FLOOD HAZARDS IN JALPAIGURI DISTRICT AND ITS MANAGEMENT

Thesis Submitted for the Degree of Doctor of Philosophy in Science (Geography and Applied Geography) Under the University of North Bengal

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2011

DEDICATED

TO

MY FAMILY

DECLARATION

The material embodied in this thesis "Flood Hazards in Jalpaiguri District and its Management" being submitted by Shri. Suprakash Roy to University of North Bengal, Raja Rammohunpur, Siliguri, District Darjeeling, West Bengal is original and has not been submitted in part or full for any other diploma or degree of any university including associateship, fellowship or any other similar title or recognition. The work of other authors or any other organisations / agencies wherever made use of, in this study have been duly acknowledged at relevant places.

Suprakash Roy

Raja Rammohunpur

Date: 30/11/11

Preface

Floodplain is built up of layers of sediment deposited by the river when it periodically overflows its normal banks. There is a natural tendency for a river to deposit sediment in its channel during times of low flow, so that an equilibrium state is attained at where the river comfortably fills its main channel under normal conditions. Therefore the river spread out automatically onto its floodplain during periods of high flow. Expansion of human settlements and cultivation in the floodplains hinders free movement of flood water and thereby creating a disaster like situation. In terms the beneficial role of flood becomes disastrous to the society, environment and the economy.

Sub-Himalayan Jalpaiguri district is endowed with an intensive network of river systems. Most of the rivers are considered to be highly notorious for their unpredictable nature, letting loose fury of flood and problem of extensive and regular bank erosion, avulsion, renders thousands of homeless during the rainy season. The majority of the rivers originates in the Himalayas and enters from a north to northwesterly direction and flows south to southeasterly direction. As many of the rivers originate at the same hill, flood often occurs simultaneously and the rivers coalesce to form a single vast sheet of water.

Deforestation via-a-vis environmental degradation in the watersheds indeed plays the decisive role in contemporary increased frequency and magnitude of flood hazards in Jalpaiguri district. Vicious cycle of degradation has already been established. Flood protection measures so far taken have been found counter-productive and instead of offering the desired protection practically complicated the problem further.

Perhaps, the only possibility to save the habitable environment lies into the pro-active watershed management. It is thus, our imperative duty to inform the people living in threshold areas i.e., prohibitive and restrictive zone within the watersheds categorically about the hard reality of possible hardship during the different stages of watershed restoration and management processes.

Acknowledgement

I express my deepest gratitude and indebtness to my thesis Supervisor Dr.Subir Sarkar, Professor, Department of Geography and Applied Geography, North Bengal University for his valuable guidance, constant encouragement and active involvement made this thesis possible.

It is needless to state that doing this research and writing this thesis has only been possible through the support of lots of different people. It is nearly impossible to thank everybody separately here without forgetting to mention anybody.

I express my gratitude to all the Faculty members of the Department of Geography and Applied Geography, North Bengal University for their constant encouragement and valuable suggestions. I express my sincere thanks to my fellow Research Scholars in the department and the Non-Teaching Staff members of the Department of Geography and Applied Geography, North Bengal University for their constant encouragement and necessary help in course of carrying out the present research.

Also special mention should be made about the field support provided by many un-named villagers in the vast district of Jalpaiguri during the field survey.

Finally, I am deeply indebted to my parent & my Brother who have always blessed me with endless love and affection. I am also thankful to my wife and my children for their constant support and for having to put up with lot of patience and sacrifice, as always. I must express my gratitude to Shri Swapan Kr. Basu for his encouragement & support throughout my life.

November, 2011 Suprakash Roy

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Introduction

Scope of work

Throughout the human history, floods have been part of his destiny. They are widely discussed today as a result of increased public awareness and greater destruction caused by them. Perhaps, flood is one of the most dramatic interactions between man and his environment, emphasizing both the shear force of natural events and man's inadequate efforts to control them.

Jalpaiguri district in West Bengal being situated not far from the Himalayan margin is endowed with an intensive network of river systems. Most of the rivers are considered to be highly notorious for their unpredictable nature, letting loose fury of flood and problem of extensive and regular bank erosion, course shifting, renders thousands of homeless during the rainy season. The majority of the rivers of Terai and Duars originate in the Himalayas and enter from a north to northwesterly direction and flows south to southeasterly direction. As many of the rivers originate at the same hill, flood often occurs simultaneously in many rivers and the rivers coalesce to form a single vast sheet of water. Moreover, the simultaneous melting of snow accumulated on high mountains and rainfall in lower reaches often caused floods of devastating nature. These along with sudden bursting of water storage in the upper catchment caused by heavy landslide that blocked river channel released unbelievable volume of water through the river Tista in 1968 and caused unprecedented devastation.

The catchments of these rivers have mostly been deforested and the clearings of the steep slopes have been used for the extension of settlement, agriculture, plantation and communication, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfalls, innumerable landslides are caused, transporting large amount of sediment to the rivers. Most of such landslides have never been treated scientifically with proper protective measures and as such those are in the habit of expanding their territories during monsoon. This often added more and more silt to the rivers, which are incapable of transporting the loads efficiently under the existing hydrological conditions, especially areas beyond the foothill.

During summer, the observed increment of the size of bars and shoals downstream to the piedmont area proves such a contention. In order to avoid such numerous islands in midst of the channel, the rivers, in their lower reaches thus, attains the significant physical characteristic of braiding which may be attributed to both incompetence and incapacity of the rivers. That is, most of the rivers can transport neither the total amount of debris nor the size of debris that is supplied to it as bed load. As a result, the riverbeds are rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods. Moreover, the narrow road and railway bridges, spanning the rivers as well as the pillars supporting them, are always considered to be the barriers, interrupting natural load movement behavior of the rivers. This often cause accelerated deposition at the bottom of the bridge and thereby, narrowing the outlets of the rivers gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and firm lands.

Although, flash flood has not been an uncommon phenomenon in the foothill area of Jalpaiguri district, the frequency and magnitude of such events have increased many folds during the recent past. Two such catastrophic events during the last decade (1993 and 1998) demonstrate the enormity of damage and ever-increasing threat to the biosphere of the sub-Himalayan North Bengal a whole.

At this moment, therefore, suggestion of flood hazard management and their active implementation is of vital concern to the resident of the district. As such, the present investigator has been studying the flood problems of the major sub-Himalayan rivers with special reference to the river Tista, Torsa, Jaldhaka, Sankosh Raidak and Mahananda to formulate management model that would be of immense help in managing the problems like flood, bank erosion, and avulsion in the sub-Himalayan Jalpaiguri district.

Hypothesis

High intensity rainfall induced flash flood are primarily nature's way of adjusting fluvial dynamics along the Himalayan margin. Such an adjustment has been deleteriously distributed by the human interferences. The river like Tista, Torsa, Jaldhaka, Sankosh, Lish, Gish Diana, Rethi, Pagli, Kaljani etc are incapable of transporting the load efficiently under the existing hydrological conditions, especially along their lower reaches. The hydrological characteristics of these rivers are highly erratic in nature in conformity with the erratic precipitation.

The increased frequency and magnitude of flood occurrences in Jalpaiguri district is essentially man induced. Inadequate and half-hearted attempt to control flood hazard through embankments and dykes are found counter-productive in the recent past. The investigator firmly believes that the flood as natural process is uncontrollable thus a different approach of flood management would be of immense help in reducing flood hazard scenario in Jalpaiguri district.

Objectives

The following objectives have been adopted to study the problem of flood hazards of Jalpaiguri district.

1. Collection and synthesize the available information, data and literature to apprehend the geographical background of Jalpaiguri district.

2. Assessment of hydrological and morphological parameters of the major rivers in Jalpaiguri district i.e., Tista, Torsa, Jaldhaka, Raidak, Sankosh and Mahananda.

3. Assessment of high intensity rainstorms as triggering factor of flood hazard in Jalpaiguri district.

4. Quantitative assessment of the nature and characteristics of the major watersheds including topographical, hydro-geomorphological, land use/land cover characteristics and the nature of land degradation including soil erosion and landslide.
5. Assessment of flood hazard in Jalpaiguri district including history of flood occurrences, causes of flood and flood producing processes, flood prediction, early warning and flood forecasting.

6. Attempt would be made to assess the impact of floods with particular reference to environmental and economic.

7. Environmental and economic cost of flood hazards in Jalpaiguri district shall be attempted. An attempt would also be made to identify the vulnerable areas using standard method.

8. To suggest flood management plans with particular reference to best alternatives.

Study area

The Jalpaiguri district lies between 26^0 16' to 27^0 00' north latitudes and 88^0 25' to 89^0 53' east longitudes comprising an area of 6227 sq. km. The rectangular shape Jalpaiguri district is elongated in east-west direction and is bordered by Assam in the east, Darjeeling district and Bhutan in the north, Darjeeling district and Bangladesh in the east and Koch Bihar and Bangladesh in the south. The total population of the district was 3403204 in 2001, showing an increase of 21.52 % during the last decade (1991 –2001). Out of the total population, 37% is schedule caste and 21% schedule tribe. The district consists of 3 sub-divisions, 13 block/panchayet samity, 16 police stations, 148 Gram Panchayets and 774 mauza including 148 tea garden mauza and 31 forest mauzas.

The sub-Himalayan Jalpaiguri district is endowed with an intensive network of river systems (figure 1.0). Most of the rivers are considered to be highly notorious for their unpredictable nature, letting loose fury of flood and problem of extensive and regular bank erosion, course shifting, renders thousands of homeless during the rainy season. The majority of the rivers of Terai and Duars originate in the Himalayas and enter from a north to northwesterly direction and flows south to southeasterly direction. The lateral gap between the two major rivers is in between 3 to 30 kilometer i.e., Torsa – Jaldhaka and Gadadhar – Raidak respectively. As many of the rivers originate at the same hill, flood often occurs simultaneously in many rivers and the rivers coalesce to form a single vast sheet of water.

Physiographically, Jalpaiguri district is a region of diverse and complex area, exhibiting a wide variety of landforms. Their genesis, mode of formation and morphological

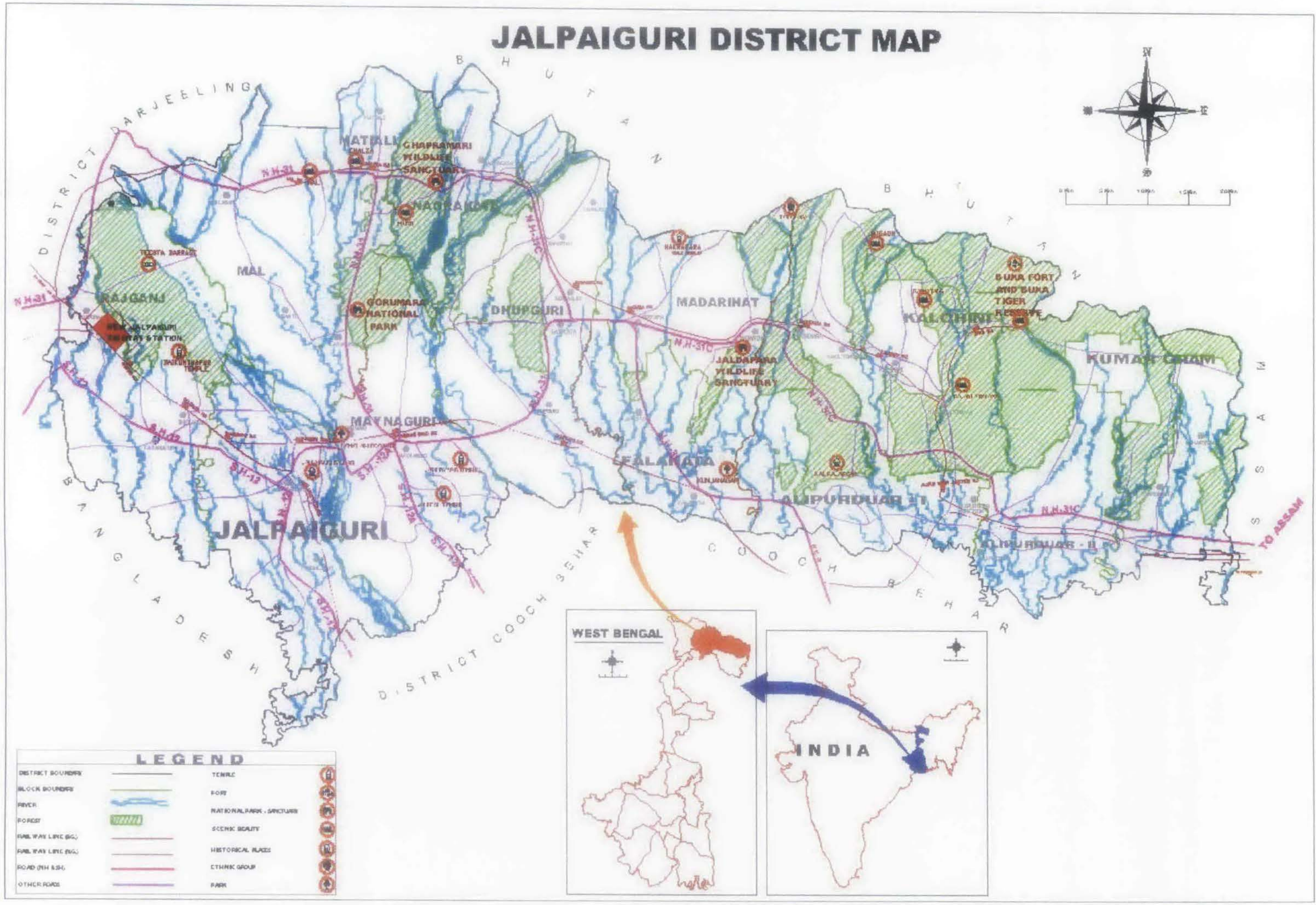


Figure 1.0 Location map of Jalpaiguri district

forms are diverse in nature. Geomorphologic history is characterized by successive catastrophic events of accelerated deposition ding the post-Pleistocene period.

The catchment area of these rivers has mostly been deforested and the clearings of the steep slopes have been used for the extension of settlement, agriculture, plantation and communication, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfall, innumerable landslides are caused transporting huge amount of sediment to the rivers. Most of such landslides have never been treated scientifically with proper protective measures and as such those are in the habit of expanding their territories during monsoon. These often add more and more silt to the rivers, which are incapable of transporting the loads efficiently under the existing hydrological conditions, especially areas beyond the foothill zone.

The history of flood occurrence in Jalpaiguri dates back to 1787, when it caused dramatic changes to the river Tista, which used to flow into the Ganga, deserted its channel and emptied itself into the Brahmaputra through an ancient spill channel. Numerous deserted riverbeds of the Tista, Torsa, Sankosh and Raidak bear the testimony to the fact that the river changed its course at ease often in consequence of heavy rains in the following years.

Documents on the floods and flood-induced evolution of the sub-Himalayan rivers are numerous and fascinating. Record reveals that up to 1787, the river Tista and Karotoya were the same river that flowed through the Atrai-Punarbhaba into the Ganga. Neotectonic activities coupled with high intensity rainfall induced flash-flood caused massive shifting of the river. The so-called whale backed subsurface ridge of the Baikanthapur-Fulbari became active and the Tista migrated eastwards bifurcating the river Karotoya.

The new Tista flowed through Rangdhamali – Jalpaiguri – Haldibari and meets Karotoya again. Thus, the once wide Tista-Karotoya valley dried up and only two narrow channels namely Karotoya and Sahu are still visible. During the flood of 1788-89, the Tista shifted further east and reached Permekhligunje – Jaldhaka of present Bangladesh. The flood of 1897 caused huge deposition and terminated the ferry service between Jalpaiguri to Barnes Ghat. The 1968 and 1993 flood caused massive destruction of Jalpaiguri district.

The natural set-up of Jalpaiguri and its converging followed by divergence in drainage system makes it an ideal place for recurrence of incidences of flood. Among the transient causes of flood, heavy and concentrated rainfall in the upper catchment is noteworthy. Records reveal that the floods of 1906, 1968 and 1993 caused by the high intensity incessant rainfall in Darjeeling and Sikkim Himalaya. Heavy and incessant local rainfall also caused large-scale inundation and flooding at Jalpaiguri town in 1952, 1972, 1998, 2000 and 2002.

About 24% of the total geographical area of Jalpaiguri district is covered by forest. Sal is gregarious but it is found in mixture of a varying proportion of the following species like *Terminalia*, *Chkraisa tabularis*, *Lagerstroemia parviflora*, *Amoora rohiruka*, *Careya arborea* etc. Tea garden, occupy a large part of the district covering 19% of its geographical area and form a characteristic land cover. Among the cultivated crops rice is the most important. In addition to organized Tea industry, many types of small scale and cottage industries have grown up to cater the growing population. Of late, tourism industry is gaining ground yet the poor infrastructure facilities impede the desired development. Jalpaiguri is well connected by rail and road network with neighbouring districts as well as to the other parts of the state.

The percentage of schedule tribe population is 18.87% and the percentage of schedule caste population is 36.71% and the total SC/ST population is 55.58% (Census Report 2001). Jalpaiguri has the highest concentration of SC/ST population in West Bengal. Interestingly, it is to be noted that there is also a fair mixture of different linguistic groups speaking various dialects and languages. On poverty parameters, the below poverty population is 36% for the rural area and 29% for the urban areas.

Methodology

To fulfill the objectives, the methodology adopted by the present investigator is rationalistic one, comprising of an integration of hydrological, geo-morphological and meteorological investigations. The proposed methodological framework for the study comprises of the details outlined as follows:

Reconnaissance survey:

The investigator obtained the basic aerial data from different government organizations, from maps published by the Survey of India topographical sheets (1:50000), US Army topographical maps (1:250000), Satellite imagery and from the work of individual researcher. These have been used under GIS platform (ArcGIS 9.2) in preparing the detailed programme of the present research work. Significant changes of the hydrological characteristics of various rivers along with geo-morphological and meteorological changes in the catchments would be followed by comparing the old documents with the newer one. Occurrences of flood hazard have been apprehended from old records and documents.

Scheme for data collection

The scheme for data collection has been carried out in two stages. Firstly, different relevant data has been collected from primary source i.e., from direct measurement at the field. Secondly, relevant data will be collected from different organizations such as Central Water Commission (CWC) and their field stations, North Bengal Flood Commission (NBFCC), Irrigation and Waterways Department, Flood Meteorological Office (IMD), different Tea Gardens, G.S.I, Kolkata, etc. and also from previously published reports.

The investigator also obtained data & necessary information from the secondary sources like census handbook of Jalpaiguri district and district Gazetteer. The data was collected from different Departments of State & Central Govt. offices.

Primary information will be collected from field surveys. Mainly questionnaire survey will be initiated in the flood-affected areas to assess the cost of flood hazard. Primary data will be generated for comparative analysis of flood hazard using Survey of India maps with satellite imageries. Field survey will also be carried out in some vulnerable areas to understand the flood mechanism and to apprehend its mitigation processes.

To assess the **flood hazards** the investigator used the contingent plan from District Magistrate office, Relief department, Jalpaiguri and North Bengal flood commissioner office, Jalpaiguri. To assess the existing protected structures and other measures the investigator depends on the record available at various Line departments.

Data Processing

As mentioned earlier that data has been collected from various sources. The reliability of the data collected from secondary sources will be checked statistically. The following methods would be applied in the processing the hydrological data of the selected rivers:

High intensity rainfall data (daily) has been gathered mostly from the tea gardens located within the study area. Daily rainfall data during the monsoon months has also been collected from the Flood Meteorology office, Jalpaiguri, IMD and from the field sites of the Central Water Commission (CWC) stations. Long term precipitation data has been collected from both IMD and tea gardens. After necessary validation the long term precipitation data of 3 tea gardens and of Jalpaiguri town (IMD) has been statistically analysed for understanding the trend and the probability using MS excel.

Methods for watershed analysis

In view of non-availability and restricted nature of topographic maps (Survey of India) of the watersheds, the investigator used the US Army Topographic Maps (1:250000) No. NG 45-3, NG 45-4, NG 45-7, NG 45-8, NH 45-16, NH 46-13, NG 46-1, NG 46-5 for the delimitation of watersheds situated across the international boundary. An attempt has also been made to analyze the catchment characteristics along with land use pattern based on the maps. Satellite image available from NRSA (LISS 3 & LISS 4), Google Earth has also been compiled for systematic quantitative analysis of the basins.

The investigator tried to analyse the nature of the terrain, geomorphology of catchment area using standard method. The land use pattern of the watersheds has been assessed from the topographical maps and updated by using satellite imagery under ArcGIS 9.2 platform.

Identification of the impact of flood was done based on both primary and secondary sources. Extensive field visits were made to assess the impact and also sample questionnaire survey has been conducted in the affected villages. Flood contingency plan of District Collectorate has also been consulted in assessing the nature and extend of flood damages. Newspaper report and other documents and manuscript have also been thoroughly consulted.

To compile the bibliography as well as reference work, the libraries of North Bengal University, Calcutta University, Jadavpur University, National Library, Kolkata, records of North Bengal Flood Control Commission, Jalpaiguri and River Research Institute, Haringhata will be thoroughly consulted.

Finally, in order to understand the flood problems of the sub-Himalayan rivers in Jalpaiguri, all the data collected from the field and various institutional sources will be analysed, processed to provide some feasible suggestions for flood management of Jalpaiguri district.

Chapter I: Geographical Set-up of the Study area

1.1 Introduction

Jalpaiguri is said to have derived its name from the olive trees (*Jalpai* in Bengali), which grew in the town and were seen even in 1900. The suffix *guri* means a place. The name might as well be associated with Jalpes, the presiding deity (Shiva) of the entire region who had been in the minds of people there from time immemorial.

The Jalpaiguri sub-division of Rangpur, so named since 1854, was conterminous with the earlier Sukhani sub-division and it was the nucleus of the district formed in 1869. The local name of a place like Jalpaiguri, which happened to be the seat of a military cantonment, thus gave first its name to the sub-division and then to the district. Earlier in March 1849, Hooker had arrived at *Jeelpigoree*, which was then 'a large straggling village near the banks of the Tista, a good way south of the forest' and at this place according to him, 'we were detained for several days, waiting for elephants with which to proceed northwards.' Naturally, *Jeelpigoree* was then a point of trans-shipment in an area covered by forests (Allen B.C., et al 1906;Dash, AJ. 1947;Gruning, J.F. 1911;Kusari, A.M. et al 1981; Mitra, A. 1951;Sunder, D. H. E. 1985).

At present Jalpaiguri district lies between $26^{0}15'$ 22.5" and $26^{0}59'$ 37.7" north latitude and between $88^{0}23'$ 13.5" and 89^{0} 53' 4.5" east longitude. It comprises of an area of 6,227 sq. km. The district consists of the Western Duars (since 1865) and the Jalpaiguri and Rajganj Thanas of Rangpur district since 1869. The district so formed on the 1st of January 1869 is bounded in the north by the Darjeeling district and Bhutan, in the east by Assam, in the south by Rangpur district in Bangladesh and Koch Bihar district and in the west by Darjeeling district and part of Bangladesh.

The long international border with the countries of Bhutan and Bangladesh has made Jalpaiguri a strategic location so far as the defence, development and economy of this region is concerned. Besides being the largest district in the northern part of the state of West Bengal, with an area of 6227 Sq. Km., this district with a population of 34,03,204 (Census 2001) is the house of many tribes and communities (Toto, Rava, Mech etc.), the abode of a variety of birds and animals, including the rare "clouded leopard", the land of 188 rivers, rivulets and vast, verdant forests, It is the largest tea producer of the state with 158 established Tea Estates. It also possesses Asia's best dolomite reserves in the Duars.

Despite these advantages, Jalpaiguri suffers from many problems. The district has a profuse store of ground water; practically the entire district is a 'white zone'. Still, there is a drinking water crisis in some remote areas and hardly 30% of the water-reserve is utilized. Production of surplus vegetables is coupled with the absence of proper storing facility, impeding the growth process altogether. Poor irrigation and routine flash floods hamper food production and escalate the flood control budget simultaneously. Illiteracy, lack of sanitation, deforestation, poor marketing facility, absence of exposure to modern technology, uncontrolled transformation of agricultural land to tea-gardens, growing unemployment in rural and urban areas, especially in the tea gardens, are the other deterrents to the developmental process.

The district has a vibrant cultural life with the many cultures contributing to its multi-textured life. Administratively, the district is divided into three sub-divisions and thirteen blocks and 16 Police Stations. There are four municipalities and one hundred and forty six Gram Panchayets. Some of the important information relevant to the district is presented below.

1.2 Geological set-up

Geological foundations of the district consist of Precambrian slates, schist, phyllites, dolomites, quartzite, gneisses, lower Gondwana and Siwalik sandstones and recent to sub-recent alluvium (Gansser A., 1964, Kalvoda, J, 1972). Geologically the area is important because coal, dolomite and enormous deposits of construction materials e.g., gravel sand, brick earth etc. The district is entirely underlain by alluvium except its northern border where hard rocks are exposed (Pawde M.B., Saha S.S., 1982). The northern part of the district experienced widespread development of alluvial fans (figure 1.1).

The several tectonic units of the Sikkimese-Bhutanese Himalaya overthrusted towards south are built mostly of metamorphic rocks (Darjeeling gneisses, Daling schist and quartzite, Damuda sandstone with quartzite and shale). To the east of Jaldhaka valley the marginal part is built of Buxa series represented mostly by dolomite and shale (figure 1.1). The Main Boundary Trust (MBT) separates them from the Siwaliks built of sandstones, conglomerates and mudstones, which are overthrusted over the Quaternary fore-deep along the Himalayan Frontal Thrust (HFT). The foreland of the Himalaya is built of Quaternary sediments which show a distinct fractional differentiation starting from boulders and gravels in the root part of piedmont fans and terraces, at distance of 5-10 km from the margin turning to sand and farther downstream to sandy loam and silt.

The fluvio-glacial deposit of the quaternary period has been widely dissected by the rivers. It is drained by innumerable south and southeast flowing rivers among which, Mahananda, Tista, Jaldhaka, Torsa, Raidak and Sankosh are noteworthy. Frequent flooding, bank erosion and avulsion are endemic environmental problems, causing heavy damage to agricultural, forest, tea garden, communication and settlement.

Uplift of the Himalayas during the Quaternary time led to the creation of faults parallel and transverse to the Himalayas in West Bengal (Valdiya K.S., 1998). These faults at some places tend along courses of rivers, often causing shifting of river channels in this region. According to the accounts of former and present geologists, the whole of North Bengal has from time to time, experienced subsidence and upliftment due to faulting. This has caused river incision, creation of swamps, escarpments, river shifting etc. at different places (Chattopadhyay G.S., Das A., 1992; Das A., Chattopadhyay G.S., 1993; Nakata T., 1989).

1.3 Topography

Physiographically, North Bengal is a region of diverse and complex area, exhibiting a wide variety of landforms. Their genesis, mode of formation and morphological forms are diverse in nature. Geomorphologic history of North Bengal was characterised by successive catastrophic events of accelerated deposition during the post-Pleistocene period (Bardhan S. et al 2007). Physiographically, Jalpaiguri district may be divided into 3 major divisions. Major topographic patterns in selected watersheds have been depicted in figure 1.2.

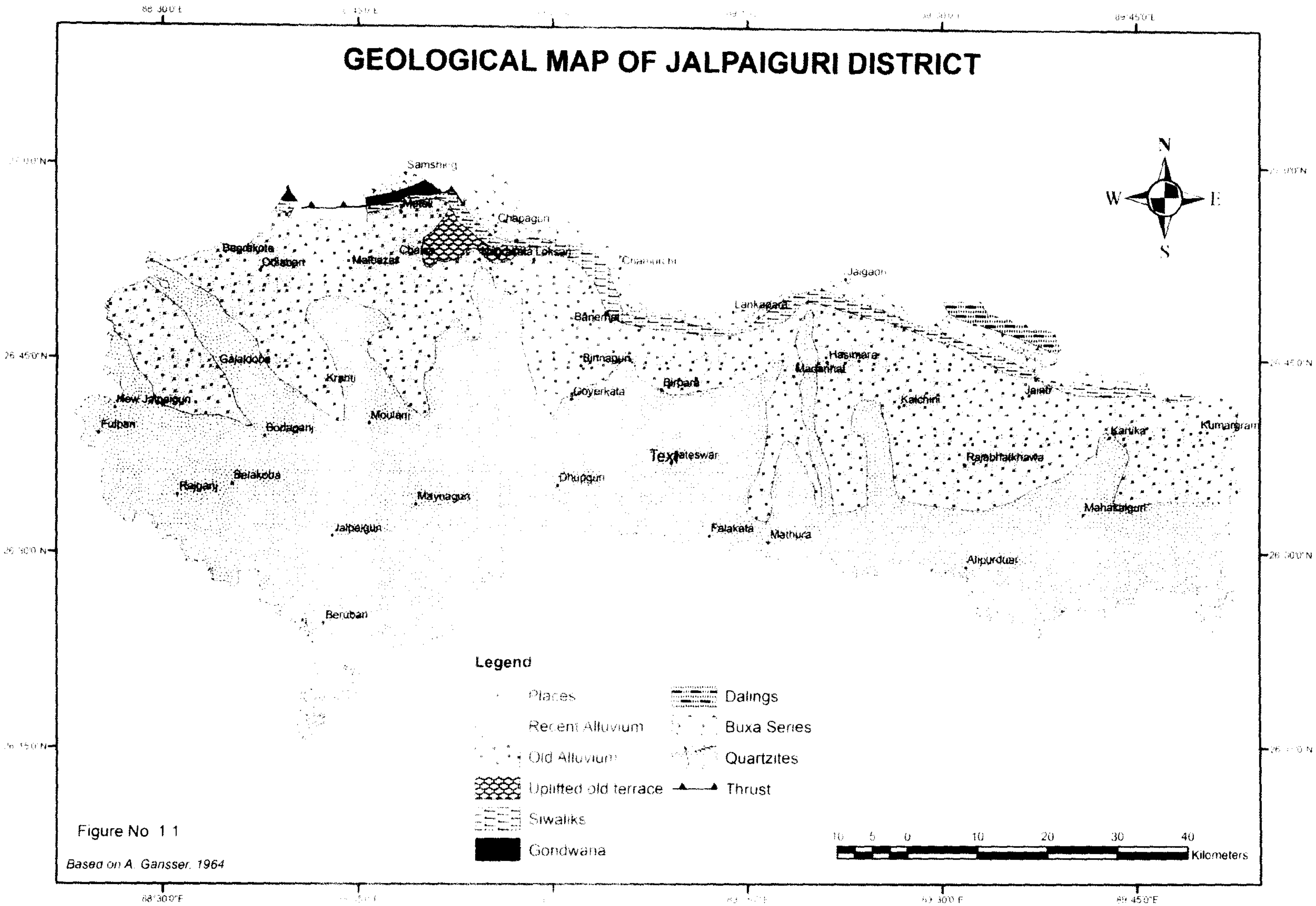


Figure No 1 1

Based on A. Gansser, 1964

1.3.1 The hills

The hilly region of Jalpaiguri district is restricted within its extreme north-eastern part at Buxa area along the international border between India and Bhutan and bounded by the 300 meter contour line. The lesser Himalayas run east to west direction within this region. These are only for small fragments of the mountainous region in the east, which is situated along the northern border of Jalpaiguri district. The Jainti-Sinchula range (700-1600 meter) is situated in this region. The hills rise abruptly from the piedmont plain (120-300 meter) and the elevation increase northwards up to 2000 meter at the Sinchula ridge. Within these, there is a mosaic of micro-topographic units comprising of convex ridges and deep-cut valleys.

1.3.2 The piedmonts

The Piedmont or sub-Himalayan zone is locally known as Duars. It covers the tilted plains at the base of the Himalayas bounded by the 300 meter contour line to the north and 66 meter to the south. It includes the entire northern half of Jalpaiguri district. This is formed due to the coalescing of several alluvial fans within the catchment area of the major rivers like Tista, Jaldhaka, Torsa, Kaljani, Raidak and Sankosh (Sarkar, S. 1990). Rivers and streams which have cut gorges have also given rise to terraces, across the undulating and low plateau like drift deposits thereby, forming a typical landscape, overlooking and often merging with the plain to the south.

1.3.3 The plains

The Plain region of Jalpaiguri district is bounded by the 66 meter contour to the north and the southern territorial boundary of the districts. Perceptible gentle gradient of land is a significant feature of the active zone. Rivers flow through meandering courses and floods are common during the rainy months. Bed load is deposited close to the channel and suspended load with finer silt and clay accumulates in back swamp areas away from the river channels.

1.4 Climate

The climate of Jalpaiguri district is noteworthy because of its position, the powerful effects of the southwestern Monsoon against the Himalayan barrier and the peculiar configuration of the ridges and valleys which deflect or allow rain-bearing winds that affect local temperature and rainfall. Seasons of Jalpaiguri district are found to be dominated by two seasons: cold and rainy, however, two more relatively short spanned seasons i.e., spring and autumn are also noticed.

Climate of Jalpaiguri district is characterized by hot and humid condition. The mean maximum temperature is 31.6^{0}C and the mean minimum temperature is 21.3^{0}C. Mean annual rainfall is 3466 mm. Most of this rainfall is received from May to September (figure 1.3). Occasional high intensity rainfall in catchments area causes devastating landslides and floods. Ground water table is situated fairly near to the surface in the district except the northern part. Ground water table stays within a depth of 2 to 10 meter during the summer except northern part. Though water resource potential is enormous so far irrigation facilities tap only a minimal fraction of this resource.

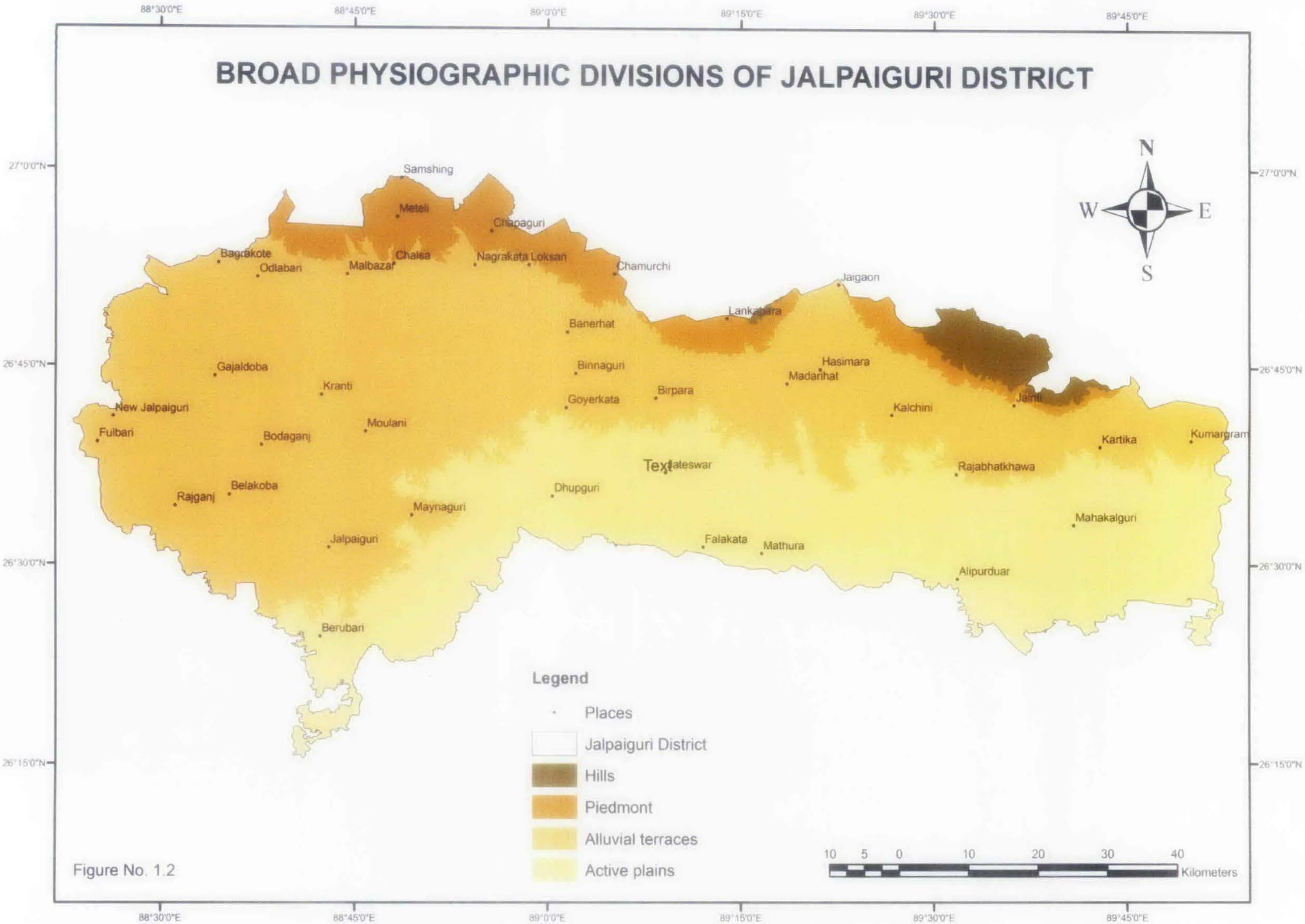
1.4.1 Temperature

Temperature records (maximum & minimum) for different recording stations show that May and June are generally the hottest months throughout the entire district. Maximum temperature recorded to be 39^{0}C in Jalpaiguri. December & January are the coldest months: minimum temperature recorded during the cold months is 6^{0}C at Jalpaiguri.

Table No 1.1

Mean Meteorological Data of Jalpaiguri Town

Month	Mean temp. in ^{0}C Max	Min	Av	Extreme temp ^{0}C Highest	Lowest	Rainfall (mm)	Humidity (%) 0830	1730	Wind vel. (Km/h)
Jan	23.6	10.7	17.2	28.8	5.0	6.9	86	57	1.8
Feb	25.0	12.2	18.6	31.1	2.2	17.0	80	50	2.4
Mar	29.5	15.8	22.7	36.1	7.8	33.3	70	43	3.5
Apr	31.7	20.1	25.9	40.0	10.6	113.3	71	52	4.7
May	31.5	22.6	27.1	39.4	16.1	302.3	79	69	4.8
June	31.3	24.3	27.8	37.2	17.2	683.8	86	79	4.2
July	31.4	25.2	28.3	37.2	22.2	773.9	87	81	3.9
Aug	31.4	25.1	28.3	37.2	21.1	658.9	87	80	2.4
Sept	31.1	24.3	27.7	35.6	21.1	560.6	83	70	1.9
Octo	30.4	21.3	25.9	35.6	21.1	150.1	80	65	1.6
Nov	27.9	16.0	22.0	33.3	9.4	14.2	84	62	-
Dec	24.9	11.8	18.4	30.0	4.3	4.3	82	66	-
Mean	29.1	19.11	24.1	40.0	2.2	3319.1	81.25	64.5	2.6


BROAD PHYSIOGRAPHIC DIVISIONS OF JALPAIGURI DISTRICT
88°30'0"E
88°45'0"E
89°0'0"E
89°15'0"E
89°30'0"E
89°45'0"E
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
N
S
E
W
Samshing
Meteli
Chapaguri
Bagrakote
Odlabari
Malbazar
Chalsa
Nagrakata
Loksan
Chamurchi
Jaigaon
Lankapara
Banerhat
Binnaguri
Hasimara
Madarihat
Gajaldoba
Kranti
Goyerkata
Birpara
Kalchini
Jainti
New Jalpaiguri
Fulbari
Bodaganj
Moulani
Kartika
Kumargram
Rajabhatkhawa
Belakoba
Rajganj
Dhupguri
Maynaguri
Mahakalguri
Jalpaiguri
Falakata
Mathura
Alipurduar
Berubari
Legend
Places
Jalpaiguri District
Hills
Piedmont
Alluvial terraces
Active plains
10 5 0 10 20 30 40
Kilometers
Figure No. 1.2

1.4.2 Rainfall

The sub-Himalayan Jalpaiguri district belongs to the rainiest parts at the Himalayan margin located north of the wide gap between the Deccan plateau and the Meghalaya upland. It has normal seasonal distribution of rainfall with 80-85% concentrated in four summer months and distinct lacks of rain during winter months. The mean annual rainfall fluctuate between 3000 and 5000 mm and the highest rainfall occurs close to the southern margin of steep front of the Lesser Himalaya in Jalpaiguri district. There is a distinct decline of rainfall in both directions: towards the interior of the Himalayas and towards the south drained by the river of Brahmaputra system.

Jalpaiguri district displays great variability in rainfall patterns. Long term data identify Jalpaiguri as the rainiest area, with mean annual rainfall reaching 3465.9 millimetre of which 2776.0 millimetre descends during the 6 monsoon months between May and October. Total rainfall over the non-monsoon period is only 689.9 millimetre. Annual precipitation gradually decreases from north to south and is 3234.0 millimetre at Koch Bihar and again towards further north into the Himalaya to only 2035.9 in Kalimpong. Uneven distribution of rainfall in the region occurs because of variations in its topographic profile and the tracks followed by monsoon depressions. Rainfall is also unevenly distributed over the year, as a result of which over 80% descend during the rainy months (table 1.1).

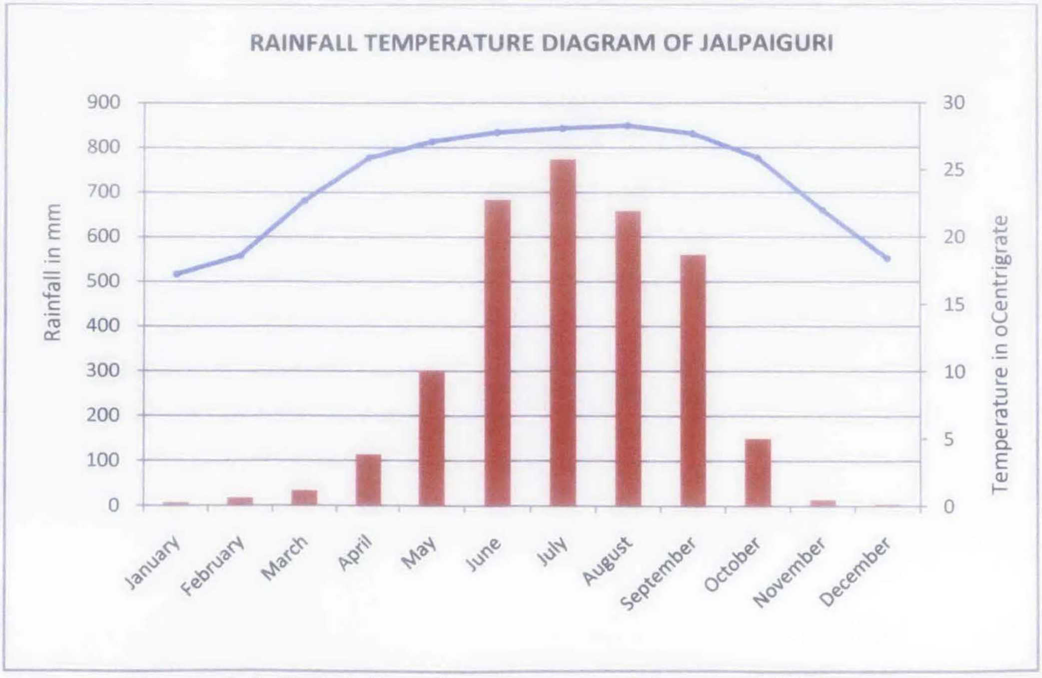


Figure 1.3. Rainfall and Temperature diagram of Jalpaiguri

1.5 Drainage

The district of Jalpaiguri covering an area of 6227 sq km is prone to frequent floods. There are a large number of rivers and rivulets originating or passing through the district of Jalpaiguri. Frequent flash flood in different parts of the district mainly due to high intensity rainstorms within the watersheds of major river systems apart from rainfall within the district itself (Jain V., Sinha R., 2003, Mukhopadhyay, S.C; 1982,Sanyal, C. C, 1968 &1969,Sen S., 1968).

The flash floods which occur due to heavy rainfall often inundate large tract of lands through which these rivers flow. It is because of the enormity of the problems that the several flood control works under taken by the irrigation and waterways Department over the years have not substantially reduced the threat of flood which every year causes loss of life and property.

The flood problems in Jalpaiguri originate from: -

1. Heavy floods caused by intensive rainfall.
2. Sedimentation and changes in river regime.
3. Run off water spilling over the river banks.
4. Bank erosion, meandering tendency of the rivers.
5. Soil erosion in upper catchment areas and there deposition in lower regions.

After the devastating floods of 1954, 1959and 1968, the issue of effective flood management in the district of Jalpaiguri received attention, it deserved at State and National level. According to the recommendations of this High Level Committee on Floods 1957, constituted by Govt. of India, the Flood control Master Plans for the rivers like Tista, Torsa, Jaldhaka, and Raidak were prepared by the Irrigation and Waterways Department, Govt. of West Bengal between 1968 to 1977. These Master Plans stressed on the need of tackling the flood problems by taking basin of each river as a unit. The recommended inter alia, treatment of hilly catchments of rivers by construction of check dams at a number of places, afforestation to same soil mantle on the hill slopes and reduce the property of landslide, gradual stoppage of shifting cultivation and indiscriminate destruction of forest cover. Based on the recommendations of Master Plan the Irrigation and Waterways Department in North

Bengal has so far built 333 km of flood embankments in the district of Jalpaiguri (Sarkar S., 2008, WAPCOS, 2003).

1.6. Soils

Variations in the micro-environments in respect of relief, drainage, climate etc. have led to the formation of different types of soils. The soil of Jalpaiguri district is characterized by its course texture, low water retention capacity, acidic in reaction (5.1 to 7.3) and poor in organic matter (0.5 to 2.2%), nitrogen (0.03 to o.2), phosphorous (29 to 40 kg/hector) and potassium (100 to150 kg/hector).The alluvial fans of the piedmont plains at the base of the mountains are principally accumulation of the coarser materials of heavy mountain wash, e.g., boulder, gravel, pebble, sand, etc. This soil (known as bhabar in northwest India) is deep and coarse at the base of the mountains. It is azonal soil with low percentage of organic carbon, K2O, P2O5 and acidic in reaction.

Soil texture changes towards the south, along the floodplains of the large rivers, comprising the southern part of Jalpaiguri district. Soil pH increases as one proceeds towards the south. Soil texture is relatively coarse towards the north but finer towards the south at Koch Bihar. The soil is mostly acidic (5.0 to 6.5) in reaction due to excessive leaching. The K2O, P2O5 contents are also low in most places, however, higher amount have been found at isolated pockets of the districts.

1.7. Natural vegetation

Jalpaiguri is one of the richest among the districts of West Bengal state in terms of forest resources. Jalpaiguri housed 1740 sq. km. forest area which includes some of the most gregarious species and endangered wildlife(figure 1.4). Altitude, edaphic and climatic factors have influenced the forest types in Jalpaiguri district. Sal is gregarious but it is found in mixture of a varying proportion of the following species like *Terminalia, Chkraisatabularis, Lagerstroemia parviflora, Amoorarohiruka, Careyaarborea* etc. Riverine forests are found in sandy soils near river beds, most important among this type are Acacia catechu and *Dalbergiasissoo* forest found along the beds of all major river runs in the piedmont zone. Wet mixed forest are found in the relatively low lying and damper areas with better edaphic condition, includes *Machilus spp. Listsaca spp., Cryptocarya spp.,Meliosma spp. Eugenia*

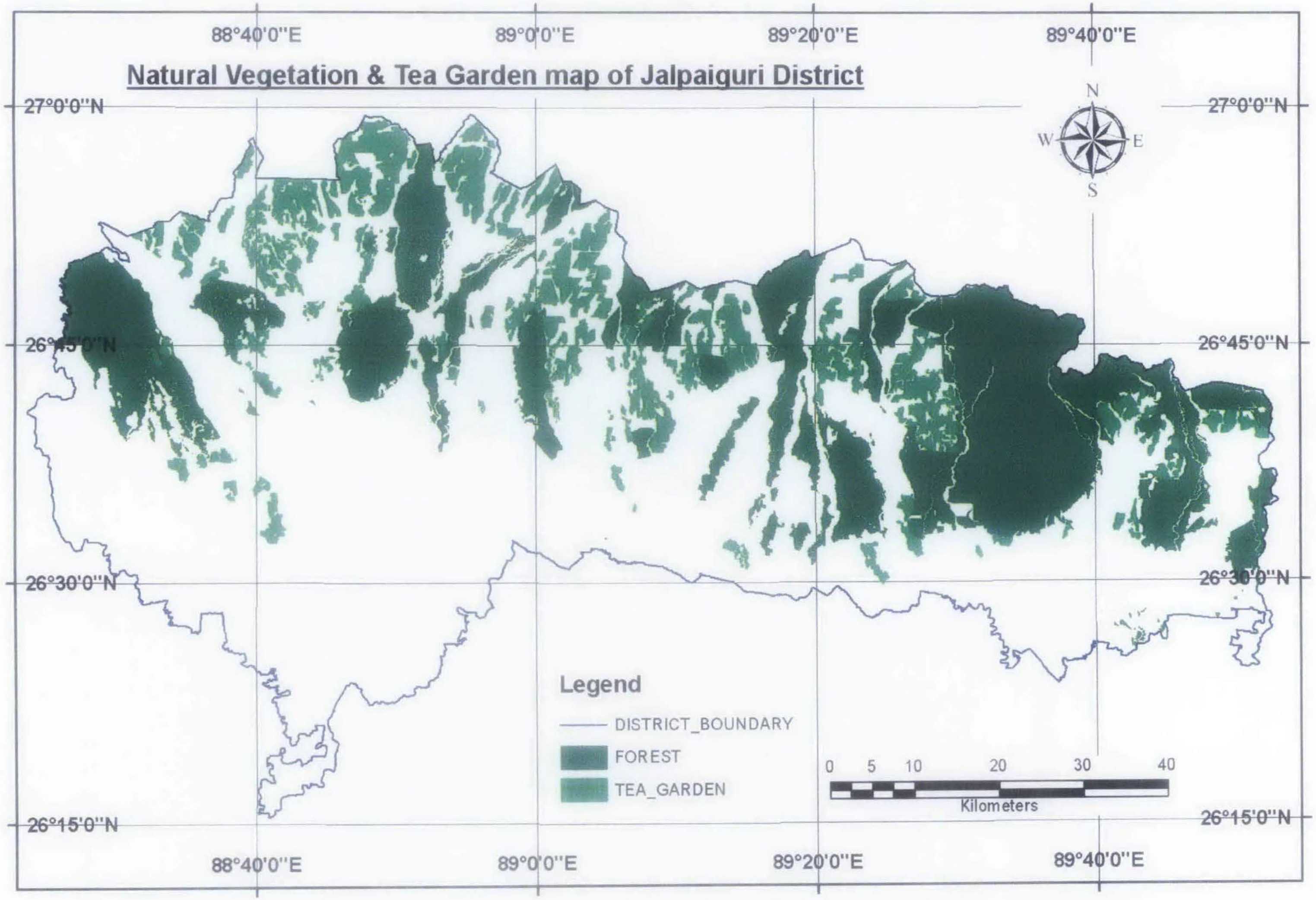


Figure 1.4 Forest and Tea Garden in Jalpaiguri District

spp. etc. Dry mixed forests with the dominating species being *Terminalia*, *Gmeline*, Sterculla, *Machilus spp.* etc. found along the interfluves of the major rivers of the district (figure 1.4).The forest can be classified into two broad groups (Champion H.G., Seth S.K., 1968).

1.7.1 The hill forest

The hill forest can further divided into sub types:

(i) Lower hill forest (up to 1000 meter altitude, comprising Sal (*Shorearobusta*) and also in mixture with a larger numbers of other species i.e., Paccasaj (*Terminuliatomentosa*), Chilauni (*Schimowalichi*), Toon (*Cedrelatoona*) and Chikrassi (*Chukrasiatabularis*) etc.

(ii) Middle hill forest (1000 to 2000 meter altitude) comprising Utis (*Alnusnepalensi*), Walnut (*Juglansregia*), Birch (*Betulaalriodes*), Pipli (*Bucklandiapopulnea*), etc. Upper hill forest comprising Oak (*Quercus*), Buk (*Quercuslameuosa*), Champs (*Michelia spp.*) Katus (*Castanopsishystrix*), Dhupi (*Cryptomeria japonica*), Toon (*Cedrela spp.*) etc.

1.7.2 Plain forest

The plain forest may further be sub-divided into 4 sub--groups such as:

(i) Riverine forests are found in sandy soil, most important among this type are *Acacia catechu* and *Dalbergiasissoo* forest found along the beds of all major rivers in the piedmont zone.

(ii) Mature forest is the most important among the plain forest, comprising the excellent Sal (*Shorearobusta*) in the foothills. Sal is gregarious but it is found to be in mixture of a varying proportion of the following species Terminalia, *Chikraisatabularis,Lagerstroemia parviflora*, *Amoorarohiruka*, *Careyaarborea*, etc.

(iii) Wet mixed forest are found in the relatively low lying and damper areas i.e., better edaphic environment, important species are *Machilus spp.*, *Listsaca spp.*, *Listacespp., Cryptocarya spp., Cinnamonum spp., Actiondaphne spp., Phoebe spp., Meliosma spp., Eugenia spp.* etc.

(iv) Dry mixed forests with the dominating species being *Terminalia, gmeline, Sterculla, Terramelespremna spp., Machilus spp.* etc. are found along the interfluves of the major rivers in Jalpaiguri district.

1.7.3 Deforestation

Jalpaiguri districts have been experiencing the worst heedless deforestation of the country in the recent past. During the last 150 years over 3000 sq. km. of forest tracts were cleared in the name of so called development. The forest covers of Jalpaiguri district has been reduced from 80% in 1850 to 28.11% by the year 2000. The consequence of such massive deforestation of gigantic magnitude involving land use transformation in 42.9% of total geographical area of the district, was most unfortunate and devastating to the contemporary fluvial devastation. The contemporary slope and fluvial devastation in the district of North Bengal particularly in Darjeeling, Jalpaiguri and Koch Bihar are caused by such heedless deforestation in the upper catchment areas in Darjeeling, Sikkim and Bhutan Himalayas.

The tremendous forest resources, unfortunately, do not play a very significant role in the economy of the district. This is because much of the forest resources are out of bounds for the common man. The plethora of forest rules and acts and Supreme Court rulings preclude the easy exploitation of forest resources even in a sustainable manner. This was perhaps necessary from the point of view of managing the environment but in my view, environment cannot possible be managed by ignoring of the realities of the condition of the people living in and around the forests. While people living outside the forest areas cannot derive any economic benefit from the rich forest areas, the approximate one lakh people living in the 77 forest villages (about 3% of the district population) does not derive much economic benefits from the forests either. Of course, when I mean economic benefits, I am referring to the legal exploitation of the forests and not illicit felling that goes on all round the year in almost all the forest areas. Living in abject poverty, segregated from the main stream of the district life, denied the basic facilities such as education and health, these forest villagers are eking out a miserable existence.

The Forest Department has tried to reduce their misery by constituting forest protection committees and eco-development committees but these people have largely been bypassed by the Panchayet Raj institutions and all other Government delivery systems. The Forest Department desires to relocate these people from within the forest areas to outside the forest areas, say the forest fringes. This has not worked out except for a few pockets. For this to succeed there has to be sufficient incentive to enable these traditions bound people to move away from the land tilled by their forefathers. One way to solve the problem perhaps is to extend all facilities to these villagers in situ. If the Government delivery mechanisms cannot reach these villagers, the help of NGOs can be taken. An experiment is already underway in the 11 forest habitations in the Buxa area where a NGO has, with Government help, launched "Buxa Siksha Jyoti Aviyan" aimed at providing primary education to the children in these villages. The gains from this experiment need to be consolidated and replicated across other similarly placed villages. Of course, we also have to add health services quickly.

What is important is to provide a choice of livelihoods to these marginalized people which do not harm the forests. The Forest Department, for example, can consider these villagers to go in for fodder and fire wood collection in the vacant spaces. Cultivation and collection of medicinal plants can also be a very sustainable livelihood for these people. At the same time, to ensure their food security, whatever land is being cultivated by these forest villagers should be made more productive through increased access to new technology and provision of irrigation. This will call for better extension services. In fact, increased agricultural productivity and increased number of crops a year particularly in the forest villages and the villages in the fringe areas, can substantially reduce the advise impact of human habitations close to the forests due to obvious reasons. An exercise to extend canal irrigation through surface water in villages around the Chilapata forest in Alipurduar through the villagers' own initiative and contribution is already being tried out. It is expected that if the proposed canal system (13 km long) comes into existence about 3000 hectares of agricultural land in 11 villages would be able to produce two to three crops a year thereby reducing the people's dependence on the forests for their livelihood.

Jalpaiguri was always known for timber. Due to the onslaught of nature and men and the sustained campaign of environmentalists and the order of the Supreme Court, felling of trees for timber is no more a viable activity for a large section of the population who used to depend on this in the past. While on the one hand, embargo on felling of trees has reduced employment opportunities for people in the forest villages and the fringe areas, it has also in a way contributed to the growth of illicit felling of timber. It must be understood that the felling of trees contributes not only to the timber for making furniture but also wood use as fuel. Since the forests are a major asset and attraction of Jalpaiguri, we need to have a comprehensive strategy to preserve them while offering adequate income generating opportunities to the people. Since a large proportion of the population still depend on wood for fuel, we should develop fuel and fodder plantation in every village to cater to the requirements of that society. For structural timber, wherever possible, the rural population may be encouraged to take up tree plantation outside forest areas. To enable Jalpaiguri to survive, the forests too must survive. However, forests can not survive without the people depending on forests living a healthy and fruitful life. It is, therefore, necessary to take a fresh look at our development efforts in and around the forests of Jalpaiguri.

1.8. Land use

Land use pattern of Jalpaiguri district is controlled by the relief, drainage, soil condition and the level of human interferences. The land use characteristics are related with the broad physiographic divisions. The following table shows the major land use types of North Bengal's districts (figure 1.5)

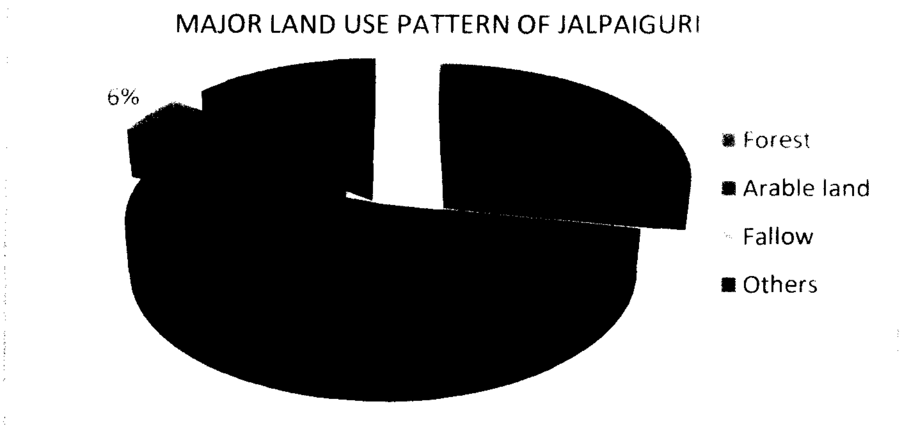


Figure No. 1.5: Land use pattern of North Bengal

1.9. Demography

As per the 2001 Census, the total population of Jalpaiguri district is 34,02,204 of whom 17,53,278 are males and 16,49,926 are females. In 1991, the corresponding figures were 28,00,543 (total), 14,53,194 (males) and 13,47,349 (females). These represent a net increase of 6,02,661 over the last decade. In percentage term basis, this is an increase of 21.5%. A significant part of the population belongs to the SCs and STs. Although, the 2001 Census does not as yet provide the date on SCs and STs an idea can be had on the basis of the 1991 Census data. As per the 1991 Census, the SC population was 10,35,971 which is 36.99% of the total population and the ST population was 5,89,225 which is about 21.04% of the total population. Thus together they constitute 58.02% of the total population. The distribution of the SCs and STs in the district is not uniform and while the STs primarily populate in the tea gardens and forest villages which are more in the northern half on the district, the SCs are more evenly distributed across the district particularly in the southern parts.

In terms of literacy the Census 2001 figures display that the total number of literates in a district is around 18.39 lakh, of whom male constitutes 10.998 lakh and females constitutes 7.391 lakh: in percentage terms 73.64% of the male population are literates and 52.90% of the females belong to this category.

The recently published Human Development Report of West Bengal places Jalpaiguri in the 10th position so far as the overall ranking of the districts in this state is concerned. This has been assessed mainly on the basis of health index, income index and literacy index. The report also states that so far as the delivery mechanism in infrastructure assets is concerned, this district is somewhat backward compared to a number of districts in the state.

1.10. Conclusion

The study area thus composed of several tectonic units of the Sikkimese-Bhutanese Himalaya overthrusted towards south are built mostly of metamorphic rocks. The foreland of the Himalaya is built of Quaternary sediments which show a distinct fractional differentiation starting from boulders and gravels in the root part of piedmont fans and terraces, at distance of 5-10 km from the margin turning to sand and farther downstream to sandy loam and silt.

Geomorphologically, the study area is diverse and complex in nature, exhibiting a wide variety of landforms. Their genesis, mode of formation and morphological forms are diverse and have been characterised by successive catastrophic events of slope wash on the hill slope followed by accelerated deposition along the piedmont during the post-Pleistocene period.

Topographically, Jalpaiguri district may be divided into 3 major divisions namely the hills, piedmonts and the plains. The hills rise abruptly from the piedmont plain (120-300 metre) and the elevation increase northwards up to 2000 meter at the Sinchula Massif. Within these, there is a mosaic of micro-topographic units comprising of convex ridges, inter-mountain valleys, high terraces and deep-cut valleys. The piedmont covers the tilted plains at the base of the Himalaya bounded by the 300 meter contour line to the north and 66 meter to the south. Perceptible gentle gradient land is a significant feature of the plains.

The climate of Jalpaiguri is characterised by extreme diversities in rainfall and temperature pattern between its northern and the southern parts. Mean maximum temperature ranges from 31.7^0 in April to 23.6^0 in December and mean minimum temperature ranges from 10.7^0 in December to 25.2^0 in July. Precipitation also exhibits similar kind of diversity that ranges from less than 3000 mm along the southern margin to over 5000 mm along the northern piedmont. Extreme diversity in geological set-up, topographic forms along with climatic elements exhibits unique biodiversity in the study area.

The district produces a huge quantity of surplus fruits and vegetables. The lack of cold storage and marketing facility are major impediment to the growth of this sector. On the other hand, those factors influence unwarranted transformation of agriculture-land to tea gardens, which again face lower acceptability in the international market. Despite profuse reserves of ground water, some parts of the district still facing drinking water crisis. Jalpaiguri has always been a deficit in its basic need of food grain production and it should immediately be brought under the high yielding stage. To grow more food and to bring more lands under agriculture, creating more irrigation facilities is a must. Tista barrage at Gajaldoba may solve the problem of irrigation in some part of the district but after completion of the project. Deforestation has been a great menace. People virtually eking out on poor agriculture depend on forest produce and forest has been the surrogate source of income.

Under the backdrop of the World's loftiest, youngest and tectonically most active Eastern Himalaya region, the study area exhibits a nature's laboratory for understanding fluvio-geomorphological processes and its ramification within the boundary of their respective catchments.

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Chapter II: River System and Drainage

2.1 Introduction

The sub-Himalayan Jalpaiguri district is endowed with intricate river systems originating from the Sikkim, Darjeeling, Bhutan and Tibetan Himalayas draining across the Himalayas (figure 2.1). The piedmont zone is dissected by mountain streams of various sizes. The proportion of river length and catchment area between zone of erosion and deposition in various types differ considerably (Starkel, L & Sarkar, S, 2002). The river systems of sub-Himalayan Jalpaiguri district have been genetically classified in following 7 types by Starkel et.al, in 2008.

