GEO-HYDROLOGICAL APPROACH FOR FLOOD HAZARD ASSESSMENT IN KOSI PIEDMONT ZONE

A dissertation submitted in partial fulfillment for
the requirement to award the Degree of

MASTER OF TECHNOLOGY

IN

HYDRAULICS AND WATER RESOURCES ENGINEERING

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August,2016

CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled **"Geo-Hydrological approach for flood hazard assessment in Kosi Piedmont Zone**" in the partial fulfillment of the requirements for the award of the degree of "Master of Technology" in "Hydraulics & Water Resources Engineering" submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of my own work carried out from January 2016 to July 2016 under the supervision of Dr. Rakesh Kumar (Professor), Department of Civil Engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

Sneha Bisht

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CERTIFICATE

This is to certify that above statement made by the candidate is correct to best of my knowledge.

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ACKNOWLEDGEMENT

I take this opportunity to express my profound gratitude and deep regards to Dr. Rakesh Kumar (Professor, Civil Engineering Department, DTU) for his exemplary guidance, monitoring and constant encouragement throughout the course of this project work. The blessing, help and guidance given by him from time to time shall carry me a long way in life on which I am going to embark.

I would also like to thank Dr. Nirendra Dev (Head of Department, Civil Engineering Department, DTU) for extending his support and guidance.

Professors and faculties of the Department of Civil Engineering, DTU, have always extended their full co-operation and help. They have been kind enough to give their opinions on the project manner and therefore I am deeply obliged to them. They have been a source of encouragement and have continuously been supporting me with their knowledge base, during the study.

Several of well-wishers extended their help to me directly or indirectly and I am grateful to all of them without whom it would have been impossible for me to carry on my work.

ABSTRACT

Kumaun Himalayan Kosi Piedmont Zone in district Nainital, Uttarakhand (India) is highly vulnerable for flood disaster due to dynamic upstream hydrological processes and its associated reshaped downstream foothill piedmont geomorphology. Rapid urbanization and land use degradation has been accumulating the vulnerability and risks of flood disaster in the region. Key objective of the study was to investigate spatial variability of flood hazard of the region through the development and integration of multiple geo-hydrological modules considering geo-structural setup, relief, climate, land use pattern, geomorphology and consequent spring hydrology and drainage hydrology. Results advocates that most of the densely populated (2610-9440 person/km^2) areas are under high to extremely high flood hazard zones which need an effective disaster risk reduction (DRR) program implementing several engineering and biological measures as recommended in the study.

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INTRODUCTION

1.1 General

Flood is one of the most numerous natural disasters in the planet; their frequency, magnitude and the cost of environmental and socioeconomic losses are on the rise throughout the world. It is a natural event or occurrence where a particular area of the earth's surface that is usually dry land, suddenly gets submerged under water and caused for several socioeconomic and environmental losses such as deforestation, land degradation, slope failure, landslides, soil erosion, water pollution etc.. Jeb and Aggarwal, 2008 define "Flooding is temporarily a state of partial or fully inundation of normally dry regions from spillover of inland or tidal waters or from the uncommon and rapid accumulation or runoff". The international disaster database (EM-DAT) centre reported that across the world, out of total annual natural disaster events, maximum 45% are flooding disaster events, whereas remaining 55% comprises of storm (23%), earthquake (14%), epidemic (8%), extreme temperature (6%), drought (3%) and wild fire (1%). Consequently, each year floods caused the death of about 60000 people and affect more than 30000000 people in the world by losing their families, homes, and livelihoods. Beside that flood devastates expensive socioeconomic development and infrastructure such as buildings, streets, canal, power, communication network, land, forest and other natural assets which account an expense of above 6000000 US dollar (Table 1.1). This quivering picture and vast scale losses of the flood disasters motivates to know its key causes.

1.2 Causes of flood disasters

There are different causes of flood disaster which can be categorized broadly as following:

1.2.1 Meteorological causes : Local meteorological dynamics and worldwide climate changes sways brought on to quicken intense rainfall events as cloudburst rainfall (CRF), extreme rainfall events (ERF) resulted in flood disasters. A cloudburst rainfall (CRF) is an extreme amount of precipitation, at times accompanied by hail and thunder that normally endures no more than a couple of minutes, yet is equipped for making flood conditions (Bull, 1964; Dewey and Bird, 1970). Cloudburst is actually a circumstance when the forces between the H_2O molecules get very high because of the quick diminishing in the temperature or overabundance of electrostatic impelling in the clouds producing the lighting to stay inside the cloud only, resulting in hyperactive power inside the cloud (Hooke and Rohrer, 1977). Due to abundance of electroforces, the water molecules do not leave the cloud even though being got denser and condensed. As the concentration of water gets increasingly higher and thus the weight gets heavier the water becomes unable to maintain force with the clouds, thus they fall and it hastens.

1.2.2 Hydrological causes : There are several causes of flood disaster in glacial and non-glacial hydrological system. In non-glacial system flood occurs because of instant surface runoff (ISR) under infertile area and hard rock regions. On the other hand in case of glacial hydrological system rapid snowmelt (RSM) is discovered as real reason of flood disaster for downstream river basin.

1.2.3 Geomorphological causes : Landform development and dynamics due to active tectonics and geo-hydrological process are categorized as geomorphological causes of flood disasters, for example, failure of hydraulic structures, glacial lake outburst (GLO), landslide dam outburst (LDO) (Hamilton, 1987; Jain et al., 1994; Jonkman, 2005).

1.2.4 Socioeconomic causes : At times small and normal flood events resultant to disaster due to socioeconomic causes such as Land use degradation (LUD), Rapid Unplanned urbanization (RUU), high population density (HPD). LUD refers to unscientific land use practices and increased built-up area and human settlements because of rapid unplanned urbanization (RUU) on exceptionally vulnerable fluvial geomorphic landforms (i.e. flood plain, river banks, low level river terraces, fluvial fans and piedmont zone etc.) resultant to high population density and consequent flood hazard risk during flood events (Valdiya and Bartarya, 1991; Valdiya, 2003).

1.3 Types of flood disasters

Mainly three types of flood are common across the world. These are river line flood, flash flood and coastal flood. Each type of flood and its characteristics has been discussed below:

1.3.1 River Line flood : It refers to undermining in the sides of valley causing instability in the bottom side of the mountains resulting in slope instability and catastrophe such as landslide. These wreck the infrastructures and natural assets especially woods, area and water. At times of river line floods, river bank erosion occurs in an enormous amount and the harvests and fertile land even get washed away. Although, sediments get stored over fields and encampments especially amid rainy season. EM-DAT records suggest that about 56% flood events are river line floods in the world which caused for more than 38000 human deaths (64% of all floods) and more than 4500000 US dollar economic losses (76% of all floods) each year while about 20000000 people (69% of all floods) affected badly (Table 1.1 and Fig. 1.1).

Fig 1.1 River Line Flood

(Source: www.icimod.org)

1.3.2 Flash flood : Flash flood accounts about 13% of total annual flood events across the world. Such type of flood events caused more than 500 human deaths (1% of all floods) and more than 500000 US dollar economic losses (9% of all floods) each year whereas about 1500000 people (5% of all floods) are affected badly (Table 1.1 and Fig. 1.2). Such floods cause extraordinary misfortune to existence and belongings as it is a standout amongst the highly destructive catastrophe because it suddenly occurs and provide less time for warning and mitigation measures that can be taken. Consequently, it results in sediment transport at an enormous and alarming rate. It also impacts the process of progressive measures which have extreme monetary and social outcomes (Brivio et al., 2002; Rawat et al., 2012c).

Fig.1.2 Flash flood

(Source: www.icimod.org)

Table 1.1: Analysis of flood disasters during 1901-2016 through EM-DAT database.

Types of Flood Disasters	Data Period	Events		Human deaths		People affected		Economic loss	
		In No.	In %	In No.	In %	In No.	In %	US $	In %
River line flood	1901-2016	2573	56	4444465	64	2520022788	69	532079215	76
	Annual	22	56	38314	64	21724334	69	4586890	76
Flash flood	1901-2016	581	13	65733	1	173391084	5	59897436	9
	Annual	5	13	567	1	1494751	5	516357	9
Coastal flood	1901-2016	85	2	5352	<1	21334939	1	10322976	1
	Annual	1	2	46	<1	183922	1	88991	1
Unclassified Flood	1901-2016	1353	29	2434337	35	920670630	24	95626072	14
	Annual	12	29	20986	35	7936816	25	824363	14
Total	1901-2016	4592	100	6949887		3635419441	100	697925699	100
	Annual	40	100	59913	100	31339823	100	6016601	100

1.3.3 Coastal flood: When seawater overflows over dry and low-lying land, coastal flooding occurs. The degree of such flooding is restrained by the geology of the coastal region subjected to flooding. There are three key causes that have been identified for the coastal flood. These are sea level rise, tsunami waves and storm surges. Coastal flood accounts about 2% of total annual flood events across the world. Such type of flood events caused more than 40 human deaths (<1% of all floods) and about 900000 US dollar economic losses (1% of all floods) each year while about 150000 people (1% of all floods) are affected badly (Table 1.1 and Fig. 1.3).

Fig.1.3 Coastal Flood

(Source: U.S.Geological Survey)

1.4 Spatial distribution of flood disaster

Further, flood disaster records of the international disaster database (EM-DAT) centre were analyzed to appraise the spatial distribution of flood disasters. Spatial distribution of flood disaster events globally varies maximum for Asia (41%) and Americas (23%) to minimum for Australia (3%) whereas Europe and Africa accounts about 13% and 19% flood events respectively.

South East Asia region recorded for the highest socioeconomic and environmental losses of flood disasters as compared to other continents. In this region each year flood caused more than 58000 human death (97% of world) and more than 3600000 US dollar economic losses (70% of world) while about 30000000 people (95% of world) are affected badly (Table 1.2). Various studies advocate that the South East Asia region is highly vulnerable for flood disasters due to increasing population, rapid urbanization, climatic conditions, active geo-tectonics, varied hydrological systems, asymmetrical relief pattern and its reshaped geomorphology (Valdiya and Bartarya, 1989; Singh, 2006). The data clearly shows that the hazard risk and losses varies in respect to geo-ecological and socioeconomic vulnerability of the flood affected regions.

Table 1.2: Analysis of global distribution of flood disasters during 1901-2016 through EM-DAT database.

Continents	Data Period	Flood Events		Human deaths		People affected		Economic loss	
		In No.	In %	In No.	In %	In No.	In %	US $	In %
Asia	1900-2016	1898	41.33	6807804	97.96	3454438385	95.02	424325473	60.80
	Annual	16	41.33	58688	97.96	29779641	95.02	3657978	60.80
Africa	1900-2016	918	19.99	27296	0.39	71744227	1.97	7999723	1.15
	Annual	8	19.99	235	0.39	618485	1.97	68963	1.15
Americas	1900-2016	1063	23.15	104902	1.51	91334523	2.51	113113442	16.21
	Annual	9	23.15	904	1.51	787367	2.51	975116	16.21
Europe	1900-2016	575	12.52	9323	0.13	16621163	0.46	137314686	19.67
	Annual	5	12.52	80	0.13	143286	0.46	1183747	19.67
Australia	1900-2016	138	3.01	562	0.01	1281143	0.04	15172375	2.17
	Annual	1	3.01	5	0.01	11044	0.04	130796	2.17
Total	1900-2016	4592	100.00	6949887	100.00	3635419441	100.00	697925699	100.00
	Annual	40	100.00	59913	100.00	31339823	100.00	6016601	100.00

1.4.1 Geo-ecological vulnerability : It assigns the condition or response of various sorts of geo-ecological factors to flood hazard (Nakata, 1972; Valdiya, 2003; Valdiya, et al., 1991; Goswami and Pant 2008). Frazzled attributes of a factor increased its susceptibility for flood disaster. These geo-ecological factors are:

- Geological and geostructural background.
- Different types of geomorphology
- Relief pattern
- Drainage pattern
- Climate
- Vegetation
- Land use and cover pattern
- Hydrological system

1.4.2 Socio-economic vulnerability : It deals with the social, economic and demographic factors that affect the resilience of communities for flood disaster (Frostick and Reid, 1989; Ferrill et al., 1996). In other words, it alludes to the inability of individuals, organizations, and societies to withstand unfavourable effects from multiple stresses to which they are revealed. These socioeconomic factors which are revealed during flood conditions are:

i. Infrastructural development
    - Road networks
    - Human settlements
    - Community buildings
    - Industries
    - Canals
    - Communication network
    - Water lines
    - Electricity

ii. Demographic structure
    - By gender
    - By different age groups
    - By literacy
    - By man power (occupations)
    - Handicapped

iii. Population density

iv. Land utilization

v. Natural resources

1.5 Background and Motivation

Presently it has been revealed from various studies that the flood disaster alludes to major losses to economy, society and surroundings. The key factor on which occurrence and extent of flood disaster rely on the susceptibility to losses caused by a particular flood event to the landscape (Rawat et al., 2011). Thus the possibility of risk of hazard either qualitatively or quantitatively can be ascertained by the magnitude of the respective hazard and its susceptibility to losses. Dynamics of hazard risk can be signified by the changes that occur in risk potential over a day and age (Rawat, 2014; Rawat et al., 2011). It has been recommended by EM-DAT that about 79% flood hazard occurs in Himalayan and its trans-boundaries countries in South East Asia. As we know that most part of the Himalaya is extremely stressed to natural disaster, but its foothill piedmont zone is prone to frequent natural hazards such as floods, landslides, erosion, etc. especially during monsoon due to various factors such as geology, geomorphology, and climatic situations (Bull, 1964; Dewey and Bird, 1970; Hooke and Rohrer 1977; Rawat et al., 2012a, 2012b). Close to that rapid growth, changes in land use practices and exploitation of assets increases the risk of flood disaster in the region. Considering all these factors, it necessitates a comprehensive study on flood disaster for the fast urbanized Himalayan foothill piedmont zone so that an effective, productive and successful plan can be executed at local level on a scale of 1:25000.

1.6 Study Area

The densely populated (500-6000 persons/km^2) foothill piedmont zone is characterised by change in land use pattern, flood hazard conditions, decrease in river discharge during non rainy season, river bed silting etc. (Thakur, 2004; Nearing et al., 2005). Hence, the foothill piedmont zone is found to be extremely vulnerable for various environmental and socioeconomic problems. The Kosi Himalayan Foothill piedmont zone in district Nainital, Uttarakhand (India) has been selected for the case illustration. The area of foothill zone is nearly 64.82 km^2 and altitude is between 300m and 505m above mean sea level. The study area lies in between latitude 29°20'41"N to 29°25'32"N and longitude 79°05'53"E to 79°09'48"E (Fig. 1.4). The climatic conditions shows variation throughout the study area. In the lower altitudes tropical climatic conditions exist, whereas sub temperate climatic conditions exists in the higher elevations of the study area. Subsequently average temperature shows the variation between less than 20^{O}C to more than 24 ^{O}C within sub-temperate and tropical climatic zones respectively. The average precipitation varies below 180 cm to 220 cm. The study area consists of rapidly urbanizing Himalaya foothill Ramnagar Municipal Town (RMT). In the past 30 years, RMPTA has undergone through urbanization in the villages resulting in the surroundings to experience various environmental changes. This town is located at the right bank of the River Kosi that itself is a non-glacial river of ninth order. This has a catchment area of about 738 km^2. During monsoon season it brings tremendous amount of water and sediment load. The geo-structural and hydrological background of the research work seems to be extremely stressed for several catastrophes such as floods, landslides, erosion and earthquake, etc..

Fig 1.4 Location map of the study area

1.7 Objectives of the Thesis

The objective of the present work is assessment of spatial variability of flood hazard in rapidly urbanizing Uttarakhand Himalaya foothill piedmont zone. In order to attain this objective the following works have been carried out:

i. Geo-environmental appraisal
   a. Geo-structural mapping (geology and lineaments)
   b. Land use and urban growth Mapping
   c. Climate zone mapping
   d. Vegetation mapping
   e. Demographic analysis

ii. Geomorphological investigations
   a. Interpretation of geomorphic features on satellite images
   b. Tectonic and fluvial landform mapping

iii. Hydrological investigations of master streams and watersheds
   a. Drainage morphometric analysis
   b. Drainage hydrology and watershed monitoring under varied geo-ecosystem
   c. Monthly, seasonal and annual stream hydrograph analysis

iv. Geo-hydrological appraisal of the natural springs
   a. Spring distribution and density
   b. Indentify the geomorphological controls on spring formation
   c. Indentify the geomorphological and rainfall controls on spring discharge
   d. Monthly, seasonal and annual srping hydrograph analysis

v. GIS overlay operation and data integration for flood susceptibility mapping

vi. Spatial variability mapping of flood hazard

vii. Recommendations and proposal of flood disaster risk reduction (DRR) plan

1.8 Organization of the Thesis

The present work has been divided into five chapters as follows:

Chapter 1: Introduction - This chapter introduces with the concept, study area and objective of the thesis.

Chapter 2: Literature Review - This chapter summarizes a comprehensive literature review on flood disaster, geo-environmental, hydrological and geomorphological control which affects the flood frequency and magnitude.

Chapter 3: Methodology and Data used - This chapter discusses about data used and the adopted methodologies for the research work carried out.

Chapter 4: Results - This chapter deals with the detailed analysis, appraisal, monitoring and mapping of natural hazards and evaluation of their risks. It comprises of comprehensive and key results of the thesis.

Chapter 5: Disscussion and Recommendation - This chapter presents discussion of flood prone areas and recommendations drawn from the study.

Chapter 6: Summary and Conclusion – This chapter presents an overview and summarizes the conclusion drawn from the study.

CHAPTER-2

LITERATURE REVIEW

Across the world a rich number of studies have been carried out in flood hazard with different approaches. Broadly these studies can be categorized in two groups: first, considers flood hazard as a hydro-meteorological process whereas second, advocates geomorphology controls the frequency and intensity of the flood hazards. Both perspectives are discussed below:

2.1 Hydro-meteorological perspective of flood hazard

The hydro-meteorological perspective comprises of geo-ecological and climatic factors of flood hazard.

2.1.1 Geo-ecological factors: Geo-ecology is an important component to carry out hydrological processes through various types of soils, land use pattern, geology, water springs, drainage density and drainage pattern (Rawat et al., 2012b). Degradration in geo-ecology raises evapotranspiration, groundwater and runoff discharging into stream networks which output as floods in the downstream floodplain areas. It has been revealed through various studies that stream hydrology gets impacted as well as early peak and high extent storm hydrographs get developed with an expansion in a watershed's measure of closed surface. (Nearing et al., 2005).

2.1.2 Climatic factors: Rainfall and consequently surface runoff shows variation according to different climatic situations but act as an input for the flood hazard (Dooge et al. 1999; Chen et al. 2007). Close to that there are various factors which cause change in climatic conditions such as rise in temperature, melting of glaciers, cloudburst, snowfall, rainfall etc. resultant in flood hazards (Rawat 2014). According to IPCC, 2014 reports it has been investigated that homogeneous changes were detected in the South East Asia and the North American sub-continents for accelerated precipitation and flood events, even though the changes were global. With the help of investigations made in 2004 it is anticipated that an increase of $1^{o}C$ in the global mean temperature would result in the expansion of runoff by 4%

globally. Adams et al. 1998 analysed that the surroundings, monetary and society are highly influenced by the climate changing factors such as rise in temperature and sea level, flood and precipitation extremes, etc..

In the present century, floods caused due to various climatic changing drivers poses serious risk to food production and agricultural society (Adams et al. 1998; Darwin and Kennedy 2000). Besides the advantageous prevalent land use pattern also gets affected due to reposition of the climate expanse towards higher elevations (Rawat et al., 2011).

2.2 Geomorphological perspective of flood hazard

According to Intergovernmental Panel on Climate Change (IPCC, 2012) the magnitude and rate of occurrence of flood disasters are highly influenced by global warming and hydro-meteorological situations whereas the response of socioeconomic loss is an output of irrelevant human intervention. Alcantara-Ayala, 2002 researched on the rate of occurrence of geo-hydrological disasters caused due to climate change for a span of about ten years (i.e. 1990-1999) and concluded that 84% of them accounts geomorphological disasters.

