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Brahmaputra river in India : an analytical study with special reference to its erosion.

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Abstract

The complex and unique riverbank erosion characteristics of the Brahmaputra River in India, the fourth largest river in the world in terms of average discharge at the mouth and second only to the Yellow River in China in the amount of sediment transported per unit drainage area, is highlighted with illustrations of the severity of erosion caused at various bank locations. First, the source and the entire course of the river are described. Riverbank erosion mechanisms and existing erosion control measures and their effectiveness in the Assam reach of the Brahmaputra River are described. As part of a joint effort for the first time between U.S. and Indian (local) investigators to understand and find solutions to this mega unique problem of the Brahmaputra River, a set of recommendations, including a phase-wise multiple solutions to the acute and potential riverbank erosion sites along this large river, is forwarded for discussion and getting feed back from international experts.

Keywords: River, erosion, restoration, Brahmaputra, Assam.

1. Introduction

The Brahmaputra River originates in a great glacier mass in Kailas range of the Himalayas (elevation 5300 m) and flows through China, India and Bangladesh for a total distance of 2880 km before emptying into the Bay of Bengal jointly with the Ganges (Figure 1). It drains a combined international area of approximately 580,000 km2. It is the fourth largest river in the world in terms of average discharge at the mouth and second only to the Yellow River in China in the amount of sediment transported per unit drainage area.

In India, the Brahmaputra River flows southerly and westerly through the states of Arunachal Pradesh and Assam over a distance of approximately 800 km. In the Himalayas range before entering India, the river is known as the Tsangpo River flowing west to east, then south through the eastern Himalayas as the Dihang River. In Assam, the Dihang River is joined by other tributaries to form the Brahmaputra River. Near the western boundary of Assam, the river turns south to enter Bangladesh changing its name to Jamuna till its confluence with the Ganges from where both the Jamuna and Ganges form the Padma flowing into the Bay of Bengal. The total length of the river in Bangladesh is approximately 240 km.

A longitudinal bank profile of the Brahmaputra presented in Goswami (1985) reveals that the river has a gradient of 0.09 to 0.17 m/km near Dibrugarh, Assam at the head of the Valley and it is reduces to about 0.1 m/km near Guwahati. Through Assam, the long term average discharge increases from 8,500 to 17,000 cubic meters per second as flows are augmented by major tributaries. The width of the river varies from one km on an individual channel to as much as 10 km in some reaches with multiple braided channels. Almost through its entire length in Assam, the river has three to six channels separated by islands and mid-channel bars under low flow conditions. These bars and islands become submerged during major floods. The pattern of channels changes frequently under flood conditions accompanied by extensive erosion of banks and disposition of sediment forming sand bars. Figure 2 presents a typical braiding in the Brahmaputra River.

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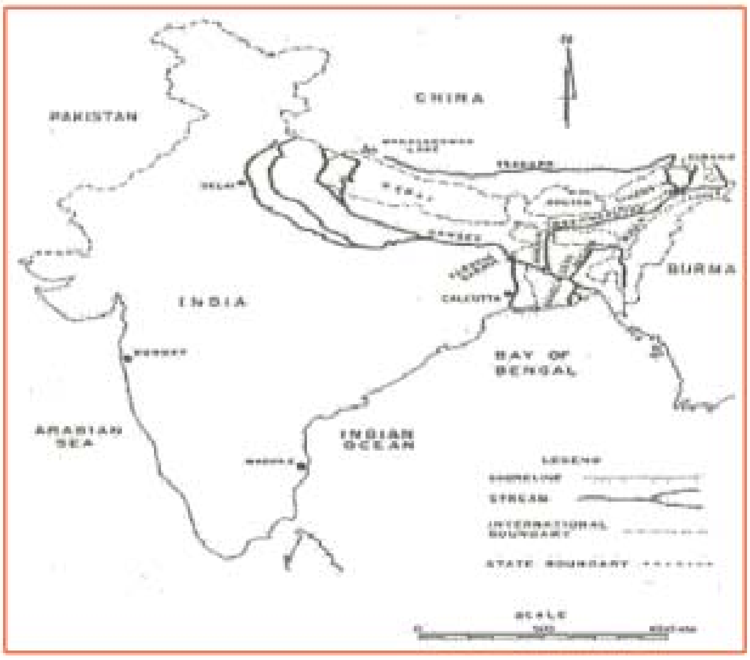

