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A Mass Balance Approach in Sediment Budgeting of Large Alluvial Rivers with Special Emphasis on the Brahmaputra in Assam

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Abstract:

Morphology of an alluvial river channel is the consequence of erosion, sediment transport and sedimentation in a river. Sediment budget accounts for the sources, sinks and redistribution pathways of sediments, solutes and nutrients in a unit region over unit time. Human activities are the most important factors that affect the variation in the pattern of river sediment load. This paper discusses sediment budget of a few large rivers by review of literature and estimation of sediment budget of Brahmaputra River in Assam using mass balance approach. An attempt has also been made to discuss human and climatic impact on sediment load of major rivers of the world. Total sediment load in the Brahmaputra River at downstream location (India-Bangladesh border) was estimated to be 814×10^6 t/year. Considering 10% of sediment load of the Brahmaputra as bed load, suspended sediment load at downstream was estimated to be 733×10^6 t/year. Tributaries, bank erosion and scouring of river bed were found to contribute 52%, 27% and 21% respectively to sediment load of Brahmaputra at downstream locations. In spite of limitations of the dependable data, future complexity due to climate change impact and hydropower dam initiative in upstream of the River, the study is a simplified approach in sediment budgeting of the Brahmaputra.

Key words: Sediment budget, Brahmaputra, Assam.

INTRODUCTION

Sediment is naturally occurring substance, originally derived from underlying bedrocks, which is broken down by weathering and erosion and is subsequently transported by the action of fluids such as wind, water or ice and/ or by the force of gravity acting on the particle itself. Although the term is often used to indicate soil-based mineral matter, decomposing organic substances and inorganic biogenic materials are also considered as sediment (Wetzel, 2001). Mineral sediments come from erosion and weathering, while organic sediment is typically detritus and decomposing material such as algae (EPA, 2014). Coarse materials are transported as bed load along the bed of a river through rolling, sliding or saltation. Finer materials are carried aloft, suspended above the channel bed by turbulent eddies, and is transported downstream as suspended load and wash load by the process of advection and turbulent diffusion. There is a balance, described as a qualitative equation by Lane (1959), between the supply of bed load at the upstream end of a channel reach and the stream power available to transport it. If both the variables are balanced, neither erosion nor deposition will predominate. Increase of volume of the sediment load in relation to the available stream power leads to aggradations with net deposition along the reach. When the stream power exceeds, degradation predominates. Sediments accumulate on flood-plain surfaces by various processes of accretion, i.e., vertical, lateral and braid bar accretion (Nanson and Croke, 1992).

The concept of 'Sediment budget' was coined in Norway (Rapp, 1960) and in the USA in the 1970-80's to account the sources, sinks and redistribution pathways of sediments, solutes and nutrients in a unit region over unit time (Slaymaker, 2003). Construction of detailed sediment budgets (Walling and Collins, 2008) relies on the mean values of the sediment load calculated at the catchment outlet. This paper discusses sediment budget of a few large rivers of the world namely the Amazon, the Mississippi, the Nile, the Yangtze and the Yellow, followed by estimation of sediment budget of Brahmaputra River in Assam, using mass balance approach.

Material and Methods

The study on sediment budget of a few large riversnamely the Amazon, the Mississippi, the Nile, the Yangtze and the Yellow River is based on review of literature. Estimation of sediment budget for the Brahmaputra River in Assam, India is attempted using a mass-balance approach from secondary data.

There are a few limitations in collecting secondary data related to Brahmaputra River:

I. Non-availability of enough hydrological data for Brahmaputra and its tributaries, particularly in Assam plains.
II. Most of the available data is discrete, i.e., confined to particular site or location and not continuous. Several organisations/

departments such as Brahmaputra Board, Water Resources Department, Assam PWD, Central Water and Power Commission, Joint River Commission, etc. are dealing with different hydrological aspects of Brahmaputra; with the result that data remained dispersed in different offices and is difficult to locate and access.

