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Archives of Applied Science Research, 2012, 4 (1):99-110
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

Impact of bank material on channel characteristics: A case study from Tripura, North-east India

Nibedita Das and Sudatta Wadadar

Department of Geography and Disaster Management, Tripura University, Suryamaninagar, Tripura (W)

ABSTRACT

The River Haora of Tripura State is a part of the Meghna Drainage System. In order to identify the nature of different bank materials and related changes in channel characteristics, an intensive field study was carried out in some selected parts of the River Haora in West Tripura District. The study area extends for a total stretch of 12.61 km from Reshambagan (23°50.208'N, 91°18.696'E.) in the downstream through Khayerpur (23°50.770'N, 91°20.709'E), Ranirbazar (23°49.679'N, 91°21.938'E), Mekhlipara (23°49.864'N, 91°21.639'E) up to Mohanpur (23°49.908'N, 91°21.639'E) in the upstream. Presence of sand, silt or clay makes the difference in the rate of liquefaction at the base of the river bank. Bank failure leads to change in channel characteristics through increase in sediment input, increase in channel width, decrease in channel depth, formation of mid channel bar, point bar etc. Moreover, human intervention leads to weakening of the bank base through illegal lifting of huge amount of sand using pumps. This activity leads to the draining out of bank toe materials towards the channel, thereby weakening of the bank base. During rainy season with increase in river stage (bank full discharge), the bank maintains an equilibrium condition with the pressure of river water. As soon as water level recedes, the equilibrium condition breaks down and bank failure takes place. The study reveals that the rate of failure is high at the sites where high percentage of sand is present in the middle or lower portion of the bank. Ultimately channel width increases and side by side changes in channel geomorphology leads to changes in channel cross-sectional area.

Key Words: Bank material, Channel width, Bank failure, Haora River, Channel characteristics.

INTRODUCTION

Bank erosion is the lateral movement of bank. Bank erosion is proportional to *erodibility* and *erosivity*. Erodibility is the resisting force which is intrinsic property of bank, whereas erosivity is the driving force which is the property of the hydraulics. Erodibility is indirectly dependent upon susceptibility to weathering as well as susceptibility to removal and transportation. Given a certain condition of applied stress, erodibility may be measured in units of volume or mass per unit area per unit time. Erodibility would depend upon the ratio between the portion comprised of particles of fine sand and the quantity and quality of the binding silts and clays. As the percentage of clay or aggregating materials increases, soils are less erodible. Shear strength of a soil also appears to be related to erodibility. The particle size distribution and water content have effect on shear strength.

In order to predict bank erosion, Bank Erosion Hazard Index and Near Bank Stress Index are calculated. Different BEHI variables include bank height ratio, root depth ratio, weighted root density, bank angle, surface protection, bank material, stratification etc. For the present study only bank material has been considered. Differential physical properties of cohesive and non-cohesive bank materials result in marked differences in erosion rates, erosion processes and failure modes. Although fine-grained materials are resistant to fluid shear, they tend to have low shear strength and are susceptible to mass failure. The amount, periodicity and distribution of bank erosion are highly variable as they are influenced by a multitude of factors. In general terms, bank erosion is accentuated under high discharge conditions (bank full stage), but the effectiveness of these flows is determined by bank condition at the time of the event. The effectiveness of weakening fluvial erosion and mass failure processes induce considerable variability in the rates of bank erosion, instability and retreat. The strength of less cohesive basal materials controls bank stability and thereby channels width [9].

Bank erosion entails two phases, namely detachment of grains from the bank and subsequent failure and collapse. Blocks of bank materials slide or fall towards the toe of the bank, where they remain until they are broken down or entrained by the flow. Failed block, in turn, may temporarily protect the toe of the bank from erosion. This pseudo-cyclic process has an important role in controlling bank form, stability and rate of retreat. Bank failure leads to change in channel character through increase in sediment input, increase in channel width, decrease in channel depth, formation of mid channel bar, point bar etc. thus change in channel geomorphology.