(i) Large transit river originated in high Himalaya. This group is represented by three rivers Tista, Torsa and Sankosh, with perennial discharge, feed both by rain and melt waters. Deep canyons in marginal part and mega-fans in the foreland indicate very high water discharge and high sediment load. Great alluvial fans and braided channels with frequent avulsions extend far up to the river Brahmaputra.

(ii) Rivers dissecting Lesser Himalaya. Only river Jaldhaka under this group drains large catchment, deeply incised also in the Duars, where it is draining the active rising blocks. As a result, its fan surface is developing farther downstream. Other rivers dissecting southern part of Lesser Himalaya with catchments between 50-100 km^2 are located in the belt of higher precipitation (Gish, Chel, Daina, Chamurchi, Reti, Gabur Basra, Jainti etc.) and form large alluvial fans. Aggradations follow upstream into the hills and farther downstream braided channels change to the meandering ones.

(iii) Seasonal or episodic rivers draining only frontal zone of the Himalaya with highly dissected catchments with an area between 10-30 km^2. The area receives the heaviest rainfall (Sukti, Pagli, Pana, Raimatang etc.) and also exhibits steep extensive fans.

(iv) Small creeks starting at the steep scarp of the Himalaya from deep gullies or great landslides, producing large fans with an area of several km^2 modelled by debris flows.

Such creeks usually join some larger river (Dimdima, Dima, Gatia etc.) further downstream.

(v) Rivers draining frontal zone of Himalaya and also the uplifted blocks of piedmont zone. The mountain catchment may differ in size up to 30 km^2, but elevated foreland facilitates down cutting and channels of Neora or Murti rivers are covered by boulders in relatively narrow gullies.

(vi) Rivers starting in middle or lower parts of alluvial fans feed by groundwater and heavy rains have low gradient and meandering pattern. Some of them are localised in the paleo-channels (like along Torsa river) and those are wide and swampy. Most of these rivers is running to the south parallel to the rivers originated in the mountains and finally join them.

(vii) Rivers starting on the flat surfaces or on scarps of tectonically raised blocks and are feed mainly by rain water like Kurti and Sukha jhora between Chel and Jaldhaka river.

Progressing downstream with changing rainfall regime, decreasing discharge, channel gradient and sediment load all rivers gradually change their pattern from braided to meandering. Only the large rivers like Tista, Torsa and Jaldhaka keep their braided character up to the junction with the Brahmaputra. The rivers of Jalpaiguri district belong to two major systems (a) the Brahmaputra River System and (b) the Ganga River System. The major rivers in the Brahmaputra systems in sub-Himalayan North Bengal are:

2.2 The drainage basins and sub-basins

The drainage system of Jalpaiguri district consists part of two major drainage systems namely the Brahmaputra and the Ganga system the two most important drainage basins of the country. The Brahmaputra system is represented in the district by its five major sub-basins i.e., the Tista, Torsa, Jaldhaka, Raidak and the Sankosh sub-system and the Ganga system is represented by the Mahananda sub-system. The maps showing the location of study area and river basins/ sub-basins in North Bengal is given at figure2.2 and tabulated in table 2.1.

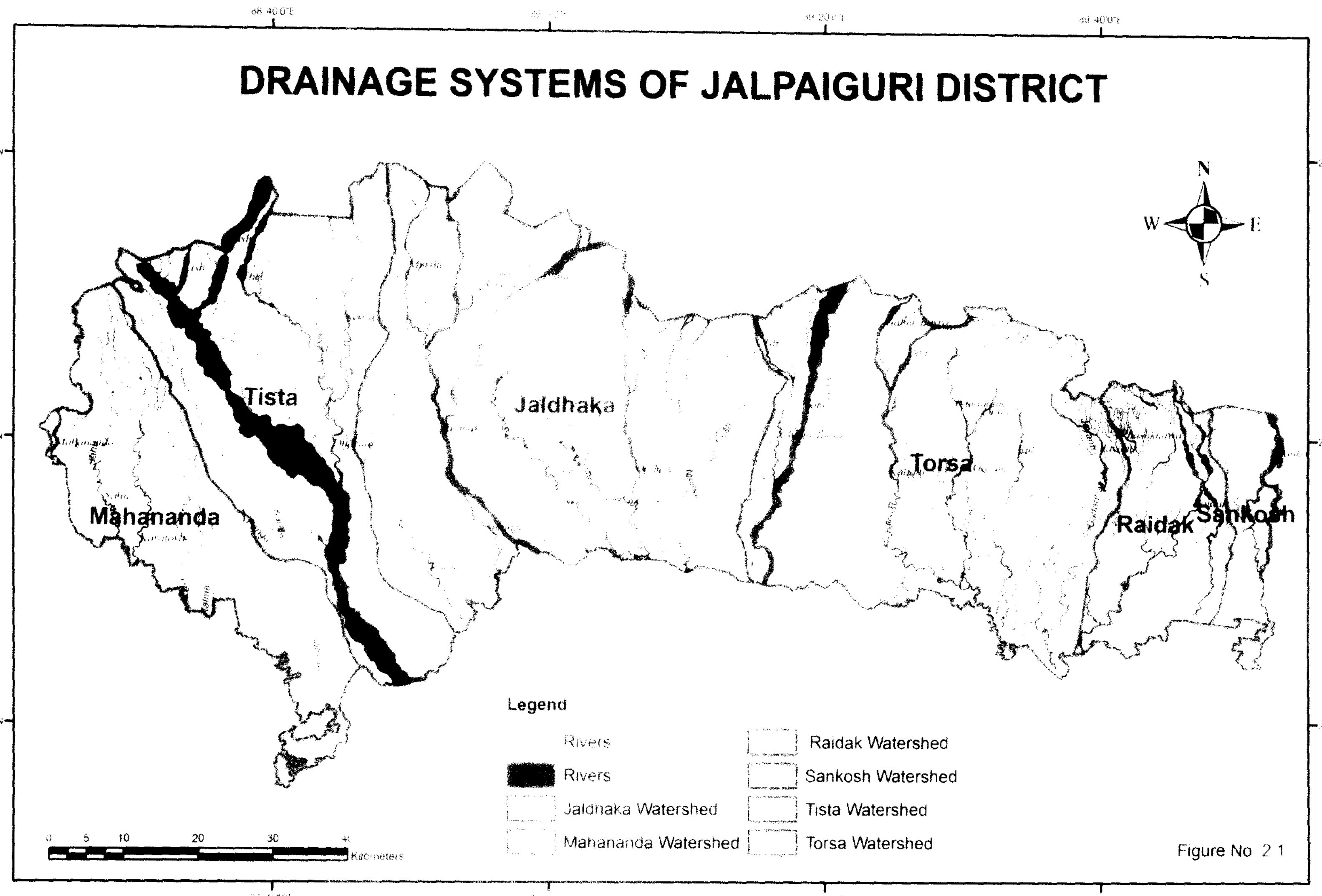
DRAINAGE SYSTEMS OF JALPAIGURI DISTRICT
Tista
Jaldhaka
Torsa
Mahananda
Raidak
Sankosh
N
W
E
S
Legend
Rivers
Rivers
Jaldhaka Watershed
Mahananda Watershed
Raidak Watershed
Sankosh Watershed
Tista Watershed
Torsa Watershed
0 5 10 20 30 40
Kilometers

Figure No 2.1

Table No: 2.1 Area of the watersheds under study

Sl No	Name of Watershed	Watershed Area in Sq. Km.					
		Total	Studied section	West Bengal	Sikkim	Bhutan	Tibet
1	Mahananda	2141*	769	2141	-	-	-
2	Tista	10248**	1206	2855	7393	-	-
3	Jaldhaka	4359**	2028	4281	78	821	-
4	Torsa	7164**	1642	3357	-	2174	1633
5	Raidak	5505**	450	692	-	4813	-
6	Sankosh	10964*	175	473	-	10109	282

* From source to Sub-Himalayan Indian territory; ** From source to Indian territory.

2.2.1 The Brahmaputra basin

The mighty Brahmaputra emanating from the Himalayas near Mansarovar Lake flows through Tibet in an easterly direction. It is known as the Tsanpo in Tibet and then as the Brahmaputra in Assam and Bangladesh. The Brahmaputra is the central waterway in north-eastern part of India. Besides its potentiality of a vast water resource for agricultural economy, it is one of the few rivers in India that is used for inland navigation. It has also the function as the main carrier channel for flood discharges for a large number of big and small rivers, originating from the Himalayan region and from Sub-Himalayan tracts (Dhar O.N., Nandargi S., 2000; Goswami D.C., 1998).

The Brahmaputra flowing through the Assam valley in a westerly course takes a southern swing near the border region of the States of Assam, West Bengal and Bangladesh. In this region, it is joined by the river Sankosh from the north. The Sankosh, which flows along the border of Assam and West Bengal, it taken as the line of demarcation of these two states, Assam and West Bengal. Among the major rivers flowing through Jalpaiguri district Tista, Jaldhaka, Torsa, Raidak and Sankosh are important.

2.2.1.1 The Tista basin

The river Tista is the biggest river in North Bengal (figure 2.2). It originates from the Tista Source Glacier (*Tista Kanyse*) or, Pauhurni Glacier near Khangehung Lake (latitude 29^0 59' N and longitude 38^0 48' E) in North Sikkim at an altitude of 6200 meter. It meets the Brahmaputra (Jamuna) at Kamarganj in Bangladesh at an elevation of 23 meter. The Tista river system, flanked by the Mahananda and the Jaldhaka on either side present a spectacular convergent and divergent drainage pattern. The convergent pattern terminates around 90 meter contour line, subsequently to which the character assumed to be one of divergent one where from, the rivers is spreading out. While, the 300 meter contour line is curving upward indicating convergence of drainage, the 66 meter line in the extreme south is systematically curved downward indicating large scale fanning out or, divergence of the channels (Mukhopadhyay S.C, 1982).

The river rising from the Himalayan hills is enlarged by the contributions of a quite a number of tributaries in the Himalayan and sub-Himalayan regions. Tracing its course in the hilly catchment, which lies in the Sikkim State, the river gets its name Tista below the confluence of two rivers Lachung from the north-eastern direction and Lachen from the north-western direction. The Lachen is fed by a tributary Zemu from the western end, while the Lachung by the tributary Sabo. The Zemu, in turn, is seen to gain in size from the contributions of two streams Lohnak and Tomya.

The combined flow of the Lachung and Lachen, after emerging from Chungthang is known as the river Tista. Further down, the river receives a tributary named Talung from the north-west, which joins the river Tista near Mangan. The Talung receives the combine flow of two tributary streams, Ringpi and Rangha. In the next lower reach of the Tista, three tributaries Bakcho-Dikchu, Rongni and Rangpo join from the north-eastern direction, one after another in the order mentioned. The confluence of the first is at Dikchu (which is above a placed called Makah), the second at Singtam and the third at Rangpo. The second tributary Rongni is the combined flow of two small streams Roro and Taksam. The third tributary Rangpo has also a tributary Rishi.

Below the confluence with the Rangpo River, the Tista river flow is further augmented by inflow through the Rangit river from the western direction. The great Rangit is principally the combined flow of three streams, Rangit, Ramam and ChottoRangit flowing from the north-west, west and south-west respectively. The outfall of the great Rangit into the Tista river is near Melli Bazar. In the next, reach below Melli Bazar, the Tista river, before it emerges into the sub-Himalayan plains of North Bengal, is joined by two small streams, Rangli and Ranghot from the west and east respectively.

DRAINAGE NETWORK OF THE TISTA BASIN

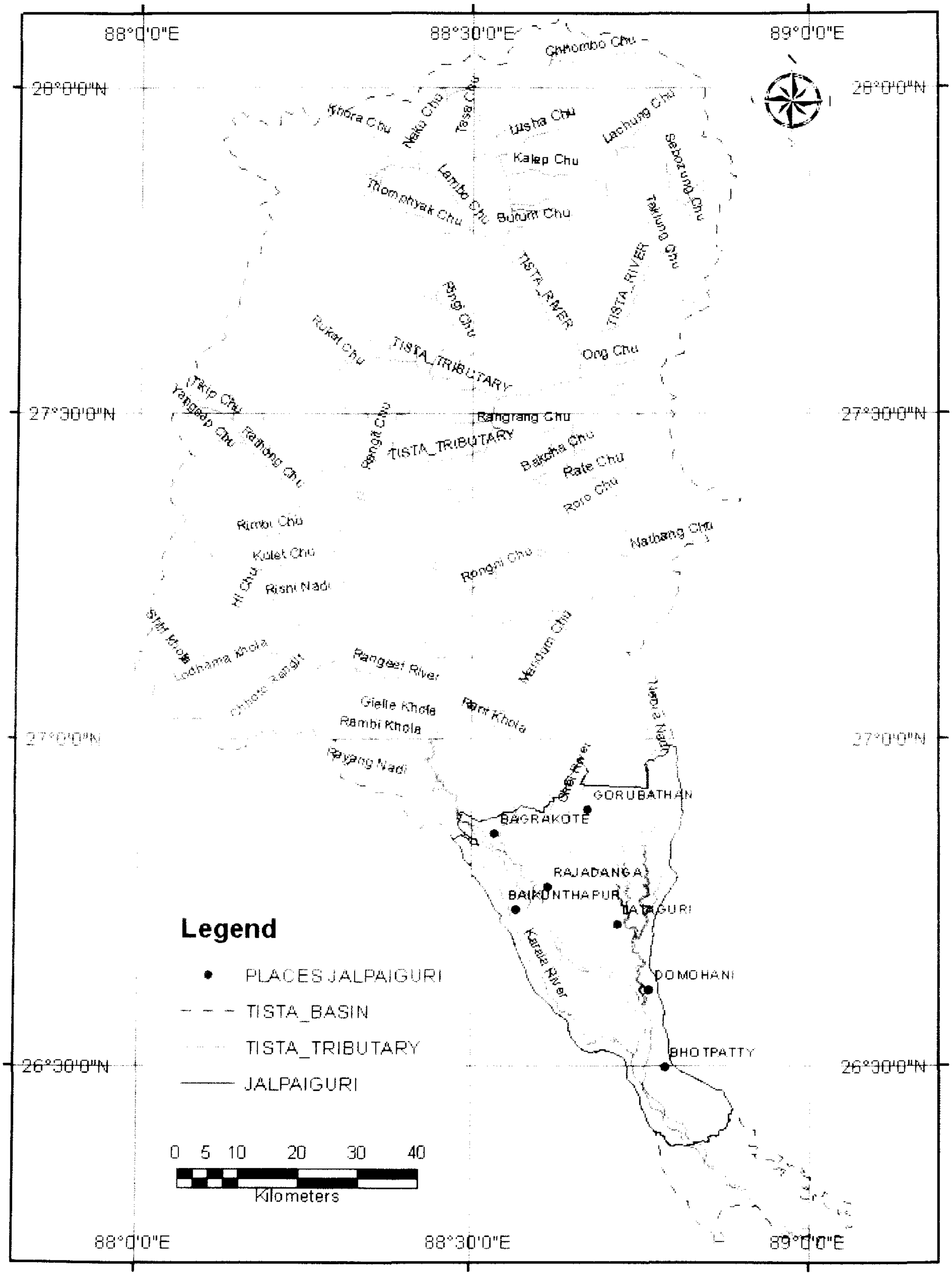

Figure 2.2 Drainage network of the Tista Basin

The river Tista below its confluence with the Rangit flows through the Darjeeling district where two small hills streams join the Tista from the western and eastern directions. The Tista after flowing for about 25 km passes through Sevok before it debauches into the plains of North Bengal. In the sub-Himalayan plains it is again joined by a number of tributaries viz. Lish, Ghish, Chel, Neora from the north-eastern end and the Karala from the north-western end (WAPCOS,2003).

In the mountain gorges, the width of river Tista is not much. At Chungthang, the width of the river is 30 meter and at Singtam 40 meter during autumn. The average depths of water are 1.8 meter and 4.5 meter respectively. Due to formation of too many channels in the plains, the river has widened considerably ranging from 2.4 km to 4.8 km near Jalpaiguri town. From Chungthang to Singtam, the bed slope varies from 35 m/km to 17 m/km. From Rangpo to Tista Bazar, the average slope is 3.8 m/km. The slope of the river at Jalpaiguri is only 0.7 m/km. The velocity is 2.4 m to 5 meter per second. The banks are alternately steep and sloping according to the position of the main channel (Sanyal, C. C. 1967& 1969). The following are the major tributaries of the Tista in Jalpaiguri district.

2.2.1.1.1 River Lish

The Lish Khola has its origin in the Pabringtar KhasMahal Block and Turung khola has its origin in the Samther Forest, highest altitude of which is about 2000m. After the merging of the Lish khola and Turung khola, the Lish river flows southwards and meets Nabgang khola on the eastern side and further 19km down Phan khola on the western side. Lish river then meet Chung khola near the junction of the road to Bagrakote Colliery. The river then flows into Jalpaiguri district and after another 10 kms meets the Tista river at a place near about Kalagaity Tea Estate.

River Lish is 20km in length and drains a total catchment area of 64 sq.km out of which 48 sq.km is hilly. The width of the river in the gorges varies from 60 to 120 m. In the Terai, the width is as great as 1000m at places. The slope of the hills on its banks is very steep varies from 40^0 to 60^0. The bed slope is 24m/km in the hilly region and 11m/km in the Terai region.

2.2.1.1.2 River Gish

The Git khola rises from the Lava Reserved forest and flows between Git beyong on the right and Pankhasari, Samabeyong Khasmahal on the left. Junction of Pembling, Gitubling and Pogrambing, it receives on its right bank, the Reang khola, Nimbong, Nakhi khola, Desi-Khola and Chamu khola are the small tributaries of the river Gish. Another river Lethi originating in the reserved forest, south of Pagrambong Khasmahal meets the Gish in Jalpaiguri district. The river Gish falls into Tista in Jalpaiguri district. The river runs through deep gorges in the hilly region. The catchment area of the river is 160 sq.km and its length is 35km. The width of the river varies from 75 m to 120 m. The bed slope is 22 m/km (Basu S.R. &Ghatowar L., 1986).

2.2.1.1.3 River Chel

The River Chel, a mountain torrent is formed by the amalgamation of two kholas i.e., Chel and Kali khola. The Chel khola originates in the Pankhasari Reserved Forest. While, the Kali Khola rising from the ridge cutting the Gish and Chel catchments on the western part of the Pankhasari Khasmahal Block flows in between the Nim and Pankhasari Khasmahal Block and meets the Chel khola near Ambiok. Ambiok khola, Dalin khola, Sukha khola etc. are the small tributaries of the Chel. South of Mal khasmahal in the Jalpaiguri district it meets Neora and takes the name of Dharala which ultimately falls into Tista above Domohani. The Chel river flows for a length of 54 km. The catchment area is 390 sq.km. The average width of the river is 90 m to 150 m and the slope of the banks is between 30^0 to 60^0. The longitude slope of Chel khola is 52 m/km.

2.2.1.1.4 River Neora

The river Neora originates from Rechilla Chawk of the Neora National Park in Darjeeling district. The river is joined by Thosum Chhu and flows through the National Park and is augmented by several streams in the way. It finally meets the Santhoke khola and Argara khola on the left. The river enters the Jalpaiguri district and meets Chel further down and then with the name Dharala falls into Tista above Domohani. The length of the river is 58km and catchment area 275 sq.km. The width of the river varies from 90 m to 120 m. The valley is mainly on steep hill sides having slopes of 40^0 to 60^0.

2.2.1.1.5 River Karala

The river Karala also known as *Kalla,* one of the tributaries of the river Tista on its right bank, originates from the Baikunthapur forest and flows down to the river Tista at King's Ghat in Jalpaiguri town. To increase the fluvial efficiency of the river Karala, during 1970s, it was re-sectioned, further down slope for 4.5 km. from its original out-fall. Now, the river meets Tista through an artificial waterway near Kadobari, 4 km south of the town. The total catchment area of the river is 141 sq. km. most of which is covered by arable land. The river divides Jalpaiguri town into two halves, the left bank i.e., Karala-Tista interfluve, having administrative offices and the right-bank, occupied by markets, residential and commercial uses

2.2.1.2 The Jaldhaka basin

The river Jaldhaka originates from Bidang Lake in Sikkim at an altitude of 4250 m to 4550 m and is locally known as Dichu in Bhutan. It flows southwards for a length of about 24 km in a straight, steep gradient through mountainous tract up to an elevation of 844 m. At this point, an important tributary namely Assom Khola joins the river Jaldhaka or Dichu on its left bank. Further flowing down, the river meets the river Nichu, a tributary from the right. The river Nichu forms the boundary line between Bhutan and India in this reach (figure 2.3).

The river Jaldhaka then receives an important tributary named Bindu Khola from left. From the confluence of Nichu and Jaldhaka, the main river Jaldhaka itself forms the boundary between West Bengal and Bhutan. The important places near about this point are Godak and Dzongsa Dzong.

From the confluence of Bindu Khola, the river flows down almost southwardly with few minor bends. The river enters into the Indian territory at the confluence of river Jiti which meets the Jaldhaka from the left. No important and major tributary except Jhalong Khola has joined the river Jaldhaka in the reach between Bindu Khola and Jiti.

Just below the confluence of Jiti, the river Jaldhaka bifurcated into two channels and suddenly turns at right angle towards east. Thereafter, two channels unite again. The river turns at right angles towards the south and bifurcates against into two channels namely

Hatinala and Jaldhaka. The Assam Link railway Line crosses the river here. The two channels again join and the combined flow is bridged by the State Highway connecting Chalsa and Nagrakata. From this road bridge, commonly known as Upper Jaldhaka Road Bridge, the river flows in a southwardly direction for 4 km with slight inclination towards west and again bifurcates into two channels. In this portion, the river flows through the reserved forest area and receives the river Ghatia from the left.

The important tributaries of river Jaldhaka are Assom Khola, Nichu Khola, Bindu Khola, Jiti, Ghatia, Kumlai, Diana, Duduya, Mujnai, Dolong, Satanga, Dharala, Girdhari and Murti which are described below:

2.2.1.2.1 River Diana

The river Diana originates in the Bhutan hill at an altitude of about 3,050 m below Dhupi Dara and flows through narrow gorges of Bhutan hills upto the Indo-Bhutan border in a southerly direction. Its length in the territory of Bhutan is 16.1km. The river enters into the Indian Union at an elevation of about 305m and has a high bank on the right which gradually reduces from 38.12 m to 9.15 m. The total length of the river is 25.76km. The bed slope is 110.96 m/km with a total fall of 2851.75 m in a length of 25.76 km. The catchment area of river Diana is 316 sq.km. out of which 222.95 sq.km is falling within the territory of Bhutan.

2.2.1.2.2 River Kumlai

The river Kumlai, also known as a Jhumur in the upper reaches, originates near about Kalabari Tea Garden. It forms the western boundary of the Kalabari Tea Garden and flows due south to the west of Angrabhasha. Total length of the river is 79km. The bed slope of the river is 0.19 m/km having a total fall of 13.12 m in a length of 68.1 km. The total length of the river is 30.59 km. The catchment area of the river is 148 sq.km.

2.2.1.2.3 River Duduya

The river Duduya is flowing on the east of the Jaldhaka and is formed by the union of several small streams like Rangli, Nonai, Rehti Khola and Dim Dima. The total length of Duduya is 33km. The catchment area of river Duduya is 72.5 sq.km.

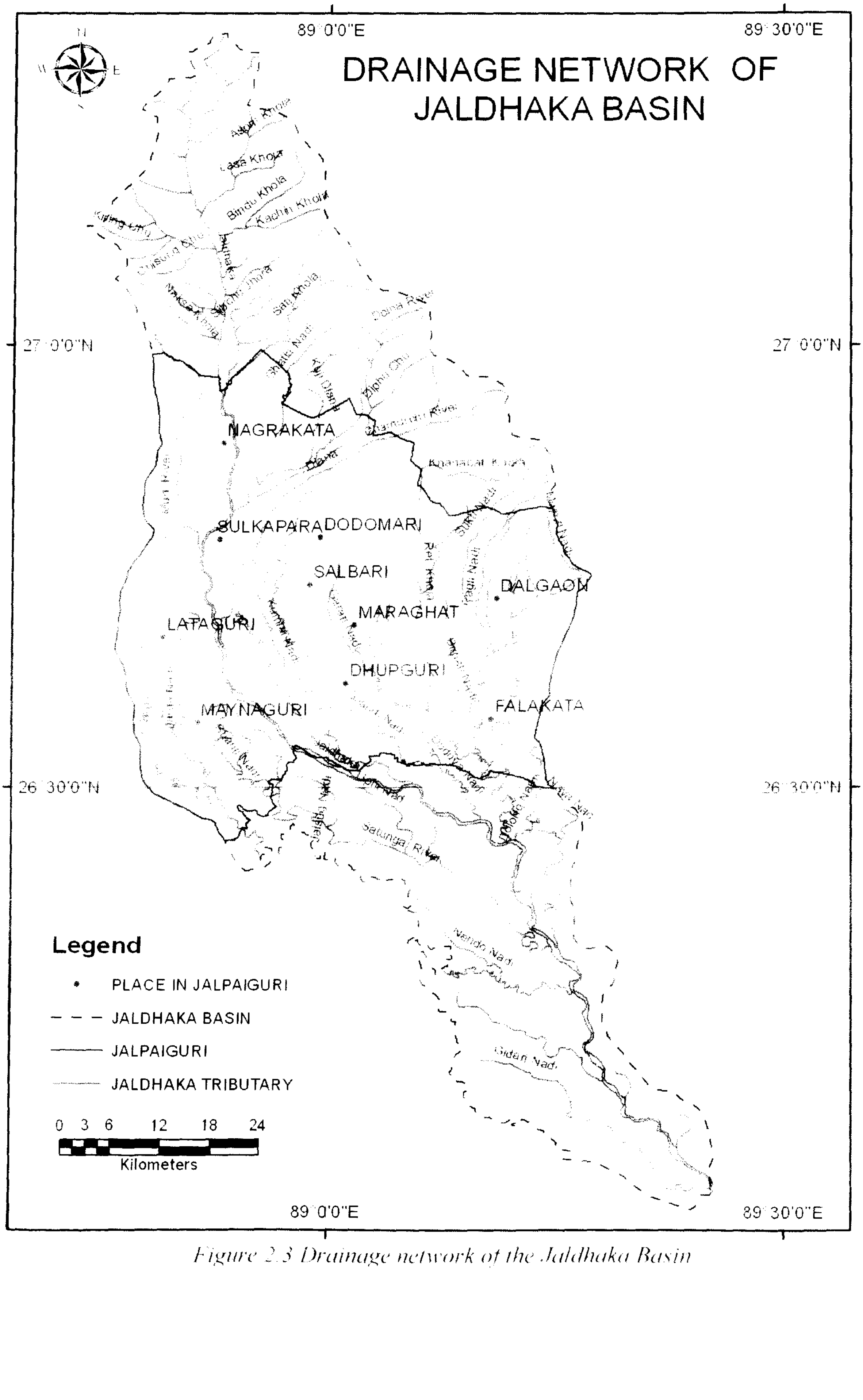

Figure 2.3 Drainage network of the Jaldhaka Basin

2.2.1.2.4 RiverMujnai

The river Mujnai a tributary of river Jaldhaka, originates in the southern slope of the Bhutan Hills. Its upper part is known as Rangari Nadi originating at an elevation of 2,500m just above the Indo-Bhutan Border. The total length of the river is 85.33 km. The bed slope is 32.3 m/km up to the railway bridge and 46 m/km. from railway bridge to the confluence. The catchment area of the river Mujnai is 452.73 sq.km, out of which the area falling in the territory of Bhutan is 31.86 sq.km and the rest 420.88 sq.km. is in the Indian Union.

2.2.1.2.5 River Dolong

The river Dolong originates near the Kadambini Tea Garden in Falakata Police Station of Jalpaiguri District. The river forms the western boundary of the Kadambini Tea Garden. The elevation at this point is 63.44m from the origin and it flows in a southerly direction. The total length of the river is 41.86 km. It flows for a length of 8.05 km in Jalpaiguri district. The catchment area of Dolong is 60.37 sq.km.

2.2.1.2.6 River Satanga

The river Satanga is an offshoot of Jaldhaka River. The river used to carry the spill water of the Jaldhaka through this distributary. A new mouth had been formed during the recent floods at the junction of Jaldhaka river. The total length of the river is 77.28km. The bed slope is 0.475 m/km having a total fall 36.6 m in a length of 77.28 km. The total area of the catchment is 442.89 sq.km.

2.2.1.2.7 Rive Dharala

At one time river Dharala one of the important rivers in North Bengal, used to drain a considerable area. In 1820, Dharala and Buri Dharala were two district rivers and flowed almost parallel to each other till they met near Gitaldah. Since then the Dharala appears to have moved westward and gradually intercepted the bed to Buri Dharala. The Dharala River on the right side originates in the upper blocks of lower Tondu reserved Forest drains a major portion of the forest. The river Dharala on the left side is known as Torsa in its upper reaches and takes off from Torsa near Kodalkheti. The river is also connected with the Jaldhaka at its junction with Dolong Nadi. This connecting channel used to be a portion of Mansai. This has now been connected to Jaldhaka near Kodalkheti.The Total length of the river is 68 km. The river lies entirely in the plains.

2.2.1.2.8 River Murti

The river Murti has been formed by the combination of several hilly jhoras, all rising from the Neora National park in the hills of Kalimpong. The origin of the river is approximately at an altitude of 2,500 m. The total length of the river from its origin upto its confluence with the Jaldhaka within Gorumara forest is about 47.5 km most of its catchment area consists of deep forest. The width varies from about 15.25 m to 475.5 m. and the natural waterway has been blocked in many places through accumulation of big boulders. These boulders have come down from the upper reaches during high floods. Due to the accretion of silt and sand in the bed of the river in the plains, the river has to take out a new course every now and then. Thus, the river cannot flow within a defined course. This is the cause of the meandering characteristic of the river. The catchment area of the river Murti at its confluence is 176.64 sq.km. and mostly consists of forests.

2.2.1.3 The Torsa basin

The river Torsa in North Bengal is notorious for the flood and unpredictable behaviour. The Torsa flows over a considerable length in the Bhutan State. However, the problem starts only when it enters the Jalpaiguri and Koch Bihar districts in the Sub-Himalayan region. The river channel in this region is wide and shallow and the slope is flat. There are a number of spill channels of the Torsa in this region and the flow in this spill channels (during high flood in the Torsa) often exceed their respective carrying capacity. As a consequence, the banks of the river Torsa overtopped and adjoining areas are inundated. The river carries large load of suspended silt, whenever deposited on the bed of the river or of the tributaries, obstruct the flow along the normal course and cause diversion along different paths. The inherent meandering tendency of these streams is in a way due to this silt loads.

The river Torsa originates in the Chumbi valley in Tibet (China) is a trans-Himalayan river in true sense. The Torsa river catchment belongs to one of the largest in the Sikkimese-

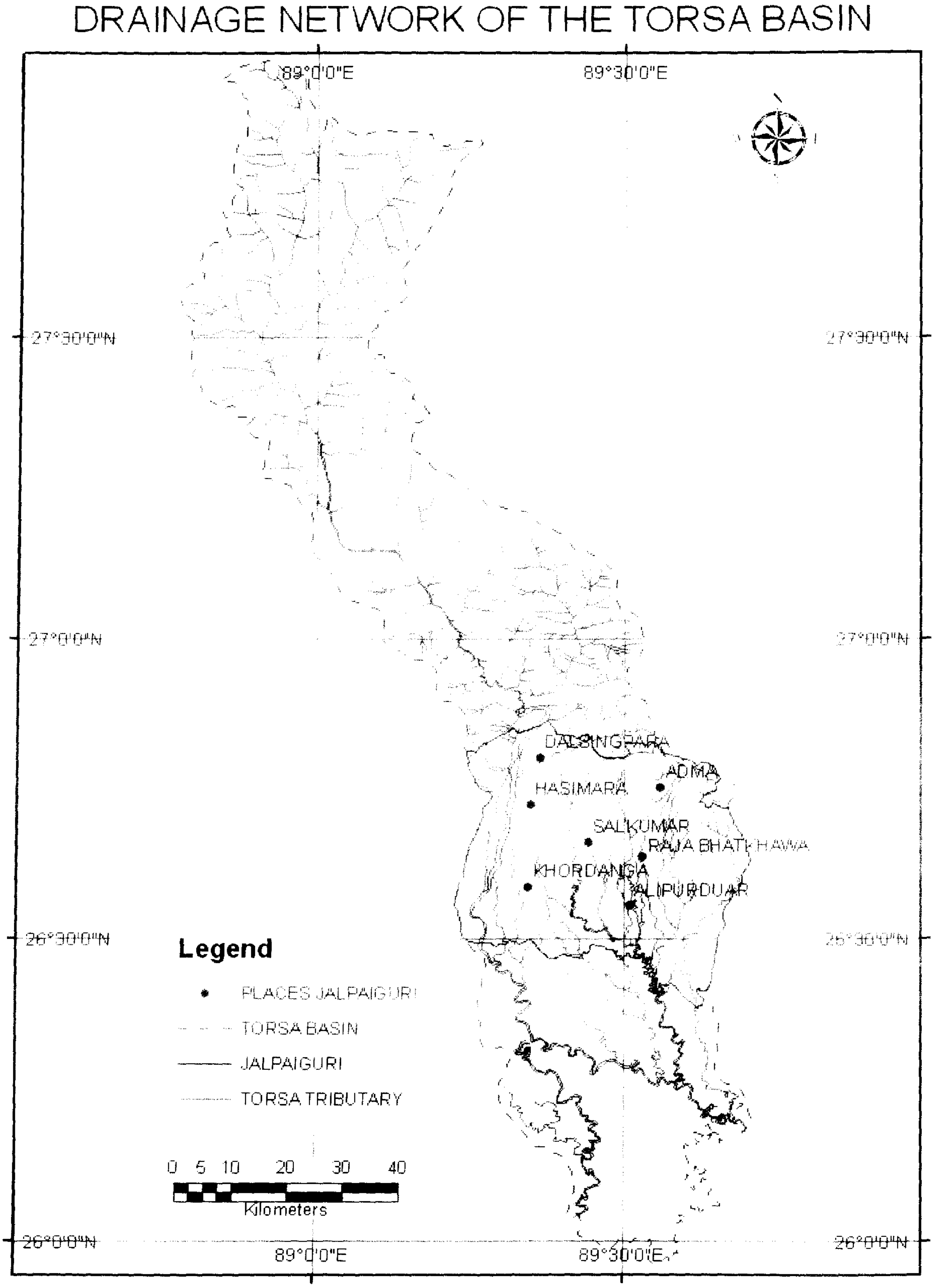

Figure 2.4 Drainage network of the Torsa Basin

Bhutanese Himalaya and drains the highest range rising to 7065 m.s.l. Its mountain catchment till Phuntsholing exceeds 4000 km^2. On the 172 km long mountain reach the Torsa (called Amo in Bhutan) is deeply cut in various metamorphic rocks partly meandering with tendency to aggradations in the marginal part of mountains. The length of the river is of the order of 365 km from its furthest extremity in Bhutan State to the Koch Bihar town (figure 2.4).

The upper reach of the river Torsa is in the State of Bhutan is known as "Amo" river, the name given to the combined flow of two hill streams at the furthest extremity, viz. the Kangpo and Kylang rivers from the northwestern and northeastern directions respectively. The "Amo" river in its next lower course is joined from the northwestern directions by three tributaries, Chimkiphu, Tangka, Namchu khola and five tributaries from the northeastern direction i.e., Tromo, Yak, Ripoloy khola, Piuna khola and Pa rivers.

The "Amo" river thus enlarged by the contribution of the above tributaries enters the Sub-Himalayan plains of the Jalpaiguri district under the name "Torsa". The "Amo" river having glacial regions at the source derives its flow from snowmelt as also from runoff from rainfall during the monsoons.

Immediately before entering the Jalpaiguri district, the "Amo" river flows in a loop path and below this loop, it flows in a southern direction through the Jalpaiguri district. There is a railway bridge over it, below this loop at Madarihat, near Hasimara. Below this bridge, the Torsa throws off a spill channel on the southeast called Sil Torsa, which rejoins the Torsa at a point south of the National Highway road running across both the Torsa and Sil Torsa rivers. In the reach between Madarihat railway bridge and National Highway road bridge on the Torsa, the Torsa is joined from the north-west by the Chhoto Torsa, this Chhoto Torsa is the combined flow of two streams, one Titi and another decayed spill channel of the Torsa. There is also a distributary thrown off from the Chhoto Torsa called "Buri Torsa" which joins the Jaldhaka River below Falakata. The Buri Torsa has an important tributary called Majnai from the Western Direction.

Below the National Highway Road Bridge, The Torsa river turns to the south-eastern direction and follows a zig-zag course, indicating of an inherent meandering tendency. The Torsa also flows by the Koch Bihar town. Shortly before its approach to this town, it throws off a distributary called the Dharala on the south, which joins the Jaldhaka-Dharala River below. Erosion and encroachment of the Torsa River to Koch Bihar town is a problem that has been engaging the attention of the engineers for a long time. It is said that as early as 1887, the royal palace was once endangered and the then State Engineer introduced a cut so as to divert the bulk of flow along the *Mora Torsa*. This arrangement, however, did not stand long and the Torsa river began to meander once again.

In the south-eastern course below the Koch Bihar town, the Torsa river is joined by four rivers from the north. These are the Gharghari, Kaljani, Gadadhar and the Raidak. The course of the river Torsa below the confluence with the Raidak, is known as Raidak. The Raidak is a tributary of the Brahmaputra River.

2.2.1.4 The Raidak basin

The river Raidak originates from the ice field of the Jomolhari (7270m the highest peak in Bhutan) – Kungphu (6894m) – Takaphu (6493m) massive of the Great Himalaya in Bhutan.The altitude of the source of Raidak is 6400m. Within the Bhutanese territory the head stream of the Raidak is known as Wong Chu. It receives two major tributary the Paro Chu and the Ha Chu. The catchment of area covers an area of 5505.2 sq. km out of which 4813 sq. km lies in Bhutan, 692 sq. km within sub-Himalayan North Bengal and only 450 sq. km is situated within the study area of Jalpaiguri district (figure 2.5).

The Wong Chu enlarged by the contribution of the Peping Chu a left hand tributary before it enters the Sub-Himalayan plains of the Jalpaiguri district under the name "Raidak". The river Raidak having ice field regions at the source derives its flow from snowmelt as also from runoff from rainfall during the monsoons.The length of Raidak river is 266.5 km out of which 167.2 km is situated in mountainous terrain of Bhutan, 99.2 km is situated in West Bengal. The present study area of Jalpaiguri district covers on 50 km stretch of its course.

The gradient of Raidak river is estimated to be 1:41.837 from its source to its confluence with the Sankosh. The gradient is much higher in the Bhutan Himalaya which has been estimated to be 1:26.786 and much lower in the West Bengal plain which has been calculated to be 1:775.0. The gradient of Raidak river in the studied section of Jalpaiguri district is 1:760.0.

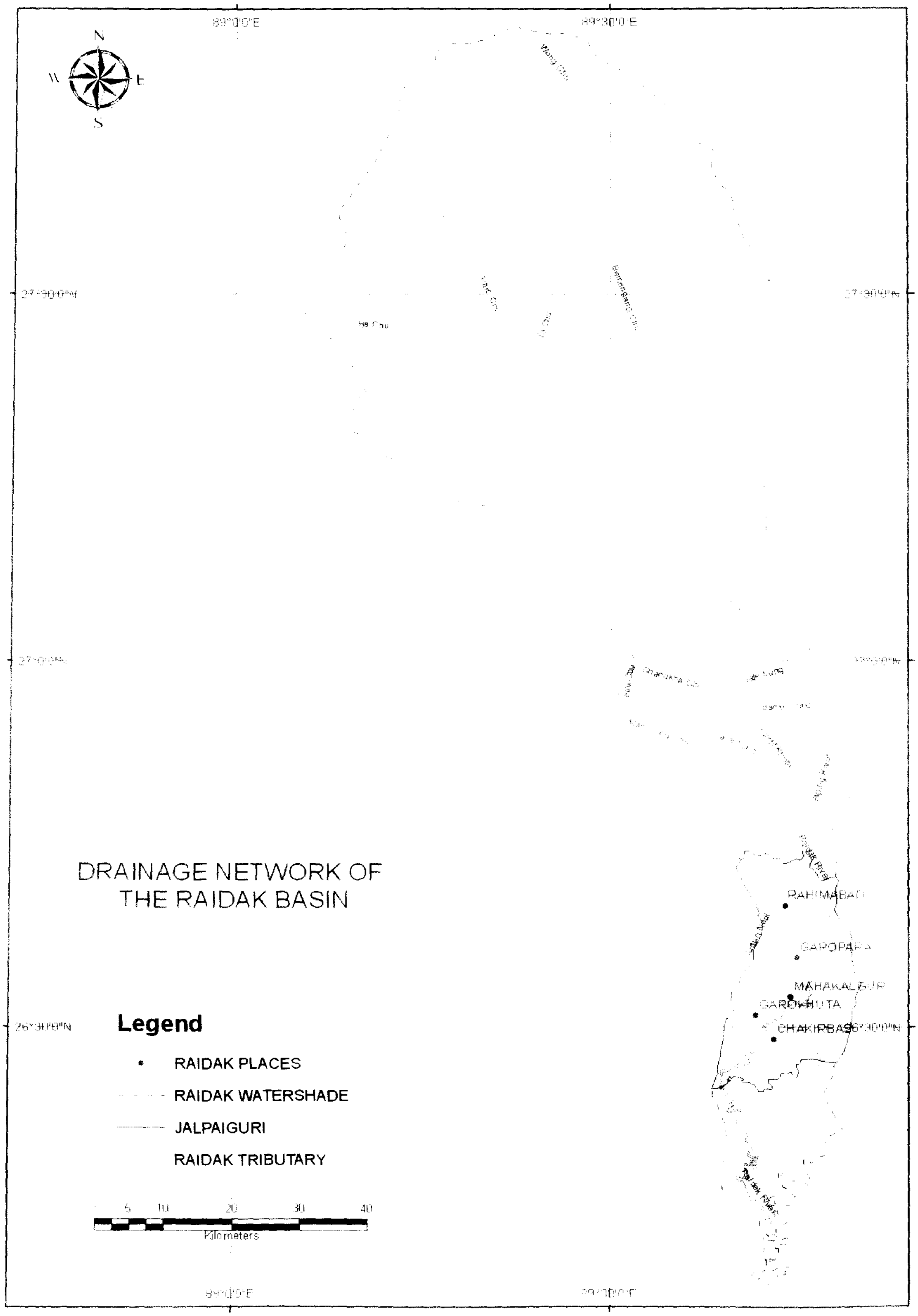

Figure 2.5 Drainage network of the Raidak Basin

2.2.1.5 The Sankosh basin

The river Sankosh originates from the Bhutan Himalaya and marks the eastern boundary of West Bengal. The catchment area covers an area of 8521 sq. km. out of which only 295.0 sq. km lies in sub-Himalayan North Bengal. The mean annual runoff of the river has been estimated to be 25000 million cubic meter. The base flow of the river has been estimated to be 85 cumecs and the mean discharge during the monsoon months is 1500 cumecs (figure 2.6).

The river Sankosh is considered to be highly notorious for their unpredictable nature, letting loose fury of flood and problem of extensive and regular bank erosion, course shifting, render thousands of homeless during the rainy season. The catchment area in Bhutan is mostly uninhabited and is covered by natural forest. However, along the Himalayan southern margin bordering with India, mining and so called development activities like construction of roads etc. have already induced large scale degradation. During heavy and concentrated rainfall, innumerable landslides are caused transporting huge amount of sediment to the river.

During summer, the observed increment of the size of bars and shoals downstream to the piedmont area proves such a contention. In order to avoid such numerous islands in midst of the channel, the rivers, in their lower reaches thus, attains the significant physical characteristic of braiding which may be attributed to both incompetence and incapacity of the rivers. That is, most of the rivers can transport neither the total amount of debris nor the size of debris that is supplied to it as bed load. As a result, the bed of the river is rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods. Moreover, the narrow road and railway bridges, spanning the rivers as well as the pillars supporting them, are always considered to be the barriers, interrupting natural load movement behavior of the rivers. This often cause accelerated deposition at the bottom of the bridge and thereby, narrowing the outlets of the rivers gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and firm lands.

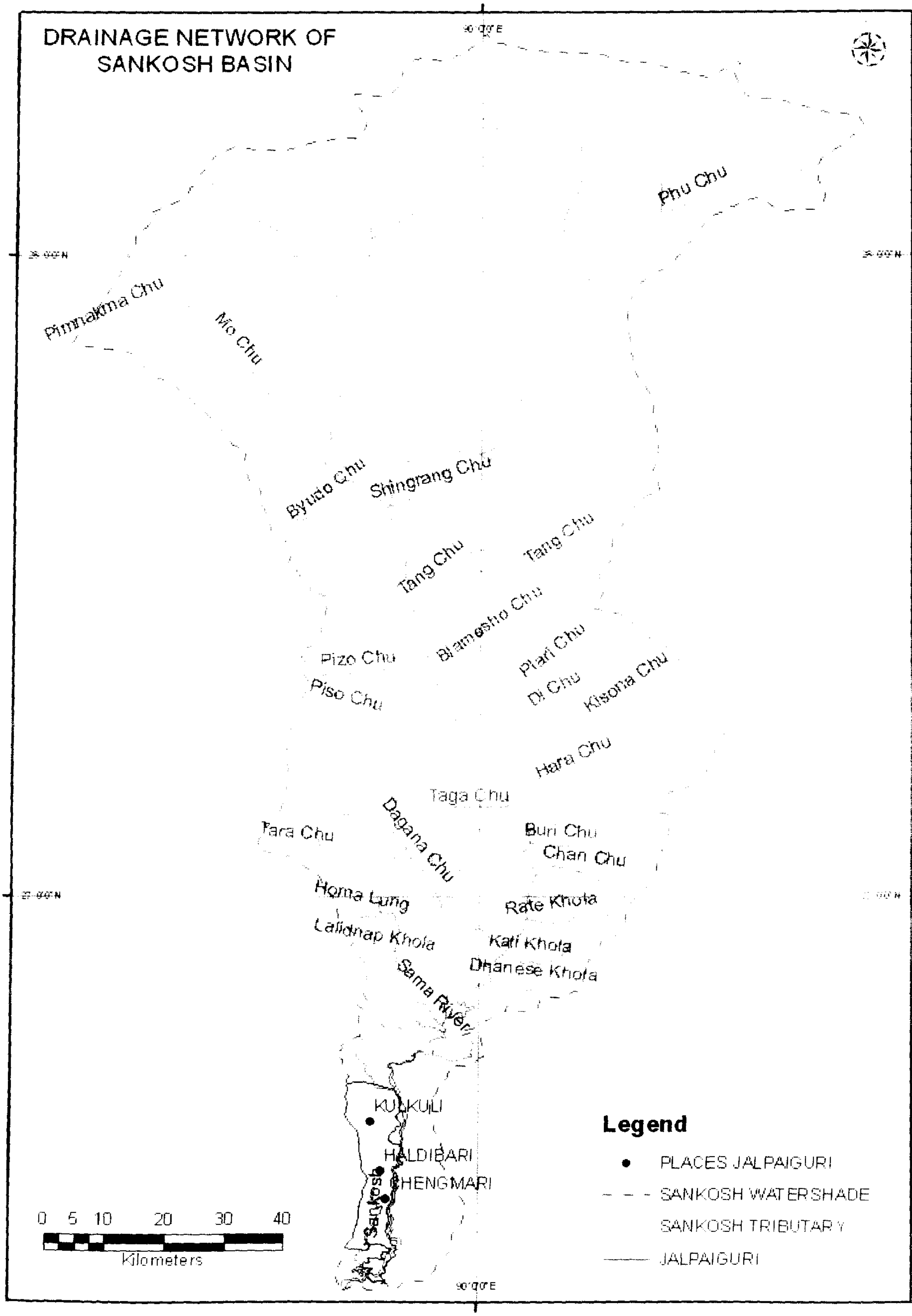

Figure 2.6 Drainage network of the Sankosh Basin

Rainfall pattern is monsoon dominated, characterized by high intensity, short duration rain storm causing transportation of huge sediment load, followed by devastating flood. Mean annual rainfall in different major segments of the watershed is given below

i) South hill margin and plains	: 3500 millimeter
ii) Lower Bhutan Himalayan	: 3000 millimeter
iii) Upper Catchment in Bhutan	: 1500 millimeter

2.2.2 The Ganga basin

The Ganga basin is bounded on the north by the Himalayas and on the south by the Vindhya Mountains. The rivers flow almost northwest to southwest. The region covers partly or fully the State of Himachal Pradesh, Hariyana, Rajsthan, Madhya Pradesh, Uttar Pradesh, Bihar and West Bengal and the Union Territory of Delhi. The first four and the West Bengal from geographical parts of other rivers basins also. The river Mahananda is the only major tributary of the Ganga system draining in Jalpaiguri district.

2.2.2.1 The Mahananda basin

The river Mahananda is a major northern tributary of the Ganga system. passing through Nepal, India and Bangladesh. It is bounded on the north by the Himalayas. the ridges separating it from the Tista river system in the east, the Ganga on the south and the Koshi river system in the west. It drains a total catchment area of 25.043 sq. km over a length of 376 km from its origin near Chimali in the Mahalidram hills to its confluence with the river Ganga (figure 2.7).

The Mahananda originates from the Mahalidram hills of the Darjeeling Himalaya near Chimali at an altitude of 2060 meter at about 6.4 km northeast of Kurseong town of West Bengal. It is also known as Mahanadi river in the hill. After flowing nearly 20 km in the hills of Darjeeling, the river enters plains near Siliguri and flows in a southwesterly direction till it is joined by the Balason river on its right bank about 4.0 km downstream of Siliguri (Sarkar, S. 1996& 1997). It forms more or less the border between India and Bangladesh between Phansidewa and Tetulia. Number of tributaries of Mahananda system is drained extreme western part of Jalpaiguri district i.e., Karotoya, Panga, Jamuna and Sahu are noteworthy.

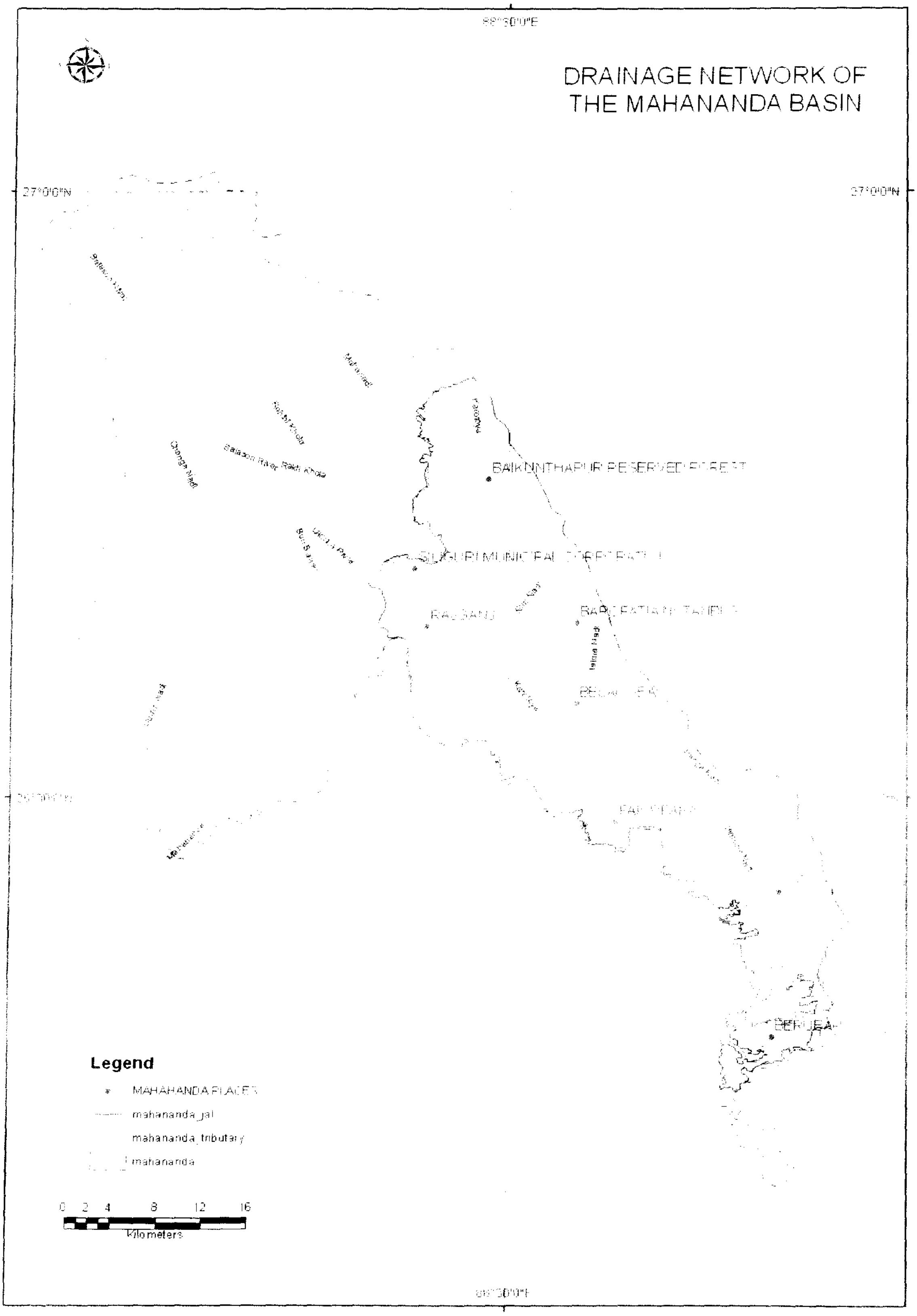

Figure 2.7 Drainage network of the Mahananda Basin

2.3. Morphological characteristics

Morphology of a river channel is associated primarily with the study of the size (bed width and depth), shape and pattern of river to be supplemented by study of structure of basin and the texture of its drainage area. Both engineers and geomorphologists are primarily concerned with the basic principles of river morphology. A river channel at any single location reflects the geology, geomorphology, biology, climate and hydrology of drainage basins that may extend hundreds of miles upstream. The whole approach of study of river morphology and river mechanics aims at evolving a long term and the most economical and permanent solution of a river problem for the utilization of the river waters for the most economical purposes. Though, solution is time taking requiring detailed and enormous efforts by all the concerned, a proper scientific engineering solution of a problem of river for its economical control is necessary (Moriswa, M, 1968; Newson, M. 1994). Morphological features of important rivers are discussed below:

2.3.1 River Tista

Unique in its complex and diverse drainage characteristics, the antecedent Tista offers a fascinating study of the evolutionary process of the Himalayan drainage under fluvial environment. The landform and drainage pattern include four-tier terraces, canyon, gorge, like valley at different altitudes, asymmetric valley, poly-profile U-shapes valley, trough lake, alluvial cone truncated ridge, spur and terraces.

The catchment has a complex hydrographic network of branching streams in hierarchical orders from its smallest tributaries to the trunk stream. The temporal variations of the Tista flow manifest watershed characteristics, which influence its run-off. The Tista, with its major tributaries maintaining a continual degradation of its course across the rising Himalayan ranges, is representative of antecedent drainage or in other sense antecedent to all the contemporary landforms in the rejuvenated Sikkim and Darjeeling (Starkel et. al., 2000).

Record reveals that up to 1787, the river Tista and Karotoya were the same river which flowed through the Atrai-Punarbhaba into the Ganga system. Neo-tectonic activity coupled with high intensity rainfall induced flash-flood caused massive shifting of the river. The so-called whale backed sub-surface ridge of the Baikunthapur- Fulbari became active and the Tista migrated eastward bifurcating he river Karotoya. Major Rennel's Atlas of 1770s shows the old course of the river and he states the Tista is a large river which runs almost parallel to the Ganges by two distinct channels situated above twenty miles from each other, and a third channel at same time discharges itself into the Meghna; but during the season of flood the Ganga runs into the Tista, whose outlet is then continued to the channel that communicates with the Meghna (Sen S., 1968; Jain V., Sinha R., 2003).

Dr. Buchanon Hamilton (1810) wrote *I must previously observed that the flood of 1787 seem totally have changed the appearance of this part of the country and to have covered it so with beds of sand that of old channels can be traced for any distance and the river that remain seldom retain the same name for above three or four miles in any part of this course. The name Karotoya, in particular is completely lost for a spea of about 20 miles and is discovered a little south from Durwani. Karotoya then continues its course to the SE fro about three miles, when it joins the old Tista and losses its name although it is at present the considerable stream but the immense sandy channel of the Tista announces its recent grandeur.* In fact when Major Rennel made this survey, the great body of the Tista came this way and joined the Atreyi; but in the destructive flood which happens in 1787, the greater part of the water of the Tista returned to its ancient bed, and has left his immense channel almost dry. During the period 1951 to 1963, the meandering width of the river increased by about 1500 m (Dash. AJ. 1947).

The new Tista flowed through Rangdhamali-Jalpaiguri-Haldibari and meets Karotoya again. Thus, the once wide Tista-Karotoya valley dried up and only two narrow channels namely Karotoya and Sahu are still visible. During the flood of 1788-89, the Tista shifted further east and reached Permekhligunje- Jaldhaka of present Bangladesh. The flood of 1897 caused huge deposition and terminated the ferry service between Jalpaiguri to Barnes Ghat. The 1922-23 flood caused further eastward migration of the river and Barnes Railway Junction and town was destroyed. Floods, during several subsequent years viz., 1948, 1950, 1952 and 1954 caused bank failure, widening and elevating the riverbed. During the period 1951 to 1963, the meandering width of the river increased by about 1500m

The 1968 flood caused massive bank failure and deposition. Temporary westward migration was also visible as the water flowed through Karala-Gadadhar-Panga-Jamuna-Karotoya. In 1969, the Tista water flowed through the Kharkharia and entered into the Panga that became a large river.

In the plain below Sevok on the Tista, the tributaries Lish, Gish, Chel, Neora originating from the foothills on the north are swollen by monsoon rains. The outfalls of these streams are into the river Tista. A high water level in the Tista often retards the speedy outflow from these rivers. As these streams also carry quite a large quantity of silt and sand, still deposition during slack current is frequent which in turns, causes shifts in their course. This silt deposition however, has a fertilizing effect on the soils. It is basically because of this reason that the basins of these streams are very fertile, and bumper crops are raised here. These basins are therefore regarded as granaries of North Bengal.

2.3.2 The Jaldhaka river

The river Jaldhaka has two distinct characteristics viz., its behaviour in the upper mountains tract right from its origin upto Nagrakata and its behaviour in its passes thorough the plains of Jalpaiguri and Koch Bihar Districts upto the confluence with the river Brahmaputra in Bangladesh.

In the hilly tract of Sikkim and Bhutan, the river receives a large number of tributaries and the river is locally known as the Dichu. It passes through steep, narrow gorges and consequently it has no scope to change its course. In this tract the bed slope is very steep. The slope exceeds at some places causing great velocity of flow particularly during high floods. Though the gorges are very deep and narrow, these consist of rock, which are soft and denuded and cannot withstand the high velocity during floods. Consequently, land slips occur rather frequently. Large quantities of detritus came down into the river and are carried down into the lower regions. The silt charge of the river increases many times during flood.

These landslips sometimes assume such proportion as to block the waterway of the channel completely and temporarily cause formation of lakes. Ultimately the dam caused by the land slip is itself pushed down and the intensity of flood in the lower regions is increased many times by the simultaneous release of the water stored in the temporary lakes. Such occurrence is almost an annual feature. During the monsoon of 1964, such a temporary lake was formed. During this year, there had been heavy downpour on the 1st, 2nd and 3rd of August in the upper Jaldhaka catchment. On the 3rd August, a huge land slide just on the appropriate bank of the river measuring about 1000m X 300m X150m was caused on the left bank of the river Jaldhaka. The cause of this land slide, as locally ascertained, was due to erosion of the bed and denudation of forest cover on the steep hill side. The river was dammed up by the land slide and a temporary lake was formed for about 1½ to 2 hours. The water level rose about 9 m. on the upstream side of the "Dam" collapse suddenly, as it must, causing serious damage to the roads and properties of the downstream area.

The behaviour of the river in the lower reach is a history of the frequent changes of its course. The river is known as Mansai, Singhimari and Dharala in its different reaches. It had changed it course frequently during the last century. The most important changes however, took place in the portion of the river which is called Mansai.

2.3.3 The river Torsa

The main problem of the river is heavy bank erosion followed by inundation. The Torsa shifted its course several times during the last century and a half and occupied different position over a tract of about 20 km from East to West in the district of Jalpaiguri and Koch Bihar. The silt charge during flood being very heavy, its cross section changes almost every season and the bed has an aggradation tendency. The meandering of the river is considerable in the alluvial tracts of North Bengal Plains. As soon as the river debauches into the plains, the slope decreases sharply with the result that big boulder and shingles are deposited on the bed. The less heavy materials are carried further down stream and get deposited on the bed as well as on the country side where the river spills over its banks, damaging vast area of cultivable land and valuable Tea gardens and forests.

The silt is deposited in the bed does even a greater damage, in such a way that it causes the bed to rise every year with consequent reduction in the water way and rise in the flood level causing greater inundation. At the same time, the river has a tendency to get wider by eroding its banks due to rising bed (Sarkar S., 2004, 2007 & 2008).

2.3.4 The river Raidak

The river Raidak has two distinct characteristics viz., its behaviour in the upper mountains tract right from its origin up to Bhutanghat and its behaviour in its passes thorough the plains of Jalpaiguri and Koch Bihar Districts up to the confluence with the river Brahmaputra.

In the hilly tract of Bhutan, the river receives a large number of tributaries and the river is locally known as the Wong Chu, Paro Chu and Ha Chu. It passes through steep, narrow gorges and consequently it has no scope to change its course. In this tract the bed slope is very steep. The slope exceeds at some places causing great velocity of flow particularly during high floods. Though the gorges are very deep and narrow, these consist of rock, which are soft and denuded and cannot withstand the high velocity during floods. Consequently, land slips occur rather frequently. Large quantities of detritus came down into the river and are carried down into the lower regions. The silt discharge of the river increases many times during flood. The behaviour of the river in the lower reach is a history of the frequent changes of its course. The river is bifurcated into Raidak I and Raidak II in Jalpaiguri district. It had changed it course frequently during the last century.

2.3.5 The river Sankosh

The river Sankosh originates from the Bhutan Himalaya and marks the eastern boundary of West Bengal. The catchment area covers an area of 10534 sq. km. out of which only 295.0 sq. km lies in sub-Himalaya North Bengal. The mean annual runoff of the river has been estimated to be 25000 million cubic meter. The base flow of the river has been estimated to be 85 cumecs and the mean discharge during the monsoon months is 1500 cumecs.

The river Sankosh is considered to be highly notorious for their unpredictable nature, letting loose fury of flood and problem of extensive and regular bank erosion, course shifting, render thousands of homeless during the rainy season. The catchment area in Bhutan is mostly uninhabited and is covered by natural forest. However, along the Himalayan southern margin bordering with India, mining and so called development activities like construction of roads etc. have already induced large scale degradation. During heavy and concentrated rainfall, innumerable landslides are caused transporting huge amount of sediment to the river. Most of such landslides have never been treated scientifically with proper protective measures and as such those are in the habit of expanding their territories during monsoon and thereby adding more and more silt to the rivers, which are incapable of transporting the loads efficiently under the existing hydrological conditions, especially areas beyond the foothill zone.