Fig. 1 : Map of India showing Assam and the Brahmaputra River system (Borah *et al.,* 1990)

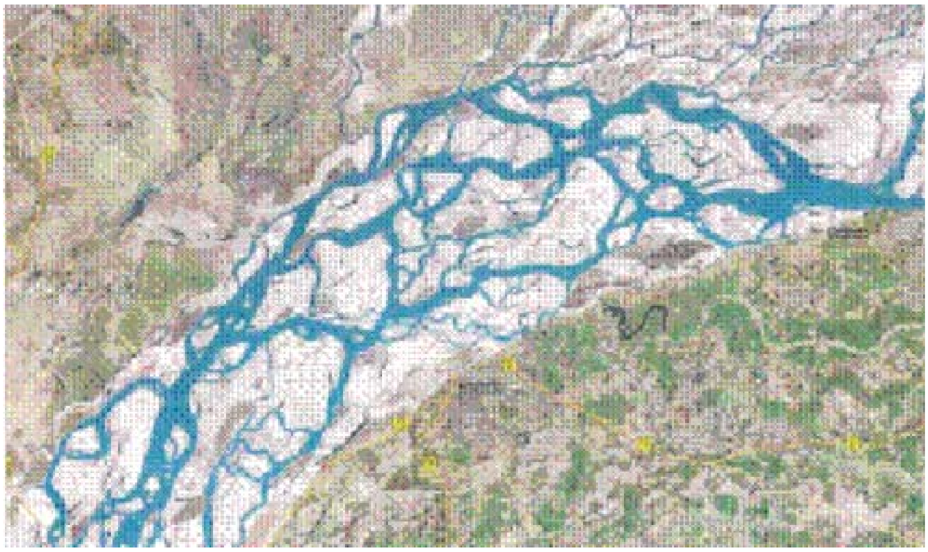

Fig. 2 : Braided channels of the Brahmaputra near Dibrugarh, Assam (http://maps.google.com/)

The unique geology and geomorphology responsible for the highly erosive characteristics of the Brahmaputra River have been studied by various authors (e.g., Coleman, 1969; Goswami, 1985; Sarma, 2005; Pahuja and Goswami, 2006; Sarkar and Thorne, 2006; Wiebe, 2006). The geology of the Brahmaputra system in Assam Plain comprises of the Higher and Lesser Himalayas. The Higher Himalayan rocks consist of schists and marbles with amphiboles at some locations. The lesser Himalaya in the Brahmaputra system drainage is composed of quartzites and schists. The Brahmaputra valley in Assam is underlain by recent alluvium (approximate 200-300 m thick) consisting of clay, silt, sand, and gravels. The present configuration of the Brahmaputra valley in Assam is known to have evolved during 2 million years of Pleistocene and recent era. The valley and its adjoining highlands constitute an extremely unstable seismic region. Two geological factors are ruling in determining the morphological character of the river in Assam. Firstly, the Himalayan ranges to the north are uplifting at a rate of the order of one meter per century. Secondly, the whole region is subject to frequent seismic movements and periodic major earthquakes. The recent earthquakes of 1897 and 1950 in Assam, both of magnitude 8.7 on the

Richter scale, were among the largest within historical experience anywhere in the world. The 1950 earthquake seriously affected the territory in Assam causing floods and erosions.

