Research Note

SEDIMENT MANAGEMENT FOR THE BRAHMAPUTRA RIVER

Atul Kumar, DoMS, IIT Roorkee

Most of the rivers originate from glaciers located high up in the mountains, and when they start trudging down the hill, it gathers pace and falls down with a lot of momentum. The sheer volume of water that falls down along with the speed it possesses is more than enough to disturb the path through which it travels and as a result, the water takes along a lot of other things which comes in its way. It can be small rocks, sands, boulders, soil and even the dead remains of animals. All these things combined are termed as sediments. These sediments are all naturally occurring and are organic as well as inorganic in nature. These fine-grained sediment is a natural and essential component of river systems and plays a major role in the hydrological, geomorphological and ecological functioning of rivers. [1] In many areas of the world, the level of anthropogenic activity is such that fine-grained sediment fluxes have been, or are being, modified at a magnitude and rate that cause profound, and sometimes irreversible, changes in the way that river systems function.[1]
And when we talk about the Brahmaputra river, the amount of water that it has and the speed with which it falls, it has all the features of a river which erodes a good portion of land in its path. Brahmaputra carries a huge amount of sediment with it and the excess of sediment becomes a problem as when it reaches a plane region, the speed decreases and as a result, it deposits all the sediment that it carries with itself. So, when the sediment is in such large amount it means that there arises a need to management these sediment to mitigate the issues that are caused by excess sediments.

1. Channel morphology and changes in the course of Brahmaputra River

Rivers are responsible for draining landmasses and carrying the water-sediment load to the ocean. In accomplishing this task, the water forms and maintains a highly organized system of physical and hydraulic features. Details of interrelations in this organized system are highly complex, and it is challenging to visualize many of them simultaneously.
In a plan view, a river's pattern is defined as the look of a stretch. When looking at plan views of most of the major rivers, they may be divided into three categories: braided, straight, and meandering [2]. Although these three types indicate the major divides, it is important to note that there is a continual gradation from one type to the next. As a result, it is typical to find multiple types of patterns along the length of a single river. The Brahmaputra River, like many other rivers, has altered course in the past and there is a good likelihood it will do so again in the future. The Brahmaputra-Jamuna River's course has shifted drastically in the last 250 years, with evidence of large-scale avulsion from 1776 to 1850 and more general westward migration of the Jamuna channel belt since then. Prior to 1843, the Brahmaputra flowed within the channel now termed the ‘old Brahmaputra’ east of the Madhupur Tract and joined the Meghna River. Sometime

between 1830 and 1860, Bristow (1999) [3] contends that avulsion of the river occurred and caused a maximum of ~80 km of lateral shifting of the river course from the east to the west of the Madhupur Tract.

Tectonic activity, shifts in the upstream path of the Teesta River, the influence of greater discharge, catastrophic floods, and river capture into an old river course have all been postulated as reasons for the channel's avulsion into its current course in several studies.[4] [5] The river avulsion was more likely gradual than catastrophic, according to a review of maps from 1776 to 1843, and may have been caused by bank erosion, maybe around a massive mid-channel bar, forcing the channel to be diverted into an existing floodplain channel. Rennell's graphic displays a series of enormous bars near the Jamuna's offtake, indicating local sediment overload and flow diversion against the banks. Because the right bank at this location reveals two enormous embayments that would funnel water down the offtake, it's possible that significant flow was formerly diverted down the Jamuna offtake.

A braided river channel, the Brahmaputra can be classified as such. The channels change back and forth between the major stream banks, which are often 4-8 miles apart, during low flow. Many channels, shoals, and islands may be seen in plan views of the river, indicating a river with low hydraulic efficiency and a high sediment load. In 1949 and 1956, gauge records and discharge measurements were started, respectively. The average annual discharge is about twice that of the Ganges, at 678,000 cusecs. If a flood is present, the first flood peak usually comes in mid-June and is marked by a very rapid increase in discharge. The discharge could rise from less than 600,000 cusecs to over 1,600,000 cusecs in a matter of days. The river level usually drops slightly after this quick initial rise, and the big flood peak occurs in the latter part of July or the first part of August. This flood period will generally last for nearly a month; then the river will again drop slightly. During the first part of September, a third flood peak will occur. In the latter part of September or first of October the river stage will begin to subside.