During summer, the observed increment of the size of bars and shoals downstream to the piedmont area proves such a contention. In order to avoid such numerous islands in midst of the channel, the rivers, in their lower reaches thus, attains the significant physical characteristic of braiding which may be attributed to both incompetence and incapacity of the rivers. That is, most of the rivers can transport neither the total amount of debris nor the size of debris that is supplied to it as bed load. As a result, the bed of the river is rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods. Moreover, the narrow road and railway bridges, spanning the rivers as well as the pillars supporting them, are always considered to be the barriers, interrupting natural load movement behavior of the rivers. This often causes accelerated deposition at the bottom of the bridge and thereby, narrowing the outlets of the rivers gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and firm lands.

2.3.6 The river Mahananda

It is well known that a phenomenon of oscillation of the principal Himalayan river over long ranges is associated with the process of building up of the alluvial Gangetic plains of North India. The oscillation process has been going on from time to time immemorial. Unfortunately, complete records of this process are not available. Some information about the oscillation of Mahananda tributaries in the distant past is available from the old records.

In addition to the shifting tendency, the river usually overflows it banks. The river and its tributaries bring heavy quantity of silt load, which gets deposited in the middle and lower reaches. Thus, the section of the river gets reduced. The flood discharge, which is not accommodated by the river section, gets spilled over the bank and inundates vast area. The river has also got erosive tendency. In 1950, very important areas at Siliguri town on the left bank of Mahananda were eroded. The bridge along the national Highway from Siliguri to Jalpaiguri was also attacked. It was considered that if this erosion was not arrested, severe damage would be cost to the town itself in addition to damaging the National Highway bridge and the railway bridge below it. There was considerable erosion of about 610 m. on the right bank of Mahananda at Phansidewa.

2.4 Conclusion

The Sub-Himalayan river under study are considered to be highly notorious for their unpredictable nature, letting loose fury of flood and problem of extensive and regular bank erosion, avulsion and flood followed by massive aggradations renders thousands of homeless during the rainy season. The majority of the river originates from the Himalayas and enters from a north to northwesterly direction and flows south to southeasterly direction. As many of the rivers originate at the same hill, flood often occurs simultaneously in many rivers and the rivers coalesce to form a single vast sheet of water.

The rivers, in their lower reaches attain the significant physical characteristic of braiding which may be attributed to both incompetence and incapacity of the rivers. That is, most of the rivers can transport neither the total amount of debris nor the size of debris that is supplied to it as bed load. As a result, the riverbeds are rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods.

The rivers under study may be divided into two major groups: (a) large transit rivers originated in high Himalaya represented by three rivers Tista, Torsa and Sankosh with perennial discharge, feed both by rain and melt waters. Deep canyons in marginal part and mega-fans in the foreland indicate very high water discharge and high sediment load. Great alluvial fans and braided channels with frequent avulsions extend far up to the river Brahmaputra and (b) rivers dissecting Lesser Himalaya. The river Jaldhaka and Mahananda fall under this group drains large catchment, deeply incised also in the piedmont, where it is draining the active rising blocks. As a result, its fan surface is developing farther downstream.

The rivers under study are not stable and process of erosion in the steep hilly catchment, transportation of sediment in the river and its subsequent progressive deposition lower down in the river with flatter slope is a continuous phenomenon. In the upper reaches in the plains, the river and their tributaries have got steeper slopes as compared to the lower reaches, thus, the carrying capacity for the silt load in the upper reaches in the plains is comparatively more than in the lower reaches. The river bed, just after it debauches into the plains, consists of shingle and sand, whereas further down in the flatter plains, the alluvial channels mostly consist of coarse and medium silt. Pronounced development of conjugal alluvial fan, produced by diverging drainage system in the catchment area of the Mahananda and Jaldhaka is very much conspicuous in the western and central part of the piedmont zone.

Most of the rivers in this region are rather straight streams. The average slope ratio of the river channel in general cases is much lower indicating an obviously steeper gradient. Average gradient of the channel varies from 1:342 in the Tista to 1:4611 in the Torsa. The river Sankosh with a gradient of 1:1833 followed by the river Jaldhaka with a gradient of 1:3129 within the active plain is rather swift river. The Tista, the largest river in the north of the Ganga-Padma system in West Bengal, although infested with innumerable island and shoals in its wide channel, is still flowing fairly fast within the studied section a gradient of 1:342.

The length of cross-sections varies considerably from one cross section to another at different locations. There is significant variation in the area of flow from one year to another indicating deposition or erosion at each of the cross sections. Smaller area of section occurs where velocity is higher. The estimation of deposition & erosion, the volume of sediment deposit or scoured over a period of time have been computed and it reveals that the average depth of deposition or scour varies from 1 cm to 18 cm in case of the river Tista, while the same is substantial in case of the river Jaldhaka and Torsa which varies from 6 cm to 72 cm and 17 cm to 72 cm respectively. There is, however, very high scouring observed in the river Sankosh of the order of 165 cm over a period of 14 years from 1986 to 2000. The above studies are only indicative in nature and in no way, can form a basis for planning of any remedial measures

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Chapter III: Meteorological Characteristics

3.1 Introduction

The sub-Himalayan Jalpaiguri district belongs to the rainiest parts at the Himalayan margin located north of the wide gap between the Deccan plateau and the Meghalaya upland. The precipitation pattern of Jalpaiguri district is noteworthy because of its position, the powerful effects of the south western Monsoon on the Himalayan barrier and the particular configuration of the ridge and valley that either deflect or allow rain-bearing wind which affect precipitation and particularly incidences of high intensity rainstorms.

It has normal seasonal distribution of rainfall with 80-85% concentrated in four summer months and distinct lacks of rain during winter months. The mean annual rainfall fluctuate between 3000 and 5000 mm and the highest rainfall occurs close to the steep front of the Lesser Himalaya in Jalpaiguri district. There is a distinct decline of rainfall in both directions: towards the interior of the Himalayas and towards the south drained by the rivers of Brahmaputra system.

Being the rainiest part of the Himalayas, Jalpaiguri district has been experiencing devastating flash floods since the time immemorial transforming not only the physical but also cultural landscape of sub-Himalayan North Bengal. The majority of the rivers of Terai and Duars originate in the Himalayas and enter from a north to northwesterly direction and flows south to southeasterly direction. As many of the rivers originate at the same hill, the high intensity induced flood often occurs simultaneously in many rivers and the rivers coalesce to form a single vast sheet of water.

The catchments of these rivers have mostly been deforested and the clearings of the steep slopes have been used for the extension of settlement, agriculture, plantation and communication, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfalls, innumerable landslides are caused, transporting large amount of sediment to the rivers. Most of such landslides have never been treated scientifically with proper protective measures and as such those are in the habit of expanding their territories during monsoon. This often added more and more silt to the rivers, which are incapable of transporting the loads efficiently under the existing hydrological conditions, especially areas beyond the foothill.

During summer, the observed increment of the size of bars and shoals downstream to the piedmont area proves such a contention. In order to avoid such numerous islands in midst of the channel, the rivers, in their lower reaches thus, attains the significant physical characteristic of braiding which may be attributed to both incompetence and incapacity of the rivers. That is, most of the rivers can transport neither the total amount of debris nor the size of debris that is supplied to it as bed load. As a result, the riverbeds are rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods. Moreover, the narrow road and railway bridges, spanning the rivers as well as the pillars supporting them, are always considered to be the barriers, interrupting natural load movement behavior of the rivers. This often cause accelerated deposition at the bottom of the bridge and thereby, narrowing the outlets of the rivers gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and firm lands (Sarkar, 1997)

Although, flash flood has not been an uncommon phenomenon in the foothills, the frequency and magnitude of such events have increased many folds during the recent past. Two such catastrophic events during the last decade (1993 and 1998) demonstrate the enormity of damage and ever-increasing threat to the biosphere of the sub-Himalayan North Bengal.

The aim of the study is to assess the long term precipitation pattern in sub-Himalayan Jalpaiguri district, trend of precipitation, to analyse the incidences of high intensity rainfall vis-à-vis rainstorm; to assess the role of extreme rainfall in causing floods and finally an attempt would be made to predict long term probability analysis of high intensity rainfall. The data has been collected from India Meteorological Department (IMD); Flood Meteorology, Jalpaiguri, North Bengal flood Control Commission (NBFCC), Jalpaiguri, Central Water Commission (CWC) field stations and needless to say the Tea Gardens. It is interesting to note that many Tea Gardens of Jalpaiguri district record and maintain daily rainfall which proves an extremely important source of information in the present study. Data thus collected & has been analysed using standard statistical methods under MS excel platform. The analytical findings have been represented in the following section.

3.2. Rainfall pattern

Sub-Himalayan North Bengal displays great variability in rainfall patterns. Long term data identify Jalpaiguri as the rainiest area, with mean annual rainfall reaching 3465.9 millimeter of which 2776.0 millimeter descends during the 6 monsoon months between May and October. Total rainfall over the non-monsoon period is only 689.9 millimeter. Annual precipitation gradually decreases from north to south and is 3234.0 millimeter at Koch Bihar and again towards further north into the Himalaya to only 2035.9 in Kalimpong. Uneven distribution of rainfall in the region occurs because of variations in its topographic profile and the tracks followed by monsoon depressions. Rainfall is also unevenly distributed over the year, as a result of which over 80% descend during the rainy months.

The area between Tista and Jainti belongs to the rainiest parts at the Himalayan margin located north of the wide gap between the Deccan plateau and the Meghalaya upland. It has normal seasonal distribution of rainfall with 80-90% concentrated in four summer months and lacks of rain during winter months (0-50 mm). The mean annual rainfall fluctuate between 3000 and 6000 mm and the highest rainfall occurs close to the steep front of the Lesser Himalaya. The records from about 30-40 rainfall stations show a very distinct decline of rainfall in both directions: towards the interior of the Himalayas and towards the lowest part of Himalayan fore-deep drained by the river of Brahmaputra system (figure3.1).

The steep southern edge of Himalaya at the elevation between 300 and 600 m a.s.l. receives 4000-6000 mm rainfall annually and decreases northwards. At 10 km from the mountain front it drops below 3000 mm, at about 30 km to 1500 mm and further upstream of river valleys goes down below 1000 mm (Baillie, Norbu 2006). The marginal part of piedmont belt (5 km wide) is getting 4500-6000 mm. Rainfall also decrease towards south, at 10 km distance from the mountain front 3800-5000 mm is recorded and at 30 km rainfall still remains above 3000 mm (Koch Bihar). It can be explained by stopping of humid air masses by the Himalayan range and frequent stabilization of the front line during several weeks. Therefore the gradient towards south is gentler than in the mountains.

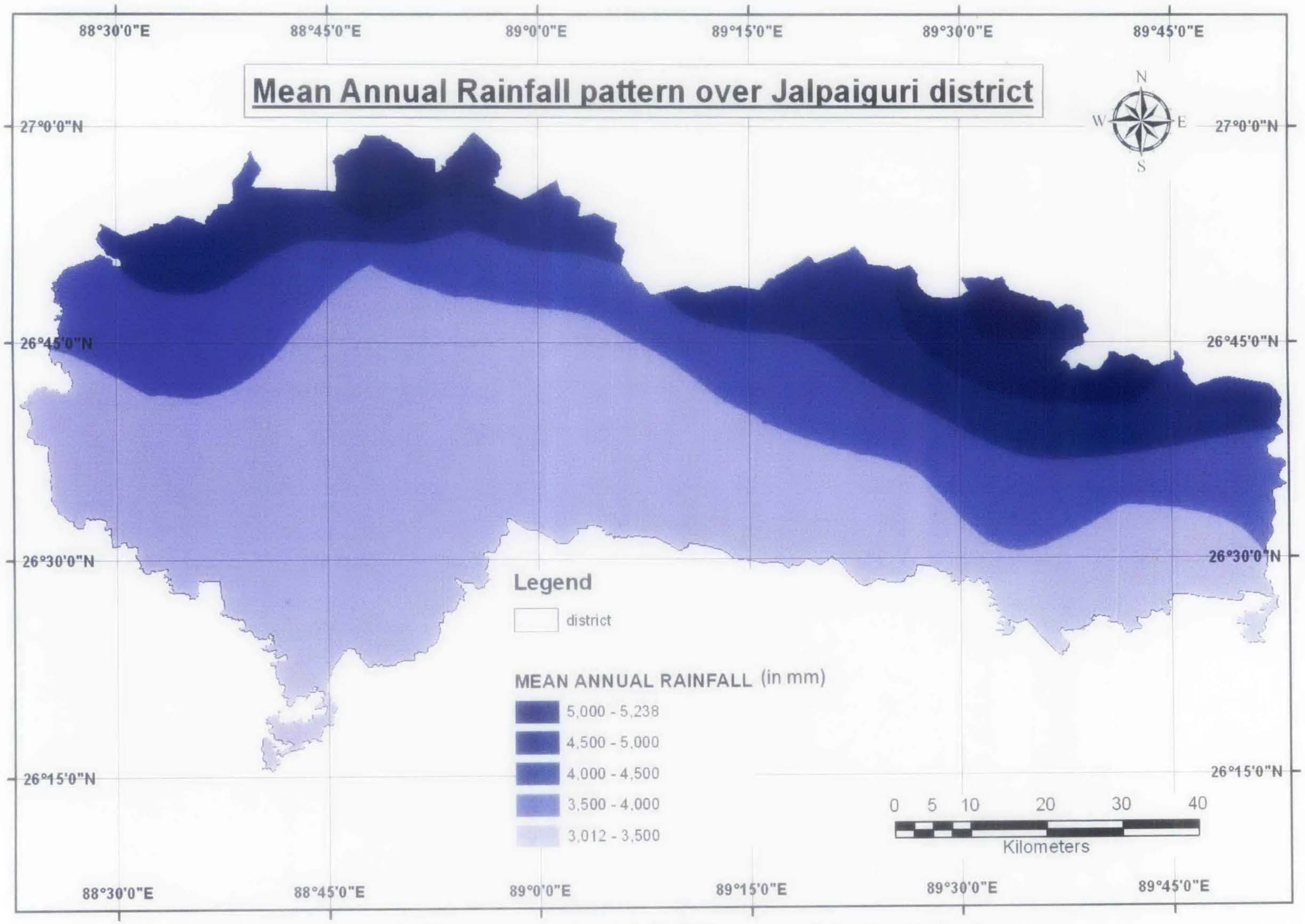

Figure 3.1 Mean annual rainfall pattern over Jalpaiguri district

Gradual increase in precipitation from east to west has been observed in the study area. Mean annual rainfall in Long view tea garden west of the river Tista is above 5000 mm and to the east in three areas similar and even higher value of about 6000 mm have been recorded.

Exceptional high annual precipitations have been recorded in areas between Tista and Jainti river since 1990 due to heavy continuous rainfalls. Particularly, the tea gardens situated in the north eastern Duars recorded unprecedented high precipitation during the months July and August (table 3.1).

Table 3.1 Heavy precipitation recorded at Tea Gardens of Eastern Duars, Jalpaiguri

Recording Stations	1993		1996		1997		1998		1999		2000	
	July	August	July	August	July	August	July	August	July	August	July	August
Bharnobari	1988	583	1904	795	652	697	1456	786	106	1092	589	1014
Dalsingpara	1313	675	1643	567	600	721	2179	542	169	1166	723	957
Chuapara	2241	719	2012	1238	843	781	1998	675	266	1425	954	1276
Kalchini	1904	553	1660	749	1225	492	1865	453	249	1024	671	923
Mechpara	1941	565	1638	874	689	642	1767	552	259	1047	595	841
Subhasini	1441	513	1848	756	604	476	1055	723	100	1142	604	850
Raimatang	1595	625	2012	669	1010	503	1234	765	176	1114	720	842
Radharani	1905	662	1668	915	772	698	1007	654	226	1366	858	1313

Among them two are characterised (figure 3.2A) i.e., in 1993 Chuapara tea garden at the piedmont east of the Torsa river recorded 2241mm in the month of July followed by Bharnobari tea garden recorded 1988 mm Mechpara tea garden recorded 1941 mm, Radharani tea garden recorded 1905 mm and Kalchini tea garden recorded 1904 mm rainfall during the month of July 1993 (figure 3.2A). Incidentally, Chuapara tea garden 19 km to the east recorded 6165 mm (Starkel, L & Sarkar, S. 2002). Incidentally, all of these recording stations are situated along the east of Torsa valley. Such an extreme rainfall over a restricted area caused devastating flash flood in Alipurduar sub-division of Jalpaiguri district.

In 1996, the piedmont area east of the Torsa river recorded heavy rainfall in the month of July again. Raimatang and Chuapara tea garden situated in the piedmont of the Bhutanese Himalaya recorded 2014mm in the month of July followed by Bharnobari tea garden recorded 1904 mm of rainfall (figure 3.2B). Incidentally, all of these recording stations are situated along the east of Torsa valley. Such an extreme rainfall over a restricted area caused devastating flash flood again in Alipurduar sub-division of Jalpaiguri district.

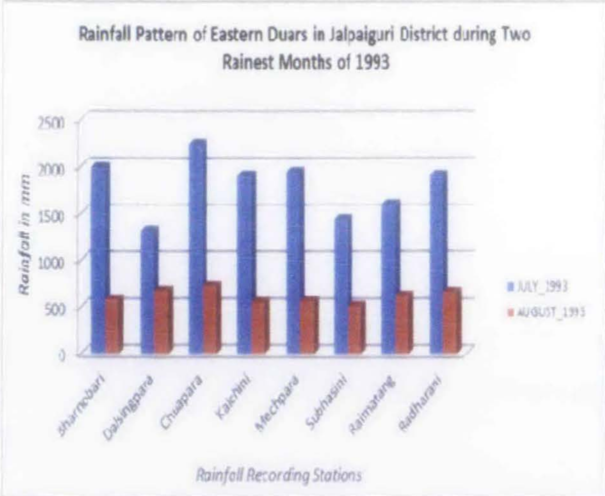

Figure 3.2A Heavy rainfall in eastern Duars during July & August, 1993

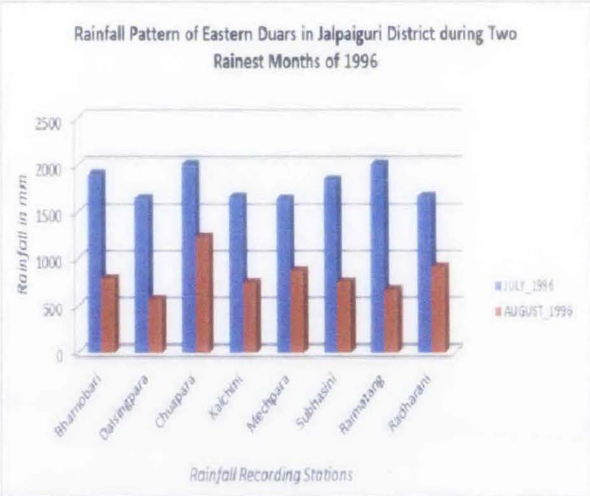

Figure 3.2B Heavy rainfall in eastern Duars during July & August, 1996

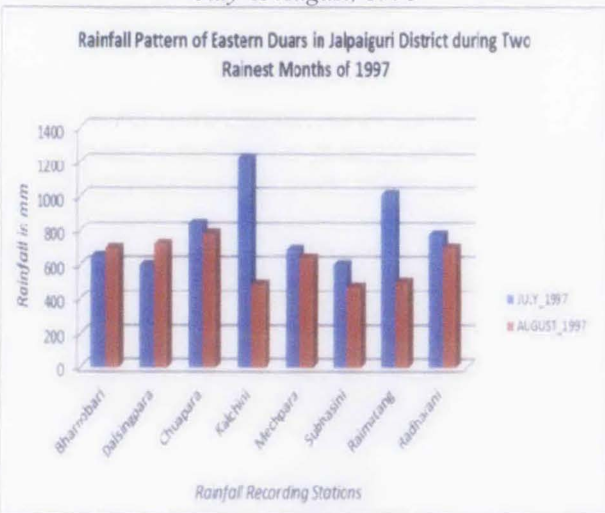

Figure 3.2C Heavy rainfall in eastern Duars during July & August, 1997

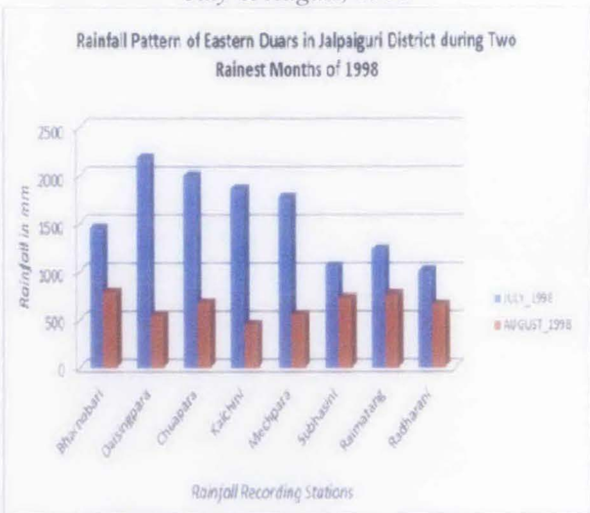

Figure 3.2D Heavy rainfall in eastern Duars during July & August, 1998

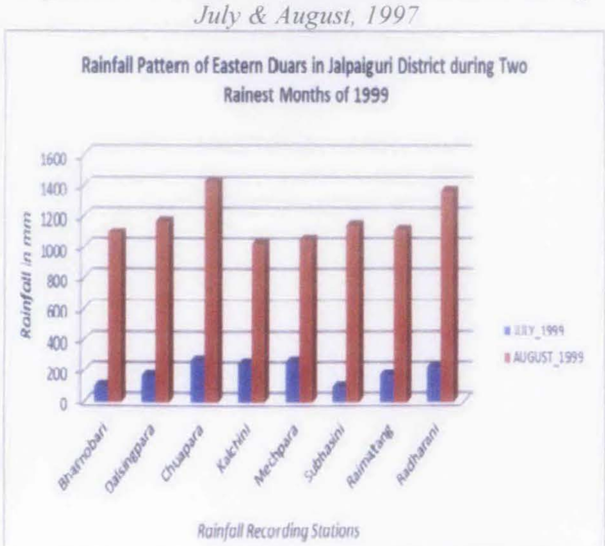

Figure 3.2E Heavy rainfall in eastern Duars during July & August, 1999

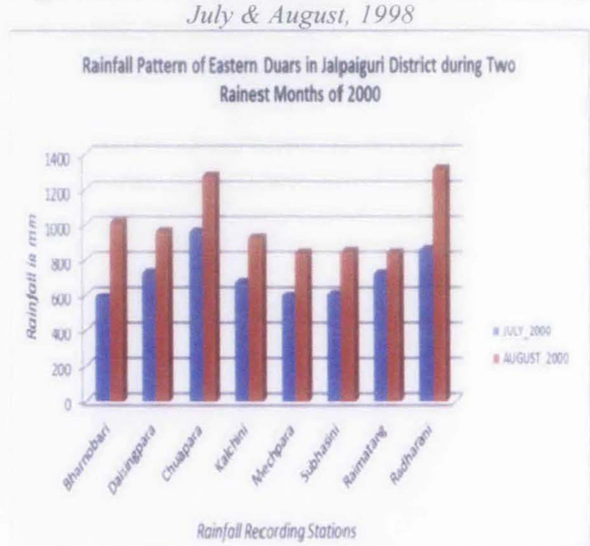

Figure 3.2F Heavy rainfall in eastern Duars during July & August, 2000

In 1997, the eastern Duars recorded no major high intensity rainstorms as a result no incidences of major flood was recorded. Only Kalchini tea garden recorded 1225 mm rainfall during the month of July. It is also interesting to note that during the year quite a good amount of rainfall was also recorded in all the tea gardens (figure 3.2C).

Very heavy rainfall was recorded again in eastern Duars of Jalpaiguri district during the month of July (figure 3.2D) i.e., in 1998 Dalsingpara tea garden at the piedmont east of the Torsa river recorded 2179 mm in the month of July followed by Chuapara tea garden recorded 1998 mm and Kalchini tea garden recorded 1865 mm rainfall during the month of July 1998. Incidentally, all of these recording stations are situated along the east of Torsa valley. Such an extreme rainfall over a restricted area caused devastating flash flood in Alipurduar sub-division of Jalpaiguri district.

It is interesting to note that the eastern Duars received more rainfall in the month of August in the year 1999 (figure 3.2E). Incidentally, no major incidence of flood was reported in 1999. In 2000, the piedmont area east of the Torsa river recorded moderately heavy rainfall in the month of August. Radharani tea garden recorded 1313 mm in the month of August followed by Chuapara tea garden recorded 1276 mm of rainfall (figure 3.2F).

3.3 Incidences of high intensity rainfall

Jalpaiguri district especially, its northern parts have been experiencing high to very high intensity rainfall. High intensity rainstorms often transformed into cloud-burst and descends as much as 784 mm of rainfall within a period of 24 hours (recorded at Hashimara, Jalpaiguri in 1993). Such a catastrophic meteorological event often caused devastating flash flood in the piedmont region and caused prolonged inundation in the plain region further south i.e., Koch Bihar and Bangladesh. Records of flood occurrences in North Bengal reveal that mostly all incidences of flood in this region caused by such high intensity rainfall events either in upper catchment or, within the district. Incidences of high intensity rainstorm in the Tista basin in 1968 (figure 3.3) and 1973 have been tabulated and shown in table 3.2 (Sarkar S., 2004).

During the period 1993-2001 several heavy rains were recorded which have been statistically elaborated in detail from Dalsingpara tea garden (Soja and Starkel 2007).

Altogether 69 days with rain >100 mm/day and 3 days >300 mm were recorded. Total rainfall in consecutive days reached between 600 to 900 mm in four occasions during the period. The highest recorded daily rainfall in the study area reached 800 mm.

Table 3.2 Rainstorms over the Tista catchment (in mm)

	Recording Stations	12. 10. 1973	13. 10. 1973	11. 7. 1996	12. 7. 1996	13. 7. 1996	14. 7. 1996	28. 6. 1999	12. 6. 1950
1	Darjeelimg	111.0	208.4	-	-	-	-	-	455.0
2	Kalimpong	125.5	286.0	-	-	-	-	-	302.0
4	Sevok	25.4	208.3	111.0	308.4	404.2	81.8	222.0	-
5	Jalpaiguri	7.8	162.0	47.2	93.8	123.6	223.8	40.4	285.0
6	Pedong	84.3	276.4	-	-	-	-	-	-
7	Chungthang	97.5	2.5	16.3	42.2	25.4	27.3	42.3	-
8	Singhik	90.6	99.8	20.4	22.0	16.8	45.6	59.2	-
9	Damthang	186.3	1.2	59.0	15.4	42.4	47.8	156.2	-
10	Munsong	63.2	253.8	19.0	22.8	24.6	54.4	165.0	-
11	Labha	200.8	0.0	268.2	61.2	0.3	7.0	166.2	-
12	Dikchu	17.2	232.2	16.6	37.4	24.0	38.8	87.4	-
13	Lachen	-	-	15.0	14.6	13.2	6.3	43.2	-
14	Algarah	100.8	200.0	27.2	98.6	160.3	39.0	-	-
15	Lachung	80.6	216.0	27.0	16.2	29.0	11.0	-	-
16	Khanitar	-	-	15.2	40.2	52.2	36.4	161.4	-
17	Sankalan	-	-	12.8	80.6	19.6	40.4	74.2	-
18	Rongli	-	-	7.4	3.6	12.6	17.4	17.0	-
19	Ressisum	100.8	230.0	-	-	-	-	-	-
20	Singlabazar	51.0	75.0	58.4	10.6	34.0	30.0	153.4	-
21	Rammam	80.6	104.0	-	-	-	-	-	-
22	Sukiapokri	61.1	0.0	-	-	-	-	-	-
25	Gangtok	77.8	92.5	12.0	53.5	28.5	44.4	79.8	-
26	Mangan	-	-	-	-	-	-	-	-
27	Phalut	168.6	6.6	-	-	-	-	-	-
28	Dentam	-	-	6.0	9.0	5.0	7.0	40.4	-
32	Neora	-	-	82.2	163.4	217.4	75.4	-	-
33	Domohani	-	-	32.4	84.2	140.8	323.6	28.0	-

Source: IMD, Govt. of India & TLDP, NHPC

Clustering of heavy and continuous rain concentrate either in every year or at 1-3 year interval is very important from geomorphological point of view. These make re-vegetation impossible and return to the former channel stability and then facilitate the propagation of instability (Brunsden, 2001). Preliminary characteristic of these events has been described by Starkel, L & Sarkar, S. 2002as well as by Soja and Starkel (2007).

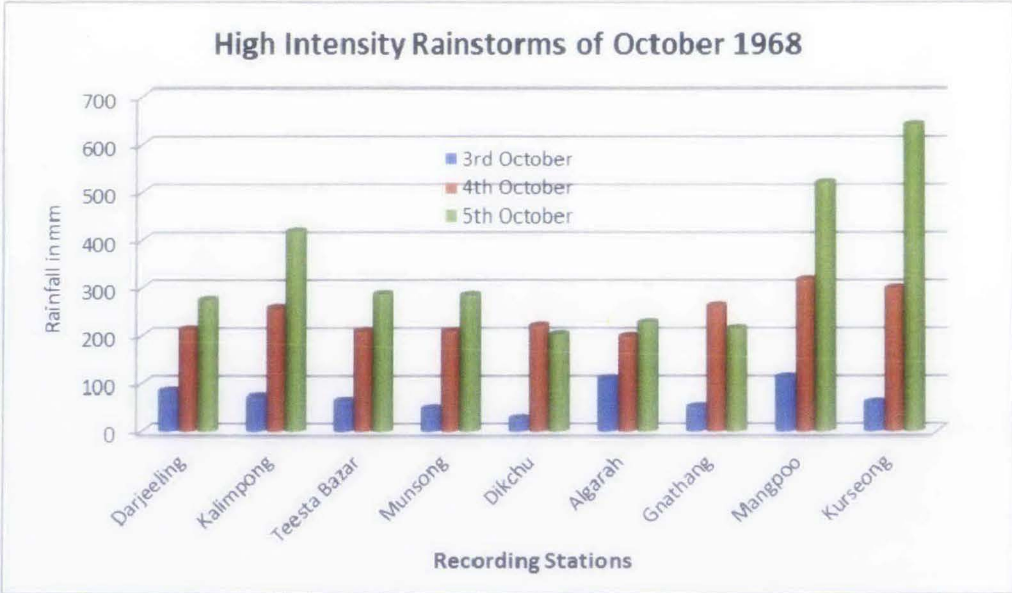

Figure 3.3 High intensity rainstorms during 1968

In 1993 continuous rain between 19 and 21 July extended to the east of Daina river. The highest value was measured at Makrapara tea garden (1606 mm) where 838 mm rainfall recorded on the 21st July and at Hasimara tea garden where 1379 mm between 19 to 21 July and 791 mm recorded on the 21st July. Much less rainfall was recorded closer to the mountain front (Starkel, L., Sarkar, S., Soja, R., Prokop, P. 2008).

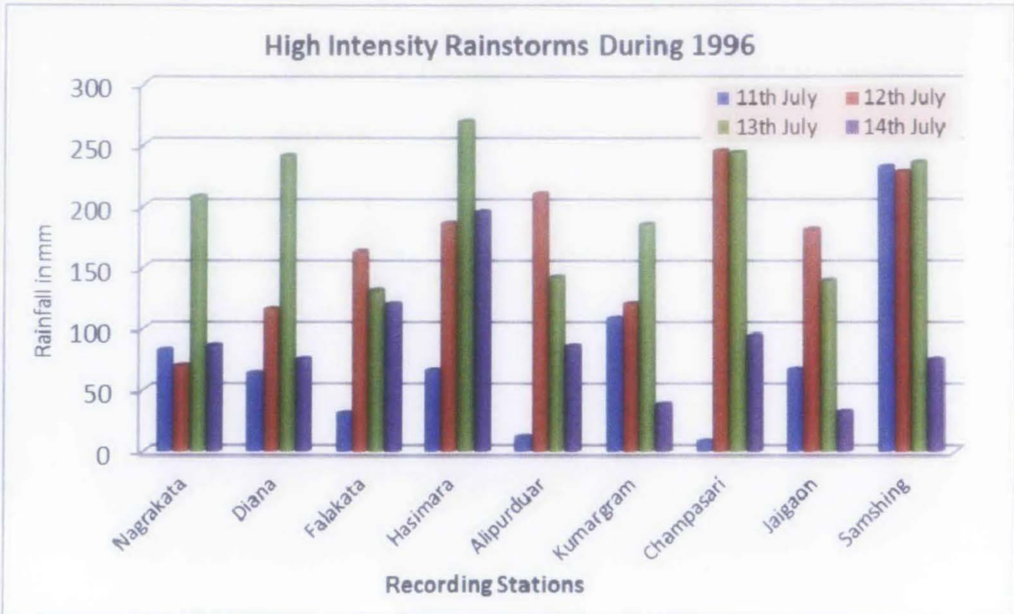

Figure 3.4 High intensity rainstorms during 1996

Table3.3 High intensity rainstorm in Jalpaiguri district during July 11-14, 1996

Stations	11.07.1996	12.07.1996	13.07.1996	14.07.1996
Nagrakata	82.1	69.6	207.8	86
Diana	63	115.4	241	75.4
Falakata	30.6	162.4	130.6	119.6
Hasimara	65.6	185.4	268.6	195.4
Alipurduar	11.4	210	142	85.6
Kumargram	108.4	120	184.6	38.4
Champasari	8.6	245.2	243.6	94.2
Jaigaon	66.3	180.4	139.2	32.1
Samshing	231.2	228	235.2	75

The 1996 event (11-14 July) was less extreme and concentrated in two areas. Samshing tea garden i.e., Murti-Diana area, Champasari i.e., Tista valley and Hasimara-Alipurduar area i.e., eastern Duars received high amount (figure 3.4 and table 3.3). Cumulative rainfall during the July 11-14 rainstorms recorded at different stations has been plotted and demonstrated in figure 3.5. It is clearly shown that the intensity of rainstorm was highest at Samshing tea garden followed by Hasimara and Champasari.

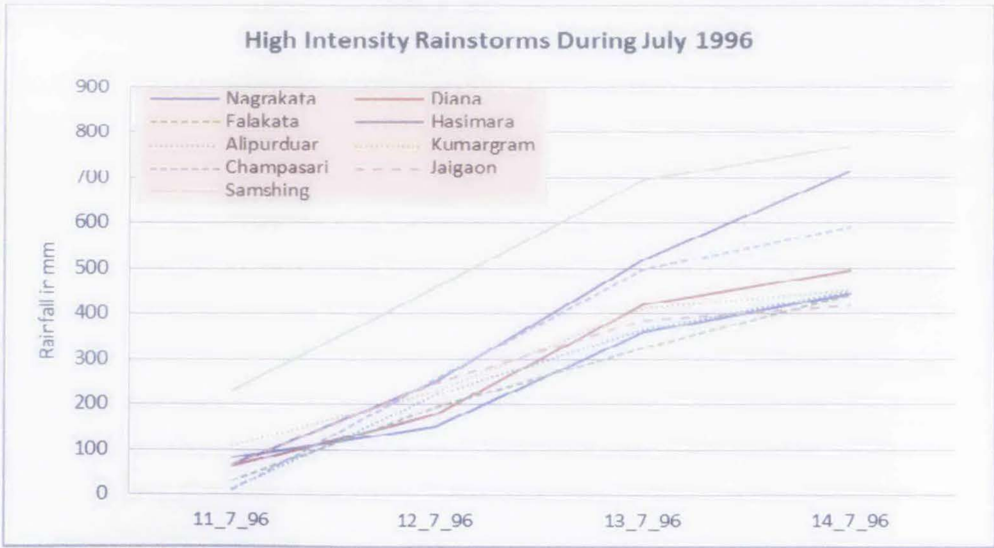

Figure 3.5 High intensity rainstorms during 1996

Three series of continuous rains were recorded in the year 1998. The first and the heaviest one was recorded in between 7-12 June that was concentrated east of the river Torsa (table 3.4). Dalsingpara tea garden recorded the highest rainfall of 1968.7 mm during the period of 6 days and closely followed by Chuapara tea garden with 1191 mm along the mountain front of Bhutanese Himalaya. The intensity of rainfall decreases in all directions i.e., Raimatang tea garden 630.5 mm, Ghatia tea garden 780.3 mm, Diana tea garden 614.6, Hasimara tea garden 535.9 mm and the intensity decreases further and Aibheel tea garden located further east recorded only 246.6 mm rainfall (figure 3.6).

Table 3.4 Cumulative rainfall during the July, 1998 rainstorm

Stations	7.6.1998	8.6.1998	9.6.1998	10.6.1998	11.6.1998	12.6.1998
Aibheel	16.9	42.4	113.7	148	183.8	246.6
Ghatia	180.1	222	355.4	490	644.4	780.3
Chuapara	297	515	665	830	1025	1191
Dalsingpara	0	508	948.7	1284	1636.8	1968.7
Diana	11	105.8	141.2	451	488.8	614.6
Hasimara	48	130.6	236.6	323.1	384.9	535.9
Raimatang	67	199.6	322.3	421.4	482.8	630.5

After 2-3 days break next heavy rain occurred between 15-18 June when the piedmont area of Jaldhaka basin recorded up to 900 mm (Jiti tea garden 874 mm) and in Torsa catchment above 500 mm. After several local heavy rains (at Dalsingpara tea garden 225 and 445 mm) the next event of continuous rain recorded between 20 and 24 July. This time rain concentrated in upper Jaldhaka basin (Ghatia tea garden 926 mm, Jiti tea garden 986 mm) and in the piedmont east of the river Torsa (Chuapara tea garden 767 mm and Dalsingpara tea garden 688 mm).

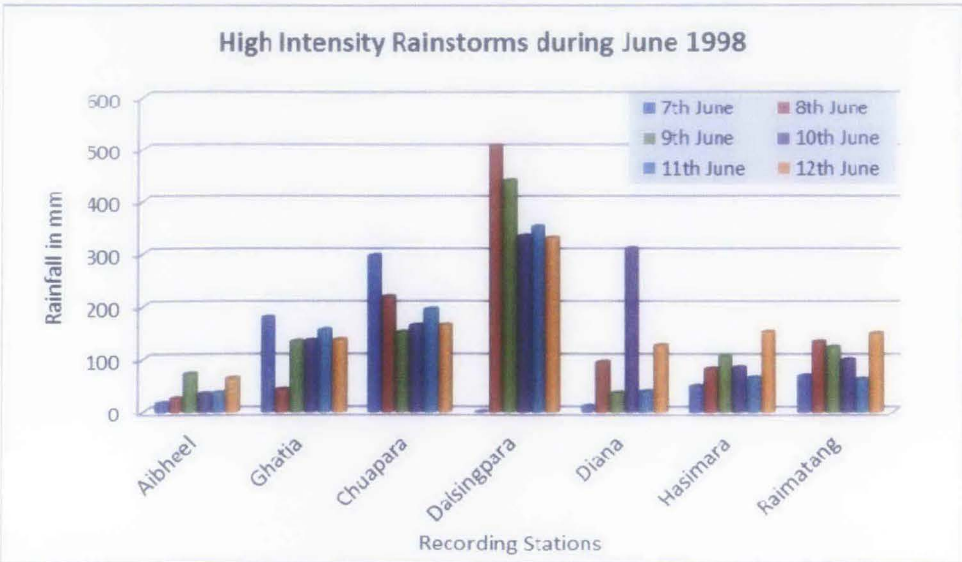

Figure 3.6 High intensity rainstorms during 1998

The year 2000 again experienced the incidences of a number of high intensity rainstorms in Jalpaiguri district and in particularly along the eastern Duars. The first event under consideration was taken place between 20thJuly to 23rd July and the second event was taken place between 1stAugust to 4th August 2000, concentrated again at the mountain front (table 3.5).

Table 3.5 High intensity rainstorms of 2000

Stations	20th July	21st July	22nd July	23rd July	1st August	2ndAugust	3rdAugust	4thAugust
Aibheel	81.2	217.6	64.9	115.9	35.8	37.0	98.3	17.9
Ghatia	137.4	374.7	132.6	115.8	64.3	77.7	381.8	33.8
Chuapara	79	131	258	251	95	120	317	75
Dalsingpara	549.4	211.3	248.4	349.3	98.5	195.0	237.5	60.0
Barabhisa	13.8	61.6	395.6	112.6	65.4	50.4	5.2	138
Chepan	14.4	77.0	283.1	87.0	33.4	123	8.2	108.6
Diana	13.8	157.0	117.0	20.6	27.8	39.2	57.4	291.8
Hasimara	3.2	250.6	258.2	59.2	52.4	123.4	26.2	0
Nagrakata	29.2	202.6	109.2	36.8	108.2	73.2	8.6	0.0
Sevok	15.8	203.2	150.6	23.2	24.8	32	58.6	207.8
Murti	15,8	203.2	150.6	23.2	24.8	32.9	58.6	207.8
Raimatang	43	112	202	198	9.7	77.5	195.6	63.5

The incidences of high intensity rainstorms that occurred during the year 2000 in Jalpaiguri district has also been represented in the following figures (nos. 3.7A, 3.7B, 3.8A & 3.8B). Dalsingpara tea garden recorded the heaviest 24 hours rainfall of 549.4 mm on the 20th July followed by 381.8 mm recorded at Gatia tea garden on the 3rd August, 374.7 mm again by Gatia tea garden on the 21st of July. Figure 3.7 shows the details of daily rainfall during the two consecutive rainstorm events and figure 3.8 shows the cumulative rainfall pattern that is recorded during the events.

Since the year 2000 there has been no high intensity rainstorms recorded in Jalpaiguri district at similar magnitude to the years 1968, 1993, 1996, 1998 and 2000. However, an event of some interest was taken place in the year 2010 and is shown in figure 3.9.

Rainfall record from the eastern part between the river Torsa and Pana for several past years reveals the occurrences of heavy rains during 3-5 consecutive days in almost every alternate year, which caused more or less local floods i.e., Chuapara tea garden recorded 578 mm between 31st July to 2nd August 2001, 726 mm between 6-10 July 2003, 549 mm between 8-11 July 2005 and Dalsingpara tea garden recorded 706 mm between 8-11 July 2005.

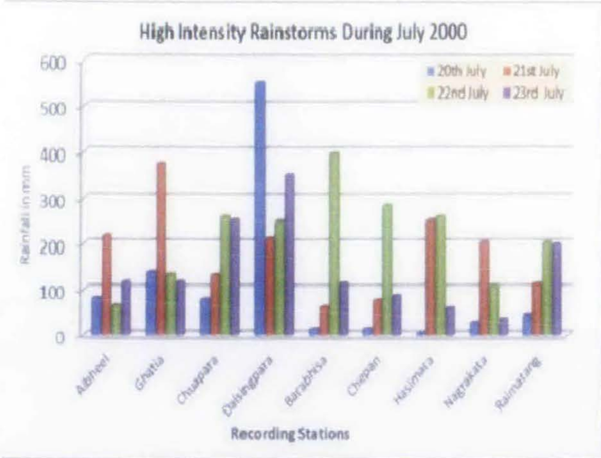

Figure 3.7A High intensity rainstorm during 2000

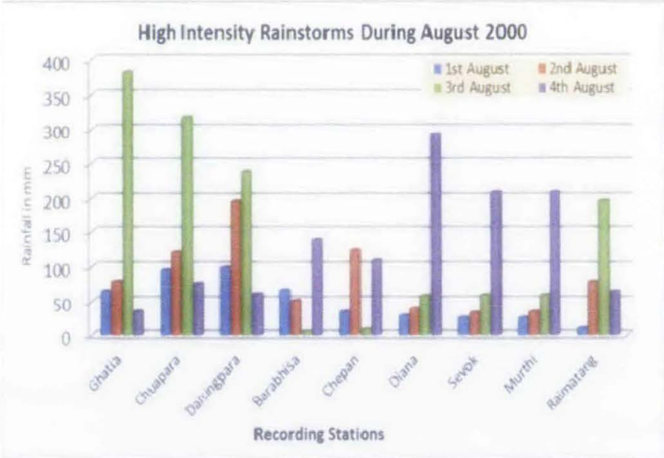

Figure 3.8A High intensity rainstorms during 2000

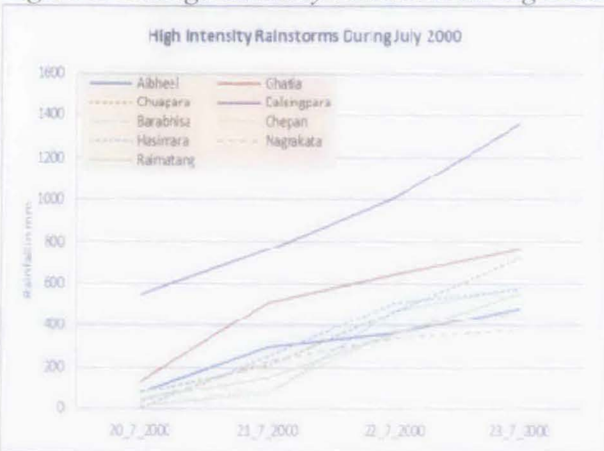

Figure 3.7B High intensity rainstorm during 2000

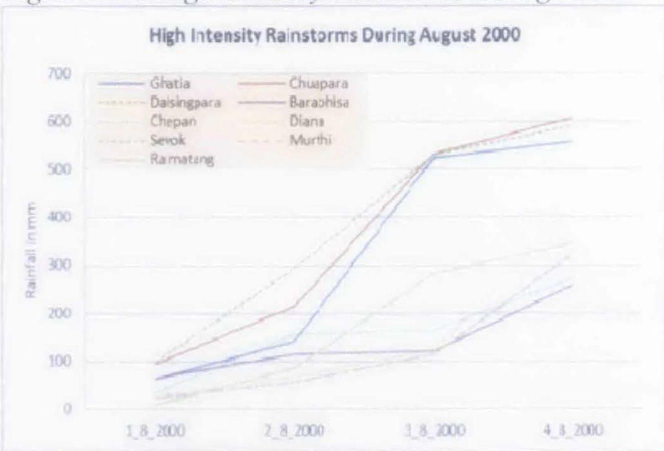

Figure 3.8B High intensity rainstorms during 2000

Many of these records show that highest recorded stations are located several km south of the mountain front. This do not means that at the Himalayan edge the rainfall could not be higher. It is clear that these rains are supplying not only to the rivers flowing from the Himalayas, but also others starting on the alluvial fans in the piedmont zone.

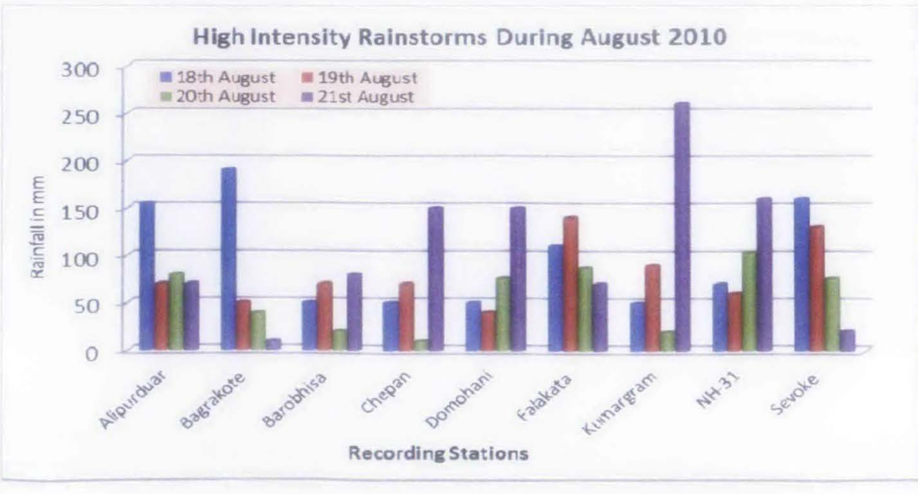

Figure 3.9 High intensity rainstorms during 2010

3.4. Long term probability analysis of high intensity rainfall

The long term annual rainfall record of four recording stations has been made available from the Jalpaiguri district from 1923 to 2010. These are Jalpaiguri town, Chuapara tea garden, Meteli tea garden and Kurti tea garden. 88 years annual rainfall reveals that during the year 1954 Jalpaiguri received the highest ever annual rainfall of 5088.0 mm while the lowest rainfall of 2089.0 mm recorded during the year 1978. The mean annual rainfall of Jalpaiguri town has been calculated to be 3394.2 mm and the maximum range of 2999.0 mm. The long term mean annual rainfall of Jalpaiguri town has been diagrammatically represented in figure 3.10.

It is very difficult to assess the progressive changes in rainfall, which is rather fluctuating in nature. One year's lower rainfall is often compensated by a higher amount in the very next year. However, the analysis of long-term running average (figure 3.10) reveals the following interesting trends:

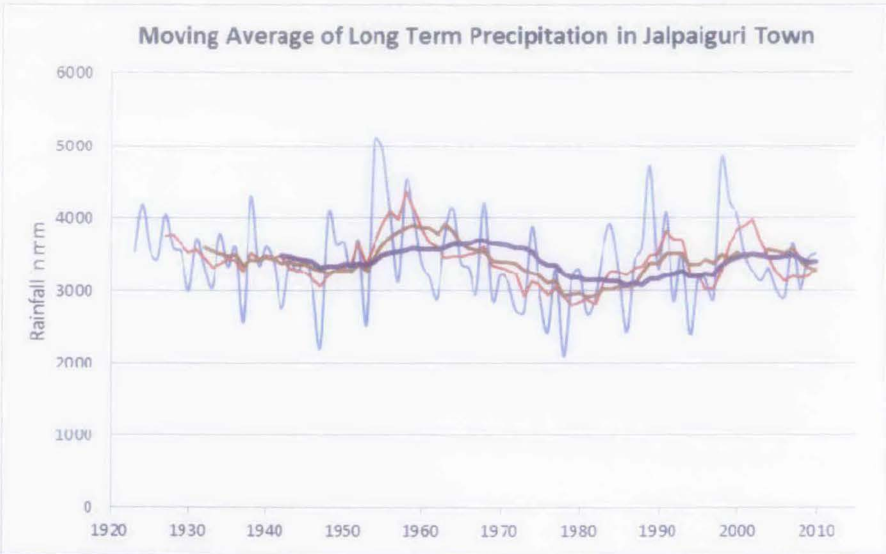

Figure 3.10 Moving average of long term precipitation of Jalpaiguri town

- The 5-years running average indicates two high rainfall periods (1960-70), followed by a low rainfall period (1940-1950 & 1970-1980).

- The 10-years running average also indicates two high rainfall periods (1960-70 &1980-90) and two low rainfall periods (1940-1950 & 1970-1980).

- Generalized patterns of long term rainfall in Jalpaiguri town has been identified from the 20-years running average (figure 3.10). It also helps to develop a long-term precipitation model for Jalpaiguri. Up to 1950, the amount of rainfall tended to decrease; from 1950 to 1970, it was slightly increased and was again an increasing tendency from 1990 onwards.

Thus there has been a 20 years return period of rainfall pattern in the case of Jalpaiguri town. The same trend is expected to be maintained during the next 20years period also. It is also revealed that the annual fluctuation in total rainfall has been increasing from 1950 onwards.

An attempt has also been made to analyse long term probability of annual rainfall in Jalpaiguri town using standard statistical techniques (figure 3.11).

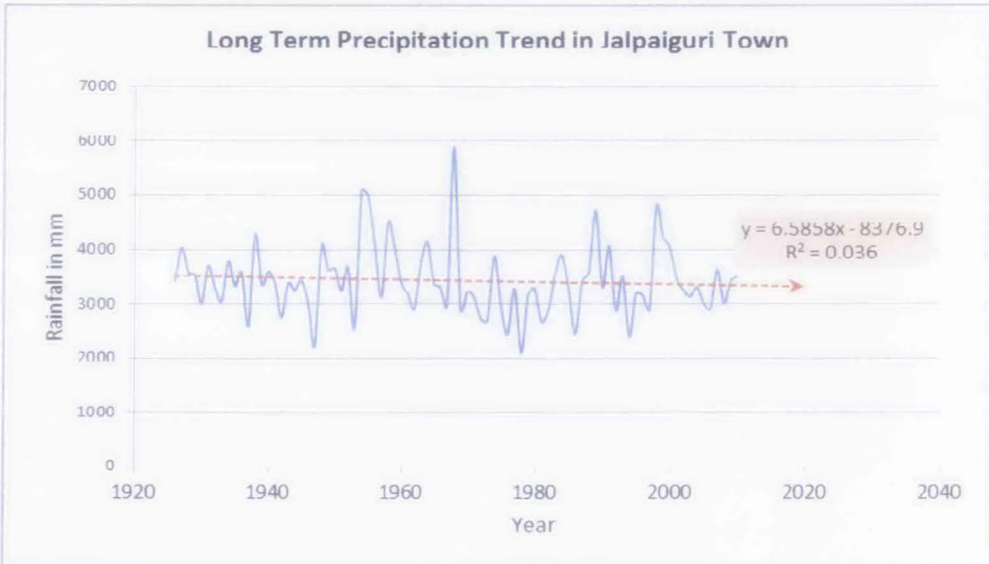

Figure 3.11 Long term precipitation trend of Jalpaiguri town

The time series analysis of available annual rainfall data clearly shows a declining trend in annual rainfall. The linear relationship as expressed in figure 3.11 reveals an annual decrease of 6.6 mm of rainfall per annum.

Annual rainfall record for 85 years of Chuapara tea garden has been accessed and analysed. It is revealed that during the year 1998 Chuapara tea garden received the highest ever annual rainfall of 7787.0 mm while the lowest rainfall of 3012.0 mm recorded during the year 1969. The mean annual rainfall of Chuapara tea garden has been calculated to be 4583.9 mm and the maximum range of 4775.0 mm. The long term mean annual rainfall of Chuapara tea garden has been diagrammatically represented in figure 3.12.

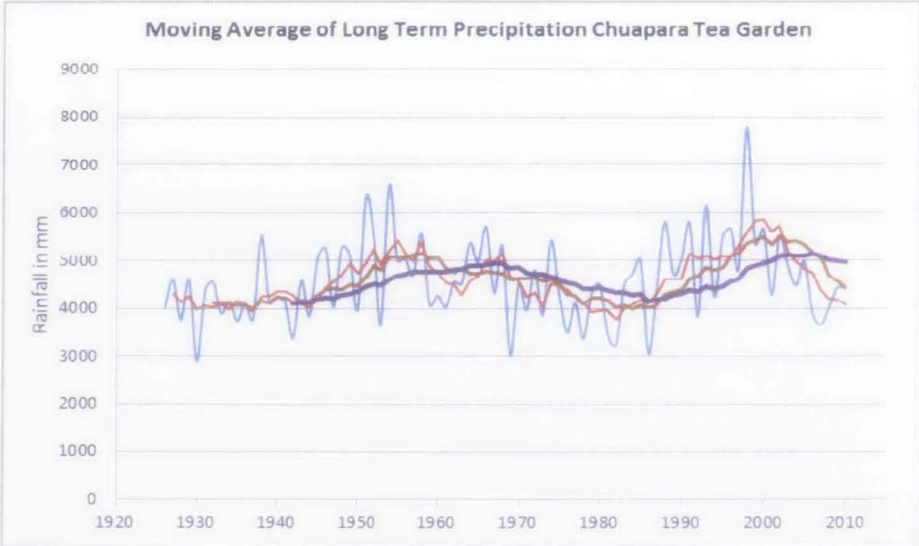

Figure 3.12 Moving average of long term precipitation of Chuapara tea garden

An attempt has also been made to assess the progressive changes in rainfall, which is rather fluctuating in nature. One year's lower rainfall is often compensated by a higher amount in the very next year. However, the analysis of long-term running average (figure 3.12) reveals the following interesting trends:

- The 5-years running average indicates three high rainfall periods (1950-60), followed by a low rainfall period (1965-1970 & 1990-2005).

- The 10-years running average also indicates three high rainfall periods (1950-60, 1965-75 and 1990-2000) and two low rainfall periods (1930-1940 & 1980-1990).

- Generalized patterns of long term rainfall of Chuapara tea garden has been identified from the 20-years running average (figure 3.12). It also helps to develop a long-term precipitation model for Chuapara tea garden. Up to 1950, the amount of total rainfall tended to decrease; from 1950 to 1970, it was slightly increased; there was again an increasing tendency from 1990 onwards.

Thus there has been a 20 years return period of rainfall pattern in the case of Chuapara tea garden. The same trend is expected to be maintained during the next 20years. It is also revealed that the annual fluctuation in total rainfall has been increasing from 1950 onwards. An attempt has also been made to analyse long term probability of annual rainfall in Chuapara tea garden using standard statistical techniques (Figure 3.13).

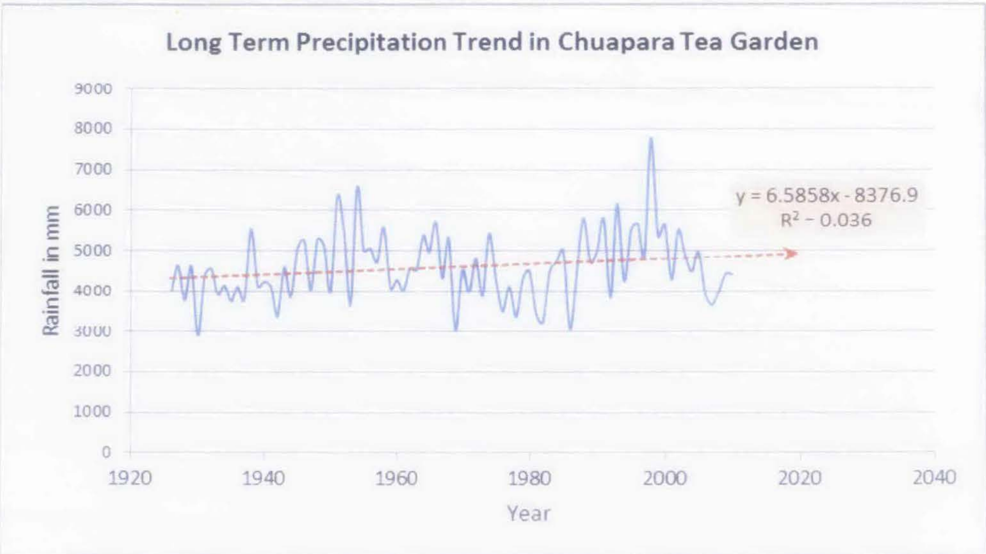

Figure 3.13 Long term precipitation trend of Chuapara tea garden

The time series analysis of available annual rainfall data clearly shows an increasing trend in annual rainfall pattern. The linear relationship as expressed in figure 3.13, reveals an annual increase of 6.6 mm of rainfall per annum.

Annual rainfall record for 87 years of Meteli tea garden reveals that during the year 1952 Meteli tea garden received the highest ever annual rainfall of 7908.0 mm while the lowest rainfall of 3357.1 mm recorded during the year 1994. The mean annual rainfall of Meteli tea garden has been calculated to be 4800.8 mm and the maximum range of 4550.9 mm. The long term mean annual rainfall of Meteli tea garden has been diagrammatically represented in figure 3.14.

It is very interesting to assess the progressive changes in rainfall of Meteli tea garden, which in spite of general fluctuating nature strongly exhibiting progressive decline in annual precipitation. However, it is clearly found that one year's lower rainfall is often compensated by a higher amount in the very next year. The analysis of long-term running average (figure 3.14) reveals the following interesting trends:

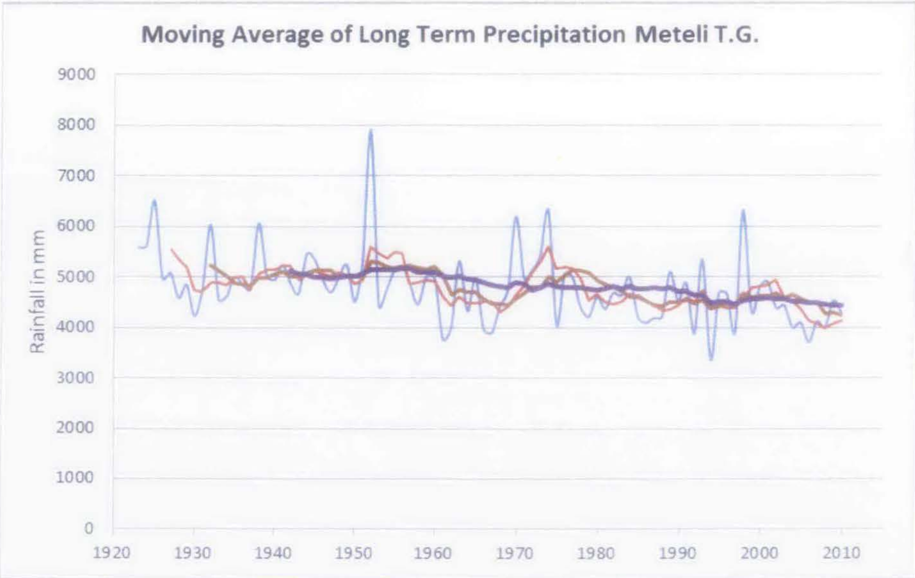

Figure 3.14 Moving average of long term precipitation of Meteli tea garden

- The 5-years running average indicates three high rainfall periods (1955-60; 1975-80 and 2000-2005), followed by three low rainfall period (1930-1935, 1965-1970 & 1985-1990).

- The 10-years running average also indicates two high rainfall periods (1950-60 &1970-80) and two low rainfall periods (1960-1970 & 1985-1995).

- Generalized patterns of long term rainfall in Meteli tea garden has been identified from the 20-years running average (figure 3.14). It also helps to develop a long-term precipitation model for Meteli tea garden. Up to 1960, the amount of total rainfall tended to stabilise followed by slightly decreasing tendency till now.

An attempt has also been made to analyse long term probability of annual rainfall in Meteli tea garden using standard statistical techniques (figure 3.15).

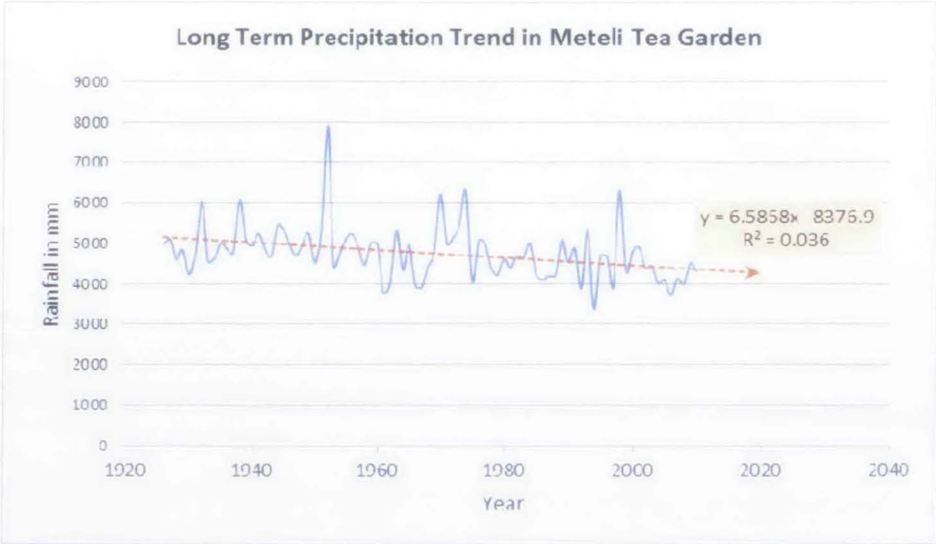

Figure 3.15 Long term precipitation trend of Meteli tea garden

The time series analysis of available annual rainfall data clearly shows a clear declining tendency of annual rainfall in Meteli tea garden area. The linear relationship has been represented in figure 3.15.

The long term annual rainfall data obtained from the Kurti tea garden has been analysed. It is revealed that during the year 1998, Kurti tea garden received the highest ever annual rainfall of 6533.4 mm while the lowest rainfall of 3160.5 mm recorded during the year 1986. The mean annual rainfall of Kurti tea garden has been calculated to be 4291.3 mm. The maximum range of annual rainfall as estimated to be 3372.9 mm. The long term mean annual rainfall of Kurti tea garden has been diagrammatically represented in figure 3.16.