Due to recent increase in human and economic loss from natural calamities, the international science community have decided to take initiatives to forecast and alleviate future disasters. This initiative includes integrating sciences such as geomorphology into management and mitigation plans. Geomorphologists are researchers familiar with the magnitude and frequency ideology and have the ability to comprehend the extreme meteorological disasters that occur because of global climate change.

Disaster mitigation studies are naturally associative and geomorphological study can prove to be really helpful in most of this research area. Future hazard risks can be predicted and managed with the help of prediction models developed by conducted various geomorphic practices. For such models, it is necessary to comprehend geomorphological study that involves comprehensive morphometric analysis and land interpretation based on intensive field surveys and mapping.

2.2.1 Morphometric analysis: The consequencess of morphometric analysis refer to geo-structural stability of the study area. Methods of morphometric analysis are divided into two main groups based on unit of study. These methods are:

(i) geomorphic mapping method in which a grid is taken as a unit of analysis (Smith 1953);

(ii) drainage basin method in which a catchment is considered as unit of analysis (Horton, 1945).

Grid method was used for the analysis of relief and drainage morphometric parameters such as absolute relief, relative relief, average slope, drainage density, and stream frequency. Drainage basin method was developed for the interpretation of different types of landforms, slope-aspect, and stream order and bifurcation ratio.

2.2.2 Landform mapping: Geomorphological mapping is an important tool to comprehend earth surface processes, geology, natural assets and hazards, and landform development (Blaszczynski, 1997). The morphometric study of landform was introduced firstly by Horton in 1932 and application of quantitative methods were made for the morphological study of landforms. The morphometric study of landforms was further developed by Strahler (1952, 1956, 1957, 1958, 1964, and 1971), Schumm (1956, 1973), Chorely (1957), Melton (1958, 1959 and 1965), Morisawa (1958, 1967), Leopold et al. (1964), Scheidegger (1965), Shreve (1967), Gregory and Walling (1968), Mathur and King (1971), Werritty and Verma (1972), Tondon (1974), Sandra and Bull (1975), Mark (1975) and many others.

Modifications in the mentioned methods have been framed out with the advancement in technology over the last few decades. The discipline of geomorphology has been transformed with the evolution in geospatial technologies, remote sensing and GIS. At present the digitized geomorphological maps are being more liable to assess flood hazard using GIS and remote sensing techniques (Tarolli et al., 2009).

Remote sensing and GIS techniques work as an important tool to create spatio-temporal data that allocate several subjects to be addressed. Geomorphological mapping concentrates on the use of imagery at different scales (Saadat et al., 2008; Schneevoigt et al., 2008). Geomorphologists also focusses on the scientific aspects for evolution of GIS databases (Gustavsson et al., 2008), geomorphological mapping software (Klingseisen et al., 2008), landform mapping and different methods for visualization of geomorphological data.

2.3 Floods in Himalaya and its foothill piedmont zone

Human made activities are constantly responsible for the degradation of the natural system of the Himalayan surroundings and affect the hydrological response of springs and rivers (Haigh et al., 1988). The most imperative issue of the Himalaya is variation in water discharge and tremendous measure of sediment load in rivers during various seasons of the year.

Preliminary survey carried out regarding the hydrological disparity in the area specified the inputs to be human intervention, uneffective development schemes and unorganized manner of infrastructure constructions, roads, etc.. Various researches (Hamilton, 1987; Haigh et al., 1988; Jain et al., 1994; Singh and Tandon, 2006) conducted for risk monitoring of flood hazard in Himalaya observed hardly two stimulating factors of flood. The outcomes provided are not accepted and agreed to as there is lack of technical basis because there are several factors that may resultant to flood and should be apprehended as well.

Geo-environmental appraisal is a key need to formulate a disaster management plan at local level or regional level as it provides comprehensive scientific guidelines for implementation of terrific and safe developmental activities existing in the prevalent geo-enviromental system considering geo-ecology, climate change and geomorphological process of the landform. Keeping this in view, the present study is carried out with developing a multidimensional GIS database on environmental geoinformatics of the rapidly urbanizing Kosi Himalaya foothills in district Nainital of Uttarakhand Himalaya. The environmental geo-database comprises of 14 flood controlling factors and their 70 sub factors pertaining to assessment of flood disaster and mitigation as discussed in the methodological section.

CHAPTER-3

METHODOLOGY AND DATA USED

The methodological procedures adopted for the present work is outlined in Figure 3.1 which reflects that the research work comprises of two main components: laboratory work, and field investigations at different stages using multiple data.

3.1 Data source

The multiple primary and secondary data used for the study are discussed below:

3.1.1 Primary data: The present work required primary data to accomplish the key objectives of the research work. It includes field surveys reports, geo-structural map (lineaments and geology), geomorphological map, land use/cover map, drainage hydrology data (comprises of drainage pattern, density,discharge pattern and runoff under varied geo-ecology), spring hydrology data (comprises of spatial distribution, density, geomorphological controls, discharge pattern).

3.1.2 Secondary data: Secondary data used in the study comprises of satellite images (LISS-III, PAN and Google Earth), toposheet (scale 1:25000), cadastral maps (scale 1:990), forest maps, district statistical handbooks, published research work (books, monograms, reports, articles, presentations etc.), and meteorological data (temperature and rainfall) monitored at number of observatories installed and running by different line departments of Uttarakhand state government.

3.2 Methods and Techniques

The methods and research techniques adopted step by step for different objectives of the study are:

3.2.1 Data collection and Geo-referencing : Indian Remote Sensing Satellite (IRS-1C), LISS III (23.50 m spatial resolution), PAN merged data of 2002 and Google earth data of 2015 were registered in indigenous GIS software (Arc GIS-10.2.2 and Erdas Imagine-14) using Topographical Sheets of Survey of India (53 O/3) of the area at scale 1:25000 to delineate multiple maps as required for the present work.

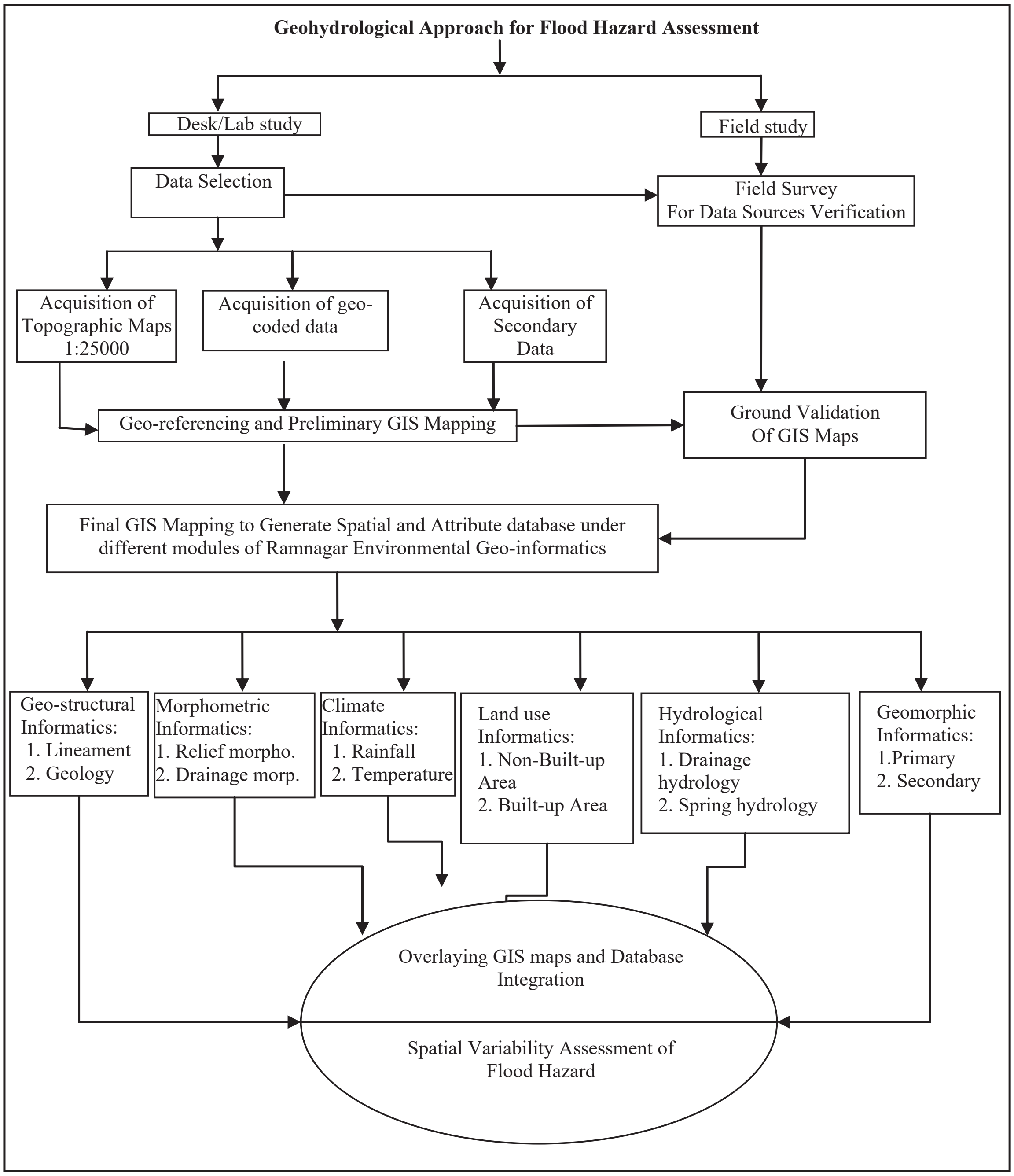


Fig. 3.1 : Flowchart showing the methodological procedure adopted for the study

3.2.2 Geo-environmental Assessment : Geo-enviromental assessment comprises of comprehensive study and geospatial mapping of geo-structural background (geology and lineaments), soils types, climate and consequent vegetation. Geo-sturctural mapping is performed by detailed field mapping and further conversion in digital maps using GIS software. For the assessment of climate in KPZ, we dealt with the study of spatial distribution of climatic parameters for a period of thirty years during 1986–2015 whereas vegetation denotes the spatial variability of different types of flora according to climatic conditions.

3.2.3 Relief morphometry analysis : Relief morphometry study consists of spatial distribution maps with their attribute data of different features. These are: Slope, absolute relief. These maps carried out through GIS mapping using multiple-dated Linear imaging Self Scanning-III (LISS – III) and Panchromatic (PAN) data of Indian Remote Sensing Satellite – 1C (IRS-1C) and Survey of India Topographical Sheets (scale 1:25000).

3.2.4 Drainage morphometry analysis : Drainage morphometry study consists of spatial distribution maps with their attribute data of different drainage factors. These are: drainage pattern, drainage density, stream types, stream order, stream number. These maps also carried out through GIS mapping using multiple-dated Linear imaging Self Scanning-III (LISS–III) and Panchromatic (PAN) data of Indian Remote Sensing Satellite – 1C (IRS-1C) and Survey of India Topographical Sheets (scale 1:25000).

3.2.5 Land use/cover mapping: Land use/cover is significant aspect of geo-environmental study (Hamilton, 1987; Haigh et al., 1988; Ives, 1989; Valdiya, and Bartarya, 1989, 1991). Land use/cover pattern of the present work are broadly classified as built up area and non-built up area, adopting digital and visual interpretation techniques (Bronstert et al., 2002; Legesse et al., 2003; Tomer et al, 2009).

3.2.6 Geomorphological mapping: The geomorphological analysis varies in definition from slope angle maps to maps containing different morphological features such as fluvial, tectonic and anthropogenic etc. (Horton, 1932; Strahler, 1971; Gregory and Walling, 1968). The geomorphic features or landforms of the present work are interpreted on satellite data and a preliminary geomorphological map is prepared (Blaszczynski, 1997). Consequently, during field mapping, some interpretation errors are observed. These are considered while mapping the final geomorphological map after overlaying other required GIS layers

(Gustavsson et al., 2008). These landforms are further classified under preliminary and secondary landforms.

3.2.7 Drainage hydrology monitoring: Stream hydrology constitutes upstream and downstream hydrological processes. Upstream hydrology carried out through representative watershed approach (Valdiya et al., 1989; Rawat et al., 2011, 2012). Total 5 watersheds (I to III order streams) selected to monitor flood discharge under natural to extremely stressed geo-ecology.

3.2.7.1 Flood discharge: It is peak discharge of the streams during rainy season. Float method is adopted in the present work to determine the flood velocity of stream along river's cross-section.

Rate of flood discharge is obtained by the following equation:

Stream discharge, Q = A * V (3.1)

Where

Q denotes stream discharge in cubic meter per second,

A denotes area of cross-section of the channel in square meter, and

V denotes velocity of stream discharge in meter per second.

The above defined method is used to measure the surface velocity. The concept is to evaluate the time taken by a floating object to cover a particular distance downstream.

$$V_{surface} = \frac{Distance\ travelled}{Time\ taken\ to\ travel\ that\ specified\ distance} = \frac{L}{t} \tag{3.2}$$

In order to determine the mean velocity, it is required to introduce a correction factor.

$$V_{mean} = k\, V_{surface} \tag{3.3}$$

Where k denotes a coefficient whose value generally range as follows:

In case of rough beds, the value of k is 0.8 .

In case of smooth beds , the value of k is 0.9 .

The most commonly used value is 0.85 .

Mean velocity is less in value as compared to the surface velocity.

3.2.7.2 Flood Runoff : It is calculated by the following equation:

$$Runoff = \frac{Discharge\ in\ liter\ per\ second}{Area\ in\ square\ kilometre} \qquad (3.4)$$

Flood Runoff has the unit of dimension [LT^{-1}].

3.2.7.3 Monitoring of Spring Hydrology : Spring hydrology consists of springs clasification, their spatial distribution, and density, geomorphological control on formation of springs and spring discharge. The research related to springs is carried out with the help of GIS and topographical sheets (scale 1:25000) and are later verified through field survey. In order to assess geo-structural control of springs in Kosi Piedmont Zone, superimposition of all GIS thematic maps of geo-ecology and geomorphology (i.e. geology, geomorphology, lineament, slope gradient and slope aspect, land use, drainage pattern etc.) over spatial distribution and density map is involved. The water discharge is monitored through representative sample spring approach because it is quite difficult to monitor water discharge data from each and every spring of the Himalayan terrain due to steep and rugged topography. Out of total 45 springs surveyed in the study region only 15 springs have been selected for intensive monitoring of water discharge. These springs are representative of all types of springs in the basin. Measurement of discharge depend upon nature of the springs (i.e. running spring or dhara and pond or seepage). Dhara discharge was measured using a measuring cylinder and stop watch and seepage discharge was measured using gravimetric method by following equations:

$$S_q = \frac{S_a * W_d}{T} * 1000 \qquad (3.5)$$

Where

S_q denotes discharge rate of running spring in liter per sec

S_a denotes surface area of running spring in square meter

W_d denotes depth of water filled during measurement in meter

T denotes time taken in sec to fill up the original water surface.

3.2.8 Data integration to assess spatial variability of flood hazard : Multiple spatial and attribute geo-database of Kosi Piedmont Zone are integrated and superimposed for identifying the vulnerability of existing geo-environmental factors and their sub factors for the flood hazards with the help of Scalogram modeling approach. It involves combination of all GIS modules; these are geo-structural setup (comprises of geology and structural lineaments), relief pattern (comprises of slope and absolute relief), climate (comprises of rainfall, temperature), land use pattern (comprises of built and non-built pattern), hydrology (comprises of drainage order, drainage pattern, drainage density and flood runoff), geomorphology (comprises of tectonic geomorphology and fluvial geomorphology). In Scalogram modeling approach (After Cruz, 1992, Rawat, 2012a, 2012b, 2012c), the important geo-factors and their sub-factors are assigned some numerical weights values. These assigned values in combination with an arithmetic operation helps in resulting a score that includes attributes.

For the preparation of Flood Hazard Index (FHI) of Kosi Piedmont Zone :

Step 1: Assigning weightage to each of 14 major geo-factors.

Step 2: Transformation of flood hazard controlling factors into weight maps by Step 1.

Step 3: Each of 14 main factors is further sub-divided into five sub-factors which already is assigned with weightage 1,2,3,4,5.

Step 4: Use of Scalogram model for flood hazard zone assessment (After Cruz, 1992, Rawat, 2012a, 2012b, 2012c) by the following operation:

$$\text{FHI (Score)} = [X1\,(An) + X2\,(An) + X3\,(An) + X4\,(An) + X5\,(An) + X6\,(An) + X7\,(An) + X8\,(An) + X9\,(An) + X10\,(An) + X11\,(An) + X12\,(An) + X13\,(An) + X14\,(An)] \quad (3.6)$$

Where;

FHI is Flood Hazard Index

X1, X2, X3, X4, X5, X6, X7, X8, X9, X10, X11, X12, X13 and X14 are major factors respectively geology, structural lineaments, relief, slope, geomorphology, land use, climate, rainfall, drainage order, drainage pattern, drainage density, flood runoff, spring density and spring discharge.

‘An’ is total weight score (such as 1+2+3+4+5=15) of existing sub-factors (respectively A1, A2, A3, A4, A5) of an individual main factor.

The assigned weights to the sub-factors are variable and can be decided experimentally or through field experience for the study region. The assigned weights indicate: 1 for very low, 2 for low, 3 for moderate, 4 for high and the final 5 for very high to extreme flood causative factors.

Finally, FHI (Score) was determined for each grid of area 0.25 km^2 and a spatial distribution map of flood hazard is prepared. This integrated weight values ranged from 14-70 throughout Kosi Piedmont Zone and have been grouped into five zones: i.e. very low (below 15), low (15-30), moderate (30-45), high (45-60) and very high flood hazard susceptibility zone (above 60).

CHAPTER-4

RESULTS

In order to study the spatial variability of Flood Hazard in the Kosi Piedmont Zone, there are total 14 major flood catastrophe triggering geo-factors and corresponding 70 sub factors have been identified through comprehensive study of six geo-hydrological sections of the study area. These are:

4.1 Geo-structural Setup

Geo-structural investigation includes a comprehensive GIS mapping for geological units and corresponding lineaments so that spatial and attribute database can be developed.

4.1.1 Lineament: Topographic lineaments are linear appearance in earth surface. Usually these are geophysical (comprises of thrusts or faults subsequent valley, structural fault succession, fold and fault aligned geomorphology etc.) and linear infrastructural components (comprises of road networks, canals, railway lines etc.). Fig. 4.1 depicts that the lineaments are generally towards SW direction from NE direction and SE direction from NW direction throughout the study area.

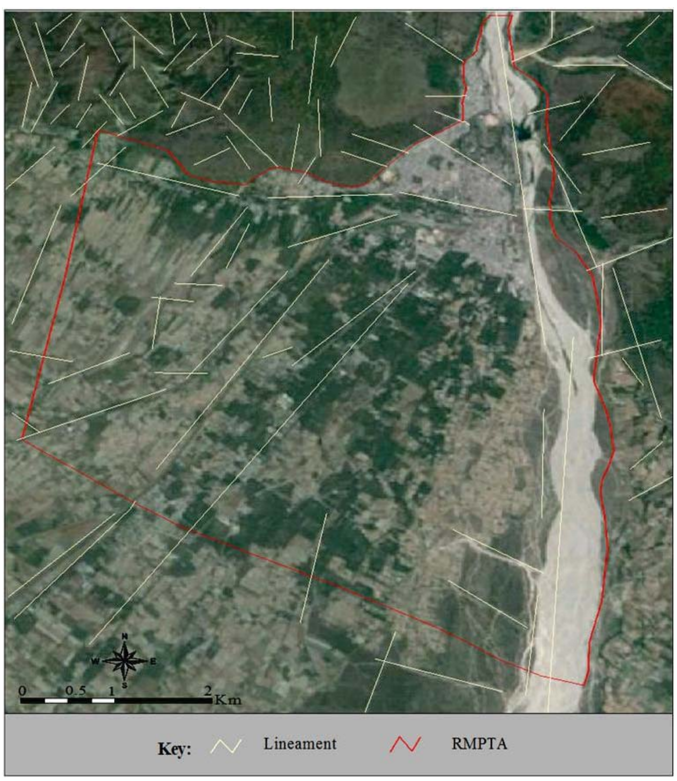


Fig. 4.1 : Lineaments

4.1.2 Geology: The study area setup over four geological sections from North (higher elevation) to South (lower elevation). These sections are Upper Sub Himalaya rocks, Middle Sub Himalaya rocks, Share zone rocks, Foothill rocks (Fig. 4.2 and Table 4.1).

