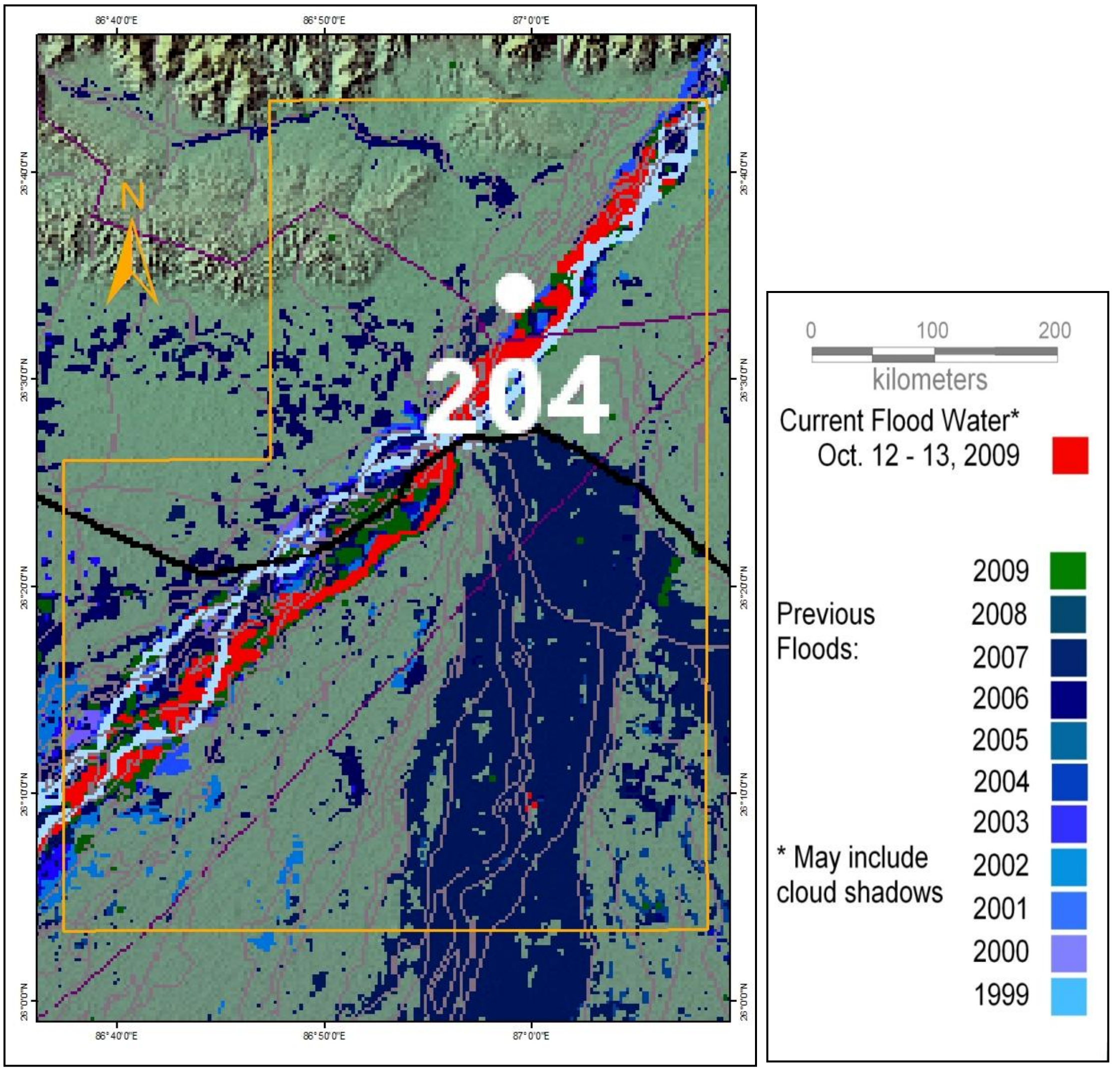


Figure 5.29: MODIS Dartmouth Flood Inundation Map

The Flood inundation map has been obtained from Darmouth Flood Observatory which is a Space-based Measurement and Modeling of Surface Water which is basically for research, humanitarian, and water Management Applications. The figure 5.29 shows the flood inundation map of the study area with gauge station 204 which falls within the study area. The flood inundation map depict the flood inundation from the year 1999 to 2009. This map has been used for the validation of the Flood risk map.