Construction of a sediment budget for the Brahmaputra in Assam is attempted using a broad mass balance approach:

Total sediment in a channel at a downstream cross section = Sediment contribution from main stream and tributaries + sediment contribution from river bank erosion + sediment contribution from scouring – sediment deposition on river bed– sediment deposition on river bank – sediment deposition on floodplains

Sediment data were collected from different sources as follows:

1. Sediment load of tributaries of the Brahmaputra were considered from work of Pahuja and Goswami (2006).
2. 60% sediments from the tributaries were considered to contribute to sediments of Brahmaputra (after Goodbred and Kuehl, 1998; Goodbred and Kuehl, 1999; Liu et al., 2009)
3. Sediment input from bank erosion and sediment sink due to deposition on river banks were calculated from erosion and deposition data for the period 1973 – 2014 (Saikia et al., 2019).
4. Annual inputs from scouring and sediment deposition on river bed were calculated from aggradation and degradation data of the Brahmaputra for the period 1957 – 1989.

Similar mass - balance equation with different data sources was used in the Yangtze River for quantitative estimation of the contribution of the river mouth reach to the sediment load before and after impoundment of the Three Gorges Dam (Wang et al., 2015).

RESULTS AND DISCUSSIONS

Sediment Budget of the Amazon River

The Amazon River accounts for almost one-fifth of global freshwater discharge (Callède et al 2010) and supplies 40% sediment flux of the Atlanttic ocean (Milliman and Farnsworth 2011). Amount of sediment transported by the Amazon River to ocean was estimated to be about 1200×10^6 tons. Erosion in the Andes mountains is the main source of sediments. Almost half of the Amazon River transport (488×10^6 t/y) is attributable to one tributary, the Rio Madeira (Martinelli et al., 1989).

The fluvial transport and storage of sediments within channel–floodplain systems can act as an important sinks of sediments. In Amazon River, the floodplains act as a temporary storage system of dissolved and particulate elements as well as an exporting system of these elements into the main stream during floods (Maurice-Bourgoin et al., 2007). Dunne et al. (1998) estimated the magnitude of sediment exchange between the channel and the flood plain through the Brazilian sector of Amazon River valley based on sediment sampling and flow records. Deposition on the sand bars and floodplain exceeded bank erosion by 500 Mt y^{-1} over a 10–16year period. Another 300–400 Mt y^{-1} were deposited in a downstream delta plain. Maurice-Bourgoin et al. (2007) documented the role of an Amazon floodplain for sediment storage from studies on network of gauging, meteorological and sediment monitoring stations and satellite data. The area under discussion is, located on the right bank of Amazon River, 900 km upstream of the mouth, contains more than 30 interconnected lakes linked to the mainstream by permanent and temporary channels. With an open-water area varying between 600 km^2 and 2500 km^2, it represents ~13% of the total flooded area of Amazon River. Sediment accumulation occurred during the five months of the flood rise, from December to April. The mean average sediment storage calculated varies between 41% and 53% of the annual flux of sediments entering the floodplain through the main channels.

Martinez et al. (2009) attempted to quantify Amazon River sediment budget from suspended sediment discharge monitoring network and remote sensing data. Suspended sediment discharge was found to increase by about 20% during 12 years from 1995. An increase in sediment discharge may be attributed to stronger erosion processes caused either by a global change (rainfall), or regional changes (land cover change resulting from deforestation for example) or both.

Sediment Budget of the Mississippi River

The Mississippi River can be divided into three sections: the Upper Mississippi River, the Middle Mississippi River and the Lower Mississippi River. The lower Mississippi River transports approximately 150 million tons of sediment annually (Thorne et al., 2008). Historically, the quantity and caliber of sediment derived from catchment erosion have been affected by changes in land-use and River management. Knox (2006) used ^{14}C and ^{137}Cs isotopic dating methods to estimate sedimentation rate and and morphologic change for a reach of the upper Mississippi River. The shift from pre-agriculture, natural land cover to landscape dominance by agricultural land use of the last 175–200 years typically increased rates and magnitudes of floodplain sedimentation in the Upper Mississippi Valley. Large floods have frequently provided major increments of sedimentation on floodplains of tributaries and the main valley upper Mississippi River. Recently, modification of River flow by flood control structures and a reduction of sediment supply by upstream dams and artificial levees have greatly reduced sediment supplied to deltaic wetlands.