This paper highlights the complex and unique soil erosion characteristics of the Brahmaputra River with illustration of the severity of erosion caused at various bank locations. Existing erosion control measures and their effectiveness are described. As part of a joint effort for the first time between U.S. and Indian (local) investigators to understand and find solutions to this mega unique problem of the Brahmaputra River, a set of recommendations, including a phase-wise multiple solutions to the acute and potential riverbank erosion sites along this large river, is forwarded for discussion and getting feed back from international experts.

2 Channel behavior with flow and river stage

The Brahmaputra is characterized by high rates of basin erosion, river bank erosion, channel migration, and sediment yield. The channel configuration of the river undergoes large changes in response to variations in the flow regime and the pattern of sediment transport. During November through March (low flow season), the river flows in highly braided channels comprised of numerous sand bars and islands (Figure 2). Beginning in May as the flow begins to rise, raising its stage (water depth) in response to high runoff from the monsoon precipitation, most of the bars as well as islands get submerged. Coleman (1969) noted that the most striking feature of the change in channel configuration of the Brahmaputra is the continuous shift of the thalweg from one location to another within the bank lines of the river. He reported that the movement of the thalweg is high during the rising stages (May through June), relatively less during the peak of the flood (July through August), most erratic during the receding stages (September through October) and very little during the low flow stages (November through March). Goswami (1985) described that the sediment transport is high during the rising stage marking aggradation of the channel while the falling trend marked by low sediment transport indicating degradation of the channel. The shifting of thalweg in relation to river flow pattern with the sediment transport and the changing of the channel configuration causes serious bank erosion of the river.

3. River bank erosion

Due to the river bank erosion and the channel migration, the Assam valley portion of the Brahmaputra River has lost approximately 7.4 % of its land area during its recent history of observations. The river bank erosion has caused major human and economic disasters than the annual flooding. The loss or the discomfort associated with the flooding is temporary but the loss of land due to river bank erosion is permanent and has a long term impact on the economy of the region and its people. Once a section of well developed land (agricultural, industrial, or residential) or productive forest land is lost due to river bank erosion, it can hardly be replaced. A mechanism to compensate citizens or the businesses impacted by bank erosion is generally not available through government rules or property insurance methods. The salient hydraulic and bank material factors responsible for bank erosion of the Brahmaputra system are i) rate of rise and fall of river water level, ii) number and position of major channel active during flood stage, iii) angle at which the thalweg approaches the bank line, iv) amount of scour and deposition that occurs during flood, v) variability of cohesive soil in bank material composition, vi) formation and movement of large bed forms, vii) intensity of bank slumping, and viii) progression of abandoned river courses to present-day channel.

Due to braided characteristics, the main stem river consists of variable number of different sized channels and sand bars which change their locations and sizes each year. As indicated earlier, the most significant bank line modifications take place during the falling stages when excess sediment is deposited as bars within channel, causing a change in local flow direction and migration of thalweg. During floods, because of change of river hydraulics (mainly, depth, velocity, and shear stress), inducing variable sediment transport characteristics and erosive forces, the channel starts shifting at some vulnerable reaches.

Key factors in causing the river extremely unstable at many vulnerable reaches, such as

Nagaghuli, Maijan, Majuli, Bhairabpur, Balikuchi, Kaziranga, Howlighat, and Palasbari, are aggradation of the riverbed, intense braiding, large water discharge, and heavy sediment load since the 1950 flood. Moreover, there is a tendency of the river to shift southward within the valley reach. The tendency has become more prominent after the great earthquake of 1950, which raised the whole landmass of the northeastern part of the valley, particularly north of the river including the Himalayan foothill region by 3 to 4 meters. This southward thrust has initiated widespread erosion in the south bank near the Dibrugarh town and is still continuing at different reaches in spite of implementation of aggressive bank protection measures.

The Water Resources Department (WRD, 2008), Government of Assam, India has identified twenty five (25) such vulnerable and severe river bank erosion sites (Figure 3). Bank erosion rates and affected households at five of those sites are presented in Table 1.

