CHAPTER 1

Introduction

1.1 Introduction

Among all the great natural agents, running water can be so intensely active as to seem truly alive. The river moves (as a continuous body), it travels (in many ways), it carries (much besides water), it blows up (all that yields), it builds up (in some places). What the river achieves is nothing less than a continuous chain of work (Crickmay, 1974). They have created much of the majestic scenery we spend our spare time visiting, they formed the floodplains on which many of our cities are built and, in many places, they have left a valuable legacy of sands, gravels and place deposits (Morisawa, 1985). Whether this action is a blessing or a curse depends entirely on its understanding (Crickmay, 1974). Rivers are dynamic and increasingly important part of physical as well as cultural environment. Their behavior is of interest to a wide variety of concerns, ranging from drinking, irrigation, flood control, navigation and water resource development to recreation. They represent a potential threat to human populations and property through flood, drought and erosion (Knighton, 1984). Analysis of river systems is not only concerned with what they look like, it also emphasizes how they behave and why they adjust in the way they do. Rivers adjust in vertical, horizontal and other available dimensions. Vertical adjustment refers to the stability of the bed, while horizontal adjustment indicates the ability of the channel to alter its bank (Fryirs *et* al., 2013). Bank retreat and the delivery of bank sediments to the flow emphasize the importance of interaction between hydraulic forces acting at the bed & bank toe and gravitational forces acting on the in-situ bank material (Carson *et* al., 1972; Thorne, 1982; Simon *et* al, 1999). Bank failure occurs due the fact that downward gravitational force dominates and exceeds the shear strength that holds the bank materials together. In this way, it disrupts transportation, destroys agricultural land, threatens adjacent structures, drastically alters environmental conditions and produces sediment that causes further problems downstream (Schumm, 1999). Therefore, the causes of bank erosion have been a topic of great concern, so a better understanding could lead to its prevention. Although, the amount, periodicity and distribution of bank erosion varies along the channel due to multiple factors. Bank erosion is a natural process but its occurrences at unexpected places hints about some anomalous process is undergoing. In general, channels with non-cohesive bed and bank materials are particularly prone to adjustment. Due to this reason, the upper Mahananda basin generally is considered to be sensitive to adjustment. In the foothill region, the bank height of the river Mahananda are large and bank angels are steepened by fluvial undercutting and by pore pressure in bank materials responsible for failure near the base of the bank, which leads to channel widening.

In this work, the main attempt is to analyze the causes and consequences of bank erosion along with the detection of the nature of bank erosion of rivers of the upper Mahananda basin in Darjeeling Himalaya.

1.2 Study area

For the analysis of bank erosion, the upper part of Mahananda river (also known as Mahanadi in Darjeeling hills) has been undertaken which originates from the Mahaldiram range near Chimli (latitude 26^{0}55’40’’ N and longitude 88^{0}19’12’’E) in the east of Kurseong, in Darjeeling district at an elevation of 2100 m above mean sea level and flows through Mahananda wildlife sanctuary and descends to the plains near Siliguri. It traverses a distance of about 470 km to join the mighty river Ganga in Malda. After leaving the hills, it flows in a southerly direction as far as Siliguri, where it changes its course a little to the west and forms the boundary line between the Terai and Jalpaiguri as far as Phasidewa in the extreme south east of the district (O’Malley, 1907, Darjeeling District Gazetteer). After that, it flows through Uttar Dinajpur, Kishanganj and Malda. It enters Bangladesh near Tentulia in Panchagarh and returns to India. However, this study has been confined to only the upper part of the river upto the confluence of the river with Balason, a little below in Siliguri at Naukaghat area, near third Mahananda bridge (latitude 26^{0}41’37’’N and longitude 88^{0}24’26’’E). Hence, the area of the basin confined within the area of 242 sq. km with the appearance of leaf shape. The rivers of upper Mahananda basin (e.g. the Babu *Khol*a, the Mana *Khola*, the Shiv *Khola*, the Jogi *Khola*, the Gulma *Khola*, the Balason, the Panchanai, etc.) are highly tortuous due to higher gradient. But in plains, they display a strong meandering and braiding tendency. The river regime being perennial exhibits wide strong seasonal fluctuation causing devastating flood during the rainy season but shrinking to the bottom of the valley with a number of shoals, bars etc. during the dry season. These rivers continue to cause intensive erosion and transport heavy loads of sand, silt, gravel, pebbles, bolder etc. annually, which on one hand gives more valuable river borne materials, on the other hand intensive erosion cause frequent destruction of many valuable structure like roads, bridges, embankment, etc. during high discharge period.