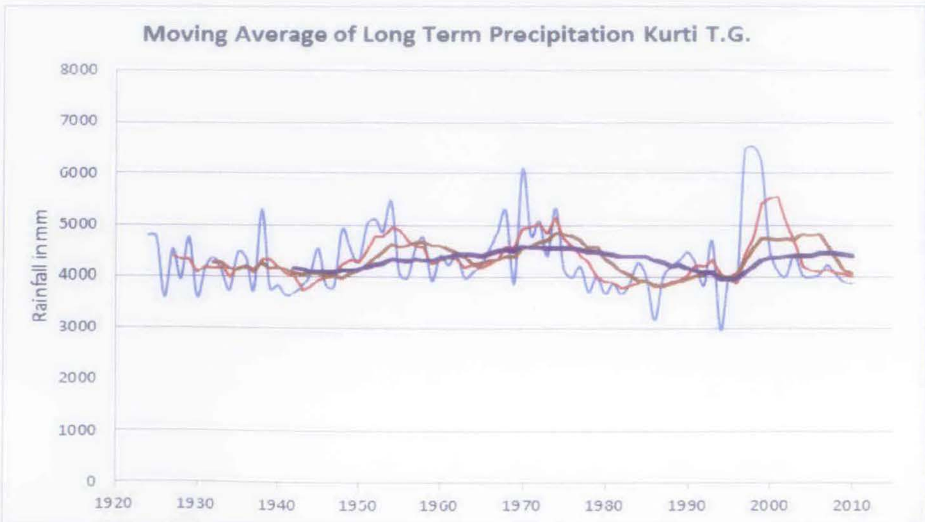

Figure 3.16 Moving average of long term precipitation of Kurti tea garden

An attempt has also been made to assess the progressive changes in rainfall, which is rather fluctuating in nature. One year's lower rainfall is often compensated by a higher amount in the very next year. However, the analysis of long-term running average (figure 3.16) reveals the following interesting trends:

- The 5-years running average indicates three high rainfall periods (1950-55, 1970-75 & 2000-2005), followed by another four low rainfall periods (1940-1945, 1960-1970, 1980-1990 & 2005 onwards).

- The 10-years running average also indicates three high rainfall periods (1950-1960, 1965-75 and 1995-2005) and two low rainfall periods (1935-1945& 1980-1995).

- Generalized patterns of long term rainfall of Kurti tea garden has been identified from the 20-years running average (figure 3.16). It also helps to develop a long-term precipitation model for Kurti tea garden. Up to 1950, the amount of total rainfall tended to increase; from 1975 to 2000, it was slightly decreased; there was again an increasing tendency from 2000 onwards.

Thus there has been a 20 years return period of rainfall pattern in the case of Kurti tea garden. The same trend is expected to be maintained during the next 20year period also. It is also revealed that the annual fluctuation in total rainfall has been increasing from 1950 onwards.

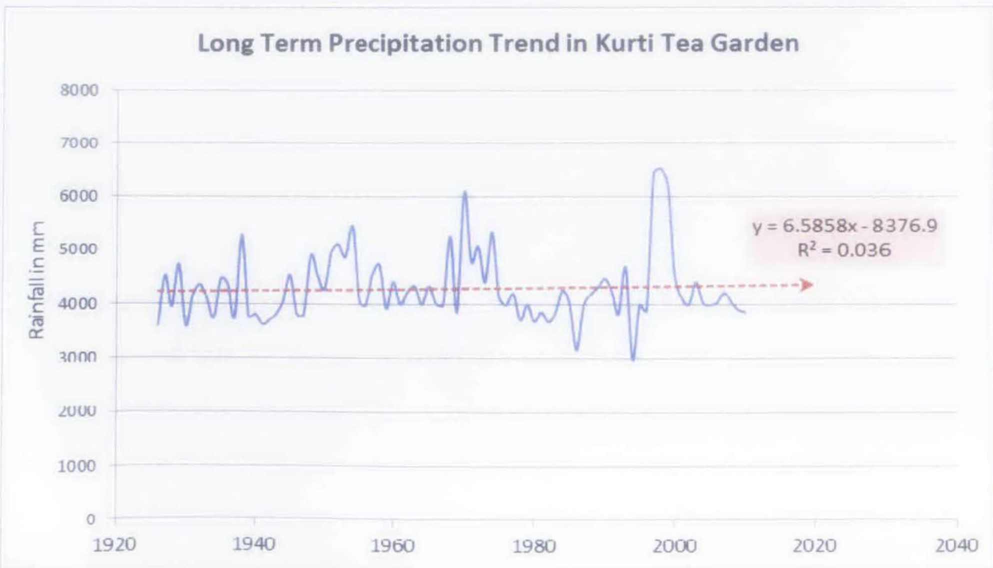

Figure 3.17 Long term precipitation trend of Kurti tea garden

An attempt has also been made to analyse long term probability of annual rainfall in Kurti tea garden using standard statistical techniques. The time series analysis of available annual rainfall data shows slight increasing tendency in annual rainfall pattern in the Kurti tea garden area. The linear relationship has been presented in figure 3.17.

It is really difficult to say anything regarding the long term trend conclusively of Jalpaiguri district. The probability analysis of the long term rainfall data of four selected recording stations make the situation further complicated. Out of the four studied stations two (Kurti and Chuapara tea gardens) exhibit an increasing tendency of annual precipitation while, the rest of the two stations namely Jalpaiguri town and Meteli tea garden clearly proves a decreasing tendency of long term precipitation.

3.5. Role of extreme rainfall in causing floods

Sub-Himalayan Jalpaiguri district have been experiencing high to very high intensity rainfall. High intensity rainstorms often transformed into cloud-burst and descends as much as 784 millimetre of rainfall within a period of 24 hours (recorded at Hasimara, Jalpaiguri in 1993). Such a catastrophic meteorological event often caused devastating flash flood in the piedmont region of Jalpaiguri district and caused prolonged inundation in the plain region further south. Records of flood occurrences in Jalpaiguri district reveals that all most all incidences of flood in this region caused by such high intensity rainfall events either in upper catchment or, within the district (Chapter V). Starkel et. al (2008) stated that "the response of river Torsa to the series of extreme rainfall is exemplified by daily discharges at Hasimara and daily rainfall at Phuntsholing at the Himalayan margin (15 km distance). During the first three days of 7-days rainstorm (June 6-12, 1998) rainfall oscillates about 200 mm and was not reflected in change of discharge however, on the 12th June heavy storm of 800 mm rain caused an increase of discharge to 2000 m^3s^{-1}. Similar relations were observed between 20-24 July 1998 and 30 July to 3 August 2000. In July 1998 after 450 mm of rain (688 mm at Dalsingpara T.E.) the river recorded a discharge of 1450 m^3s^{-1} and in the year 2000 after 900 mm of rain (500 mm in one day) the river Torsa recorded highest discharge of 3800 m^3s^{-1}. The gradual rise of water level and then rapid drop is one of important characteristic of the Torsa floods".

An attempt has been made in this section to correlate the relationship between incidences of high intensity rainstorms and flood discharge through the respective rivers. The daily rainfall data has been collected from the IMD, Govt. of India and tea gardens. Such study has been carried out in the river Jaldhaka and Torsa and has been depicted in the following sections.

3.5.1 The 1993 flood

In July 1993, the eastern Duars of Jalpaiguri district particularly Alipurduar subdivision experienced severe flash flood in associated with huge loss of lives and properties. The apparent reason of such a devastating flood was very high intensity rainstorms that occurred in localized area of eastern Duars and southern slope of Bhutanese Himalaya (table 3.1). The hydrological record as maintained by the Central Water Commission (CWC) at Hasimara station for the river Torsa and NH-31 station for the river Jaldhaka has been obtained and mean rainfall record available from the tea garden and IMD sources have plotted and diagrammatically represented in figure 3.18 for the river Torsa and figure 3.19 for the river Jaldhaka.

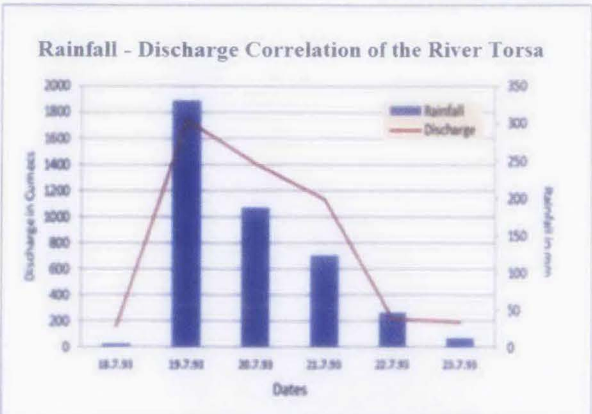

Fig 3.18 Relationship between rainfall and flood discharge in Torsa river

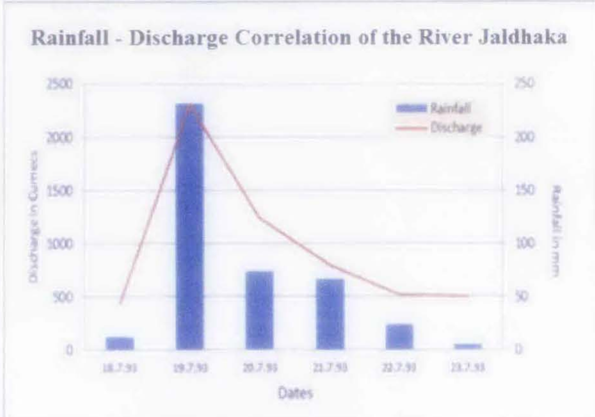

Fig 3.19 Relationship between rainfall and flood discharge in Jaldhaka river

3.5.2 The 1998 flood

Jalpaiguri district experienced three series of high intensity rainstorms in associated with flood. The first one was recorded in between 7-12 June that was concentrated east of the river Torsa (table 3.4). Dalsingpara tea garden recorded the highest rainfall of 1968.7 mm during the period of 6 days and closely followed by Chuapara tea garden with 1191 mm along the mountain front of Bhutanese Himalaya. The intensity of rainfall decreases in all directions i.e., Raimatang tea garden 630.5 mm, Ghatia tea garden 780.3 mm, Diana tea garden 614.6, Hasimara tea garden 535.9 mm and the intensity decreases further and Aibheel tea garden located further east recorded only 246.6 mm rainfall (figure 3.6).

After 2-3 days break next heavy rain occurred between 15-18 June when the piedmont area of Jaldhaka basin recorded up to 900 mm (Jiti tea garden 874 mm) and in Torsa catchment above 500 mm. After several local heavy rains (at Dalsingpara tea garden 225 and 445 mm) the next event of continuous rain recorded between 20 and 24 July. This time rain concentrated in upper Jaldhaka basin (Ghatia tea garden 926 mm, Jiti tea garden 986 mm) and in the piedmont east of the river Torsa (Chuapara tea garden 767 mm and Dalsingpara tea garden 688 mm).

The hydrological record as maintained by the Central Water Commission (CWC) at Hasimara station for the river Torsa and NH-31 station for the river Jaldhaka has been obtained and mean rainfall record available from the tea garden and IMD sources have plotted and diagrammatically represented in figure 3.21 for the river Jaldhaka and figure 3.20 for the river Torsa.

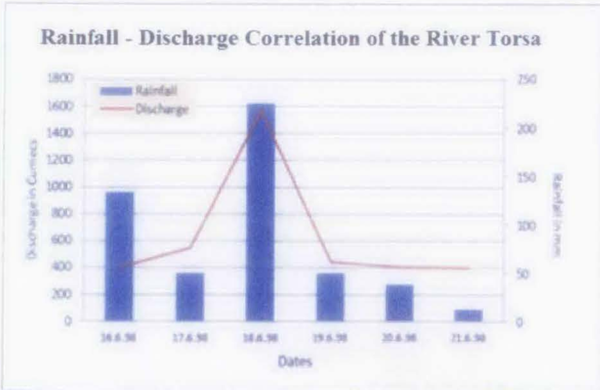

Fig 3.20 Relationship between rainfall and flood discharge in Jaldhaka river

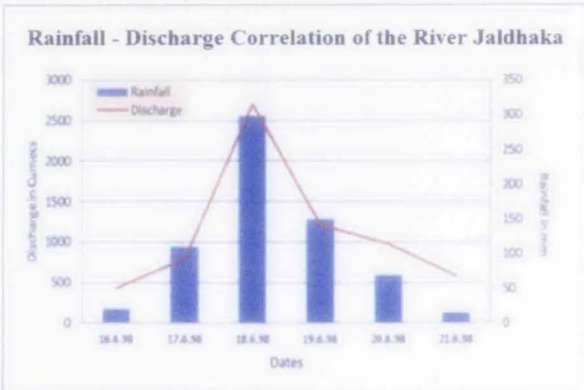

Fig 3.21 Relationship between rainfall and flood discharge in Torsa river

3.5.3 The 2000 flood

The year 2000 again experienced the incidences of a number of high intensity rainstorms in Jalpaiguri district and in particularly along the eastern Duars. The first event under consideration was taken place between 20th July to 23rd July and the second event was taken place between 1st August to 4th August 2000, concentrated again at the mountain front (table 3.5).Such high intensity rainstorms also caused severe flash flood in associated with huge loss of lives and properties in many parts of the district.

The hydrological record as maintained by the Central Water Commission (CWC) at Hasimara station for the river Torsa and NH-31 station for the river Jaldhaka has been obtained and mean rainfall record available from the tea garden and IMD sources have plotted and diagrammatically represented in figure 3.23 for the river Jaldhaka and figure 3.22 for the river Torsa.

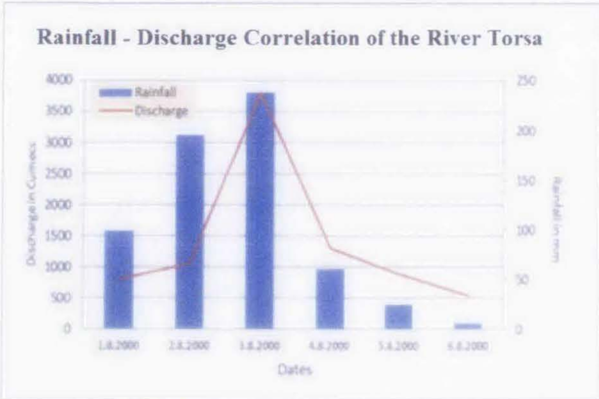

Fig 3.22 Relationship between rainfall and flood discharge in Jaldhaka river

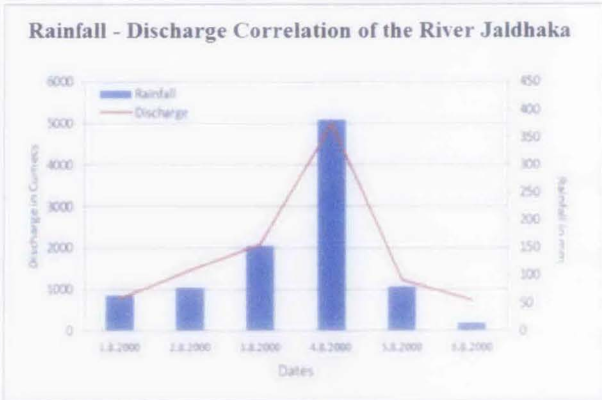

Fig 3.23 Relationship between rainfall and flood discharge in Torsa river

3.5.4 The 2002 flood

In July 2002, the eastern Duars of Jalpaiguri district experienced severe flash flood in associated with huge loss of properties along with massive aggradations. The apparent reason of such a devastating flood was very high intensity rainstorms that occurred in localized area of eastern Duars and southern slope Bhutanese Himalaya. The hydrological record as maintained by the Central Water Commission (CWC) at Hasimara station for the river Torsa and NH-31 station has been obtained and mean rainfall record available from the tea garden and IMD sources have plotted and diagrammatically represented in figure 3.24 for the river Torsa.

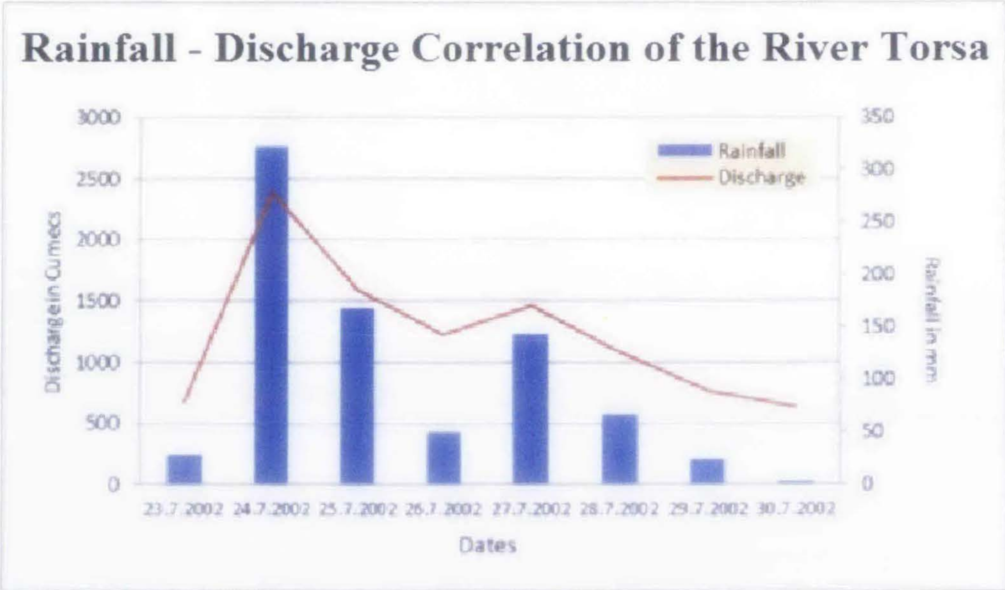

Fig 3.24 Relationship between rainfall and flood discharge in Torsa river

It is thus apparently found that there exist good relationship between the occurrences of high intensity rainstorms and floods in sub-Himalayan Jalpaiguri district. The relation is found more pronounced in case of the river Jaldhaka as its watershed is mostly situated in the lesser Himalaya within a unique hydro-meteorological zone. In the other hand the Torsa being a trans-Himalayan river system is situated in a complex hydro-meteorological zone. Its upper catchment being situated in Tibetan plateau receives insignificant amount of rainfall.

3.6. Conclusion

High intensity rainstorms are found most commonly occurred in sub-Himalayan Jalpaiguri district especially along its northern boundary with the Himalayan margin. Frequency and magnitude of such events have been found significantly reduced at a distance of 20 km from the rising Himalayas. It is also conclusively proved that such events often culminate with flash flood along the downstream in Jalpaiguri district. It is observed that higher the intensity of rainstorm then higher the magnitude of flood in the downstream. Numerous examples of such relations have been depicted in the chapter with 24-hour rainfall record obtained mostly from tea gardens across the district along with their corresponding flood discharge obtained from the respective CWC gauging stations located in the river Jaldhaka and Torsa.

The complex and imposing topography i.e., high mountains, deep gorge like valley, steep slope and alignment to the prevailing moisture laden cloud have exhibited its influence on the regional distribution of high intensity rainstorms. The temporal variations of the flow manifest characteristics of the watershed that influences its run-off. It is observed that the rainstorms of the sub-Himalayan Jalpaiguri district generally do not exceeded 4-day duration. The general synoptic situation associated with the rainstorms is the prevalence of eastern end of the monsoon trough. The severe rainstorms are associated with the presence of depression/low over the respective watershed.

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Chapter IV: Characteristics of major Catchments

4.1 Introduction

Land use pattern of catchment has very important role in regulating the overall hydrological processes of the river. The six selected rivers namely, Tista, Torsa, Jaldhaka, Raidak, Sankosh and Mahananda have their watershed extended beyond the territorial boundary of India. Except the Mahananda and Tista all other rivers have their source along with considerable catchment area situated in Bhutan and in Tibet (China). It is also true that all the six rivers flow downstream to Bangladesh further south. The watershed characteristics has been assessed up to these points only as hydro-geomorphologically any change in watershed will have its implication at its outfall i.e., selected stations.

In view of non-availability and restricted nature of topographic maps (Survey of India) of the watersheds, the investigator used the US Army Topo Sheets (1:250000) No. NG 45-3, NG 45-4, NG 45-7, NG 45-8, NH 45-16, NH 46-13, NG 46-1, NG 46-5 for the delimitation of watersheds situated across the international boundary. An attempt has also been made to analyse the catchment characteristics along with land use pattern based on the maps. Satellite image available from NRSA and Google Earth has also been used to identify various features and updated land use data. The entire analysis has been carried out under GIS platform (ArcGIS and Global Mapper).

4.2 Hydro-geomorphic characteristics

Hydro-geomorphic characteristics of the drainage basins have considerable significance in analysing flood behavior in its down streams. The sub-Himalayan Jalpaiguri district is drains by major drainage systems like Tista, Jaldhaka, Torsa, Raidak, Sankosh and Mahananda. All these rivers are originating from beyond the geographical boundary of the state of West Bengal and some of them in fact originate from beyond the territory of India. Hydro-geomorphological characteristics of the concern drainage basins are discussed under two sub-headings i) Hydrological characteristics and ii) geomorphological characteristics.

4.2.1 Hydrological characteristics of drainage basins

When alluvial river has to be harnessed for irrigation, power, navigation, flood management etc., changes in the river regime take place in terms of channel widening, bank erosion, local scour aggradation & degradation leading to changes in slope etc. These changes in river regime take place because the equilibrium of the river is disturbed by human interferences (Jain V., Sinha R., 2003; Moriswa, M, 1968; Sen S., 1968). By studying the hydraulic characteristics of the river, likely changes in the river behaviour may be assessed through mathematical modeling or taking recourse to the physical methods. A few parameters such as peak discharge, channel slope variation, sediment load, aggradations & degradation of major rivers have been studied and are described below:

Peak discharge of the Tista, Torsa, Jaldhaka, Raidak, Sankosh and Mahananda rivers have been calculated at some strategic locations (WAPCOS, 2003) by various agencies (table 4.1).

Table No. 4.1
Calculated peak discharge of rivers under study

Name of river	Reach from origin up to	Catchment area (Sq. km.)	Length from origin (km)	Discharge (Peak) m^3/sec
Tista	(i) Snow line	2479	10	--
	(ii) Rango (Sikkim Border).	6220	132	12072
	(iii) AndersonBridge	7612	150	16309
	(iv) CoronationBridge	9359	173	17367
	(v) Domohani, Jalpaiguri	9568	234	20067
	(vi) Bangladesh Border	10205	276	21428
Torsa	(i) Up to Tibet-Bhutan boundary	1735	70.8	4283
	(ii) Phuntsholing	4045	132	12159
	(iii) NH 31, Hasimara	3872	147	12538
	(v) Koch Bihar	4533	258	13575
	(vi) After confluence with Kaljani	6045	287	16024
	(vii) Bangladesh Border	6407	296	16362
Jaldhaka	(i) SikkimBhutan Boundary	78	64	787
	(ii) Nagrakata	648	72	3716
	(iii) NH-31 Crossing	1626	96	8795
	(iv) Mathabhanga	4092	175	10067
	(v) Indo-Bangladesh boundary.	4766	218	10698
Sankosh	At Chepan/Barobhisa	10534	208	22297
Raidak	At Bhutanghat	4813	167.2	14530
Mahananda	NH 31, Champasari, Siliguri	175	26	995

Source: Master Plan for Flood Management &North Bengal Flood Control Commission, Jalpaiguri

The channel slope of the river in North Bengal varies depending upon the terrain characteristics. The aspects are discussed below according the physiographic set-up. The details of gradient of major rivers are given in table 4.2. Average gradient of the channel varies from 1:13 in the Mahananda to 1:29 in the Sankosh. The Torsa with a gradient of 1:21 (within the studied section) has four major tributaries with moderate gradient. The Tista, the largest river in the north of the Ganga-Padma system in West Bengal, although infested with innumerable island and shoals in its wide channel, is still flowing fairly fast within the studied section a gradient of 1:23.

Table No. 4.2
Gradient of the major rivers (physiographic region wise) in North Bengal

River	*Gradient*	*Hilly region*	*Piedmont zone*	*Active Plain*
Mahananda	1:13	1:7	1:185	-
Tista	1:23	1:32	1:215	1:342
Neora	1:196	1:17	1:307	-
Dharala (West)	1:3421	-	1:1561	1:4652
Jaldhaka	1:16	1:12	1:198	1:3129
Mujnai	1:2315	-	1:295	1:4000
Dharala (East)	1:7786	-	-	1:7786
Torsa	1:21	1:20	1:162	1:4611
Raidak	1:42	1:27	1:128	1:852
Kaljani	1:1056	-	1:154	1:2583
Jainti	1:1990	1:13	1:132	1:3656
Sankosh	1:29	1:38	1:112	1:1833

4.2.1.1 The river in hills and piedmont

Most of the rivers in this region are rather straight streams. The average slope ratio of the river channel in general cases is much lower indicating an obviously steeper gradient. The river Mahananda along its hilly course attains the highest gradient of 1:7 among the rivers under study, followed by the Jaldhaka (1:12), the Torsa (1:20) and the (Tista 1:32). Hydrological characteristics of the major identified watersheds have been depicted in table 4.3.

Pronounced development of conjugal alluvial fan, produced by diverging drainage system in the catchment area of the Mahananda and Jaldhaka is very much conspicuous in the western and central part of the piedmont zone. Series of contour lines arched down slope in a systematic pattern extending even below the 66 meter contour line, where the edges of the fans are loosing arched form. In the eastern section of the piedmont zone, particularly in the Tista and Sankosh catchments, the fan formation is of a subdued type. There are some streams diverging out locally, but the overall trend of run is that of earlier parallel or converging. From the Torsa to the Raidak, the tributaries like Alaikuri, Diana, Jainti, Dharsi, Dhaula etc. are running more or less parallel to each other and the contour lines maintained a general east-west direction without any significant arched form, either upward or downward. The river Sankosh along its piedmont course attains the highest gradient of 1:112 among the rivers under study, followed by the Torsa (1:162), the Mahananda (1:185), the Jaldhaka (1:198) and the (Tista 1:215).

Table No 4.3 Watershed Characteristics

Name of Watershed	Highest elevation (m)	Lowest elevation (m)	Max. length of watershed (km)	Max width in km	L/B ratio	Watershed gradient
Mahananda	2040	50	105	46	2.28	1:18.95
Tista	8585	41	211	83	2.54	1:40.49
Jaldhaka	5964	40	155.5	52	2.99	1:38.09
Torsa	7313	30	230	46	5.00	1:31.67
Raidak	7270	30	193	62	3.11	1:37.52
Sankosh	7516	30	220	122	1.80	1:34.03

4.2.1.1 The rivers in active plains

The streams, which are coming out from the Lesser Himalayas are entirely rain-fed and are generally non-perennial. The Mahananda and Jaldhaka systems are entirely rain-fed. Excepting the main Tista and its tributaries the great Rangit, all other channels within this system are rain-fed. The Torsa and the Sankosh have their origins in the glaciers in the Himalayas. The drainage pattern in this area is still divergent. Wide rivers frequently overflow its shallow bank during torrent but water clears out speedily without causing water logging while leaving behind fresh silt (Mukhopadhyay, SC; 1982).

Average gradient of the channel varies from 1:342 in the Tista to 1:4611 in the Torsa. The river Sankosh with a gradient of 1:1833 followed by the river Jaldhaka with a gradient of 1:3129 within the active plain is rather swift river. The Tista, the largest river in the north of the Ganga-Padma system in West Bengal, although infested with innumerable island and shoals in its wide channel, is still flowing fairly fast within the section a gradient of 1:342.

4.2.2 Sediment load

When the raindrops fall on the soil devoid of vegetation, each raindrop explodes on contact with the ground. By this, the soil particles are dislodged from their position and are drifted along with the flowing sheet of water. The runoff i.e. the excess of rain water which has not infiltrated into the ground washed the soil and erodes the surface. The basic source of sediment in rivers is the erosion of land surface and to some extent erosion ofbeds. The ratio of total sediment charge at any given point in a river varies as 0.8 powers on the drainage area on an average. The sediment load due to the flat slopes of a river gets deposited in the bed and the causes the river channel to meander to find equilibrium condition of discharge, velocity, silt load, slope and flow section.

The rivers in North Bengal are not stable and process of erosion in the steep hilly catchment, transportation of sediment in the river and its subsequent progressive deposition lower down in the river with flatter slope is a continuous phenomenon. In the upper reaches in the plains, the river and their tributaries have got steeper slopes as compared to the lower reaches, thus, the carrying capacity for the silt load in the upper reaches in the Plains is comparatively more than in the lower reaches. The river bed, just after it debauches into the plains, consists of shingle and sand, whereas further down in the flatter plains, the alluvial channels mostly consist of coarse and medium silt. The hydrological characteristics of major watersheds in sub-Himalayan North Bengal is shown in the following table.

Table 4.4Hydrological characteristics of major watersheds

Watershed	Area in km^2	Discharge		Mean discharge		Mean annual runoff m.m^3	Mean annual suspended load (m.m.ton)
		Base flow	Mean maxima	Non-monsoon	Monsoon		
Sankosh	8521	85.0	3000	125.0	1500	16262	3.62
Tista	7900	30.0	5000	40.0	2000	21510	15.89
Raidak	4570	20.0	3000	30.0	700	6195	4.26
Torsa	3920	20.0	1000	40.0	400	7657	2.73
Jaldhaka	1590	13.0	2500	25.0	600	6628	4.03
Mahananda	250	1.0	300	1.2	60	2411	0.85
Balason	350	1.8	400	4.2	70	1264	1.47

It is evident that sub-Himalayan rivers in North Bengal are producing largest amount of sediment (per unit area) at global scale. The mean annual sediment yield from these rivers would be estimated about 30 million metric ton or 15.76 million cubic meter suspended load. The magnitude of such a huge load may be visualized when the materials if spread uniformly will create a hill with dimension of 250x250x250 meter. The frequency and magnitude of sediment load depends on the magnitude of extreme event i.e., in 1968 flood estimated 3.5 million ton sediment transported in 3 days (3-5th October).

Suspended load concentration is also found very high and a maximum of 1.5gm/litre has been recorded in the river Jaldhaka during 2002 flood. The Jainti watershed in western Duars recorded the highest amount of suspended load of 7570 metric tons per sq. km. per year which is nearly 3 times more than that of Yellow river the highest at global scale. The Torsa watershed is producing the least amount of suspended load among the major watersheds in North Bengal which is only 520 metric tons per sq. km. per year i.e., about 14 times less than that of the Jainti watershed. Another worst degraded watershed is the Mahananda that yielded about 3265 metric tons/year/sq.km (Sarkar, 2008).

4.2.2.1 Aggradation and degradation

In an alluvial river, the state of equilibrium is achieved, if the discharge, sediment load, sediment size and slope are balanced. A change in any of these parameters will disturb the equilibrium and the river starts to change its course resulting in aggradation and degradation (Moriswa, M. 1968; Starkel, L & Sarkar, S. 2002). During the process of meandering in the alluvial plains, the river course goes on shifting with the change of meandering pattern, with consequent bank erosion at different places. For the purpose of assessing the extent of aggradation / degradation, the cross-section of various rivers studied by the NBFCC for different years has been analysed (NBFCC, 1965).

It was that the length of cross-sections varies considerably from one cross section to another at different locations. There is significant variation in the area of flow from one year to another indicating deposition or erosion at each of the cross sections. Smaller area of section occurs where velocity is higher (WAPCOS, 2003).

It was also observed that the average depth of deposition or scour varies from 1 cm to 18cm in Tista river, while the same is substantial in case of Jaldhaka and Torsa, varying from 6 cm to 72 cm and 17 cm to 72 cm respectively. There is, however, very high scouring observed in Sankosh river of the order of 165 cm over a period of 14 years from 1986 to 2000. The above studies are only indicative in nature and in no way, can form a basis for planning of any remedial measures (WAPCOS, 2003).

4.2.3 Geomorphic characteristics

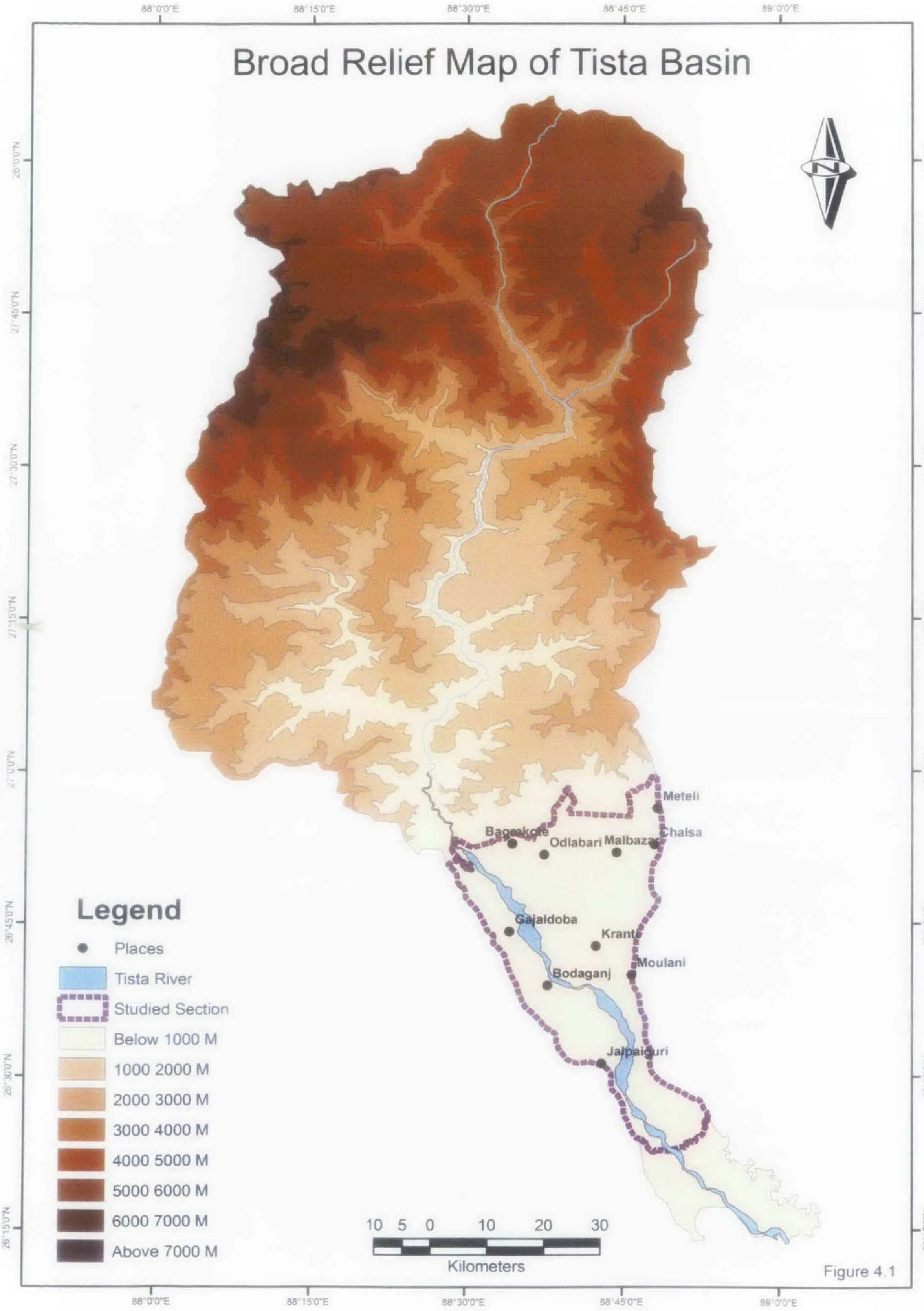
The watersheds under consideration include trans-Himalayan Rivers like the Tista, Torsa, Raidak and Sankosh. While, watersheds like Mahananda and Jaldhaka belongs to lower Himalayan system. The rivers are fed by glacier or ice fields and are supplemented by high intensity rainstorms occurred in sub-Himalayan North Bengal. Each of the watersheds displays unique and fascinating geomorphic characteristics of its own (table 4.5). An attempt has been made to assess geomorphic characteristics of the watersheds in the following sections.

Table No 4.5
Area under different elevation zones for the studied watersheds

Watersheds	Area in sq.km under different altitude zones (meter).							
	< 1000	1 - 2000	2 - 3000	3 - 4000	4 - 5000	5- 6000	6 - 7000	> 7000
Mahananda	141	34	0	0	0	0	0	0
Tista	1834	1946	1647	972	807	2061	247	34
Jaldhaka	857	368	301	76	24	0	0	0
Torsa	288	627	770	801	969	388	29	0
Raidak	809	556	1385	1783	622	106	32	2
Sankosh	542	2501	2458	1690	1178	1308	855	2

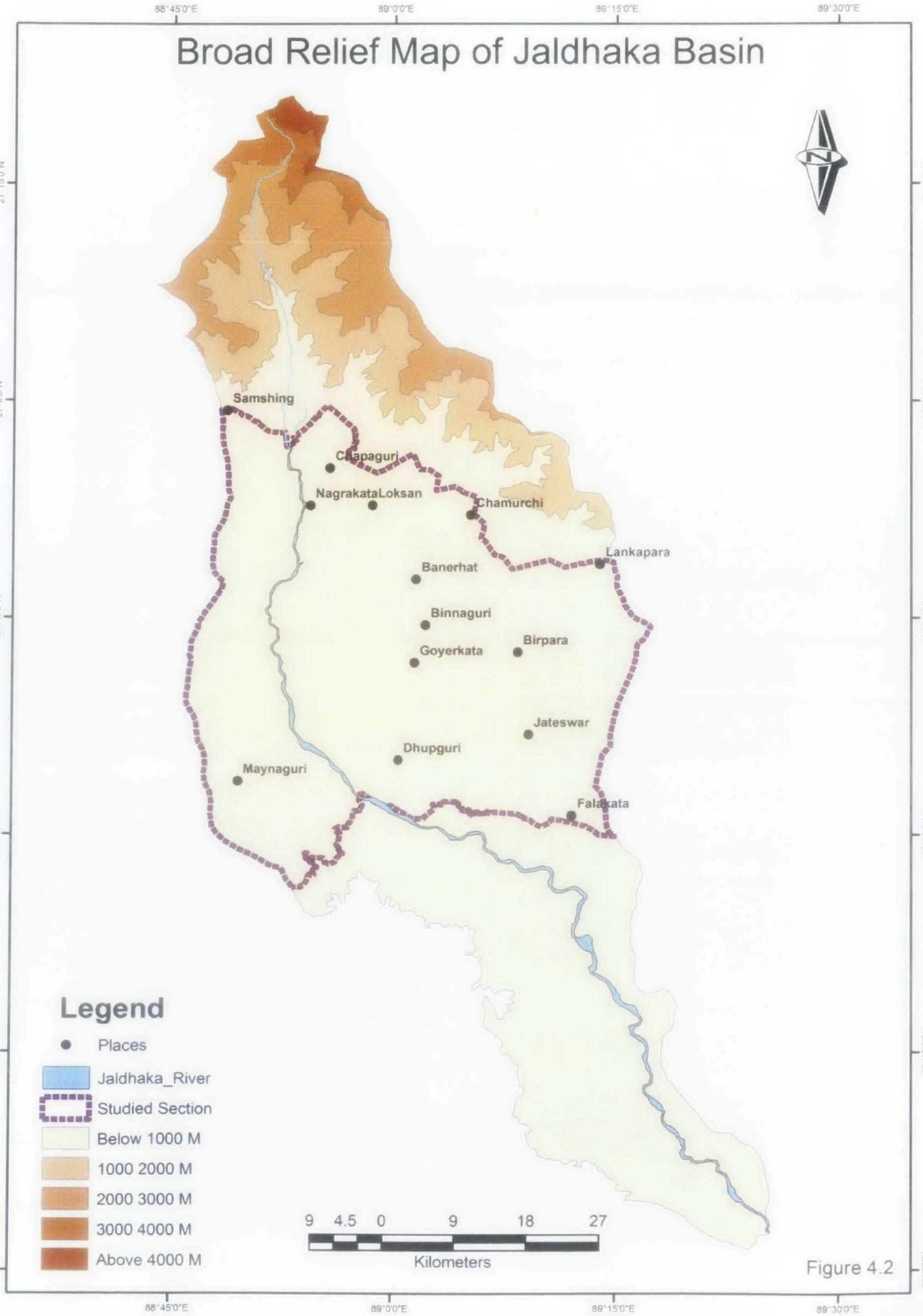
4.2.3.1 The Tista Watershed

The river Tista originates from a cluster of glaciers at the southeastern base of the Kanchenjangha Massif (mean altitude >7000 meter) the second loftiest peak in the World. The Tista watershed under study thus extends from the Kanchenjangha peak (8585 meter) to the gauging station at Domohani (80 meter) thus exhibits fascinating topographic diversities. The total amplitude has been estimated to be 8000 meter within an aerial distance of 178 km.



Broad Relief Map of Tista Basin
88°0'0"E
88°15'0"E
88°30'0"E
88°45'0"E
89°0'0"E
28°0'0"N
27°45'0"N
27°30'0"N
27°15'0"N
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
N
Meteli
Bagrakote
Odlabari
Malbazar
Chalsa
Gajaldoba
Kranti
Moulani
Bodaganj
Jalpaiguri
Legend
Places
Tista River
Studied Section
Below 1000 M
1000 2000 M
2000 3000 M
3000 4000 M
4000 5000 M
5000 6000 M
6000 7000 M
Above 7000 M
10 5 0 10 20 30
Kilometers

Figure 4.1



Broad Relief Map of Jaldhaka Basin
88°45'0"E
89°0'0"E
89°15'0"E
89°30'0"E
27°15'0"N
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
26°0'0"N
Samshing
Chapaguri
NagrakataLoksan
Chamurchi
Lankapara
Banerhat
Binnaguri
Birpara
Goyerkata
Jateswar
Dhupguri
Maynaguri
Falakata
Legend
Places
Jaldhaka_River
Studied Section
Below 1000 M
1000 2000 M
2000 3000 M
3000 4000 M
Above 4000 M
9 4.5 0 9 18 27
Kilometers

Figure 4.2

The mean gradient of Tista watershed under studied section has been estimated to a staggering figure of 1:21 one of the steepest at global scale for a comparable size watershed. Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.1.

4.2.3.2 The Jaldhaka Watershed

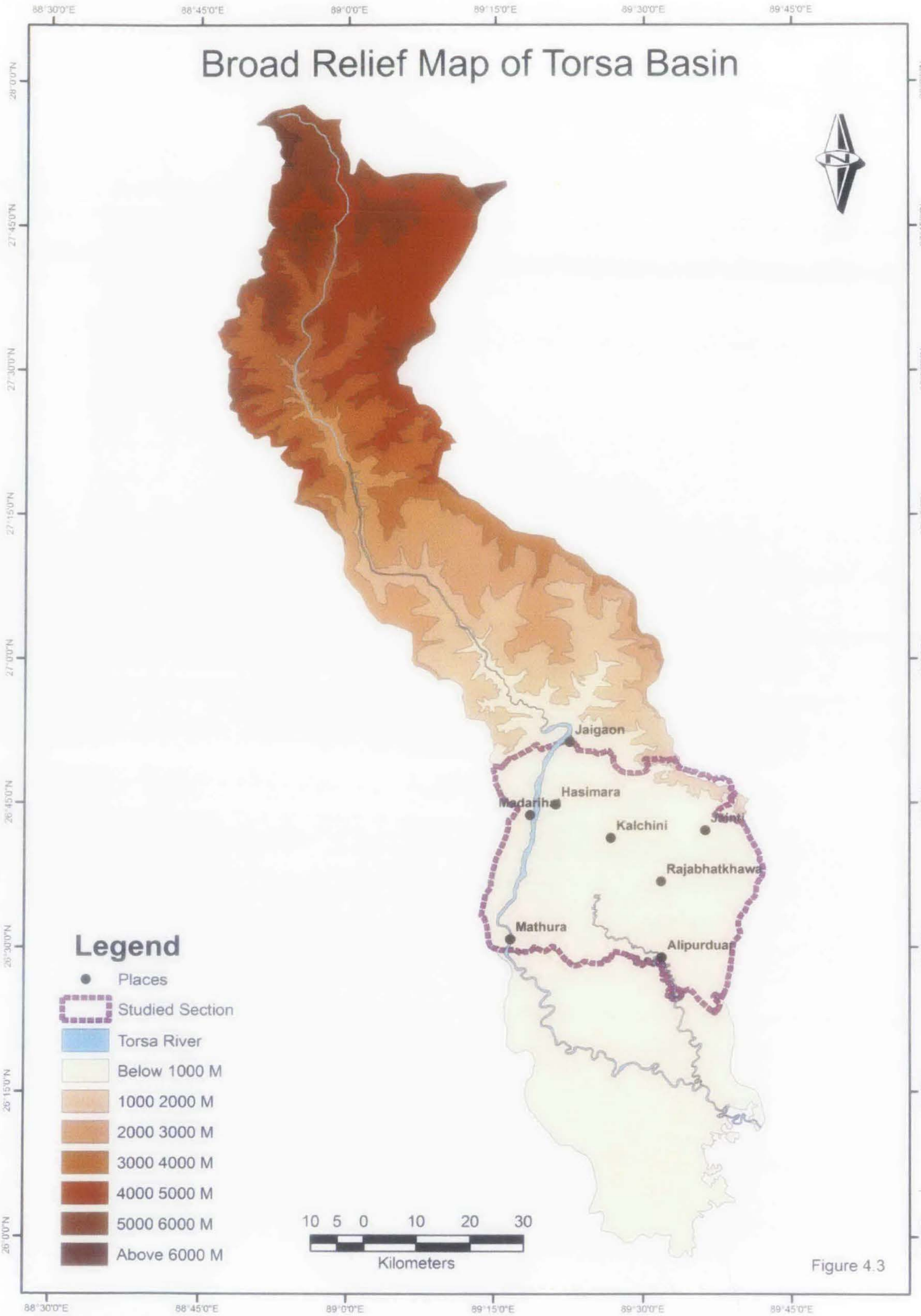
The river Jaldhaka originates from Bidan Lake in Sikkim near the famous Kalimpong-Lhasa Trade Route (*Silk Route*) along Indo-China border in Sikkim (mean altitude >5000 meter). The Jaldakha watershed under study thus extends from Nangpo (5964 meter) at tri-junction point (boundary among India, China (Tibet) and Bhutan) to the gauging station at Dhupguri (88 meter) thus exhibits fascinating topographic diversities. The total amplitude has been estimated to be 5876 meter within an aerial distance of 86 km. The mean gradient of Jaldhaka watershed under studied section has been estimated to a staggering figure of 1:15 one of the steepest at global scale for a comparable size watershed. Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.2.

4.2.3.3 The Torsa Watershed

The river Torsa originates from Chumuk glacier of Great Himalaya in Chumbi valley in Tibet (China) (mean altitude >6000 meter). The Torsa watershed under study thus extends from the Chumbi valley (China) to the gauging station at Hasimara thus exhibits fascinating topographic diversities. The total amplitude has been estimated to be 7197 meter within an aerial distance of 147 km. The mean gradient of Torsa watershed under studied section has been estimated to a staggering figure of 1:20 one of the steepest at global scale for a comparable size watershed. Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.3.

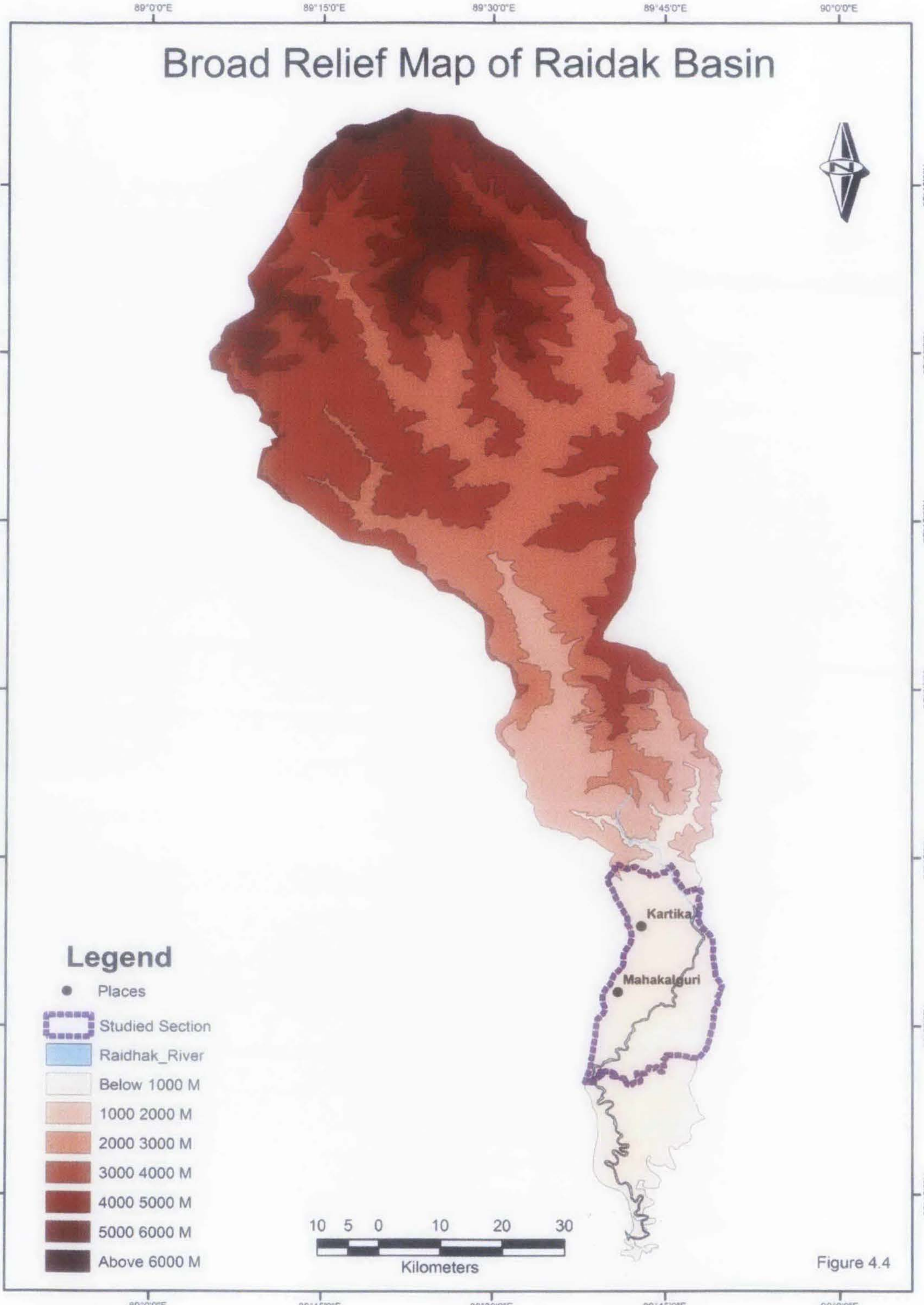
4.2.3.4 The Raidak Watershed

In the hilly tract of Bhutan, the river receives a large number of tributaries and the river is locally known as the Wong Chu, Paro Chu and Ha Chu. It passes through steep, narrow gorges and consequently it has no scope to change its course. In this tract the bed



Broad Relief Map of Torsa Basin
88°30'0"E
88°45'0"E
89°0'0"E
89°15'0"E
89°30'0"E
89°45'0"E
28°0'0"N
27°45'0"N
27°30'0"N
27°15'0"N
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
26°0'0"N
N
Jaigaon
Hasimara
Madariha
Kalchini
Jainti
Rajabhatkhawa
Mathura
Alipurduar
Legend
Places
Studied Section
Torsa River
Below 1000 M
1000 2000 M
2000 3000 M
3000 4000 M
4000 5000 M
5000 6000 M
Above 6000 M
10 5 0 10 20 30
Kilometers

Figure 4.3



Broad Relief Map of Raidak Basin
89°0'0"E
89°15'0"E
89°30'0"E
89°45'0"E
90°0'0"E
27°45'0"N
27°30'0"N
27°15'0"N
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
Kartika
Mahakalguri
Legend
Places
Studied Section
Raidhak_River
Below 1000 M
1000 2000 M
2000 3000 M
3000 4000 M
4000 5000 M
5000 6000 M
Above 6000 M
10 5 0 10 20 30
Kilometers

Figure 4.4

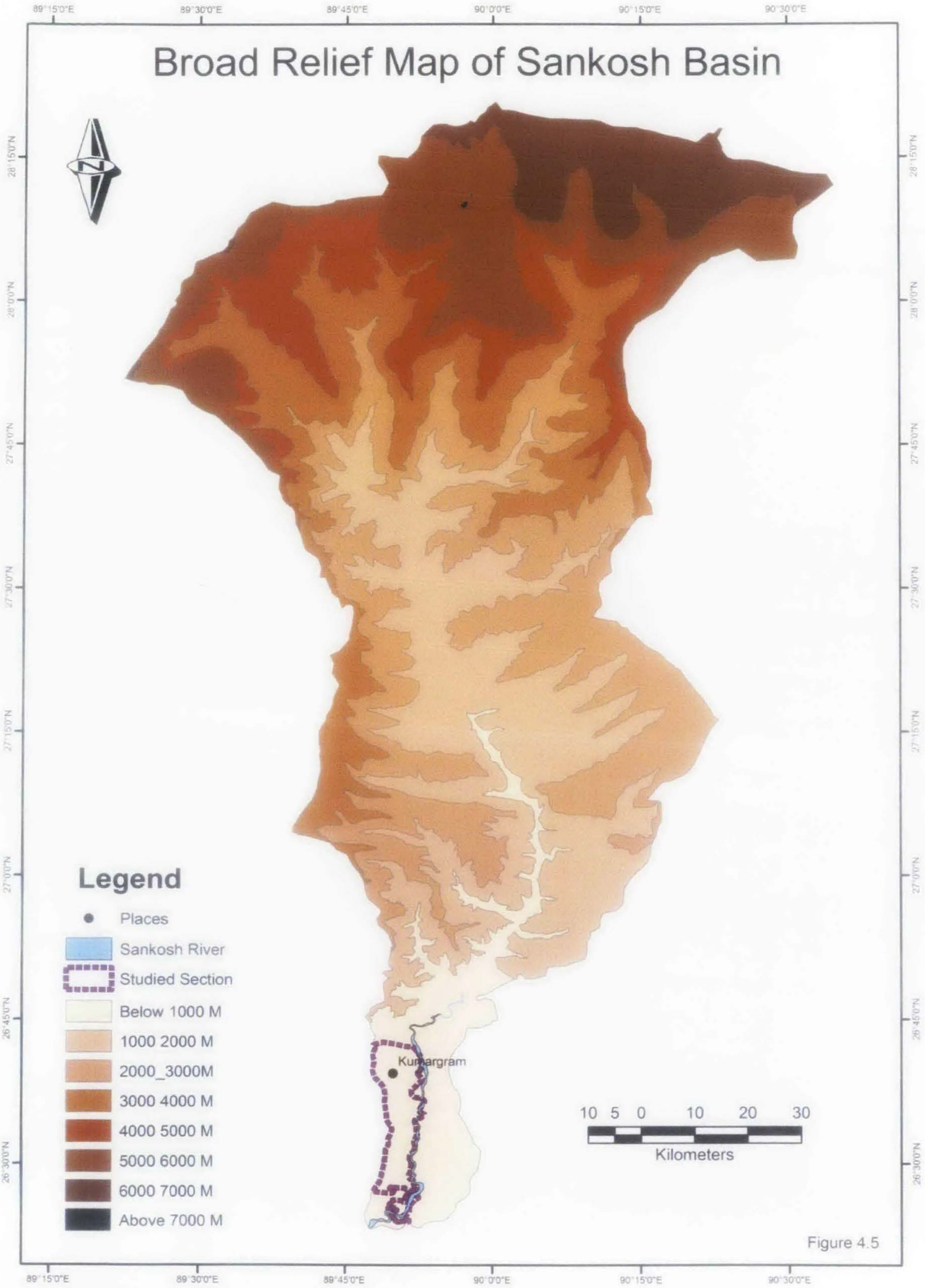
slope is very steep. The slope exceeds at some places causing great velocity of flow particularly during high floods. Though the gorges are very deep and narrow, these consist of rock, which are soft and denuded and cannot withstand the high velocity during floods. Consequently, land slips occur rather frequently. Large quantities of detritus came down into the river and are carried down into the lower regions. The silt charge of the river increases many times during flood. The behaviour of the river in the lower reach is a history of the frequent changes of its course. The river is bifurcated into Raidak I and Raidak II in Jalpaiguri district. It had changed it course frequently during the last century.Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.4.

4.2.3.5 The Sankosh Watershed

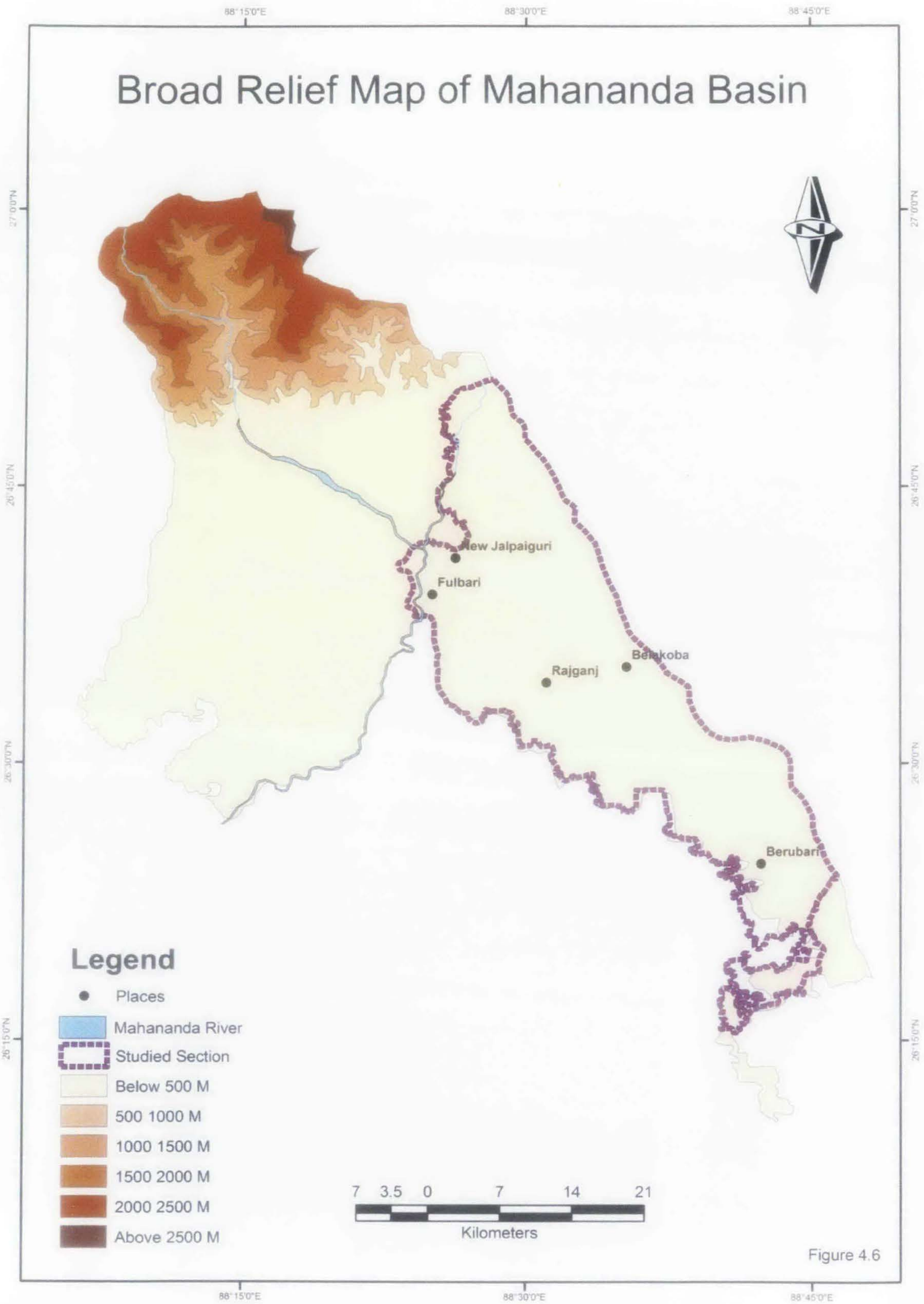
The river Sankosh originates from a cluster of ice fields from the Bhutan-Tibet (China) border (mean altitude >6500 meter). The Sankosh watershed under study thus extends from Tibet-Bhutan border Tamrei Gangri (7516 meter) to the gauging station at Domohani (48 meter) thus exhibits fascinating topographic diversities. The total amplitude has been estimated to be 7468 meter within an aerial distance of 208 km. The mean gradient of Sankosh watershed under studied section has been estimated to a staggering figure of 1:28 one of the steepest at global scale for a comparable size watershed. Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.5.

4.2.3.6 The Mahananda Watershed

The river Mahananda originates from Chimli in Dow Hills, Kurseong at an altitude of 2040 meter. The Mahananda watershed under study thus the smallest one extends from the Dow Hills to the gauging station at Champasari (125 meter) thus exhibits fascinating topographic diversities. The total amplitude has been estimated to be 2070 meter within an aerial distance of 26 kms. The mean gradient of Mahananda watershed under studied section has been estimated to be of 1:14. Topographic parameters of the studied watersheds have been assessed from the US Army Topographic Sheets and tabulated in table 4.5 and diagrammatically represented in figure 4.6.



Broad Relief Map of Sankosh Basin
Legend
Places
Sankosh River
Studied Section
Below 1000 M
1000 2000 M
2000_3000M
3000 4000 M
4000 5000 M
5000 6000 M
6000 7000 M
Above 7000 M
Kumargram
10 5 0 10 20 30
Kilometers
Figure 4.5



Broad Relief Map of Mahananda Basin
88°15'0"E
88°30'0"E
88°45'0"E
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
N
New Jalpaiguri
Fulbari
Belakoba
Rajganj
Berubari
Legend
Places
Mahananda River
Studied Section
Below 500 M
500 1000 M
1000 1500 M
1500 2000 M
2000 2500 M
Above 2500 M
7 3.5 0 7 14 21
Kilometers

Figure 4.6

4.3 Land use characteristics

Watershed land use constitutes an important controlling parameter in the overall process-response mechanism of respective fluvial system. Land use transformations have had cascading effects in fluvial dynamics of each of the studied catchments. Land use/cover data were derived from the Satellite images (Google Earth 2008) and US topographic maps at scale of 1:250000.

Six land use/cover classes were delimited: forests, cultivated & settlement, tea plantation, rocky wastes, ice field and glaciers. The boundaries between them were manually digitized on screen using visual interpretation technique under GIS platform. The analytical findings have been tabulated in table 4.6 and 4.7.

Table No 4.6

Land use pattern of selected watersheds from source up to Indian territory

Watershed	Area in sq. km under different land use category						
	Forest	Cultivated & Settlement	Tea Plantation	Rocky wastes	Ice field	Glaciers	Watershed Area
Mahananda	587	1328	237	0	0	0	2144
Tista	4339	2641	307	1749	1100	105	10189
Jaldhaka	1376	2694	211	79	0	0	4370
Torsa	3321	2350	163	920	48	8	7129
Raidak	3704	804	67	914	45	0	5472
Sankosh	6995	618	15	2019	1294	12	10879

Table No. 4.7

Land use Pattern of the Watersheds situated within Jalpaiguri district

Watersheds	Area	Forest	Agriculture & Settlement	Tea Garden	Rocky Land	Ice Field & Glacier
Tista	1204	194	705	307	0	0
Torsa	1645	896	619	163.2	0	0
Jaldhaka	2033	474	1409	211	0	0
Mahananda	771	114	652	5	0	0
Raidak	451	158	264	32.7	0	0
Sankosh	176	73	87	15	0	0

4.3.1 Land use in Tista watershed

The spatial distribution of major land use/cover zone of the Tista catchment has been shown in figure 4.7 and tabulated in table4.6 and that of situated within Jalpaiguri district has been diagrammatically represented in figure 4.8B. The 42% of the total catchment area is still under forest cover in the Tista basin located in Sikkim and West Bengal. Arable use and settlement occupy about 26% and another 3% occupied by tea garden. Nearly one third of the catchment area remains beyond limit of possible human interferences includes rocky wastes (17%), ice field (11%) and glacier (1%).