Table 5.16: Blocks with different Flood Risk Index

Flood Risk Index	Associated Blocks
Very High to High	Basantpur,Chattarpur, Narpatganj, Supaul,Deurmaniya, Ramangamakatti, Ko.Madhepura, Buarwa, Madahwapur, Portaha, Trikola, Baramjhiya, Dharampur, Harinagar, Gautampur, Lokahi.
Moderate to High	Narshinghatappu, Ramnagar butaha,Dhuskee, Kaptanganj,Sunsari, Pipra, Laukahi, Theliya, Dharampur, Rupnagar, Ordaha, Lohajara, Prasabani,Haripur,Singheshwar , Raghopur.
Moderate to Low	Mahendranagar, Prakashpur, Singhiya, Bakdhanwa, Sunderpur, Jogidaha, Hadiya, Jandaul, Mahadeva, Bhagwatpur, Dadha, Koiladi, Pratapganj, Singheshwar, Kishanpur, Haripur, Narshingatappu, Gautampur, Ramnagar, Inarwa,Sunsari, Jalpapur, Dhuskee, Kaptanganj, Ordaha, Rupnagar, Dharampur, Kanchanpur, Lohajara, Bhagwatpur, Prasabani, Mahadeva, Bathnaha, Koiladi, Dadha, Bhagwatpur, Mainkuder, Sripurjabdi, paschim Kusaha, Madhepura,
Low to Very Low	Kishanpur, Saraigarh-Baptiyahi, Nirmali, Lalapati, Chinnamasta, Sankarpura, Rampuramthaniya, Basain (Ko), Joginiya-1, Joginiya-2, Badgama, Dhodhanpur, Dharampur,Madhuban

Chapter 6

Discussion

For the study of risk analysis 89 blocks including both Nepal and Bihar (India) have been analyzed with the total area of 3286 sq.km. The final risk map was generated with the multiplication of both maps (Hazard *vulnerability). Here each parameter have been assigned different weightage factors using Saaty 9 point scale to define the relative importance, which decides the dominance of the factors over the other. The final risk map is represented with the graduated color map which was further categorize to assign the values to each block using histogram into different Flood risk Index range.

From the analysis it has been investigated that due to the change in the river dynamics, there is change in the geomorphology of the area, the formation of vast stretch of sand sheets and swamps and marches, rejuvenation of palaeochannels, formation of flood plains along the new channels, formation of channel bars due to high sedimentation load which has been marked out during field visit. The vast stretch of sand sheets has turn agricultural land into barren land of no use as the thickness of the sand deposition is very deep.

The risk map in general depicts the environment form, the concern and the vulnerability of the population in the area that is prone to the hazard; hence the risk map takes into account the population, the areas of human activities like towns and settlements, roads river linkage, the cultivated areas, that are delimited and arranged into order of importance for the management priority.

The final flood risk map obtained by the integration of the different thematic layers in GIS environment has been validated with the MODIS Dartmouth flood inundation map (Figure 5.17) of October12-13, 2009 for the study area. This inundation map showing flooded areas from period 1999 to 2009, which has been serving as the latest information source for the validation of the map. When risk map is compared with the flood inundation map of 2009, the areas which fall in the category of high to very high risk index are the regions coincide with the areas that was inundated during flooding.It supports the fact that the avulsion zone falls within these blocks, and risk in those areas are due to the high population density ie.1483 – 2043 persons /sq.km. These blocks are also fed up by high rainfall which ranges from 1608 mm yr to 2433 mm/yr, low slope angle, nearness to the active channels. Some of the bocks include Chatarpur, Basantpur, Tribeniganj and Narpatganj where there is high FHI and High FVI.

The block of Raghopur, Singheshwar, Pipra and Madhepura (India), fall in the moderate risk zone although they are not showing any inundation as verified from the MODIS inundation map, has attributed to high degree of road river intersections of small channels which cause backwater logging and poor drainage condition. Low slope along with the marshes and swamps as derived in the geomorphology map from satellite image of LISS-4 makes the condition more worst.

As from the comparison of generated risk map and the MODIS flood inundation map most of the blocks which are more vulnerable to risk lies in the Bihar region with high to moderate risk zone as compared to Nepal due to Kosi river flooding.