4.1.2.1 Upper Sub Himalaya Rocks: The Upper Sub Himalaya rock represents boulders, cobbles, pebbles, conglomerates and clay lenses; covered about 11% (8.72 km^2) area of the Kosi piedmont zone (Table 4.1 and Fig. 4.2).

4.1.2.2 Middle Sub Himalaya Rocks: The Middle Sub Himalaya rocks are characterized by large sandstones; covered about 15% (10.17 km^2) area of the study region (Table 4.1 and Fig.4.2).

Table 4.1 : Attribute Data of Geology in Kosi Piedmont Zone

Geological Sections	Major Rock Types	Covered Area	
		km^2	%
Upper Sub Himalaya Rocks	Quartzitic pebbles and boulders	8.72	11
Middle Sub Himalaya Rocks	Micaceous sandstones	10.17	15
Share Zone Rocks	Rock blocks, cobbles and boulders	5.09	6
Foothill Rocks	Gravel, pebbles, sand, silt and clay	48.68	68
Total	All above	72.65	100

4.1.2.3 Share Zone Rocks: The Share zone lithology exposed as heavy sediments which comprises of boulders, rock blocks, and cobbles and are spread over deep undergoing Middle Sub Himalaya Foothill Zone covering about 6% (5.09 km^2) area of the region (Table 4.1 and Fig. 4.2)

4.1.2.4 Foothill Rocks: The Foothill rocks composed of inadequately sorted sediment which varies from very heavy gravel to finer silt and clay covering maximum proportion of about 68% (48.68 km^2) of the piedmont zone (Table 4.1 and Fig. 4.2).

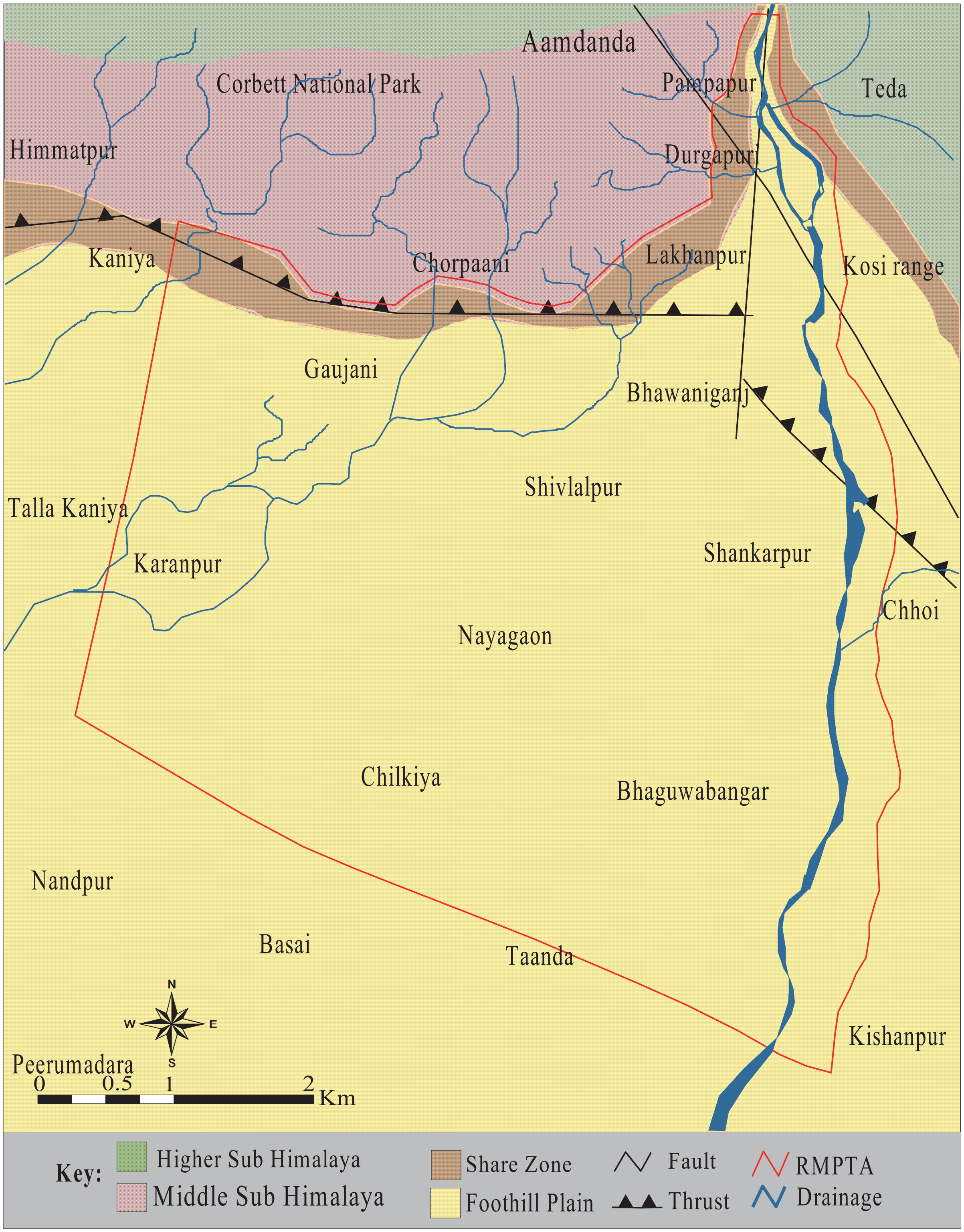


Fig. 4.2 : Geology

4.2 Climate

The study area have four climatic zones whose altitude varies in the range of 308m to 506m and their spatial variability of meteorological features are as depicted in Table 4.2 and Fig.4.3.

4.2.1 Zone of Tropical Climate : This zone extends in the southern part of the Kosi Piedmont Zone and spreads over 18% (13.08 km^2) of the research area. In this zone, the altitude varies between 308 m to 326 m above MSL. Variation in annual temperature and precipitation is investigated as 25-26^oC and 170cm - 185cm respectively (Table 4.2 and Fig.4.3).

4.2.2 Zone of Subtropical Climate : This zone spreads over major portion of about 62% (45.04 km^2) of the study region where altitudinal variability is in the range of 326 m to 412 m above MSL. Variation in annual temperature and precipitation lies between 24-26^oC and 185cm - 205cm respectively (Table 4.2 and Fig. 4.3).

Table 4.2 : Attribute data of Climate in Kosi Piedmont Zone

Climate Zones	Altitudinal Variability (in m)	Average Temperature (in °C)	Average Rainfall (in mm)	Covered Area	
				km^2	%
Tropical Climate	308-326	>26	<185	13.08	18
Sub Tropical	326-412	24-26	185-205	45.04	62
Moist Sub Tropical Climate	412-452	22-24	205-225	7.99	11
Sub Temperate Climate	452-506	<22	>225	6.54	9
Total	-	-	-	**72.65**	**100**

4.2.3 Moist sub-tropical climatic zone : This zone extends in the North-West part of the Kosi Piedmont Zone and spreads over 11% (7.99 km^2) of the research area. In this zone, the altitude varies between 412 m to 452 m above MSL. Variation in annual temperature and precipitation is investigated as 22-24^oC and 205cm - 225cm respectively (Table 4.2 and Fig.4.3).

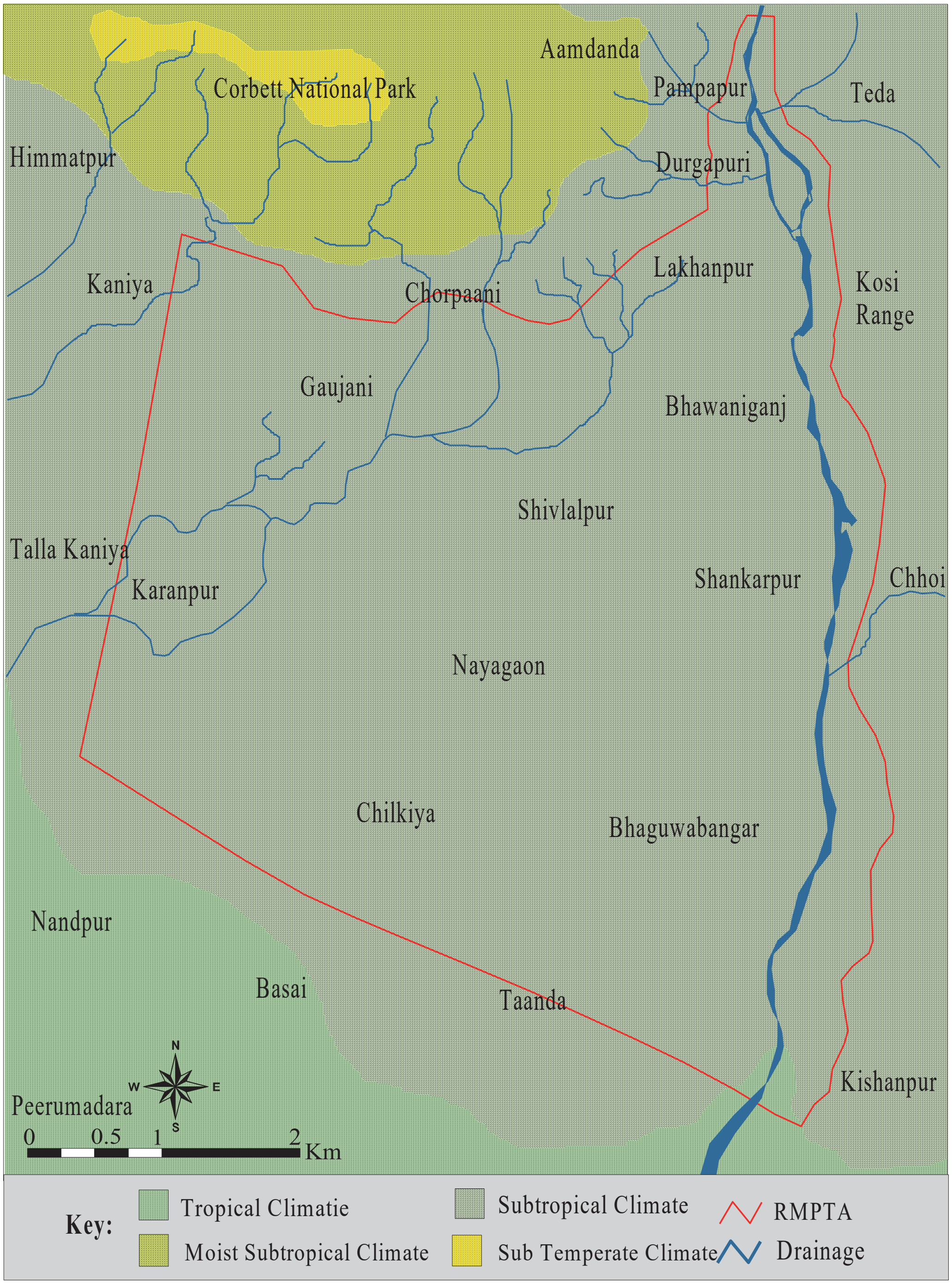


Fig. 4.3 : Climatic Zones

4.2.4 Sub-temperate climatic zone : This zone spreads over minimum portion of about 9% (6.54 km^2) of the Kosi Piedmont Zone. In this zone, the altitudinal variability is in the range of 452 m to 506 m above MSL. Variation in annual temperature and precipitation lies below 22°C and 220cm - 235cm respectively (Table 4.2 and Fig. 4.3).

4.3 Land Use / Land Cover

Human made actions such as using the land for residential purposes, agriculture, industries, mining etc. are reflected by land use. When the land is occupied by water, desert, natural vegetation, etc. it falls under the class of land cover (Rawat et al. 2012d). In the present study, we have classified the land use / land cover trend of the Kosi Piedmont Zone as built up and non-built up area.

4.3.1 Built-up area : It indicates all the structural setttlements such as dams, roads, bridges, etc. This area is further classified into two categories; these are settlements and colonized waste land. This basically constitutes about 26% (18.889 km^2) of the Kosi Piedmont Zone (Table 4.3 and Fig. 4.4). The above mentioned categories are further described as:

4.3.1.1 Settlements : The Kosi Piedmont Zone have three kind of settlements. Such settlements totally cover an area of about 18% (13.077 km^2) of the study region. Among these:

(i) Domestic Purpose such as residential buildings, farmhouses,etc.

(ii) Official Purpose such as government sectors, private companies, institutions,etc.

(iii) Commercial Purpose such as shops, market, hotels, etc.

4.3.1.2 Colonized waste land : It has been reported that in order to have better living, individuals are migrating from the hilly zones (rural areas) to Kosi Piedmont Zone. Basically this trend has seen to come in existence since after the bifurcation of state Uttarakhand from Uttar Pradesh in the year 2000. About 30 percent of the colonizing land is sold to immigrants for their utilization of residential buildings whereas rest of the 70 percent land is unsold by the brokers so that they can make an immense profit by selling them at higher rates in the coming years. Hence such area falls under the category of waste land built up area and extends over an area of about 8% (5.812 km^2) of Kosi Piedmont Zone (Table 4.3 and Fig.4.4).

4.3.2 Non built-up area: This constitutes about 74 percent (53.76 km^2) of the study region. It includes:

4.3.2.1 Vegetation Cover : This is reflected by the combined proportion of forest land and shrubs land which constitutes 40 percent of the research area (Table 4.3 and Fig. 4.4).

4.3.2.2 Agricultural Land : Crop land along with horticultural land reflects the proportion of agricultural land and contributes to 30 percent area of Kosi Piedmont Zone (Table 4.3 and Fig. 4.4).

4.3.2.3 Riverbed : This shows the minimum proportion 3% (2.18 km^2) area of the study region (Table 4.3 and Fig. 4.4).

Table 4.3 : Attribute data of Land Use / Land Cover pattern in Kosi Piedmont Zone

Land Use / Land Cover Categories		Covered Area	
		km^2	%
Built up Area	Settlements	13.077	18
	Colonized Waste Land	5.812	8
	Total Built up Area	18.889	26
Non Built up Area	Crop Land	16.710	23
	Horticultural Land	5.090	7
	Forest Land	22.520	31
	Shrubs Land	7.270	10
	Riverbed and Sandbars	2.180	3
	Total Non Built up Area	53.760	74
Gross Total of Built up and Non Built up Area		72.650	100

4.4 Relief Pattern

4.4.1 Absolute Relief: It is expressed as the highest elevation in a unit above MSL. As per the research conducted, the Kosi Piedmont Zone is sub-divided into six classes of absolute relief. The value of absolute relief lies in the range between 308m – 506m above MSL. About 36 percent area (26.15 km^2) of the Kosi Piedmont Zone comes under the category of

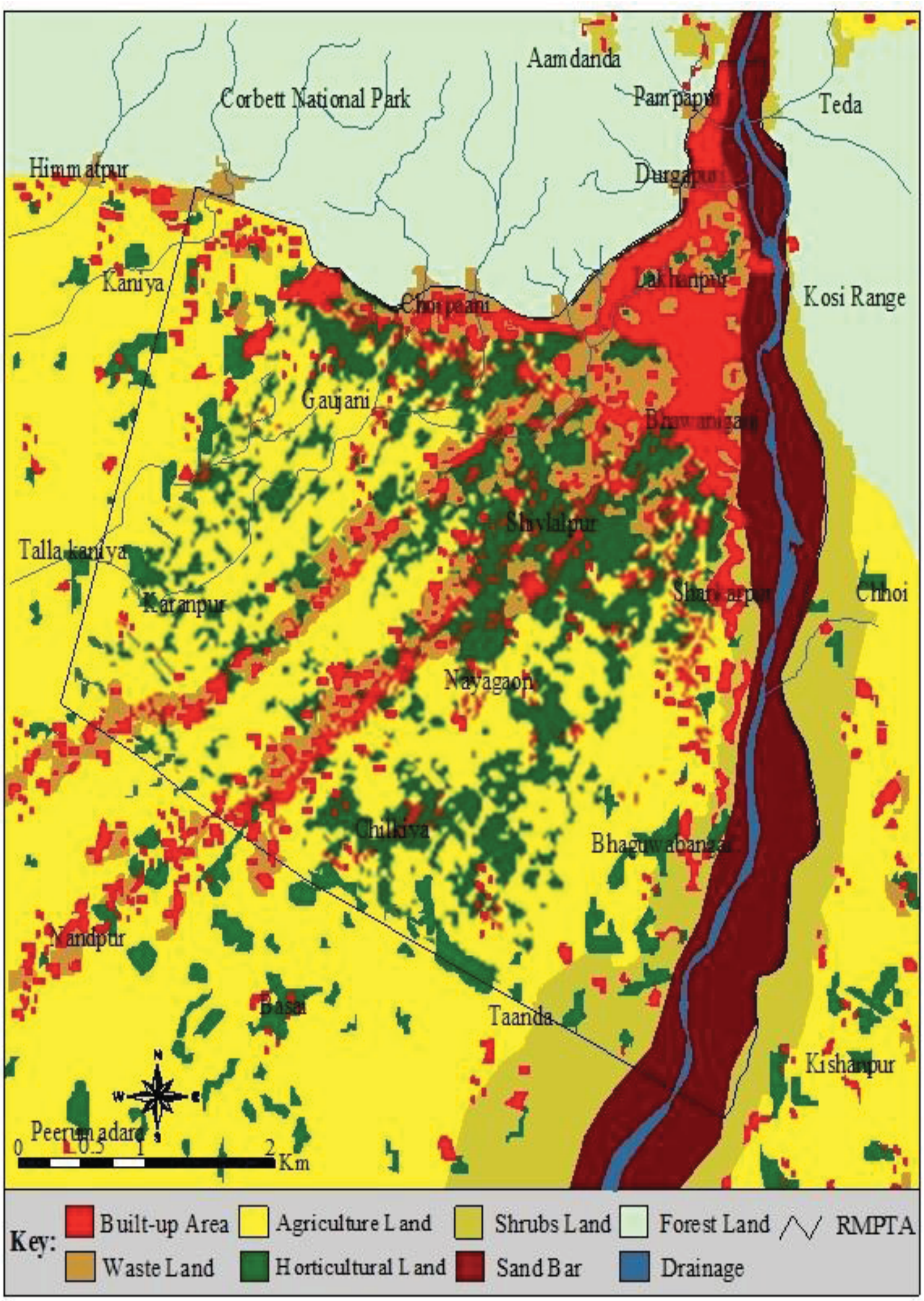


Fig. 4.4 : Land Use / Cover

low relief zone. The contribution to zone of high relief is very less that is nearly 6% area (4.36 km2) of the study region. Table 4.4 and Fig. 4.5 depicts the comprehensive details:

Table 4.4 : Attribute data of Absolute Relief in Kosi Piedmont Zone

Relief Categories	Covered Area		Major Proportion Of Existing Places
	km²	%	
308-330	26.15	36	Tarai and southern Bhabar alluvial plain
330-360	17.44	24	South to middle Bhabar alluvial plain
360-390	11.62	16	Northern Bhabar alluvial plain and Kosi river valley
390-420	7.99	11	Down slopes of the Siwalik Foothills
420-450	5.09	7	Middle slopes of the Siwalik Hills
450-506	4.36	6	Hill tops of the Siwalik hills
Total	72.65	100	All above

4.4.2 Slope : It is expressed as the angle of inclination of the ground surface on the horizontal plane. The observation of topographical features become convenient with the help of angle of slope. As per the observations, it has been suggested that about 44 percent area of the covered zone i.e. 31.97 km^2 have slope value ranging below 4^O . The highest proportion of slope above 20^O is reflected by minimum covered area of about 4 percent. Further details are provided in Table 4.5 and Fig. 4.6.