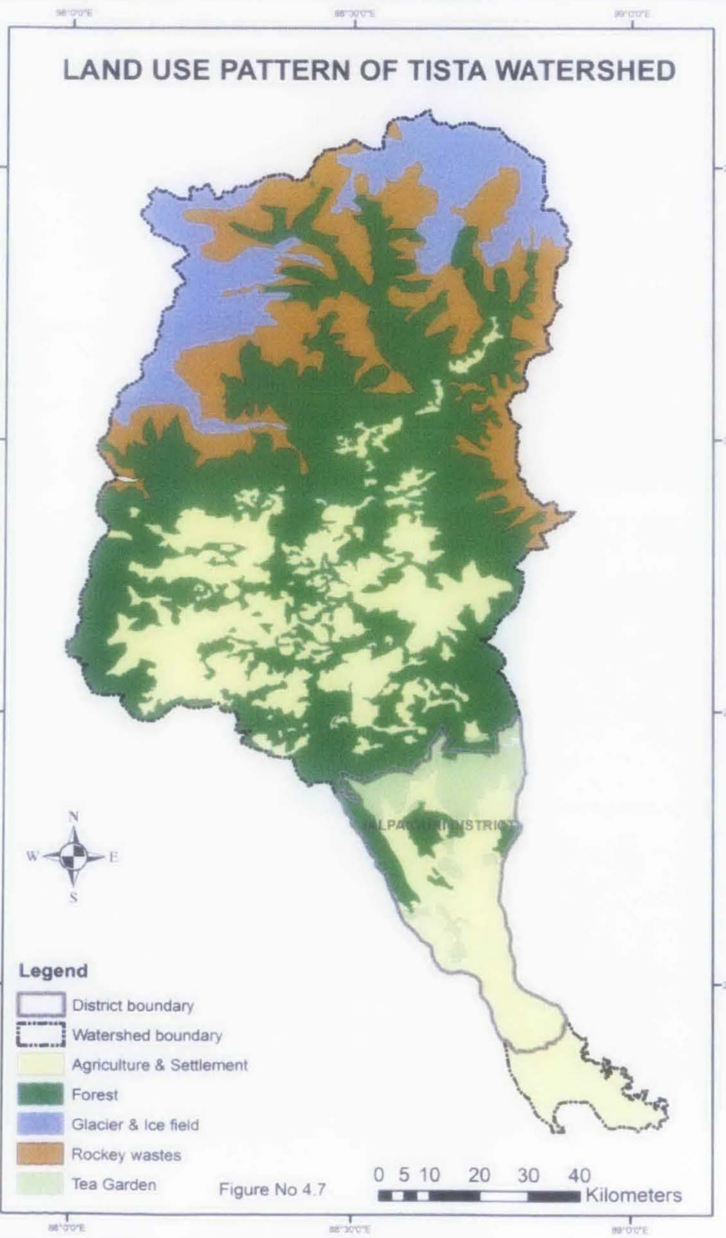


Figure No 4.7

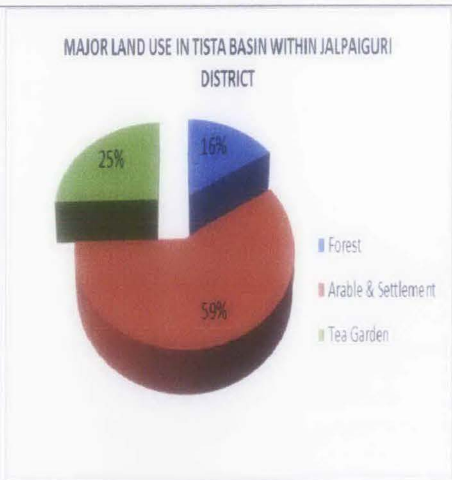


Figure 4.8A Land use of Tista Watershed in Jalpaiguri District

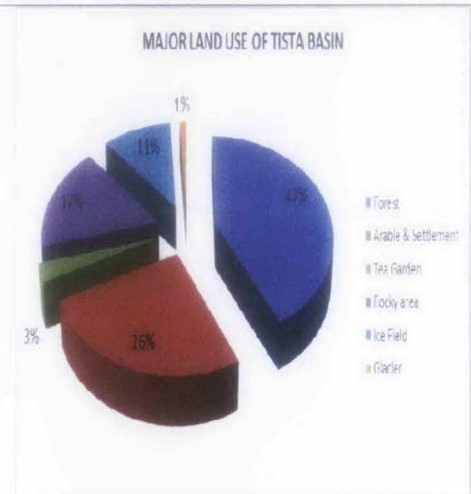
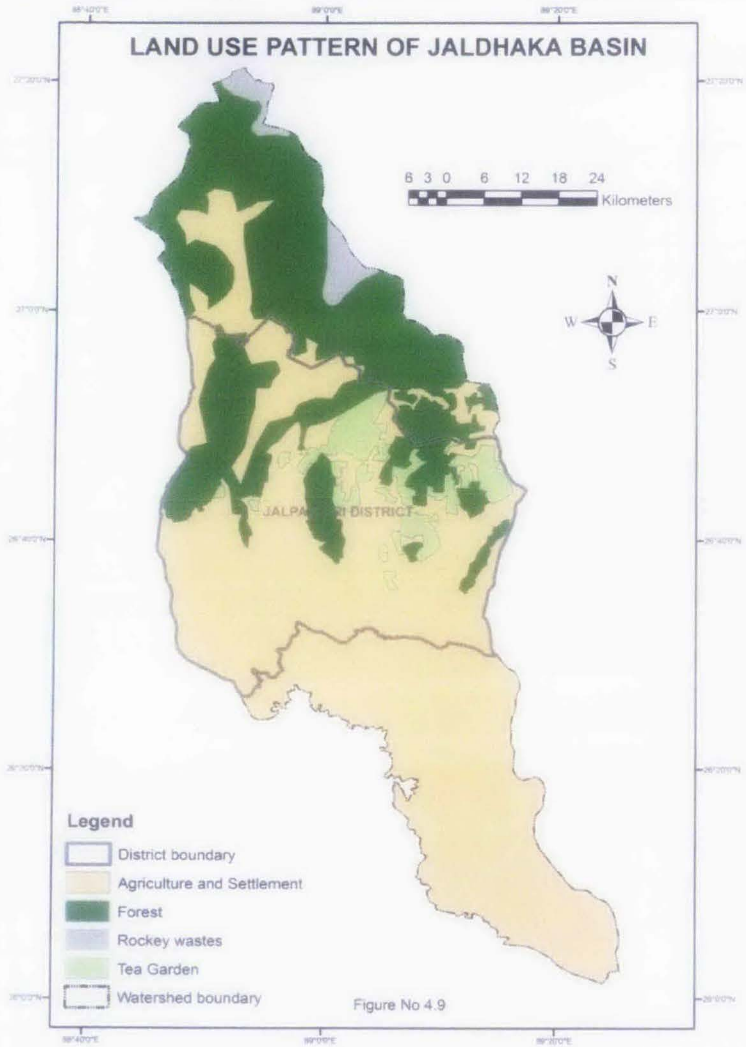


Figure 4.8B Land use of Tista Watershed

Land use of Tista watershed situated within Jalpaiguri district is tabulated in table 4.7 and diagrammatically represented in figure 4.8A. Only 16% of the total watershed area situated in Jalpaiguri is covered by forest and another 25% is under tea plantation. While 59% of the total area under direct utilization in the form of settlement and under cultivation.



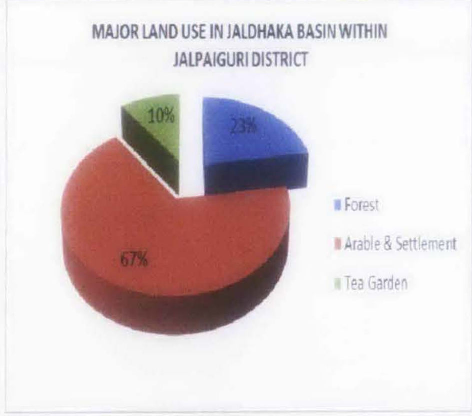


Figure 4.10A Land use of Jaldhaka watershed in Jalpaiguri District

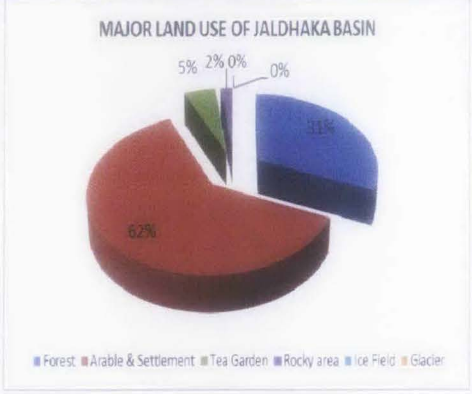


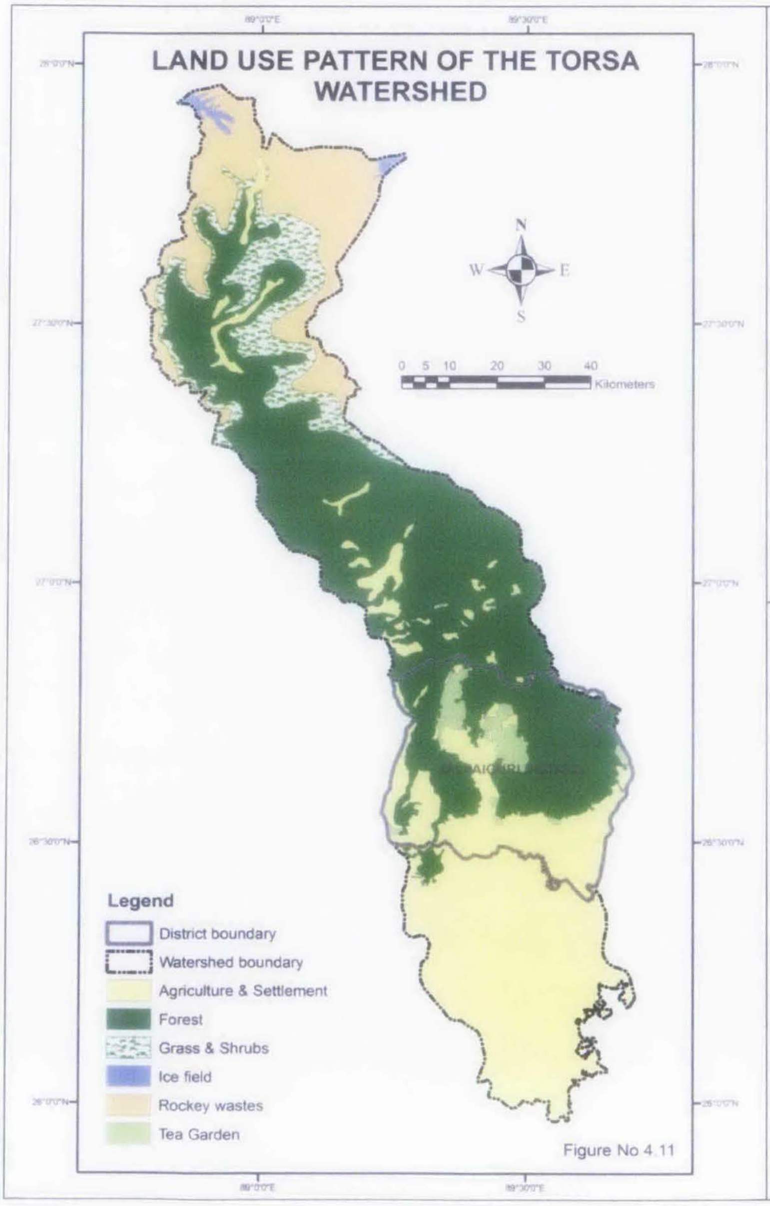
Figure 4.10B Land use of Jaldhaka watershed

4.3.2 Land use in Jaldhaka watershed

Land use pattern of Jaldhaka watershed has been assessed based on Satellite images obtained from IRS and Google Earth (2007) on standard GIS platform (Global Mapper 8.0). The analytical result has been represented in table no. 4.6 and 4.7. It is interesting to note that only 67% of the watershed has been under the influence of human interference of different levels, whereas 31% of the total watershed area is being under natural forest cover. Only 2%

area of the watershed has been identified as rocky wastes. The spatial distribution of major land use/cover zone of the Jaldhaka watershed has been shown in figure 4.9 and diagrammatically represented in figure 4.10B.

However the land use of Jaldhaka watershed within Jalpaiguri district is rather interesting and has been diagrammatically represented in figure 4.10A. It is found that 67% of the total area is covered by arable farming and settlement and another 10% is under tea plantation. While, forest cover an area of 23% of the total watershed in Jalpaiguri district.



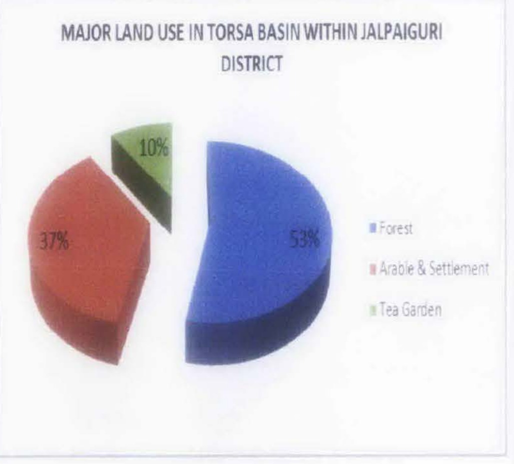


Figure 4.12A Land use of Torsa watershed in Jalpaiguri District

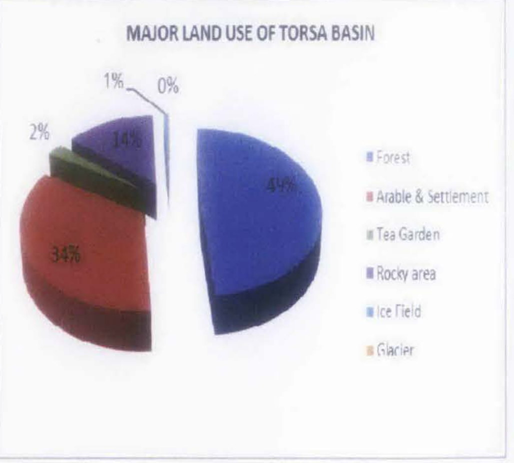


Figure 4.12B Land use of Torsa watershed

4.3.3 Land use in Torsa watershed

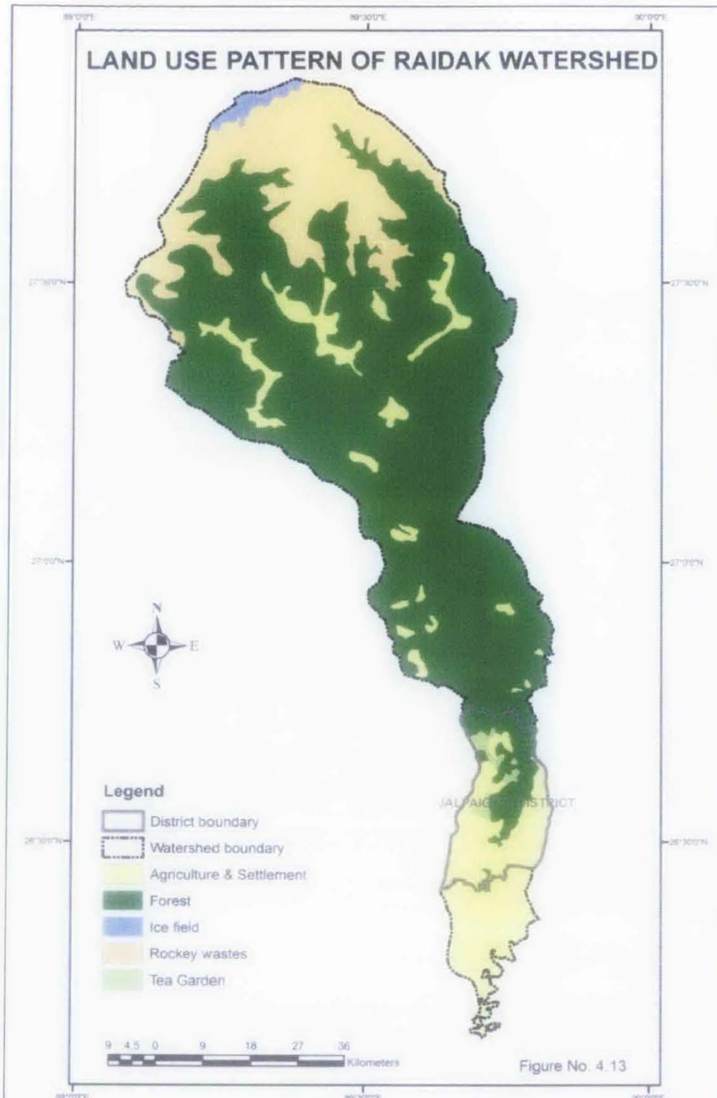
Land use pattern of the Torsa watershed has been assessed based on Satellite images obtained from IRS and Google Earth (2007) on standard GIS platform (Global Mapper 8.0). The analytical result has been represented in table no. 4.6 and spatial distribution of major land use/cover zone of the Torsa watershed has been shown in figure 4.11 and diagrammatically represented in figure no. 4.12B. It is noticeable here that only 36% of the watershed has been under the influence of human interferences of different levels. On the other hand, 49% of the total watershed area is being under natural forest cover and the remaining 15% area remains beyond the limit of human interference includes rocky area, ice field and glaciers.

However the land use of Torsa watershed within Jalpaiguri district is rather interesting and has been diagrammatically represented in figure 4.12A and tabulated in table 4.7. The Torsa watershed retains the largest area of Jalpaiguri, is famous for pristine forest which is over 53% of the area. Tea garden covers an area of another 10%. The remaining 37% of the watershed is under arable farming and settlement.

4.3.4 Land use of the Raidak watershed

The land use pattern of Raidak watershed is shown in table 4.6 and the spatial distribution of major land use/cover zone of the Raidak watershed has been shown in figure 4.13 also diagrammatically represented in figure 4.14B. It is observed that 67% of the total watershed is still under natural forest cover which is mostly situated in Bhutan and another 16% is identified as rocky land of high hills and steep scarps again situated in Bhutan. Only 15% of the total watershed area has been identified under direct human interference in the form of either agriculture or settlement (figure 4.14B).

However the land use of Raidak watershed within Jalpaiguri district is rather interesting and has been diagrammatically represented in figure 4.14A and tabulated in table 4.7. The Raidak watershed also retains 35% under forest and another 7% area covered by tea garden. While, the settled and arable use covered an area of 58% of the total.



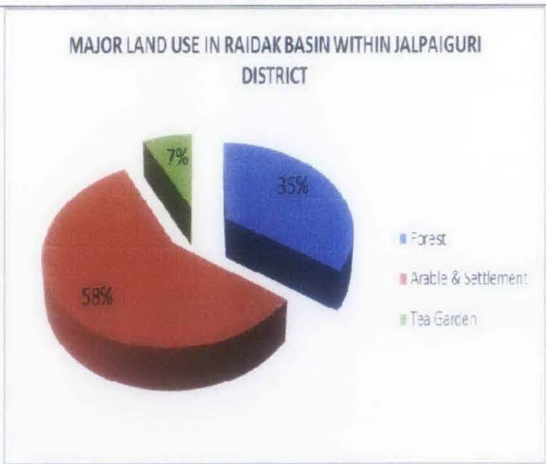


Figure 4.14A Land use of Raidak watershed in Jalpaiguri District

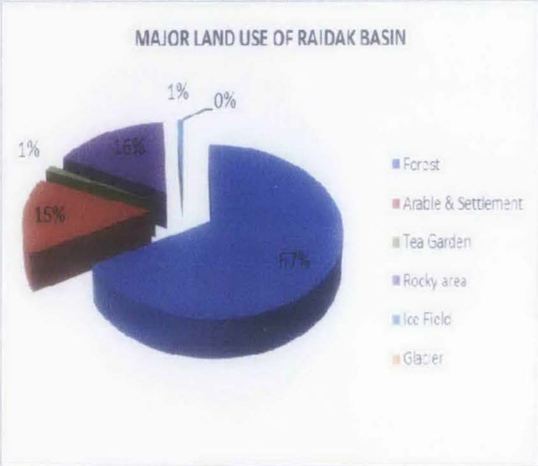
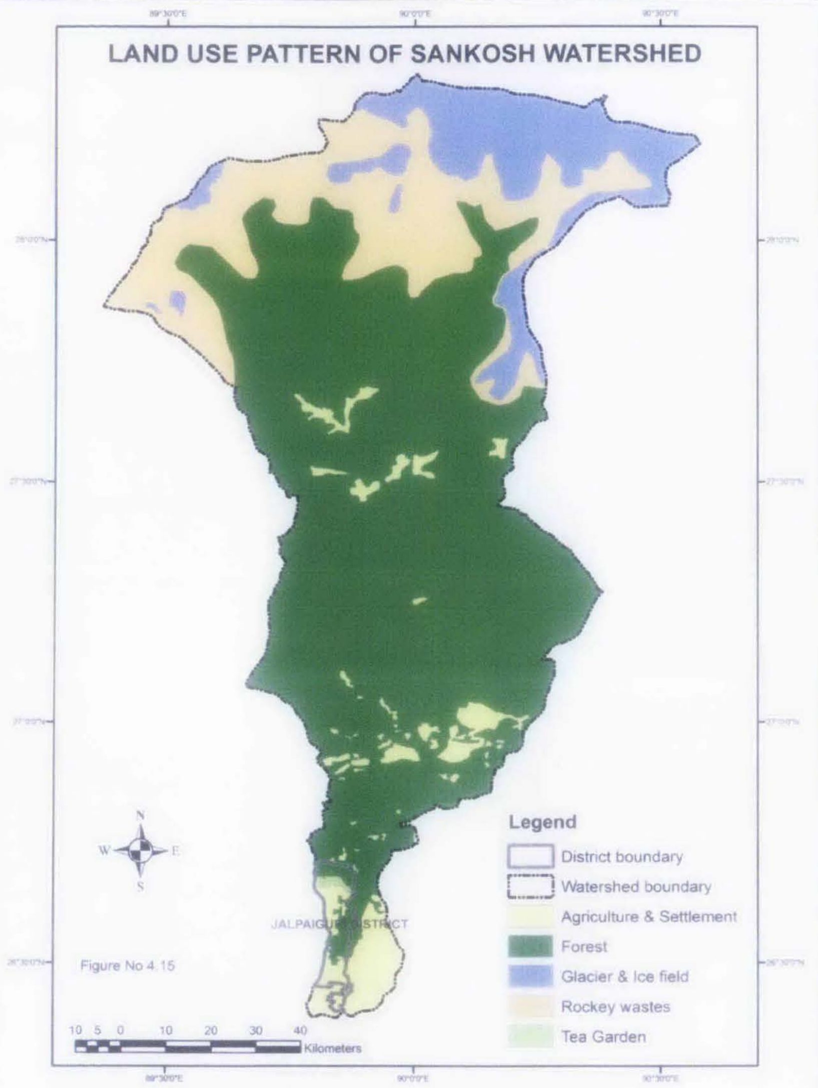


Figure 4.14B Land use of Raidak watershed

4.3.5 Land use of the Sankosh watershed

The existing land use of Sankosh watershed has been assessed based on Satellite images obtained from IRS and Google Earth (2007) on standard GIS platform (Global Mapper 8.0). The analytical result has been represented in table no. 4.6 and spatial distribution of major land use/cover zone of the Sankosh watershed has been shown in figure 4.15 and also diagrammatically represented in figure no. 4.16B. It is interesting to note that only 6% of the watershed has been under the influence of human interference of different levels. On the contrary, 64% of the total watershed area is being under natural forest cover. Rocky wastes and ice field cover 18% and 12% of the total catchment respectively.

However the land use of Torsa watershed within Jalpaiguri district is rather interesting and has been diagrammatically represented in figure 4.16A.



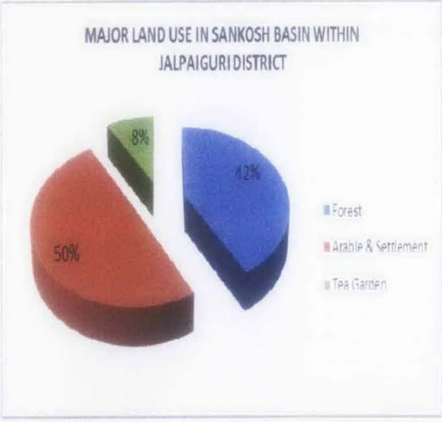


Figure 4.16A Land use of Sankosh watershed in Jalpaiguri District

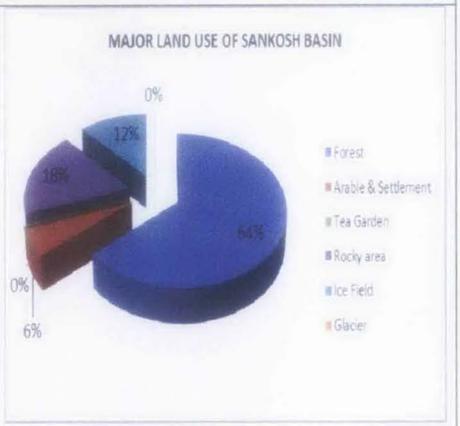
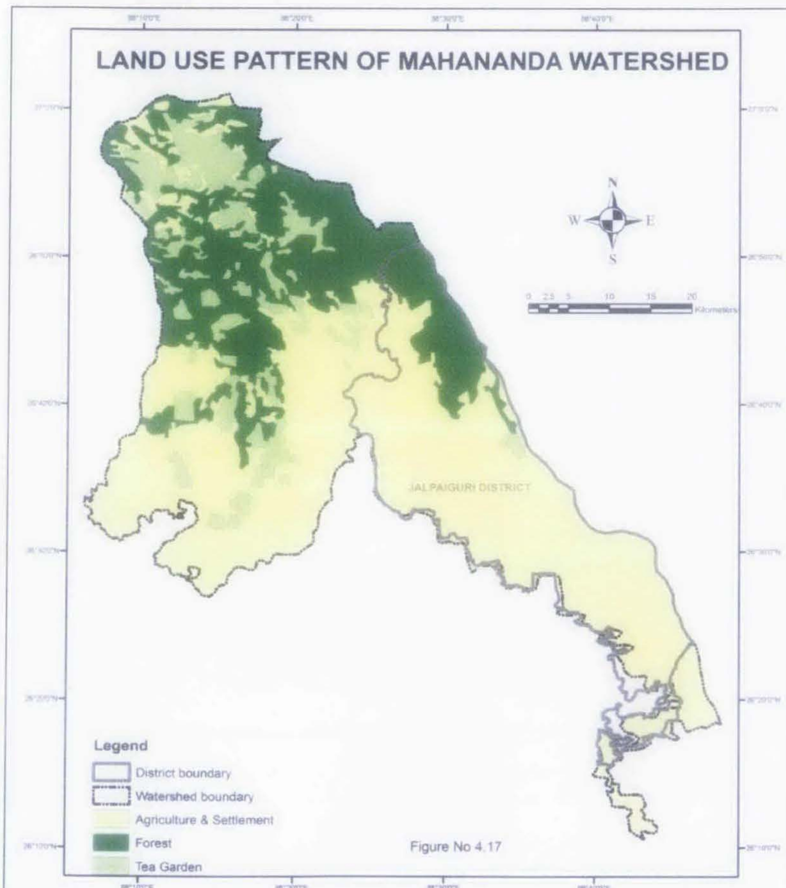


Figure 4.16B Land use of Sankosh watershed

4.3.6 Land use in Mahananda watershed

The land use of Mahananda watershed has been assessed based on Topographical maps and Satellite images obtained from Google Earth (2007) on standard GIS platform (Global Mapper 8.0). The spatial distribution of major land use/cover zone of the Mahananda watershed has been shown in figure 4.17. The analytical result has been represented in table no. 4.6 & 4.7 and diagrammatically represented in figure no.4.18B.It is to be noticed that 73% of the total watershed has been under the influence of human interference of different levels. On the contrary, 27% of the total watershed area is being under natural forest cover.

However the land use of Mahananda watershed within Jalpaiguri district is rather interesting and has been diagrammatically represented in figure 4.18A. It is observed that 85% area of the watershed in Jalpaiguri district is under the impact of human interferences of different degrees. Only 15% area of Mahananda watershed in Jalpaiguri district is still under forest cover.



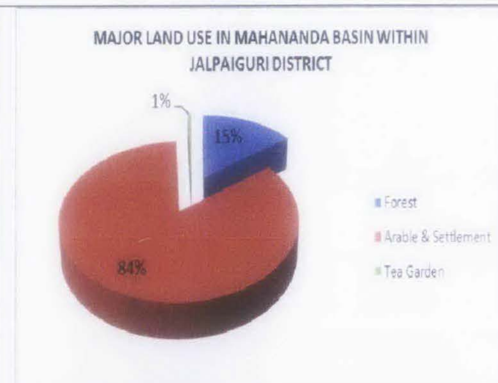


Figure 4.18A Land use of Mahananda watershed in Jalpaiguri District

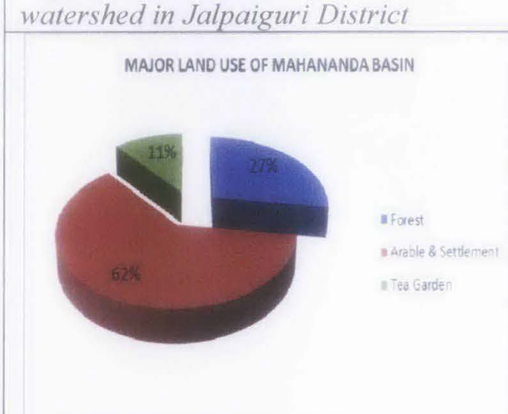


Figure 4.18B Land use of Mahananda watershed

4.4 Land use transformation

Data for the assessment of land use transformation in the studied watersheds has been obtained from multiple sources. The topographical of SOI of different editions within Indian territory representing forest, tea gardens and other land uses. For the Bhutanese part, mainly forested and detail information does not exist. These were supplemented by satellite pictures, which served to calculate the main land use types in the piedmont zone and hilly part of particular river catchments. Google image also been used for updating under GIS platform. Among the major land use types forest, arable and settled area, tea garden, rocky wastes, ice field and glacier are identified and depicted in different maps and diagrams.

Gradual depletion of the forest from north to south at the expense of agriculture is the most remarkable feature of present day land use. The land use pattern reflects the relief of three large geomorphic units: mountains, alluvial fans and plains (Starkel, L., Sarkar, S., Soja, R., Prokop, P. 2008). Each of them has different climatic conditions, lithology, and soils. These determine human activity, which is realised mainly through development of the various forms of agriculture, settlement and in minor extent mineral extraction. Present day land use is the result of human impact ongoing from centuries but its changes were accelerated when the British East India Company took control of Bengal in the mid-19th century. Since then large scale heedless deforestation initiated due to foundation of tea plantations and heavy demand of timber for railway and building construction. The 20^{th}century was marked by demographic explosion. Population was additionally increased through migration of people from Nepal and Bangladesh to the Indian part of Himalayas and migration from Bengal plains to tea plantations located close to the Himalayan foreland.

4.4.1 Mountains

Most of the mountain area is grown by various types of natural forest. It changes from moist deciduous with dominant *Shorearobusta* up to 1000 m. through tropical evergreen with *Quercus* and *Castanopsis*up to 2000 m. and Rhododendron pure stand in between 2500-2800 m, to temperate coniferous at the elevation 3000-3500 m. Only upper part of the Jaldhaka and Torsa catchments is covered by sub-alpine fir forest, which gradually changes to alpine grasslands above the upper timberline at approximately 4000 m (Champion, Seth 1968).

The margin of mountains is usually densely populated and human impact on environment is more visible compare to upper part of Himalayas. This relationship is less evident only in Siwalik zone of Lish and Gish catchments built up of unconsolidated sandstones and pebbles not suitable for settlements. In both catchments the most deforested area is shifted 5 km northward, where deep weathered Daling,quartzite and phyllites are dominant (Basu, Ghatowar 1988). This area has long been turned into cultivated fields or quarrying coal from thin belt of Damuda series and has the highest population density (200 persons/km^2).

Deeper into the mountains the relationship between major river valleys and deforestation is visible. The river channel widths in their upper and middle courses are stable but closer to the mountain margin they extend laterally. The settlement in this area is confined to the gentle slopes of intermountain valleys suitable for agriculture and close accessible transport routes. This is due to road construction along river courses, which was a dominant feature in the colonization process. The population density in this area is still high but it gradually decreases towards the east to 120 persons/km^2 in the Chel and Jaldhaka catchments near Bhutan border. The irregular, small deforested patches are connected with dispersed settlement of people which practice slash and burn agriculture till now. The area of Bhutan has lowest population density in the whole investigated area. It comes to 40 persons near the border with Indian plains where Phuntsholing, the largest town in the mountains with 20000 inhabitants is located. The quarrying of dolomite along the base of Indo-Bhutan hills has only local influence on forest cutting but increase the instability of slopes causing large scars of vegetation. The population density decreases towards the north to 7 persons/km^2 in the middle part of Torsa catchment and to 1 person/km^2 in its upper part. The small catchments east of Pana river in Bhutan are less settled and forested by more than 90%.

4.4.2 Alluvial fans of Terai and Duars

The mountain foreland is built up of alluvial fans and higher elevated terraces. The extension of fans is roughly bounded by the 100 m contour. A significant part of this area is covered by sanctuaries and reserved forest. It consists mainly of *Shorearobusta* the most valuable commercial tree. This forest is mixed with patches of pure deciduous forest with *Schimawallichii* or Acacia Catechu (Champion, Seth 1968). The largest reserved forests are located along Jaldhakariver - Tondoo Forest, Torsa - Barajhor Forest and between Dima and Jainti - Buxa Forest. Thus the area under forest increase from 13-33% in Lish, Gish, Chel, Jaldhaka, Reti, Torsa and Pana catchments to above 76% in Dima, Bala and Jainti catchments.

Tea plantation occupies the largest part of the alluvial fans of the Lish, Gish, Chel, Rethi and Pana catchments. The forest clearance under tea plantations combined with the building of roads and railways has given rise to settlement and trade. The rural population density reaches now 300-500 persons/km^2. The roads and railways were built above normal flood levels. Many embankments were constructed along transport lines that were cross the rivers. These gave impulse to development many of small urban centres as local administrative headquarters often at the junctions of rivers and new transport routes.

Decrease in the river gradients at the outlet from the mountains causes decrease of transport capacity and cause extensive deposition of material eroded from mountains. The overloaded rivers are liable to shift their braided courses significantly. In many places land surrounding the rivers built of boulders and gravels is covered by grasses with sparse trees or swampy vegetation. The wide braided channels cover 10%, which is substantial part of the total area.

Annual floods cause direct loss of forest, tea gardens and settlement lead to changes in land use/cover. Study in the Buxa Reserve Forest in Jainti catchment show that 850 ha of forest and 75 ha of tea garden was destroyed by bank failure and shifting river courses between 1993 and 1999 (Sarkar, 2008). One of the most important indirect effects of floods is change in soil properties in terms of productivity. During devastating floods of 1954 about 10 sq. km of cultivated land had been wasted by deposition of silts in the Gish catchment (Basu, Ghatowar 1988). Accumulation of calcium by floodwater over alluvial fans causes alkalinity of the soil that decreases productivity and quality leading to abandonment tea plantations and dead trees (Sarkar, 2008).

4.4.3 Alluvial plain

At the distance of 20-25 km from the mountain front the fans coalesce in extensive alluvial plain, gradually lowering from 100 to 50 meter and built up of fine grained sediments over bank deposits. The river gradients and channels width diminishes and they turn from braided to meandering. The area covered by active channel decrease to 4% of the total plain area. Along major rivers there are elevated parts of levees or embankments, which are several kilometres in length. These are favoured sites for larger settlements. River banks are not completely protected as a result some parts of floodplain are inundated every year. Alluvial soils offer one of the most productive agricultural lands in the region. As a result, this area experienced the massive transformation of land use/cover system. Nearly all of the natural forests of the plain have been cleared by a process of agricultural colonisation ongoing for centuries. Tea plantations and forest preserved only on higher river terraces or remnants of alluvial fans in the north-eastern part of the plain. Almost the whole area was converted to intensive settled paddy/rice cultivation. Rural population density exceeds 500 persons/sq.km and in some places reaches 1000 persons/km^2, which is among the highest known in the human history.

4.5 Land degradation

The sub-Himalayan North Bengal is a region of wide variety of renewable and non-renewable resources. Of late, this repository of natural wealth has been subjected to virtual plunder. In consequence, the watershed ecosystems are fast loosing their resilience and regenerative capacity. Since the British occupation, the physico-cultural set-up of this region has been seriously disturbed. Extensive heedless deforestation, tea plantation, haphazard construction, huge population influx induced illogical slope cultivation, inadequate drainage, in other words, unscientific and unplanned use of land has led to the establishment of vicious cycle of degradation. As a result, during heavy and concentrated rainfall, catastrophic soil erosion and innumerable landslips are caused, contributing huge sediment load to the rivers which are incapable of transporting the load efficiently under the existing hydrological conditions especially along their lower courses beyond the foothills. The river beds are rising, resulting in lessening of cross sectional area, which being incapable of arresting unusual monsoon discharge and cause devastating floods, endangering the vital line of communication, human habitations, farm lands and forests (Sarkar, S. 2007& 2008).

The picture is just opposite during non-monsoon months, when paucity of water hinders the local people from reaping any benefit out of the soils, in conjunction with the rivers themselves.

Erosion, transportation and deposition are primarily nature's way of adjusting fluvial dynamics within its watershed system. Such an adjustment has been found to be deleteriously disturbed by the human interference particularly in the sub-Himalayan watersheds. Implementation of various development schemes, construction of human settlement and road to cater the ever-increasing population, exploitation of forest produce to generate work potential, boosting of agricultural growth, tourism, mining and quarrying, on the Himalayan immature geology trigger the disaster, huge and complex, never encountered before (Sarkar, 1999).

The situation was not so desperate even 100 years back. The hills were densely forested with very thin population and the hormonal relation between the upper and lower parts of the watersheds were well preserved. Extensive heedless deforestation, haphazard construction of roads and settlements, unscientific and illegal mining activities, inadequate drainage, in other words – unscientific and unplanned usage of land, has led to the establishment of vicious cycle of degradation. During heavy and concentrated rainfall, catastrophic soil erosion and innumerable landslides are caused to transport huge amount of sediments from the upper part of the catchment to the parent river. These rivers are incapable of transporting the load efficiently under the existing hydrological conditions, especially along their lower reaches. The river beds are thus elevating at many places at an alarming rate resulting in lessening of cross sectional areas. The reduced cross sections being incapable of arresting the unusual monsoon discharge caused devastating flood, causing heavy damage to the land and properties. It also endangered the priceless forest lands, wild life vis-à-vis bio-diversity and vital line of communication and strategic infrastructure (Starkel L., 1972).

Effect of watershed degradation

The effects of contemporary watershed degradation in the sub-Himalayan West Bengal have been demonstrated most visibly. Some of the striking effects are listed below:

(i) visible edaphic drought
(ii) deterioration of quality and quantity of surface water
(iii) drying up of springs and jhoras
(iv) reduction of ground water recharge
(v) deterioration of soil quality
(vi) increased frequency and magnitude of floods in the lower sections
(vii) increased frequency and magnitude of accelerated soil erosion and mass movements
(viii) river metamorphism vis-à-vis avulsion
(ix) enlargement of river valley
(x) loss of forest resources including biodiversity
(xi) climatic change.

4.5.1 Soil erosion

At global scale on an average 115 metric tons of soil and other slope materials eroded in every sq. km. of surface area. The countries belongs to Asia recorded the highest amount of 220 metric tons/km^2/y^{-1} and Australia accounts for the lowest amount of only 90 metric tons per sq. km. per year. Highly developed countries in Europe in spite of their high population density and high intensity land use practices could able to keep a low rate of soil loss of only 77 tons/km^2/y^{-1} . Thanks to adequate watershed management practice adopted by the European countries especially since the World War II. Comparatively higher degree of illogical human interferences in watersheds of Latin and South American countries yielded 148 tons/km^2/y^{-1} in compare to its counterparts of North America which recorded about 113 tons/km^2/y^{-1} . Presence of virgin forest in large parts of central African watersheds is responsible for less soil erosion in the African countries which is estimated to be 92 ton/km^2/y^{-1}.

Table 4.8 Sediment yield from the major watersheds

Rivers	*Watershed (km^2)**	*Load (ton/hect/y^{-1})*	*Total sediment in m.ton*
Sankosh	8521	4.25	3.62
Raidak	4570	9.26	4.26
Torsa	3920	6.96	2.73
Jaldhaka	1590	25.35	4.03
Tista	7900	20.12	15.89
Mahananda	245	32.65	0.80

* *Basin area estimated up to the respective gauging sites*; ** Based on Sarkar, S, 2008.

Mean denudation rate at the global scale has been estimated to be 0.34 mm per year. Denudation rate in Asian countries is two times more than global rate i.e., 0.70 mm per year. India is the leader among the Asian countries accounts for 1.21mm/y^{-1} which is about 4 times more than global scale. The Himalaya watersheds again account 3 times more than the national rate i.e., 3.75 mm/y^{-1}. East Himalayan watersheds accounts the highest rate and observation made in Mahananda watershed in Darjeeling Himalaya recorded a massive high rate of 5.56 mm/y^{-1} which is 4.5 times more than the national rate and 16 times more than the global rate of denudation (Sarkar, S., 1991).The following table (No. 4.8) depicts the rate of sedimentation in some major watershed in the world along with sub-Himalayan watersheds.

It is observed that the eastern Himalayan watersheds recorded very high rate of sediment yield as the Mahananda watershed recorded as high as 32.65 ton per hectare per year followed by the Jaldhaka with 25.35 ton, Tista with 20.12 ton per hectare per year. The Sankosh watershed is least inhabited and recorded 4.25 ton of sediment yield/hectare/year.

It is already mentioned that sub-Himalayan rivers in North Bengal are producing largest amount of sediment (per unit area) at global scale. The mean annual sediment yield from these rivers would be estimated about 30 million metric ton or 15.76 million cubic meter suspended load. The magnitude of such a huge load may be visualized when the materials if spread uniformly will create a hill with dimension of 250x250x250 meter. The frequency and magnitude of sediment load depends on the magnitude of extreme event i.e., in 1968 flood estimated 3.5 million ton sediment transported in 3 days (3-5th October). Bed load transport in these watersheds has been found enormous. Recent study on thermoluminscence & radio-nuclii dating in Tista watershed reveals an estimated amount of 15 million ton of bed load of huge dimension (up to 25 meter diameter) transported during the said period (Starkel L et. al., 2000).

Table 4.9

Base flow and mean maxima ratio of major rivers

Sl. No.	*River*	*BF:MM Ratio*	*Watershed situation*
1	Sankosh	35.29	Mostly natural
2	Tista	166.67	Moderately degraded
3	Raidak	150.00	Moderately degraded
4	Torsa	50.00	Marginally degraded
5	Jaldhaka	192.00	Moderately degraded
6	Mahananda	300.00	Highly degraded
7	Balason	222.22	Highly degraded

Suspended load concentration is also found very high and a maximum of 1.5gm/liter has been recorded in the river Jaldhaka during 2002 flood. The Jainti watershed in western Duars recorded the highest amount of suspended load of 7570 metric tons per sq. km. per year which is nearly 3 times more than that of Yellow river the highest at global scale. The Torsa watershed is producing the least amount of suspended load among the major watersheds in North Bengal which is only 520 metric tons per sq. km. per year i.e., about 14 times less than that of the Jainti watershed. Another degraded watershed of Mahananda yielded about 3265 metric tons per year per sq.km area.

The fluctuation of water flow in these rivers also found noteworthy which reflects the overall health of the respective watershed. The ratio between the base flow and mean maxima is of interest in this regard. The table 4.9 shows such ratio along with generalized watershed pattern.

It is observed that the Mahananda watershed is one of the most degraded in sub-Himalayan North Bengal which reflects with huge base flow mean maxima ratio of 1:300. In fact, massive human intervention into the delicate hill slope hydro-geomorphic system along with heedless deforestation drastically reduced rain water retaining capacity in the watershed. The consequence of such destructive intervention demonstrates through the increase in frequency and magnitude of mass movements in the hill slopes and devastating floods followed by avulsion and aggradations in the piedmont and plains.

On the contrary, the Sankosh watershed which is mostly situated in less habited Bhutan hills still retain its natural set up which has been reflected by its ten times less base flow mean maxima ratio i.e., 30.

4.5.2 Landslides

Landslide is the most pervasive of natural hazards that undermine the economic and cultural development of Darjeeling and Sikkim Himalaya. The diversity in slope components, geometry, site and situation, micro-regional susceptibility to degradation processes, micro-geology, micro-climate, depth of soil, its physical and chemical properties, vegetation with differential canopy and root system, unplanned growth of settlement, road and sewer systems, have led to recurring landslides. Extensive heedless deforestation, slope cultivation, haphazard construction, inadequate drainage had led to the establishment of vicious cycle of degradation, heavy and concentrated rainfall aggravating the problem further(Sarkar, S. 1999; Starkel L. et. al., 2000).

It is found that each landslide has its own peculiarities and its initiation is not due to any single factor. Of the various factors, water has the most deleterious effect. The toe erosion has admittedly caused some of the landslides. Many recent landslides are caused due to unscientific and unplanned usage of hill slopes and valleys. Every landslide is an individual problem, despite the fact that most of such cases have found to be initiated by common trigger mechanism. The solution to each problem has to be determined for individual site, though it may lie in combination of a few well established methods viz. retaining structure, drainage, afforestation, rock bolt, sheet pile, restriction of settlement and unplanned construction along the vulnerable hill slopes.

Landslides occur in almost all types of slopes composed of various rocks in the Darjeeling Himalaya. Composite slides also take place involving soil or talus and underlying rocks. Slope failure is caused by shearing where the plane-of-shear, taking the form of an arc of a circle; in section leaving a parabolic outline of the slipped portion. The most common occurrence of landslide is found along the springs (locally known as *Jhoras*), where rock debris gets detached from their parent body along the slope and form channels. Later, such channels, while carrying drainage water are gradually widened by lateral erosion. Innumerable *nalas* (drainage channels) on hill slopes develop due to slope failure and many landslides in tea gardens and forests look like scars from a distance (Sinha, BN, Verma, RS & Paul, DK, 1975, Starkel L et. al., 2000).

Landslides on rocky surfaces seem to be primarily influenced by the structural elements of the parent rock. Sliding also occurs in bedding and foliation in rocks with prominent joints and shear planes along the slope. Observations in the soil-covered slopes reveal that slopes having an angle below 30^0 were not generally affected by slides. The talus materials are formed due to weathering and loosening of rocks along the joints and foliation planes of the parent rocks. Such material, whether dry or in a permanently drained state, are stable at an angle of even 45^0 and the stability is not necessarily impaired by an occasional wet spell. Slope failure in such materials, however, occurs by seepage pressure of percolating water during heavy precipitation.

The tea garden slopes are generally formed of talus materials with a thin soil cover. Most of the slides have affected the materials but at some places, slides along the joints of the underlying rocks have also been observed. Generally, the displaced materials scour long channels down the slope, which are visible as scratched scars on hill slopes. The width of these scoured channels originally does not exceed more than 25m or so but by subsequent erosion, they are further widened. Thus, once the slide has occurred, it generally remains a permanent feature and increases in dimension.

Identification of landslide-prone areas has been performed with the help of "Check-List" where each separate and discrete slope unit has been classified according to their stability rating. Rating has been done according to a scale from stable through the degrees of potential instability to those slopes, which have already failed. Special attention has been paid to the old slides, which could become re-activated. The excavation position and depth, drainage diversion across the hill, loading of the upper slope and valley, cutting of basal support, unscientific construction and land-use, deforestation, legacies from the past slope movement, relief, drainage, slope materials, etc. have been accounted for in the "Check-list".

Generally, deforested tracts, tea gardens, urban and other settle areas are more susceptible than the natural forested tracts. Geologically, the Daling rocks (phyllites, slates, schists, feldspar, etc.) and Damuda rocks (sandstones, shales etc.) are more susceptible to landslide. Landslides are found more frequently occurred along the major roads in Darjeeling, Sikkim and Bhutan Himalaya and also along the major waterways. Among the studied watersheds, the Tista and Mahananda are the worst affected by landslides followed by the Jaldhaka watershed. The Sankosh watershed is the least affected by landslide menace as most part of the watershed is uninhabited in Bhutan.

The analysis of landslide in the eastern Himalaya reveals that each of the slides has its own characteristics and is not induced by any single factor. Of the various factors, water has the most deleterious effect. Some of them have admittedly been caused by toe erosion of the drainage elements and the others due to the effects of unscientific and unplanned human interferences. The choice of remedial measures thus, should be made after careful analysis of the causative factors. The design of the preventive structures should depend on the geomorphologic, geo-hydrological and geo-technical framework of the site.

In view of the ever-increasing problem of landslides in the Himalaya, man must be aware of the possible dangers that he is inviting, due to his careless dealing with nature. It is true that one has to make room for the growing population and in this pursuit he has to utilize every piece of land available. But the precautions that have to be adopted should not be neglected. In many places revetments are not maintained properly, the weep-holes are choked, the drains are dumped with garbage, restricting free drainage of water. Moreover, the present land-use system should be properly evaluated. The construction of high-rise buildings should be stopped immediately. The people should be provided with alternative source of energy, may be through mini-hydel project, tapping the perennial springs, and perhaps this can be the only option to prevent them from cutting down more trees. It is of utmost priority to develop mass awareness among both local people and tourists, so that they become aware of the possible dangers that they are inviting by interfering with the natural laws.

4.6 Conclusion

Gradual depletion of the forest from north to south at the expense of agriculture is the most remarkable feature of present day land use in all the studied catchments. The structure and relief together with climatic and soil conditions determine human activity, which is realized mainly through development of the various forms of agriculture, settlement and in minor extent mineral extraction.

Present day land use pattern is the result of human impact ongoing from centuries but its changes were accelerated when the British East India Company took control of Bengal in the mid-19th century. Since then large scale heedless deforestation initiated due to foundation of tea plantations and heavy demand of timber for railway and building construction. The 20thcentury was marked by demographic explosion.

Most of the mountain area is grown by various types of natural forest. It changes from moist deciduous with dominant *Shorearobusta* up to 1000 meterthrough tropical evergreen with *Quercus* and *Castanopsis* up to 2000 meter and *Rhododendron* pure stand in between 2500-2800 meter to temperate coniferous at the elevation 3000-3500 meter. Only upper part of the Jaldhaka and Torsa catchments is covered by sub-alpine fir forest, which gradually changes to alpine grasslands above the upper timberline at approximately 4000 meter (Champion, Seth 1968). The margin of mountains is usually densely populated and human impact on environment is more visible compare to upper part of Himalayas.

Deeper into the mountains the relationship between major river valleys and deforestation is visible. The river channel widths in their upper and middle courses are stable but closer to the mountain margin they extend laterally. The settlement in this area is confined to the gentle slopes of intermountain valleys suitable for agriculture and close accessible transport routes. This is due to road construction along river courses, which was a dominant feature in the colonization process.

The mountain foreland is built up of alluvial fans and higher elevated terraces. The extension of fans is roughly bounded by the 100 m contour. A significant part of this area is covered by sanctuaries and reserved forest. It consists mainly of *Shorearobusta* the most valuable commercial tree. This forest is mixed with patches of pure deciduous forest with *Schimawallichii* or *Acacia catechu* (Champion, Seth 1968). Tea plantation occupies the largest part of the alluvial fans. The forest clearance under tea plantations combined with the building of roads and railways has given rise to settlement and trade.

The alluvial plains further south are favoured sites for larger settlements. River banks are not completely protected as a result some parts of floodplain are inundated every year. Alluvial soils offer productive agricultural lands in the region. As a result, this area experienced massive transformation of land use/cover system. Nearly all of the natural forests of the plain have been cleared by a process of agricultural colonisation ongoing for centuries.

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Chapter V: Flood Hazards in Jalpaiguri

5.1 Introduction

Throughout the human history, floods have been part of his destiny. They are widely discussed today as a result of increased public awareness and greater destruction caused by them. Perhaps, flood is one of the most dramatic interactions between man and his environment, emphasizing both the shear force of natural events and man's inadequate efforts to control them. The holy bible has an account of the greatest flood to ever happen. The following chapters out of Genesis tell how God explained to Noah to build the ark before the great flood. God said to Noah, *Seven days from now I will send rain to the earth for forty days and forty nights, and I will wipe from the face of the earth every living creature I have made* (GENESIS, 7:4,7).

Defining a flood is difficult, partly because floods are complex phenomena and partly because they are viewed differently by different society, people and government. For most practical purposes and certainly in popular usage a meaningful flood definition should incorporate the notions of damage and inundation. Chow (1956) defines *a flood is a relatively high flow which overtaxes the natural channel provided for run-off.* Ward (1987) provided the most comprehensive definition that: *a flood is a body of water which rises to overflow land which is not normally submerged.*

The sub-Himalayan West Bengal being situated not far from the Himalayan margin and cris-crossed by the sub-Himalayan rivers has always been liable to floods. The reasons for high floods are excessive rainfall within small duration in small catchments and continuous rainfall of several days in bigger catchments. The simultaneous melting of snow accumulated on high mountains and rainfall in lower reaches often caused floods of devastating nature. These along with sudden bursting of water storage in the upper catchment caused by heavy landslide that blocked river channel released unbelievable volume of water through the river Tista in 1968 and caused unprecedented devastation (Kusari, A.M. et al. 1981; Ramaswamy C., 1987; Sarkar S., 2004b; Sanyal, C.C, 1969, 1970 and Sen S., 1968).

North Bengal is endowed with an intensive network of river systems. Most of the rivers are considered to be highly notorious for their unpredictable nature, letting loose fury of flood and problem of extensive and regular bank erosion, course shifting, renders thousands of homeless during the rainy season. The majority of the rivers of *Terai* and *Duars* originate in the Himalayas and enter from a north to northwesterly direction and flows south to southeasterly direction. The lateral gap between the two major rivers is in between 3 to 30 kilometer i.e., Torsa – Jaldhaka and Gadadhar – Raidak respectively. As many of the rivers originate at the same hill, flood often occurs simultaneously in many rivers and the rivers coalesce to form a single vast sheet of water.

The catchment of these rivers has mostly been deforested and the clearings of the steep slopes have been used for the extension of settlement, agriculture, plantation and communication, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfall, innumerable landslides are caused transporting huge amount of sediment to the rivers. Most of such landslides have never been treated scientifically with proper protective measures and as such those are in the habit of expanding their territories during monsoon. These often add more and more silt to the rivers, which are incapable of transporting the loads efficiently under the existing hydrological conditions, especially areas beyond the foothill zone. As a result, the river-bed is rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods. Moreover, the narrow road and railway bridges, spanning the rivers as well as the pillars supporting them, are always considered to be the barriers, interrupting natural load movement behavior of the rivers. This often cause accelerated deposition at the bottom of the bridge and thereby, narrowing the outlets of the rivers gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and firm lands (Sarkar S., 2007).

5.2 History of occurrences of major floods

The first recorded disastrous flood of this region occurred in 1787. It caused dramatic changes to the river Tista, which used to flow into the Ganga, deserted its channel and emptied itself into the Brahmaputra through an ancient spill channel. Numerous deserted riverbeds of the Tista, Torsa, Sankosh, Raidak and Jaldhaka bear the testimony to the fact that the river changed its course at ease often in consequence of heavy rains in the following years.

Historical documents on the floods and flood-induced evolution of the sub-Himalayan rivers viz., Bolt, 1772: Buchanan-Hamilton,1810; Dash, A. J., 1947; Furgusson,1770-79; Hunter,1787; Sunder, D. H. E. 1985; Gruning, J.F. 1911; Rennel,1779; Mitra,1964; Sanyal,1969 etc are numerous and fascinating. Record reveals that up to 1787, the river Tista and Karotoya were the same river that flowed through the Atrai-Punarbhaba into the Ganga. Neo-tectonic activity coupled with high intensity rainfall induced flash-flood caused massive shifting of the river. The so-called whale backed subsurface ridge of the Baikanthapur-Fulbari became active and the Tista migrated eastwards bifurcating the river Karotoya.

Table 5.1

History of Flood Occurrences in Jalpaiguri district

Year	Magnitude	Triggered by	Affected areas
1787	V	Earthquake, landslide followed by heavy rainfall	Jalpaiguri, Koch Bihar and parts of Darjeeling district; the Tista river shifted from the Ganga to Brahmaputra
1840	IV	Heavy rainfall in the catchment area	Jalpaiguri, Koch Bihar and part of Darjeeling district; the river Torsa and Sankosh shifted their courses.
1881	III	Heavy rainfall in Darjeeling Sikkim and Bhutan hills	Jalpaiguri and part of Koch Bihar districts.
1892	III	High rainfall in the Catchment areas	Jalpaiguri and Koch Bihar districts, river Jaldhaka shifted its course.
1902	IV	Incessant rain in Sikkim and Darjeeling hills	Jalpaiguri and Darjeeling districts caused heavy damages to land and property.
1906	III	Heavy rainfall in North Bengal Plains amounting over 1000mm in 72 hours	Parts of Jalpaiguri district and most part of Koch Bihar district were affected caused heavy damage to land and properties.
1922	II	Heavy rains in Sikkim	Parts of Darjeeling and Jalpaiguri districts
1948	II	Heavy rains in the North Bengal Plain	Parts of Jalpaiguri and Koch Bihar districts
1950	IV	High intensity rain in upper catchments of the Tista, Jaldhaka, Mahananda rivers and landslides in hill slopes	Heavy damage to land and properties in entire North Bengal particularly communication lines. Heavy damage to human and animal life was also reported
1968	V	Cloud-burst over large parts of Sub-Himalayan West Bengal, 1200mm rainfall recorded at Himalayan margin caused landslides & damming of river	Jalpaiguri was worst affected, also affecting Darjeeling and Koch Bihar districts, heavy damage to lives, land and properties; massive deposition was taken place in many parts of North Bengal
1969	II	Heavy local rainfall	Jalpaiguri district
1972	II	Heavy rainfall in the catcment	Parts of Jalpaiguri and KochBihar districts
1980	II	Incessant rains in the catchment areas	Jalpaiguri, Koch Bihar and parts of Darjeeling districts

1993	IV	Cloud-burst over the Lower Bhutan-Darjeeling Himalaya Hasimara recorded 850mm/ 24 hours	Alipurduar sub-division of Jalpaiguri district was devastated, massive fluvial transformation were taken place.
1998	IV	Cloud-burst over the lower Bhutan hills, 1250mm in 72 hours, massive landslide & debris flow in Bhutan hills	Foothill area was devastated, shifting of river courses, destruction of forest, tea garden, settlement, communication lines and deposition of course sediments.
2000	III	Heavy rainfall in the catchment area followed by drainage congestion	Koch Bihar and part of Jalpaiguri and Darjeeling districts were affected.
2002	II	Heavy rainfall in the catchment area along with the local drainage congestion	Malbazar, Kalchini, Madarihat Blocks in Jalpaiguri district and many parts of Koch Bihar district.
2003	III	Heavy rainfall in catchment area on July 1 i.e., Jalpaiguri 182, Banarhat 221, Malbazar 175 and Hasimara 189 mm in 24 hours.	30000 people are affected in Jalpaiguri , 70m embankment of I&W Dept. damaged
2003	III	High intensity rainfall in Duars on August 7, causes flood i.e., Central Duars TG 424,Hasimara200,Malbazar19 8 and Banarhat recorded 264 mm in 24 hours	215 m long embankment washed away, 500 acre of Tea Garden land destroyed. Massive bank erosion takes place in Pana, Gabur Basra and Reti rivers.
2004	II	Cloud burst in Lish-Gish catchment cause flush flood along Lish valley, Bagrakote GP of Mal block.	At Ramnagar basti, Bagrakote river Lish breach her left embankment for 200 meter destroying 200 homesteads and others. 1000 people remains homeless.
2005	II	Heavy rainfall in catchment area on 10th May i.e., Jalpaiguri 178, Alipurduar 152 in 24 hours.	Large scale destruction of crops from Jalpaiguri district was reported.
2007	III	Very heavy rainfall in Jalpaiguri on August 16 (350 mm in 24 hours).	Over 25000 families affected, 6500 homestead destroyed and 4500 hectare of arable land affected.
2008	II	Heavy rainfall in catchment area on 20th June in Jalpaiguri district causes large scale flood in Mal area.	Railway bridge over Gish river near Odlabari was destroyed.
2009	I	Heavy rainfall in catchment area on 20-21 August in Jalpaiguri district causes large scale flood in Mal area.	2 died in Jalpaiguri in flood. 25000 family affected in Jalpaiguri sadar and Maynaguri.
2010	I	Heavy rainfall in catchment area on 19th August in Jalpaiguri.	414 families affected in Falakata.

The occurrences of floods during the following 224 years along with their estimated magnitude, triggering mechanism and effects are tabulated in table 5.1. The characteristic features of some of the major floods of Jalpaiguri district is given below:

The floods of 1922

The flood of 1922 during 23rd to 28th September was caused by cyclonic rainfall of practically unprecedented magnitude. The rainfall in the central area in one week was about 10 times the normal weekly precipitation, which was nearly three times the normal precipitation for the month of September, and approached the normal rainfall for the whole of three months of July, August and September. In other words, the flooded area received in one week practically as much rain as it would have received in certain years during the whole monsoon period. The railway embankment in Jalpaiguri district hampered quick draining away of the flood-water, and thus served to prolong the duration of the flood. However, with such a heavy rainfall, a flood of practically the same magnitude was bound to occur, had there been no railway line in existence. Though no records are available with regard to flood damages, it was classified as very severe and extensive flood with huge loss of property. It affected the parts of Jalpaiguri district.

The floods of 1968

The rivers in North Bengal, particularly in the western half, from Jaldhaka to Mechi witnessed an unprecedented flood, during 3rd October to 5th October 1968 which caused number of breaches in many embankments and damage to anti-erosion works, revetments and spurs. The damages caused due to the river Tista were unprecedented in magnitude. The Jalpaiguri town protection embankment was breached at eleven places. Embankment on both the banks of the river Tista were breached and washed away, two numbers solid spurs was outflanked and thirty numbers permeable spurs of Jalpaiguri embankment were washed away.

The floods of 1993

In the year 1993, the damages to flood protective structures on different rivers were very high. The damages by the river Kaljani were maximum at the Alipurduar Town where the Alipurduar Town Protective embankments were breached by overtopping due to its highest recorded discharge. During the period from 18.7.1993 to 21.7.1993, there was very intensive rainfall in Jalpaiguri district and the lower catchments of the river Kaljani. In the upper catchments, the rainfall recorded at Hasimara within the adjacent catchment of Torsa on 19.7.1993, 20.7.1993 and 21.7.1993 were 220 mm, 368 mm and 790.60 mm respectively. Such incessant heavy rainfall in the entire catchment caused heavy floods in the river Kaljani and its tributaries. It is seen from the records of the North Bengal Flood Control Commission that the design discharge adopted for the river Kaljani at Alipurduar is 112480 cusec (3468 cumec) in respect of all the flood protective works (NBFCC, 1965; WAPCOS, 2003). From the recorded rainfall of July 1993 and considering other relevant factors, it has been calculated that the peak discharge through the river Kaljani on 20.7.1993 was 140237 cusec (3971 cumec).