The Study Area: The River Haora is a west flowing river located in the western part of Tripura, the second smallest state of North-East India. It extends from 23º44' N to 23º55'50'' N latitude and 91 º 15 'E to 91 º 35' E longitude. The Haora River is a sub-basin of the River Titas of Bangladesh which is again a sub-basin of the River Meghna. In order to identify the relation between nature of bank material and channel cross-sectional area, a stretch of 12.61 km from Reshambagan (23°50.208'N, 91°18.696'E.) in the downstream through Khayerpur (23°50.770'N, 91°20.709'E), Ranirbazar (23°49.679'N, 91°21.938'E), Mekhlipara (23°49.864'N, 91°21.639'E) up to Mohanpur (23°49.908'N, 91°21.639'E) in the upstream was selected. The distances among the sites are 4.5 km, 3.06 km, 0.40 km and 4.65 km respectively.

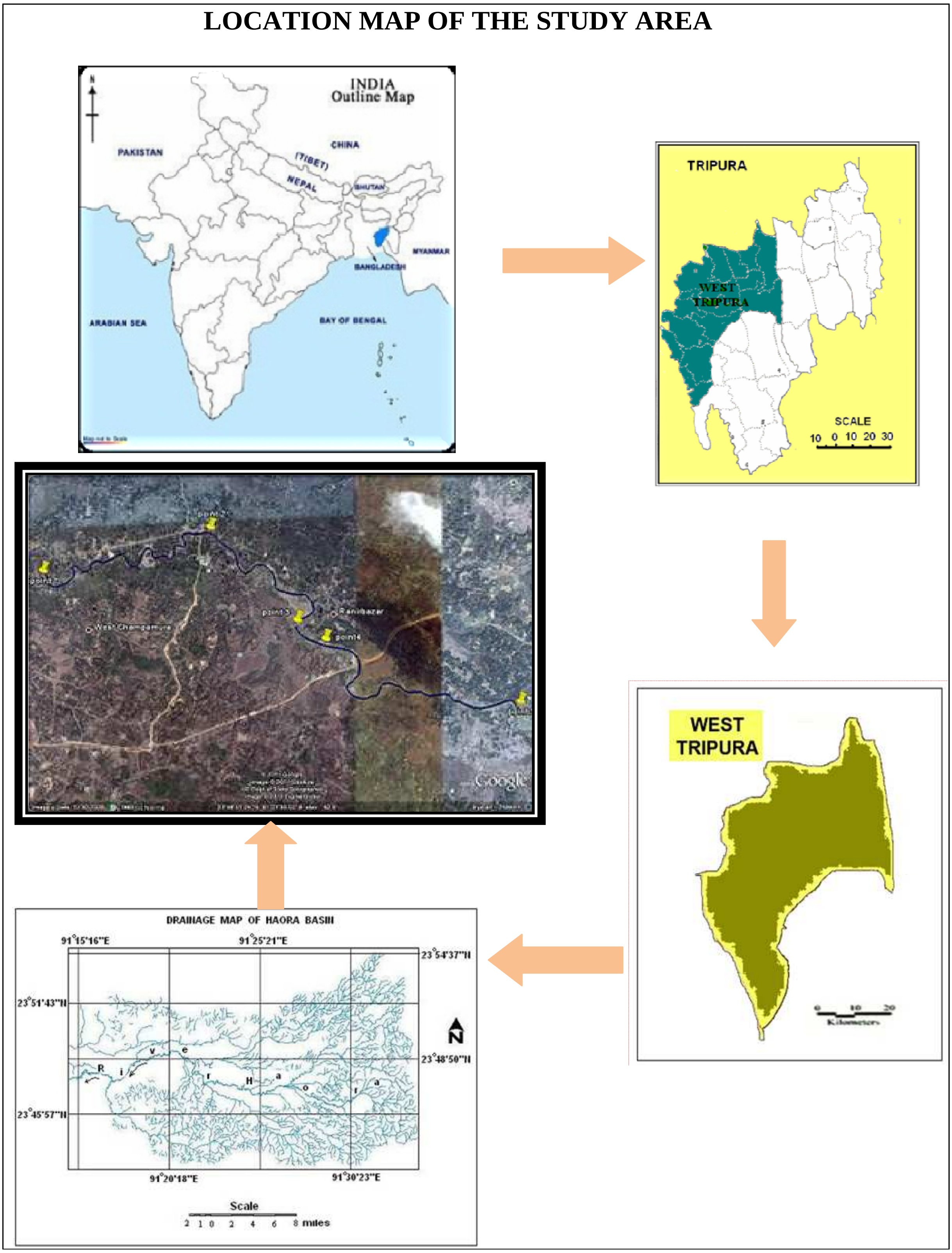

Fig. 1: Location map of the study area.