Sediment Budget of the Nile River

The Nile is the longest river in the world stretching more than 6800 km across north-eastern Africa (Fielding et al., 2018) to its delta in Egypt on the Mediterranean Sea. The Nile has three main tributaries: the White Nile, the Blue Nile and the Atbara. Sediment supplied to the Nile trunk in Egypt is dominated by contributions from the Blue Nile (50–61%) and Atbara (30–42%) (Padoan et al., 2011). Major portion of White Nile sediment load is trapped in swamps in South Sudan and do not reach the main Nile trunk, thus accounting for less than 3% of the sediment reaching the modern delta. ElMonshid et al (1997) estimated the sediment load of the Blue Nile at the entrance of the river to Sudan to be 140 million tons per year (Ahmed, 2008). Detritus supplied to the Nile trunk is derived from the volcanic Ethiopian highlands, Precambrian basement rocks and Phanerozoic sedimentary cover that blankets much of the region, together with a contribution from Aeolian sources (Fielding et al., 2017). However little is known about the changing influences of tectonics and climate through time (Paul et al., 2014; Woodward et al., 2015).

Sediment Budget of the Yangtze River

The Yangtze is the largest River in China and ranks the third in the world (He et al., 2012). In the Yangtze River, the amount of sediment discharged to the East China sea accounts for 68% of the total sediment supplied into the trunk River in the middle and lower reaches. The remaining 32% is deposited in the River channel and linked lakes. Dai and Lu (2010) examined the sediment process in two large flood years, i.e., 1954 and 1998 based on the re-evaluated sediment supply from the tributaries and the data from selected gauge stations on the main channel. Total supplied sediments of 58% and 52% were deposited in the river channel and floodplain in 1954 and 1998 respectively. The floodplains and channels in the middle and lower reaches of Yangtze River played an important role in regulating sediment discharge during extreme flood events.

Sediment Budget of the Yellow River

The Yellow River was once the world's largest sediment carrying River and peaked at about 1.6 Gt /yr in the middle of the twentieth century. Butthe river is one exception where erosion and sediment delivery have successfully been reduced (Wang et al., 2016). For control of soil erosion and ecosystems restoration in an effective way, the Chinese government has adopted various measures and policies like construction of silt dams (Zhao et al., 2016; Jin et al., 2012), reservoirs (Huang et al., 2019), terraces (Liu et al., 2018) and policy of returning farmland to forests (Deng 2014; Zhou et al., 2009). These measures have altered sediment supply in natural watersheds and the geomorphology of rivers, thereby affecting the soil erosion and drastically reducing sediment load in the Yellow River (Yu et al., 2013). Nearly 90% of the sediment load was originated and transported from the Loess Plateau in the middle reach (Wang et al., 2007). The current input of sediment from the Loess Plateau is less than one quarter of what it was before 1980 (Wang et al., 2016) and the sediment export to the ocean is now only 10.7% of the 1950s' level (Yu et al., 2013).

Sediment Budget of the Brahmaputra River in Assam, India

Originated as the Yarlung Tsangpo from Angsi glacier near Manasarovar lake in the Kailash range in southern Tibet, the Brahmaputra a transboundary river flowing to the Bay of Bengal through China (Tibet), India and Bangladesh. The Brahmaputra basin in India is shared by Arunachal Pradesh (41.9%), Assam (36.3%), Nagaland (5.5%), Meghalaya (6.1%), Sikkim (3.7%) and West Bengal (6.5%) (Ojha and Singh, 2004). The Brahmaputra is an extremely dynamic, predominantly braided river. The river is unique due to peculiar drainage pattern through diverse environments, high sediment load, critical flood and bank erosion problem. Sediment yield of Brahmaputra (852.4 t/km2 /y) is the highest in the world (Latrubesse, 2008). Causes of high sediment load in the river are young lithology, seismicity, unconsolidated sedimentary rocks of the Himalayas, steep slope of the river and tributaries, heavy rainfall in monsoon months (June -- September), deforestation and faulty land use practice like jhum cultivation and forest fire.

Wasson (2003) attempted construction of an approximate sediment budget for the Ganga-Brahmaputra catchment based on published data and Nd/Sr tracer results. Subramanian and Ramanathan (1996) reported highly variable sediment load of Brahmaputra River ranging from 402 to 710 million t/y^{-1}. Islam et al. (1999) estimated suspended load flux ranging from 402 to 1157 million t/y^{-1} for the Brahmaputra to the Bay of Bengal. In this paper, sediment budgeting is studied from a mass balance approach.