The floods of 1999

In 1999, the State of West Bengal suffered from cyclone and high precipitation during monsoon months i.e. between June to October. In the last week of August the district experienced high rainfall varying between 100 cm in 24 hours for about three days. This resulted heavy discharge passing through the rivers of the district. It caused widespread inundation and bank erosion including damage to spurs, revetment works and existing embankments in the Jalpaiguri district.

There was heavy rainfall during August 1999. On 9.7.1999, the rainfall at Jalpaiguri was 474 mm which was a record rainfall crossing the previous record of 390 mm on 8th July 1892. This year the rainfall up to 13.10.1999 was about 1100 mm. Because of this heavy rain and flood, heavy damages occurred to the embankment structures. Out of total existing length of embankment of 434.00 km in the district, 1.75 km was breached, 10.46 km was severely damaged, 20.44 km was partially damaged and 8.65 km revetment works were damaged.

The floods of 2000

Due to concentration of heavy rainfall during the months of June 2000, earlier part of July 2000 and first week of August, 2000 in the hilly areas of Darjeeling, Sikkim and Bhutan, Synchronised with heavy rainfall in the Duars area of Jalpaiguri and Alipurduar, the river

Sankosh, Raidak-I, Raidak-II, Kaljani, Torsa, Mujnai, Basra, Pana, Diana, Jaldhaka, Tista, and other tributaries were in high spate and the water levels of these rivers crossed even extreme danger levels. The heavy concentration of flood with high velocity and thrust leading to rise in water levels caused several breaches in the embankments specially in the foothill zones under Alipurduar Sub-Division. It also caused severe damages to the structures, embankments, spurs due to erosion and scour.

The unique feature of the flood during the first week of August, 2000 was that, though there was less rainfall at Jalpaiguri but heavy and incessant rains occurred in the Bhutan and adjacent foothills amounting to more than 500 mm on 2nd and 3rd August, 2000. Thrust of the rainfall and eventual discharge was such that the rain gauge station at Chukka on Raidak river was washed out and there were heavy landslides in the Bhutan territory leading to deposition of boulders and debris in rivers in Alipurduar.

5.3. Flood hydrographs

Flood hydrograph is the plot of discharge or water-surface elevation against time during a flood event and defines the slope of the flood wave at the location of the gauging station. Hydrographs at successive locations can be used to define the changing slope of the flood wave as it moves down wards. In the study area the flood hydrograph is mostly depend on the high intensity rainfall and catchment characteristics.

The flood hydrograph is an important guide to flood characteristics it gives the information of peak discharge and water level, the duration of flooding, time taken to attain peak condition and the total volume of the flood water. The rate of discharge provides the basis for most methods of predicting flood magnitude and frequency. However, the other dimensions of flooding the velocity of flood water, water depth and area of inundation.

5.3.1 Factors affecting flood hydrograph

The factors that affect the shape of the hydrograph can be broadly grouped into climatic factors and physiographic factors. Each of these two groups contains a host of factors and the important ones are listed in table 5.2. Generally, the climatic factors control the rising limbs and the recession limb is independent of storm characteristics, being determined by catchment characteristics only. Many of the factors listed in table 5.2 are interdependent. Further, their effects are very varied and complicated. As such only important effects are listed below in qualitative terms only.

Table No- 5.2 Factors affecting flood hydrograph

Physiographic Factors	***Climatic Factors***
Basin characteristics : Shape Size Slope Nature of Valley Elevation Drainage Density *Infiltration characteristics:* Land use and cover Soil type and geological condition Lakes, swamps and other storage *Channel Characteristics*: Cross-section, roughness and storage capacity	Storm, characteristicPrecipitations, intensity, duration, magnitude and movement of storm. Initial loss Evapotranspiration

(Based on Subramanya, 1994)

5.3.2 Components of hydrographs

As indicated earlier, the essential components of a hydrographs are: (i) the rising limb, (ii) the crest segment, and (iii) the recession limb. A few salient features of these components are described below:

The rising limb of a hydrograph, also known as concentration curve represents the increase in discharge due to the gradual building up of storage in channels and over the catchment surface. The initial losses and high infiltration losses during the early period of a storm cause the discharge to rise rather slowly in the initial period. As the storm continues, more and more flow from distant parts reach the basin outlet. Simultaneously the infiltration losses also decrease with time. Thus under a uniform storm over the catchment, the runoff increases rapidly with time. As indicated earlier, the basin and storm characteristics control the shape of the rising limb of a hydrograph.

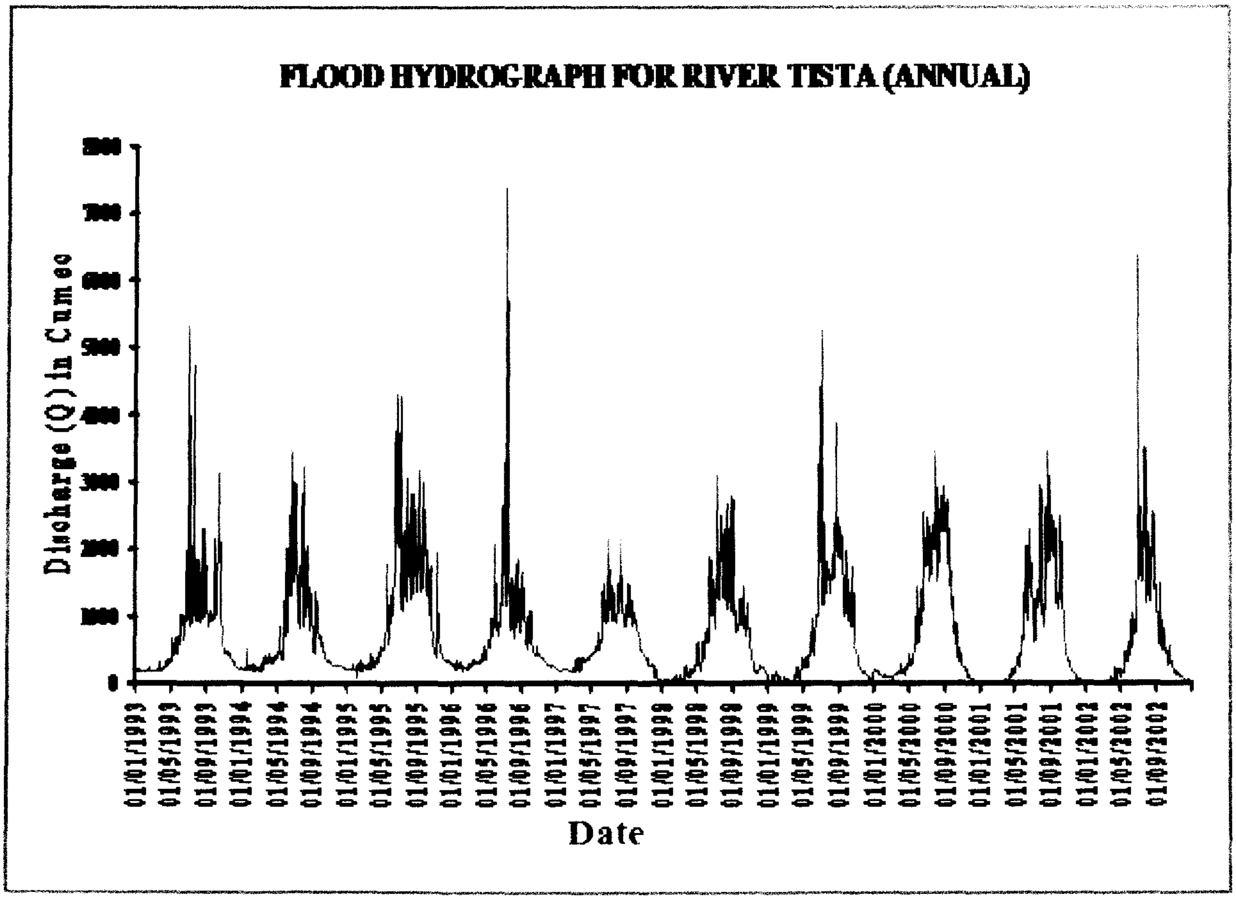
The crest segment is one of the most important parts of a hydrograph as it contains the peak flow. The peak flow occurs when the runoff from various parts of the catchment simultaneously contribute to the maximum amount of flow at the basin outlet. Generally the large catchments, the peak flow occurs after the cessation of rainfall, the time interval from the centre of mass of rainfall to the peak being essentially controlled by basin and storm characteristics. Multiple-peaked complex hydrographs in a basin can occur when two or more storms occur in close succession.

The recession limb which extends from the point of inflection at the end of the crest segment to the commencement of the natural ground water flow represents the withdrawal of water from the storage built up in the basin during the earlier phases of the hydrograph. The starting point of the recession limb, i.e., the point of inflection represents the condition of maximum storage. Since the depletion of storage takes place after the cessation of rainfall, the shape of this part of the hydrograph is independent of storm characteristics and depends entirely on the basin characteristics.

5.3.3 Characteristics of flood hydrographs for rivers under study

The shape of the basin influences the time taken for water from the remote part of the catchment to arrive at the outlet. Thus occurrence of the peak and hence the shape of the hydrograph are affected by the basin shape. Fan-shaped , i.e. nearly semi-circular shape catchments give high peak and narrow hydrographs while elongated catchments give broad- and low peaked hydrographs. Multi-peaked complex hydrograph is produced by a catchment of composite shape. Moreover, multi-peaked hydrographs may be produced, if the next rainfall occurs before the direct runoff of the previous rainfall ceases (Mukherjee, 2008).

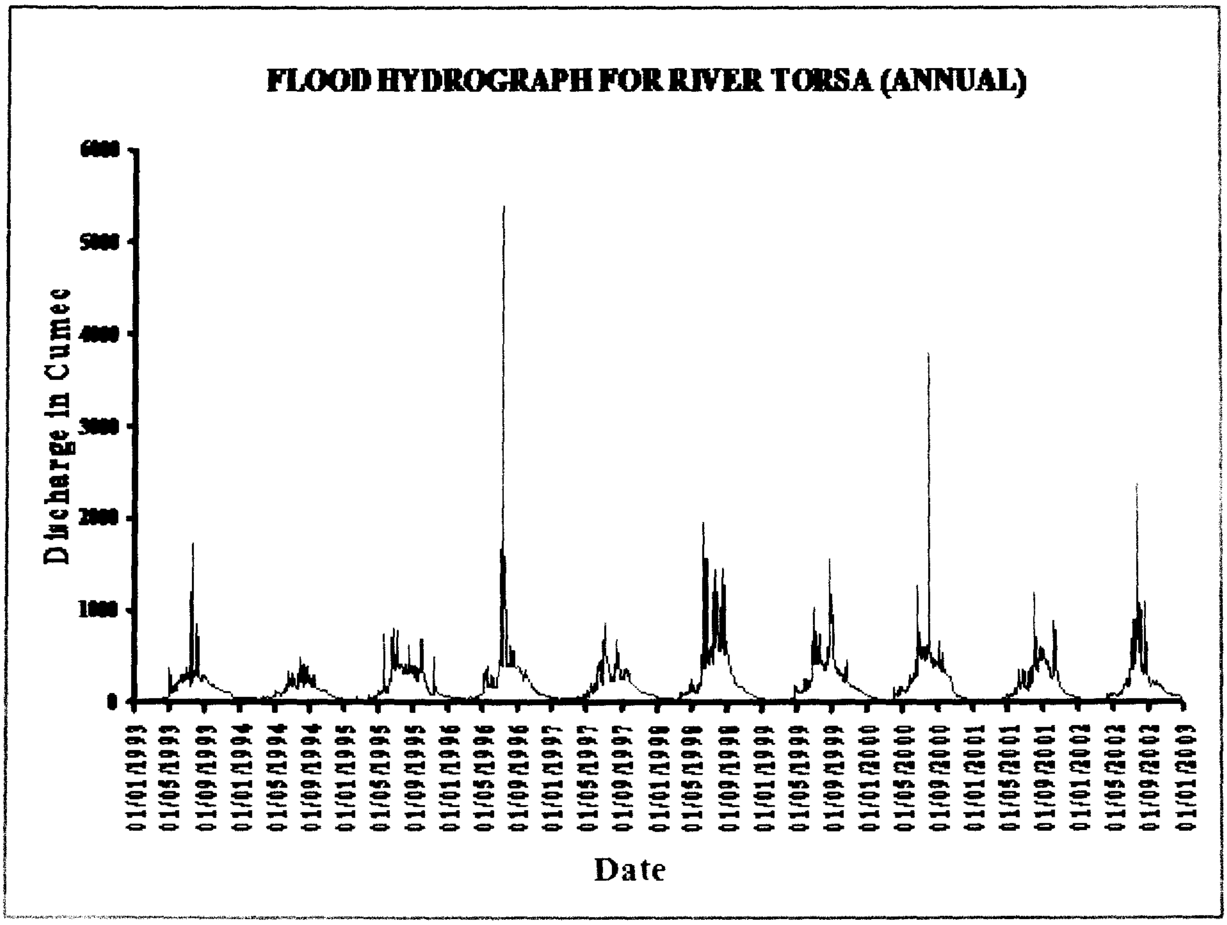
In case of river Tista (figure 5.1), flood hydrographs have been constructed for consecutive ten years (i.e., from 1993 to 2002) from the available data. From the constructed flood hydrographs, it has been observed that in case of all the ten years under consideration, the flood hydrographs are multi-peaked. So, it can be inferred that rainfall occurs before the direct runoff of the previous rainfall ceases. Moreover, it has been pointed out that the flood hydrographs for the years of 1993, 1994, 1995,1996,1998,1999 and 2002, are skewed to the left which indicates that the peak occurs relatively quickly. Again, the flood hydrographs for the years of 2000 and 2001 are skewed to the right which indicates that the peak occurring with a relatively longer lag. But, only for the year 1997, peak occurs at an intermediate time, neither very quickly nor at a longer lag.



Based on Mukherjee, M, 2008

Figure 5.1 Flood hydrograph of the river Tista.

It has also been observed from the plotted hydrographs that there is always a base-flow component throughout the ten years duration under consideration is varying from a minimum value of 6.267 cumec to a maximum value of 173 cumec. Hence, it can be interpreted that river Tista is a perennial river where there is always some flow above the river bed level. Moreover, the base-flow contribution is more significant up to the year 1997 and decreased thereafter.

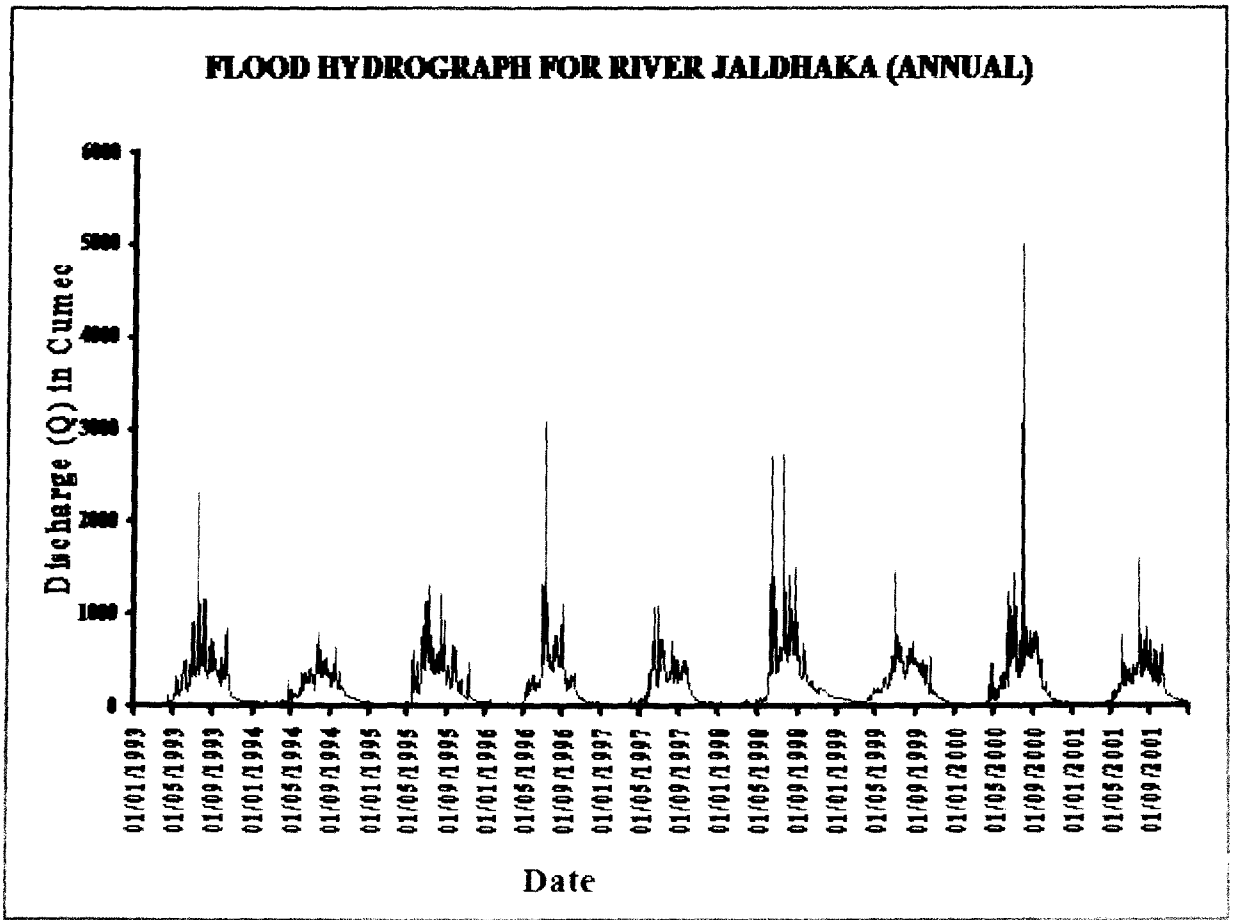


Based on Mukherjee M 2008

Figure 5.2 Flood hydrograph of the river Torsa

In case of river Torsa (figure 5.2), flood hydrographs have been constructed for consecutive ten years (i.e., from 1993 to 2002) from the available data. From the constructed flood hydrographs, it has been observed that in case of all the ten years under consideration, the flood hydrographs are multi-peaked. So, it can be inferred that rainfall occurs before the run-off of the previous rainfall ceases. Again, the flood hydrographs for the years 1993, 1995, 1996, 1997, 1998, 2001 and 2002 are skewed to the left, which indicate that the peaks occur relatively quickly. For the years 1999 and 2000 the flood hydrographs are skewed to the right, which indicates peak occurring with a relatively longer lag. But, only for the year 1994, peak occurs at an intermediate time, neither very quickly not at a longer time.

It has also been observed from the plotted hydrographs that there is always a base-flow component throughout the ten years duration under consideration is varying from a minimum value of 18.96 cumec to a maximum value of 36.02 cumec. Hence, it can be interpreted that river Torsa is a perennial river, where always there is significant flow above the river bed level.

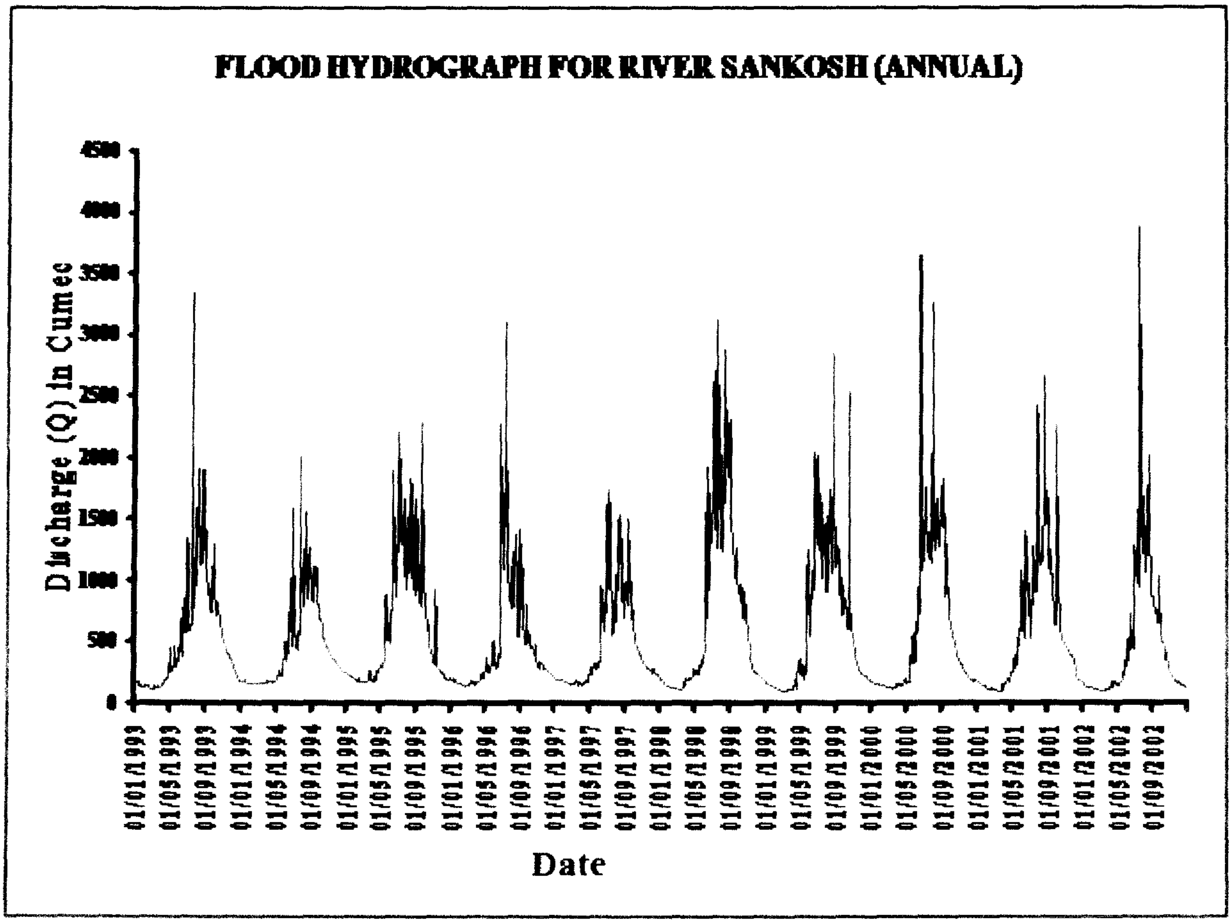


Based on Mukherjee M 2008

Figure 5.3 Flood hydrograph of the river Jaldhaka

In case of river Jaldhaka (figure 5.3) flood hydrographs have been constructed for consecutive nine years (i.e., from1993 to 2001) from the available data. From the constructed flood hydrographs, it has been observed that in case of all the nine years under consideration, the flood hydrographs are multi-peaked. So, it can be inferred that rainfall occurs before the run-off of the previous rainfall ceases. Again, the flood hydrographs for the years 1993, 1995, 1996, 1997, 1998 and 2000 are skewed to the left, which indicates that the peak occurs relatively quickly. For the years 1999 and 2001, the flood hydrographs are skewed to the right, which indicates peak occurring with a relatively longer lag. But, only for the year 1994, peak occurs at an intermediate time, neither very quickly not at a longer time.

It has also been observed from the plotted hydrographs that there is always a base-flow component throughout the nine years duration under consideration is varying from a minimum value of 11.17 cumec to a maximum value of 28.07 cumec. Hence, it can be interpreted that the river Jaldhaka is a perennial river, where always there is some flow above the river bed level. So, river Jaldhaka can be classified as perennial.



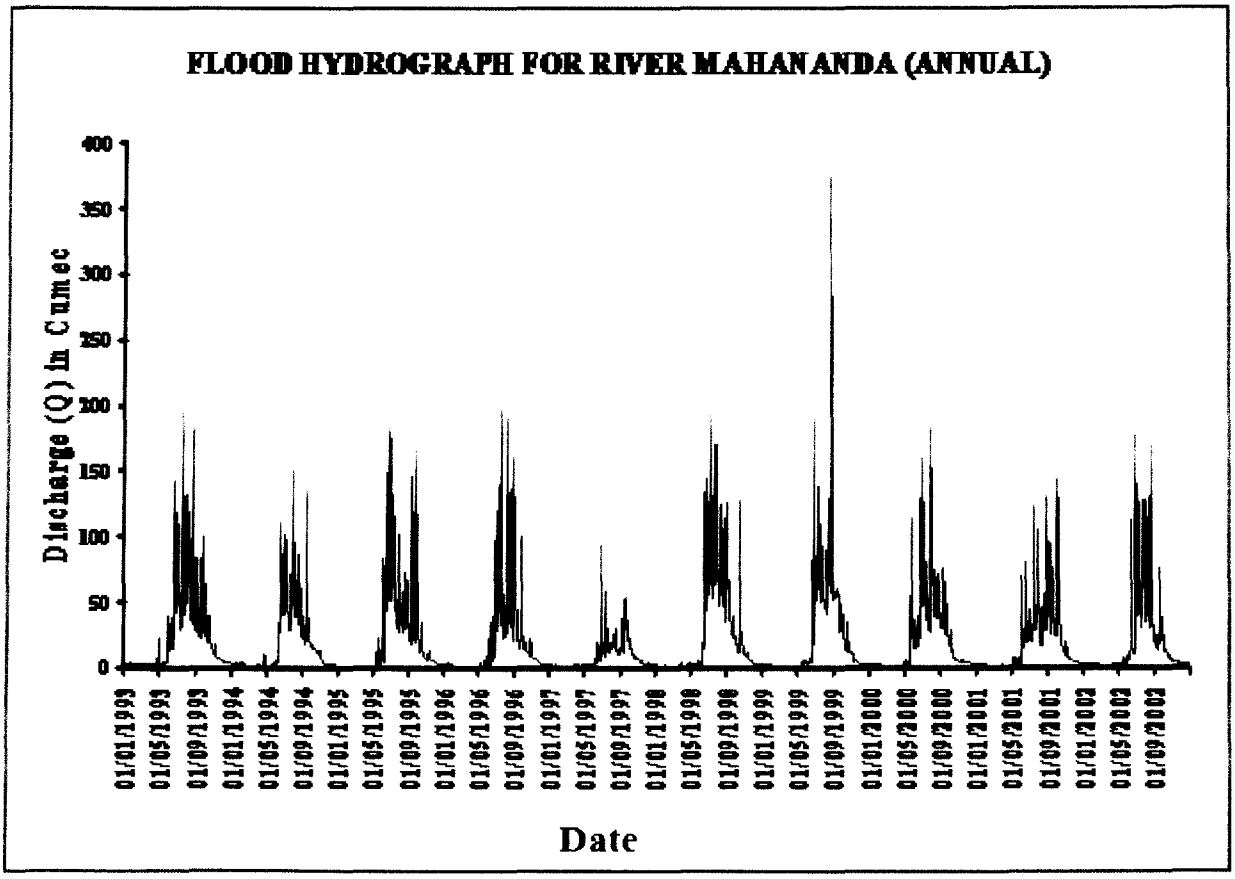
Based on Mukherjee M. 2008

Figure 5.4 Flood hydrograph of the river Sankosh

In case of river Sankosh (figure 5.4), flood hydrographs have been constructed for consecutive ten years (i.e., from1993 to 2002) from the available data. From the constructed flood hydrographs, it has been observed that in case of all the ten years under consideration, the flood hydrographs are multi-peaked. So, it can be inferred that rainfall occurs before the run-off of the previous rainfall ceases. Again, the flood hydrographs for the years 1993, 1994, 1996 and 2000 are skewed to the left, which indicates that the peak occurs relatively quickly. For the years 1998, 1999, 2001 and 2002, the flood hydrographs are skewed to the right.

which indicates peak occurring with a relatively longer lag. But, for the year 1995 and 1997 peak occurs at an intermediate time, neither very quickly not at a longer time.

It has also been observed from the plotted hydrographs that there is always a base-flow component throughout the ten years duration under consideration is varying from a minimum value of 90 cumec to a maximum value of 164.6 cumec. Hence, it can be interpreted that river Sankosh is a perennial river where there is always some flow above the river bed level. Moreover, the base-flow contribution is more significant up to the year 2000. Then the base-flow is throughout more or less steady for the period under consideration.



Based on Mukherjee, M, 2008

Figure 5.5 Flood hydrograph of the river Mahananda

In case of river Mahananda (figure 5.5), flood hydrographs have been constructed for consecutive ten years (i.e., from1993 to 2002) from the available data. From the constructed flood hydrographs, it has been observed that in case of all the ten years under consideration, the flood hydrographs are multi-peaked. So, it can be inferred that rainfall occurs before the run-off of the previous rainfall ceases. Again, the flood hydrographs for the years

1993,1995,1996,1998 and 2000 are skewed to the left, which indicates that the peak occurs relatively quickly. For the years 1994 and 2001, the flood hydrographs are skewed to the right, which indicates peak occurring with a relatively longer lag. But, for the year 1997, 1999 and 2002, peak occurs at an intermediate time, neither very quickly not at a longer time.

It has also been observed from the plotted hydrographs that there is always a base-flow component throughout the ten years duration under consideration is varying from a minimum value of 0.504 cumec to a maximum value of 2.228 cumec. Moreover, it has been observed that base-flow contribution is very small for all the ten years under study. Hence, like other rivers under consideration, river Mahananda cannot be classified as perennial river. It is better to classify as intermittent river, particularly when the base-flow is negligible, around 0.5 cumec.

It has been observed from the above constructed flood hydrographs shown in figures 5.1, 5.2, 5.3, 5.4 and 5.5, that two main features are there which are common for all the rivers under study i.e., Tista, Torsa, Jaldhaka, Sankosh of the Brahamputra basin and Mahananda of the Ganga basin. In all the cases the flood hydrographs are multi-peaked, so it can be inferred that rainfall occurs before the direct runoff of the previous rainfall ceases. Except the river Mahananda, remaining all the rivers may be classified as perennial rivers having significant base flow contribution throughout the year. While, the river Mahananda may be classified as intermittent river. This has been corroborated from the findings furnished from the constructed hydrographs.

The flood hydrographs which have been constructed from consecutive ten years (i.e from 1993-2002) from the available data reveals that in majority of the cases the peaks are skewed to the left and in some cases are skewed to the right. The fact reveals that the peak occurs relatively quickly when the hydrographs are skewed to the left and the peak occurring with a relatively longer lag when the hydrographs are skewed to the right.

5.4 Causes of flood

Jalpaiguri district is endowed with an intensive network of river systems. Most of the rivers are considered to be highly notorious for their unpredictable nature, letting loose fury of floods and problem of extensive and regular bank erosion, course shifting and rendering thousands of people homeless during the rainy reason. The majority of the rivers of Terai and Duars originate in the Himalayas and enter from north to northwesterly direction and flow south to southeasterly direction. The lateral gap between the two major rivers is in between 3 to 30 km. i.e., Torsa – Jaldhaka and Gadadhar – Raidak respectively. As many of the rivers originate from the same hill, flood often occurs simultaneously in many rivers and the rivers coalesce to form a single vast sheet of water.

The catchment area of these rivers has mostly been deforested and the clearings of the steep slopes have been used for the extension of settlement, agriculture, plantation and communication, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfall, innumerable landslides are caused transporting huge amount of sediment to the rivers (photo 5.3 & 5.4). Most of such landslides have never been treated scientifically with proper protective measures and as such those are in the habit of expanding their territories during monsoon (photo 5.1 & 5.2). This often added more and more silt to the rivers, which are incapable of transporting the loads efficiently under the existing hydrological conditions, especially areas beyond the foothill zone (Sarkar, S., 1996; Sarkar S., 2008).

There are many causes of floods in the district as a whole. All the causes create huge flood condition in the study area. Some causes are similar to the floods of different places of India and West Bengal. But few causes are highly local which is predominant in the district of Jalpaiguri. Such causes are foothill situation of the area, lateral gap of the rivers are thin, high intensity of the rainfall in the district and avulsion etc.

5.4.1 Transient causes

Among the transient causes of flood, heavy and concentrated rainfall in the upper catchment is noteworthy (Starkel, L., Sarkar, S., Soja, R., Prokop, P. 2008). Records reveal that the floods of 1906, 1968 and 1993 caused by the high intensity incessant rainfall in Darjeeling and Sikkim Himalaya. Heavy and incessant local rainfall also caused large-scale inundation and flooding at Jalpaiguri district in 1902, 1906, 1950, 1952, 1968, 1972, 1980 and 1998 (table 5.1).

Photo 5.1Deforested catchment in the Hills

Photo 5.2 Landslide along the Tista Valley

5.4.1.1 Grazing

Grazing rights, privileges, and concessions for forest produce. Minor timber etc, are generous and vary from state to state. Forest regulations admit such rights. Tribal people in state have their free rights to grazing and extracting minor forest produce. Overloading degrades the watershed. Sediment discharge and overland flow volume increase from such degraded catchments. The situation becomes more acute in places where livestock population is very high. Some areas are having this problem of the district and the upper catchments of the main rivers of the Jalpaiguri district facing the problem.

5.4.1.2 Forest fire

Forest department have a practice of administering regulated fire in moist regions for encouraging natural regeneration of teak (*Tectona grandis*), sal (*Shorea rebusta*), deodar (*Cedras deodars*) etc. This is mostly done to check the growth of evergreen tree, shrubs and woods, reduce depth of leaf litter and create a conductive site for the germination and establishment of seedlings. However, the unregulated wild fires are fraught with danger for defecating watershed conditions. Such incidences are numerous. They damage the soil and rob the forest of its productive and protective capacity hence, the normal hydrological functioning of the forest watershed gets upset.

5.4.1.3 Surface mining

Large scale surface mining of minerals for manufacturing of cement and especially for the extraction of dolomites in the Bhutan hills make radical change in river behaviour of the Jalpaiguri district. It is noticed that spilling and massive sand and debris deposition in the multi-cropped agricultural field. This has caused national loss in term of the agricultural and tea productivity and also has adverse effects to the people residing in the adjacent area. Buxa-Jainti area is the worst affected by this problem followed by Chamurchi-Reti-Pagli-Makrapara-Lankapara area (Starkel, L & Sarkar, S, 2002). The details indicating the cause and nature of silt-deposition of some of the vital locations are given in table 5.3.

Photo 5.3 Deep seated landslides along Bhutanese border caused massive deposition in Pana-Gabur Basra valley.

Photo 5.4 Parminder landslide in Lish catchment caused huge deposits in the valley

5.4.1.4 Deforestation

Deforestation has several environmental affects like air pollution, soil pollution, climatic change and soil erosion etc. But flood occurrences are very prominent due to the deforestation in the upper and lower catchments of the river basin in the recent years. Jalpaiguri district is famous for the vast forest tracks and for their luxuriant growth of natural vegetation is facing the problem of large scale deforestation or forest clearings due to the expansion of agricultural lands, tea gardens, roadways, railways, rapid urban isotones or settlements etc. these causes landslides, sheet erosion, slope failure and top soil erosion in the upper catchment areas of the leading river of the district, which enhance the debris flow and large scale sedimentation in the riverbeds of all the rivers of the district and acute the flood problem of the district. This reckless deforestation also affects the climate of the study area.

Table 5.3

Causes and nature/extent of silt deposition along the river beds

Location	River	Down-stream	Siltation (m/year)	Causes	Results
Pagli Bhutan	Pagli	Tulsipara, Lankapara	1.0	Extraction of dolomite and deforestation in the Bhutan hills caused landslides and siltation downstream.	The embankment on the left bank of river Pagli is being breached almost every year and raising of embankment necessary every year.
Madarihat Totopara Road	Titi Bangri	Madarihat Totopara	1.0	Extraction of dolomite from the Bhutan hills and deforestation in Bhutan causing excessive landslides and siltation at the downstream	Left bank and the road between Madarihat & Totopara gets cut-off even during normal flood. Spilling is a recurrent problem in this area affecting the lands and properties.
Chamurchi	Rehti Sukriti	Chamurchi Binanguri Army Cantonment	0.45	Quarrying and blasting in Bhutan hills aggravating the problem of landslides and other problems	The situation is aggravating gradually in downstream area and structures are likely to be affected.
Jaigaon	Hasimara Jhora	Jaigaon	1.0	Excessive deforestation in Bhutan hills and landslides therefrom	The road connecting Jaigaon to Phuntsholling gets delinked frequently, areas on both banks get inundated.

Based on field observations

5.4.1.5 Landslides

The mountainous upper catchments experience landslides which contribute substantial amount of silt to stream flow. Compared to the mountains in the Deccan plateau or central

India, the Himalayan ranges experience serious landslides. No systematic or reliable data are available on the extent of the problem and the amount of sit contributed from this source. With the increasing activities of road construction in the Himalayan region, road engineers annually face the land slide problems for clearing the debris and keeping the roads open (Sarkar, S., 1991;Starkel L et. al., 2000). Therefore, the volume of debris contributed by the slides along the Himalayan roads may furnish a first approximation of the silt estimates contributed from this source, though numerous landslides occurring in inaccessible areas will remain beyond any possible estimation. Under the circumstances, an effort may be made to give a partial view of the serious problem of land slide infesting the entire stretch of the upper catchments of the flood prone rivers of the Brahmaputra river systems. Due to its characteristic geological formations and being in the seismic region, the problem in the upper catchments is, however, quite complex. The contributory factors for the land slides in the region may be summarised as follows:

(i) The stresses set up in the rocks by the fold the thrust movements leading to deformation of original physical character as well as in jointing and shearing.

(ii) Erosion and chemical weathering which loosen up such strained rocks along the fracture and joint planes and gradually widen gaps between the planes.

(iii) High rainfall and lack of proper drainage condition which reduce the frictional resistance to sliding of the loose and firmer rocks alike, thereby increasing the chances of land slides.

(iv) Increasing deforestation and shifting cultivation (Jhum & un-terraced cultivation on steep slopes) cause intensive erosion of top spills.

(v) In a metamorphic country, there is often an alternation of hard compact strata such as quartzite and marble with slates and phylites. When such strata have steep dip, they offer suitable condition for rock slides and the harder strata slides over the softer rocks lubricated by moisture.

The eastern Duars is mostly spread over the areas situated at the foot of Bhutan hills, where bed-slopes of rivers and jhoras coming down from hills are flattened considerably all of a sudden. Naturally, such sudden flattening of bed-slopes causes normal deposition of silts and reduces discharge-carrying capacity of the river resulting change of rivers-courses as well as spilling over banks due to inadequate and reduced waterways. However, this process of normal siltation takes place slowly and the results are visible after lapse of a number of years.

Since slopes of Bhutan hills in this region are unstable, landslides occur frequently at different places. The situation is aggravated further when green cover of hill slopes is removed artificially by the inhabitants. The process of mining associated with blasting further reinforces and boosts up the possibility of occurrence of massive and frequent landslides. These land masses come down and cause considerable rising of river beds, due to accumulation of huge debris and silts, especially at the transition zone where steep slopes are flattened and at other upstream reaches.

5.4.1.6 Rapid urbanisation

Rapid urbanisation in the Jalpaiguri district is experienced since long back. Jalpaiguri town is a divisional town from the British period and the district as a whole is well connected with Bangladesh before partition. After independence the district witnessed huge infiltration from Bangladesh, it is most important factor for the rapid urbanisation in the district. The towns of the district is also very closely spaced like Jalpaiguri, Maynaguri, Dhupguri, Falakata, Birpara, Malbazar, Hasimara, Nagrakata, Goirkata, Binnaguri, Madarihat, Jaigaon and Alipurduar etc. other important factors are huge potential of tourism in the Duars region, development of Tea Gardens, bordering areas of Bhutan and Assam, normal population growth, and air force and army bases make rapid growth of urbanisation of the district.

This urbanisation process leads large scale deforestation because forest lands are been encroached by the people which enhance the soil erosion, bank erosion and other problems and ultimately encourage the flood problem. People also encroaches the flood plains and during normal floods the situation became vulnerable.

5.4.1.7 Shifting of river courses or avulsion

This is the most significant hazard of the district. Avulsion is often found in the foot hills and Duars area of Jalpaiguri district. Avulsion not only causes the floods of severe nature but also defoliates the flood situation and flood havocs of the district significantly. Shifting of river courses in the Jalpaiguri district is so often due to the rise of river bed levels, high deposition of silts and coarse materials in the river beds, soil erosion and landslides in the upper catchment of the rivers and bank erosion. Rivers are very closely spaced in the district, so the lateral gap of the rivers of the foothill areas is very small and the river coalesces makes the shifting quite normal. Shifting of the rivers creates prolonged flood condition and gave birth of the high magnitude of flooding and havocs. River Tista, Jaldhaka, Sankosh, Torsa and many other rivers shifted their channels in the past.

5.4.1.8 High intensity rainfall

High intensity rainfall is the mother of all problems particularly the flooding of the Jalpaiguri district. Sudden maximum downpour creates the situation of flood in the district. The nature of the flood is mainly flash flood. Cloud burst or maximum rainfall in a short span always aggravate the situation of flooding in the district since long past. The flood history of the district gives no clean conception of the cause that is high intensity rainfall or cloud burst is the main cause behind the major floods of the district. Floods of 1922 is due cyclonic rainfall in one week was about 10 times of the normal rainfall. Major floods of 1954, 1968, 1993, 1999 and 2000 all are caused due to unprecedented high intensive rainfall. Occurrences and distribution of high intensity rainfall has already been discussed in chapter III.

5.4.1.9 Construction of road and railway bridges

This is also a factor for the flooding in the district. The narrow road and railway bridges, spanning the rivers as well as the pillars supporting them, are always considered to be the barriers, interrupting natural load movement behaviour of the rivers. This often cause accelerated deposition at the bottom of the bridges and thereby, narrowing the outlets of the river gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and farm lands.

5.4.1.10 Continuous encroachment by the people

Huge encroachment of the forest land and flood plains mainly vulnerable areas of the district causes huge damage in the floods by the people day by day due to the increase in population, development purposes, infrastructural needs, tourism and for defense purposes huge encroachment is noticed. Encroachment of the forest land degrading the situation of soil erosion and large scale debris flow and encroachment in the flood plains restricts the river flow of the region. Sometimes in the monsoon period normal discharge causes flood because rivers are not hampering the habitation but the habitation disturbing the normal river flows.

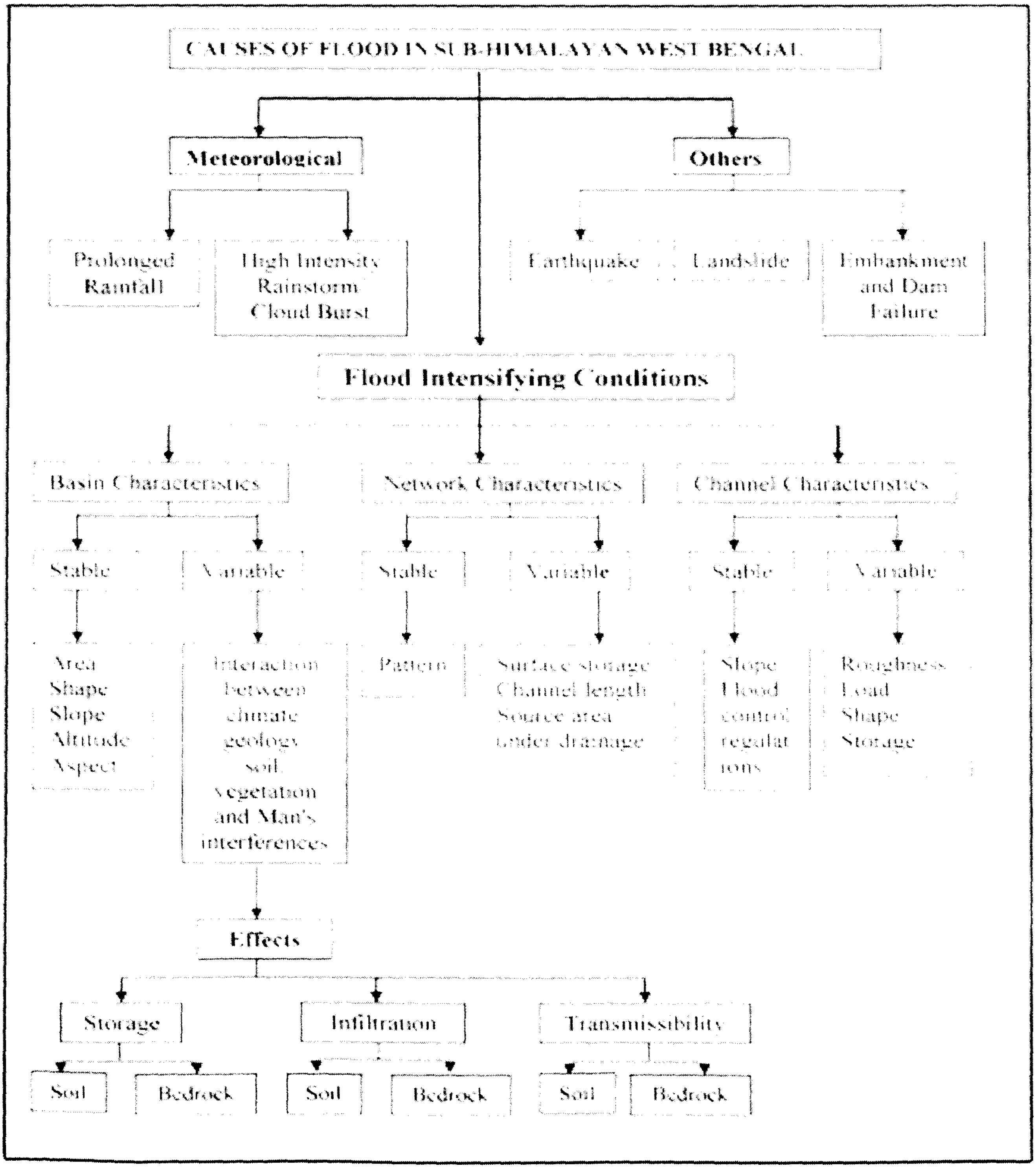


Figure 5.6 Causes of flood in sub-Himalayan Jalpaiguri district (Based on Sarkar, 2008)

5.4.1.11 High siltation process in the river beds

The entire study area is come under the periphery of hills, foot hills, alluvial fans and piedmont plains. It is the area where rivers are entering the plains from mountainous course, therefore high amount of silts and other bed materials are deposited by all the rivers of the district. As most of us know that rise in river beds decreases the river depth which ultimately leads to the spilling of the river banks at the time of high discharge mainly in monsoon season. This siltation process is very common and normal process of this region because most of the rivers enter in the plains in this district. After entering in the plains the velocity of the rivers decrease many fold for the flattened nature of the topography leads to the huge sedimentation of coarse variety is often found and sometime landslides in the upper catchments brings huge flow of the earth materials and these materials sometime block the channels like dams. When these dams are breached at the time of peak discharge causes floods in the surroundings. Siltation process is also responsible for the avulsion or silting of the river courses because large scale deposition of the debris in the river beds blocked the channels and increase the altitude of the river beds, mostly the rivers are carries world's highest sediment flow in the study area and channels find another route which causes avulsion and inundation of a new area.

5.4.2 Permanent causes

Among the permanent causes of flood at Jalpaiguri. environmental set-up of the catchment area, size and shape of drainage basins, fluvial dynamics of the rivers, stream networks and geometry of the channels etc. are more important. These along with the lag-time behavior of the rivers control the flood patterns of Jalpaiguri.

5.4.2.1 Topographical situation

Maximum altitude of the Jalpaiguri district is 1925 metre and minimum altitude is 41 meter the relative relief is 1884 meter. Maximum slope is 39.5^0 and minimum slope is 0.6^0 and average slope of this district is 19.78^0. And the altitude decreases sharply southward in the piedmont region of the district. The entire northern part of the district lies in the foot hills of the Himalayan range. This topographical nature is an ideal situation for the heavy sedimentation in the piedmont plains, flash floods in the high rainfall period and some water logging situation in the southern part of the district. Most of the rivers of the district are of high velocity and vulnerable for bank erosion, floods and sedimentation. So, the floods are so often and unpredictable in this district.

5.4.2.2 Drainage congestion

Here the network of the drainage is very high and the lateral gap between the two rivers is very less in this region. Only 3 to 30 kms are the lateral gap of the rivers in this district. So, rivers are very closely spaced which may create a problem of the river coalesces in the floods or heavy discharge in the rainy season.

5.4.2.3 Low lying or water logging areas

Low lying and water logging situation mainly in the southern part of the district cause prolong floods in this area. Here the slope and altitude are both minimum. So, the ideal situation of water logging is found in the southern part of the district.

5.5. Flood producing processes & impact of flood

The major rivers of sub-Himalayan North Bengal originated from Sikkim, Bhutan and Darjeeling hills (except Torsa which rises from Tibet). The rainfall is very copious being of the order of about 350 cm. on the average in a year ranging between 100 cm to 600 cm. The area lies in the seismic belt which was, by and large, undisturbed in the past. A condition of equilibrium was maintained in the area and the rivers were generally in regime state and hence, stable except in some years of exceptionally high floods. Very heavy precipitation for long duration in the catchment, synchronized with heavy local rainfall, causes enormous flood discharge in the rivers.

Landslides and floods are the major problems of the North Bengal situated in sub-Himalayan area. All major disasters have occurred due to abnormal rains in this area causing landslides in the gorges, through which the major rivers follow their course. These gorges are very deep and narrow. These consist of soft rocks which can't withstand high velocity during the rains. As a result, erosion occurs throughout the length of all these rivers and land occur fairly frequently. Due to these land slips, large quantities of detritus come down into the river, thus silting up the river bed in lower reaches. These land slips some time assume such magnitude as to block the waterway of the channel completely, forming temporary lakes. Ultimately the dam caused by these land slips, is itself pushed down, increasing the intensity of flood many times, by simultaneous release of water stored in the temporary lakes along with the storm water in the catchment areas of the rivers.

In the upper terrain, the rivers flow through the narrow gorges with high velocity carrying high silt load. In the plains, the rivers intend to accommodate the discharge as the longitudinal slope and the velocity of flood decreases to a great extent. This sudden reduction of velocity does not allow the heavy boulders, silt etc. to flow downwards resulting in the increase of river bed levels near one of its banks and tracing another course through a relatively deeper portion. This phenomenon is largely responsible for the change in the river course over a period of time.

With the increase of population and with improved communication facilities, there has been continuous encroachment of forest land. In additional there has been large scale deforestation, cultivation on steep slopes, uncontrolled grazing of cattle, extraction of forest produce by dragging on slopes causing aggravation of land slope and surface erosion. The wiping away of high river bank also causes overflow of banks even at low water levels and thereby diversion of flow through neighbouring deep water. In this process, channel happens to abandon the old course entirely.

The problems in the hills, where river flows in gorges so erosion of soil cover and land slips causing loss of agricultural area and forests. But the problem in the plains is extremely acute being erosion, avulsion and inundation of valuable agricultural lands, tea gardens, villages and towns. The inundation not only damages the crops for a particular season but also leaves behind large deposits of coarse sand making such land unfit for cultivation for quite long time. The large scale dislocation of vital communication links such as railway, national highways connecting Assam with rest of India, running East-west, is caused in almost all years due to flooding and avulsion of the rivers flowing north to south (Sarkar S., 2004).

Contributory factors for reduction in carrying capacity of rivers, thereby resulting floods and erosion are:-

i) Intensive top soil erosion and landslides in hills.

ii) Each year enormous quantity of silt and detritus coming down into the rivers in hilly areas are further carried down into the lower reaches and get deposited into the river bed in the plains, thereby constantly reducing the waterway of river. This deposition into the bed in plains is due to sudden reduction of velocity where the gradient of river bed suddenly drops from 40 m/km in hills to 0.70 m/km in plains.

iii) Due to reduction of velocity, the rivers, in turn, try to make up the waterway by eroding the banks. The rivers also widen with formation of shoals and braided channels.

iv) Human occupancy in the dry bed of river and in flood plain obstructs the free spilling and natural flow of river which elevates the river level.

v) Rapid urbanisation without scientific planning also cuts off the free spilling area.

vi) Waterway provided to some existing bridges of PWD and railway Dept. is quite inadequate to cope with the maximum flood discharge. This causes abnormal high afflux on the upstream of bridge and, as such, multiplies the flood problems to a great extent. The PWD bridge at Alipurduar has been found responsible for aggravating the flood havoc in 1993.

vii) Avulsion of one river into another one or even a tendency to avulse by way of erosion of banks and by wiping out vast tract of land with structures thereon also poses serious problems.

viii) Increasing indiscriminate deforestation creates ecological imbalance and multiplies the flood problems.

5.6 Flood prediction

Flood prediction is also known as flood estimation. Prediction using the information of meteorological, hydrological, and catchment to estimate extreme flooding condition of a particular river. Estimation of the flood is very much necessary for the design of structure such as flood embankments, dams, resources, bridges and culverts. This is also an essential input to the design of channel improvement schemes, aimed of increasing the flood carrying capacity of channels and to attempts to plan and mange land use in order to minimise flood risk and flood damage. Sometimes one can confuse with flood estimation and flood forecasting, the latter is essentially carried out in real time often of a very precise nature on the magnitude, depth, timing and duration of the forthcoming flood event. And flood forecasts are normally associated with appropriate tracing and evacuation procedure.

Flood prediction will depend on the rainfall data, discharge capacity and gauge levels. Flood prediction often helps in designing the protective measures and also largely influences the land use planning of the district.

5.7. Flood forecasting

Flood forecasting means prediction of how high a river or stream is likely to rise at a specific location and time. For issuing flood forecasts, the observation and collection of hydrological and hydro-meteorological data, flood meteorological data regarding general meteorological situation, rainfall quantity for the past 24 hours and heavy rainfall warning for the next 24 hours. The data transmission is done on real time basis from the hydrological and meteorological stations to flood forecasting stations through VHF/HF wireless sets at the data collection stations.

For real time issue of flood forecasts, telemetry based has been successfully installed by CWC in Mahanadi and Chambal rivers. In telemetry, the probe is located where the event to be measured is taking place. This differentiates telemetry from remote sensing whereas the probe is also located at a distance i.e., a radio reporting rain gauge is in the domain of telemetry where as a rainfall sensing radar is in the domain of remote sensing.

Recent advances in electronics have now made it possible to install a system which can collect data over a large area in the catchment and transmit this data accurately and quickly to a control station where the data is stored and analysed. Using only the rainfall data in the catchment, it is possible to operate a conceptual rainfall-runoff model to forecast the runoff at the site of interest.

In practice, runoff (or gauge) observations at number of key location will also be required to divide the catchment into convenient sized sub-catchments, and to correct the model status periodically. A telemetry based flood forecasting system consists of four main components:

FLOOD FORECASTING MODEL

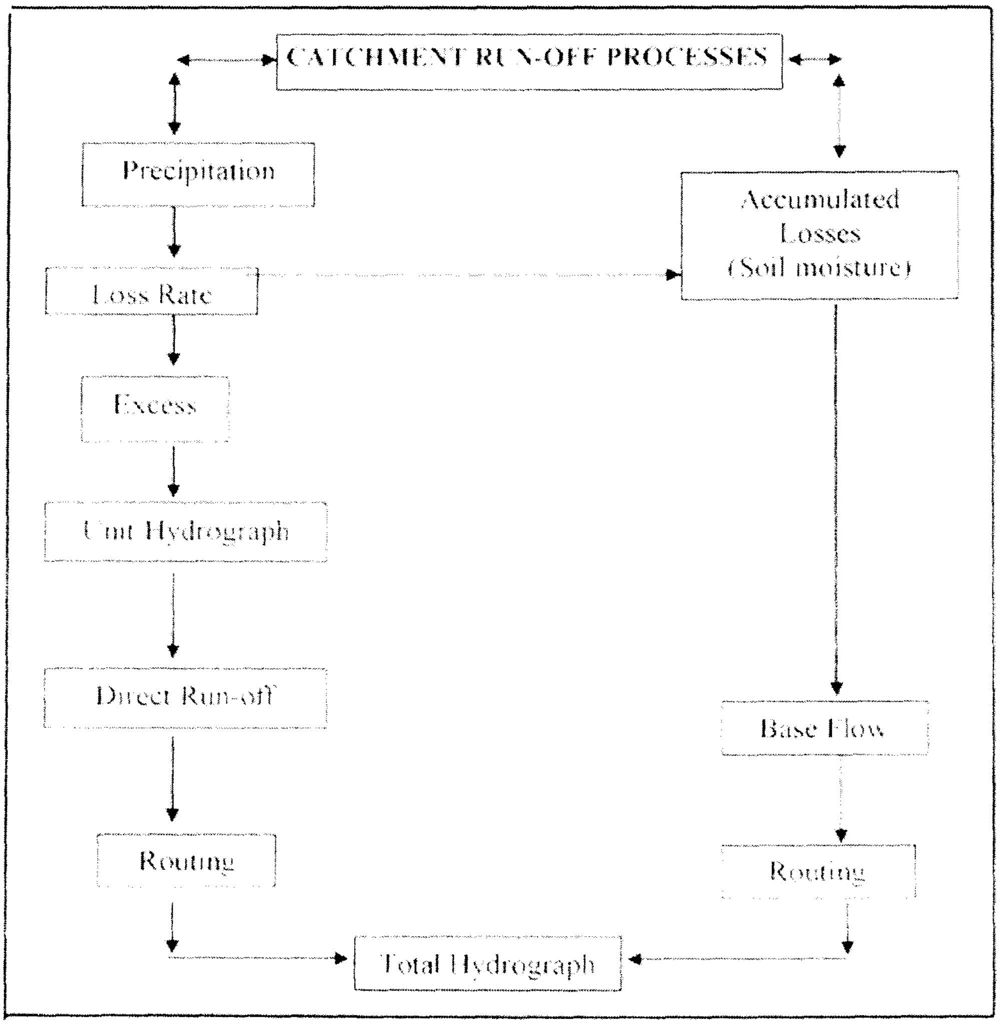


Figure 5.7 Flood forecasting model

Sensors and data loggers for data collection

- Wireless communication system for data transmission
- Computers for data storage and analysis
- Computer software for mathematical modeling

Data is sensed by sensors located in the field (Remote Stations) and temporarily stored in a data logger, also located in the field. A wireless communication device connected to the data logger transmits the data to the Master Control Station (MCS) where it is received in a computer and transmitted to concerned flood forecasting Front End Computer (FEC). The FEC makes a rough check on the data and detects whether the data as transmitted has been received correctly without any error. Then it makes further checks to determine whether the data is within reasonable limits with respect to time of the years, data received from that station a little time earlier and with respect to data received from other nearby stations. This process is called data validation. If the data does not pass the various tests, then the sending stations is requested to send it again. If acceptable data is not received after a reasonable number of attempts, then that particular data field is tagged as 'missing data'. The data so obtained by the FEC is sent to another computer for storage and analysis. In rare instances when the data is not received correctly, statistical procedures are used to fill missing data. The final data, received or computed is then stored in a permanent data base.

A mathematical model uses this data to compute runoff, flood levels etc. at various locations on the river. The model can also assist in reservoir regulation, canal regulation and general decision making which is largely a matter of software selection which can be easily upgraded from one level to other (figure 5.7).

5.8 Conclusion

Deforestation via-a-vis environmental degradation in the watersheds of the sub-Himalayan river indeed plays the decisive role in contemporary increased frequency and magnitude of hazards. Vicious cycle of degradation has already been established in the sub-Himalayan watersheds. Perhaps, the only possibility to save the habitable environment lies into the pro-active watershed management. It is thus, our imperative duty to inform the people living in threshold areas within the watersheds (prohibitive/restrictive zone) categorically about the hard reality of possible hardship during the different stages of watershed management processes.

Let us tell our people living in threshold areas (prohibitive/restrictive zone) categorically that you are living in an unsafe area and it is not possible to provide you security against possible flood. The land use pattern, house type must be suitable to cope up the possible threat. The traditional art and life style of ***living with flood*** must be adhered to. However, the life both human and animal along with movable property must be protected through the construction of Flood Shelter nearby preferably within the radius of 5 km (Sarkar, S. 2007).

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Chapter VI: Impact of Flood Hazard

6.1 Introduction

Bank failure, river shifting and river depositions, associated with flash floods, are primarily nature's way of adjusting fluvial dynamics along the Himalayan margin. Such an adjustment has been deleteriously disturbed by the human interferences. Implementation of various development schemes, construction of human settlement and road to cater the ever-increasing population, exploitation of forest produce to generate work potential, boosting of agricultural growth, tourism, mining and quarrying, on the Himalayan immature geology have triggered the huge and complex disasters (Basu S.R., Ghatowar L., 1988; Dutt G.N., 1966; Sarkar, S. 2007; Starkel L et. al., 2000).

The situation was not so desperate even 50 years back. The hills were densely forested with very thin population and the harmonic relation between the upper and lower catchments were well preserved. Extensive heedless deforestation, haphazard construction of roads and settlements, unscientific and illegal mining activities, inadequate drainage, in other words - unscientific and unplanned usage of land, has led to the establishment of vicious cycle of degradation. During heavy and concentrated rainfall, catastrophic soil erosion and innumerable landslides are caused to transport huge amount of sediments from the upper part of the catchments in the Darjeeling, Sikkim and Bhutan Himalayas to the river (Sarkar, S., 1991, 1996 & 2004). The river like Mahananda, Tista, Lish, Gish, Chel, Jaldhaka, Daina, Rethi, Torsa, Pana, Jainti, Dima, Kaljani, Sankosh, Raidak, Bala, Pagla, Gabarbasra etc. are incapable of transporting the load efficiently under the existing hydrological conditions, especially along their lower reaches (Froehlich, W. Soja, R. & Sarkar, S. 2000). The riverbeds are thus elevating at many places at an alarming rate resulting in lessening of cross sectional areas. The reduced cross sections being incapable of arresting the unusual monsoon discharge caused devastating flood, causing heavy damage to the land and properties. It also endangered the priceless forest lands vis-a-vis wild life, tea gardens, arable lands, settlements and the vital line of communications (Sanyal, 1969; 1970).

Although, flash flood has not been an uncommon phenomenon in the foothill area of Jalpaiguri, the frequency and magnitude of such events has increased many fold during the recent past. Two such catastrophic events during the last decade (1993 and 1998) demonstrate the enormity of damage and ever-increasing threat to the biosphere of the sub-Himalayan West Bengal (NBFCC, 165; WAPSOS, 2003). Some observations and measurements made on the effect of flood are represented below:

6.2 Flood characteristics

The dangers of flood waters are associated with a number of different criteria, not necessarily independent of each other but creating different types of clearly recognizable hazards. A summary of the criteria and related hazards is given below.

a) *Depth of water* often effects building stability against flotation and foundation failures, flood proofing, and vegetation survival have different degrees of tolerance to inundation. In each case these can usually be identified and the depth of hazard be established.

b) *Duration of inundation* is of utmost importance since damage or degree of damage is often related to it. This applies to structural safety, the effect of interruption in communications, industrial activity and public services, and the life of plants including agriculture.

c) *Velocity of flood water* causes high erosive forces and hydro-dynamic pressures. These features often result in complete or partial failure of structures by creating instability or destroying foundation support. Dangerously high velocities can occur on the flood plains as well as in the main river channel that might cause large scale death of animal and human lives.

d) *Rate of rise of river level* and discharge is important in its relation to the time available for giving flood warnings or making arrangements for evacuation and flood fighting arrangements. Rate of rise can therefore, influence planning permission for flood plain occupation and its zoning.

e) *Frequency of occurrence* is related to the overall damage cause by flood. Potential damage in a flood plain relates to the cumulative effect of depth, duration and velocity hazards measured over a long period of time. This will very often, but not exclusively, influence decisions on planning permission, especially if the hazard can be measured in quantitative terms. Cumulative frequency of occurrence of the various hazards is a consideration that farming communities throughout the world have always taken into account, usually on the basis of experience and intuitive reasoning, as they decide the type and intensity of agricultural or livestock farming to employ in regions susceptible to floods.

f) *Seasonality of flood* vis-à-vis inundation of land during a growing season can have a completely destructive effect on agricultural production. Seasonality in large floods is therefore an important influence on severity of flood hazard.