In order to study the relation between nature of bank material and channel characteristics the knowledge on *geological formation* of the study area is essential. Tripura is located in a neo-tectonic zone, considered as a part of Assam-Arakan geological province. The province was a basin which reflects a tectonically mobile trough whose evolution has taken place gradually from the mobile geosyncline by the uplifts of the earlier region and consequent reaction of basement lineament near shield area. The rock formation of this area is represented by the sedimentary rocks which range in age from Miocene to *loosely consolidated sediments* of Recent Period. The rocks are *siltstone, sandstone and clay*. The rock types are repeated as layers one over the other. There is a layer of alluvium which is of Recent Series. The study area is characterized by the presence of newer and older alluvial *soils*. Few parts of the river basin are occupied by red sandy and lateritic soil. The study area falls under humid tropical climate with an average annual *rainfall* of > 2200 mm. The amount of *bank full discharge* is 155.761 m^3/s. The river carries 3418.4259 metric ton *sediment load* composed of coarse, medium and fine texture of sand particles. The River Haora is a 6^{th} *order* stream with *bifurcation ratio* of 4.10. The overall drainage character is coarse with streams having *dendritic pattern*. Dissection is very high (> 0.9) in the hilly areas i.e. the source region where drainage density is high (> 6 mile/sq. mile). Bank instability and erosion frequently results in excessive sediment input into the channel and thus affects the channel morphology through increasing width and decreasing depth.

Aims and Objectives

Aim of this research work is to study the nature of bank material and its effect on the river. It is achieved through the following objectives:

(1) To analyse the nature of river bank materials of some selected sites through soil sample analysis.
(2) To study different hydrological parameters of the River Haora of those selected sites.
(3) To establish the relation between the nature of bank material and channel width.

MATERIALS AND METHODS

The whole work has been done on the basis of primary data collected from the field through intensive observations and measurements.

Data Base:

- SOI topographical map No. 79M/5 and 79M/9 of 1:63,360 scale.
- Satellite image from Google Earth.
- Soil samples collected from different parts of the river bank.
- Measurement of width and depth of the river at selected sites.
- Measurement of river bank slope using Clinometer.
- Measurement of suspended load using Suspended Load Measurer.
- GPS survey at those points.
- Literature survey.

Methods:

- Marking of GPS points on the image in Google Earth.

- Drawing of cross-sections using hydrological data and Clinometer readings measured in the field.
- Calculated cross-sectional area (W*D), wetted perimeter (length of the contact line between water and river bed and bank) and hydraulic radius (cross-sectional area / wetted perimeter).
- Adobe Photoshop 7.0 was used for better representation of the cross-sections.
- Drying of sediment samples.
- Soil Hydrometer Test carried out in the Fluvial Hazard Analysis Laboratory of the Department.
- Identification of soil types from Textural Triangle.

RESULTS AND DISCUSSION

Cross Section I at Khayerpur:

Plate 1: Cross-section site at Khayerpur (23°50.770'N, 91°20.709'E)

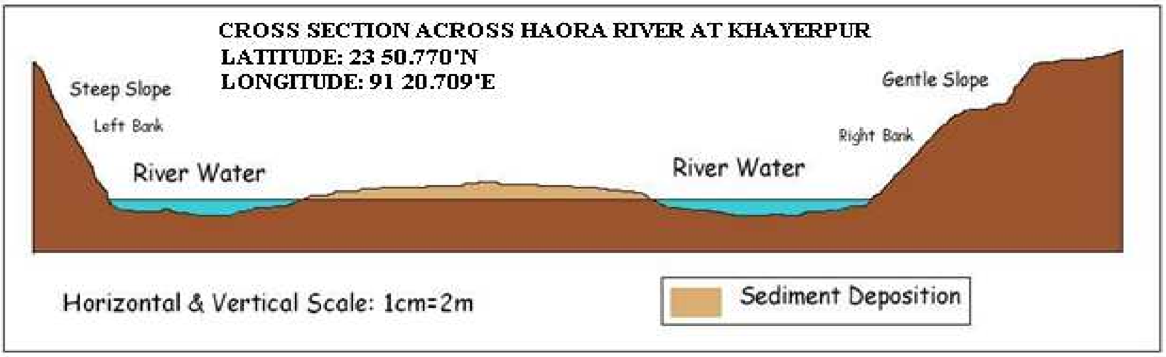

Fig. 2: Cross-section across the Haora River at Khayerpur

Season : Pre-monsoon
Water width : 20 m
Average Depth : 0.24 m
Cross Sectional Area : 4.8 m^2
Wetted Perimeter : 16 m
Hydraulic Radius : 0.3 m
Sediment Load : 165 mg / l

