



CAUSES AND CONSEQUENCES OF FLUVIAL HAZARDS – *A Hydro-Geomorphic Analysis in Duars Region, India*

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Abstract:

Bank failure, river shifting and river depositions, associated with flash floods, are behavioural response of rivers, adjusting fluvial dynamics in the Duars region along the Himalayan margin. Such an adjustment has been deleteriously disturbed by the human interference in most cases. Most of the Duar's Rivers are known to be highly virulent for their unpredictable nature, devastating floods, extensive bank erosion and channel shifting especially during the rainy season. Implementation of various development schemes, construction of human settlement and roads 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 huge and complex disasters. Practically, the entire North Bengal has been suffering from the agony of floods, especially during the monsoon months. The social, agronomical and ecological repercussions of the huge devastation caused by these floods are multi-faceted. Although it is difficult to comprehend the severity of the situation in all encompassing manner, a brief attempt has been made to capture and delineate the important problems faced by this region.

KEYWORD:

Fluvial dynamics, Flashing foot-hill Rivers, High velocity and sediment discharge, unplanned land use planning, Bed-material load, devastating bank failure, channel avulsions, Catchment Area Mining.

INTRODUCTION

Human activities have had a huge impact on the environment and landscape, through industrialisation and land-use change, leading to climate change, deforestation, desertification, land-degradation, and air and water pollution. These impacts are strongly linked to the occurrence of geomorphological hazards, such as floods, landslides, floods, soil erosion, and others (Ayala & Goudie, 2010). These hazards are strongly related to geomorphology since they are important ingredients of the Earth's surface dynamics. Hazards are the result of sudden changes in long-term behaviour caused by minute changes in the initial conditions (Scheidegger, 1994). The dynamism of the Earth's surface is enclosed within a temporal and spatial scale. The response of the landform to the changes caused by the processes corresponds to the magnitude and frequency of the events, the resistance of the involved materials and the size of the concerned landform (Summerfield, 1991). Natural hazards take place in a certain place and during a specific time, but their occurrence is not instantaneous. Time is always involved in the development of such phenomena. For example, the intensity and duration of rainfall in conjunction

with the nature of the fluvial system, developed also on a time basis, would determine the characteristics of the flooding. The contribution of geomorphology to the field of natural disasters is mainly through the elaboration of hazard assessments. In general, such assessments comprise stages like mapping, modelling, prediction and management proposals, using field observations, photogrammetry, geographical information systems and remote sensing the zonation and mapping of different hazards is done. Modelling approaches consider not only the understanding of present, but past events, leading to accurate predictions of the consequences a geomorphic hazard may have on a determined landscape under a given conditions. Thus, geomorphological work includes not only the understanding but also the mapping and modelling of Earth's surface processes, many of which directly affect human societies. In addition, geomorphologists are becoming increasingly involved with the dimensions of societal problem solving, through vulnerability analysis, hazard and risk.

STUDY AREA:

The study area primarily includes the major river basins and their interflaves which covers the districts of Darjeeling, Jalpaiguri, and Cooch Behar, bounded by latitudes 25°58'N and 27°13'N, and longitudes 87°59'E and 89°05'E. This area represents a zone of transition between the Himalayan Mountains and the Gangetic plains, and displays the typical characteristics of the Himalayan foothills. This part of the foothill zone located to the east of Teesta River is known as the Duars in West Bengal. The entire region is entangled and traversed by a number of large and small rivers and curving the area with typical hydro-geomorphic characteristics. The river system of the studied area is controlled by Teesta, Torsa, Jaldhaka, Raidak, Sankosh etc. and play decisive role for the re-orientation of economy and environment. (Fig. 1)

The Himalayan foothill regions exhibit a young geology containing weak and fragile landscapes. Over the last two-three decades, population of the Duars has been raising rapidly exerting an undue pressure on the forest resources which has led to the ecological degradation in the region. In view of such degradation and increasing geomorphic hazards from the foothill streams, this paper attempts to identify the type and process of geomorphic hazards induced by the streams.