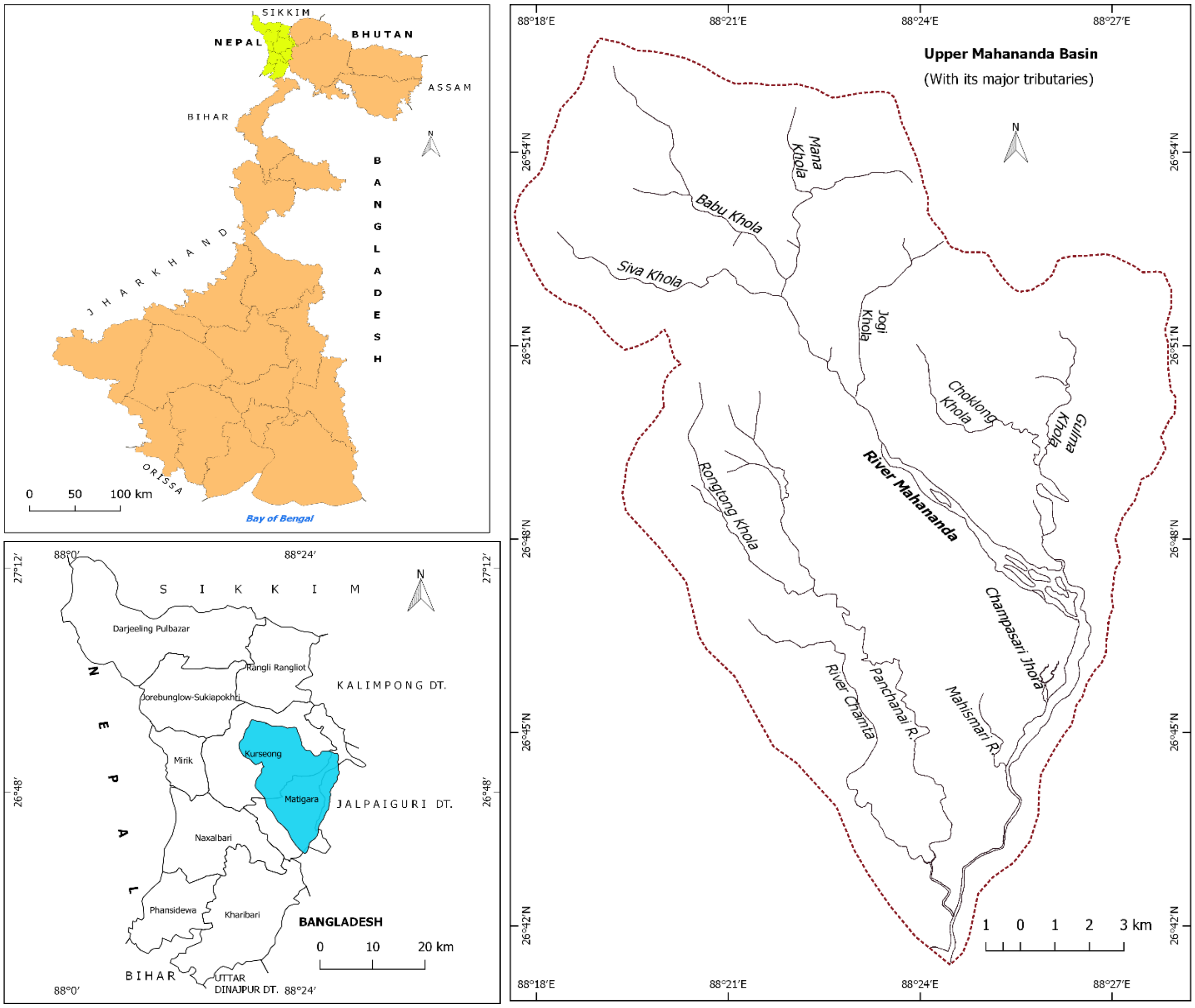

Figure 1.1 Location map of the study area.

1.3 Problems associated with bank erosion in the study area

Darjeeling District is located within the Lesser and Sub-Himalayan belts of the Eastern Himalayas which have a complex geological structure, extensive network of rivers, rivulets, *jhoras*, undulating topography, abandon luxuriant forest cover etc. which make it one of the most famous tourist destinations. However, its beauty seems to be disrupted due to overexploitation as well as unscientific modification of natural resources. Extensive deforestation, unscientific way of land use activity, urbanization, haphazard construction work (i.e. embankment, etc.) on river bed without considering the natural behavior of river system, rapid colonization in active floodplain zone, haphazard and unscientific bed material extraction, suction of water from river bed during non-monsoonal period etc. are responsible for deterioration of the rivers channel in upper Mahananda basin. Moreover, the heavy and concentrated rainfall (from 2500 mm to 4000 mm per annum), frequent slope failure, abundant surface as well as subsurface flow, higher gradient, huge bed load etc. add more and more sediment to the river Mahananda which is incapable of transporting the bed loads under existing hydrological condition and create numerous bars and shoals in plain area, hence reducing the transportation capacity, rising river bed in some places, deposition of sediment in front or bottom of bridge which create more hydraulic pressure on the adjoining banks and collectively produced bank failure and caused flood in this area. However, it has been found that embankments along the bank are made regularly. Even then, during monsoonal period, the river Mahananda and its tributaries especially the Gulma *khola*, the Panchanai, the Mahismari, the Balason have been experiencing a continuous process of bank failure, damages of