At this site a wide mid channel bar is visible with a width of 14.25 m. The depth of water is very shallow (only 0.24 m) in both sides of the bar (highest depth in the left of the bar is 0.56 m, and highest depth at the right of the bar is 0.53m). The left bank has a steep slope, i.e. 65°, the right bank has a gentle slope and this bank has some breaks in slope. The average slope of the right bank is 28°37.3'. As the field survey was carried out during pre – monsoon season, there was lack of water in the river and huge channel deposition prevalent. Cross-sectional area (W*D) is only 4.8 m^2, wetted perimeter (length of contact between water and channel bed and bank) is 16 m which means less water is in contact with the channel, so friction from the bed and banks is reduced. Hydraulic radius (cross sectional area / wetted perimeter) is 0.3 m which means the river is aggrading in character.

In order to know the nature of bank materials, soil samples were collected from bank top, middle and bottom. Due to the absence of any basal slope the samples were collected from the bottom itself. Then percentage of sand, silt and clay in the samples were calculated by Soil Hydrometer Test in the laboratory. Then SDA International Soil Textural triangle was used to determine the exact soil type present at different parts of the river bank.

Table 1: Analytical Results of Soil Samples Collected From Different Parts of the River Bank at Khayerpur (February, 2011)

Particle / Position	Sand (%)	Silt (%)	Clay (%)	Soil type
Bank top (0 m)	75	24	01	Loamy sand
Middle (1 m)	80	19	01	Loamy sand
Bottom (2 m)	85	13	02	Loamy sand

Source: Measured by the researcher in the Laboratory

Less cohesive bank material i.e., sand dominates the middle and bottom of the bank, leads to maximum erosion which ultimately leads to failure of the upper bank. This process is directly responsible for the increase in channel width and channel accretion in the downstream.

CROSS SECTION II:

Season : Pre-monsoon
Water width : 24 m
Average Depth : 0.0152 m
Cross Sectional Area : 0.36 m^2
Wetted Perimeter : 13 m
Hydraulic Radius : 0.028 m
Sediment load : 124 mg / l

In this profile two mid channel bars are present. Amongst them one is small with a width of 3.4 m and the other is large with a width of 13.6 m. At the right bank the signs of human intervention are prominent. From the profile it is seen that water is present at the right bank just like a pool. It is formed due to human intervention through continuous collection of sand from the river bed. The slope is also cut off by the people in the right bank. Therefore an abrupt change in slope is found. The right bank has a gentle slope of 27° whereas the left bank is steeper with an angle of 47°40'. Here the river is extremely shallow (0.0152 m) and therefore all hydraulic variables show very low values. Wetted perimeter is 13 m and cross sectional area is only 0.36 m^2. 0.028m hydraulic radius indicates very high aggrading character of the river at this cross-sectional point.

