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HYDROLOGICAL AND SEDIMENT TRANSPORT ANALYSIS OF THE BRAHMAPUTRA RIVER AT PANDU SITE (2000–2016)

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Abstract

The sediments carried and deposited by a river plays a very important role in understanding the history of a river. The Brahmaputra river, known for its dynamic flow and sediment transport regime, is one of the largest rivers in the world which plays a critical role in shaping the fluvial landscape of North East India. The river flows through steep tertiary Himalayan ranges and is known to carry huge amount of sediments ranking second after the Yellow river in China. The region through which it flows is highly vulnerable to erosion and is geologically unstable. The basin has an average annual discharge of 19,820 cumec, and average annual sediment load of 735 million metric tonnes. The sediments brought by the river and its innumerable tributaries are affecting the floodplain and its hydrological behavior. Here, in this paper an attempt has been made to analyse the hydrological behavior of the basin and its relation with sediment load and concentration. For carrying out this study secondary data was used for the year 2000 to 2016. The sediment data was collected from the Central Water Commission (CWC) at the Pandu monitoring site between 2000 and 2016 which revealed significant temporal fluctuations in sediment load and concentration. These variations are primarily influenced by seasonal monsoonal rainfall, upstream erosion, anthropogenic activities, and natural factors such as landslides and glacial melt.

Key words: The Brahmaputra River, Hydrological Behavior, Sediment Load, Sediment Concentration.

Introduction

Sediment is a fragile material that is broken down by the process of erosion and weathering and are transported by, suspended in or deposited by water or air or accumulated in beds by other natural agents. The U.S Geological Survey (USGS) defines fluvial sediments as fragmentary rocks and materials which are transported by, suspended in, or deposited from water; it includes chemical and biological precipitates and decomposed organic materials, such as humus. Sediments that are carried by a river system is essential for the economic, environmental and social aspects for the dwellers of the river basin (Apitz 2012; Fischer et al., 2017). The mighty Brahmaputra river originating from the Chemayungdung glacier of the Tibetan plateau is highly dynamic in nature and carries one of the highest sediments yields in the world after the Yellow river in China in terms of sediment transport per unit of drainage area (Bhagabati, 2002). The basin has an average annual discharge of 19, 820 cumec, and average annual sediment load of 735 million metric tonnes and a specific flood discharge of 0.149 cumec/ sq.km. The sediments of the Brahmaputra River are derived from a geologically diverse source region that includes high-grade metamorphic and igneous rocks of the Eastern Himalayas, as well as ophiolitic complexes associated with the Indus–Tsangpo Suture Zone (Searle, 1986). This tectonically active and lithologically varied terrain significantly influences the composition, texture, and geochemical signatures of the sediments transported by the river (Singh et.al 2003).

The Brahmaputra plain which is composed of the sediments brought by the river Brahmaputra and its innumerable tributaries are affecting the floodplain and its hydrological conditions due to its rising population pressure since decades due to various developmental activities and changes in its land use and land cover categories (Ray et.al 2015). The sediments carried and deposited by a river plays a very important role in understanding the history of a river (William, 2012) Sediments play an important role in understanding the health, behavior and the future of the river systems. Such study can provide us information about the origin or the source of the sediments, the ways of transportation and it provides information about their modes of deposition. Such information is useful for predicting floods, managing riverbanks, and planning development near rivers. In the Himalayan region such studies can help to study the impact of climate change on the region. The Brahmaputra river basin having such a large drainage area is heavily charged with sediments (Coleman,

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1986) and being part of the Himalayan region, which is mostly composed of tertiary sediments which are vulnerable to erosion occupies great importance in terms of sediment studies. This paper is thus an attempt to study an overview on its sediment characteristics and its relation with water discharge.

Objectives

The main objective of this study is-

1. To analyse the source, texture and transport mechanism of sediments of the Brahmaputra river and
2. To assess seasonal variations, sediment-discharge relationships and interannual trends.