MAJOR RIVER SYSTEM OF DUARS – AN OVERVIEW

It is a well known fact that the foot hills of North Bengal, i.e. Duars region is a zone of high intensity rainfall due to its geographical location and topographical position. The major rivers of the Brahmaputra System, namely the Teesta, Jaldhaka, Torsa, Raidak, Sankosh, etc. originate from Sikkim, Bhutan and Darjeeling Himalayan range. The rainfall is very copious, being of the order of about 3500mm on an average, and ranging from 1000mm to 6000mm. Very heavy precipitation for long duration in the upper catchments, synchronised with heavy local rainfall in the foothills causes enormous flood discharges in the rivers. The Foothill Rivers are flashing in nature. During moderately high in the upper catchments in the hills boulders, gravel and silt are carried downstream with high velocity. When the rivers enter the plains, the velocity is suddenly reduced and the sediment is deposited on the river bed. The rivers try to make up for the reduction in velocity by eroding their banks, forming wide braided channels. The problem in the hills, where the rivers flow in gorges is erosion of soil cover and land slips causing loss of forest and agricultural land. But the problem in the plains is more acute, including erosion, siltation, bank failure, avulsion, and inundation of valuable agricultural lands, tea gardens, villages and towns. Large scale dislocation of vital communication links such as railway, national highways running east-west and connecting Assam and the North East to the rest of India, is frequent due to flooding and avulsion of north-south flowing rivers. Avulsion of one river into another neighbouring one, and also a tendency to avulse by way of lateral erosion, wiping out vast stretches of land along with structures thereon, also pose serious problems.

Mahananda and its tributaries, Mechi and Balason constitute the main rivers belonging to the Ganga System. There is no flood problem in hills of Darjeeling district. However, during heavy rainfall, land slips and landslides do occur due to unstable hill slope formations and steep slopes. Bank erosion is a common feature of Mahananda River system. It is caused in the vicinity of Siliguri town due to high velocity of the river. The river brings huge quantity of detritus consisting of gravels and sand, which gets deposited in the plains, causing reduction in channel capacity. Due to land slips and landslides, valuable tea garden lands, roadways, railways or towns situated on the banks of rivers get damaged. The Mahananda catchment in the plains of Darjeeling and Jalpaiguri districts is comparatively immune to floods. The Mechi River, at its high flood stage, causes inundation of the Naxalbari area of Darjeeling district. The river also causes bank erosion in the vicinity of Siliguri town due to the high velocity developed by flow down the

hilly region.

FLUVIO-MORPHIC HAZARDS AND CONSEQUENCES:

North Bengal is endowed with an intensive network of river systems. In general, the Foothill Rivers carry very little water in the dry season. They flow in a braided pattern within a wide floodplain underlain by deposits of all sizes ranging from boulders to coarse sand. However, during the monsoons, the river dynamics is drastically altered as huge volumes of water and sediments come down the channels. Most of the rivers are considered to be highly notorious for their unpredictable nature, devastating floods, extensive bank erosion and course shifting during the rainy season. Majority of the rivers of North Bengal Terai and Duars originate in the Himalayas and enter West Bengal from a north/north westerly direction, flowing towards south/ south east. The lateral gap between two major rivers ranges from 3km (Jaldhaka-Torsa) to 30km (Gadadhar-Raidak). As many of the rivers originate from the same hill ranges, floods often occur simultaneously in all of them and the rivers coalesce at the foothills to form a single vast sheet of water. (Fig. 2)

Flash Floods in the Foothill Regions of Darjeeling and Jalpaiguri Districts: Although flash flood has not been an uncommon phenomenon in the foothill areas of Darjeeling and Jalpaiguri, the frequency and magnitude of such events has increased many folds during the recent past. Two such catastrophic events in the recent past (1993 and 1998) demonstrate the enormity of damage and ever increasing threat to the biosphere of the Sub-Himalayan West Bengal. 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, unplanned 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 a 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 rivers. The rivers like Balason, Mahananda, Tista, Lish, Gish, Chel, Jaldhaka, Diana, Rehti, Pagli, Torsa, Gaburbasra, Pana, Dima, Kaljani, Bala, Jainti, Raidak, Sankosh, etc. are incapable of transporting the load efficiently under the existing hydrological conditions, especially along their lower reaches. 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 can cause devastating floods, leading to heavy damage to land and property. It also endangers the priceless forest lands, tea gardens, arable lands, settlements and vital lines of communication. Flash floods, even in small rivulets bring down huge amount of water and sediment within a short span of time, and may cause massive damage.