6.3 Environmental impact

It is well understood that the flood problem in sub-Himalayan Jalpaiguri district is a natural process that cannot be stopped. Contemporary flood disaster of Jalpaiguri is essentially man induced. The following processes are in fact responsible for increasing frequency and magnitude of flood disaster (figure 6.1):

- Degradation in catchment area
- Construction of unplanned and wanton embankments
- Filling up of wetlands/depression for the extension of agriculture &settlement
- Encroachment of river valley
- Converting dormant/seasonal/paleo-channel into arable and/or settled area

Flood, like many other natural processes have many beneficial effects on the economy and environment. The traditional flood protective measure (embankment) deprived North Bengal to receive beneficial effects at the one end and accelerates the darker side of flood (aggradations, bank failure, avulsions) at the other end.

The detrimental effect of embankment in controlling flood hazard has been demonstrated globally and it is proved to be counter productive. In North Bengal the NBFCC constructed 747 km long embankments in Jalpaiguri, Darjeeling and Koch Bihar districts in the name of flood protection. It could protect 870 sq. km area at the cost of 5400 sq. km area brought under threat of flood hazard in Jalpaiguri, Koch Bihar and Darjeeling district.

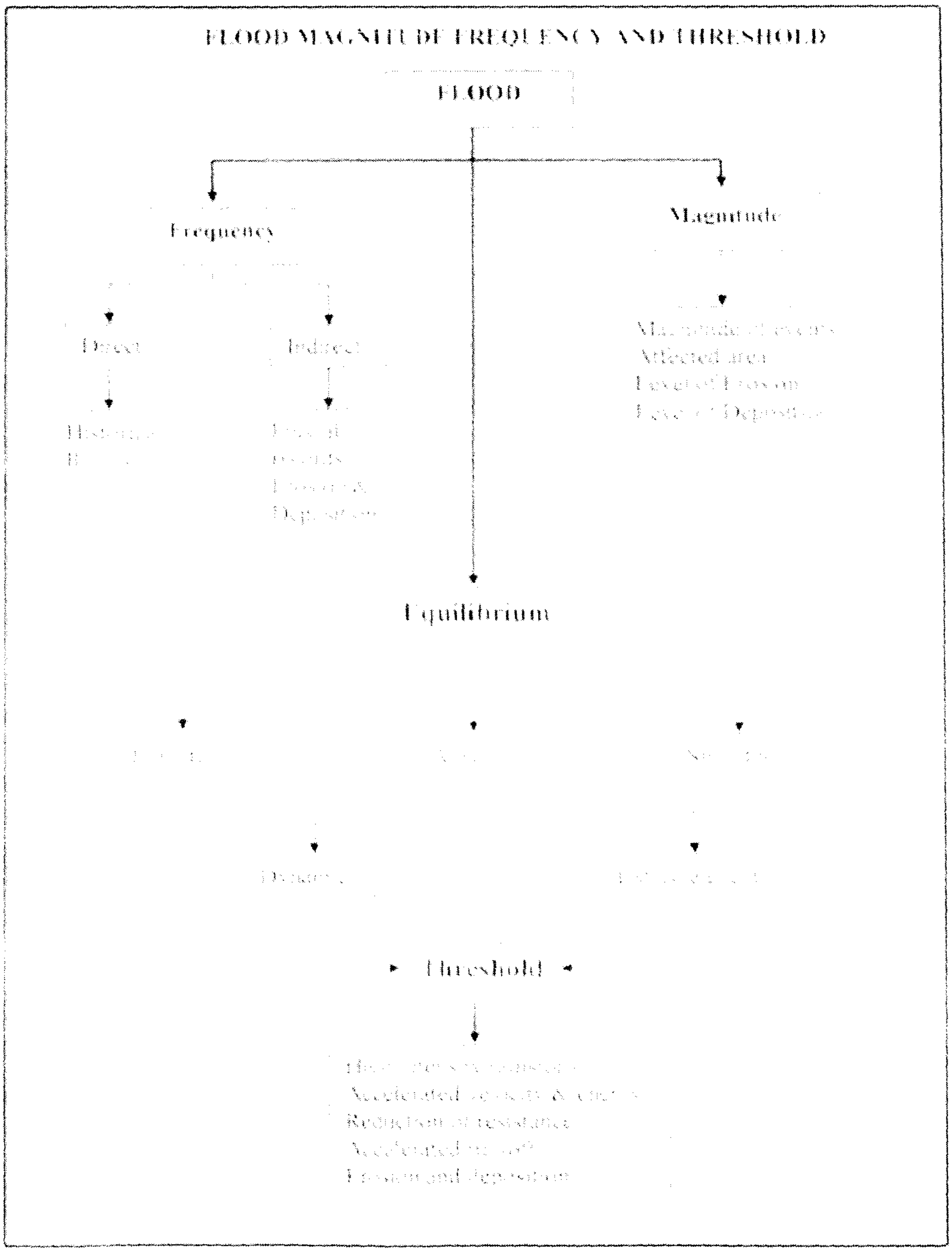

Figure 6.1 Increasing flood frequency and magnitude

Following are the major effect of embankment on the fluvial dynamics of sub-Himalayan rivers:

- Aggradation vis-à-vis rising of riverbed at an alarming rate and in many cases river bed are now higher than the ground level inducing avulsion.

- Providing false security among the local inhabitants and instrumental for large scale human settlement in the river valley e.g., between embankment and active channel.

- Responsible for making the North Bengal's river more unpredictable

6.3.1 Rising of river bed

During monsoon, high intensity rainfall induces innumerable landslides and mass movements, which transport huge amount of loads from the upper catchment to the rivers, which are incapable of transporting the load efficiently under the existing hydrological conditions. Thus, the river beds are rising at many places, resulting in the lessening of cross sectional areas, which being incapable of arresting the unusual monsoonal discharge can cause devastating floods, endangering the vital lines of communications, human habitation, firm lands, forest stands and wild life (photo 6.1 &6.2). During the period 1984 to 2006, the river beds of most of the rivers along the Himalayan margins got elevated significantly (Sarkar S., 2008). The amount of elevation at various locations of these rivers is given in table 6.1

Table 6.1 Rising of river beds(in metre) during the period 1984 – 2006*

Rivers	*Rising of bed level*	*Location of measurement*	*Period of measurement*
Torsa	0.900	NH 31 Bridge, Madarihat	1985-2005
Sankosh	0.800	NH 31 Bridge	1987-2003
Balason	1.124	Near Matigara Tea Garden	1984-2006
Mahananda	1.980	NH 31 Bridge, Champasari	1984-2006
Kaljani	1.310	Near Alipurduar	1992-2002
Lish	2.490	Bagrakot	1982-2004
Gish	1.980	Odlabari	1982-2004
Diana	2.012	NH 31 Bridge	1990-2005
Rethi	2.410	Near Chamurchi	1990-2003
Dima	1.800	Near Rajabhatkhowa	1991-2003
Bala	2.145	Near Santalabari	1991-2003
Jainti	3.050	Jainti	1991-2003
Pagli	2.540	Near Makrapara	1993-2003

* *Based on Sarkar S., 2004a; 2007; 2008.*

Photo 6.1. Embankment accelerates river deposition vis-a-vis rising of river bed at the Gish valley near Odlabari.

Photo. 6.2 Embankment induced river bed rising at the Bala valley near Santalabari.

6.3.2 Bank failure and enlargement of river valley

Rising of river beds often invites devastating bank failure. Field study reveals that massive bed material deposits on the Lish, Jainti, Pagi, Bala, Rethi, Diana and Dima during the flood of 1993 and 1998 caused massive bank failure in these rivers at a distance of about 1 to 10 km from the Himalayan margin (photo 6.3 &6.4). Such bank failure often cause addition burden of silt load to the river. The study on the 1993 flood in the river Jainti revealed that such deposit amounts over 150,000 cubic meters of materials into the river bed, within a stretch of 950 metres near Jainti.

Photo 6.3 Bank failure along the Torsa valley near Satali

Photo 6.4 Bank erosion along the Bala valley in Buxa Tiger Reserve

River valley widening is another significant manifestation of the devastating flash flood in the sub-Himalayan Jalpaiguri district. Study on the river Jainti, Dima, Bala, Pana etc. since 1993 revealed that such increase in some sections is as high as 250% during the last 8 years (Sarkar S., 2008). Comparative analysis of old Topographic maps and recent Satellite imageries show that most of the small and medium rivers in this area expanded as much as two to three times in their valley width during the last 100 years (photo 6.5 &6.6). There is every possibility to form a coalesceing mega-valley within next 50 years in the event of an extreme event like very high intensity rainstorm followed by flash flood of great magnitude.

Photo 6.5 Enlargement of valley due to massive deposition along Dima valley.

Photo 6.6 Enlargement of valley of river Titi near Totopara

6.3.3 River shifting vis-à-vis migration

Rising of riverbeds and bank failures often culminates into the shifting of rive course. Many rivers of this region demonstrate such shifting of which the Torsa, Tista, Jaldhaka, Jainti, Chel, Daikhowa, Jhumur, Daina, Rethi, Pana etc. are noteworthy during the recent past. Such shifting often cause devastation to the arable lands, forest stand, settlements and communication lines.

6.3.4 Loss of forest resources and biodiversity

One of the most important direct loss caused by the unscientific and illegal mining activities in the Sub-Himalayan Jalpaiguri and adjacent Bhutan is the destruction of Jalpaiguri`s rich forest, the best in West Bengal. Recent study conducted by the author reveals, that in between 1993 to 1999, 850 hectares of good forest land was destroyed either by bank failure or by shifting river courses. Over 2 million trees were destroyed – the market price for which are approximately 15,000 million rupees (photo 6.7 & 6.8).

Huge dolomite dust transported by air and river water accumulates on the forest floor, and rises the pH value of the soil (pH 7.5 to 8.1 recorded near Jainti by the author). Alkalinity of the soil hinders the availability of phosphate to the plants. Non availability of phosphate along with alkalinity is found to be responsible for dying of valuable timber especially Sal around Santalabari-Jainti area.

Survey during 1999, reveals that over 5000 trees were dead around Santalabari-Jainti. In addition to this, dolomite dust is also found to be responsible for the destruction of undergrowth rich bio diversity of this area (photo 6.9 & 6.10). This also exerts detrimental effects on the wild life of this region. Shifting of river courses like Jainti, has also destroyed rich bio diversity of this region. It also affects the animal migration. Moreover calcium richness in the fodder and drinking water may cause health hazard to the wild life (Sarkar S, 2004a).

Photo 6.7 Remnants of once dense forest in Buxa Tiger Reserve near Jayanti

Photo. 6.8 Remnants of once dense forest in Reti Reserve Forest near Deklapara, Birpara

6.4 Economic impact

During monsoon, high intensity rainfall induces devastating floods in sub-Himalayan North Bengal causing large damage to the environment, society and the economy in addition to loss of animal and also human lives. Floods also endanger the vital lines of communications and installations, human habitation, firm lands, forest stands and wild life. From the point of view of economic sense the loss was huge and unimaginable and so far no attempt has been made to make an economic cost assessment of flood hazard in sub-

Himalayan Jalpaiguri district. The assessment made by the investigator has been presented in the following sections.

Photo 6.9 Dying Sal tree in Buxa Tiger Reserve, due to deposition of dolomite at Bala valley near Santalabari in 1999.

Photo 6.10 Remnant of once gregarious Sal tree in Buxa Tiger Reserve, in 1996

6.4.1 Loss of tea gardens

Tea gardens of Jalpaiguri and Darjeeling districts are also threatened by flood disaster. In between 1993 to 1999, about 75 hectares of tea garden land was lost forever due to bank failure and floods (photo 6.11). Accumulation of calcium on the tea garden soil has detrimental effects both in terms of productivity and quality. Productivity is decreasing in many tea gardens and the quality is also deteriorating. This has already posed a serious threat to the tea export market. Moreover, such contaminated tea may cause serious health hazards to the consumers. The situation is worst in Makrapara tea garden which lost its 75% of plantation area and 80% of productivity during the past 10 years.

Photo. 6.11 Massive erosion of Rajabhat Khawa Tea Garden near Kalchini

6.4.2 Impact on agriculture

Due to large scale sedimentation in the foot hill regions destroy the arable land. In the study area shifting of river causes are very normal phenomena, many rivers of the district shifted their channels several times which ultimately destroy the vast tract of arable land. Another important sector is widening of the river valleys, sometimes coalesces of the river valleys destroyed the arable land. It also degrades the soil due to unlimited release of dolomite through the air and water accumulation of calcium on the soil surface. This increase the pH value of the soil and makes the soil fertile to sterile.

The largest economic flood-related losses are in the agricultural sector. Obviously most losses to agriculture result from the drowning of crops. Susceptibility to drowning depends on the type of crop and duration of flooding. Some are quickly killed by a relatively small amount of superfluous water. Others can resist as much as a few days of submersion. Even crops that thrive on large amounts of standing water will be killed if the water stagnates as in Koch Bihar district example. Other agricultural losses occur in the submersion of crop storage facilities. Grains and other crops will quickly spoil if saturated with water, even for a short time. An additional negative impact on the agricultural sector is the erosion of topsoil by the floods. Here the impact is indeed long term, resulting in the reduced productivity of the land and possibly eventual abandonment.

Flooding, however, is not all bad. For some agricultural areas flooding is a positive and necessary event. These lands depend on the periodic silt deposits for added nutrients to the soil. Flooding also serves other advantages including the filtering or dilution of pollutants that enter the waterways, flushing of nutrients in river systems, preserving of wetlands, recharging of groundwater, and maintaining of river ecosystems by providing breeding, nesting, feeding and nursery areas for fish, shell fish, migrating waterfowl and others.

6.4.3 Loss of land and property

Floods of Jalpaiguri district are very erratic in nature where heavy rainfall of short duration in the upper catchment and the lower catchment of the rivers causes huge discharge of the water in the rivers. Which ultimately breached the protection structures like embankment and spurs etc. and inundate the forests, arable land and thickly populated areas suddenly, this sudden floods create huge loss for agricultural land, tea garden, houses, livestock and property.

6.4.4 Impact on health

In floods, deaths usually exceed injuries. Surgical needs are low and are generally only during the first 72 hours. Floods may create conditions that promote secondary threats of water borne and vector borne diseases. A slight increase in deaths from venomous snake bites has been reported but not fully substantiated.

In sub-Himalayan Jalpaiguri district dolomite dust and its accumulation through flood water in the foothill area is causing serious health hazard to the local people through the contamination in water, air and food. Study reveals that the incidence of kidney stone is found two times more among the people residing in Jainti-Rajabhatkhawa-Chamurchi-Birpara-Makrapara-Lankapara area.

6.4.5 Deterioration of surface and sub-surface water quality

Flood water also carry large amount of dolomite dust dissolving calcium to the river water and thereby deteriorating water quality of these rivers. This has destroyed the aquatic diversity of these rivers. Deforestation also alters the soil water relationship dramatically. It reduces the `lag time` significantly and increases surface run-off and thereby the probability of floods. Dissolved calcium also moves through the subsurface through the soil pores and thereby deteriorates the quality of sub-surface water.

6.4.6 Deterioration of soil quality

Unlimited release of dolomite through the air and water cause accumulation of calcium on the soil surface. This increases the pH value, which have detrimental effects to many traditional crops, especially tea. In some extreme cases calcium crust may also develop and thereby, once fertile soil may turn sterile.

6.4.7 Impact on built-up area

The following are the major identifiable impact of flood disaster on built-up areas including housing or other small buildings in rural settlements in sub-Himalayan Jalpaiguri district:

i) Houses washed away due to the impact of the water under high stream velocity. The houses are commonly destroyed or dislocated so severely that their reconstruction is not feasible.

ii) Flotation of houses caused by rising waters. This occurs when light-weight, typically wood houses are not securely anchored. They can be removed too far from their foundations for relocation and repair.

iii) Damage caused by inundation of house. The house may remain intact and on its foundation, but the water damage to materials may be severe. Repair is often feasible but may require special procedures to dry out properly.

iv) Undercutting of house. The velocity of the water may scour and erode the house's foundation or the earth under the foundation. This may result in the collapse of the house or require substantial repair.

v) Damage caused by debris. Massive floating objects such as trees and other houses may impact on standing houses and cause significant damage.

Photo 6.12 Destroyed Jainti bridge during 1993 Alipurduar flood

Photo 6.13 Large scale destruction caused by floods of 1998 in Alipurduar

6.4.5 Impact on development

Increased magnitude and frequency of flood occurrences in sub-Himalayan North Bengal have had significant effect on the long-term economic growth of the affected region. Indirect and secondary effects on the local and national economy include reduction in family income, decline in the quality and quantity of tea production, unemployment, increase in income disparities, and decline in income. In addition, relief and reconstruction efforts often compete with development programs for available funds (photo 6.12 & 6.13).

The loss of crops and the need to find alternate sources of income have often caused small-scale migrations of farmers and skilled workers from the area to different states of India. Small marginal farms usually cannot survive economically following a major flood. Farmers are often forced to sell their land because they cannot afford to rehabilitate it. This may result in a substantial increase in the number of people migrating to urban areas, and thus a related housing shortage.

6.5 Conclusion

During monsoon, high intensity rainfall induces devastating floods in sub-Himalayan North Bengal causing large damage to the environment, society and the economy in addition to loss of animal and also human lives. Floods also endanger the vital lines of communications and installations, human habitation, firm lands, forest stands and wild life.

Foothill region of this district is traversed by numerous small streams which may be characterized by a common phenomenon, called avulsion i.e. changing river course. Huge sediment load carried by these streams gets deposited in this zone causing deterioration of channels day by day. The area being very rich in forest land, tea garden etc. suffers heavy losses every year due to these sand and chemical deposits from flood water.

Flood situation of the blocks of Alipurduar-I, Alipurduar-II, Kumargram, Nagrakata, Dhupguri, Madarihat, Falakata, Kalchini lying to the left of the river Jaldhaka is very acute. The rivers Kaljani, Torsa, Raidak etc. cause flood through numerous streams descending from Bhutan hills which are very much flashy in nature. National Highway and Railway bridge opening of waterways are also not adequate enough to cater to such flood discharges. The area needs to be given special emphasis since it is very rich in natural resources of forest and tea gardens.

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Chapter VII: Flood Hazard Assessment

7.1 Introduction

Bank failure, river shifting and river deposition in association with high intensity rainfall induced flash flood in the Himalayan forelands in Jalpaiguri district of North Bengal are primarily nature's way of adjusting fluvial dynamics. Such an adjustment has been deleteriously distributed by the human interferences. The catchments of the rivers like Diana, Khanabati (Rethi-Dimdima), Pagli, Sukriti, Pana, Kaljani, Dima, Jainti, etc. have been seriously disturbed by various kinds of interferences.

As a result, during heavy and concentrated rainfall, catastrophic soil erosion and innumerable landslides are caused transporting huge amount of sediment to the rivers which are incapable of transporting the load efficiently under the existing hydrological conditions, especially along their lower reaches (Froehlich, W. Soja R. & Sarkar S. 2000). The situation has aggravated further due to quarrying activities in some places. Riverbeds are rising at many sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing devastating floods, bank erosion and avulsion (NBFCC, 1965).

Flash flood has not been an uncommon phenomenon in the region. But the frequency and magnitude of such events has increased many fold during the recent past. Such catastrophic events during 1968, 1993, 1998 & 2000 demonstrate the enormity of damage and ever-increasing threat to the society, economy and the environments (Starkel, L & Sarkar, S, 2002; Starkel et. al, 2008).

7.2. Assessment of cost of flood hazard

Cost of flood hazard is a specialized subject involving an assessment of its multi-dimensional effects. Such cost involves from the loss of individual's immovable properties, livestock, crops etc. area measurable unit and also involves agony, sufferings and even human life constitute a part of the cost which is not simply measurable. Destruction of virgin forests due to flood have had an unimaginable environmental cost. In fact, such a loss along with its priceless biodiversity can never be measured in terms of money. Thousands of years nature's process culminate into a virgin forest and under no circumstances it can be reverted. Flood induced course debris deposition on fertile flood plain often convert the once fertile arable area into barren and wasteland which have had tremendous downstream effect in terms of socio-economic arena of the affected area. Similarly, the accumulation of dolomite in the soil of duars contiguous to Bhutanese territory has already made irreparable damage to the soil with a cascading effect on biodiversity as well as agro-ecosystem of sub-Himalayan Jalpaiguri district. Such an effect is not measurable rather adjustable at the cost of high level technical skill with adopting capability of the stakeholders.

An attempt has been made in this chapter to assess the cost/impact of flood hazards in sub-Himalayan Jalpaiguri district. Data for such an assessment has mostly been accessed from secondary sources (Sarkar, 2007; 2008 & WAPCOS, 2003).

7.2.1. Assessment of environmental cost

During monsoon, high intensity rainfall induces innumerable landslides and mass movements, which transport huge amount of loads from the upper catchment to the rivers, which are incapable of transporting the load efficiently under the existing hydrological conditions. Thus, the river beds are rising at many places, resulting in the lessening of cross sectional areas, which being incapable of arresting the unusual monsoonal discharge can cause devastating floods, endangering the vital lines of communications, human habitation, firm lands, forest stands and wild life. The following are the specific impacts:

7.2.1.1 Rising of river bed

A detail account on the rising of river bed during the period between 1984 to 2006, due to flood induced aggradations has been made in chapter VI and shown in table 6.1. It is observed that most of the rivers of sub-Himalayan Jalpaiguri district exhibit an abnormal rise in their respective bed. The large transient rivers like Tista, Torsa, Sankosh show a rise between 0.8 to 1.0 meter. While, the river originating from lower Darjeeling and Bhutan hills exhibited much higher rate of rise. The river Jainti, Pagli, Lish, Rethi, and Bala recorded a rise of 3.05, 2.54, 2.49, 2.145 and 2.012 meter respectively. In fact the watershed of these rivers are situated along the southern slope of rising Himalayan frontier and acts like a barrier to the rain bearing south west monsoon and yielded heaviest rainfall of the region. As a result, innumerable landslides are caused to transport to huge materials during high intensity rainstorm induced flood (Sarkar, 2007, 2008).

The mining activities in Bhutan also produce huge quantity of loose materials on the slope. During monsoon, high intensity rainfall induces innumerable landslides and mass movements, which transport huge amount of loads from the upper catchment to the rivers, which are incapable of transporting the load efficiently under the existing hydrological conditions. Thus, the river beds are rising at many places, resulting in the lessening of cross sectional areas, which being incapable of arresting the unusual monsoon discharge can cause devastating floods, endangering the vital lines of communications, human habitation, firm lands, forest stands and wild life (Sarkar, 2004).

7.2.1.2 Bank failure and avulsion

Rising of riverbeds often invites devastating bank failure. Field study reveals that massive bed material deposits on the Lish, Jainti, Pagle, Bala, Rethi, Diana and Dima during the flood of 1993 and 2003 caused massive bank failure in these rivers at a distance of about 1 to 10 km from the Himalayan margin. Such bank failure often cause addition burden of silt load to the river. The study of the 1993 flood caused deposits over 150,000 cubic meters of materials into the river bed (Sarkar, 2004). The study on the river Pagli, near Lankapara shows that over 75 million cubic meter debris was deposited along a stretch of 6.5 kilometer in between the year 1993 and 2000 (WAPSOS, 2003).

Rising of riverbeds and bank failures often culminates into the shifting of river course. Many rivers of this region demonstrate such shifting of which the Jainti, Chel, Dima, Bala, Daikhowa, Jhumur etc. are noteworthy. There exist innumerable evidences of avulsion and river metamorphosis in old maps and records.

The first recorded disastrous flood of this region occurred in 1787. It caused dramatic changes to the river Tista, which used to flow into the Ganga, deserted its channel and emptied itself into the Brahmaputra through an ancient spill channel (Dhar O.N., Nandargi S., 2000). Numerous deserted riverbeds of the Tista, Torsa, Sankosh, Raidak and Jaldhaka bear the testimony to the fact that the river changed its course at ease often in consequence of heavy rains in the following years.

Historical documents on the floods and flood-induced avulsion of the sub-Himalayan rivers viz., Allen B.C. et. al, 1906; Dash, A.J., 1947; Gruning, J.F. 1911; Imperial Gazetteer,1909; Rennel,1779; Mitra,1964; Sanyal,1969 etc. are numerous and fascinating. Record reveals that up to 1787, the river Tista and Karotoya were the same river that flowed through the Atrai-Punarbhaba into the Ganga. Neotectonic activity coupled with high intensity rainfall induced flash-flood caused massive shifting of the river. The so-called whale backed subsurface ridge of the Baikanthapur-Fulbari became active and the Tista migrated eastwards bifurcating the river Karotoya.

7.2.1.3 Enlargement of river valley

River valley widening is another significant detrimental effect of degradation in the upper catchment especially in the Bhutan Himalaya. Comparative analysis of old Topographical maps and recent Satellite imageries show that most of the small and medium rivers in this area expanded as much as three times in their valley width during the last 100 years. Field measurement by the NBFCC also reveals that the valley width of the sub-Himalayan small and medium rivers i.e., Jainti, Dima, Bala, Pana, Basra, Turturi and Buxa Jhora increase by 250% during the period of 1992-2010. There is every possibility to form a number of coalesceing mega-valley in near future i.e., (i) Lish-Gish-Chel mega-valley; (ii) Jaldhaka-Diana-Kuji Daina-Gatia mega-valley; (iii) Pagli-Titi-Sukriti mega-valley; (iv) Dima-Bala mega-valley; (v) Pana-Basra mega-valley etc.

7.2.1.4 Forest and biodiversity

One of the most important direct environmental cost caused by the heedless degradation in the upper catchment in the sub-Himalayan Jalpaiguri and adjacent Bhutan is the destruction of rich natural forest - the biodiversity hotspot at Global scale. Between 1993 to1999, 850 hectares of good forestland was destroyed either by bank failure or by shifting river courses. Over 2 million trees were destroyed – only the market price of lost timber was approximately 15,000 million rupees.

Dolomite dust transported by overland flow and river accumulates on the forest floor, are found to be responsible for the destruction of undergrowth vis-a-vis biodiversity and health hazard to the wild life. Alkalinity of soil hinders the availability of phosphate to the plants ultimately leads to death of over 5000 Sal trees at Jainti & Santrabari during 1998-2000 (Sarkar, S, 2008).

7.2.2 Assessment of economic cost

It is rather difficult if not impossible to assess the economic cost of flood hazards. This is especially true in case of Jalpaiguri district where frequent flood of different dimensions affect a wide range of economic activities. An attempt has been made in the following sections to assess the economic cost of some of the recently occurred flood hazard in Jalpaiguri district.

7.2.2.1 Loss of tea gardens

In between 1993 to 1999, 75 hectares of tea garden land was lost forever due to bank failure and floods. In monitory terms this amounts to 1,500 million Rupees. And between 2000 to 2010 another 54 hectares of tea garden land was lost forever due to bank failure and flood induced accumulation. Makrapara tea garden situated in Bhutan border has been assessed as the worst affected. Over 65% of its total area is affected and production also reduced by 60% in 1980s.

Accumulation of calcium on the tea garden soil has detrimental effect both in term of productivity and quality. Productivity is decreasing in many tea gardens and the quality is also deteriorating.

7.2.2.2 Deterioration of water & soil quality

Dolomite and calcium rich river water is destroying the aquatic diversity and also deteriorating water quality. Dissolved calcium also moves into the subsurface through the soil pores and thereby deteriorates the quality of sub-surface water.

Unregulated release of dolomite causes accumulation of calcium in the soil. This increases the pH value that has detrimental effects to many traditional crops including tea. In some extreme cases calcium crust may also develop and thereby, once fertile soil may turn sterile.

7.2.2.3 Health hazard

Dolomite contamination in the Sub-Himalayan West Bengal and Bhutan cause serious health hazard to the local people. Study reveals that the incidence of kidney stone is two times more among the people residing in Jainti-Rajabhatkhawa-Chamurchi-Birkand-Makrapara-lankapura area.

7.3 Identification of vulnerable areas

For addressing the issue of flood management and anti-erosion programme one of the most important and immediate task is to identify the reaches which have already been attacked by the river during floods or are prone to get adversely affected in future. Implementation of any flood control measure would entail identification of such locations, possible causes of failure and a set of viable solutions.

7.3.1 Identification of vulnerable river bank

Identification of vulnerable river bank involves the study of fluvial dynamics of the concern river section, past occurrences of failure along with the level of human interferences in the studied sections. WAPCOS in 2003 made a detail field survey and identify susceptible and/or vulnerable river banks of the river Tista in Jalpaiguri district (table 7.1).

The vulnerable sites have also been plotted in map (figure 7.1). It is observed that the tributary streams of the Tista system at the debauching point have a tendency of eroding its bank and also under the continuous filling up of channel beds as a result flooding becomes an annual feature. However, along the extreme south of the district near its confluences vast sheet of water engulfed vast tracts under prolonged inundation. Nine vulnerable sites have

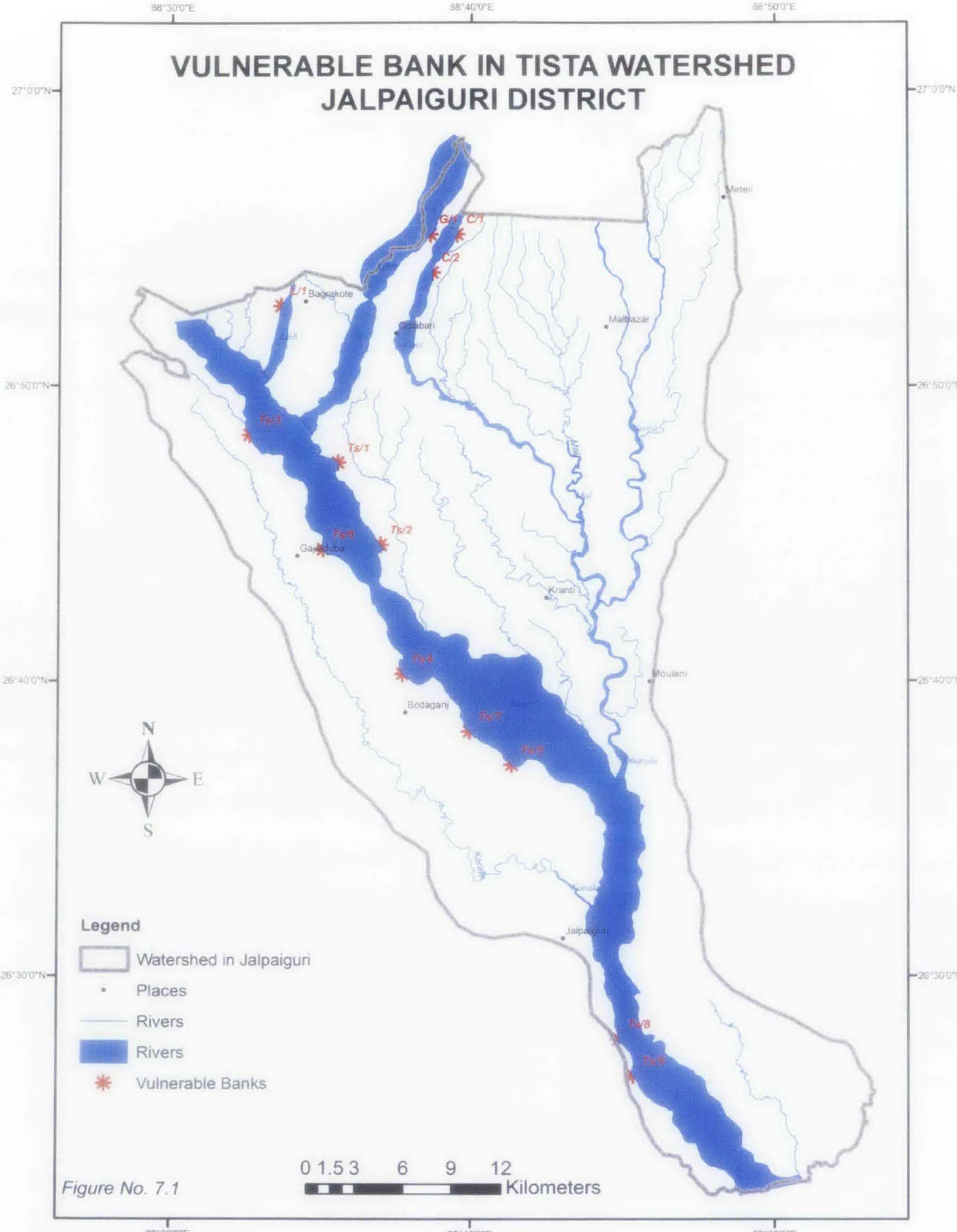

VULNERABLE BANK IN TISTA WATERSHED
JALPAIGURI DISTRICT
88°30'0"E
88°40'0"E
88°50'0"E
27°0'0"N
26°50'0"N
26°40'0"N
26°30'0"N
Meteli
G/1
C/1
C/2
L/1
Bagrakote
Odlabari
Malbazar
Ts/1
Ts/1
Ts/5
Ts/2
Gajoldoba
Kranti
Ts/4
Moulani
Bodaganj
Ts/7
Ts/6
N
W
E
S
Jalpaiguri
Ts/8
Ts/9
Legend
Watershed in Jalpaiguri
Places
Rivers
Rivers
Vulnerable Banks
0 1.5 3 6 9 12
Kilometers

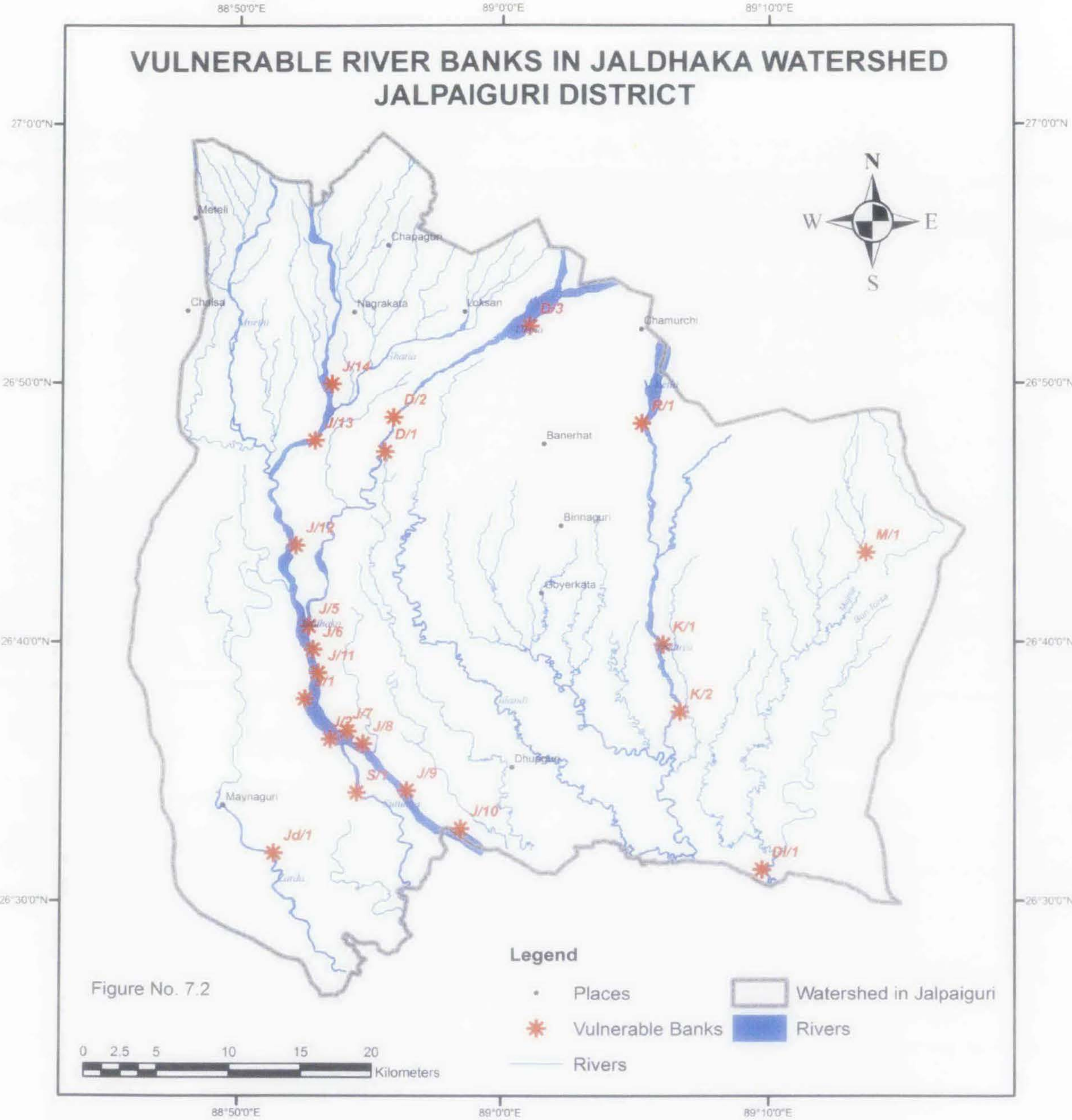
Figure No. 7.1

been identified along the both banks of the river Tista. A number of vulnerable sites have also been identified along the river bank of Lish, Gish and Chel.

Table – 7.1
Vulnerable zones in Jalpaiguri district along the Tista valley

SOI Ref.	*No.*	*River / Stream*	*Location*	*Remarks*
78 B/9	L/1	Lish	Bridge 1 km south of Weshabari	Regular maintenance of the guard wall required.
	G/1	Gish	Bridge 1 km east of Mynabari	Regular maintenance of the guard wall required.
	C/1	Chel	Bridge 2 km south east of Mynabari	Regular maintenance of the guard wall required.
	C/2	Chel	3 km southeast of Mynabari	Older channel may rejuvenate at any time.
78 B/10	Ts/1	Left bank of Tista	Adjacent to Apalchand Forest	Main flow towards the left bank canal of Tista Barrage
	Ts/2	Left bank of Tista	Adjacent to Changmari Reserve Forest	Course/flow may be straightened.
	Ts/3	Left bank of Tista	2 km north east of Baikunthapur	Presently river flowing along the embankment which may be affected during high discharge.
	Ts/4	Right bank of Tista River	Adjacent to Raipur Tea Garden	Embankment may affected
	Ts/5	Right bank of Tista	½ km north of Paharpur	Embankment may affected
	Ts/6	Right bank of Tista	1 km east of Bodaganj	Embankment may affected
	Ts/7	Confluence of Chuchuka and Tista	Adjacent to eastern Jalpaiguri Town	Embankment may affected
78 B/11	Ts/8	Tista	In and around Mandalghat	River Tista may breach embankment during high discharge.
78 B/15	Ts/9	Tista	In and around Mandalghat	River Tista flows along the embankment may be affected during high discharge.

The vulnerable sites along the river Jaldhaka has been tabulated in table 7.2 and diagrammatically represented in figure 7.2. It is observed that the tributary streams of the Jaldhaka system at the debauching point have a tendency of eroding its bank and also under the continuous filling up of channel beds as a result flooding becomes an annual feature.



VULNERABLE RIVER BANKS IN JALDHAKA WATERSHED
JALPAIGURI DISTRICT
88°50'0"E
89°0'0"E
89°10'0"E
27°0'0"N
26°50'0"N
26°40'0"N
26°30'0"N
N
W
E
S
Meteli
Chapaguri
Chalsa
Nagrakata
Luksan
Chamurchi
Banerhat
Binnaguri
Gayerkata
Dhupguri
Maynaguri
D/3
J/14
D/2
R/1
J/13
D/1
J/12
M/1
J/5
J/6
K/1
J/11
K/2
J/7
J/8
S/1
J/9
J/10
Jd/1
Dl/1
Legend
Places
Watershed in Jalpaiguri
Vulnerable Banks
Rivers
Rivers
0
2.5
5
10
15
20
Kilometers

Figure No. 7.2

However, along the extreme south of the district near its confluences vast sheet of water engulfed vast tracts under prolonged inundation. Over 13 vulnerable sites have been identified along the both banks of the river Jaldhaka. A number of vulnerable sites have also been identified along the river bank of Diana, Rethi, Khanabati, Mujnai, Jarda and the spill channel Satanga.

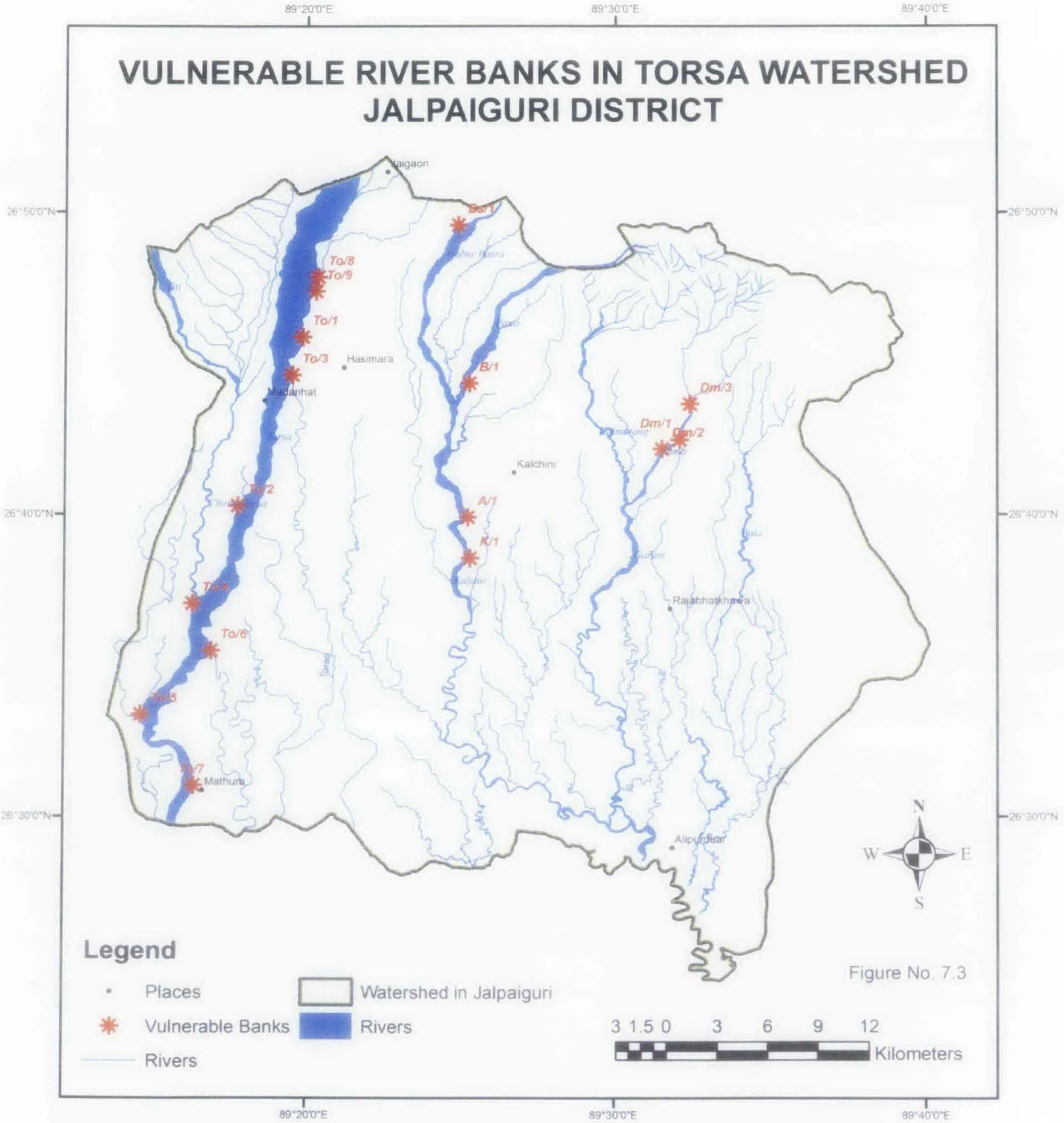
Table – 7.2

Vulnerable zones in Jalpaiguri district along the Jaldhaka valley

SOI Ref	***No***	***Rivers***	***Location***	***Remarks***
78 B/14	J/1	Jaldhaka	Right bank of river Jaldhaka and west of Purba Baragila	The river bank line is very near to embankment.
	J/2	Jaldhaka	Right bank of river Jaldhaka 1 km south of Betagara	Susceptible zone for bank failure, high discharge may affect the embankment.
	J/3	Jaldhaka	0.5km south of Dhawlaguri	The river bank line is very near to embankment.
	J/4	Jaldhaka	Right bank of river from south of NH-31 up to Kadamtali	Susceptible zone for bank failure, high discharge may affect the embankment.
	J/5	Jaldhaka	Left bank of river Diana adjacent to Jaldhaka Tea Garden upto Phataktari	Zone of bank failure, older channels may be activated during high discharge, embankment may totally be destroyed.
	J/6	Jaldhaka	Adjacent to Diana Reserve Forest, a linear zone along the left bank of Diana Nadi starting from Garialtari to Gadhayar Kuthi.	The abandoned spill channel may reactivate some water may pass out through Jhumar Nadi in December 1998 situation prevails.
78 F/3	J/7	Jaldhaka	South of Maguramari village and east of Jore Simuli	River flows along the embankment, may be affected during high discharge.
	J/8	Jaldhaka	Left bank of Jaldhaka	Abandoned spill channels may be reactivated during peak monsoon, also the embankment may be affected during high discharge
	J/9	Jaldhaka	Left bank of Jaldhaka River	River presently flows along embankment.
	J/10	Jaldhaka	Left bank of Jaldhaka near north west of Angarkataparoduti.	It may be reactivated and may affect the embankment during high discharge.
	J/11	Jaldhaka	South of Bhandani and the junction of Daukhawa Nadi	Older channel may be rejuvenated.

78 B/13	D/1	Diana	Left bank near about 1.5km north east of Ridaypur village	Rangati nala now being an active spill channel may inundate a large area during high discharge.
	D/2	Diana	Right bank of Diana, adjacent to Diana Reserve Forest.	Presently river flowing along the embankment which may be affected during high discharge.
	J/12	Jaldhaka	Left bank of river Jaldhaka south of Bamandanga.	Embankment may be affected during high discharge.
78 F/8	J/13	Jaldhaka	Near Takimari	Spill channel of Jaldhaka river, which is almost abandoned now, may be reactivated causing serious damage of the embankment.
78 F/2	J/14	Jaldhaka	North of Rangapani Balasi along the left bank of the Jaldhaka river.	Present course of river Jaldhaka flows along the embankment, which may be affected during high discharge
	K/1	Khanabati	East of Lakshipur	Due to shifting of river, some portion of adjacent road has been damaged.
	K/2	Khanabati	0.5km south of Kazipara	Road adjacent to the river may get affected during high flood situation.
	M/1	Mujnai	0.5km south of Rangali bazna	Road adjacent to the river may get affected during high flood situation.
78 B/15	Jd/1	Jarda	2 km south east of Panisala village	Jarda Nadi flows besides the road thus threatening it.
	S/1	Satanga	Adjacent to Baraghara village	A seasonally active spill channel joins with Satanga just at the point of intersection with the road.
78 F/1	Dl/1	Dharala	Left bank adjacent to Khengti village	Older channel may rejuvenate at any time.
	D/3	Diana	Left bank 2 km east of Red bank tea garden.	Bank failure zone along Diana river.
	Rt/1	Rethi	Elongated zone from Chamurchi to Riabari tea garden	Rehti khola flows along the embankment.

The vulnerable sites along the river Torsa has been tabulated in table 7.3 and diagrammatically represented in figure 7.3. It is observed that the tributary streams of the Torsa system at the debauching point have a tendency of eroding its bank and also under the continuous filling up of channel beds as a result flooding becomes an annual feature.


VULNERABLE RIVER BANKS IN TORSA WATERSHED
JALPAIGURI DISTRICT
89°20'0"E
89°30'0"E
89°40'0"E
26°50'0"N
26°40'0"N
26°30'0"N
Jaigaon
Hasimara
Madarihat
Kalchini
Rajabhatkhawa
Alipurduar
Mathura
To/8
To/9
To/1
To/3
To/2
To/6
To/5
To/7
B/1
A/1
K/1
Dm/1
Dm/2
Dm/3
N
S
W
E
Legend
Places
Vulnerable Banks
Rivers
Watershed in Jalpaiguri
Rivers
3 1.5 0 3 6 9 12
Kilometers
Figure No. 7.3

However, along the extreme south of the district near its confluences vast sheet of water engulfed vast tracts under prolonged inundation. Nine vulnerable sites have been identified along the both banks of the river Torsa. A number of vulnerable sites have also been identified along the river bank of Dima, Gabur Basra, Alikuri, Kaljani and Basra.

Table – 7.3

Vulnerable zones in Jalpaiguri district along the Torsa valley

SOI Ref	*No*	*River / Stream*	*Location*	*Remarks*
78 F/6	To/1	Torsa	Adjacent to Nilpara Reserve Forest	Though these points the Torsa may get rejuvenated but it may affect the Jaldapara sanctuary.
	To/2	Torsa	Adjacent to Jalapara Reserve Forest	
	To/3	Torsa	Left bank of Sil Torsa	Presently river flowing very close to the embankment which may be affected during high discharge.
	A/1	Alaikuri	Adjacent to Kalchini tea Garden, left bank of Alaikuri River	River Alaikuri is presently flowing along the embankment, which may get affected during high discharge.
	B/1	Buri Basra and River Kaljani Junction	Near Dakshin Mendabari	Buri Basra Badi may in future get connected/joined in Kaljani River at this point.
	Dm/1	Dima	Right bank of Dima adjacent to the Buxa Reserved Forest.	The shifting of the river course Dima towards west gradually eroding the Tea Garden.
	Dm/2	Dima	Right bank of Dima adjacent to the Buxa Reserved Forest	The shifting of the river course Dima towards west gradually eroding the Tea Garden.
78 F/7	To/4	Torsa	Right bank of Torsa, area between Chapaguri and Kalpani	It is a prominent bank failure zone, very close to the adjacent road, may cause a serious damage during high flood.

	To/5	Torsa	Right bank of Torsa, near Bheledanga and Ghugumari	Torsa presently flows along the adjacent roadway, which may cause damage during high flood situation.
	To/6	Torsa	Area of railway and roadway bridge on Torsa near Ghugumari.	This zone is a vulnerable zone due to abnormal trend of the curvature of Torsa, which may cause damage to the adjacent roadway and railway.
78 F/11	To/7	Torsa	Left bank of torsa near south of Taliguri and east of Ghargharian	Presently river flows along the embankment. Further eastward shifting of Torsa may affect the embankment Torsa may engulf the Ghargharia Nadi.
	Kj/1	Kaljani	Right bank of Kaljani near Maruganjhat	Further shifting of river banks may affect the adjacent road.
78 F/5	To/8	Torsa	East of Jaigoan Tea Garden	The rivers are affecting the adjacent Tea Garden and orchards.
	To/9	Torsa	Left bank of river Torsa and west of Dalsingpara Tea Garden.	Due to bank failure Dalsingpara Tea Garden may be affected in future as the river flows along the embankment.
	Bs/1	Barsa	Right bank of Basra Nadi adjacent to Gabur Basra Reserve Forest	The river flows presently along the embankment and already destroyed flow portion of the embankment.
78 F/9	Dm/3	Dima	Buxa will Reserve Forest.	Areas of active landslide

The vulnerable sites along the river Raidak has been tabulated in table 7.4 and diagrammatically represented in figure 7.4. It is observed that the tributary streams of the Raidak system at the debauching point have a tendency of eroding its bank and also under the continuous filling up of channel beds as a result flooding becomes an annual feature. However, along the extreme south of the district near its confluences vast sheet of water engulfed vast tracts under prolonged inundation.

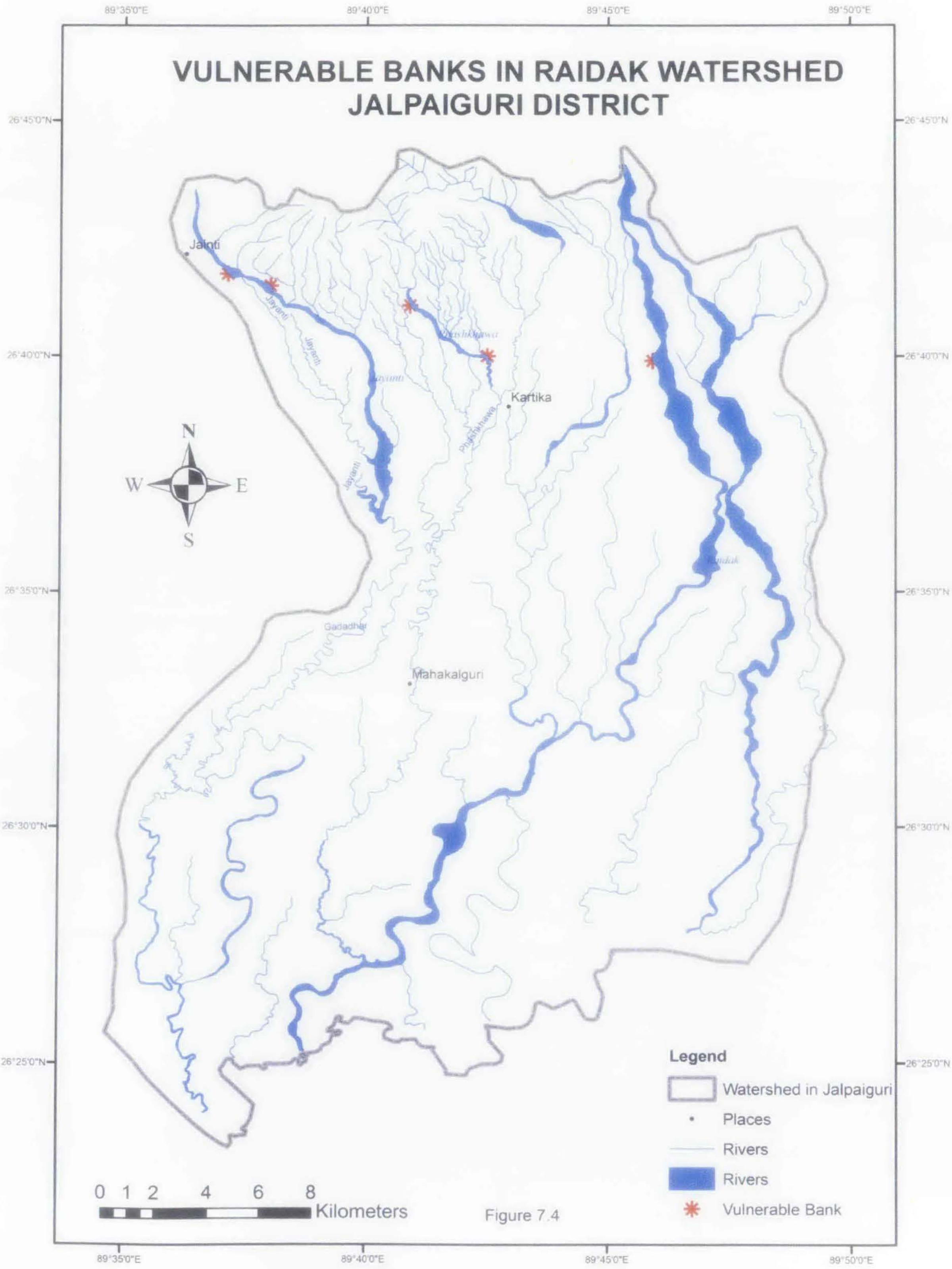

VULNERABLE BANKS IN RAIDAK WATERSHED
JALPAIGURI DISTRICT
89°35'0"E
89°40'0"E
89°45'0"E
89°50'0"E
26°45'0"N
26°40'0"N
26°35'0"N
26°30'0"N
26°25'0"N
Jainti
Jayanti
Kartika
Mahakalguri
Gadadhar
Raidak
N
E
S
W
Legend
Watershed in Jalpaiguri
Places
Rivers
Rivers
Vulnerable Bank
0 1 2 4 6 8
Kilometers
Figure 7.4

Table – 7.4
Vulnerable zones in Jalpaiguri district along the Raidak valley

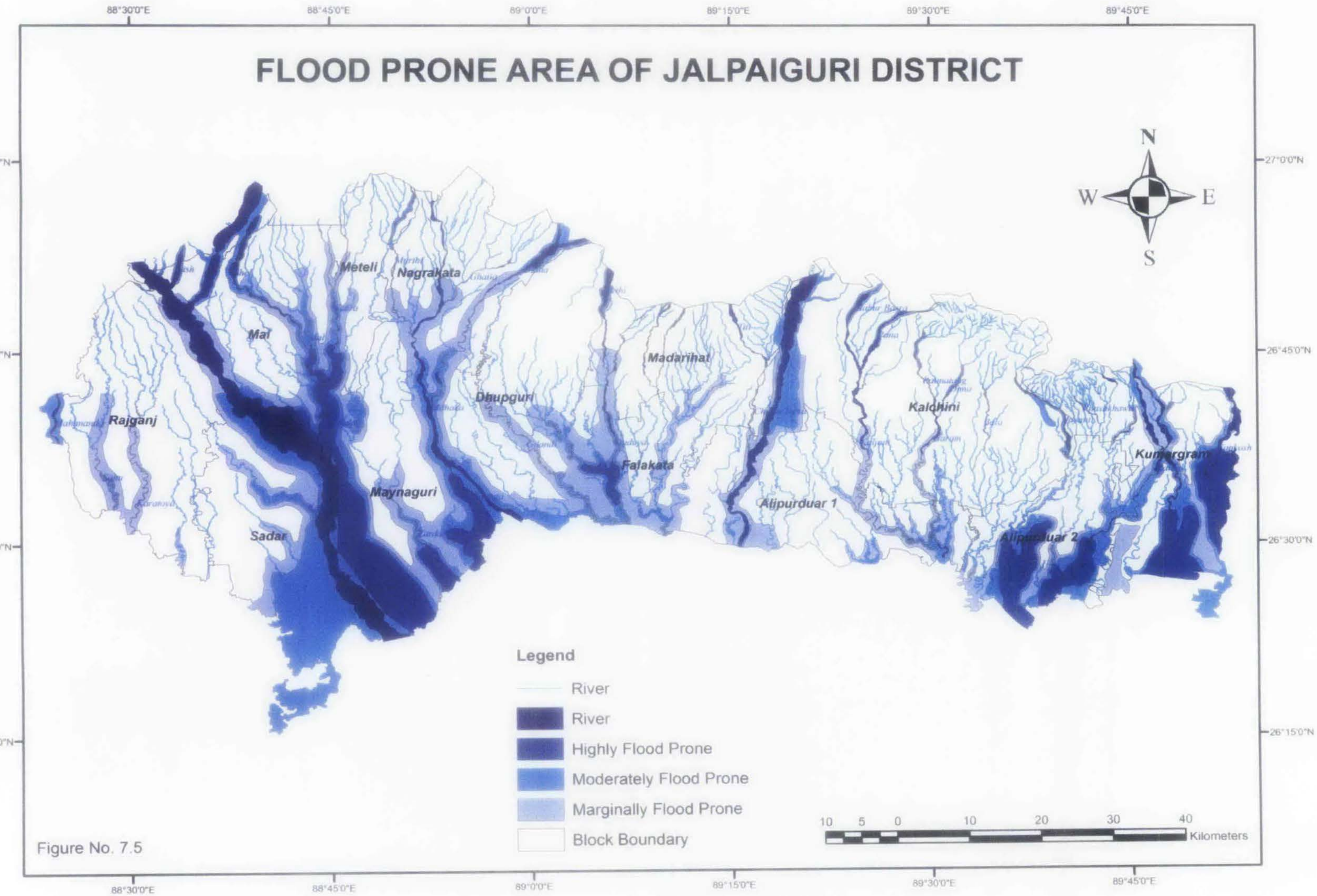
SOI Ref	*No*	*River / Stream*	*Location*	*Remarks*
78 F/14	R/1	Kulkuli Nala and Raidak river	1.5 km west of Chengmari	Older embankment has been eroded; road is presently being affected by Raidak -I. Kulkali Nadi is acting as a spill channel of Raidak river.
78 F/10	Jn/1	Jainti	North of Tapgaon Forest	River Jainti flows along the embankment presently, which may be affected during high discharge.
	P/1	Phaskhoa	Left bank of Jainti near Garokhutta	River almost engulfing the road.
	P/2	Phaskhoa	Adjacent to Kohinoor Tea Garden	River almost engulfing the road.
78 F/9	Jn/2	Jainti	North of Buxa Duar	River Jainti has eaten up considerable area of her high bank.

7.3.2 Identification of vulnerable area

In the previous section the vulnerable river banks have identified, assessed and maped for further analysis. An attempt has been made in this section to identify spatially flood hazard prone or vulnerable area in Jalpaiguri district. Such identification, characterization and mapping is of pre-requisite for any flood management plan. In fact, degree of management need depends on the degree of vulnerability including intensity, frequency and magnitude of probable flood disaster with defined return period. Vulnerability assessment of flood hazard in sub-Himalayan North Bengal has been carried out based on:

1. Magnitude and frequency of past flood occurrences
2. Nature of drainage conditions and
3. Terrain characteristics.

Survey of India topographical maps, satellite image and other secondary sources has been applied to assess the above mention vulnerability assessment parameters. The flood hazard vulnerability vis-à-vis flood prone map thus prepared is shown in figure 7.5. It is interesting to note that 35.91% of the total geographical area of Jalpaiguri district is flood prone. The flood prone area in Jalpaiguri district has been categorized into the following 3 broad categories:



FLOOD PRONE AREA OF JALPAIGURI DISTRICT
88°30'0"E
88°45'0"E
89°0'0"E
89°15'0"E
89°30'0"E
89°45'0"E
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N
N
S
W
E
Meteli
Nagrakata
Mal
Rajganj
Dhupguri
Madarihat
Kalchini
Falakata
Maynaguri
Sadar
Alipurduar 1
Alipurduar 2
Kumargram
Legend
River
River
Highly Flood Prone
Moderately Flood Prone
Marginally Flood Prone
Block Boundary
10 5 0 10 20 30 40
Kilometers

Figure No. 7.5

7.3.2.1 Highly flood prone area

These are the areas which are highly susceptible to disastrous flash floods and prolonged inundation causing massive devastation to the land and properties. A total area of 382.96 sq. km (6.15% of the total geographical area of the district) has been identified as highly flood prone (figure 7.5). Kumargram block was worst affected followed by Alipurduar 2, Maynaguri, Mal and Falakata. Among the rivers Sankosh, Raidak, Jaldhaka and the left bank of the river Tista inundate large tracts of country side almost every year during high intensity and prolonged rainfall in the catchments. Following areas have been identified under this category:

a) Raidak - Gadadhar interfluve
b) Torsa - Kaljani interfluve
c) Mansai - Torsa interfluve
d) Dhaula - Raidak interfluve
e) Jaldakha - Gilandi area
f) Changmari - Mekhliganj area
g) Jaldakha - Gilandi confluence area

7.3.2.2 Moderately flood prone area

These are the areas which are moderately susceptible to disastrous flash floods and prolonged inundation causing considerable loss of the land and properties. A total area of 888.61 sq. km (14.27% of the total geographical area of the district) has been identified as moderately flood prone (figure 7.5). Among the blocks Kumargram, Alipurduar 2, Sadar, Maynaguri, Mal, Falakata, Kalchini, Alipurduar 1, Rajganj, Sadar and Madarihat has been found affected. The following areas have been identified under the category of moderately flood prone:

a) Dhaula - Raidak interfluve
b) Reti-Pagli-Sukriti area
c) Duduya - Jaldhaka interfluve
d) Torsa - Kaljani interfluve
e) Barobhisa – Kumargram

f) Dima - Pana - Kaljani area
g) Dima - Jainti - Dharasi interfluves
h) Totopara area
i) Bagrakot - Odlabari area
j) Rangdhamali - Jalpaiguri - Haldibari area
k) Jaigaon - Hasimara area

7.3.2.3 Low to marginally flood prone area

These are the areas which are marginally susceptible to disastrous flash floods and prolonged inundation causing some degree of loss of the land and properties. A total area of 964.73 sq. km (15.49% of the total geographical area of the district) has been identified as moderately flood prone (figure 7.5). Almost every blocks of Jalpaiguri district fall under this category. However, the blocks Kumargram, Alipurduar 2, Alipurduar 1, Falakata, Dhupguri, Maynaguri, Sadar, Mal and Nagrakata blocks have been identified as more susceptible to flood hazard of different degrees. It is also interesting to note that almost every rivers flowing through Jalpaiguri district are found to be prone to cause flood. The following areas have been identified under the category of marginally flood prone area:

a) Neora - Chel interfluve
b) Duduya - Jaldhaka interfluve
c) Mara Torsa area
d) Dhaula - Raidak interfluve
e) Dima - Jainti - Dharasi interfluves
f) Mansai - Torsa interfluve
g) Raidak - Gadadhar interfluve
h) Kaljani - Dima area
i) Dhupguri - Falakata area
j) Birpara - Lankapara - Chamurchi - Makrapara area

7.3.2.4 Flood free zone

It is interesting to note that 64.09% of the total geographical area of Jalpaiguri district i.e., 3990.7 sq. km has been considered as normally flood free. However, in case of extreme event of massive, prolonged and widespread rainstorm as it was happened in 1968 many area hitherto identified as safe zone may also be affected by flood or similar kind of disaster. Out of the identified safe zone, 1.83% area has been identified as hilly area where topography itself is limiting factor for the probability of causing flood. The piedmonts (foot hills) zone covered another 7.5% of the identified safe zone within Jalpaiguri district. These are also topographically protective zone however it is observed that some isolated sections within this area have been suffered from bank failure induced flood hazard. The remaining 50% of the identified safe zone has been identified in alluvial fan and terraces. These are the area situated 5 to 10 meter higher than the active flood plain and are occupied by either natural forest or tea garden.