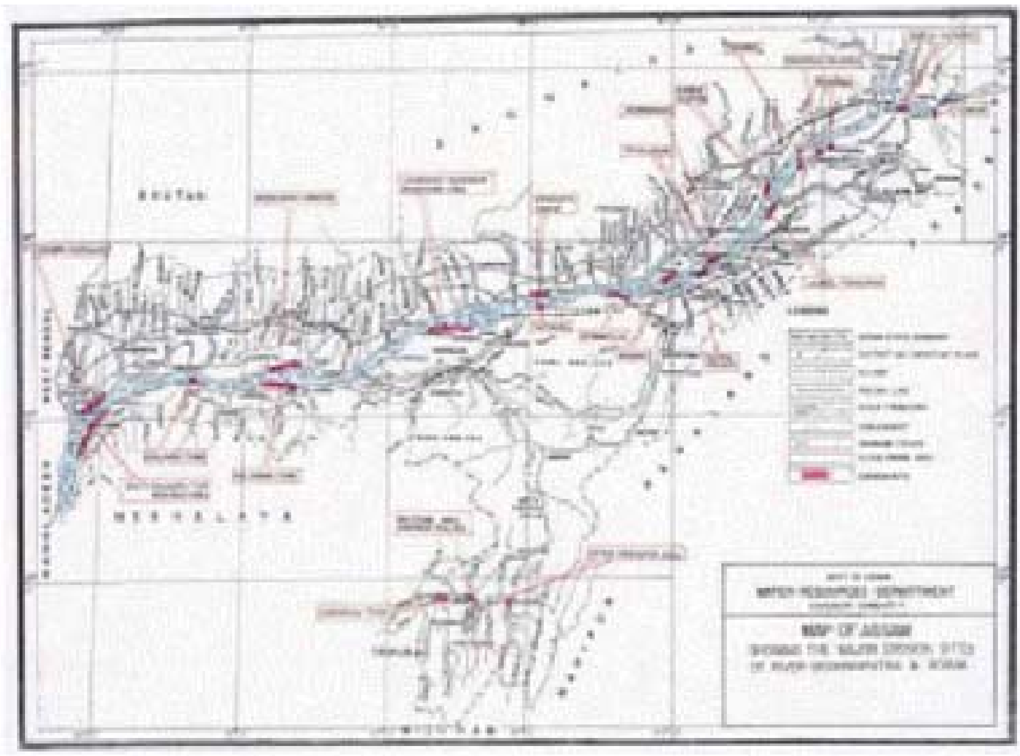

Fig. 3: Locations of Severe Bank Erosion in the Brahmaputra River in Assam (WRD, 2008;

Table 1: Brahmaputra Riverbank Erosion Data at Various Locations (WRD, 2008)

Site	Area of land Eroded (ha)	Bank line Eroded length (km)	Rate of erosion (m/yr)	Number of house holds affected	Number of households lost
Rohmrnia	8,435	9		1,580	
Dibrugarh Town	491	25	4.72	4036	768
Matmara	3,640	13	69.20	2186	199
Kaziranga	491	21	18.46	2613	238
Palashbari	16,037	25	22.00	12530	1656

The records of the last century show a general trend of widening of the Brahmaputra in Assam. The widening trend is clearly visible when comparing erosion and accretion rates over different periods. Long-term observations on width changes of the river are available, although data from different authors are not directly comparable. According to some estimates, the Brahmaputra occupied around 4,000 kmýÿ in the 1920s and expanded to around 5,000 kmýÿ by the early 1970s. A major avulsion (shifting of riverbed) upstream of Dibrugarh added many hundred additional square kilometers to the area within the river banks during the 1990s. Nowadays, the Brahmaputra occupies about 6,000 kmýÿ (WRD, 2008).

In general, the losses due to erosion show an increasing trend. Reports available with Water Resources Department indicate that 3,860 kmýÿ of land were lost since 1954, with about 80 kmýÿ per year. The erosion wiped out more than 2,500 villages and 18 towns, including sites of cultural heritage and tea gardens affecting the lives of nearly half a million people. About 130 river reaches are presently classified as being under moderate to severe erosion and 25 as very severe. A comparison between the value of land lost to riverbank erosion and inundation flood damage between 1954 and 1969 indicates that the costs of riverbank erosion were 35% to 85% of the losses caused by the ravages of flood, chronic to the region.