2. Floods in the Brahmaputra River

The Brahmaputra River is one of those rivers that, by the standards of a typical river, carries a massive volume of water. Along with a large amount of water, it also runs at a rapid speed, carrying a lot of sediment with it, which causes a variety of problems, one of which is floods in the river, which occur on a frequent basis. Floods have become a regular component of the Brahmaputra's annual cycle. Every year during the south-west monsoon, the Brahmaputra's main channel and tributaries overflow their banks, triggering disastrous floods in the Assam Plains, resulting in massive loss of life, property, and infrastructure. Large floods with flow rates of 70 000–100 000 m3 s-1 have a 100-year return period. [6] Floods near Guwahati with a 25-year recurrence with a discharge of 60 000 m3 s-1. In recent times, the highest flood discharge was recorded in 1962 near Guwahati as 73 000 m3 s-1. The average annual flood at Pandu near Guwahati has a magnitude of ~50 000 m3 s-1 with a recurrence period of ~2.6 years. [7] The bank full discharge here is 35 000 m3 s-1 which occurs every year on the Brahmaputra. [6] The flash floods of the Himalayan tributaries contribute huge peak discharges leading to flooding of the plains.

During the past 50 years, larger flood events occurred in 1954, 1962, 1966, 1972, 1973, 1977, 1978, 1983, 1984, 1987, 1988, 1991, 1993, 1995, 1996, 1998, 2000 and 2003.

Floods affect almost 10,000 km2 of land in Assam each year, accounting for 12.25 percent of the state's geographical area. About 12.5 million people were affected by the flood of 1998, which submerged 38 000 km2 (about half of Assam). [8] Similarly, in 1988, 46 500 km2 of land was devastated, including 13,350 km2 of cropland, affecting tens of millions of people in 10,000 settlements.

The Brahmaputra Plain in Assam is about 80 kilometres wide, yet its unit flood flow is extraordinarily high. The combination of a high flow during the south-west monsoon, a narrow valley flat, and a low gradient results in drainage congestion and flooding. The Shillong Plateau appears to have obstructed the Brahmaputra River near Guwahati, causing the valley flat to narrow. This along with the deposition of sediment upstream as islands and sandbars in the channel has reduced the carrying capacity of the Brahmaputra.

Flooding of the Brahmaputra has also occurred in the past due to tectonic disturbances. The major earthquake of magnitude 8.7 in 1897 partially halted the Brahmaputra's flow, causing widespread flooding of the riverine plain. Similarly, the 1950 earthquake (magnitude 8.7) in Dibrugarh blocked the flow of the Brahmaputra, causing up to 3 m of siltation on the bed, reducing flow capacity and resulting in further floods in subsequent years. Floods in the Assam Plains are also a result of anthropogenic activities. Deforestation in the higher reaches has shortened the amount of time rainwater stays in the basin, making floods more likely. [8]

The drainage system has been harmed by poorly built road and railway embankments. The presence of approximately 4000 km of embankments in Assam, roughly a third of the entire length of embankments in India, demonstrates the country's reliance on structural flood control measures. Floods on a huge river like the Brahmaputra, on the other hand, are difficult to manage with embankments. The Brahmaputra Basin's dynamic tectonics also discourages the installation of flood-control facilities. The construction of upstream storage reservoirs is seen to be an effective flood control measure.

Structural methods, on the other hand, are not a complete flood-control solution on the Brahmaputra. Non-structural methods such as flood forecasting and warning, flood plain regulation, and disaster release have all been suggested as ways to improve non-structural approaches.

3. Erosion in Brahmaputra River

The Brahmaputra River, as we all know, transports a significant volume of water and travels at a fast speed. So, when a river's water falls from a considerable height in such a large volume, it causes erosion of soils and other things along the river's path. This erosion phenomenon occurs on a massive scale in the Brahmaputra River, causing siltation and other problems in the river.