Table 4.5: Attribute data of slope variability in Kosi Piedmont Zone

Slope Categories	Covered Area		Exiting Villages having Major Proportion Of Respective Slope Categories
	km²	%	
Below 4	31.97	44	Tarai and southwestern Bhabar alluvial plain
4-8	11.62	16	Upslope of Tarai and southwestern Bhabar alluvial plain
8-12	13.80	19	Northern Bhabar alluvial plain and Kosi river valley
12-16	6.54	9	Down slops of the Siwalik Foothills
16-20	5.81	8	Middle slops of the Siwalik hills
Above 20	2.91	4	Hill tops of the Siwalik hills
Total	72.65	100	All above

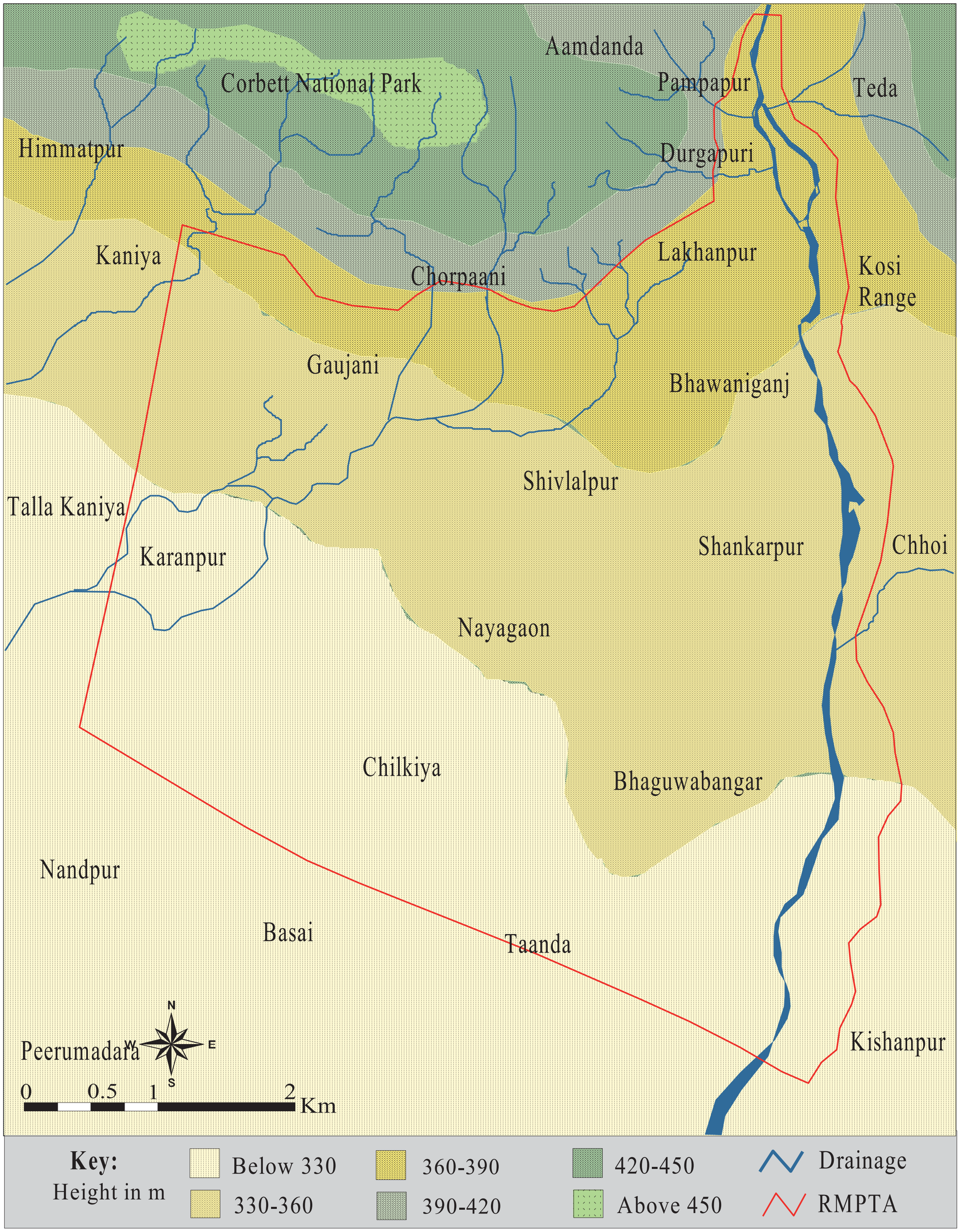
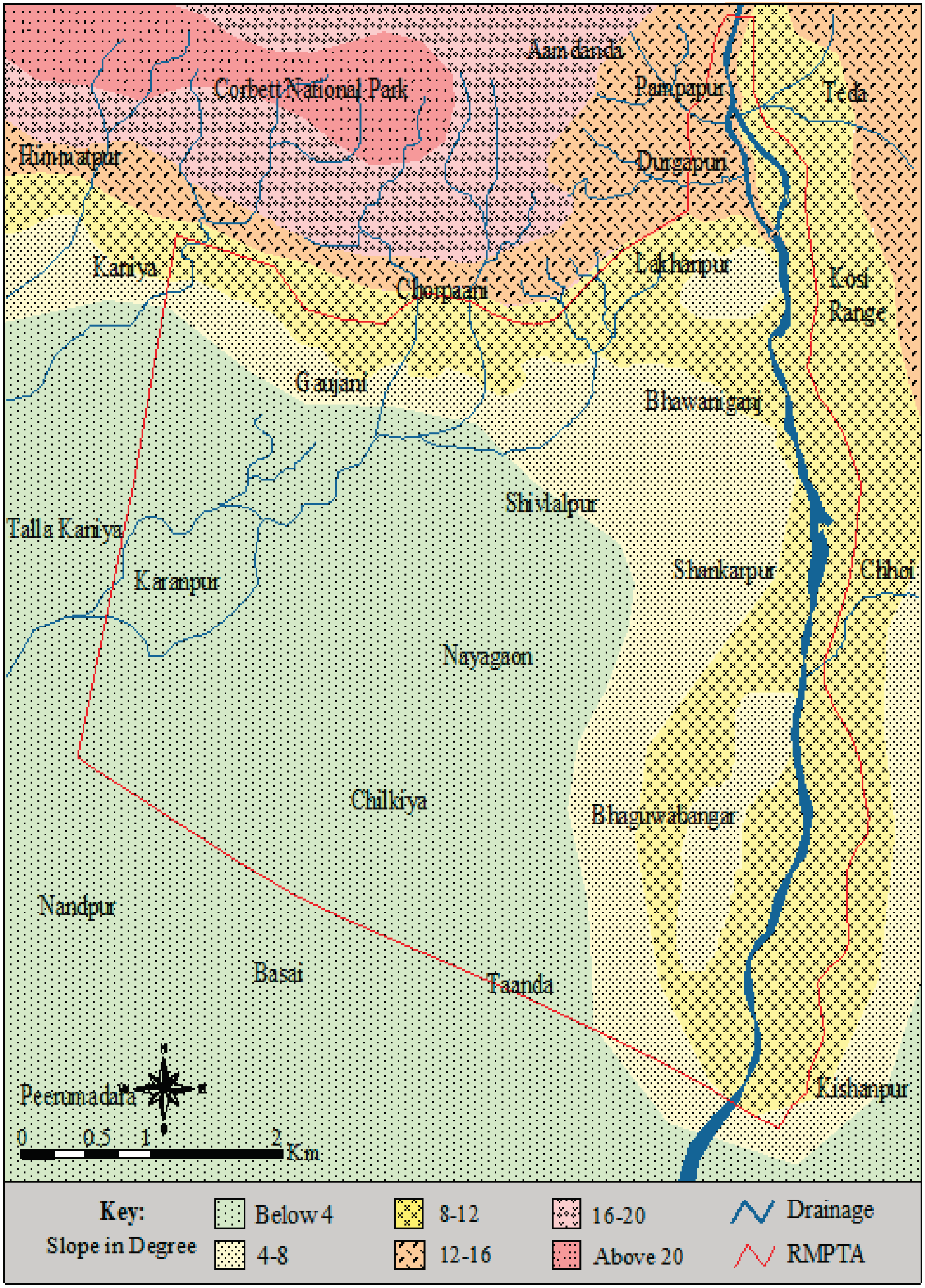


Fig. 4.5 : Relief



Aamdanda
Corbett National Park
Pampapur
Teda
Himmatpur
Durgapur
Kaniya
Lakhanpur
Chorpaani
Kosi
Range
Gaujani
Bhawanigang
Shivlalpur
Talla Kaniya
Shankarpur
Chhoi
Karanpur
Nayagaon
Chilkiya
Bhaguwabangar
Nandpur
Basai
Taanda
Peerumadara
Kishanpur
0 0.5 1 2 Km
Key:
Slope in Degree
Below 4
4-8
8-12
12-16
16-20
Above 20
Drainage
RMPTA

Fig: 4.6 : Slope

4.5 Geomorphology

All the investigated geomorphic landforms with the help of satellite data have been categorised under preliminary landforms and secondary landforms according to their origin, development and characteristics as following:

4.5.1 Preliminary landforms: The landforms which are comparatively older than secondary landforms and provides platforms for the development of dynamic younger landforms in the present work are considered to be preliminary landforms. The major preliminary landforms observed in the study area are: Geo-structural linear features (tectonically active lineaments such as thrusts, faults and other linear features), Gravelled Sub Himalaya hills, Foothill piedmont, multilevel river terraces (Fig. 4.7), alluvial plain, drainage dividers, long and gentle-dip slopes (Fig. 4.8 and Fig. 4.9).

4.5.2 Secondary landforms: Comparatively younger landforms; which have been developed and being reshaped over large regional preliminary landforms, recognized as secondary landforms. The investigated secondary landforms throughout the study area are: Younger alluvial fans, terrace scarps, debris flow sites, tectonic valleys and subsequent streams, abandoned channels, triangular facets (Fig. 4.8 and Fig. 4.9).

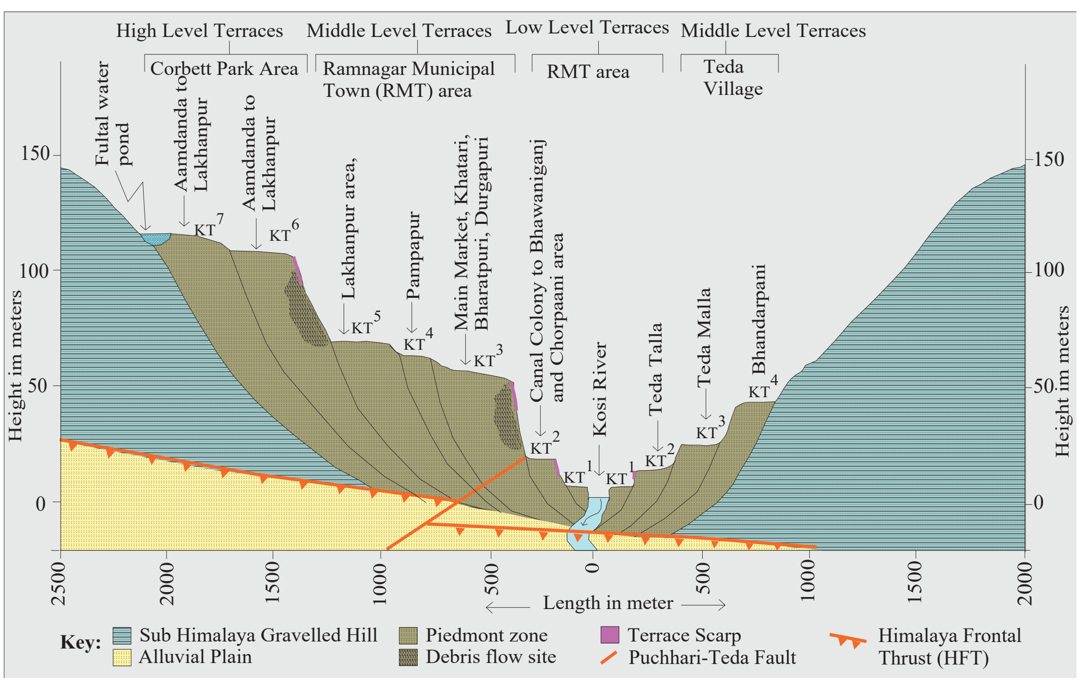


Fig. 4.7 : Kosi Piedmont Cross-Section

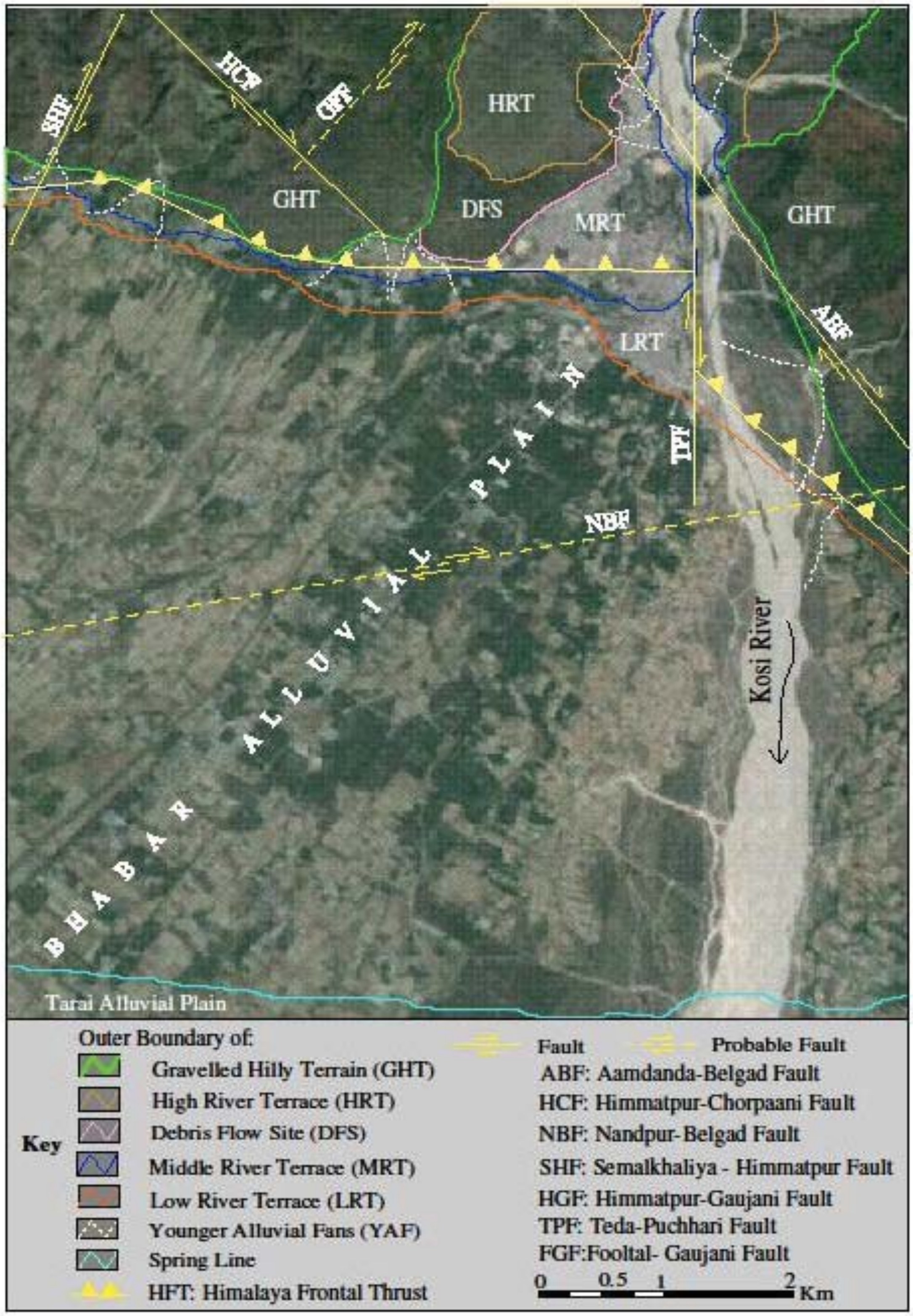


Fig. 4.8 : Geomorphic Features

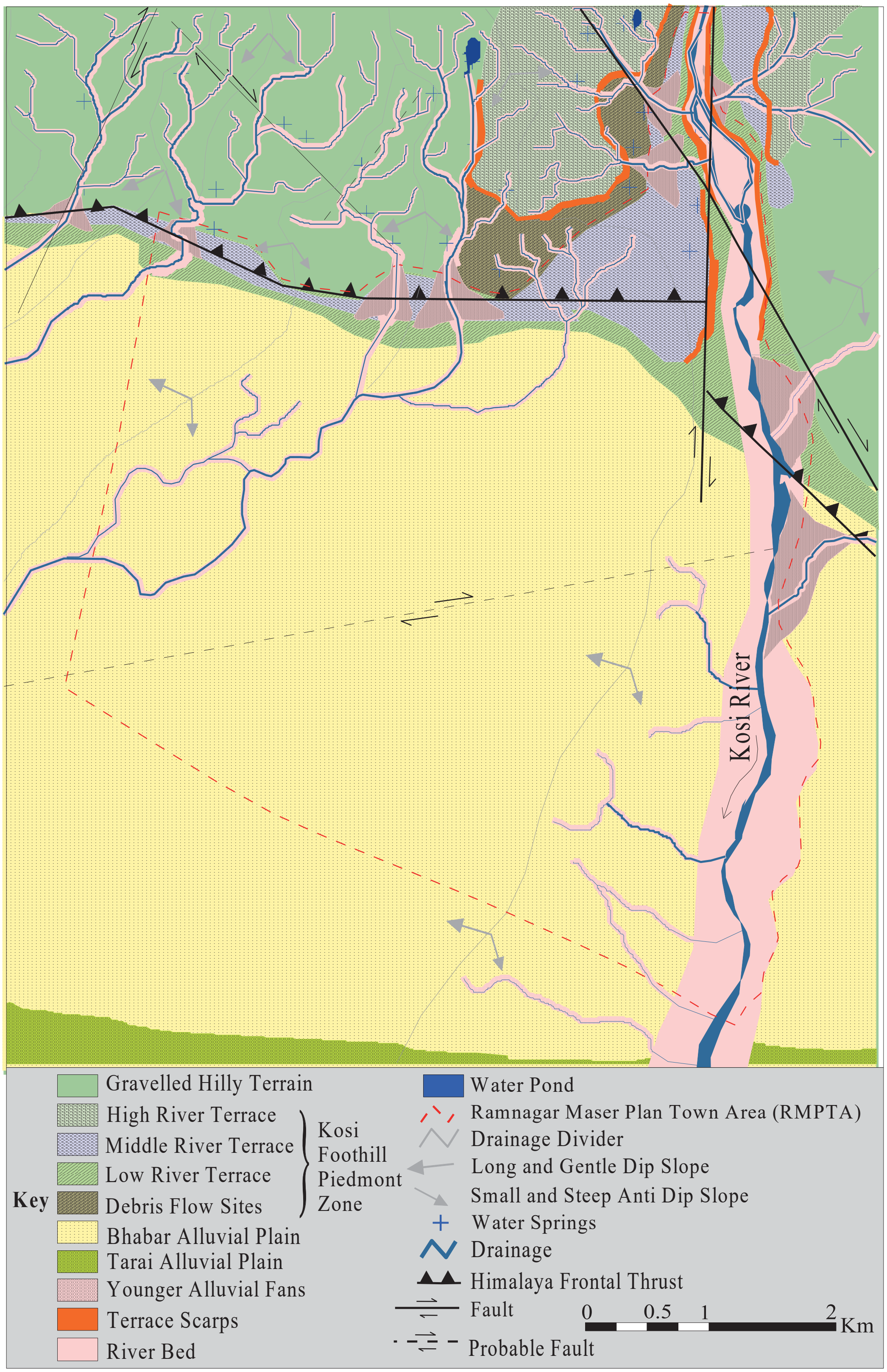


Fig. 4.9 : Geomorphic Landforms

4.6 Hydrology

4.6.1 Spring hydrology: It has been observed that there are various kind of springs that exist in Kosi Piedmont Zone. Their density and spatial distribution have been mentioned below:

4.6.1.1 Spatial Distribution of various kind of Springs: On the basis of trend of discharge, existence of two classes of springs are observed in the Kosi Piedmont Zone (Table 4.6 and Fig. 4.10). These are:

i. Perenninal Springs : 20 in number
ii. Non-Perennial Springs : 25 in number

Therefore there are total 45 springs that are observed in the study region.