Sediment input from tributaries of the Brahmaputra River in Assam

The major Rivers and tributaries within the state of Assam with high sediment load are shown in Figure 1.

Volume of sediments to the Brahmaputra River from tributaries in a year (from Pahuja and Goswami, 2007) = 51,316 ha m = 513.2×10^6 m^3.

Considering sediment density 1.36 g/cm^3 from Agarwal and Singh (2007), mass of suspended sediments collectively contributed by tributaries in a year was found to be 698×10^6 t.

Floodplains are important sites for sediment storage in fluvial systems (Phillips, 1992; Steiger et al., 2001; Noe and Hupp, 2009). Approximately one third of the annual sediment load of the Ganges-Brahmaputra is deposited in the river flood-plains (Goodbred and Kuehl, 1998; Goodbred and Kuehl, 1999). Liu et al. (2009) mentioned that 30-50% River-derived sediments of the Tibetan Rivers like Yellow, Yangtze, Brahmaputra, Ganges, Indus, Mekong and Irrawaddy are trapped in the river's low reaches and contribute to extensive floodplain and delta plain development.

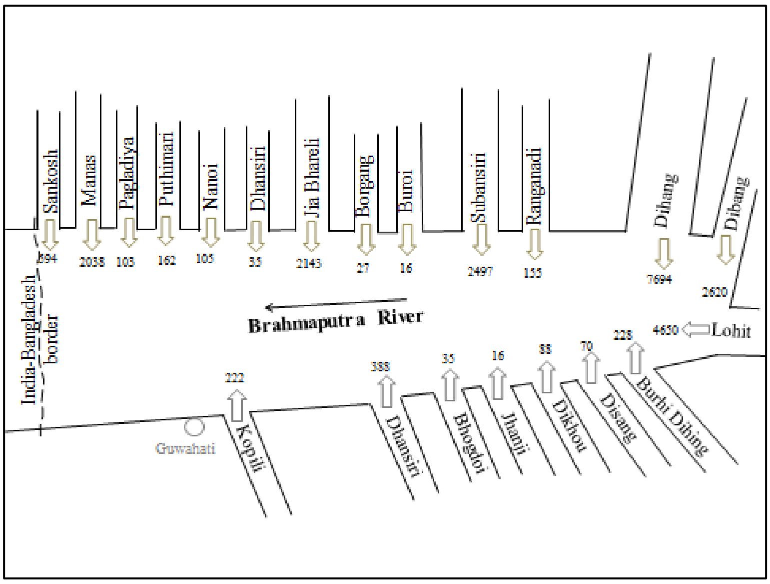

Figure 1. Rivers/ tributaries within Assam with high sediment load
**(The numbers indicate annual average suspended sediment load in ha m)*river deposits in the Tista Fan, Bangladesh

Sediment deposited on river bed and floodplain =279×10^6 t (i.e., 40% of 698×10^6 t, considering trapping of 40% of riverine sediments)

Net sediment contribution from all rivers/ tributaries to total sediment at downstream location = 419×10^6 t (60% of total sediments).

Sediment contribution from scouring of river bed

Development and movement of scour have significant influence on the total sediment transports in the Brahmaputra; they may equate up to 25% of total sediment transports in Brahmaputra (FAP24, 1996).

Scour during 1957 – 1989 = 5649.6×10^6 m^3
Scour in a year = 5649.6×10^6 m^3/32 =177×10^6 m^3
Mass of sediment from scouring = 241×10^6 t

Sediment deposition on river bed

Deposition in bed during 1957–1989 = 1625×10^6 m^3
Volume of deposition in a year = 1625×106 m^3/32 = 51×106 m3
Mass of deposited sediment in a year = 69×10^6 t

Sediment contribution from river bank erosion

From Saikia (2017), bank erosion in the Brahmaputra in 41 years (1973 – 2014) = 1557 km^2
Thus, bank erosion in a year = 1557 km^2/41 = 38 km^2 = 38×10^6 m^2. Average difference of yearly observed highest and the lowest water levels of Brahmaputra for the period 1914 – 1990 was 4.7 m. Assuming depth of bank erosion as 4.7 m, volume of bank erosion in a year = 179×10^6 m^3
Mass of eroded materials = 243×10^6 t

Sediment deposition in banks

From Saikia (2017), total deposition in Brahmaputra (Between Dibrugarh and Dhubri in Assam) during 1973–2014 = 204 km^2
Bank deposition in a year = 204 km^2/41 = 4.97 km^2 = 4.97×10^6 m^2
Garzanti et al. (2010) suggested that dominant bedform in Brahmaputra are sand dunes with heights ≤6 m and wavelengths (λ) ≤330 m. Considering sandbars as spherical domes of height 6 m and radius of base 82.5 m (half of λ/2), average height of deposition is 3 m.