Rise in River Bed Levels: The jurisdictions of Jalpaiguri and Alipurduar Irrigation Divisions is mostly situated over areas situated at the base of the Darjeeling, Sikkim and Bhutan hills, where the bed slopes of rivers and jhoras coming down from the hills are flattened considerably all of a sudden from about 40m/km to about 0.7m/km. This reduces discharge carrying capacity of the rivers and streams and causes natural deposition of silt resulting in change of river courses as well as spilling over banks due to inadequate and reduced waterways. However, this process of natural siltation takes place slowly and the results are visible only after a lapse of a number of years. Since the slopes of the Bhutan hills in this region are unstable, landslides occur frequently at different places. The situation is aggravated further when the green cover of the 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. In order to avoid the numerous bars and shoals formed, the rivers attain the significant physical characteristic of braiding, which may be attributed to both reduced competence and capacity. 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 beds of some rivers are rising, resulting in the lessening of cross sectional areas, which being incapable of incapable of arresting the unusually high monsoon discharges, allow water to spill, causing floods. The process of siltation is, however, meagre in downstream reaches of the rivers. During the period 1984-2000, the river beds of most of the rivers along the Himalayan margin got elevated significantly (Table 1).

The bed level of River Pagli, a major tributary of Jaldhaka, originating in the Bhutan hills and entering India near Lankapara, has been rising at the rate of 1.5m per year as recorded by the North Bengal Flood Control Commission. The details indicating the cause and nature/extent of silt deposition at some vital locations under Alipurduar Irrigation division are summarised in (Table 2).

Bank Failure: Rising of riverbeds often invites devastating bank failure. With excessive siltation and rise of the river bed, the depth of the river valley is reduced. The river tries to compensate for the loss in cross sectional area due this loss in depth by widening its valley. This results in the banks being attacked. The most common mechanism of failure is by undercutting of the bank followed by slumping of the overhanging material. Bank failure is common in both the foothill regions as well as the alluvial plains further downstream. The river banks, being composed of unconsolidated, non-cohesive alluvial fan material, are particularly susceptible to failure. Field study reveals that massive bed material deposits on the Lish, Diana, Rehti, Jainti, Pagli, Bala and Dima during the floods of 1993 and 1998 caused massive bank failure in these rivers at a distance of about 1-10 km from the Himalayan margin. Such bank failure often cause additional burden of silt load to the river. The study on the 1993 flood in the River Jainti revealed that such deposits amounts to over 150,000 cubic metres of materials added into the riverbed within a stretch of 950 metres near Jainti.

Shifting of River courses: Rising of riverbeds and bank failures often culminate into the shifting of the river course. Several studies have shown that the floods often serve as the triggering mechanism for such avulsions.

Re-occupation of pre-existing channel during flooding seems to be the most favourable mechanism of avulsion in the study area. In response to hydrological variability (mainly flood magnitude), lateral erosion and local aggradations, the channel avulses into a nearby channel. After avulsion, the pre-avulsion channel carries significant flow for some time but eventually aggrades and becomes a misfit channel. Low stream power, high sediment yield and proximity of the mountain front have triggered decadal-scale avulsions, some of which may have been tectonically controlled. However, bank instability and hydrological variations are more likely to have caused these avulsions here. Apart from major avulsions, local channel movements through cut-offs and river capture have also influenced the channel movements. Many rivers of this region demonstrate such shifting, of which Torsa, Jainti, Chel, Daikhowa, Jhumur, Diana, Jaldhaka, Rehti, Pana, etc. are noteworthy during the recent past. Such shifting events often cause devastation to the arable lands, forest stands, settlements and communication lines.