roads, settlement, bridge, embankment, agricultural land, tea garden etc. Bank erosion of river Mahananda is more prominent at Champasari, Gulma, Salugara, Betgada, Palash, Tarabari, Dimdima *busti* area. Government response to this problem has been limited to the structural measures only and most often measures are taken immediately after the disaster and intervention is taken in the form of relief provision. On the other hand, huge loads of boulders are utilized in anti-erosion work as well as in other constructional work subsequently gets deposited to the river bed at the time of collapse of those structural barriers, which ultimately changes the channel morphology and flow regime of the river. Keeping in view of the above mentioned problem, the study on bank erosion of the upper Mahananda basin has been taken into consideration for better understanding of the nature, cause and consequences of bank erosion.

1.4 Hypothesis of the study

i. There may be a correlation existing among the hydraulic parameters of the river with the bank erosion and failure.
ii. Valley widening associated with an increased number of bars and shoals indicates massive aggradations.
iii. There may be evidence of incision of terrace formation inside the hilly portion that may be evidence of neo-tectonic activity.
iv. Human interventions may also be responsible for bank failure of the study area.

1.5 Aims and objectives of the study

Following are the aims and objectives for the present study:

i. To identify the major bank erosion sites in the study area.
ii. To study the geomorphic characteristics of the study area for better understanding of the occurrences of bank erosion.
iii. To study the cause and mechanism of the bank erosion of the study area.
iv. To examine the relation between the bank materials and the hydraulic parameters of the bank failure sites.
v. To suggest some measures for conservation of overall environmental condition of the fragile area of the Himalaya.