Properties of River Bank Material and Erosion Mechanism

Goswami(1985) reported that predominant sizes of suspended sediments and bed materials of the Brahmaputra River at Pandu, Assam are 0.06 and 0.09 mm, respectively, which are fine sand. The bank material of the river mostly consists of varying proportion of fine sand, silt with only occasional presence of minor amount of clay (generally less than 5%). The particle size distribution of bank materials shows two distinct characteristics (Goswami, 1985): i) a relatively fine grained top stratum and ii) a coarser substratum. The finer sediments represent vertical accretion from overbank flows while the coarser sediments presumably represent channel bars and islands accreted laterally through meandering of the channel.

The fine sand and silty nature of the river bank material and the unstable bank line along the most part of the river create a highly favorable environment for bank erosion. Bank failures are composed of violent actions of the flowing water and the weak geotechnical properties of the bank materials (Thorne and John, 1979; Pizzuto and ASCE, 2007). The bank formation and rate of recession are controlled by the fluvial processes, whereas the mechanism of bank failure is determined by the engineering properties of the soils. Shear failures in the upper bank materials appear to be by far the most widespread mode of bank failure. This may be caused either by undercutting the upper bank materials by strong currents during the high flows or by over steepening of the bank slopes. Overhanging cantilevered blocks are produced during the undercutting which leads to eventual falls and over steepening causes steep slopes due to

migration of thalweg closer to the bank during the falling stages (Coleman, 1969). The bank materials in the Brahmaputra are highly susceptible to erosion by the river due to their high moisture content, low clay content and poorly graded fine sand and silt. Photographs of typical river bank failures at selected locations of the Brahmaputra River are presented in

Fig. 4 : River Bank Failure of the Brahmaputra River at Palasbari, Assam

Fig. 5 : River Bank Failure of the Brahmaputra River at Rohmori, Assam

Fig. 6 : River Bank Failure of the Brahmaputra River at Neamatighat, Jorhat District, Assam

A public sector flood and erosion control program to curb the chronic ravages of floods and riverbank erosion started in Assam after the declaration of National Flood policy in 1954. An extensive network of earthen flood embankments was erected all over the state of Assam in the main stems of the Rivers Brahmaputra, Barak and their tributaries as immediate and short-term measures under the "food for work" program.

The short and medium term measures taken up under this initiative include erosion control and river training works that mostly comprise of bank revetments, stone spurs, boulder deflectors, timber dampeners, pile screens, reinforced concrete porcupines, Leet Fanci and other pro-siltation devices. In addition, the Water Resources Department of Assam also constructed 86 major sluice gates, 539 medium and minor sluice gates, and about 855 km of drainage channels to provide drainage and dewatering facilities. The emergency situations arising in flood seasons were mostly taken care of by installation of temporary dowel bund with empty cement bags, back filling with bamboo pallisading, A-Type spurs, bamboo porcupines, breach closing works, bamboo cribs etc. All of the above measures have provided somewhat reasonable protection to about 1.65 million hectares (50%) of area out of the state's total flood prone area of 3.12 million hectares, assessed by the Rastriya Barh Ayog, Government of India.