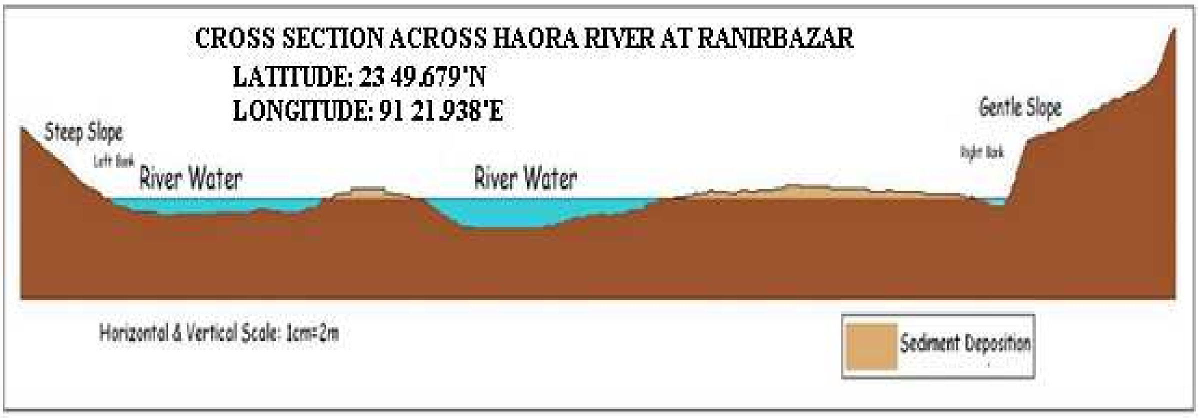

Fig. 3: Cross-section across the Haora River at Ranirbazar

Plate 2: Cross-section site at Ranirbazar (23°49.679'N, 91°21.938'E)

In order to know the nature of bank materials, soil samples were collected from bank top, middle and bottom and the percentage of sand, silt and clay in the samples were calculated with the help of Soil Hydrometer Test in the laboratory. Then SDA International Soil Textural triangle was used to determine the exact soil type present at different parts of the river bank.

Table 2: Analytical Results of Soil Sample Collected From Different Parts of the River Bank at Ranirbazar (February 2011)

Particle / Position	Sand (%)	Silt (%)	Clay (%)	Soil type
Bank top (0 m)	75	15	10	Sandy loam
Middle (1 m)	85	15	00	Loamy sand
Bottom (2 m)	90	10	00	Sand

Source: Measured by the researcher in the Laboratory

At Ranirbazar site, soil texture in the middle portion of the bank is loamy sand type as at Khayerpur. But the practice of sand collection using machine leads to the deepening of the channel (4-5 feet) at both the banks and thereby weakening of the bottom of the banks where sand is the dominant particle. In this way channel becomes wide through bank failure.

CROSS SECTION III:

Plate 3: Cross-section site at Mekhlipara (23°49.864'N, 91°21.639'E)

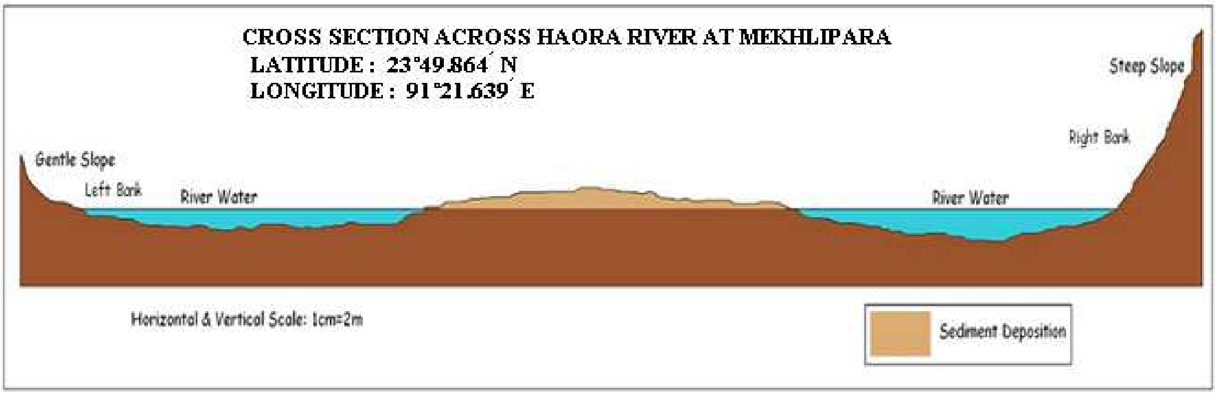

Fig. 4: Cross–section across the River Haora at Mekhlipara

Season : Pre-monsoon	
Water width : 28 m	
Average Depth : 0.0152 m	
Cross Sectional Area : 12.40 m^2	
Wetted Perimeter : 20 m	
Hydraulic Radius : 0.62 m	