Deposition and erosion rates are quite high in rivers as heavily laden with sediment as the Ganges and Brahmaputra. Controlling soil erosion is one of the most important actions that India must take in relation to the Brahmaputra. In the northeast India catchment area, soil erosion is a big issue. According to the Brahmaputra Board of India’s Ministry of Water Resources, “Due to heavy deposition of silt, the river has frequently changed its course. Excessive silt deposition has also given rise to braiding and meandering pattern in the alignment of the river system.” Many reasons contribute to high siltation, including landslides caused by severe rainfall in the area, earthquakes, and man-made actions such as changes in agricultural patterns and exploitation of forest resources in the hills above the valley through which the river flows. North Indian experts also point out that coping with floods and soil erosion is a serious challenge for the region's population.

Physical and chemical erosion rates in the Brahmaputra Basin are higher than those in the Ganga, and much higher than the world average, due to the heavy runoff and lithology of the Eastern Himalaya. [9] [10] The Brahmaputra's total erosion is 1.5 to 2 times higher than the Ganga's. The origins of clastic silt and dissolved materials in the Brahmaputra Basin were examined by Singh and France-Lanord (2002) and Singh et al. (2005). [10] The following section shows the erosion rates for each of the previously mentioned zones. The impact of numerous factors on physical and chemical erosion in the Brahmaputra Basin has also been investigated.

The assumption behind tracing sediment in the Brahmaputra Basin is that the Sr and Nd isotope compositions of the sediments match those of their source rocks. Because the weathering intensity in these sediments is low, the assumption is very likely to be correct for Himalayan rivers. [11] The Brahmaputra Basin's rapid water discharge and short sediment residence time indicate that weathering in the basin is very constrained and that sediment composition change is minimal. [12] The low quantity of clay in the sediment, as well as the composition of that clay, confirm this. [11] The two end-member mixing model was used to calculate the proportions of sediment contributed by the various zones in the basin. The findings revealed that nearly half of the Brahmaputra's sediment originates upstream of Pasighat. [13] The Eastern Syntaxis Zone is also the largest source of sediment to the river, according to isotope data and sediment abundance. Due to variables like as low flow, gentle slope, and the occurrence of knickpoints on the Tsangpo prior to its entry into the gorge that cuts through the Eastern Syntaxis, Tibet's contribution is minimal. [14]

The erosion rates in different regions of the Brahmaputra Basin are variable. The Eastern Syntaxis Zone has the largest sediment production, or physical erosion rate, while Tibet has the lowest. In addition, not all of the material eroded by rivers ends up in the oceans. Rather, it is deposited in river channels and flood plains in large amounts. River-borne sediments have accumulated in some reservoirs behind dams. And, for a variety of reasons, both natural (tectonics, earthquakes) and manmade (pollution), the rate of sediment deposition in these river systems is not in equilibrium with the reported rates of erosion (deforestation, dredging, urbanization). Over 900 kilometres from Dibrugarh to Dhubri, the sedimentation rate in the Brahmaputra Basin drops (1 cm/year to 0.2 cm/year).

4. Impact of climate change on Brahmaputra River

Climate has a significant impact on the geography of any river, and it also has a direct impact on any river. And the changes in climate that are occurring as a result of numerous anthropogenic activities and other industrialised factors are likely to have an impact on the Brahmaputra river. In addition, many sources have made estimates in this regard, which have been reviewed in various studies.

Because of its location on the eastern Himalayan fringe, fragile geo-environmental setting, and economic underdevelopment, the Brahmaputra sub-basin is sensitive to climate change consequences. It was revealed courtesy of comprehensive assessment done in 2015 across some five major river basins in the region of the Hindu Kush Himalayas that:

(i) average temperatures across the region is expected to increase by about 1– 2°C (in places by up to 4– 5°C) by 2050;

(ii) the monsoon is expected to become longer and more erratic;

(iii) precipitation across the region could increase by 5 percent on average and up to 25 percent by 2050;

(iv) extreme rainfall events are becoming less frequent, but more intense, and are likely to keep increasing in precipitation intensity; and

(v) glaciers will continue to suffer substantial mass loss.

As per ICIMOD 2015 eastern Himalayas are experiencing warming of around 0.1 to 0.4°C every decade and some simulation models indicate that there can be widespread warming happening in northeast India almost by 1.8 to 2.1°C in 2030s with INCCA 2020 predicting that rainfall of even higher intensity can happen during the monsoon season. [15] [16] In the paper by Datta and Singh (2004), it is stated that since 80 percent of the flow that takes place in the Brahmaputra river happenes in monsoon period and any irregular change in rainfall or monsoon changes will be a cause of greater concequences. [17]

Again, glacial melt accounts for more than 12% of the Brahmaputra's river flow, and rising temperatures resulting in glacial melt would result in enhanced summer flows for a few decades, followed by a decrease in flow as the glaciers vanish.