Some of the blocks of Nepal and Bihar which represents moderate risk index zone which has been attributed to either high to moderate hazard index and low vulnerability index such as those of Narshinghatappu, Babiya,Dhuskee Inarwa, Supaul ,Prakashpur have high FHI which indiacte the area to be inundated by and low FVI, or vice versa,

The blocks such as Pipra, Saraigarh baptiyahi, Kishanpur, Nirmali, Lalapati, show low to moderate FRI but have high flood hazard index whereas the vulnerability to life and property is low.

The risk map generated is not just on the basis of inundation data but it is the result of integration of several parameters which consider geomorphology, distance to active channels, slope,and rainfall. It is not simply a hydrological approach but an integrated approach in GIS environment and at the same time vulnerability map depictsall the possible consequences of the floods on the population and society, Therefore comprenehensive study on vulnerability requires the information about the suceptibility of different elements at risk like population density, LULC, and RI/RD intersection density .

Chapter 7

Summary and Conclusions

The Risk analysis conducted in this thesis is based on an efficient methodology with an objective to delineate the flood hazard areas, flood vulnerability area, and finally produced the combined risk areas in the upper Kosi River Basin. The risk analysis of the study area represents an exploratory methodology based on morphological, topographical, demographical data which can be ultimately used for the delineation of the risk areas affected by the different parameters like population, Slope, Rainfall, Land-use. This analysis has finally focused on the identification of the factors that controls the flood hazard and vulnerability in the study area. It is accomplished by the AHP technique with the GIS based overlay analysis. The application of this methodology is not restricted to Kosi river but can be applied to any river reach.

A combination of different data sets such as remote sensing images (Liss–IV, Landsat–7), population data (LANDSCAN GLOBAL), topographic maps (Survey of India, Texas Library), block boundary maps available from different regional centers. Digital Elevation Model (SRTM) have been used to identify the final risk areas the upper parts of Kosi Basin including some parts of Nepal.

Geomorphic mapping for different time period was carried out with the aid of satellite / remote sensing images for Prior and Post Avulsion Period to understand the evolution of the landforms in the Alluvial fan and predict the connectivity of the paleochannels. The different geomorphic units namely active channel belt, active flood plains inactive flood plain, minor active channel deposits, channel bar deposits, and the fan surface. An additional a very distinctive avulsion channel and avulsion deposit has been mapped in, the post avulsion image of Liss–IV image covering a large part of the Fan surface.

The decision factors identified are rainfall, population Density, distance to active channel, landuse land cover, slope of the area, geomorphic features. Thematic maps were prepared using several image processing techniques and GIS operation at different scale. Each of the thematic layers (Classified data sets) were brought to same scale.

Analytical Hierarchy Process (AHP) is multi criteria decision making techniques which provide a systematic approach for assessing and integrating the impacts of various parameters, involving several level of dependent and independent, qualitative as well as quantitative information. The weightage has been assigned taking into the consideration the flood hazard and vulnerability potential of the area, which ultimately lead to the risk zonation. Using ARC-GIS model builder, Overlay analysis of all the thematic layers was carried out to generate separate Flood hazard Map, Flood Vulnerability map and their combination to produce final risk map. The point to be considered during overlay analysis is that all the thematic layers should have discrete values rather than continuous values for assigning weightage. The format of the thematic layers should be in GRID to suit the current framework of AHP analysis.

The AHP analysis and flood hazard map were validated with MODIS Flood inundation Map of August 18, 2008. The results are satisfactory and it validates the logic followed in the analysis and the model developed. It has been observed that in Hazard map the dominant factor is rainfall followed by geomorphology, slope, and distance to active channel, which ultimately contribute to the flooding of the study area. Many of the areas are showing water logging and filled up quickly by water. Population density is contributing factor to the vulnerability of the area followed by the landuse landcover, and road river intersection. Hence, the final risk map generated by combining all the dominant factors as well as the contributing factors to flood risk.