Channel widening and resultant loss of land: As already mentioned, river widening is another significant manifestation of the devastating flash floods in the Sub-Himalayan West Bengal. Rivers tend to wide their valley to cope with excessive discharge during flash floods, as well as to make up for the loss in cross-sectional area due to siltation of beds. Study on the river Jainti, Dima, Bala, Pana, etc. since 1993 revealed that such increase in some sections have been as high as 250% during the last 8 years. 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 2-3 times in their valley width during the last 100 years. There is every possibility to form a coalescing mega-valley within next 50 years in the course of extreme events like very high intensity rainstorms followed by flash floods of great magnitude.

Loss of Forest Resource and Biodiversity: One of the most important direct losses caused by flash floods is the destruction of the rich tropical forests. Rivers encroach on adjacent forest lands by channel shifting or bank failure. Study in the Buxa Tiger Reserve area revealed that in between 1993 and 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 were approximately 15,000 million Rupees. Shifting of rivers like Jainti, Diana, etc. has destroyed rich biodiversity of the forests adjacent to them. Huge dolomite dust transported by the floodwaters accumulates on the forest floor and raises the pH value of the soil (pH 7.5-8.1 recorded near Jainti). 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. Dolomite dust deposited on the forest floor has also been found to be responsible for the destruction of undergrowth and the rich biodiversity of this area. Loss of forest lands also exerts detrimental effects on wild life of this region through habitat destruction. The forests of North Bengal, which are directly linked to forests of Bhutan and Assam, form important migration corridors for wildlife. Fragmentation of the forest tracts thus also hinders animal migration.

Loss of Tea Gardens, Arable Lands and Settlements: Bank erosion and river channel shifting lead to loss of acres of valuable tea gardens, agricultural fields, settlement area and lines of communication. In between 1993 to 1999, 75 hectares of tea garden land was lost forever due to bank failure and floods, the losses amounting to Rupees 1,500 million. Loss of acres of fertile agricultural land due to channel shifting, bank failure and devastating floods deserve special mention.

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 on many traditional crops, especially tea. In some extreme cases, calcium crust may also develop and thereby once fertile soil may turn sterile. Though inundation of the riverine alluvial lands is generally considered to be a blessing, it is not so in the Duars region. The rivers originate from Bhutan hills which are full of dolomite, limestone, talc, gypsum, etc. All these minerals contain calcium carbonate and other basic materials. Natural pH values of these river waters are 11-13 which is highly alkaline. The river banks have a series of tea gardens, which need acidic soil, with pH values less than 7. If flood waters inundate a garden, the entire garden becomes unproductive. Accumulation of calcium on the tea garden soil has detrimental effect both in terms of productivity and quality. Productivity is decreasing in many tea gardens and the quality of tea produced 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 customers.

Deterioration of Water Quality and health hazards: Dolomite dust also results in dissolving calcium into the river water and thereby deteriorating water quality of these rivers. This has destroyed the aquatic diversity of these rivers and also affects soil-water relationship adversely. Formation of calcium crust of soil surface prevents infiltration and reduces the lag time significantly and increases surface runoff and thereby the probability of floods. Dissolved calcium also infiltrates into the subsurface through the soil pores and thereby deteriorates the quality of subsurface water as well. Dolomite dust and its accumulation through floodwater in the foothill area is causing serious health hazard to the local people through the contamination of water, air and food. Study reveals that the incidence of kidney stone is found to be 2 times more among the people residing in Jainti-Rajabhatkhawa-Chamurchi-Birkand-Makrapara-Lankapara area.