Despite the increased interest in quantifying freshwater resources and assessing freshwater susceptibility to global change, basin-wide evaluations of the effects of climate and land use change on freshwater availability in the Brahmaputra basin are still scarce. [18]

5. Data sharing issue with Brahmaputra river

When a river of the maginitide and size of Brahmaputra happens to be cause of regular flood and cause of deaths then it becomes ever so important to do proper forecasting so that it can help in saving human lives. In such case, the quality of data collected to do forecasting is very critical. However, the data and the information available for forecasting, concerning the Brahmaputra river, is not up to the mark and has become a major issue.

Thousands of lives and properties are lost every year as a result of flash floods along the Brahmaputra and its tributaries, primarily in the Indian states of Assam, Meghalaya, and West Bengal, as well as Bangladesh. Intense rainfall in the upper portions of the basin, steep topography, vulnerable land, deforestation, and urbanisation are all contributing factors. Every year, large sections of fresh agricultural land and natural woods are flooded. Only by developing robust and efficient flood forecasting and warning technologies will it be feasible to save lives and property from flooding (Protective and preventive measures). There are now just a few agreements in place for hydro meteorological and land use data sharing between these three countries. The sharing of such information can help with flood predictions and warning, giving people enough time and opportunity to protect their lives and property.

As per the MOU and the direct exchange mechanism is states, India is supposed to get hydrological information like water level, discharge, and rainfall from China regarding three stations which are Yarlung: Nugesha, Yangcun and Nuxia located in Tibet. Twice a day at 0800 hrs and 2000 hrs (Beijing Time) these information has to be provided during the high flow season of May 15 to October 15 every year.

Given the data on hydro meteorological volatility in the Brahmaputra system, the current data-sharing mechanism is anticipated to be only marginally helpful in providing early flood warning for the Brahmaputra. Nugesha, Yangcun, and Nuxia, the three approved hydrological sites for data exchange, are all in the rain-shadow zone, with annual average precipitation ranging from 0-500 mm.

The river Yarlung's discharge more than doubles as it passes through Nuxia, makes the 'great bend,' and enters India, according to discharge data. India is primarily concerned about the 320-kilometer stretch of river between Nuxia, the final hydrological station from which India receives flood-period data, and Tuting, the first hydrological station within Indian territory. However, no data is available for this rainy section of the river's trip.

6. Gap in Policies causing ineffectiveness of institutions

Policy is critical in natural resource management because it establishes a government framework for guiding long-term decisions and evolves in response to human-environmental interactions. The Brahmaputra Board, an autonomous statutory agency established under an Indian Parliament Act called the Brahmaputra Board Act (Act 46 of 1980) under the Ministry of Irrigation, was the first formal institutional solution for the control of the Brahmaputra in India. The board's authority is not limited to the Brahmaputra sub-basin, but also includes all of northeast India and the portion of West Bengal that is part of the Brahmaputra sub-basin. As a result, the board's jurisdiction extends to the Barak sub-basin (which enters Bangladesh as Meghna).

However, a recent examination of the Brahmaputra Board's operations indicated that it lacked the teeth and mandate for comprehensive development of the Brahmaputra sub-basin in India in terms of land use and natural resource management. There were a few shortcomings like extra emphasis was given on the state of Assam etc and it is discussed in one of the papers of Observer Research Foundation.[19]

A task force chaired by the chairman of the Central Water Commission set up by the Ministry of Water Resources in August 2004 and a nodal group chaired by the chairman of the Central Water Commission set up by the Ministry of Water Resources in August 2011 both recommended strengthening the institutional setup for managing the Brahmaputra sub-basin in India. The operating structure for the stronger organisation was suggested by the nodal group.