1.6 Methodology

In order to bring a reasonable outcome of the attempted work with keeping in view certain parameters and circumstances, the following methodology has been followed:

Pre-field work

In order to get an overview of the geomorphic character of the proposed area, its geology, geomorphology, climatic condition, soil condition, have been studied by consulting already published documents, maps, Survey of India Topographical maps no. 78 B/5 and 78 B/6 having scale 1: 50000, diagram, Cartosat 1-DEM. Long profile of the channel has been prepared from the topographical map at an interval 2 km. Slope map prepared by the National Bureau of Soil Survey & Land Use Planning (NBSS & LUP) has been used to know the overall soil character of the basin. Daily gauge height was collected from the official websites of the Irrigation & Waterways Department daily flood report. Land use and land cover map was prepared from the Sentinel 2 image, 2015, with spatial resolution 10 m. Data related to the population scenario of the area was collected from the District Census Handbook of Darjeeling District, 1981-2011. Classification of slope was done from Cartosat-1 DEM.

Field work

To get an overview of the physio-geomorphic condition of the study area, the researcher did fieldwork regularly so that the geomorphic character of the area and its relation to the bank erosion can be identified. During fieldwork, especially in monsoon, GPS was used to get spatio-temporal (from 2016 to 2018) distribution and variation of the bank erosion types. Bank erosion rate in the year of 2016-18 was measured by measuring temporal variation of distance between bank line and nearby permanent structures and also by erosion pins. At least 3 erosion pins were installed along each exposed bank, one was placed near the top of the bank just after the break of slope, and one was placed in the middle and one at the bank toe. Pins were made of wood and iron, having diameter about 1-2 cm. Pins were inserted before monsoonal season. Monthly exposure of the pins was measured by scale and finally the sum of all exposure measurements gave the total erosion rate of those selected sites.

The amount and periodicity of river bank erosion is highly variable due to the involvement of a large number of factors. To find out the dominating causes of bank erosion in the upper part of the river, hydrological, meteorological, pedological data were collected from the field observation and other authentic sources. Rainfall data was collected from different tea estates situated at different locations within the basin and also from daily flood reports of the West Bengal Irrigation and Waterways department.

In order to understand the mechanism of the erosion, information on discharge, velocity, geometry of cross section, character of bank materials, etc. have been incorporated. Cross-sectional surveys were done on the month of April and November-December 2016-2018 by using the Auto-level and the Dumpy Level instrument. Width of the channel, flow depth, velocity have been measured directly from the field.

Samples of bank materials were collected from the 14 erosion sites and tested in the Laboratory, with special reference to mechanical properties of the bank soil (sand, silt and clay content). Sieving method was used for it. Vernier caliper was used to measure pebble size. Abney level, cardboard, Compass, Clinometer, ranging rod and tape were used for measuring bank angle, bank height. Rough sketch of the bank profile was drawn in the field during survey time and finalized in Microsoft PowerPoint.

Cross-section of the valley was done to measure terrace height in the hilly part. At some locations Abney level was used to find bank height from channel bed. Anthropogenic activities in the form of extraction, land use, construction on the river were studied by field survey. Weightage-method has been used for the purpose. Bank Erosion Hazard Index (BEHI), Near Bank Stress (NBS) & Bank Erosion Vulnerability Zonation models were used to know the susceptibility of the bank from erosion. A scheduled survey, group discussion among the people and workers in the field was done to know different aspects related to changing fluvial characteristics.

The effect of bank erosion on the adjoining sites has been studied by direct field observation, socio-economic survey among the inhabitants of the affected sites, reports of different official data and reports published by individual researchers etc. Sample of bank site vegetation were taken from the field and charts were prepared for their distribution along the channel throughout the study area. ‘Picture this’ app was used to identify plant species in the field. GPS coordinates were used to map location of spurs, embankment and other conventional measures and were documented in GIS platform.