FACTORS RESPONSIBLE FOR THE HAZARDS:

The Duars region is flood-prone by nature because of its proximity to the Himalayan hills and the intensive network of rivers. There was a disastrous flood in 1787 when the Tista deserted its channel towards the Ganges and emptied itself into the Brahmaputra. There had also been floods in the Tista in 1881, 1892, 1902 and 1906. Floods recurred in 1922-23, 1948, 1950, 1954, 1968, 1993, 1999, 2000, and so on. No decade escaped from the floods. All the riverbeds in the district have risen to the height of 1 to 2.5 metres in between 1985 and 1999. Severe bank erosion has caused diversion of the course of the rivers namely the Tista, Lish, Gish, Chel, Diana, Rethi, Jalbhaka, Gilandi, Pagla, Dima, Jayanti, Kaljani and the Raidak etc. between 1993 and 1999. The riverbeds of the district have expanded by 2 to 4 times in the last 100 years. If the destruction of the environment continues at the present rate, in all probability by 2,050 creation of a coalescing Mega-valley consisting of some rivers within the radius of 3 to 15 kilometres at the Himalayan foothills is obvious. This would mean forever destruction of nearly two-thirds of the Tea Gardens and Forests of the area.

The contributory factors for reduction in carrying capacity of rivers, thereby resulting in floods and erosion can be summed up as follows:

Rainfall Pattern: North Bengal is one of the rainiest parts of the Himalayan margin. Mean annual rainfall fluctuates between 3000 and 6000 mm and the highest totals occur close to the steep front of the Lesser Himalaya. Till late 1980's, the Duars region used to be characterised by well distributed rainfall from the end of April to the end of October. Such a pattern, which is favourable for the growth of tea bushes, was conducive to rapid establishment of the tea industry in this area during the first half of the 20th century. The agricultural practices adopted by the local population was also synchronised to a well distributed monsoon rainfall pattern, assuming a low to medium rainfall during April-May, medium to heavy rainfall during June-August, and medium rainfall during September-October. Two common crops cultivated here are jute (beginning of April to mid August) and rice (beginning of August to end of November). In the absence of irrigation schemes, the agriculture here was mostly rainfall dependent. However, during the late 1980's and 1990's, this crucial climatic phenomenon of well distributed rainfall has given way to increasing frequency of concentrated spells of heavy rain. This causes the months of April and May to be mostly dry, with extra heavy rainfall in July and August, and again, a relatively dry September-October. Tea bushes are sensitive to such climatic fluctuations. Production of tea has been falling and the tea industry is incurring losses. Such rainfall events are also harmful to the existing agricultural pattern. Moreover, continuous heavy rainfall concentrated within a few days, or sometimes a single day increases the risk of flash floods. The danger is even more when such rainfall events occur in late monsoon months, when the groundwater and surface storage potentials are already filled up, leading to a huge volume of surface runoff. Due to unprecedented

concentrated rainfall, wide variation of discharges can be observed in the rivers. River Pagli, mentioned earlier, displays the worst case of the above mentioned problem. Prior to 1996, the maximum discharge was estimated at 365 cumecs. In the year 1996, it was observed to be as high as 965 cumecs. This massive rise of discharge caused failure of almost all structures which were constructed by the North Bengal Flood Control Commission for protection of its adjacent areas. Simultaneous occurrence of snowmelt on the high mountains and rainfall in the lower reaches sometimes lead to overflowing of the perennial rivers.

Deforestation: The catchment areas of the hilly streams which were thickly wooded till the beginning of the 20th century soon fell prey to the aggravation of landslips and surface erosion with the large scale deforestation, jhum cultivation on steep slopes, uncontrolled grazing of cattle, extraction of forest produce etc. Massive deforestation has been taking place in North Bengal over the past two decades. The land is cleared for extension of settlements, agriculture, plantations and communication lines. Mining activities in the upper catchment areas of rivers also contribute to deforestation. Illegal cutting of expensive timber, both in India and Bhutan is a prime cause of deforestation. In spite of strict legal restriction, large scale theft of forest wood is still taking place due to poor infrastructure of the Forest departments of both the countries. Poverty, backwardness, and ill-will of the people are prime causes of such illegal activity. Deforestation has far reaching consequences in aggravating the flood situation. In the absence of forests, rainfall may get reduced or be concentrated in short irregular spells. Exposure of bare rock and soil surfaces increases soil erosion, degradation of land and landslides in weak rock strata. All these contribute to increase in sediment load of rivers, ranging from boulders to sand sized particles, and consequent siltation and rising of river beds.