Volume of deposition = 15×10^6 m^3
Mass of deposited sediments = 20×10^6 t

Now, Total sediment in a channel at a downstream cross section = Sediment contribution from main stream and tributaries + sediment contribution from River bank erosion + sediment contribution from scouring – sediment deposition on River bed– sediment deposition on River banks & floodplains
= 419×10^6 t + 243×10^6 t + 241×10^6 t – 69×10^6 t – 20×10^6 t= 814×10^6 t

Lane and Borland (1951) postulated that suspended load of a river carries 90% of the sediment, while bed load transport accounts for approximately 10% of sediment. Thus, 90% of the total suspended sediment load at a catchment outlet may be explained by the total amount of sediments coming from upstream nested catchments (Gay et al., 2014). Considering 10% of sediment load of Brahmaputra as bed load, suspended sediment load at downstream is 733×10^6 t (90% of 814×10^6 t).

Table 1. Sediment load of Brahmaputra from different studies

Suspended sediment load (10^6 t y^{-1})	Reference	Gauging stations/ sampling locations	Period of measurement
617	Coleman, 1969	Bahadurabad, Bangladesh	1958 – 1962
541	BWDB, 1972	Bahadurabad, Bangladesh	1967 – 1969
1157	Milliman and Meade, 1983	Bahadurabad, Bangladesh	1966 – 1967
402	Goswami, 1985	Pandu, Assam	1955 – 1979
650	Hossain, 1992	Bahadurabad, Bangladesh	1982 – 1988
721	Islam, 1999	Bahadurabad, Bangladesh	1989 – 1994
595-672	Darby et al., 2015	Bahadurabad, Bangladesh	1981 – 1995
733	Present study	Secondary data compiled from multiple sources	Different period for different data

Based on these estimates, a schematic sediment budget for Brahmaputra in Assam can be arrived at Fig. 2.

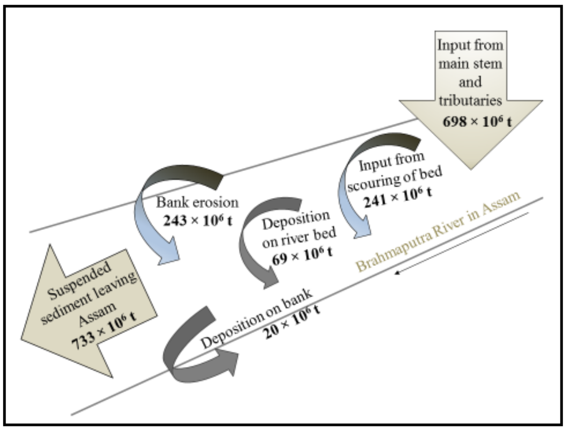

Figure 2. A schematic diagram to show sediment budget for Brahmaputra River in Assam

Sediment deposition on river bed/ banks and contribution to sediment load from different sources are shown in Figure 3. Tributaries including the main stem are the major contributor of sediment in Brahmaputra. More than half of total sediment of Brahmaputra at downstream (i.e., 52%) comes from the main stem and the tributaries (Figure 4). Calculated mass of eroded materials from bank erosion in a year was 243×10^6 t. Amount of yearly deposition on River bank and floodplains was 20×10^6 t. 223×10^6 t sediments (27%) were contributed to annual sediment load of the River from bank erosion.