Post field work

Microsoft PowerPoint, paint etc. have been used for the representation of necessary data and diagrams. Relevant photographs have been used to support each observation. Overlay techniques were used to show the bank line shifting and measuring the eroded area from 2011-18. The GIS software (Q-GIS 2.18, GlobalMapper, ArcGIS 10.1), Google Earth images etc. were used for preparing the necessary maps. Shifting of the water line throughout the year has been shown using historical Google Earth images and Digital Globe images.

An attempt was made to find the relation among bank materials characteristics, hydraulic parameters and erosion rate of the selected site. MS Excel has been used for the tabulation of data. Suitable statistical techniques (e.g. correlation, regression etc.) have been used to find out the empirical relationship among the different variables.

Flood report of India 2014, 2015, 2017, Anti-erosion handbook published by Central Water Commission (CWC) were used for better understanding the conservational measures taken by the government. Annual report of Water and Irrigation Department Siliguri (2009-2016), was consulted to identify the vulnerable points, rescue centers, annual investment in erosion protection work etc.

All the information collected during the entire research period and the actual measures taken by the concerned authorities have been discussed and analyzed. Finally, the researcher has made some suggestions to solve and manage the problem and to reduce the resultant loss.

1.6 Review of Literatures

The Darjeeling Himalayas being a very fragile terrestrial system have encouraged many studies and investigations for its geological, geomorphological, climatic and fluvial characteristics by researchers, government as well as non-government authorities.

First scientific document of the area was prepared by Hooker (1854), his 2-year travel from the year of 1848-1849 depicted the regional geomorphology and typical drainage system of the region. In his diary, he also mentioned a few hydraulic characteristics of river Mahananda which support its navigability for large boats.

Geology of the area was firstly studied by Mallet (1874), and then followed by many scholars, Ghosh (1950), Gansser (1964), Banerjee *et* al. (1980), Acharya (1989), Bhattacharya (2015) etc.

Bengal district Gazetteers of Darjeeling district, written by O'Malley (1907) has consulted for better understanding the district overview such as history of Darjeeling, physical features, natural calamities, socio-economic condition of the people as well as history of other developmental activities of the area.

After the bed, the bank is the second most important component of the river channel. The river bank gradually descends up to the riverbed and thereby may put significant impact on the morphological equilibrium of the channel in relation to its ambient environmental setup. A number of works have been done on bank erosion to understand its cause, mechanism & consequences. Leopold *et* al. (1964), Crickmay (1974), Chorley (1979), Knighton (1984), Morisawa (1985), Fryirs *et* al. (2013), Schumm (2005), have explained hydraulics of stream flow, fluvial processes, mechanics of fluvial erosion & deposition, river morphology, adjustment techniques of channel and its nature of change through time. Schumm (1999) deliberately discussed the stream bank mechanics and the role of bank and near bank processes in incised channels. Also, the complexity of erosion and its response in the fluvial environment.

Starkel (1972, 2004), Froehlich *et* al. (1992, 2000) demonstrated the role of extreme precipitation in causing catastrophic damages over slopes and on floodplains in the area.

The upper portion of the basin is highly landslide prone. Many scholars viz. Lahiri (1973), Sarkar (1999, 2011), Starkel *et* al. (2000, 2014), Mondal *et* al. (2015) have done work to explore the causes of the phenomena in the area. Especially, the hillslope around Paglajhora is notorious for its subsidence history that was initiated during the 1950 landslides in Darjeeling hills.

Several techniques have been developed for measurement and monitoring of bank erosion, but each technique has its own advantage and limitations. Knighton (1972), Lewin *et.* al (1977b), Thorne *et* al. (1979), Hooke (1979), Lawler (1989b, 1992, 1993), Thomas *et* al. (2005), Luppi *et* al. (2009), James *et* al. (2013) had suggested different techniques related with measurement of riverbank erosion.