Landslides: The Himalayan ranges in the upper catchments of the North Bengal Rivers are prone to serious landslides due to their characteristic geologic composition. Also, increasing deforestation, construction and mining activities in recent years are causing intensive erosion of topsoil. Deforestation in the rivers catchments for expansion of settlements plantations, agriculture and communication disrupt the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfall, innumerable landslides are caused transporting huge amount of sediments to the rivers. Road engineers annually face the problem of clearing landslide debris and keeping the roads open. As many of these landslides occur in inaccessible areas, no systematic of reliable data are available on the extent of the problem and the amount of silt contributed from this source. Major disasters have occurred due to abnormal high rains in the upper catchments, causing landslides in the gorges through which the rivers flow. These narrow, steep sided gorges are often cut out of soft rocks which fail due to heavy rain and high velocity of the rivers. Large volumes of sediment come down into the river, silting up their lower reaches. These land slips sometimes assume such magnitude as to completely block the waterway, forming temporary lakes behind rock dams. Ultimately, the dam bursts with increasing pressure of water. This increases the intensity of flood many times, due to simultaneous release of water stored in the temporary lake along with the storm runoff in the upper catchments of the rivers. Most of the landslides have never been treated scientifically with proper protective measures and they are in the habit of expanding their territories during monsoon. This often adds more and more silt to the rivers, which are incapable of transporting the loads efficiently under the existing hydrological conditions, especially beyond the foothill zones.

Catchment Area Mining: The Bhutan hills adjacent to North Bengal are endowed with valuable minerals like dolomite, limestone, gypsum, talc, quartzite etc. Minerals and building materials are quarried for industrial and construction purposes. Open quarrying is being practised in the hilly catchments of rivers with dumping of the overburden on hill slopes. With heavy shower, the whole material is washed down the rivers and leads to huge increase in silt charges of the flood waters. Hectares of land are cleared for mining and are left barren. There arises a responsibility on the part of the mine owner to rehabilitate the mine spoils so that the mine area recovers under an adequate vegetation cover and contributes least amount of sediment to the stream flow. Legislations have been passed to limit mining activities in both India and Bhutan. However, even in the Indian region, illegal mining activities are going on. Due to continuous quarrying of minerals for manufacture of cement and especially for extraction of dolomites in Bhutan hills, radical change in river behaviour has been noticed in recent years, causing spilling and massive sand and debris deposition in the fields otherwise fit for multiple cropping. This phenomenon has caused national loss in terms of fertile lands and adverse aspects of floods affecting the people.

In-Stream Quarrying: Quarrying of boulders from the river beds is a controversial issue. Though few experts are in favour of quarrying boulders from river beds which are a victim of siltation, most experts think that it is a threat to the river ecological balance. Due to the natural deposition of boulders near the

gorges, a number of hydraulic jumps are created in the longitudinal profile of the river. These cause substantial dissipation of kinetic energy of the streams and reduce the chances of devastation downstream. Extraction of boulders from the river bed near the gorges where they are generally abundant tends to disturb the regime of the river on the upstream side and it is observed that the quantity extracted is replaced by boulders rolling down from upstream within the next flood season. The hill slopes which are resting over these boulders beds are disturbed and have a tendency to slip. The boulders available from the slips settle in the cavity formed due to quarrying, whereas the finer particles, which are 8-10 times the boulders in quantity, are washed further down by flood waters and settle on the river beds in the plains. It has also been observed that quarrying of gravels from relatively lower reaches are being done nearer to the existing bank line instead of the middle third, which invites the main flow near to the bank and causes bank erosion. Moreover, in the lower reaches of the river, the river tries to erode its banks and widen itself to compensate for the loss of depth due to siltation. The bank protection and other works are taken up with boulders extracted from the river beds itself near the gorges. Engineers have lost sight of the bed effects of such extraction in their zeal to protect the areas in the lower reaches. As more boulders are extracted, the trouble is increasing day by day and the whole affair has turned into a vicious cycle.