4.6.1.2 Spring density: On the basis of the distribution of springs as depicted in Table 4.6 and Fig. 4.11, the study area is investigated to have four classes of spring density:

i. Very Low Spring Density
ii. Low Spring Density
iii. Moderate Spring Density
iv. High Spring Density

Detailed study of the existing villages that fall under the above mentioned classes is depicted in Table 4.7.

Table 4.6 : Attribute data on spatial variability of spring density in Kosi Piedmont Zone

Spring Density Zone	Spring Density (Springs/Km^2)	Number of Springs in Respective Zone						Covered Area	
		Perennial		Non-perennial		Total			
		No.	%	No.	%	No.	%	km^2	%
Very Low	Below 2	1	2	5	11	6	13	53.03	73
Low	2-3	6	13	3	7	9	20	4.36	6
Moderate	3-4	6	13	6	13	12	27	10.17	14
High	Above 4	12	27	6	13	18	40	5.09	7
Total	**All Above**	**25**	**56**	**20**	**44**	**45**	**100**	72.65	100

Table 4.7 : List of Existing Villages in Different Spring Density Areas

Spring Density Categories	Existing Villages in the Zones
Very Low	Peerumadara, Nandpur, Kishanpur, Basai, Chilkiya, Bhaguwabangar, Karanpur, Talla Kaniya, Nayagaon, Shivlalpur, Gaujani, Bhawaniganj, Chhoi, Shankarpur
Low	Upslope of Kaniya,Chorpaani, Lakhanpur, Northern part of Chhoi
Moderate	Extreme up and down slopes of Siwalik Hills around Himmatpur, Corbett Park, Teda, Aamdanda, Kaniya, Chorpaani, Lakhanpur, Kosi Range
High	Mid-slopes of Siwalik Hills around Himmatpur, Corbett Park, Teda, Aamdanda, Kaniya, Chorpaani, Lakhanpur, Kosi Range

4.6.1.3 Geomorphological Control on Springs Formation : On the basis of controlling factors, the above investigated perennial and non-perennial springs are further classified into five different classes as shown in Table 4.8 and Fig. 4.12:

4.6.1.3.1 Thrust Spring: The study zone have 3 such springs i.e. 7 percent of total existing springs (Table 4.8 and Fig. 4.12).

Table 4.8 : Geomorphological control on springs formation

Types of Springs	Total number of springs	% of total springs	No. of Sample springs
Thrust springs	03	7	03
Fault springs	11	24	03
Fluvial springs	9	20	03
Colluvial springs	13	29	03
Shear zone controlled	9	20	03
Total	**45**	**100**	**15**

Fig. 4.10 : Spatial Distribution of Perennial and Non-Perennial Springs in KPZ

4.6.1.3.2 Fault spring: The KPZ have 11 fault springs i.e. 24 percent of total existing springs (Table 4.8 and Fig. 4.12).

4.6.1.3.3 Fluvial Spring: As per the investigations, these are 9 in number and contributes 20 percent to the total number of existing springs in KPZ (Table 4.8 and Fig. 4.12).

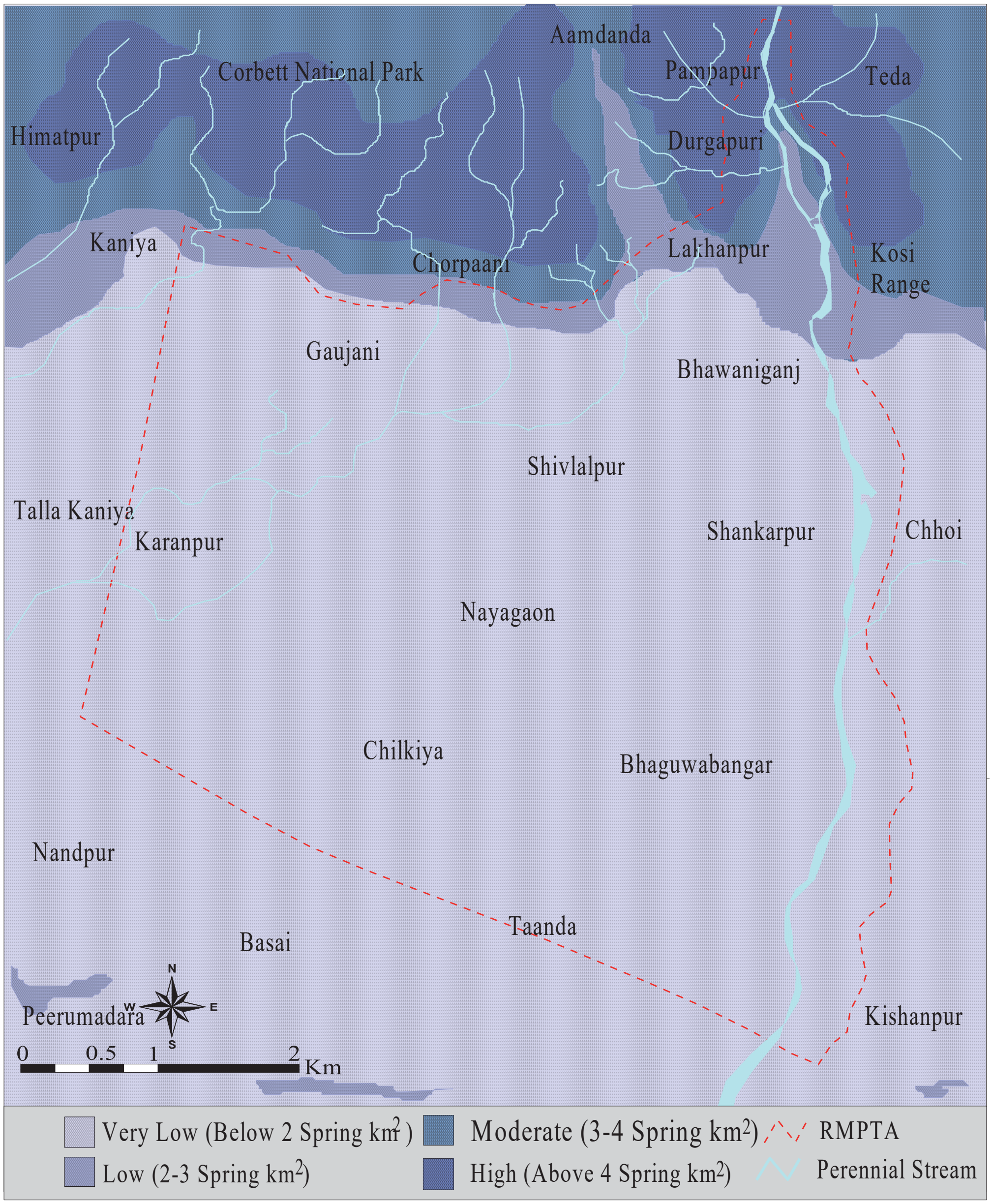


Fig. 4.11 : Spring Density

4.6.1.3.4 Colluvial springs : The study zone have 13 such springs that constitutes 29 percent of total existing springs in the covered area (Table 4.8 and Fig. 4.12).

4.6.1.3.5 Shear springs : As per the investigations, these are 9 in number and contributes 20 percent to the total number of existing springs in KPZ (Table 4.8 and Fig. 4.12).

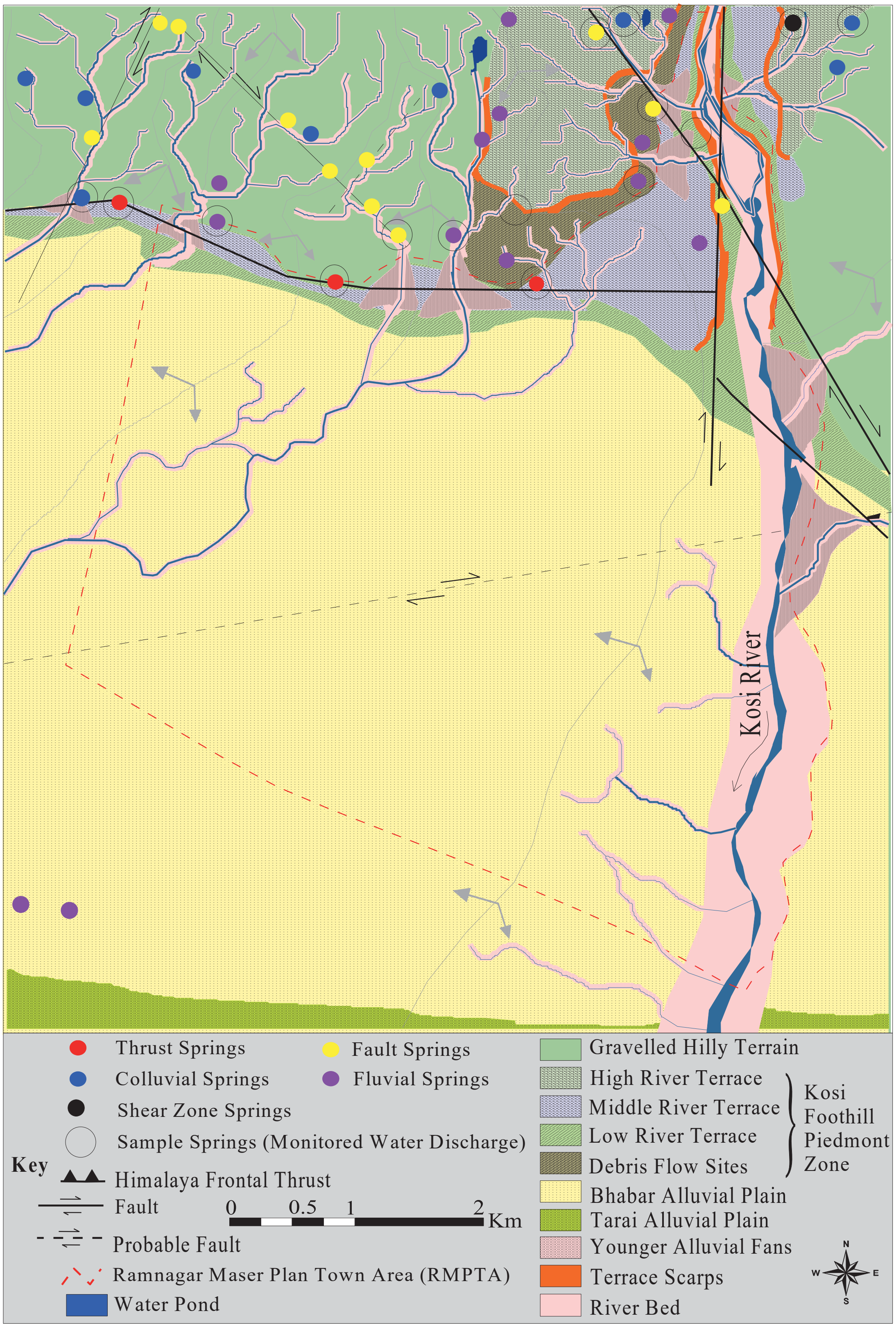


Fig. 4.12 : Geomorphological control on Springs formation

4.6.1.4 Spring Discharge : Following observations are inferred from the research made on a sample of 15 springs taken in the KPZ during 2015 for hydrograph analysis:

4.6.1.4.1 Monthly Spring discharge : Following key points are observed from Table 4.9 and Fig. 4.13 :

- The rising limb of the hydrograph varies according to precipitation rate.
- Increase in discharge rate is observed basically from the month of May.
- The approach limb of the hydrograph is provided by the discharge data of month April and December.
- The month of August is mainly responsible for the development of rising limb of the hydrograph.
- The recession limb of the hydrograph is provided by the discharge data of months : January, February and March.

Table 4.9 : Monthly Variation in Spring Discharge

Springs	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Avg.
Thrust springs	7.53	8.08	9.17	3.54	7.45	67.7	92.46	132.60	79.08	26.10	9.72	6.44	37.49
Fault springs	6.01	6.46	7.36	0.40	8.09	56.00	76.08	110.20	66.04	21.32	7.81	5.11	30.91
Share zone springs	5.26	5.67	6.47	1.10	6.63	50.30	68.10	97.80	58.20	19.00	6.88	4.45	27.49
Fluvial springs	4.36	4.71	5.40	0.90	5.56	43.40	58.44	84.00	49.92	16.18	5.75	3.67	23.52
Colluvial springs	3.03	3.29	3.82	0.30	3.61	33.20	44.16	63.60	37.68	12.02	4.09	2.50	17.61
Rainfall (mm)	69.33	51.75	41.65	23.62	34.17	262.72	456.11	491.26	245.14	34.17	16.46	16.59	145.25

4.6.1.4.2 Seasonal Spring discharge : For our analysis, we arranged the data in three classes of season:

i. Pre-monsoon Season Discharge (from month of February to May)
ii. Monsoon Season Discharge (from month of June to September)
iii. Post-monsoon season Discharge (from month of October to January)

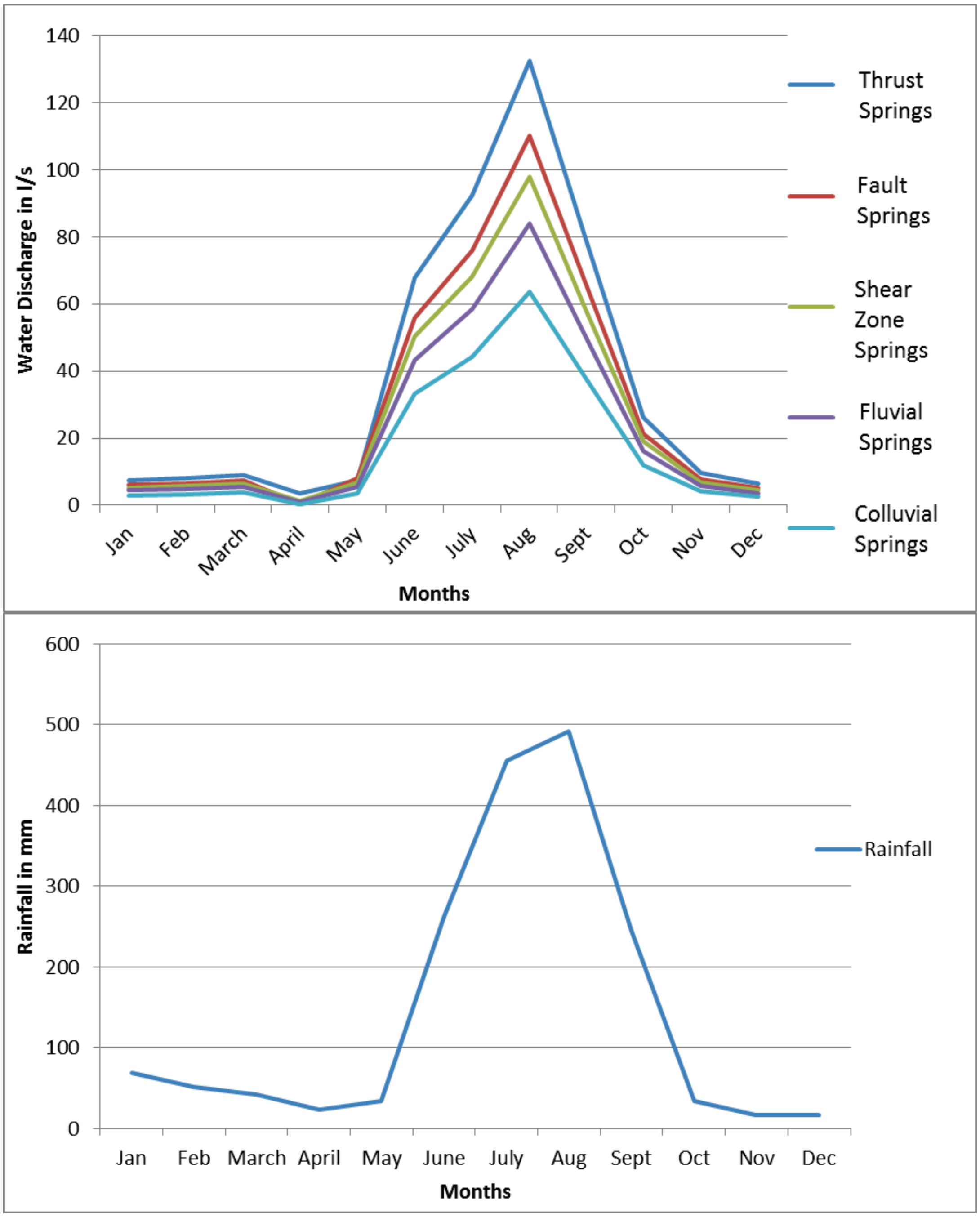


Fig. 4.13 : Monthly Hydrograph of spring discharge under different geomorphological control (above) and rainfall pattern (below)

4.6.1.4.2.1 Pre-monsoon spring discharge : This contributes to approach limb (base flow) of spring hydrograph. It varies maximum to 7.06 l/s for thrust controlled springs to minimum 2.76 l/s for colluvial springs whereas for fault, shear zone and fluvial controlled springs it is found in the range 5.58 l/s, 4.97 l/s, and 4.14 l/s respectively in the KPZ (Table 4.10 and Fig.4.14).

Table 4.10 : Seasonal variation in spring discharge

Types of Springs	Pre Monsoon Discharge	During Monsoon Discharge	After Monsoon Discharge	Annual Avg. Discharge
Thrust springs	7.06	92.96	12.45	37.49
Fault springs	5.58	77.08	10.06	30.91
Shear zone springs	4.97	68.60	8.90	27.49
Fluvial springs	4.14	58.94	7.49	23.52
Colluvial springs	2.76	44.66	5.41	17.61
Rainfall (mm)	37.80	363.81	34.14	145.25

4.6.1.4.2.2 Monsoon spring discharge : This contributes to rising limb (peak flow) of spring hydrograph. It vary maximum 92.96 l/s for thrust controlled springs to minimum 44.66 l/s for colluvial springs whereas for fault controlled, shear zone controlled and fluvial controlled springs it is found to be 77.08 l/s, 68.60 l/s, and 58.94 l/s respectively in the study area (Table 4.10 and Fig. 4.14).

4.6.1.4.2.3 Post-monsoon spring discharge : This contributes to recession limb (falling) of spring hydrograph. It vary maximum 12.45 l/s for thrust controlled springs to minimum value 5.41 l/s in case of colluvial springs whereas for fault controlled, shear zone controlled and fluvial controlled springs it is found as 10.06 l/s, 8.90 l/s, and 7.49 l/s respectively in the study region (Table 4.10 and Fig. 4.14).