This new proposal calls for the existing Brahmaputra Board to be restructured into a new institution called the Brahmaputra River Valley Authority (BRVA). The Authority will comprise a policy-making Governing Council (Council) and an executive agency, the Executive Board (Board). The Authority is in charge of developing complete integrated river basin management (IRBM) in the Indian Brahmaputra sub-basin. The Authority is envisioned as a self-contained autonomous institution with a mandate for the development and control of all water-related activities in the northeastern region of India, with the entire Brahmaputra sub-basin in India as the planning unit. It is also supposed to appraise and monitor water resources projects and take care of its implementations on a basic need or on any special request put forward by any state government in the northeastern region. The terms of reference of the proposed Authority, therefore, stand as:

• integrated multidisciplinary basin planning ensuring their implementation by member states;
• investigation, planning and design, appraisal, clearance, monitoring and implementation of works in consultation with states;
• promotion of sustainable water resources management;
• integrated flood management, flood forecasting;
• hydropower development to the extent provided for national interest. [19]

Given the international transboundary nature of the Brahmaputra sub-basin, even such an institutional response may not be sufficient. More so, because national-level basin management measures can handle a segment of the basin but might lead to spatial imbalance, which may not be conducive to addressing environmental security concerns. On the other hand, there's a chance that this will pose a greater threat to the region's environmental security.

A mention of the UN Convention on the Law of Non-Navigational Uses of International Watercourses would be appropriate at this point. The convention, which was adopted by the United Nations on May 21, 1997, governs the use and conservation of all international waters, including surface and groundwater. The UN statement was written in response to rising water demand in the coming years, with the goal of conserving and managing water resources for current and future generations. While there is little doubt that this agreement is the most important step in developing international water law after the Helsinki Rules of 1966, it has only been ratified by 36 nations, with the majority of countries, particularly a few key ones, remaining outside its ambit. [20] The controversy regarding the convention is mostly related to Article 7 of the document, entitled "Obligation not to cause significant harm," which requires that member states who are "utilizing an international watercourse in their territories […] take all appropriate measures to prevent the causing of significant harm to other watercourse states" and compensate sharing states for any such harm (UN 1997). Two big basin nations, India and China, are non-signatories to the Brahmaputra Sub-Basin Convention (India abstained, while China protested). There is no agreement among significant players in the Brahmaputra sub-basin to take downstream issues into account.

As a result, it's critical to consider downstream concerns in order to develop a better system for human well-being and environmental sustainability at the river basin scale. As a result, the concept of IRBM has been conceived of globally through the institutional vehicle of RBO, which typically arise as transboundary river basin authority, generally with autonomous status, to govern the river basin holistically.

7. SWC policy used in Yellow River Basin, China

Extensive soil erosion and water loss in China's Loess Plateau has historically resulted in soil degradation and water shortages, affecting crop yields and worsening rural poverty, arable land loss, and biodiversity loss on-site. [21] It has also caused sedimentation in the Yellow River (which has the world's highest sediment load), which has reduced reservoir capacity, caused the riverbed to rise, increased the risk of flood disasters, increased the cost of river bank maintenance, and necessitated more water to flush the sediment to the sea. [22] [23] [24]

Soil erosion control in China's Loess Plateau has mostly relied on the development and implementation of measures that have significantly reduced the Yellow River's sediment load throughout time.

Many factors influence the implementation of soil and water conservation policies, but they appear to operate successfully in China since there are few conflicts between local farmers and downstream regions. [25] [26] Other human behaviours, on the other hand, play a role in SWC and natural resource management. Economic actions, for example, are typically driven by survival or other rewards, and can be influenced by policy; religion, culture, and consciousness can play an indirect role in both economic activities and policy formation. [27] [28] [29] [30] [31] Locals are motivated by survival and money to plant or dig up medical herbs with little regard for policy, legislation, or social responsibility. A poorly formulated policy could also lead to the extinction of the land. The SWC policy in YRB has a long-term goal and addresses a specific issue, although some measures were too bold and/or urgent, and did not take biophysical and economic feasibility into account, e.g. proposing to build many reservoirs for siltation and over-optimistically planning for total soil erosion control in a way that neglected the complexity of the ecological system and power of natural processes. [32] With a better understanding of the complexities of environmental and socioeconomic processes across the YRB, SWC became the most essential answer for both rural development and flood disasters, and SWC policy improved rationally as a result.