In this profile the biggest mid-channel bar with a width of 14.50 m is found. At the right side of the bar, depth of water is comparatively more (1.18m). The height of the bar from water level is 0.52 m. The right bank is steep with an average angle of 56°40' whereas the angle of the left bank is 33°30' i.e., gentler than the right bank. Though Mekhlipara is located 3.46 km upstream of Khayerpur, still the River Haora is wider at Mekhlipara (36.75 m) than at Khayerpur (30 m). The reason is the widening of the channel through bank erosion along the right bank due to the presence of less cohesive materials as evident from the soil sample collected from the site and tested and then analysed. Cross sectional area (12.40 m^2), Wetted perimeter (20 m) and hydraulic radius (0.62 m) – all are higher at Mekhlipara compared to Khayerpur. Higher wetted perimeter indicates that at this cross-sectional point comparatively more water is in contact with the river bed and so friction of water with bed and bank is more which leads to loss of stream energy. More friction means more erosion in the banks of the river where sand predominates. Moreover, loss of energy means more aggradation. The hydraulic radius supports this fact that the river is aggrading in character in Mekhlipara where vast flood plain is present along its left bank.

Table 3: Analytical Results of Soil Samples Collected From Different Parts of the River Bank at Mekhlipara (February, 2011)

Particle / Position	Sand (%)	Silt (%)	Clay (%)	Soil type
Bank top (0 m)	75	25	00	Loamy sand
1 m	80	19	01	Sandy loam
Middle (2 – 4 m)	90	10	00	Sandy
Bottom (5 - 6 m)	70	30	00	Sandy loam

Source: Measured by the researcher in the Laboratory

The bank is very steep (nearly perpendicular) from bank top up to 4 m and after that the basal slope exist with gentle slope. Steeper slope contribute to sediment transport and to bank erosion and are often associated with coarse heterogeneous materials [12]. Non-cohesive bank material i.e., sand dominates the bank with maximum percentage at 2 - 4 m depth (90%), leads to maximum erosion which ultimately leads to widening of the channel. The lower part of the original bank is not visible during the field survey due to the presence of soils deposited through bank failure. Therefore the basal portion is protected from erosion, though during monsoon season with increase in water level and velocity, this portion usually removed and the original bank with non-cohesive materials gets direct attack of the river velocity.

Again, human intervention in the form of sand collection from the channel bed leads to deepening of the channel which is again supplemented by materials from the bank toe. This anthropogenic activity is also responsible for the weakening of the non-cohesive soil at the bottom of the bank and ultimate failure of the upper portion during rainy season. Local people are of the opinion that bank failure has increased in recent years due to such activity.

Moreover, Mekhlipara site shows a vast barren land which is also another reason behind the presence of wider channel. Vegetation cover, especially the role of root networks may reinforce bank materials, thereby increasing resistance to erosion [8, 10]. If discharge, slope, bend curvature, bank texture and bank heights are constant, a river migrating through cleared or cultivated floodplain may erode at almost twice the rate of rivers reworking forested flood plain [6]. Beeson and Doyle [3] supported these findings, observing that non-vegetated banks were nearly five times more likely to undergo notable erosion compared with vegetated banks.

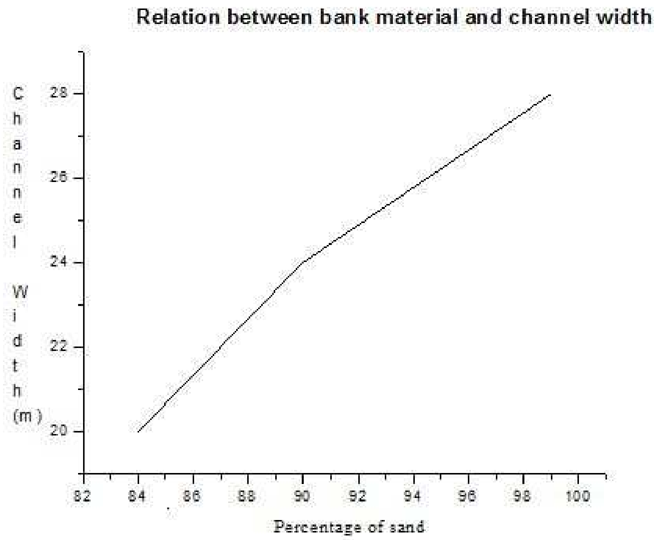

Fig. 5: Relation between bank material and channel width

Vegetated banks tend to have a more open soil fabric and are better drained. Soil is strong in compression but weak in tension. Roots are the reverse, so they reinforce the tensile strength of soils by up to an order of magnitude relative to root-free samples [5]. These impacts may be offset, in part by the additional loading applied to banks by vegetation cover. In large scale cohesive banks critical failure surfaces may be well below the root zone. Vegetation structure also influences pattern and rates of flow dynamics adjacent to the banks. Stems and trunks of bank vegetation alter the distribution of near-bank velocity and boundary shear stress. The density and pattern of trees may exert a significant influence on the distribution of form drag, influencing the capacity for detachment and entrainment [9]. The distribution of woody debris also influences the effectiveness of bank erosion processes [13].