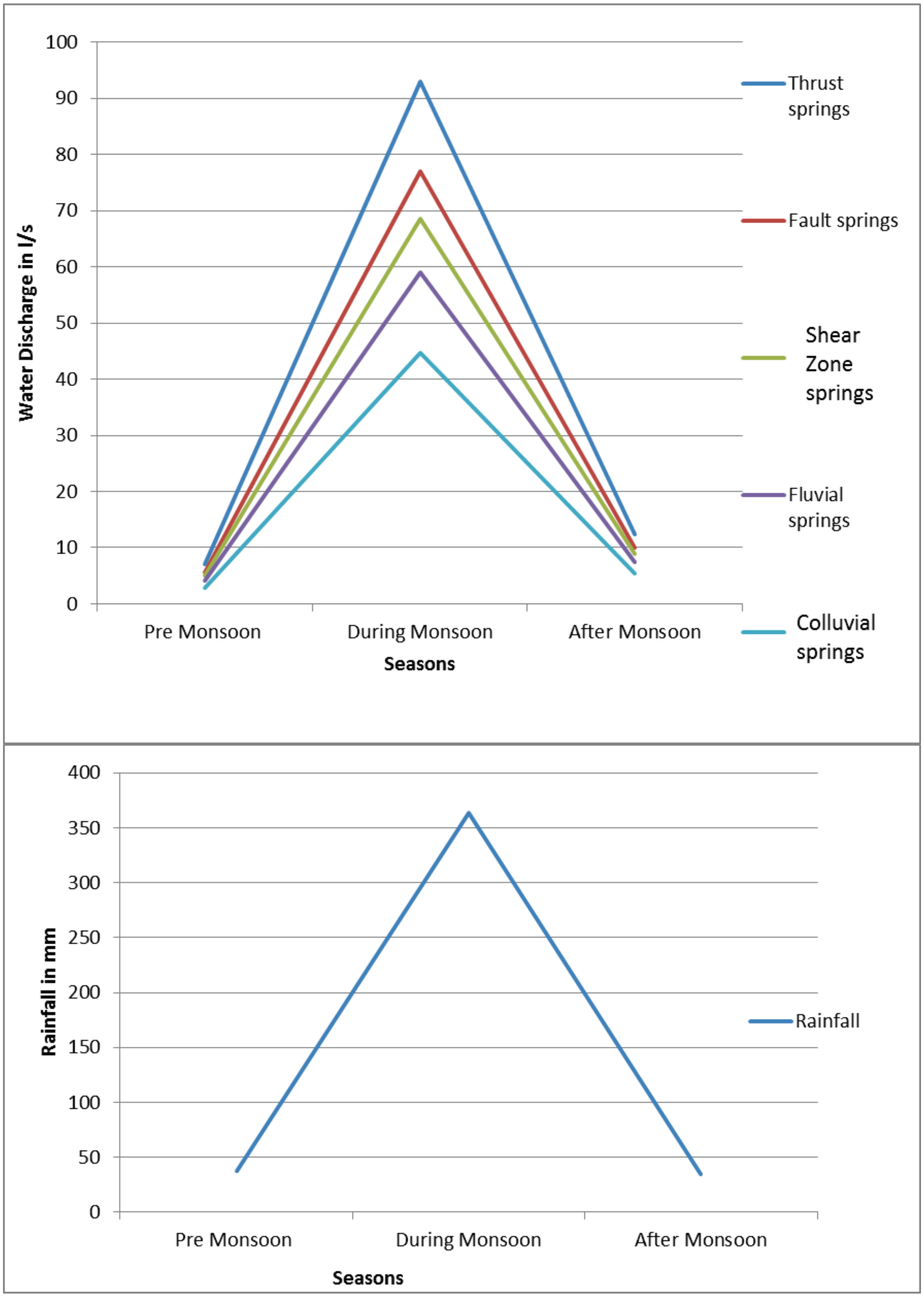


Fig. 4.14 : Seasonal Hydrograph of Spring discharge under different geomorphological control (above) and rainfall pattern (below)

4.6.1.4.3 Annual Spring discharge : Following key points are observed from Table 4.10 and Fig. 4.15:

- Thrust controlled springs shows the highest rate of average annual discharge ranging 37.49 l/s.
- Minimum rate of average annual discharge value 17.61 l/s is reflected by colluvial springs.
- The average value of annual discharge reflected by fluvial , shear , and fluvial controlled springs is 30.91 l/s , 27.49 l/s, 23.52 l/s respectively.

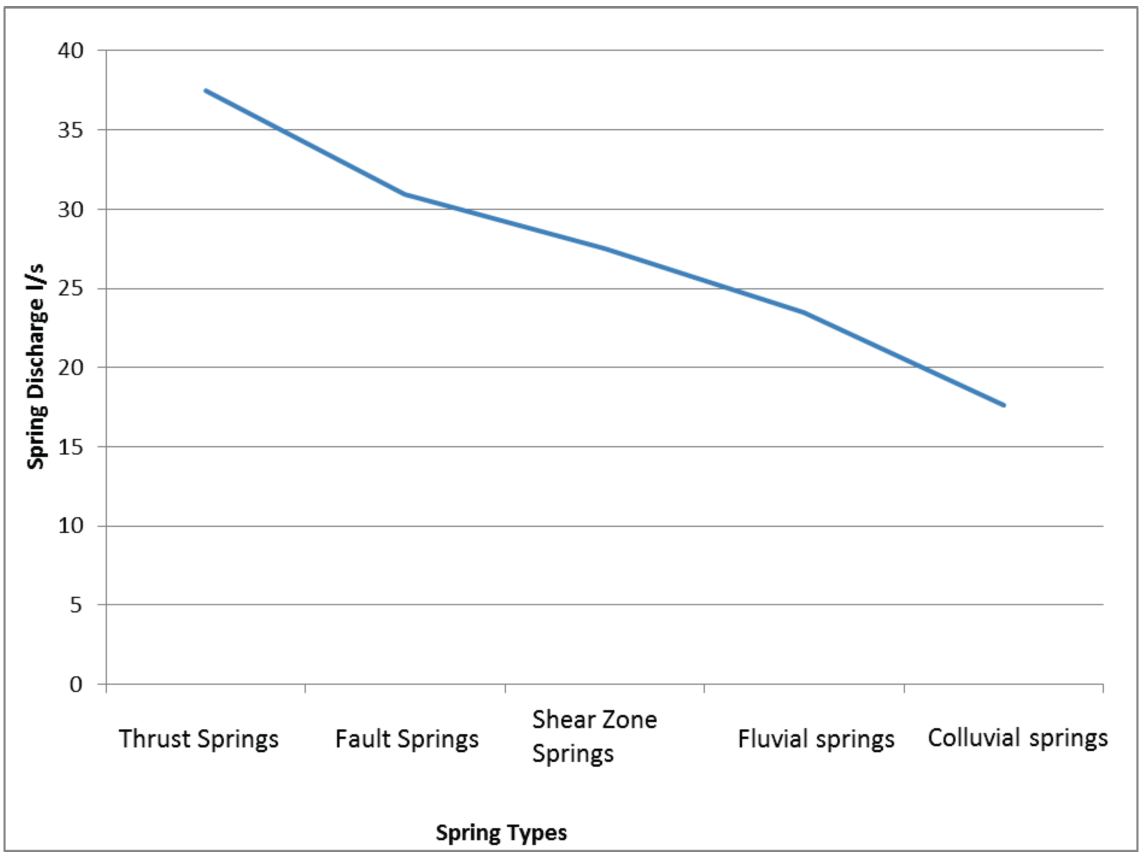


Fig. 4.15: Annual hydrograph of spring discharge under different geomorphological control

4.6.2 Drainage hydrology

The goal of the present study is to focus on various parameters such as stream order, drainage pattern, stream density, spatial distribution of springs in Kosi Piedmont Zone.

4.6.2.1 Drainage pattern and order: Drainage map of the study area shows elongated, triangular, oval, less circular to circular drainage pattern. The streams are perennial streams and non- perennial streams ranging from order first to ninth. There are 113 streams in KPZ out of which 41 are perennial and 72 are non-perennial constituting 36 percent and 64 percent of total existing streams in covered area (Table 4.11 and Fig. 4.16). It is observed that there are 72 first order streams, 28 second order stream whereas 10, 2 and 1 are third order, fourth order and ninth order streams respectively in the Kosi Piedmont Zone.

Table 4.11 : Attribute data of different order streams in Kosi Piedmont Zone

Stream Orders	Perennial Streams		Non Perennial Streams		Total Streams	
	In Number	% of Total	In Number	% of Total	In Number	% of Total
1st	18	16	54	48	72	64
2nd	12	11	16	14	28	25
3rd	8	7	2	2	10	9
4th	2	2	0	0	2	2
5th	0	0	0	0	0	0
6th	0	0	0	0	0	0
7th	0	0	0	0	0	0
8th	0	0	0	0	0	0
9th	1	1	0	0	1	1
All	**41**	**36**	**72**	**64**	**113**	**100**

4.6.2.2 Drainage distribution and density : Drainage density refers to the length of streams per unit area. The Kosi Piedmont Zone has been divided into four drainage density zones (Table 4.12 and Fig. 4.17).

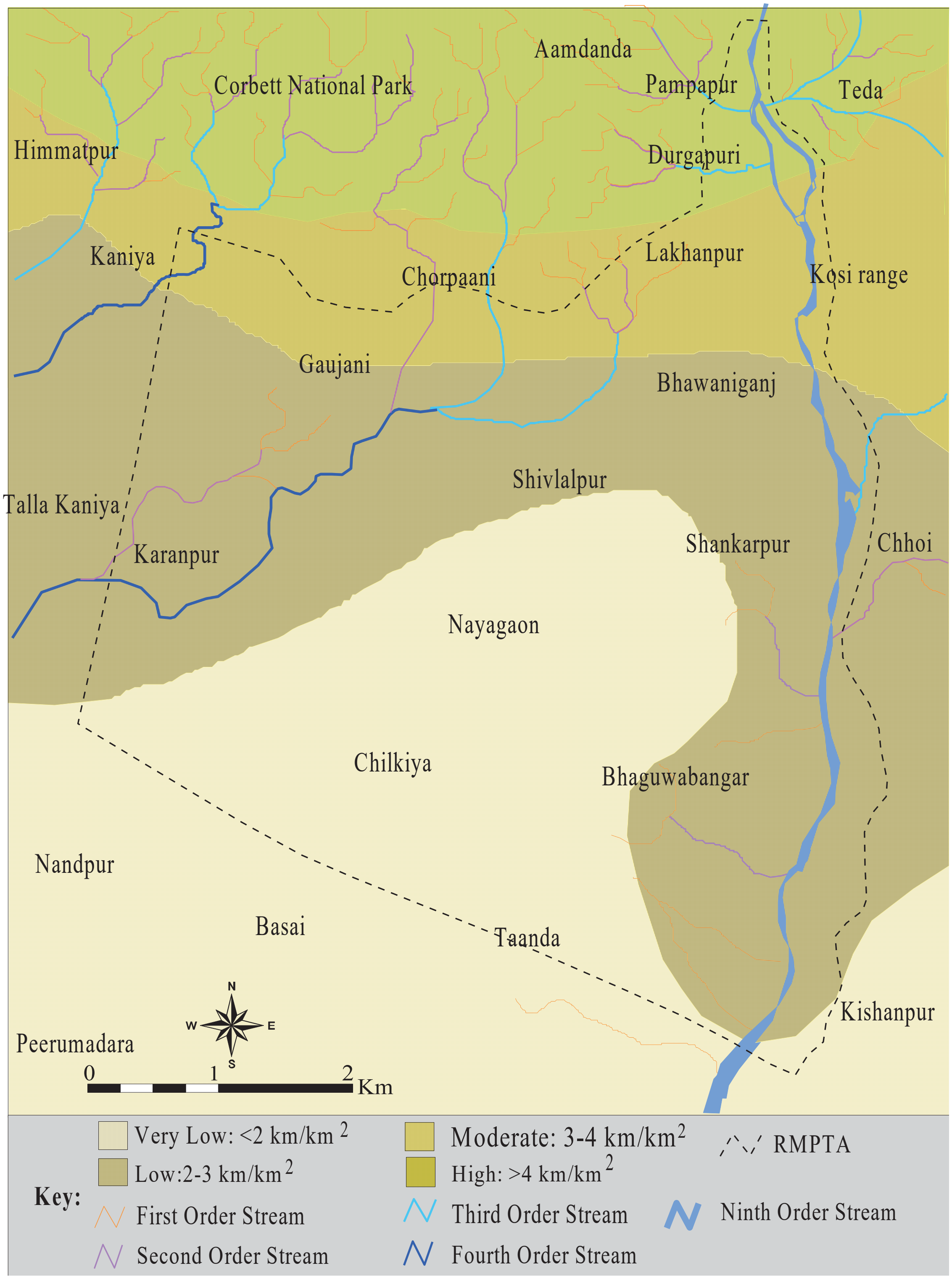


Fig. 4.16 : Stream order and Density

Table 4.12 : Attribute data of drainage density with existing stream orders in KPZ

Drainage Density Zones	Drainage Density (Km/Km^2)	Number of Different Order Streams in Respective Zone									Covered Area	
		I	II	III	IV	V	VI	VII	VIII	IX	km^2	%
Very Low	Below 2	1	0	0	0	0	0	0	0	1	26.15	36
Low	2-3	11	1	4	2	0	0	0	0	1	26.88	37
Moderate	3-4	14	5	5	0	0	0	0	0	1	8.72	12
High	Above 4	55	20	7	0	0	0	0	0	1	10.90	15
Total	**All Above**	-	-	-	-	-	-	-	-	-	72.65	100

4.6.2.3 Flood runoff: It is peak flow of surface runoff during heavy rainfall in the monsoon period. The least stressed land surface has flood runoff rate of 164 $l/s/km^2$ in Kaniya zone. The extremely stressed condition for flood is observed in Chorpaani region as rate of flood runoff is 864 $l/s/km^2$ whereas zones of Bharatpuri and Aamdanda falls under the category of highly and very highly stressed zones (Fig. 4.17 and Table 4.13).

Table 4.13 : Flood magnitude and runoff in Kosi Piedmont Zone under varied geo-ecosystem (1995-2015)

Sample watersheds under different geo-environmental status	Area (Km^2)	Geo-ecological characteristics							Geo-ecological Status	Flood Hydrology	
		Geology and Geomorphology (in %)				Land use (in %)		Avg. Slope		Flood Magnitude (m^3/s)	Flood Runoff ($l/s/km^2$)
		Upper Siwalik	Middle Siwalik	Piedmont Alluvium	Gangetic Alluvium	Built-up	Natural				
1. Himmatpur	1.65	6.0	93.0	1.0	0.0	1.5	98.5	16^0	Naturally balanced	0.14	86
2. Kaniya	2.71	9.0	90.0	1.0	0.0	2.0	98.0	15^0	Least stressed	0.44	164
3. Teda	3.48	4.0	87.4	0.6	8.0	13.0	87.0	17^0	Moderate stressed	1.98	570
4. Bharatpuri	1.30	2.0	98.0	1.5	0.5	14.0	86.0	19^0	Highly stressed	0.83	640
5. Aamdanda	1.42	98.0	00.0	1.6	0.4	18.0	82.0	18^0	Very highly stressed	1.04	735
6. Chorpaani	6.15	0.0	97.0	2.5	0.5	20.0	80.0	21^0	Extremely stressed	5.31	864
Kosi River Basin	738	-	-	-	-	-	-	-	-	284.13	385
Average in KPZ	-	-	-	-	-	-	-	-	-	**41.98**	**492**

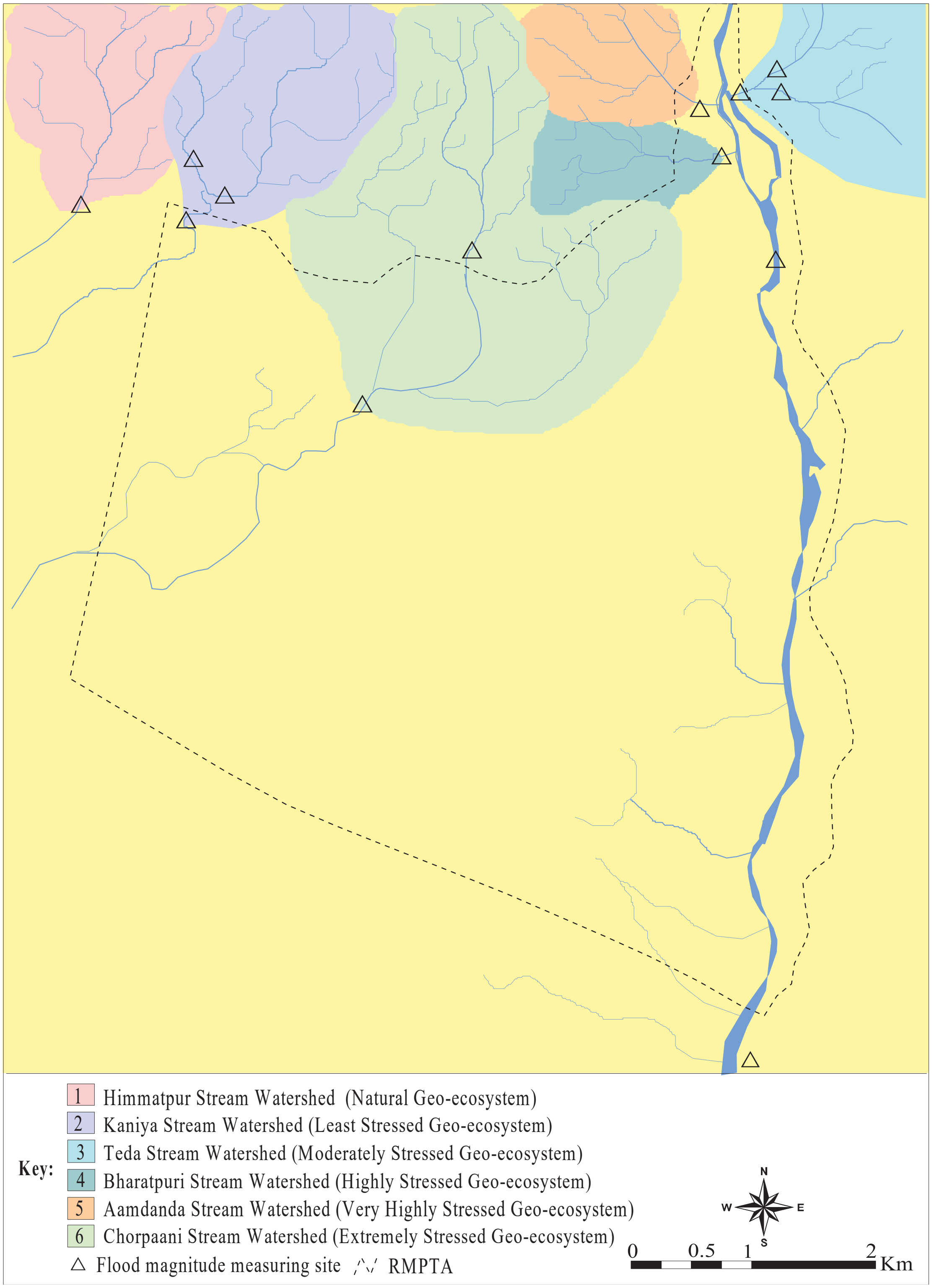
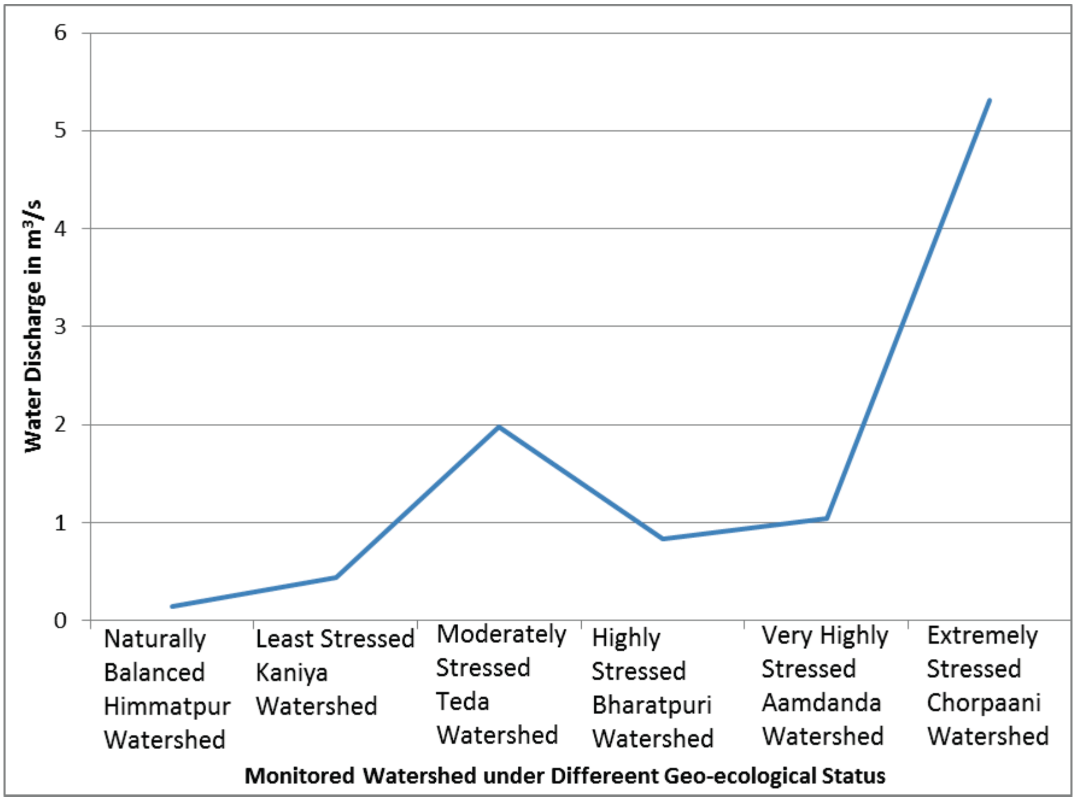