Stream bank mechanics, bank processes and the role of bank and near-bank processes have been examined by Thorne (1982, 1999), Simon *et* al. (1999), etc. Being a natural process its measurement and prediction still not easy, because so many factors are associated with it.

There are many thesis on fluvial characteristics of the region. Ghatwar (1986) made detailed study of the fluvial dynamics of the twin basins of the Lish-Gish River. Sarkar (1989) made a detailed study on Geo-environmental appraisal of the upper Mahananda basin of the Darjeeling Himalaya, which analyses its pedo-geomorphology, soil, slope, drainage system, landslide incidence etc. Bhattacharya (1993) carried out a comprehensive study on the problem of management of the Rakti basin; Lama (2003) studied the environmental geomorphology of the Balason river basin.

The development of alluvial fan in the foothills of Darjeeling Himalayas was studied by Basu *et* al. (1990) in which the geomorphological and pedological characteristics of the region along with the roles of rivers like Mahananda and their tributaries in the evolution of alluvial fan spread over the vast Terai plain of North Bengal has also mentioned.

Sediment deposited in stream channels reduces water carrying capacity, resulting in overflows that are more frequent and greater floodwater damages to adjacent properties (Julien, 1998). Jana (1995), Tamang (2013) examined the extraction sites mainly preferred to the bank of the river to reduce both labour and transportation cost which ultimately lowers the bank side bed, helps diversion of channel flow towards bank during high discharge period in the study area.

Piegay *et* al. (1997) described various options of bank erosion management based on geomorphological, ecological and ecological criteria.

A series of case studies in the Darjeeling-Sikkim Himalayas have been done by Basu *et* al. (2003) in the article of 'causes and consequences of landslides in the Darjeeling-Sikkim Himalayas, India' to provide a better understanding of this acute natural disaster problem.

Focks, *et* al. (2006) discussed the importance of Vetiver grass for river bank protection measures in different environmental conditions. Evette *et* al. (2009) examines the different forms of bioengineering techniques used to manage rivers and riverbanks, mainly in Europe.

The impact of bank erosion involves primarily the loss of homestead land, housing structure, and cultivable land, crops, infrastructure & communication system. Rahaman (2010), Mondal *et* al. (2012), Baishya (2013), Chatterjee *et* al. (2013) discussed the socio-economic impact of bank erosion on society.

Sarkar (2011) explained the evolutionary history of the valley in the Shiv khola basin. It was first recorded by Dutta in 1966. The gigantic paleo-mass movement, higher permeability, heavy rainfall, thick colluvium deposits are associated with the formation of the slumping valley.

In the ‘Handbook for Flood Protection, Anti erosion & River Training Works’ Central Water Commission, Annual flood report of India (2013-2014) has made a detail discussion about the modern flood management and anti-erosion strategies including a detail view regarding the uses of different construction materials in different environment for the design of flood embankment, bank revetment, spur, drainage improvement work etc. which help to give some strategic measures to protect bank erosion in considering the nature of the river and overall environmental condition one of the most fragile part of the Himalaya.

In the article of semi-quantitative approaches for Landslide assessment, Mandal *et* al. (2015) described about the geomorphic properties such as slope angle, slope aspect, slope curvature, lithological composition and lineament as well as behavior of slope materials and its relationship with landslip in the Shiv *khola* watershed.

Tamang (2015), Wiezaczka *et* al. (2018), deliberately discussed the effect of boulder lifting on the fluvial characteristics of the lower Balason basin and its impact on the fluvial environment and also on the surrounding people. It alters channel geometry, disrupting the pre-existing balance between the sediment supply and transporting capacity. It can lower the valley floor water table and frequently leads to destruction of bridges and channelization structure. The local community at the bank side area also depend on it for their livelihood on this activity.

Mondal *et* al. (2020) examined riparian buffers for riverbank modification in mitigating erosion in rural West Bengal. In this paper, they have discussed the government policies and local people involvement related with the scheme for erosion management and monitoring.

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