Major contribution (52%) of sediment loads from bank erosion is common in most of the rivers (Bull, 1997; Church and Slaymaker, 1989; Lawler et al., 1999). But sediment load of Brahmaputra can't be compared with that of other Tibetan rivers like Yellow and Yangtze in case of sediment input from bank erosion. In Yellow River, bank-to-channel sediment transfer process was found to cause the overall increase in channel deposition with little influences on the down-stream suspended sediment load and transport (Ta et al., 2013). A remote sensing investigation on a 1479 km-long reach of Yangtze River for the period of 1970 – 1998 indicated that volume of bank failure (267×106 m3) and volume of bed deposition (291×106 m3) was almost same (Xu et al., 2001). But, in case of Brahmaputra, volume of bank erosion in a year (243×106 m3) was more than ten times of volume of deposition (20×106 m3).

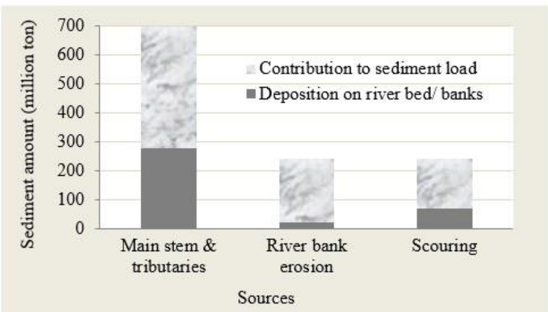

Figure 3. Deposition of sediment and contribution to sediment load to the Brahmaputra from different sources

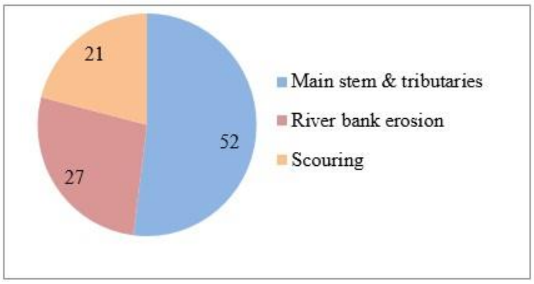

Figure 4. Percent contribution to sediment load of the Brahmaputra from different sources

Modified Sediment Load due to Human Interventions

Human activities are the most important factors that affect the variation in the pattern of river sediment load (Syvitski et al., 2005; Walling, 2006). Liu et al (2008) showed that the average annual sediment yield per area has been decreased significantly in Yellow River over the past 10 years mainly due to impacts of human activities, including the operation of hydropower stations/ reservoirs, construction of dams, as well as soil conservation programs. Liu et al. (2008) showed marked decrease in annual sediment yield at the Lijin Station on the Yellow River in 1961, 1980 and 2000. Before 1960, Yellow River was under essentially natural conditions. From 1960 to 1964, the Sanmenxia reservoir was in operation for impounding water and trapping sediment. Thus, annual sediment transport downstream decreased dramatically. From 1965 to 1973, the operating mode of the Sanmenxia reservoir was changed to provide flood detention and sediment flushing. Thus, both annual sediment transport and runoff increased during this period. From 1974 to 1985, the operating mode of the Sanmenxia reservoir was further modified to provide for “storing clear water during low flow seasons and releasing turbid water during flood periods”. Since 1980, due to increased water consumption by agriculture and industry and soil and water conservation projects, both annual sediment transport and runoff on the Lower Reach of the Yellow River decreased significantly (Liu et al., 2008).

During the past 50 years, the sediment loads are in increasing trend in most of the upstream stations of the Yangtze River basin, but in decreasing trend at other stations (Zhang et al., 2006). Studies by Xu and Milliman (2009) revealed that after the impoundment of the Three Gorges Reservoir (TGR), 60% of the sediment entering the TGR was trapped in flood seasons. Downstream of the TGR, substantial channel erosion is significant. However, downstream channel erosion (70 Mt/y) has not yet counteracted TGR trapping (118 Mt/y) and sediment delivered to the Yangtze estuary will probably continue to decrease.

Amazon River, Nile River, Mississippi River and Red River are other examples where reservoirs and dam construction has changed sediment dynamics of the floodplains. Expansion of hydropower and agricultural activity have recently modified Amazon’s land surface processes (Forsberg et al., 2017; Latrubesse et al., 2017; Anderson et al., 2018), which have implications on discharge and sediment flux in the Amazon River (Nobre et al 2016). Fine suspended sediments flux in the Amazon River was found to be linked to rainfall and higher coarse suspended sediment flux was related with discharge. Hence, climatic conditions that control rainfall input have profound impact on discharge and sediment flux of a river (Armijos et al., 2020).