Human Encroachment: With the increase of population and with improved communication facilities, there has been continuous human encroachment on forest lands within the river catchments. Human occupancy in the dry river bed of river and in active flood plain obstructs the free spilling and natural flow of river, which results in siltation. In this area a railway and a national highway exists side by side roughly parallel to the mountain front at a distance of 0-5 km. There are many cases of encroachment on the waterway at the road and railway crossings in order to reduce the construction cost. The narrow road and railway bridges spanning the rivers as well as the pillars supporting them are always considered to be barriers to the natural flow of the rivers, interrupting their natural load movement behaviour. This obstructs the free flow of water and causes extreme drainage congestion, heavy siltation on the upstream side of the structure, followed by bank erosion and widening of the river bed. Waterway provided at some existing bridges of PWD and Railway is quite inadequate to cope with maximum flood discharge. This causes abnormal high afflux on the upstream side of the bridge and multiplies flood problems to a great extent. Often there is accelerated deposition at the base of the bridge, gradually narrowing the outlets further. Such constrictions, sometimes worsened by the entanglement of trees uprooted by voluminous flows of the flood often multiply its effects many times, damaging the bridges, human habitations and farmlands.

CONCLUSIONS:

Geomorphological research can provide theoretical and applied approaches to the prevention of natural disasters in terms of origin and dynamism of the physical processes. Furthermore, geomorphologists could also offer important contributions based on the understanding of the interaction between natural hazards (natural vulnerability) and the societies (human vulnerability). Consequently, they should be involved to a greater extent. Hazard assessment is a key part within the risk analysis process. Certainly, geomorphologists have contributed enormously on this matter. Nevertheless, a greater progress would be achieved if vulnerability analysis were also taken into account.

The North Bengal Rivers undergo drastic changes in response to variation in flow regime and sediment transport pattern. The major rivers in this region, the Mahananda, Teesta, Jaldhaka, Torsa, Raidak, Sankosh, along with their tributaries, have been experiencing a continuous process of migration by way of bank erosion during flood periods. The severity of floods has further amplified under the influence of human intervention. If this recurrent phenomenon is not mitigated, it would be difficult to achieve the economic development of the region in spite of the activities and efforts being undertaken by various agencies.

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Table 1: Rise in River bed Levels during 1984-2000

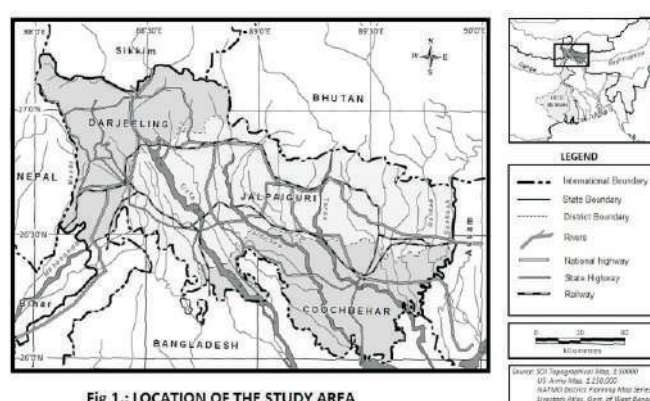
River	Period of Measurement	Location of Measurement	Amount of Elevation (m)
Tista	1985-2000	Jalpaiguri town	1.100
Jaldhaka	1986-2000	NH-31 bridge, Gadhaierkuthi	0.900
Torsa	1985-2000	NH-31 bridge, Madarihat	0.900
Sankosh	1987-2000	NH-31 bridge	0.800
Balason	1984-2000	Near Matigara tea garden	1.124
Mahananda	1984-1999	NH-31 bridge, Champasari	1.980
Kaljani	1992-2000	Near Alipurduar	1.310
Lish	1982-2000	Bagrakot	2.490
Gish	1982-2000	Odlabari	1.980
Diana	1990-2000	NH-31 bridge	2.012
Rehti	1990-2000	Near Chamurchi	2.410
Dima	1991-2000	Near Rajabhatkhawa	1.800
Bala	1991-2000	Near Santalabari	2.145
Jainti	1991-2000	Jainti	3.050
Pagli	1993-2000	Near Makrapara	2.540