Fig. 4.17 : Sample watersheds selected for flood discharge monitoring under varied geo-ecological status



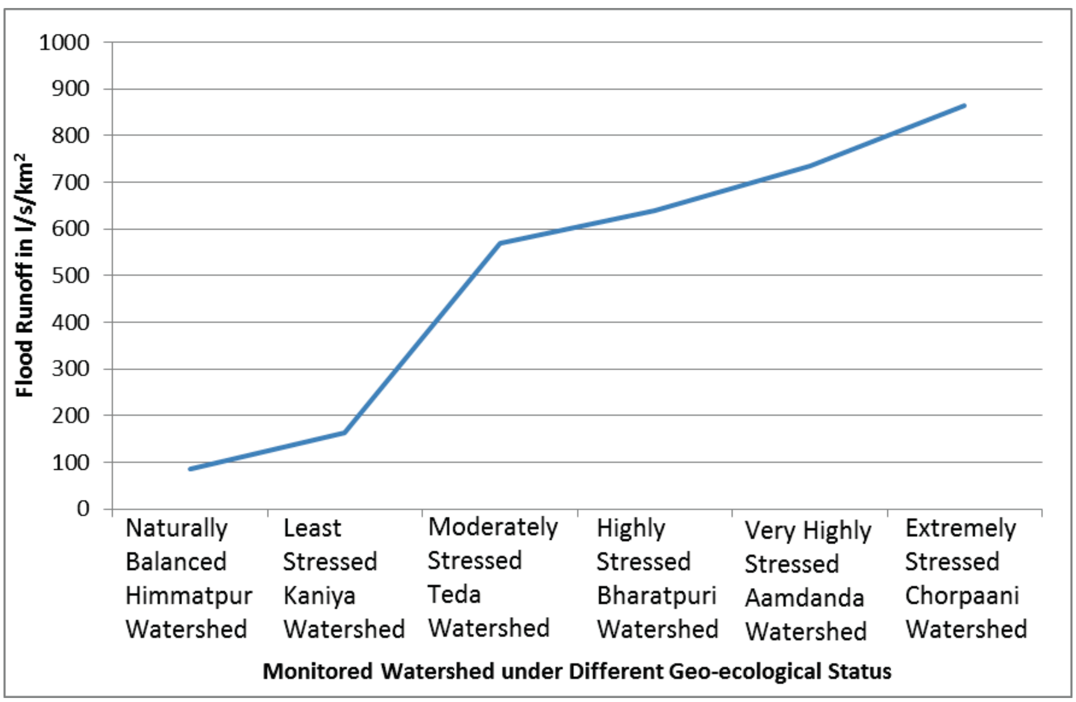


Fig. 4.18 : Watershed Hydrograph of Flood discharge (above) and subsequent Flood runoff under varied geo-ecological status

4.7 Flood Hazard Assessment

4.7.1 Data Integration to assess Flood Hazard

A map depicting the spatial variability of flood hazard is prepared by considering major flood controlling factors. These are assigned different weightage values with the help of Scalogram model equation (Table 4.14). The integrated weight values ranging from 14-70 is observed for the Kosi Piedmont Zone. These values are categorised into four classes:

i. Very low hazard susceptibility zone (<15)

ii. Low hazard susceptibility zone (15- 30)

iii. Moderate hazard susceptibility zone (30-45)

iv. High hazard susceptibility zone (45-60)

v. Very High hazard susceptibility zone (>60)

Table 4.14 : Flood Hazard Weightage Assignment

Sub-Factors: A	Ramnagar Environmental Geoinformatics (Main factors): X														Assigned Weightage For Flood Hazard potential
	Geo-structural Setup		Relief Patten		Geomorphology	Land use/cover	Climate		Hydrology						
									Drainage Hydrology				Spring Hydrology		
	Geology with rock types	Structural lineament	Relief (m)	Slope classes	Landforms	Built and non built pattern	Climatic zones	Average rainfall (cm)	Drainage order	Drainage pattern	Drainage density (Km/Km²)	Flood runoff (l/s/km²)	Spring Density (S/km²)	Monsoon Discharge (l/s)	
	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(X7)	(X8)	(X9)	(X10)	(X11)	(X12)	(X13)	(X14)	
A1	Higher Sub Himalaya quartzitic rocks	Fold aligned hills	Above 450	Below 4°	Gravelled hilly terrain	Forest land	Tropical	Below 150	Below II order	Elongated (<0.7)	Below 1	Below 100	Below 1	Below 30	1 for Low Hazard
A2	Middle Sub Himalaya massive sandstones	Joint/Fractures zones	420-450	4°-8°	High level fluvial terraces	Scrubs land	Sub tropical	150-175	II-IV order	Triangular (0.7-0.8)	1-2	100-200	1-2	30-50	2 for Moderate Hazard
A3	Large rock blocks and boulders of Share zone	Shear zone	390-420	08°-12°	Middle level terraces	Agriculture land	Moist sub tropical	175-200	IV-VI order	Oval (0.8-0.9)	2-3	200-400	2-3	50-70	3 High Hazard
A4	Alluvium made up of gravel, pebble, sand and silt	Fault/thrust aligned valley	360-390	12°-16°	Low level terraces, terrace scarp, landslide and debris flows areas,	Barren land and waste land	Sub temperate	200-225	VI-VIII order	Less circular (0.9-0.10)	3-4	400-600	3-4	70-90	4 for Very High Hazard
A5	Alluvium made up of sand, clay, silt, sandy clays	Combination of above	Below 360	Above 16°	Bank cut area, gulling & rills, flood plains, younger alluvial fan,	Built-up area of settlement, road and brittle paths etc.	Temperate	Above 225	Above VIII order	Circular	Above 4	Above 600	Above 4	Above 90	5 for Extreme Hazard

4.7.2 Spatial Variability of Flood Hazard

Fig. 4.19 illustrates the spatial distribution of flood hazard susceptibility zones in different locations in the study area and the description is as follows:

4.7.2.1 Very low flood hazard zone: Upstream areas having very low rate of flood runoff (below 100 $l/s/km^2$) due to least stressed natural geo-environment of dense forest cover on Upper Siwalik sandstone and gravels in the northern areas are identified under very low flood hazard susceptibility (Fig. 4.19). Out of the total area of the Kosi Piedmont Zone about 10% (7.27 km^2) area is under very low flood hazard susceptibility zone, around dense reserved forest area of Corbett Park, Teda, Kosi Range and Chhoi (Table 4.15 and Fig. 4.19).

4.7.2.2 Zone of Low flood hazard : Mid- stream areas having slightly higher rate of flood runoff (100-200 $l/s/km^2$) due to comparatively stressed geo-environmental background of fairly dens and shrubs land on high level fluvial terraces made up of Middle Siwalik massive sandstones identified as low susceptibility zone of flood hazard which accounts for 9% (6.54km^2) part of the study area around down slopes of northern areas covered by fairly dense forest (Table 4.15 and Fig. 4.19).

4.7.2.3 Zone of Moderate Flood Hazard : The areas having moderate rate of flood runoff (200-400 $l/s/km^2$) in middle level terraces because of fragile geo-environment (comprising large rock blocks and boulders under share zone covered by shrubs and crops with 200 cm annual rainfall) are identified for moderate susceptibility zone of flood hazard. This zone accounts maximum 51% (37.05 km^2) part of KPZ around Bhawaniganj, Shivlalpur, Shankarur, Bairajal, Talla Kaniya, Karanpur, Nandpur, Nayagaon, Bhaguwabangar, Chilkiya, Tanda and Basai (Table 4.15 and Fig. 4.19).

4.7.2.4 Zone of High flood hazard : The land surface of low level terraces and its adjoining Bhabar alluvial plains receive high rate of flood runoff (400-600 $l/s/km^2$) from upstream areas. Consequently this zone has high susceptibility of flood hazard which accounts for about 18% (13.08 km^2) part of the area around Aamdanda, Pampapur, Bharatpuri, Durgapuri, Teda, Kosi Range, Chorpaani, Gaujani, Kaniya, Himmatpur, Karanpur and Peerumadara (Table 4.15 and Fig. 4.19).

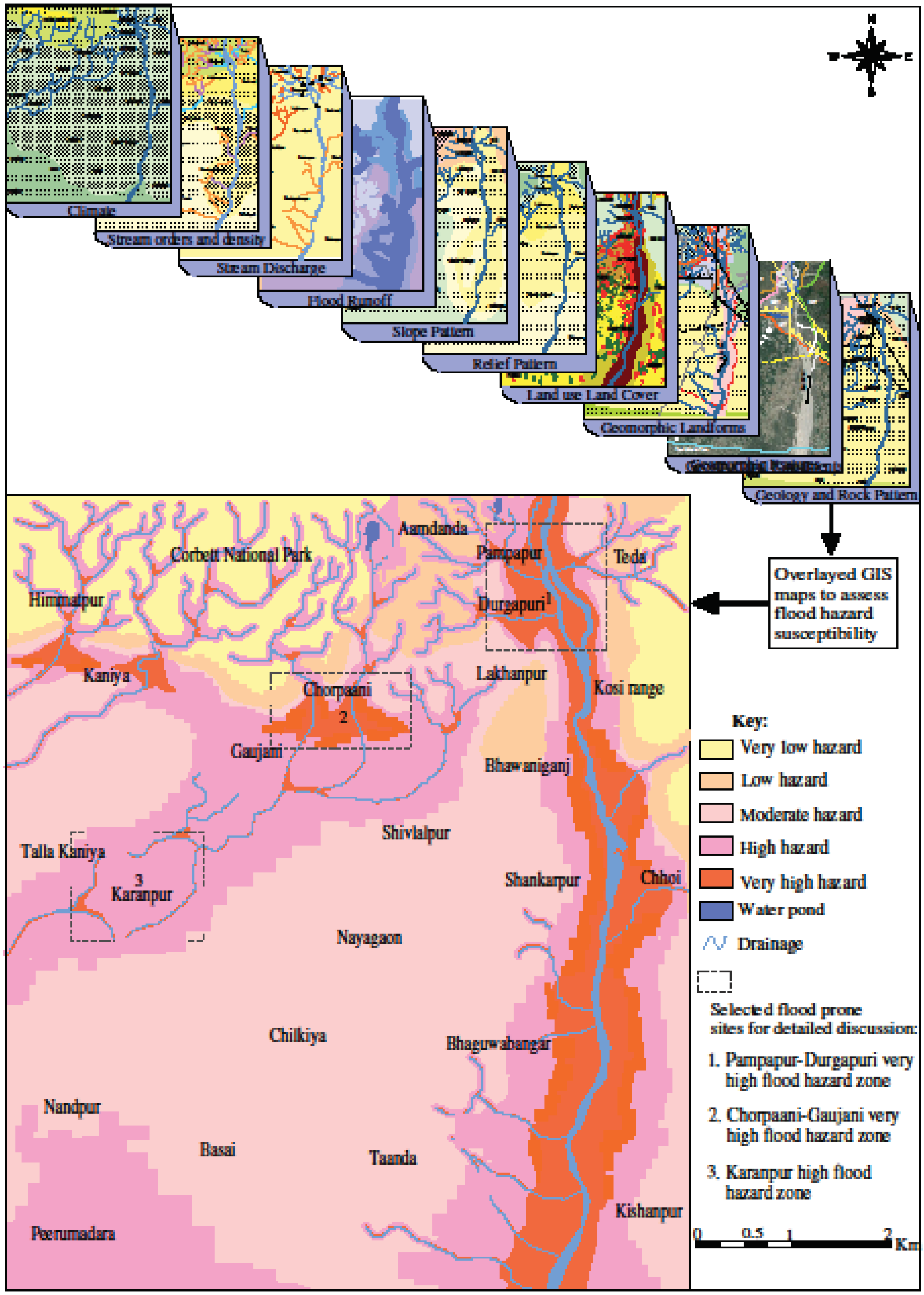


Fig. 4.19 : Flood Hazard Map

Table 4.15 : Spatial variability of flood hazard susceptibility in Kosi Piedmont Zone

Flood hazard susceptibility zone	Accumulated weight values	Area covered		Existing locations having major proportion of the respective flood hazard susceptibility zone
		Km²	%	
Very Low	Below 15	7.27	10	Upslopes of Corbett Park Teda, Kosi Range and Chhoi
Low	15-30	6.54	9	Down slopes of Corbett Park, Teda, Kosi Range and Chhoi
Moderate	30-45	37.05	51	Bhawaniganj, Shivlalpur, Shankarpur, Bairajal, Talla Kaniya, Nandpur, Nayagaon, Bhaguwabangar, Chilkiya, Tanda
High	45-60	13.08	18	Aamdanda, Pampapur, Bharatpuri, Durgapuri, Teda, Kosi Range, Chorpaani, Gaujani, Kaniya, Himmatpur, Karanpur and Peerumadara
Very High	Above 60	8.72	12	Pampapur, Bharatpuri, Durgapuri, Teda, Chorpaani, Gaujani, Himmatpur and Karanpur
Total	14-70	72.65	100	All above

4.7.2.5 Very high to extreme flood hazard susceptibility zone: Landforms under river bank cut area, gulling, rills, flood plains, younger alluvial fans, located along streams and sub-streams receives extreme rate of flood runoff (above 600 l/s/km^2) from upstream areas have very high to extreme susceptibility to flood hazard in the area. This zone covers about 12% (8.72 km^2) of the area mainly Pampapur, Bharatpuri, Durgapuri, Teda, Chorpaani, Gaujani, Himmatpur and Karanpur (Table 4.15 and Fig. 4.19).

4.8 FLOOD HAZARD INDEX (FHI)

Multiple spatial and attribute geo-database of Kosi Piedmont Zone are integrated and superimposed for identifying the vulnerability of existing geo-environmental factors and their sub factors for the flood hazards with the help of Scalogram modeling approach.

Fig.4.20 : Selected Unit (Coloured Grid Cell) for Sample Flood Hazard Index Formulation in the Study Area

Formulation of Unit Flood Hazard Index: Unit flood hazard index denotes the accumulated weightage value for this particular unit. For example a unit of .25 Km^2 area has been selected to formulate flood hazard index (FHI) in the study area (Fig. 4.20). The existing geoenvironmental factors and their sub factors of this unit have been summarised in Table. 4.16.

FHI (Score) =[X1 (A5) + X2 (A4) + X3 (A5) + X4 (A4) + X5 (A5) + X6 (A5) + X7 (A2) + X8 (A2) + X9 (A5) + X10 (A5) + X11 (A4) + X12 (A5) + X13 (A5) + X14 (A5)]

FHI (Score) =[X1 (4) + X2 (0) + X3 (4) + X4 (2) + X5 (3) + X6 (8) + X7 (2) + X8 (2) + X9 (1) + X10 (1) + X11 (2) + X12 (5) + X13 (1) + X14 (1)]

Accumulate weight value = 5+4+5+4+5+5+2+2+5+5+4+5+5+5=61

61 accumulate weight value determined for very high flood hazard zone under which the accumulated weight value accounts above 60. So this unit shows moderate flood hazard.

Table 4.16: Determination of Unit Flood Hazard Index

Sub-Factors: A	(Main factors): X														Assigned Weightage	Accumulated Weight Values of Existing Sub Factors: A1, A1, A3 A4 A5
	Geo-structural Setup		Relief Patten		Geomorpho-logy	Land use/cover	Climate		Hydrology							
									Drainage Hydrology				Spring Hydrology			
	Geology with rock types	Structural lineament	Relief (m)	Slope classes	Landforms	Built and non built pattern	Climatic zones	Average rainfall (cm)	Drainage order	Drainage pattern	Drainage density (Km/Km^2	Flood runoff ($l/s/km^2$)	Spring Density (S/km^2)	Monsoon Discharge (l/s)		
	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(X7)	(X8)	(X9)	(X10)	(X11)	(X12)	(X13)	(X14)		
A1	-	-	-	-	-	-	-	-	-	-	-	-			1	**0**
A2			-				Sub tropical	150-175				-	-	-	2	**4**
A3	-	-	-	-			-	-	-	-	-	-	-	-	3	**0**
A4		Fault/thrust aligned valley		12°-16°	-	-	-	-	-	-	3-4	-	-	-	4	**12**
A5	Alluvium mad up of sand, clay, silt, sandy clays	-	Below 360	-	Bank cut area, gulling & rills, flood plains, younger alluvial fan,	Built-up area of settlement, road and brittle paths etc.	-	-	Above VIII order	Circular	-	Above 4	Above 600	Above 4	5	**45**
Sum	**5**	**4**	**5**	**4**	**5**	**5**	**2**	**2**	**5**	**5**	**4**	**5**	**5**	**5**	**61**	

CHAPTER-5
DISCUSSION AND RECOMMENDATION

The present work advocates that the area has emerged dynamics of flood disaster risk due to rapid urbanization and land use degradation. Despite that, unfortunatelly these densely populated areas have been growing since last three decades with new socio-economic and infrastructural development under high to extreme flood hazard susceptibility zone. Three most vulnerable densely populated built-up areas in Kosi Piedmont Zone are under high to extreme risks of flood disaster and the potential hazard zones identified in the present study are described below:

5.1 Pampapur-Durgapuri :- Zone of very high to extreme susceptibility of flood hazard: This site is one of the most densely populated flash flood prone areas of Kosi Piedmont Zone as it lies in extremely vulnerable wider surface of the alluvial fans which are formed by thick younger sediment deposits at the mouth of streams along the right bank of Kosi River floodplain in the North of KPZ (Fig. 5.1). The site lies between the latitude 29°24'02"-29°24'47"N and longitude 79°07'31"-79°08'30"E which covered an area of about 2.14 km^2. This extreme flood prone zone has very high population density of about 9440 persons/km^2 (Census 2011) whereas thirty years back it was quite low about 475 persons/km^2 (Census 1981). High rate of population growth and urbanisation has multiplied the vulnerability and socio-economic risks of flood disaster due to very high to extreme flood hazard potentiality of the location.