Till now, the responsible public agencies have taken a piece-meal approach to deal with the riverbank erosion problem during emergency situations depending on availability of funds. There is no holistic or a long-term strategy based on a systematic understanding of the problem and development of engineering solutions. Extensive riverbank protection or anti-erosion work was started only after the flood protection embankments became more and more vulnerable to breaches from erosion. About 70% of the total present day embankment system of the state was built from the mid-1950s until the end of the 1970s with a large setback distance away from the riverbank, in some cases, up to two kilometers. However, the network of earthen embankments did not prove to be a full-proof tool for flood control. In many tributaries, the embankments prevented the transport of silt to the wide floodplains and riverine wetlands during annual floods when floodwater overflowed banks. As a result, the deposition of silt within the river beds and floodplains within the embankments reduced the effective flood flow area and conveyance capacity of the rivers. The structural integrity of the earthen embankment system also became vulnerable due to poor cohesive property of the sandy silt material, and led to annual occurrences of levy breaches and untold miseries of the masses across the region. Since then, more emphasis was laid on building anti-erosion/bank protection works commencing about 20 years after embankment construction. Wherever the embankments are away from the riverbank, they are mostly functioning well along the Brahmaputra – provided they are not eroded. The comparison of embankment failures during the high 2004 flood indicates that more than 50% of the embankments along the Brahmaputra failed from erosion.

The population density in the floodplains indicates the need for adequate flood and erosion management (structural – non-structural) measures. There are numerous towns and urban centers along the Brahmaputra River whose existence today can not be imagined in absence of the existing town protection works. Dibrugarh town in upper Assam is a glaring example and tells a success story in riverbank protection in Assam. The town was on the verge of extinction due to severe erosion after the devastating flood of 1954, a consequence of the 1950 earthquake.

An aggressive Dibrugarh Town Protection Work was implemented that saved the town from additional ravage of extreme erosion by the mid-1950s. Following the completion of riverbank protection work, the flood embankments were erected and the town was protected from flooding allowing it to develop and prosper till today, more than 50 years. This stands in sharp contrast to many other areas in Assam where embankments were retired up to 10 times, without providing reliable bank protection. A direct comparison with the former (lost) town of Palasbari with the area protected from erosion 30 years after the town had been eroded reveals a comparable level of cost for structural work with the difference of substantial land losses and the erosion of the town. The comparison of these two examples supports that "riverbank protection" comes first and can be feasible by long-term approach despite the higher initial investment cost. This policy has been more and more adopted by different government committees on flood damage mitigation. Over time, riverbank erosion is gradually acknowledged as major problem with justification not only for town protection but also for protection of agricultural and forested lands. However, it is understood that the approach of "erosion protection first" has only a chance for large-scale success, if based on more cost effective technologies, drawing on from internationally adopted methods and management practices.

4. Summary, Conclusions, and Recommendations

The Brahmaputra River has destroyed nearly 4000 km2 since last five decades at a rate of 80 km2 per year and erosion also wiped out more than 2500 villages affecting nearly 500,000 people. Though severe erosion caused by the Brahmaputra at various locations such as Majuli Island, Rohmoria, Kaziranga area etc. are well known, limited efforts has been made for the erosion control measures. An effective road map for long term solutions of flooding and riverbank erosion of this big river is yet to be developed. Both flood and erosion control in the Brahmaputra River basin is to be strategized in both short and long terms to address and assess the salient problem issues and develop cost effective measures or solutions. The following recommendations are forwarded for discussion, getting feed back from international experts, follow up investigations, and finally adopting and implementing the measures found effective:

- Examine successful erosion control measures in major rivers of the world.
- Strengthen and monitor anti-erosion measures already built at Majuli Island and other severely eroded towns along the river.
- Armor existing embankments located at urban and other strategic locations.
- Phase-wise solutions for the mitigation of erosions may include a combination of measures including strategic dredging, protection of erodible bank materials with anchored bulkhead or tie back sheet piles, spurs, toe, and bank revetments.
- Improve data quality and quantity by extending rain, flow, and sediment monitoring network using state-of-the-art equipments.
- Develop advanced and efficient computational tools (numerical models) capable of utilizing the detailed hydro-meteorological data and predicting real-time flooding and hydraulic characteristics of the river for planning and designing effective flood and erosion control measures.
- Consider physical modeling to study severe and potential scour sites and their control.
- Take advantage of modern technologies such as Satellite Image based morphological studies to warrant perspective on changes to river bank lines, river movement and indication of erosion risk along the river.

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