Source: North Bengal Flood Control Commission, Jalpaiguri

Table 2: Causes and Nature/ Extent of Silt Deposition

Location	River	Adjoining downstream areas under Indian territory	Rate of siltation per year	Cause of excessive siltation	Result
Pagli-Bhutan area	Pagli	Tulsipara, Lankapara, etc.	1.5 m	Extracting of dolomite from Bhutan hills and deforestation in Bhutan areas jointly causing excessive landslides and siltation downstream	The embankment on the left bank of river Pagli is being breached almost every year and necessity of raising the embankment arises every year.
Madarihat-Totopara road	Titi-Bangri	Madarihat, Totopara, etc.	1.0 m	-Do-	The same problem is being faced on the left bank and the link road between Madarihat and Totopara gets cut off even during moderate flood. Spilling is a recurrent problem in this area affecting the lands and adjoining inhabited areas.
Chamurchi	Rahti-Sukreti	Chamurchi, Binnaguri army cantonment, etc.	0.43 m	Quarrying and blasting in Bhutan hills aggravating the problem of landslides and other problems thereafter	The situation is aggravating gradually and adjoining areas and structures are likely to be affected very soon.
Jaigaon	Hasimara jhora	Jaigaon	1.0 m	Excessive deforestation in the Bhutan hills and landslides thereon	The adjoining road connecting Jaigaon to Phuentsholing in Bhutan gets delinked frequently. Areas on both banks get inundated.

Source: North Bengal Flood Control Commission, Jalpaiguri



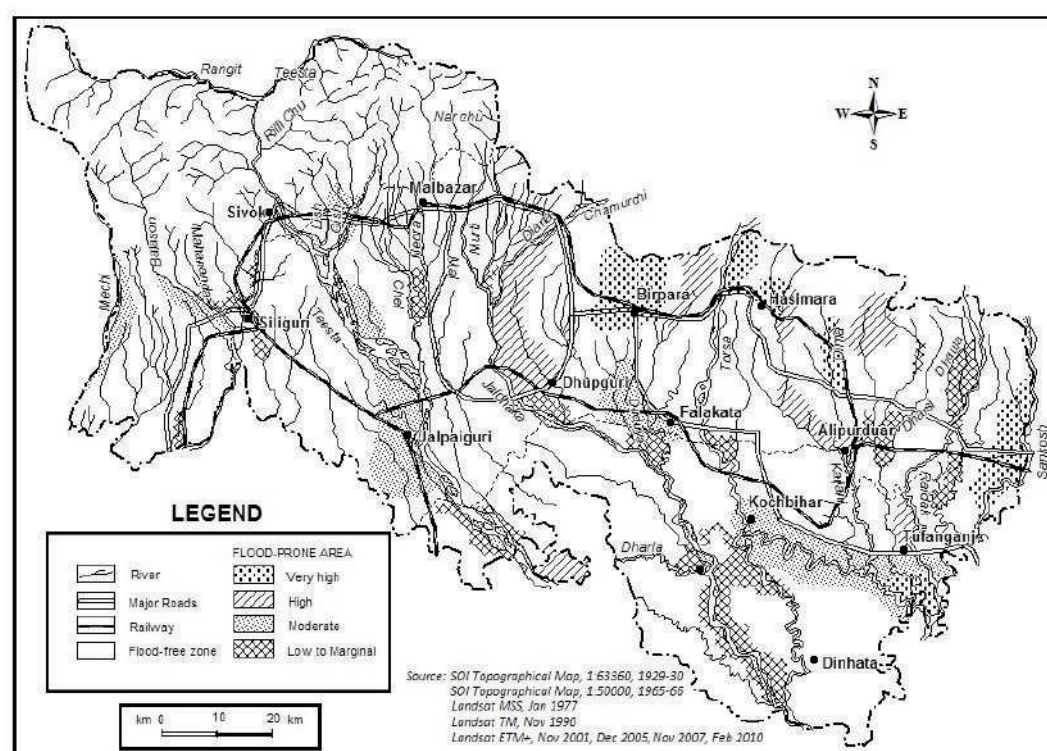


Fig. 2: FLOOD-PRONE AREAS OF SUB-HIMALAYAN NORTH BENGAL