7.4. Conclusion

Bank failure, river shifting and river deposition in association with high intensity rainfall induced flash flood in sub-Himalayan Jalpaiguri district are primarily nature's way of adjusting fluvial dynamics in the sub-Himalayan North Bengal. Such an adjustment has been deleteriously distributed by the human interferences. The catchment area of these rivers has mostly been deforested and the clearings of the steep slopes have been used for the extension of settlement, agriculture, plantation and communication, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfall, catastrophic soil erosion and innumerable landslides are caused transporting huge amount of sediment to the rivers which are incapable of transporting the load efficiently under the existing hydrological conditions, especially along their lower reaches. As a result, the riverbeds are rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods.

Moreover, the narrow road and railway bridges across the rivers as well as the supporting pillars are always considered to be the barriers, interrupting natural load movement behavior of the rivers. This often cause accelerated deposition at the bottom of the bridge and thereby, narrowing the outlets of the rivers gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and firm lands.

Flash flood has not been an uncommon phenomenon in the North Bengal plains. But the frequency and magnitude of such events has increased many fold during the recent past. Such catastrophic events during 1968, 1993 &1998 demonstrate the enormity of damage and ever-increasing threat to the society, economy and the environments of North Bengal.

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Chapter VIII: Flood Hazard Management

8.1 Introduction

Disaster management requires multi-disciplinary and pro-active approach. Besides various measures for putting in place institutional and policy framework, disaster prevention, mitigation and preparedness enunciated in this paper and initiatives being taken by the Governments, the community, civil society organizations and media also have a key role to play in achieving the goal of moving together, towards a safer India. The message being put across is that, in order to move towards safer and sustainable development, development projects should be sensitive towards disaster mitigation.

The mission is vulnerability reduction to flood hazards, be it natural or manmade. This is not an easy task to achieve, keeping in view the vast population, and the multiple causative factors to which this region is exposed. However, if we are firm in our conviction and resolve that the society is not prepared to pay the price in terms of casualties and economic losses, the task, though difficult, is achievable (Sarkar S., 2008).

The proposed steps towards vulnerability reduction, putting in place prevention and mitigation measures and preparedness for a rapid and professional response. With a massive awareness generation campaign and building up of capabilities as well as institutionalization of the entire mechanism through a techno legal and techno-financial framework, we are gradually moving in the direction of sustainable development.

The various prevention and mitigation measures are aimed at building up the capabilities of the communities, voluntary organizations and Government functionaries at all levels. Particular stress is being laid on ensuring that these measures are institutionalized considering the vast population and the geographical diversity of the region. This is a major task for the implementing agencies to put in place mitigation measures for vulnerability reduction. The ultimate goal is to make prevention and mitigation a part of normal day-to-day life.

The flood hazard management in sub-Himalayan Jalpaiguri district may be discussed under the headings:

8.2. Short term area specific structural measures

A large variety of methods of engineering and non-engineering nature are under application around the world in mitigating flood disaster. At the global scale, the commonest form of flood mitigation measures includes channelization and detention facilities.

Channelization involves construction of open channels is a commonly used method of reducing the size of a floodplain or floodway. To prevent erosion, channels can be lined with grass, wire-enclosed rock, concrete, riprap or cobblestones placed a few layers deep. Open channels allow water to enter them at almost any point, thus compensating for inadequate tributary collection systems.

Detention facilities such as dams, store flood waters and release them at lower rates, thus reducing or eliminating the need for major downstream flood control facilities, the construction of which would disrupt the developed areas. Perhaps the greatest disadvantage of detention facilities, assuming a structurally sound facility, is the false sense of security that such structures create among the general public as they assume the detention facility has eliminated any flood hazard; that they are consequently totally unprepared for the possibility of a flood that exceeds the design capacity of the facility. An attempt has been made to outline some of the important measures adopted by different agencies to mitigate the impact of flood hazard in sub-Himalayan North Bengal.

Structural measure of flood hazard mitigation involves both engineered and non-engineered structures. These include construction of embankments, dykes, river channel re-shaping and river training etc. (NBFCC, 1965). However, before advocating for any comprehensive plan for hazard mitigation, it is imperative to evaluate the past structural measures adopted for mitigation of flood hazard. The following structural measures are adopted in sub-Himalayan North Bengal.

8.2.1 Embankment, dykes and bed-bars

Construction of marginal embankment along the bank of the river has been generally resorted to for preventing the floods from spilling its natural banks. This has been the easiest and quickest method of saving the land and people from the fury of floods. Though there has been a controversy about their feasibility, it still remains one of the favourite short term measures which can be implemented at the demand of the public (NBFCC, 1965). It is observed that embankments, dykes, spurs and bed-bars are most commonly used as structural measure adopted in the study area since 1954 devastating flood (figure 8.1). Flood, like many other natural processes have many beneficial effects on the economy and environment. The traditional flood protective measure (embankment) deprived North Bengal to receive beneficial effects at the one end and accelerates the darker side of flood (aggradations, bank failure, avulsion) at the other end (Sarkar, S. 2007; 2008).

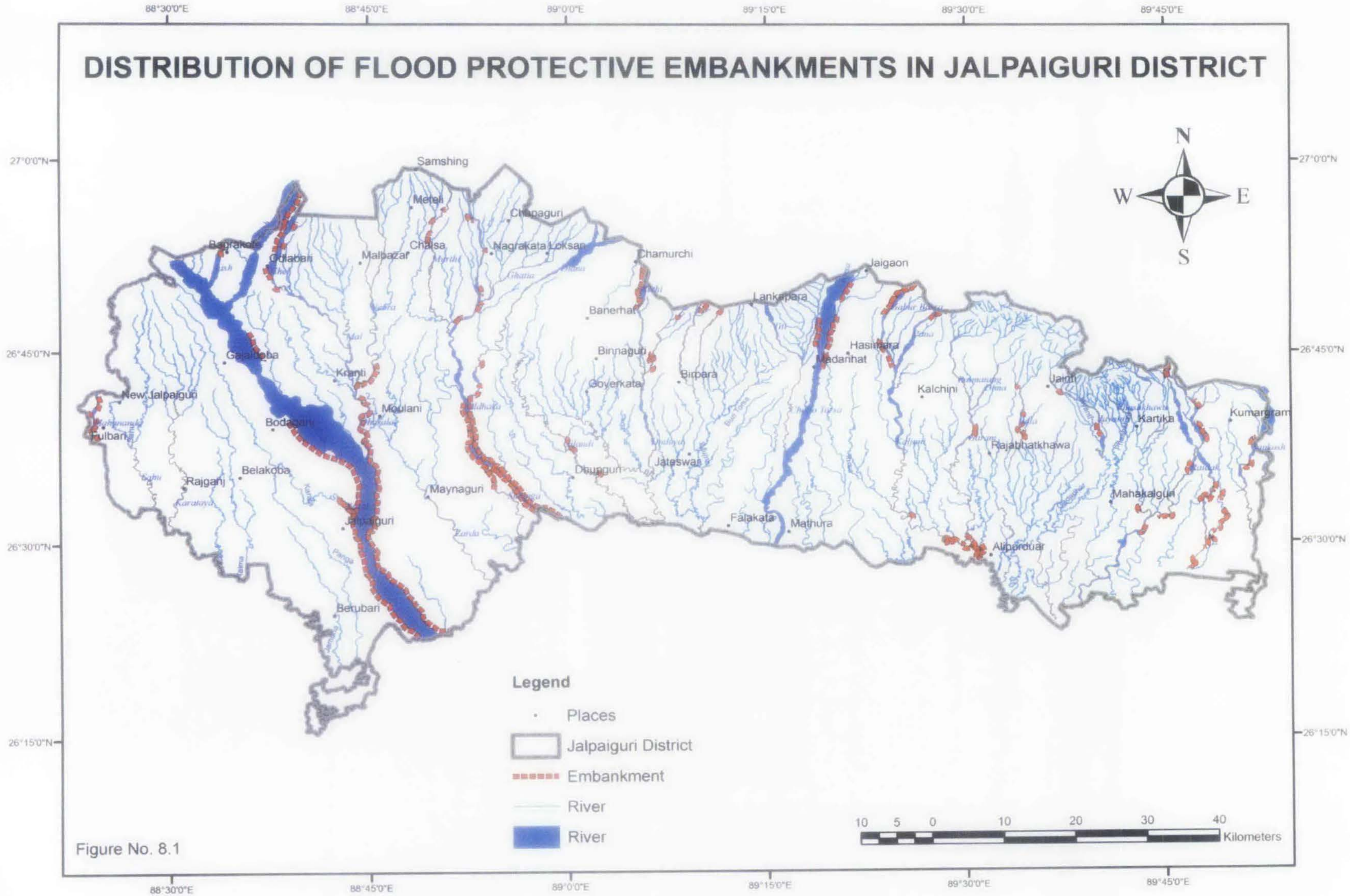
The detrimental effect of embankment in controlling flood hazard has been demonstrated globally and it is proved to be counter-productive. The North Bengal Flood Control Commission so far constructed 364 km long embankments in Jalpaiguri district in the name of flood protection. It could protect 494 sq. km area at the cost of another 1400 sq. km area brought under the threat of flood hazard. Following are the major effect of embankment on the fluvial dynamics of sub-Himalayan river:

- Aggradation vis-à-vis rising of riverbed at an alarming rate and in many cases riverbed is now higher than the ground level inducing avulsion.

- Providing false security among the local inhabitants and instrumental for large scale human settlement in the river valley e.g., between embankment and active channel. Responsible for making the North Bengal's river more unpredictable

Keeping in mind the inadequacy of such structural measures in controlling flood menace over a large area and its long term adverse effects on environment, the following suggestions are proposed (a) embankments should only be constructed in strategic and high priority area with proper layout and materials i.e., ACM and (b) the existing embankments should be strengthened and be properly maintained since breaching of such structures often caused catastrophic loss and avulsion.

Though construction of embankment as proposed in the Master Plans of Tista, Jaldhaka and Torsa basins, the same is to be reviewed further. First of all, the longitudinal slope of the river as well as average slope of the terrain required to be analysed to assess the



DISTRIBUTION OF FLOOD PROTECTIVE EMBANKMENTS IN JALPAIGURI DISTRICT
N
S
E
W
Samshing
Metali
Chapaguri
Chalsa
Malbazar
Nagrakata
Loksan
Bagrakote
Odlabari
Chamurchi
Jaigaon
Lankapara
Banerhat
Binnaguri
Birpara
Hasimara
Madarihat
Gajaldoba
Kranti
Moulani
New Jalpaiguri
Fulbari
Bodaganj
Belakoba
Rajganj
Maynaguri
Jalpaiguri
Berubari
Goyerkata
Dhupguri
Jateswar
Falakata
Mathura
Kalchini
Jainti
Rajabhatkhawa
Kartika
Kumargram
Mahakalguri
Alipurduar
Legend
Places
Jalpaiguri District
Embankment
River
River
10 5 0 10 20 30 40 Kilometers
88°30'0"E
88°45'0"E
89°0'0"E
89°15'0"E
89°30'0"E
89°45'0"E
27°0'0"N
26°45'0"N
26°30'0"N
26°15'0"N

Figure No. 8.1

gradation of sediments being carried by the river. As observed from the study the slopes of the rivers further south at International border is flat enough and the suspended sediment of lighter density along with fertile silt content is noticed. Therefore, flooding of surrounding areas has resulted in fertility of the area. Loss of crops during monsoon in such areas is supplemented, by increase in production during non-monsoon period. Embankments should, therefore, be judiciously constructed in this zone to protect densely populated areas against direct thrust of flood (WAPCOS, 2003).

In the piedmont (foothills) region, the rivers carry sand during flood due to steeper slope. Flooding of agricultural land results sand casting, thereby productivity of land is totally lost. Low and permeable embankment may be suitable so that sand to a great extent would be filtered.

Due to increase in population and developmental activities, breaching of embankment causes heavy loss due to damage of property. Hence, to reduce frequency of breaching of embankments, the embankments already constructed should be able to withstand a flood of 100 years return period. For rural areas, however, where only agricultural land is required to be protected, embankments may be designed against a flood discharge of 25 years returns period. It is suggested that major embankments in bank of main rivers like Tista, Jaldhaka, Kaljani, Torsa should be protected against a flood of 100 years return period (WAPCOS, 2003).

Construction of embankments along the rivers of Jalpaiguri district has since been started from the year 1954 and these are being constructed, or proposed to be constructed wherever felt necessary. Maintenance cost of these embankments is exorbitantly high. However, the same is very much warranted to contain the likely damage due to floods.

8.2.2. De-silting of wet land & riverbeds

Low lying areas, spill zones, left out course of rivers/oxbow lakes, *beel* areas and other water bodies act like detention reservoirs which moderate direct flood flow. With gradual construction of embankments, the spill zones have been cut off from the main flow resulting spills over banks. Such water bodies, though not capable for receiving flood from upper valley through main course, can absorb local run-off to quite an extent. Reclamation of land through drainage schemes was one of the primary objectives in past. Such reclaimed lands suffered from drainage congestion and spreading of habitation in urban areas even in the low lying areas which as posed severe problems as on today.

It is therefore suggested that water bodies, perennial or seasonal, should be kept free from any man made activities. Detailed investigation works need to be carried out for regulation of flow into and out of these water bodies through introduction of technically feasible control devices to enable these to act as storage reservoirs during dry period and detention basins to absorb local surface runoff (WAPCOS, 2003).

Among the other structural measures, widening of existing road and railway bridges and culverts across the rivers should be initiated to ensure free and uninterrupted natural load movement of the rivers. This will also reduce the chance of avulsion and flood to some extent.

Small irrigation channels cut by the villagers or, *Jampoi* often accelerate avulsion. The *Jampoi* shall be brought under the direct supervision of GP as well as I &W department followed by the necessary structural modifications depending their respective vulnerability. River lifting, tube well and rainwater harvesting should be promoted to phase out the *Jampoi*.

8.3. Short term area specific non-structural measures

The structural measures as proposed in the previous section are found insufficient in providing a full protective umbrella against flood menace. The following are the major short term area specific non-structural measures proposed for the said purpose:

- Catchment area protection and improvement through afforestation and scientific land-use and slope management. This is a lag term protective measure which will control sediment production and maintain hydrological cycle. It will also improve the fluvial efficiency, competency and navigability of rivers.

- Early warning system is also considered to be one of the components of flood mitigation.

- People's participation through education and creating awareness among the potential victims also proposed as a mitigating measure for reducing flood damage. During the execution of the present project, a large number of youths from the local schools and volunteers have initiated massive campaign programme regarding the flood safety rules among the local resident, particularly among those who are residing in high risk zones.

8.3.1. Flood plain zoning

Flood plain zoning is an important and useful non-structural measure of flood management becoming more and more popular. Flood plain zoning means segregate the different sections of flood valley of a river into different category of its hazard potential and management needs. It is proposed to identify and map the following three categories of potential flood hazard zone along the river valley based on (i) topographic details, (ii) past occurrences of flood hazard, (iii) frequency and magnitude of floods and (iv) nature of protection measures already adopted.

1. Identification of *prohibitive zone* and listing of families settled in fringe area, land use practice, domestic animals, source of drinking water and other services existed in such zone

2. Identification of *restrictive zone* and listing of families settled in buffer zone, land use practice, domestic animals, source of drinking water and other services existed in such zone.

3. Identification of *warning zone* and listing of families settled, land use practice, domestic animals, source of drinking water and other services existed in such zone.

It is also equally important to make a projection of possible damages under different degree of human intervention/development project in the respective identified zone.

Digitization, geo-referring and development of GIS with attachment of data related to the hazards shall be adhere to and on-line linkage with the stakeholder agencies to facilitate decision maker to take right decision at right time. High resolution satellite image can also be integrated with GIS platform to quick retrieval of ground reality and also to upgrade the existing database. This will further help in preventing of human encroachment in flood valley and construction of flood shelter (Geo-referred) in high priority area at G. P. level (Sarkar, S. 2010).

8.4 Long term measures

It is now well understood that flood as a natural hydro-geomorphic process cannot be controlled neither it should be attempted any more. The term flood management is more frequently be used instead of flood protection across the globe. It is also understood that in the name of so called flood prevention and protection the measures so far taken in the sub-Himalayan Jalpaiguri district in stakeholders interest in fact found counter productive. In fact, such measures instead of serving its original purpose aggravate the basic problem further. The problem of flood hazard in Jalpaiguri district has been complicated further which demands successful implementation of long term measures to sustainable phase out of the problem. Some of the long term measures applicable in the study area have been discussed in the following section.

8.4.1 Watershed management

Deforestation via-a-vis environmental degradation in the watersheds of the sub-Himalayan river indeed plays the decisive role in contemporary increased frequency and magnitude of flood hazard in Jalpaiguri district. Vicious cycle of degradation has already been established in the sub-Himalayan watersheds most probably except Butanese part. Perhaps, the only possibility to reduce the flood hazard in sub-Himalayan Jalpaiguri district lies into the pro-active watershed management in catchment area in Darjeeling-Sikkim-Bhutan. It is thus an intra and international affairs and co-operation among the states and nations. However, some activities may be possible to adopt within our own national territory. Cooperation between India and Bhutan has already been initiated in this regard. Competent authority should take initiative to inform the people living in threshold areas within the watersheds (prohibitive/restrictive zone) categorically about the hard reality of possible hardship during the different stages of watershed management processes (Sarkar, S., 1991; Sarkar, S. 2007).

The model future course of action for comprehensive watershed management plan in sub-Himalayan watersheds should include (i) identification of *degradation prone area* and plot it on map at gram panchayet level; (ii) *Degradation/Deforestation zoning* of micro-watershed at gram panchayet level on mauza map; (iii) identification of *prohibitive zone* and listing of families settled in fringe area, land use practice, domestic animals, source of drinking water and other services existed in such zone; (iv) identification of *restrictive zone* and listing of families settled in buffer zone, land use practice, domestic animals, source of drinking water and other services existed in such zone; (v) identification of *potential threatened zone* and listing of families settled, land use practice, domestic animals, source of drinking water and other services existed in such zone (Sarkar, 2011).

8.4.1.1 Watershed budgeting

Comprehensive watershed management also require watershed budgeting which includes the total interaction between man and nature. In fact it's a budgeting between the nature's productivity and human society's demand (Starkel. L., Sarkar. S., Soja, R., Prokop. P. 2008). A balance between these two is the key to the success i.e., the sustainable watershed management

Requirements: Peoples' yearly consumption requirements of essential items viz. cereals, fruits, fat, milk, sugar, pulses and nuts, vegetables, meat and egg etc. should be assessed considering their respective consumption on per day capita basis. Similarly, the needs for concentrates (rice brawn, pulse husk and oil cakes), dry fodder, green fodder, grass etc. for the bovine stock of cows, she-buffaloes and cattle should be worked out.

Production: Based on the average yield figures, gross net production of cereals pulses, oilseeds, vegetable etc. is assessed. Similarly, the milk yield, meat, chicken, eggs and cattle feeds, is estimated and the surplus/short falls are worked out.

Action Plan: Watershed concept is evolved for managing the soil moisture regimen. Rainwater is harvested to the maximum possible extent in the upper reaches, stored, conserved and distributed in an efficient manner for feeding the soil moisture. The moisture in uplands moves downwards and maintains the moisture in lowlands. Rainwater harvesting along with various measures helps in checking the velocity of water and recharging groundwater. In this way, rainwater retention, retarding and recharging increase the resource situation and improve water movement. The improvement in soil moisture increases the biomass production proportionately. An effort is made herein to present some details on preparation of a plan for a possible understanding of the listed disciplines and their interrelationships.

Survey: First step is collection of data on the status of the watershed characteristics. Information could be collected from the local, district, and state government and central government departments and through detailed canvassing in the specific watershed. A proforma indicating the inventory of watershed management plan has been evolved for ready reference, restricting the length in proportion to the Government's decision about the per hectare expenditure for watershed development.

Technical Backdrop: An essential requisite for watershed management is actual assessment of land, soil and ecological regime of the area. The objective is to determine the extent of land damage, erosion condition and rate of soil loss. It helps in classifying the lands suitable for different activities and fixes area-wise measures together with methodologies to be adopted for soil conservation. It gives a detailed picture of soil moisture status, an important prelude in deciding the mode of greening. Overall appreciation of present species and practices vis-a-vis land use forms a basis in choosing the activities and deciding their priorities for implementation.

Watershed Plan: The end product of survey, investigation, data collection, data processing, and reporting of various aspects on different disciplines is formulation of integrated multi-disciplinary annual action plans. It is to be shaped by the competent authority with due consideration to integration, approach, concept and technical backdrop, appropriate technology, socio-economic conditions, and the last but not the least in any way the people's active participation. It is needless to say that emphasis should rest with soil and water conservation in growing greenery with simple and affordable scientific inputs. The plan should include facilities on agro-industrial infrastructures, community participation and supporting data. It is natural to envisage quantitative treatment, as far as possible, as to status, technical background, plan, programme and projection. The plan should pronounce the estimates, outlays, funds requirement and assign the job responsibilities within a specified time schedule.

8.4.2 Land use control

The purpose of Land-use regulation is to obtain the beneficial use of flood-prone areas with a minimum of flood damage and a minimum expenditure on flood protection. Some of the many adverse implications of human occupancy of flood plains have been repeatedly emphasized, as has the impracticability, in most cases, of abandoning such areas altogether (Sarkar, S. 2007). Land-use regulation aims, therefore, at a policy which combines the abandonment of limited parts of the flood-prone areas with the careful regulations of land-use in the remainder of such areas.

8.4.3 Construction of check dam/reservoir/barrage

Construction of check dams/reservoir/barrage often considered as one of major long term structural measures adopted against flood problem around the world. Thousands of Dams/Reservoirs were so far been constructed across the world under the Multipurpose River Valley Development Projects. Of late, we observed and understood the irreparable damage that caused to the fluvial environment due to such mega-intervention. As a result, the human society becomes aware and gradually favours small check dams to be constructed across sub-watersheds to check soil erosion and ground water recharge.

In sub-Himalayan Jalpaiguri district only one barrage with a length of 921.5 m has been constructed under Tista Barrage Project at Gajoldoba for a design flood discharge of 20,100 cumec. The project is proposed to be executed in three phases. First phase of the project envisaging irrigation potential of 9.23 lakh hectare is divided into three stages. Under stage I, three pick up barrages have been constructed on the rivers Tista, Mahananda and Dauk. Out of five main canals, Tista-Mahananda Link canal (25.75 km) and Mahananda main canal (30.45 km) have been constructed in all respects while the other canals are under various stages of construction. A dam on the river Tista has also been proposed near Gail khola in the district of Darjeeling. However, its location has since been changed and proposed at 800 m upstream of Sevok Coronation Bridge. Apart from supply of irrigation water, it will generate 600 MW of hydro-power and partially contribute to flood management in entire North Bengal which also work for the Jalpaiguri district.

The Tista barrage constructed at Gajoldoba in the district of Jalpaiguri has an important role in regulating the flow of the river Tista. It has been observed that guided barrage operations have helped to reduce shoal down-stream of barrage and thereby preventing scour to the Apalchand Forest on the left bank of the river Tista. There are provisions for construction of barrages across the river Jaldhaka, Raidak, and Torsa under stage-II of the project to utilise the water resources of these rivers.

In the Torsa basin, 50 check dams have been proposed for flood moderation in its Master Plan. It suggested that the detailed survey and investigation of these schemes may be carried out the detailed report may be prepared to establish techno-economic viability and take up construction depending upon the priority and availability of funds (WAPCOS, 2003). It is felt that these dams would be more effective in the tributaries rather than the main river. Five alternative sites for the construction of a multipurpose reservoirs having flood control/moderation as one of the components have also been suggested in Phuntsholing to Dorokha reach of river Torsa. All above sites lie in Bhutan where the river passes through hilly terrain. Detailed survey and investigation is required to be carried out for establishing the most viable site.

Construction of 50 check dams has been proposed in the Master Plan of river Jaldhaka. However, their locations and other features are yet to identified. Three multi-purpose reservoirs have also been suggested in the Master Plan as given below (WAPCOS. 2003): (i) on the river Diana: Catchment area: 260 sq. km; (ii) on the river Murti: Catchment area: 130 sq. km; (iii) on the river Jaldhaka: Catchment area: 390 sq. km.

In the Mahanda basin, two barrages have been constructed one across the river Mahananda at Phulbari, district Jalpaiguri and the other across the river Dauk in Chopra, district of North Dinajpur.

Setting up *hydro-meteorological stations* covering the whole watershed to monitor: a) rainfall, b) temperature, c) humidity, d) discharge, e) sediment load and other hydrological parameters and f) land use pattern shall be taken/strengthen immediately to develop prototype model. This is a must to understand the mechanism of flood generating forces and to evolve a full proof flood forecasting model in sub-Himalayan Jalpaiguri district.

8.5 Flood preparedness and response

In order to respond effectively to foods, Ministry of Home Affairs has initiated National Disaster Risk Management Programme in all the flood-prone States. Assistance is being provided to the States to draw up disaster management plans at the State, District, Block/Taluka and Village levels. Awareness generation campaigns initiated to sensitize all the stakeholders on the need for flood preparedness and mitigation measures. Elected representatives and officials are being trained in flood disaster management under the programme. Bihar, Orissa, West Bengal, Assam and Uttar Pradesh are among the 17 multi-hazard prone States where this programme is being implemented with assistance from UNDP, USAID and European Commission.

8.5.1 Preparedness

Floods which are natural hazard need not become a disaster, if we are prepared to deal with them. Some preparedness measures that we need to carry out at the individual and at the government level are:

8.5.1.1 Pre disaster

Individual Preparedness:

- Know the route of the nearest safe shelter
- First Aid kit should be ready with extra medicines for snake bite and diarrhea
- Tie up all valuables at the top of the roof
- Radio with extra batteries, torch, ropes to be kept ready
- Store dry ration, kerosene, biscuits, baby food for at least for 7 days
- Water proof bags, polythenes to store clothes and valuables
- Be ready with umbrella and bamboo sticks (to protect yourself from snakes)
- Identify a highland/mound for the cattle and have sufficient fodder for them

- As soon as you receive warning tune to the local news in the radio/Television for the latest update
- Don't spread rumors. Get authentic data and then announce it
- Check your emergency kit

If you have to Evacuate

- Pack clothes, essential medicines, valuables, personal papers in a water proof bag
- Inform the Disaster management team member to the place that you are shifting .
- Raise furniture and appliances to a higher place
- Switch off all electrical appliances
- Put sandbags in the toilet bowl and cover all sewage backflow
- Lock your house and take the route suggested
- Don't into water of unknown depth and current

Government Preparedness:

- Update all the resource inventory
- Control room should be functional for 24 hours
- Identify all the shelter places where people could be evacuated
- Activate all the First Aid and the Rescue and Evacuation team
- See to it that there is no blockage in the flow of the river
- Ascertain the availability of dry food, drinking water and medicines
- Ascertain the fodder availability for cattle's
- Mobilise boats, vehicles which will help in evacuation and rescue operation and also in the distribution of relief
- Prior storage of food grains in the vulnerable pockets
- Identify the relief centers
- Inspect, strengthen and repair all the approach roads and culverts
- Provide mobile wireless sets the villages likely to be cut off
- Arrange adequate hand pumps where wells are likely to be inundated
- Liaison with army, Navy, Coast guards and the Railways locally
- Prepare maps of alternate route, resources available

8.5.1.2 During disaster

Individual

- Drink boiled water or put halogen tablets
- Keep food covered. Don't take heavy meals and eat food that is hot
- Use raw tea, rice water, coconut water during diarrhea
- Be careful of snake bites as snake bites are common
- Don't let children stay in empty stomach
- Avoid entering flood water. Stay away from water which is above knec depth

Government

- Carry out rescue and evacuation
- Operation of Control Room and provide warning update
- Provide relief materials
- Mobilizing resources like boat, dry food, temporary shelter
- Ensuring the availability of medicines, drinking water, tankers etc.
- Co-ordination at various levels and agencies
- Mobile health units to be made available
- Damage assessment of life, livestock, crop and livelihood

8.5.1.3 Post disaster

Individual

- Listen to the latest flood bulletin before moving from the shelter place
- Use recommended routes to return back
- Dry all electrical equipment before using it
- Avoid touching any loose wire
- Beware of snake bites
- Clean the house and disinfect the surrounding by using bleaching powder

Government

- Rescue people who are stranded
- Restore roads and power supply
- Provide safe drinking water
- Check outbreak of any epidemics
- Mobile health teams to be mobilized
- Take the help of the NGOs

- Carry out damage assessment
- Ensure that adequate, timely and speedy credit is available to the farmers for purchasing agricultural inputs and cattle.

8.5.2 Flood hazard response

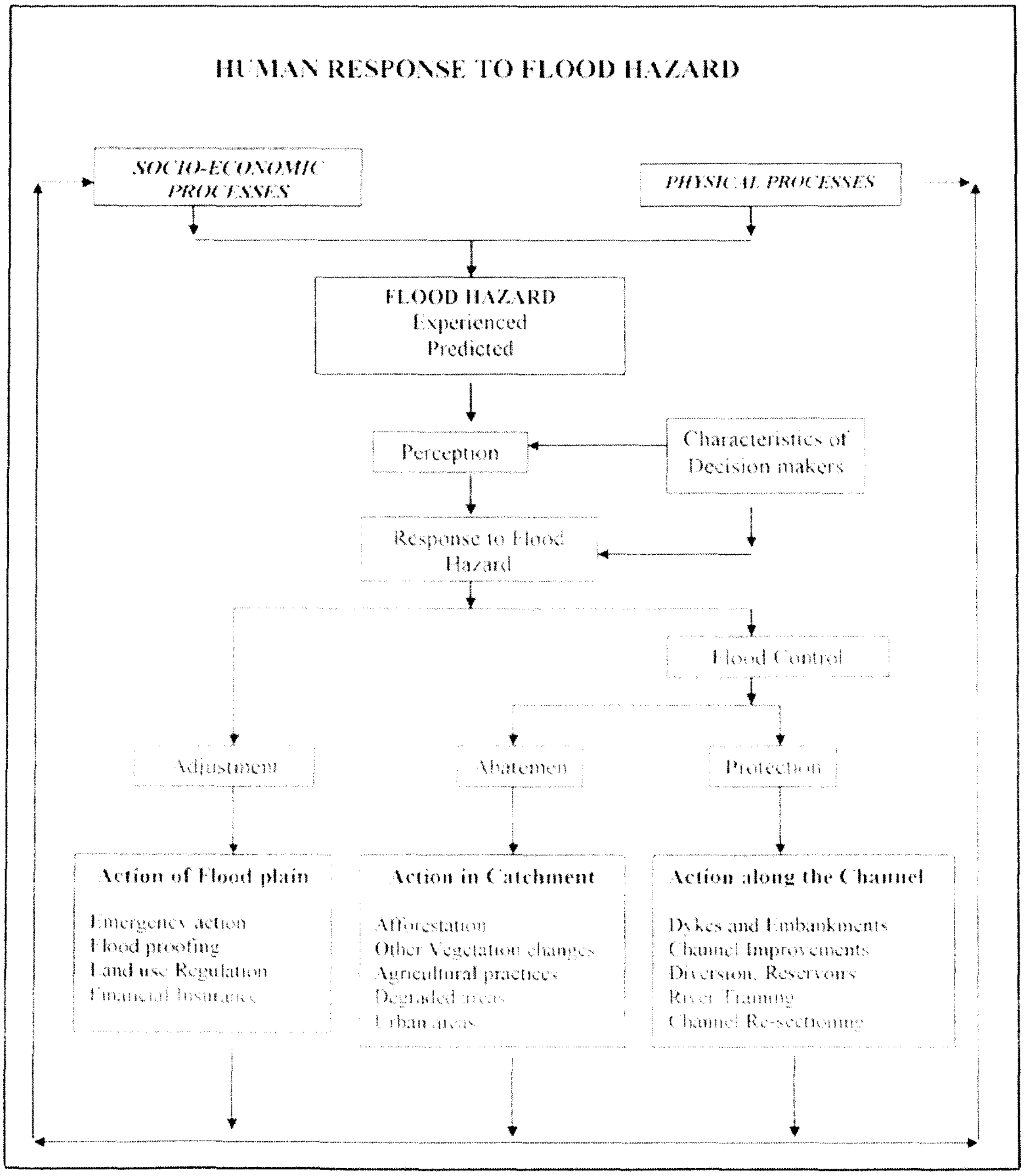
The majority of the deaths and much of the destruction created by floods are largely preventable. A great deal can be done to lessen the impact of a disaster. The stakeholders as well as engineers, planners, politicians and others needs to understand the nature of the hazard and decision and a commitment needs to be made to provide mitigation measures to reduce flood damage. Human response to flood hazard is a complex socio-economic processes and diagrammatically represented in figure 8.2.

Reduction of harmful effects of a flood requires actions on three fronts: reducing the vulnerability of the physical settlements and structures in which people live; reducing the vulnerability of the economy; and strengthening the social structure of a community so that community coping mechanisms can help absorb the impact of a disaster and promote rapid recovery (Baker, V.R. et. al. 1988; Kale, V. S. (ed.); 1998).

The *first step* in vulnerability reduction for human settlements is to identify the high-risk areas. This is done by relating a natural hazard, such as a flood, to the terrain and to the probability that such an event will occur. This activity is known as risk mapping. Flood risk mapping, for example, would indicate the areas likely to be covered by water during floods of given magnitude.

The *second step* in vulnerability reduction is to identify those communities that are particularly susceptible to damage or destruction. This is done by relating risk to agriculture, pisciculture, and animal husbandry etc. life supporting activities.

The *third step* is the selection of a vulnerability reduction strategy consisting of a comprehensive floodplain management program. The objective of such a program should be the absolute reduction of flood damage potential. This can be accomplished by (a) preventing an increase in flood damage potential resulting from new development in floodplains, and (b) reducing the flood damage potential in already developed floodplains. Both approaches must be used if the objective of reduced flood damage potential within a community is to be realized.



Based on Sarkar, S, 2008

Figure No. 8.2 Human Response to flood hazard

8.6 Preventive approaches

Preventive floodplain management approaches usually consist of land use controls, such as floodplain regulations and sub-division regulations, which are applied to the 100-year floodplain. Briefly, the procedure is to define the 100-year water surface elevations, flood outlines and floodway. The floodway is the channel and the portion of the adjacent floodplain required to pass the 100-year flood without significantly increasing the water surface elevation, assuming the remainder of the floodplain is not available to convey flood water.

Once the floodplain and floodway are defined, potential development agencies have the options, which are subject to regulation, of leaving the floodplain in open space, developing the fringe area, or modifying the floodplain or floodway to remove areas from the floodplain. Development that occurs under any of these options will essentially be free from major flood damage up to and including the 100-year flood event (Mukhopadhaya S.C., 2010).

It is important to work with development agencies to make them aware of the flood hazard, the need for addressing the hazard and the options available to them as noted above. Experience has shown that these agencies have recognized the need to address the flood hazards and have exercised the options available to them to build quality developments safe from flooding during the 100-year event. Other preventive approaches include:

1. The acquisition of floodplain land, or at least the development rights to the land, by the overseeing agency. This could take the form of land swaps that provide alternatives to development of the site.
2. Incentives to encourage for future development on safer sites with safer methods.
3. Diversification of agricultural production that include identification and planting of flood-resistant crops or adjustment of planting season, if possible, to avoid coinciding with the flood season; establishment of cash and food reserves.
4. Reforestation, range management and animal grazing controls to increase absorption and reduce rapid runoff.
5. Construction of raised areas or buildings specified as refuge areas if evacuation is impossible.

8.7 Remedial approaches

In developed floodplain areas, where a high flood damage potential already exists, simply applying land use controls to defined floodplains will not have an immediate impact on the flood damage potential. Additional actions must be implemented if the goal is to reduce a community's flood damage potential. Remedial floodplain management involves the planning, design, construction and maintenance of facilities to reduce the flood damage potential in an already developed floodplain. The remedial options available include construction of flood control works, flood-proofing of existing installations, flood detection and warning systems, acquisition and relocation or demolition of structures, and public awareness programs.

8.7.1 Flood detection, forecasting and warning

Flood detection vis-à-vis forecasting and warning systems can be effective in reducing loss of life and property damage. In flash flood locations the major benefit will be reduction in loss of life. In slow-rising flood situations major savings from reductions in flood damage can be accomplished. Flood forecasting systems can range from inexpensive networks of volunteers, rainfall and stream stage observers and simple rule curves to sophisticated networks of telemetric gauges, AWS and computer models (Mukherjee, M. 2008).

The ability to forecast flooding is limited to the time during which changes in the hydrological conditions necessary for flooding to occur have begun to develop. The formulation of a forecast for flood conditions requires information on current hydrological conditions such as precipitation, river stage, water equivalent of snowpack, temperature, soil conditions over the entire drainage basin, as well as weather reports and forecasts.

In small headwater regions a forecast of crest height and time of occurrence is all the information required to initiate effective adjustments; the relatively rapid rate of rise and fall makes the period of time above flood stage relatively short. In lower reaches of large river systems where rates of rise and fall are slower, it is important to forecast the time when various critical stages of flow will be reached over the rise and fall. Reliability of forecasts for large downstream river systems is generally higher than for headwater systems.

Methods for warning the public should be well thought out, documented, and practiced on an annual basis. Ways to disseminate warnings include radio, television, warning sirens and public address systems. Users of detection and warning systems should be aware that all members of the public will not respond in the desired manner to warnings. An understanding of how and why people respond to warnings is an essential ingredient in any warning system.

Warning time for peak or over bank conditions can range from a few minutes in cloudburst conditions to a few hours in small headwater drainages to several days in the lower reaches of large river systems. As with forecasting, the time and reliability of the warning increase with distance downstream where adequate knowledge of upstream conditions exists. The data collection network is necessary for collecting the information, the technical expertise required for interpretation, and the communication system needed to present timely information to potential victims, which are the services that many poor and developing nations find difficult to provide. Fortunately, the Flood Meteorological wing of India Meteorological Department is maintaining recording stations, monitoring and disseminating to the concern agencies for sub-Himalaya catchments. Flood warning is disseminated by following means:

- High priority telegram
- Doordarshan
- All India Radio
- Bulletins in the press
- Satellite based disaster warning systems
- Teleprint & Telex
- Telephone and
- Government channel

8.7.2 Human resource development

Human resource development at all levels is critical to institutionalization of flood disaster mitigation strategy. The National Centre for Disaster Management at the national level has been upgraded and designated as the National Institute of Disaster Management. Besides, the other functions assigned to the National Institute of Disaster Management include development of exhaustive National level information base on disaster management policies, prevention, mechanisms, mitigation measures; and providing consultancy to various

States in strengthening their disaster management systems and capacities as well as preparation of disaster management plans and strategies for hazard mitigation and disaster response.

8.7.3 Awareness generation

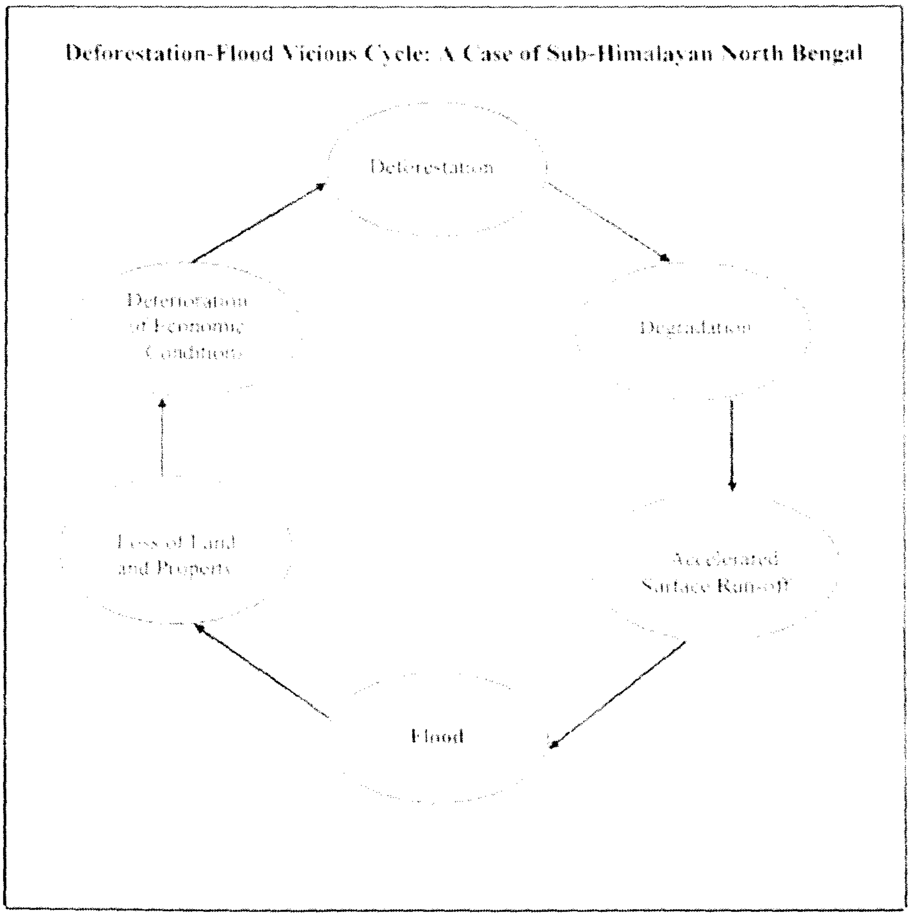
Recognizing that awareness about vulnerabilities is a sine qua non for inducing a mindset of disaster prevention, mitigation and preparedness, the Government has initiated a nation-wide awareness generation campaign as part of its overall disaster risk management strategy. Apart from the use of print and electronic media, it is proposed to utilize places with high public visibility viz. hospitals, schools, railway stations and bus terminals, airports and post offices, commercial complexes and municipality offices etc. to make people aware of their vulnerabilities and promote creation of a safe living environment. A novel method being tried is the use of government stationery viz. postal letters, bank stationery, railway tickets, airline boarding cards and tickets etc. for disseminating the message of disaster risk reduction. Appropriate public awareness programs should be implemented for the following purposes:

a) to make floodplain occupants and/or owners aware of identified flood hazards;
b) to encourage individuals to take actions such as flood proofing and developing escape plans, to mitigate their flood potential;
c) to make individuals aware of the existence and operation of flood warning plans and
d) to encourage individuals to keep drainage ways clean and to report potential maintenance problems.

8.8 Conclusion

Flood hazard mitigation involves measures to reduce the effects of disaster causing phenomena. All actions to reduce the impact of a disaster that can be taken prior to its occurrence, including preparedness and long term risk reduction measures. It also includes the planning and implementation of measures to reduce the risks or man-made hazards, and the process of planning for effective response to disaster which do occur. Disaster mitigation includes scientific analysis of risk assessment, social, economic, legal and technical processes in the development of mitigation measures and administration and political processes in application of these measures.

Floods are caused not only by rain but also by human changes to the surface of the earth. Farming, deforestation, and urbanisation increase the runoff from rains; thus storms that previously would have caused no flooding today inundate vast areas. Not only do we contribute to the causes of floods, but reckless building in vulnerable areas, poor watershed management, and failure to control the flooding also help create the disaster condition. For the intensively utilized floodplains of sub-Himalayan North Bengal, the application of these approaches will require considerable political will and co-operation by the stakeholders.



(Based on Sarkar, S, 2008)

Figure 8.3 Deforestation – flood vicious cycle

Deforestation via-a-vis environmental degradation in the watersheds of the sub-Himalayan river indeed plays the decisive role in contemporary increased frequency and magnitude of hazards. Vicious cycle of degradation has already been established in the sub-Himalayan watersheds. Perhaps, the only possibility to save the habitable environment lies into the pro-active watershed management. It is thus, our imperative duty to inform the people living in threshold areas within the watersheds (prohibitive/restrictive zone) categorically about the hard reality of possible hardship during the different stages of watershed management processes.

Let us tell our people living in threshold areas (prohibitive/restrictive zone) categorically that you are living in an unsafe area and it is not possible to provide you security against possible flood. The land use pattern, house type must be suitable to cope up the possible threat. The traditional art and life style of ***living with flood*** must be adhered to. However, the life both human and animal along with movable property must be protected through the construction of Flood Shelter nearby preferably within the radius of 5 km.

The model future course of action for comprehensive watershed management vis-à-vis flood management plan in sub-Himalayan North Bengal shall include:

1. Identification of *flood prone area* and plot it on Cadastral map (Scale 1:3960) at Gram Panchayet level.
2. Flood plain zoning of the major rivers at Gram Panchayet Level on Mauza map.
3. Projection of possible damages under different degrees of hazard.
4. Identification of sites for Flood Shelter and facilities needed.
5. Digitization, geo-referring and development of GIS with attachment of data related to the hazard. An on-line linkage with the forecasting agencies will help decision maker to take right decision at right time.
6. It will be possible to arrange for emergency evacuation, rescue for human and animal and also for movable commodities.
7. The GIS thus developed will also be of great help in providing efficient relief measures.

Although, the task is enormous, expensive and time consuming, yet the concern departments with the help of Gram Panchayet can initiate such programme. Expert agency can also be engaged. Such approaches although, would not control flood yet it will definitely reduce the loss and sufferings of the victims to a maximum extent. A portion of the money that spend for the construction of traditional flood protection may be kept aside as the emergency fund for the possible victims.

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Chapter IX: Summary and Conclusions

Jalpaiguri district in West Bengal being situated not far from the Himalayan margin is endowed with an intensive network of river systems. Most of the rivers are considered to be highly notorious for their unpredictable nature, letting loose fury of flood and problem of extensive and regular bank erosion, course shifting, renders thousands of homeless during the rainy season. The majority of the rivers originates in the Himalayas and enters from a north to northwesterly direction and flows south to southeasterly direction. As many of the rivers originate at the same hill, flood often occurs simultaneously in many rivers and the rivers coalesce to form a single vast sheet of water. Moreover, the simultaneous melting of snow accumulated on high mountains and rainfall in lower reaches often caused floods of devastating nature. These along with sudden bursting of water storage in the upper catchment caused by heavy landslide that blocked river channel released unbelievable volume of water through the river Tista in 1968 and caused unprecedented devastation.

The catchments of these rivers have mostly been deforested and the clearings of the steep slopes have been used for the extension of settlement, agriculture, plantation and communication, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfalls, innumerable landslides are caused, transporting large amount of sediment to the rivers. Most of such landslides have never been treated scientifically with proper protective measures and as such those are in the habit of expanding their territories during monsoon. This often added more and more silt to the rivers, which are incapable of transporting the loads efficiently under the existing hydrological conditions, especially areas beyond the foothill.

During summer, the observed increment of the size of bars and shoals downstream to the piedmont area proves such a contention. In order to avoid such numerous islands in midst of the channel, the rivers, in their lower reaches thus, attains the significant physical characteristic of braiding which may be attributed to both incompetence and incapacity of the rivers. That is, most of the rivers can transport neither the total amount of debris nor the size of debris that is supplied to it as bed load. As a result, the riverbeds are rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods. Moreover, the narrow road and railway bridges, spanning the rivers as well as the pillars supporting them, are always considered to be the barriers, interrupting natural load movement behavior of the rivers. This often cause accelerated deposition at the bottom of the bridge and thereby, narrowing the outlets of the rivers gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and firm lands.

Although, flash flood has not been an uncommon phenomenon in the foothill area of Jalpaiguri district, the frequency and magnitude of such events have increased many folds during the recent past. Two such catastrophic events during the last decade (1993 and 1998) demonstrate the enormity of damage and ever-increasing threat to the biosphere of the sub-Himalayan North Bengal a whole.

At this moment, therefore, suggestion of flood hazard management and their active implementation is of vital concern to the resident of the district. As such, the present investigator has been studying the flood problems of the major sub-Himalayan rivers with special reference to the river Tista, Torsa, Jaldhaka, Sankosh, Raidak and Mahananda to formulate management model that would be of immense help in managing the problems like flood, bank erosion, and avulsion in the sub-Himalayan Jalpaiguri district.

The study area is composed of several tectonic units of the Sikkimese-Bhutanese Himalaya overthrusted towards south are built mostly of metamorphic rocks. The foreland of the Himalaya is built of Quaternary sediments which show a distinct fractional differentiation starting from boulders and gravels in the root part of piedmont fans and terraces, at distance of 5-10 km from the margin turning to sand and farther downstream to sandy loam and silt.

Geomorphologicaly, the study area is diverse and complex in nature, exhibiting a wide variety of landforms. Their genesis, mode of formation and morphological forms are diverse and have been characterised by successive catastrophic events of slope wash on the hill slope followed by accelerated deposition along the piedmont during the post-Pleistocene period.

Topographically, Jalpaiguri district may be divided into 3 major divisions namely the hills, piedmonts and the plains. The hills rise abruptly from the piedmont plain (120-300 metre) and the elevation increase northwards up to 2000 meter at the Sinchula Massif. Within these, there is a mosaic of micro-topographic units comprising of convex ridges, intermountain valleys, high terraces and deep-cut valleys. The piedmont covers the tilted plains at the base of the Himalayas bounded by the 300 meter contour line to the north and 66 meter to the south. Perceptible gentle gradient land is a significant feature of the plains.

The climate of Jalpaiguri is characterised by extreme diversities in rainfall and temperature pattern between its northern and the southern parts. Mean maximum temperature ranges from 31.7^0 in April to 23.6^0 in December and mean minimum temperature ranges from 10.7^0 in December to 25.2^0 in July. Precipitation also exhibits similar kind of diversity that ranges from less than 3000 mm along the southern margin to over 5000 mm along the northern piedmont. Extreme diversity in geological set-up, topographic forms along with climatic elements exhibits unique biodiversity in the study area.

The district produces a huge quantity of surplus fruits and vegetables. The lack of cold storage and marketing facility are major impediment to the growth of this sector. On the other hand, those factors influence unwarranted transformation of agriculture-land to tea gardens, which again face lower acceptability in the international market. Despite profuse reserves of ground water, some parts of the district still facing drinking water crisis. Jalpaiguri has always been a deficit in its basic need of food grain production and it should immediately be brought under the high yielding stage. To grow more food and to bring more lands under agriculture, creating more irrigation facilities is a must. Deforestation has been a great menace. People virtually eking out on poor agriculture depend on forest produce and forest has been the surrogate source of income.

Under the backdrop of the World's loftiest, youngest and tectonically most active Himalayas, the study area exhibits a nature's laboratory for understanding fluvio-geomorphological processes and its ramification within the boundary of their respective catchments.

The Sub-Himalayan river under study are considered to be highly notorious for their unpredictable nature, letting loose fury of flood and problem of extensive and regular bank erosion, avulsion and flood followed by massive aggradations renders thousands of homeless during the rainy season. The rivers, in their lower reaches attain the significant physical characteristic of braiding which may be attributed to both incompetence and incapacity of the rivers. That is, most of the rivers can transport neither the total amount of debris nor the size of debris that is supplied to it as bed load. As a result, the riverbeds are rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods.

The rivers under study may be divided into two major groups: (a) large transit rivers originated in high Himalaya represented by three rivers Tista, Torsa and Sankosh with perennial discharge, feed both by rain and melt waters. Deep canyons in marginal part and mega-fans in the foreland indicate very high water discharge and high sediment load. Great alluvial fans and braided channels with frequent avulsions extend far up to the river Brahmaputra and (b) rivers dissecting Lesser Himalaya. The river Jaldhaka and Mahananda fall under this group drains large catchment, deeply incised also in the piedmont, where it is draining the active rising blocks. As a result, its fan surface is developing farther downstream.

The rivers under study are not stable and process of erosion in the steep hilly catchment, transportation of sediment in the river and its subsequent progressive deposition lower down in the river with flatter slope is a continuous phenomenon. In the upper reaches in the plains, the river and their tributaries have got steeper slopes as compared to the lower reaches, thus, the carrying capacity for the silt load in the upper reaches in the plains is comparatively more than in the lower reaches. The river bed, just after it debauches into the plains, consists of shingle and sand, whereas further down in the flatter plains, the alluvial channels mostly consist of coarse and medium silt. Pronounced development of conjugal alluvial fan, produced by diverging drainage system in the catchment area of the Mahananda and Jaldhaka is very much conspicuous in the western and central part of the piedmont zone.

Most of the rivers in this region are rather straight streams. The average slope ratio of the river channel in general cases is much lower indicating an obviously steeper gradient. Average gradient of the channel varies from 1:342 in the Tista to 1:4611 in the Torsa. The river Sankosh with a gradient of 1:1833 followed by the river Jaldhaka with a gradient of

1:3129 within the active plain is rather Swift River. The Tista, the largest river in the north of the Ganga-Padma system in West Bengal, although infested with innumerable island and shoals in its wide channel, is still flowing fairly fast within the studied section a gradient of 1:342.

The length of cross-sections varies considerably from one cross section to another at different locations. There is significant variation in the area of flow from one year to another indicating deposition or erosion at each of the cross sections. Smaller area of section occurs where velocity is higher. The estimation of deposition & erosion, the volume of sediment deposit or scoured over a period of time have been computed and it reveals that the average depth of deposition or scour varies from 1 cm to 18 cm in case of the river Tista, while the same is substantial in case of the river Jaldhaka and Torsa which varies from 6 cm to 72 cm and 17 cm to 72 cm respectively. There is, however, very high scouring observed in the river Sankosh of the order of 165 cm over a period of 14 years from 1986 to 2000. The above studies are only indicative in nature and in no way, can form a basis for planning of any remedial measures.

High intensity rainstorms are found most commonly occurred in sub-Himalayan Jalpaiguri district especially along its northern boundary with the Himalayan margin. Frequency and magnitude of such events have been found significantly reduced at a distance of 20 km from the rising Himalayas. It is also conclusively proved that such events often culminate with flush flood along the downstream in Jalpaiguri district. It is observed that higher the intensity of rainstorm the higher the magnitude of flood in the downstream. Numerous examples of such relations have been depicted in the chapter with 24-hour rainfall record obtained mostly from tea gardens across the district along with their corresponding flood discharge obtained from the respective CWC gauging stations located in the river Jaldhaka and Torsa.

The complex and imposing topography i.e., high mountains, deep gorge like valley, steep slope and alignment to the prevailing moisture laden cloud have exhibited its influence on the regional distribution of high intensity rainstorms. The temporal variations of the flow manifest characteristics of the watershed that influences its run-off. It is observed that the rainstorms of the sub-Himalayan Jalpaiguri district generally do not exceeded 4-day duration. The general synoptic situation associated with the rainstorms is the prevalence of eastern end of the monsoon trough. The severe rainstorms are associated with the presence of depression/low over the respective watershed.

Gradual depletion of the forest from north to south at the expense of agriculture is the most remarkable feature of present day land use in all the studied catchments. The structure and relief together with climatic and soil conditions determine human activity, which is realized mainly through development of the various forms of agriculture, settlement and in minor extent mineral extraction.

Present day land use pattern is the result of human impact ongoing from centuries but its changes were accelerated when the British East India Company took control of Bengal in the mid-19th century. Since then large scale heedless deforestation initiated due to foundation of tea plantations and heavy demand of timber for railway and building construction. The 20thcentury was marked by demographic explosion.

Most of the mountain area is grown by various types of natural forest. It changes from moist deciduous with dominant *Shorea robusta* up to 1000 meterthrough tropical evergreen with *Quercus* and *Castanopsis* up to 2000 meter and *Rhododendron* pure stand in between 2500-2800 meter, to temperate coniferous at the elevation 3000-3500 meter Only upper part of the Jaldhaka and Torsa catchments is covered by sub-alpine fir forest, which gradually changes to alpine grasslands above the upper timberline at approximately 4000 meter. The margin of mountains is usually densely populated and human impact on environment is more visible compare to upper part of Himalayas.

Deeper into the mountains the relationship between major river valleys and deforestation is visible. The river channel widths in their upper and middle courses are stable but closer to the mountain margin they extend laterally. The settlement in this area is confined to the gentle slopes of intermountain valleys suitable for agriculture and close accessible transport routes. This is due to road construction along river courses, which was a dominant feature in the colonization process.

The mountain foreland is built up of alluvial fans and higher elevated terraces. The extension of fans is roughly bounded by the 100 m contour. A significant part of this area is covered by sanctuaries and reserved forest. It consists mainly of *Shorea robusta* the most valuable commercial tree. This forest is mixed with patches of pure deciduous forest with *Schima wallichii* or *Acacia catechu*. Tea plantation occupies the largest part of the alluvial fans. The forest clearance under tea plantations combined with the building of roads and railways has given rise to settlement and trade.

The alluvial plains further south are favoured sites for larger settlements. River banks are not completely protected as a result some parts of floodplain are inundated every year. Alluvial soils offer one of the most productive agricultural lands in the region. As a result, this area experienced the massive transformation of land use/cover system. Nearly all of the natural forests of the plain have been cleared by a process of agricultural colonisation ongoing for centuries.

During monsoon, high intensity rainfall induces devastating floods in sub-Himalayan North Bengal causing large damage to the environment, society and the economy in addition to loss of animal and also human lives. Floods also endanger the vital lines of communications and installations, human habitation, firm lands, forest stands and wild life.

Foothill region of this district is traversed by numerous small streams which may be characterized by a common phenomenon, called avulsion i.e. changing river course. Huge sediment load carried by these streams gets deposited in this zone causing deterioration of channels day by day. The area being very rich in forest land, tea gardens etc. suffer heavy losses every year due to these sand and chemical deposits from flood water.

Flood situation of the blocks of Alipurduar-I, Alipurduar-II, Kumargram, Nagra-kata, Dhupguri, Madarihat, Falakata, Kalchini lying to the left of the river Jaldhaka is highly problematic. The rivers Kaljani, Torsa, Raidak etc. cause flood through numerous streams descending from Bhutan hills which are very much flashy in nature. National Highway and Railway bridges opening of waterways are also not adequate enough to cater to such flood discharges. The area needs to be given special emphasis since it is very rich in natural resources of forest and tea gardens.

Bank failure, river shifting and river deposition in association with high intensity rainfall induced flash flood in sub-Himalayan Jalpaiguri district are primarily nature's way of adjusting fluvial dynamics in the sub-Himalayan North Bengal. Such an adjustment has been deleteriously distributed by the human interferences. The catchment area of these rivers has mostly been deforested and the clearings of the steep slopes have been used for the extension of settlement, agriculture, plantation and communication, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfall, catastrophic soil erosion and innumerable landslides are caused transporting huge amount of sediment to the rivers which are incapable of transporting the load efficiently under the existing hydrological conditions, especially along their lower reaches. As a result, the riverbeds are rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods.

Moreover, the narrow road and railway bridges across the rivers as well as the supporting pillars are always considered to be the barriers, interrupting natural load movement behavior of the rivers. This often cause accelerated deposition at the bottom of the bridge and thereby, narrowing the outlets of the rivers gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and firm lands.

Flash flood has not been an uncommon phenomenon in the North Bengal plains. But the frequency and magnitude of such events has increased many fold during the recent past. Such catastrophic events during 1968, 1993 &1998 demonstrate the enormity of damage and ever-increasing threat to the society, economy and the environment.

Flood hazard mitigation involves measures to reduce the effects of disaster causing phenomena. All actions to reduce the impact of a disaster that can be taken prior to its occurrence, including preparedness and long term risk reduction measures. It also includes the planning and implementation of measures to reduce the risks or man-made hazards, and the process of planning for effective response to disaster which do occur. Disaster mitigation includes scientific analysis of risk assessment, social, economic, legal and technical processes in the development of mitigation measures and administration and political processes in application of these measures.

Floods are caused not only by rain but also by human changes to the surface of the earth. Farming, deforestation, and urbanization increase the runoff from rains; thus storms that previously would have caused no flooding today inundate vast areas. Not only do we contribute to the causes of floods, but reckless building in vulnerable areas, poor watershed management, and failure to control the flooding also help create the disaster condition. For the intensively utilized floodplains of sub-Himalayan North Bengal, the application of these approaches will require considerable political will and cooperation by the stakeholders.

Deforestation via-a-vis environmental degradation in the watersheds of the sub-Himalayan river indeed plays the decisive role in contemporary increased frequency and magnitude of hazards. Vicious cycle of degradation has already been established in the sub-Himalayan watersheds. Perhaps, the only possibility to save the habitable environment lies into the pro-active watershed management. It is thus, our imperative duty to inform the people living in threshold areas within the watersheds (prohibitive/restrictive zone) categorically about the hard reality of possible hardship during the different stages of watershed management processes.

Let us tell our people living in threshold areas (prohibitive/restrictive zone) categorically that you are living in an unsafe area and it is not possible to provide you security against possible flood. The land use pattern, house type must be suitable to cope up the possible threat. The traditional art and life style of ***living with flood*** must be adhered to. However, the life both human and animal along with movable property must be protected through the construction of Flood Shelter nearby preferably within the radius of 5 km.

The model future course of action for comprehensive watershed management vis-à-vis flood management plan in sub-Himalayan North Bengal shall include:

8. Identification of *flood prone area* and plot it on Cadastral map (Scale 1:3960) at Gram Panchayet level.
9. Flood plain zoning of the major rivers at Gram Panchayet Level on Mauza map.
10. Projection of possible damages under different degrees of hazard.
11. Identification of sites for Flood Shelter and facilities needed.

12. Digitization, geo-referring and development of GIS with attachment of data related to the hazard. An on-line linkage with the forecasting agencies will help decision maker to take right decision at right time.
13. It will be possible to arrange for emergency evacuation, rescue for human and animal and also for movable commodities.
14. The GIS thus developed will also be of great help in providing efficient relief measures.

Although, the task is enormous, expensive and time consuming, yet the concern departments with the help of Gram Panchayet can initiate such programme. Expert agency can also be engaged. Such approaches although, would not control flood yet it will definitely reduce the loss and sufferings of the victims to a maximum extent. A portion of the money that spend for the construction of traditional flood protection may be kept aside as the emergency fund for the possible victims.

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