Despite this, SWC policy gave very little attention to the entire basin's water deficit problem. The Huayuankou Hydrological Station's runoff followed the same pattern. Water limitations have already had an impact on the development of the lower reaches. Because there are no policies concentrating on RRS (Ratio of Runoff detained to Sediment detained), our study recommends that, in light of this gap, current policy should pay more attention to water shortages when lowering sediment load. [33] [34] [35]

8. Important projects involving the Brahmaputra River

i. NW 2- National Waterway 2 is India's one of the major inland waterway. It is a section of the Brahmaputra River having a length if 891 km between the Bangladesh border near Dhubri and Sadiya in Assam, India. [36] At present, this waterway plays an important role in handling and movement of cargo vessels and passenger ferries. The movement of cargo by waterways is economically cheaper and also more eco friendly as compared to roadways and railways. However, the use of waterways for transportation of cargo has been very limited until recent past as more attention was given to developing better roadways and railways.

The government of India and Assam government has realised this and have started to shift their focus on using this mode of transportation in best way possible. The SAGAR vision propsed by the honerable prime minister of India also gives a clear sign that the time to develop this mode of transportation has come.

Currently there are terminals located at 12 locations and there is a possibility that this number will go up in the future. [37] To support these project and ensure that all the development happening in this field gives the expected result it is important that we keep the river in its best form and manage the sedimentation problem in the best possible way.

ii. Assam Inland Water Transport Project- The project aims to improve the passenger ferry infrastructure and services in Assam and also improve the institutional capacity and framework for inland water transport in Assam. The project was approved on December 13, 2019 and is supposed to be completed by the end of 2024. [38] The idea is to improve the inland water transport by upgrading the quality of terminals and ferries used for transportation.

The Brahmaputra river divides Assam into two halves and the northern half is the under developed part. People of northern part still have to cross the river to travel to southern part in order to fulfill some essential need for themselves. And the current transportation facility only allows people to cross river in day time as the boats used to travel are not equipped to travel in night time. Similar sort of problem affects the life of people in monsoon season when rain is around. This project aims to better the transport facility that are available for the people of northen assam.

iii. Brahmaputra Express Highway- Construction of 890 km of express highway along the entire length of Brahmaputra in the Assam state from Sadiya in the east to Dhubri in the west has been would be started soon by the Assam government. [39] This will develop both banks of the river Brahmaputra and will consequently reduce the problem of erosion caused by the river.Survey for the work has already been started. The silt dug out by the dredging of the river will be utilized for the construction of the road.

9. Stakeholders Involved

Brahmaputra River is one of the major river of India and when we talk about the stakeholders involved in it then they are both national-level as well as state-level stakeholders there.

Inland Waterways Authority of India (IWAI), founded in 1986, is one of the authorities involved which is in charge of the waterways of India. [40]

Along with them the Assam government is the other stakeholder involved. The general public of Assam living on or near the banks of the river is one important stakeholder when we are talking about the Brahmaputra River.

These stakeholders play an important role in whatever decision is taken regarding the Brahmaputra river. All the major projects discussed above are mostly involve IWAI and Assam government. The financial help or funding for these project are arranged by these two government bodies only either by government funding or by taking funds from other bodies like World Bank. In past, IWAI has generated funds from National Clean Energy fund, Central Road Fund and by selling government bonds.

10. Opportunities

a. Preparing sustainable and eco friendly sediment management techniques to help resolve the sedimentation problem in Brahmaputra River

b. Understanding and optimum use of dredging for tackling sedimentation problem as it's expensive method
c. Regular inspection of sediment type in the river and then building a stategy to tackle the sedimentation problem because different types of sediment needs to be dealt with differently
d. Developing a better data informed forecasting techniques to tackle the flood problem in Assam
e. Increasing the use of inland water transportation as it is more economical and eco friendly option

11. Research Directions

a. Analyzing the details of the river and its sediment so as to formulate an effective plan to manage the sediments
b. Understanding the type of sediment carried by Brahmaputra and how these sediments can be used for different purposes
c. Analyze the impact of sediment accumulation on the regular floods that happen in Brahmaputra river
d. Estimation of how much the sedimentation problem affects the aquatic life and the ecological balance of the region

References:

[1] P. N. OWENS, * R. J. BATALLA, A. J. COLLINS, B. GOMEZ, D. M. HICKS, A. J. HOROWITZ, G. M. KONDOLF, M. MARDEN, M. J. PAGE, D. H. PEACOCK, E. L. PETTICREW, W. SALOMONS and N. A. TRUSTRUM., 2005. FINE-GRAINED SEDIMENT IN RIVER SYSTEMS: ENVIRONMENTAL SIGNIFICANCE AND MANAGEMENT ISSUES

[2] LEOPOLD, L. B., WOLMAN, M. G. and MILLER, J. P., 1964. Fluvial Processes in Geomorphology. Freeman, San Francisco, Calif., 522 pp.

[3] Bristow, C.S. (1999) Avulsion, river metamorphosis and reworking by underfit streams: a modern example from the Brahmaputra River in Bangladesh and a possible ancient example in the Spanish Pyrenees. In: Fluvial Sedimentology 6 (Eds Smith, N.D. and Rogers, J.), Special Publication of the International Association of Sedimentologists, No. 28, 221–230.

[4] Coleman, J.M. (1969) Brahmaputra River: channel processes and sedimentation, Sedimentary Geology, 3, 129–239.

[5] La Touche, T.H.D. (1910) Relics of the great Ice Age in the plains of northern India, reprinted (1919). In: Report on the Hooghly River and its Head waters, The Bengal Secretariat Book Depot, Calcutta, v. I, 21–22.

[6] Goswami, D.C. (1998) Fluvial regime and flood hydrology of the Brahmaputra River, Assam. In: Flood Studies in India (V.S. Kale, Ed.), Geological Society of India, Bangalore, pp. 51– 75.

[7] Bhattacharyya, N.N. and Bora, A.K. (1997) Floods of the Brahmaputra River in India, Water Int. 22, 222–229.

[8] Valdiya, K.S. (1999) Why does river Brahmaputra remain untamed?, Curr. Sci. 76, 1301–1304.

[9] Sarin, M.M., Krishnaswami, S., Dilli, K., Somayajulu, B.L.K.and Moore, W.S. (1989) Major ion chemistry of the GangaBrahmaputra river system: weathering processes and fluxes to the Bay of Bengal, Geochim. Cosmochim. Acta 53, 997– 1009.

[10] Galy, A. and France-Lanord, C. (2001) Higher erosion rates in the Himalaya: geochemical constraints on riverine fluxes, Geology 29, 23–26.

[11] Singh, S.K., Sarin, M.M. and France-Lanord, C. (2005) Chemical erosion in the eastern Himalaya: major ion composition of the Brahmaputra and δ13C of dissolved inorganic carbon, Geochim. Cosmochim. Acta 69, 3573–3588.

[12] Stallard, R.F. (1995) Tectonic, environmental, and human aspects of weathering and erosion: a global review using a steady-state perspective. Ann. Rev. Earth Planet. Sci. 23, 11–39.

[13] Singh, S.K. and France-Lanord, C. (2002) Tracing the distribution of erosion in the Brahmaputra watershed from isotopic compositions of stream sediments, Earth Planet. Sci. Lett. 202, 645–662.

[14] Zeitler, P.K., Meltzer, A.S., Koons, P.O., Craw, D., Hallet, B., Chamberlain, C.P., Kidd, W.S.F., Park, S.K., Seeber, L., Bishop, M. and Shroder, J. (2001) Erosion, Himalayan geodynamics, and the geomorphology of metamorphism, GSA Today, 4–9.

[15] ICIMOD (2015). The Himalayan Climate and Water Atlas: Impact of Climate Change on Water Resources in Five of Asia's Major River Basins . Kathmandu: ICIMOD.

[16] INCCA (2010). India: Greenhouse Gas Emissions 2007. Indian Network for Climate Change Assessment (INCCA), The Ministry of Environment & Forests, Govern.

[17] Datta, B. and Singh, V. P. (2004). Hydrology. In The Brahmaputra Basin Water Resources , ed. V. P. Singh, N. Sharma, C. Shekhar and P. Ojha. Boston: Kluwer Academic Publishers, pp. 139– 95.