CONCLUSION

The above study in a part of Haora River shows strong relation between nature of bank material and channel character. The presence of high percentage of sand in the middle portion or bottom of the bank leads to much wider channel with bar deposition within the channel (mid-channel bar) or adjacent to the bank (point bar), thereby decreasing the depth and wetted perimeter of the channel. Though all the three sites are vulnerable to bank erosion, Mekhlipara is the most vulnerable due to the presence of maximum amount of non-cohesive sand (90%) in the bank just above the basal slope (2 – 4 m).

Moreover, the role of vegetation cover in checking the bank erosion has been proved again. Mekhlipara bank line is devoid of any sort of vegetation whereas other sites have such land cover. Due to the presence of non-cohesive materials river banks are susceptible to erosion at all the sites that have been studied. Therefore, not only during bank-full discharge, but at the time of increased stress which leads to weakening of the soil, bank failure takes place. For example, Wolman [12] determined that a large summer flood induced little bank erosion on dry banks while lesser winter flows caused considerable bank retreat when acting on thoroughly wetted banks.

Direct impact of bank erosion is sedimentation which is responsible for changing nature of the river. Simultaneously effects of such changes are felt in the daily life of the inhabitants. Water transport such as ferry service has been stopped. The occupational structure has been changed e.g., river based occupation like fishing, boating etc has been stopped. Bank failure leads to sedimentation in the downstream which ultimately changes the river character. The city will suffer from drinking water supply in near future. So the trend of change in geometry of the River Haora creates a vulnerable situation at present, which requires a good management plan specially to protect the cultural landscape.

Recommendations

Some measures should be taken to protect the present erosion sites as well as the vulnerable sites to be affected. The structures made from masonry, stone, iron, cement etc. are bad for vegetative growth and do not provide habitat for species that are living around water and vegetation. There is a need for cheaper methods of bank protection where the local people can participate [15].

Bio-engineering for protection of stream bank is an eco-friendly technique of low cost river bank protection, easy to construct, using natural and local materials, so that will harmonized with environment.

- *Angular interlocking of stones:* Sufficiently large stones may be used to lining the bank. More angular stones will interlock and thus provide greater stability. Placing a layer of the gravel or stone under the large riprap material will help to prevent erosion of finer bank materials from beneath the rocks. To avoid undermining at the toe can be used of stone aprons, which extend well out into the river bed.
- *Timber planks or logs:* Vertical timber posts or pile driven vertically into the stream bed can be used to protect the lower part of a bank especially where a cliff on the meander bend exists.
- *Vetiver grass:* Vetiver grass is a crop very easy to grow. These can grow at various level of fertility of land in wet and dry conditions. These do not need maintenance. Leaf, blade, root and also young plant grow in dense formations. Its root grows vertically downwards more than 3 m, so that is not competing with other crops. Vetiver grass lives over 10 years. It does not expand wild outside from plan area. It will not become an intruder into the local vegetation. The dense vetiver leaves arrest surface erosion. The deep roots bind the soil.
- *Bamboo plantation:* Bamboo also belongs to grass family. Tripura is very rich in bamboo. Its stalk diameter reaches up to 30 cm, with length of about 40 meters. Planting of bamboo along the bank nearer to the water level can be proved beneficial.
- *Ipomea carrnia:* It grows into a group of clump with branches as thick as a human finger. Its leaf is thin. The root system is strong, growing downward. It can be grown from cuttings or seeds. Its cultivation is easy and without maintenance. Hence ipomea carrnia can be planted on sediment brought by the streams and can reduce the velocity of currents. Thus it is good material for protection of stream banks.

• *Restriction in sand collection:* People may be allowed to collect sand manually from the channel bars only. It will help to modify the channel depth.

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