Thus, it has been concluded that the approach used in this thesis is very much useful in delineating the flood hazard map, the flood vulnerability map and ultimately to the flood risk map in the Upper Kosi basin. Some of the important conclusions drawn as follow:

a. Remote sensing based geomorphic mapping approach of the study area for the pre and post avulsion images have brought on some interesting changes in the landscape in consequences with the large avulsion belt within the fan surface recognized by widespread sand deposition.
b. Many of the paleochannels on the fan surface have been reactivated after avulsion and due to its longitudinal connectivity it has become the main conduit for the movement of water to the main Ganga river.
c. The Flood risk map has been generated from the public domain data with the use of satellite imagery in a cost effective way. The approach followed can be applied in

many of the flood prone area where availability of the data is poor and resources are limited. Use of high-resolution data and DEM will increase the efficiency of the model.

d. The use of spatial –AHP has been used in the flood hazard mapping and it has been further elaborated with other datasets to generate risk map with more precision.
e. The flood risk map is based on the integrated effect of different parameters and not just based on few years of inundation data. Hence it is not only the hydrological phenomenon but integrated response of the basin. It has been observed that some of the areas are not inundated but still have high risk due to the population factor.
f. Flood risk map has been classified on the basis on the dominance of the different factors and risk is evaluated, it has considered the population and the landuse landcover as priority as these are more important while considering the risk of the area.
g. The approach followed can be applied at any scale depending on the availability of the data. For, instance block level risk map can be generated. The basic merit of the map lies on the user friendliness, the cost effectiveness and the easily availability of the maps.

The work presented can be further improved for accuracy and visualization and can be extended along the following lines:

a) Use of high resolution DEM data, will improve the accuracy of the model and to generate inundation map with high accuracy.
b) Use of high resolution rainfall data for the analysis will predict more accuracy in hazard assessment.

7.1 Flood risk management strategies

Flood risk management is the part of all the social and environmental processes aimed at minimizing loss of life, injury and material damage. There is no strategy that is optimal for any situation. The aim of the management should be, to mitigate the flood damage rather than prevention which will vary with the social system that is being managed. In response to the information, management strategies are aimed at interaction between the individuals, society, the organization and the environment which should be linked with the input of data sources to define the output.

The study area is not a typical flood affected area as it has been affected by breaching of the Kosi river at Kusaha. The best management strategies that required by the management planners and the government to mitigate the associated risk is both structural and non-structural measures. Since the Kusaha breach was an embankment failure, there should be probabilistic analyses on the flood events and flood level predictions in the past years and the desired level should be chosen so that it can control major flooding. Better understanding of the river hydraulics and hydrology of the River and their associated watershed lead to improved flood management strategies. One of the major weaknesses of this strategy always remains is that it is not known which areas will be flooded first as all areas are protected to the same level and therefore large areas need to be evacuated during flood events. There is a need for producing reliable risk maps indicating the probable risk zones which could help the strategy planners to get action during future floodings. Due to changes in land use in the river catchment and changes in climates, the strategy constantly needs for improvement to implement flood protection works, which usually constrains the river in a more rigid way and limits the natural dynamics of a river.

In recent years there is more focus on minimizing the consequences of floodings, which is another way to reduce flood risks. Strategies based on learning to live with floods and impact minimization by the application of differential flood risks and adapting land use are known as“resilience flood risk management” strategies (M. Vis et al, 2003).

Resilience flood risk strategies include the applications of early flood warning systems and evacuation plans, differentiated safety standards for different land uses, spatial planning including acceptance of floodings in less valuable areas, measures to improve recovery after floodings, damage compensation plans and insurances, etc… Resilience flood risk management is based on the acceptance that different areas need different levels of protection and that it is better to know where floods take place first during extreme events in order to limit flood damage and generally improve the safety of all people and properties in the flood prone areas (Kersting, 2006).

Flood maps are often perceived as static, the situation shown on the maps are conditional and are often based on certain events and assumptions. For example. the condition of a region in minor flooding and major flooding of the non rainy scenario or rainy condition will lead to the change in the scenario. Therefore the maps should be updated so that it can include the dyanamic behaviour of the floods.

The knowledge of the research has to be communicated to the enduser which means that there by the landuse planners, the stake holders, the emergency planners have to be involved in this process so that the idea of approach can reach upto the base level, the community itself can develop the map with the possible flood areas, evacuation routes, disaster related facilities, so that they will be able to develop the better understanding of the risk and be able to discuss the and make proper mitigation strategies.

Cross border mapping (this is the concept followed by most of the European countries) within the same country with different approaches and concepts can be used by the decision makers, government and public are confronted .This harmonised concept are of particular importance considering the validation of the maps. This will allow to compare the flood risk developed by different methods giving a broad view. It will give more confidence to the validation to those areas where sufficient calibration is not possible.

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