[18] Srinivasan, R., Ramanarayanan, T. S., Arnold, J. G. and Bednarz, S. T. (1998). Large area hydrologic modeling and assessment: Part II Model application. Journal of American Water Resources Association , Vol. 34, No. 1, 91– 101

[19] Bandyopadhyay, J., Ghosh, N., & Mahanta, C. (n.d.). Irbm for Brahmaputra Sub-basin. Observer Research Foundation.

[20] Raj, K. and Salman, S.M.A. "International Groundwater Law and the World Bank Policy for Projects on Transboundary Groundwater", In Groundwater: Legal and Policy Perspectives: Proceedings of a World Bank Seminar edited by Salman, S.M.A. New York: World Bank Publications, 1999.

[21] Meng Q. Soil and Water Conservation of Loess Plateau. Zhengzhou: Yellow River Water Conservancy Press; 1997. p. 509–22 (in Chinese).

[22] Zhao W. Sediment of the Yellow River. Zhengzhou: Yellow River Conservancy Press; 1996. p. 35–55 (798-796, in Chinese).

[23] Wu B, Wang G, Ma J, Zhang R. Case study: river training and its effects on fluvial processes in the lower Yellow River, China. J. Hydraul. Eng. 2005;36(2):85–96. (in Chinese).

[24] Mu X, Wang F, Li R, Zhang X. Further discussion on the effect of soil and water conservation on water resources in the Yellow River Basin. Tsukuba: Tsukuba Asian Seminar on Agricultural Education (TASAE)/UNESCO-APEID; 2004. p. 29–36.

[25] Ervin CA, Ervin DE. Factors affecting the use of soil conservation practices — hypotheses, evidence, and policy implications. Land Econ. 1982;58(3):277–92.

[26] Knowler D, Bradshaw B. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 2007;32(1):25–48.

[27] Wossink A, Swinton SM. Jointness in production and farmers' willingness to supply nonmarketed ecosystem services. Ecol. Econ. 2007;64(2):297–304.

[28] Vignola R, Vignolaa R, Koellner T, Scholz RW, McDaniels TL. Decision-making by farmers regarding ecosystem services: factors affecting soil conservation efforts in Costa Rica. Land Use Policy 2010;27(4):1132–42.

[29] Wang F, Li R, Wen Z. Analyses of factors effecting on eco-environmental benefits of cropland conversion. Bull. Soil Water Conserv. 2002;22(3):1–4. (in Chinese).

[30] Throsby D. Culture in Sustainable Development: Insights for the Future Implementation of Article 13 (Convention on the Protection and Promotion of the Diversity of Cultural Expressions). UNESCO; 2008.

[31] Bhagwat SA, Ormsby AA, Rutte C. The role of religion in linking conservation and development: challenges and opportunities. J. Study Relig. Nat. Cult. 2011;5(1):39–60.

[32] Mu X, Li R. Strategic status of soil and water conservation on solving water problems in China. Bull. Soil Water Conserv. 1999;19(3):1–6. (in Chinese).

[33] Wang F, Li R, Jiao F, Yang Q, Tian J. Cropland conversion and its environmental effect in the Loess Plateau, China — a pilot study based on the national experimental bases. J. Geogr. Sci. 2005a;15(4):484–90.

[34] Wang F, Mu X, Li R, Jiao J. Water cost of sediment control of soil and water conservation in Hekou and Longmen section of Yellow River. Bull. Soil Water Conserv. 2005b;25(6): 28–32. (in Chinese).

[35] Mo L, Wang Y, Wang F, Mu X. Analysis of the runoff cost for sediment control by soil and water conservation measures in North China. Bull. Soil Water Conserv. 2007;27(6): 90–4. (in Chinese).

[36] National Waterway 2 - Wikipedia
https://en.wikipedia.org/wiki/National_Waterway_2

[37] IWAI website
http://iwai.nic.in/waterways/national-waterways/national-waterways-2?id=2524

[38] The World Bank website
https://projects.worldbank.org/en/projects-operations/project-detail/P157929

[39] Government of Assam Water Resources website
https://waterresources.assam.gov.in/portlet-innerpage/brahmaputra-express-highway

[40] Inland Waterways Authority of India
https://en.wikipedia.org/wiki/Inland_Waterways_Authority_of_India