Before the High Aswan dam, the Nile River carried an average of 124 million ton of sediment to the sea in a year, and deposited another 9.5 million tons on the flood plain. But due to construction of that dam, 98% of the sediment goes to the bottom of the Nasser reservoir (Billi, 2010). In Mississippi River, prior to 1930s, the floodplain was the major sediment source. But due to human modifications in terms of dams & reservoirs, artificial levees, dikes, concrete revetments and a series of channel cutoffs, floodplain provides only a minor amount of sediments today. Major degradation to the channel including the growth of channel bars has occurred as a result of these engineered modifications (Kesel, 2003). Similarly, the impoundment of two large reservoirs in the Da and the Lo watersheds in the 1980s has resulted in a considerable reduction (70%) of the total suspended load carried to the sea by the Red River (Le et al., 2007).

Sediment load in rivers has changed significantly due to climate change impacts and human activities like economic development, industrial restructuring, population migration, and urbanization. Urbanization rate is found negatively correlated with sediment load and cultivated land area is found positively correlated with sediment load. The decrease of cultivated land area in many river basins makes the sediment load gradually decrease (Zhong et al., 2020). About 50% of the world’s rivers show a significant decline in river sediment load (Roy et al., 2017; Vigiak et al., 2017; Zhao et al., 2017; Liu et al., 2019; Shi et al., 2019), affecting the structure, processes, and functions of societies and ecosystems (Syvitski et al., 2005; Ukkola et al., 2015; Walling et al., 2003).

Generic conclusions on sediment load by Brahmaputra River system is near to impossible due to wide diurnal, seasonal and annual variations in the sediment-carrying capacity of the river (Subramanian and Ramanathan, 1996). Paucity of dependable data for the main stem and tributaries also bring lot of uncertainty to sediment quantification for the Brahmaputra River.

Sediment transport in the Brahmaputra River is highly controlled by the monsoon regime with large depositional fluctuations within the braided channels (Roy and Sinha, 2014) resulting change in morphology of the river by flood and bank erosion. The Brahmaputra valley has been facing a heavy instability of landmass due to river bank erosion, believed to be accelerated after the 1950 earthquake. After the declaration of National Policy in 1954, a huge network of flood embankments along Brahmaputra and its tributaries was erected across the state. As of December, 2018, length of embankments in the state of Assam is 4486.44 km out of which 1031.8 km is in the Brahmaputra river. Flood and erosion prevention attempts by embankments to secure floodplain communities would result in higher velocities and increased scour and erosion from a smaller cross-sectional area. Mosselman (2006) observed increased erosion rate in the Brahmaputra, particularly where bank protection measures were applied.

Climate change impact (ICIMOD, 2009) and hydropower dam initiative in upstream of Brahmaputra, i.e., Arunachal Pradesh (The Ecologist Asia, 2003), has added further complexity in the sediment flux regime of the river. Fischer et al. (2017) estimated increase of sediment load of the Brahmaputra River due to projected climate change induced high water discharge by 40% by the end of the century (2075–2100) compared to levels in 1986–1991. Again, the construction of reservoirs can considerably reduce the sediment load (Walling and

Fang, 2003), and large-scale damming of the upper Brahmaputra and its tributaries could counteract the increase in sediment delivery to the delta.

SUMMARY AND CONCLUSIONS

Sediment dynamics of the major rivers of the world are changing due to climate change impacts and anthropogenic activities particularly dam construction, population migration, agriculture, urbanization and engineered modification for channel improvement. Based on the mass balance approach, contribution of tributaries, bank erosion and scouring to suspended sediment of Brahmaputra at Indo-Bangladesh border are 52%, 27% and 21% respectively.

Major limitation of the present sediment budget for the Brahmaputra River in Assam is that, data for different components were from different sources and different periods and have different reliabilities, which might lead to the uncertainty associated with the results presented herein. River bank protection by embankments, dam initiatives in the upstream of the river and potential climate change impacts have added further complexity in sediment flux regime of the Brahmaputra River. Attention is essential on sediment management in a river to restore and rejuvenate the structure, processes, and functions of societies as well as ecosystem and management of flood & bank erosion hazards.

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