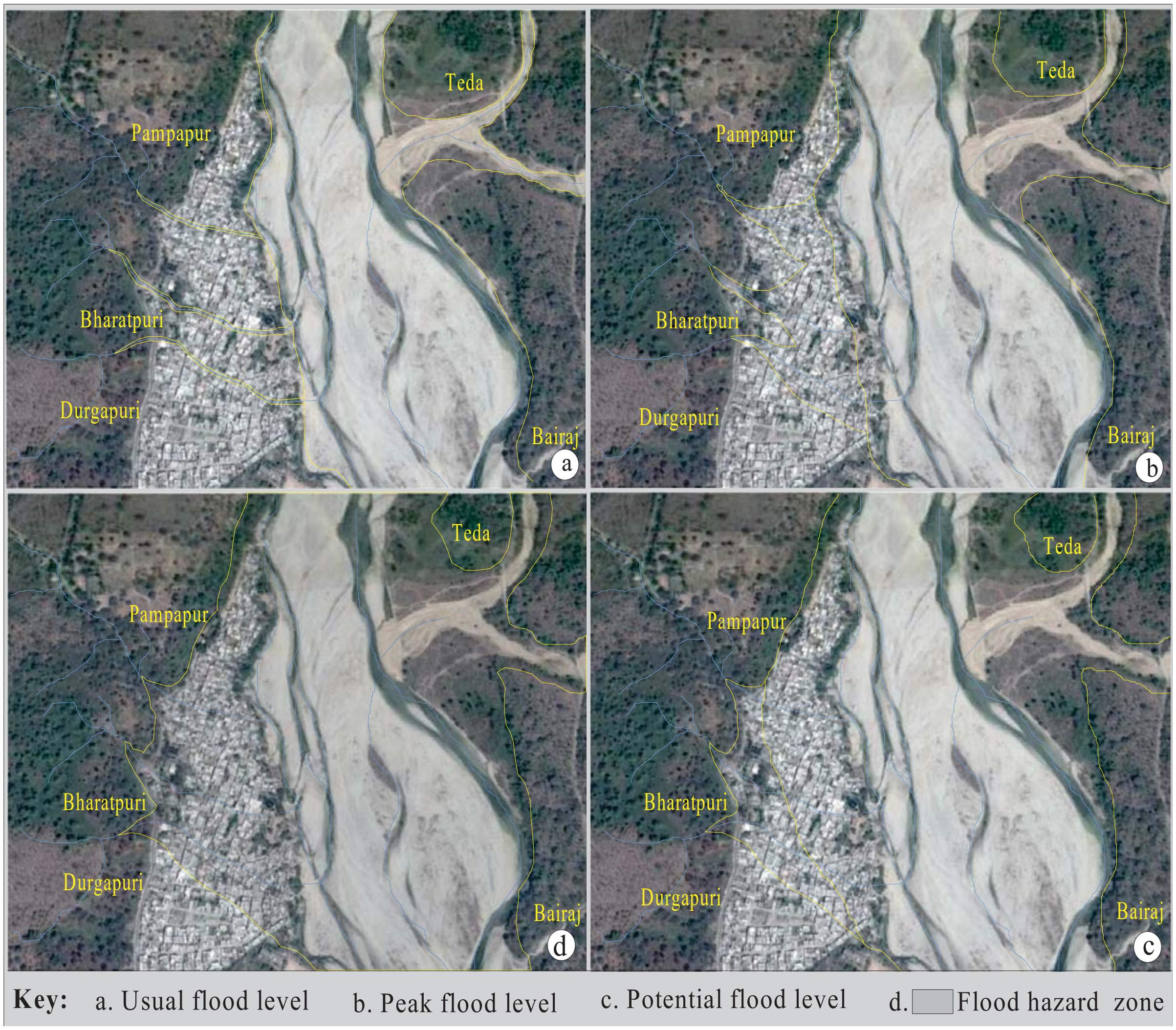


Fig. 5.1 : Flood level conditions in Pampapur-Durgapuri

5.2 Chorpaani-Gaujani :- Zone of very high to extreme susceptibility of flood hazard: This densely populated flash flood prone area of Kosi Piedmont Zone located on extremely vulnerable alluvial fan (Fig. 5.2). This zone has covered an area of about 2.15 km^2 and lies between the latitude 29°23'25"-29°23'58"N and longitude 79°05'51"-79°06'47"E. This vulnerable zone has been experiencing rapid urbanization process and new settlements and colonies are coming up. Consequently, population density has increased from 74 persons/km^2 to 2610 persons/km^2 during last three decades (Census 1981 and 2011) resultant to increasing vulnerability and socio-economic risks due to very high flood hazard potentiality of the location

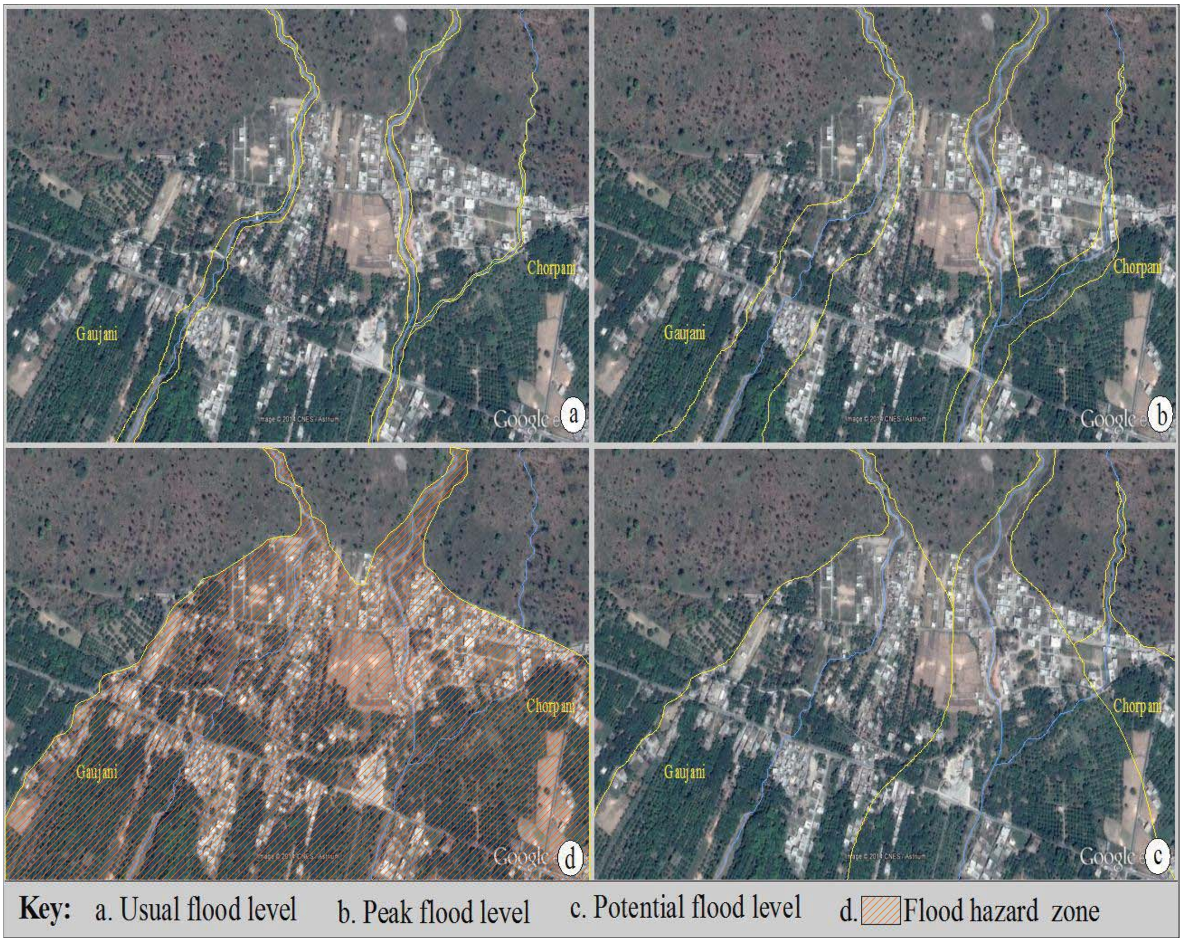


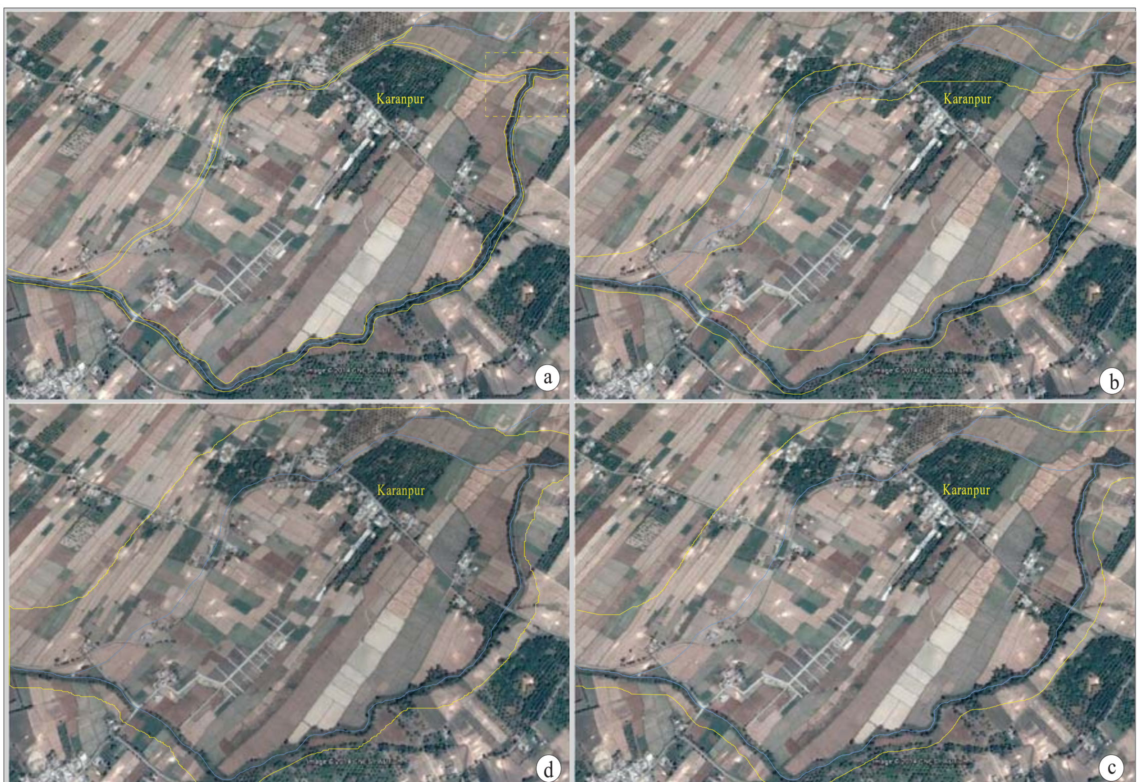
Fig. 5.2 : Flood Level Conditions in Chorpaani-Gaujani Zone

5.3 Karanpur :- Zone of susceptibility of high flood hazard : It is a river line flood prone zone of the Kosi Piedmont Zone along the right bank of Fooltal river which flows from up slopes of Siwalik Himalaya to Gangetic plain in the North-West part of the town (Fig. 5.3). This river brings very high volume of monsoon flood runoff and sediment from rapidly urbanizing upstream area (Chorpaani-Gaujani Himalaya Foothill Piedmont Zone). The river has caused tremendous amount of erosion along the banks washing away crops and productive land. Sometime it deposits unsorted sediments over agricultural fields and settlements. The zone coveres an area about 2.54 km^2 lying between the latitude 29°22'20"-29°23'02"N and longitude 79°05'15"-79°05'44"E. Karanpur is a newly affected flood prone area caused due to over flow of the Fooltal river. (Fig. 5.3). There are two key causes for such events –

i. Rising river bed due to high rate of sedimentation which comes with surface runoff of rapidly urbanizing (constructions and developing colonies, roads and settlements etc.) upstream area (Chorpaani-Gaujani Himalaya Foothill Piedmont Zone).

ii. Farmers occupied the flood plain of the river banks from both sides to enlarge their agricultural land and leave very narrow space for stream flow only.

Fig. 5.3 demonstrates the site from where the monsoon peak flood flow of the Fooltal river diverts towards Karanpur area as the flood runoff following natural river course and adequate depth and width of the river bed. At peak discharge during floods, the Karanpur inhabitants have great threat for socio-economic risks in each monsoon season.



Key: a. Usual flood level; b. Peak flood level; c. Potential flood level; d. Flood hazard zone; Flood diverted site selected for discussion

Fig. 5.3 : Flood Level Conditions in Karanpur Zone

After detailed study of flood hazard and their potential risks as mentioned in Chapter 4, following engineering and biological measures can be suggested in different hazard prone areas of the Kosi Piedmont Zone. These measures can be categorized in two sections as they may time to exist in the required flood hazard sites. A brief discussion on both types of measures is given below:

5.4 Immediate Short term Measures

Such measures are expensive than others. These are generally engineering measures which can develop within short time period and may require further maintenance and reconstruction each year after heave floods.

5.4.1 Dewatering of the Slope

This is considered as the most effective and practical measure of landslide control and slope stabilization. This measure diverts the water away from the landslide area by improving surface and sub-surface drainage systems. Following methods can be proposed for dewatering of slope:

5.4.1.1 Surface Drainage Diversion : It has been proposed that streams and water courses must be diverted around the crown of the slide and the potential hazard area through properly lined drains and ditches with adequate gradient to prevent entry of water into open joints, tension cracks, etc. This is particularly useful for slopes which are subjected to rapid drawdown (Bandari, 1985).

5.4.1.2 Sub-Surface Drainage Diversion : It includes tunnels, sub-surface trenches, deep seated counter fort drains, drills, vertical drainage holds, horizontal boreholes, slope seepage ditches, drainage wells of ferroconcrete, and drainage wells with liner plates.

The diversion of water is one of the less expansive measures in flood hazard management, but it should be well planned before emergency stage has arrived. This diverts the run-off away form the flood affected area. The diversion of flood water could be in form of surface diversion by canals and underground diversion by tunnels.

5.4.2 Construction of Retaining Walls

In order to provide support at the base of the threatened slopes or sliding mass, and to prevent toe erosion, a variety of retaining walls viz., buttresses, cribbing, gabions etc. can be constructed. Retaining walls are used extensively as effective measure for stabilizing precipitous slopes especially along roads.

5.4.3 Check Dams

To increase the infiltration, small check dams are suggested to be constructed along small streams. These check dams will prevent run-off on down slope areas and check the soil erosion.

5.4.4 Embankments

Embankments have been proposed along several streams and their tributary channels in the watershed where the life and property of people is at risk of frequent floods.

5.4.5 Contoured Benches and Terraces

Contoured benches and terraces have been proposed to be lined in the erosion prone areas along-with planting of trees and grasses. Number of vulnerable sites have been identified and suggested for construction of contour-benches and terraces to control erosion in the flood hazard zones.

5.4.6 Coir Netting

It may be recommended against flood induced erosion and landslides throughout the study area.

5.5 Long term and Sustainable measures

These are generally biological measures. Such measures take long time for their development to give their benefits in the flood hazard management. Land use planning and community awareness development on disaster risk management are some of them as discussed below:

5.5.1 Land use planning

Land use planning is an effective, eco-friendly and low cost biological measure. A comprehensive sustainable land use planning must be developed considering all flood hazard (geology, geomorphology, relief characteristics, drainage hydrology, spring hydrology, watershed geo-ecosystem) and disaster (land use pattern, infrastructural development, population and other demographic setup) controlling factors

5.5.2 Community Awareness Development

It is also a long time taking measure of disaster management. This measure has two aspects to develop disaster management awareness in the society. First aspect is to examine the public awareness level about disasters and their multiple impacts on society and environment. Second is to formulate different awareness programmes about disasters management which will develop and enrich community awareness level about disasters.

CHAPTER-6

SUMMARY AND CONCLUSION

As chapter 1 introduce that the flood is one of the most numerous natural disasters in the planet; their frequency, magnitude and the cost of environmental and socioeconomic loss are on the rise throughout the world. The international disaster database (EM-DAT) centre reported that across the world, out of total annual natural disaster events, maximum 45% are flood disaster events whereas remaining 55% comprises of other types of disasters. Consequently each year floods caused for death of about 60000 people and affect more than 30000000 people in the world by losing their families, homes, and livelihoods. Beside that floods devastates expensive socioeconomic development and infrastructure. This quivering picture and large scale losses of flood disaster motivates to know its key causes.

There are several different causes of flood disaster which can be categorized broadly as meteorological causes (comprises of local meteorological dynamics and global climate changes impacts, cloudburst rainfall, extreme rainfall events etc.), hydrological causes (to instant surface runoff under barren land and hard rock areas, rapid snow melt induced flood, geomorphological causes (comprises of glacial lake outburst landslide dam outburst, and failure of dams and other hydraulic structures) and socioeconomic causes (comprises of land use degradation, rapid unplanned urbanization and high population density).

Compiling previous research work and available international disaster database (EM-DAT) the present study concluded that across the world the South East Asia region has highest socioeconomic and environmental losses of flood disasters due to high geo-ecological and socioeconomic vulnerability (increasing population, rapid urbanization, dynamic seasonal climatic conditions, active geo-tectonics, varied hydrological systems, asymmetrical relief pattern and its reshaped geomorphology) of the region to flood disasters. Further international disaster database (EM-DAT) accounts that in this region each year flood caused for more than 58000 human death (97% of world) and more than 3600000 US dollars economic losses (70% of world) while about 30000000 people (95% of world) affected badly.

In order to that South East Asia's regional flood data recorded by EM-DAT, suggests that about 79% flood events occurs in Himalayan and its trans-boundaries countries in this region. Though each and every part of the Himalaya are more to less susceptible for natural calamities, but its foothill piedmont zone due to complex structural geology, geomorphology, and seasonality in hydro-meteorological conditions experience natural disasters very frequently, specially flood, erosion, landslides during monsoon period. Beside that rapid urbanization resultant to high rate of land use change and natural resource degradation which has been accumulating the vulnerability and socioeconomic risks of flood disaster in the region. Keep in view these factors the fast urbanized Himalayan foothill piedmont zone need to comprehensive study on flood hazard for the implementation of effective sustainable developmental planning at local level on a scale of 1:25000.

The Kosi Himalayan Foothill piedmont zone in district Nainital, Uttarakhand (India) has been selected for the case illustration. The study area lies in between latitude 29°20'41"N to 29°25'32"N and longitude 79°05'53"E to 79°09'48"E. The climatic conditions shows variation throughout the study area. The study area consists of rapidly urbanizing Himalaya foothill Ramnagar Municipal Town (RMT). In the past 30 years, RMPTA has undergone through urbanization in the villages resulting in the surroundings to experience various environmental changes. The geo-structural and hydrological background of the research work seems to be extremely stressed for several catastrophes such as floods, landslides, erosion and earthquake, etc..

The main objective of the proposed study was to monitor spatial variability of flood hazard integrating multiple traditional and modern methodologies and geo-techniques. Geo-hydrological results advocates that the study area is highly vulnerable for flood disaster due to dynamic upstream hydrological process which reshaped its downstream piedmont geomorphology. Rapid urbanization resultant to high rate of land use change and natural resource degradation which has been accumulating the vulnerability and socioeconomic risks of flood disaster in the region. Subsequently the spatial variability of flood hazard varied from very low for geo-ecologically balanced system to extreme high for geo-ecologically stressed system throughout the region. Comparative study of demographic setup (land use pattern and populating density) and flood hazard zone map suggests that the most of the densely populated (2610-9440 person/km^2) areas are under moderated to extremely high flood hazard zones which need to implement a effective disaster risks reduction (DRR) program to manage such flood events.

Finally the study proposed DRR program with the recommendation of several engineering and biological measures. The engineering measures includes dewatering of the flood prone area (by surface drainage diversion and sub-surface drainage diversion), structural constructions (comprises of retaining walls, check dams, embankments, contoured benches and terraces coir netting etc.) whereas most effective eco-friendly and low cost biological measures comprises of comprehensive scientific sustainable land use planning and aware the local community to hazards and disaster risk management.

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