Methodology

For carrying out this study secondary data sources are used which includes collection of information from various sources such as e-journals, books, atlas etc. The data for analyzing the sediment texture and discharge and sediment load was collected from the Brahmaputra Board and Central Water Commission, Guwahati for the years 2000 to 2016. The sediment texture data and sediment load and concentration were collected from Pandu site. The data were then represented graphically for further analysis.

Study area

The study area is the entire Brahmaputra river which originates in the Tibetan plateau in China. It is one of the largest river basins in the world having a catchment area of 5,80,000 sq. km. The basin lies between $88^0$11’ to $96^0$57’ E longitude and $24^0$44’ to $30^0$3’ N latitude. The river originates in the Chemayungdung glacier and flows through the Tibetan plateau in China and enters India through Arunachal Pradesh and drains itself in the mouth of Bay of Bengal in Bangladesh. It flows for a distance of 2880 kms before debouching itself into the Bay of Bengal. The mighty Brahmaputra river is joined by numerous north and south bank tributaries in the state of Assam. The Brahmaputra basin is bounded on the north by the eastern Himalayas, on the east by the Naga-Patkai range of hills running along the Indo-Burma border, on the north east the Mishimi massif, on the south by the Assam range of hills and the Shillong Plateau, while on the west by the ridge separating it from the Ganga basin. The whole catchment forms an integral part of the monsoonal regime of south east Asia. The region experiences average annual rainfall of 230 cm per year while the Himalayan region experiences an average rainfall of 500 cm per year. The region has varied natural vegetation and is ecologically rich with very fertile soil. The maximum and minimum temperature of the basin is 38.79 ^{0}C during summer and 16.16 ^{0}C during winter season. The total population of the basin according to 2011 census is 27, 580, 977 persons and most of the people are inhabited in the plain region rather than the hilly areas. Majority of the people are dependent on agriculture and allied land-based activities.

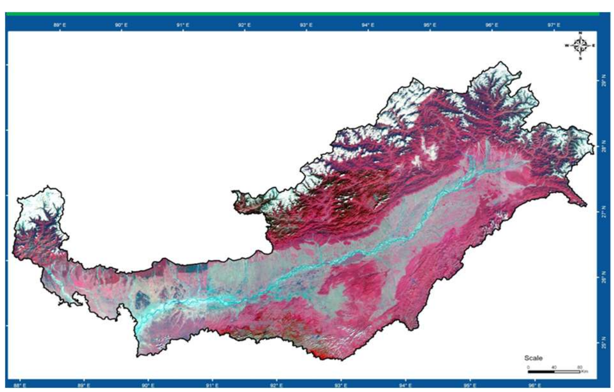

Figure 1: Satellite Imagery of the Brahmaputra River Basin

Source: Project Report of CWC and ISRO (version 2.0)

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Results and discussion

Sediments are derived from the parent material subjected to erosional processes by which particles are detached and transported by gravity, wind, water or a combination of these agents. Sediment particles vary in size from large boulders to colloidal size fragments and vary in shape from round to angular. The sediments carried by the river are generally in three forms suspended sediments, dissolved sediments and bedload. Sediments carried by streams are generally of two types fine sediment and coarse sediments. Fine sediments have diameter less than 0.062 mm and they tend to travel through the stream with the same velocity as the water (Guy, 1966). Erosion can be considered as one of the causes of the occurrence of fine sediments in a basin. Coarse sediment has diameter greater than 0.062 mm as is generally found to be deposited near the bed of the stream. They are transported both as suspended load and bed load. The mode and rates of transportation depend on the properties of the fluid, the sediment, the flow, and the channel geometry (Colby, 1961).

The river Brahmaputra originates at an elevation of 5300 m (Goswami, 1985) at the Chemayungdung glacier and flows through the Tibetan plateau bearing the name Tsangpo. The gradient here is moderately steep. Flowing through the Tibetan plateau on reaching at its extreme end the river enters a 32 deep narrow gorge at Pe near Namcha Barwa (Goswami, 1985). The gradient of the river is steepest here as compared to the entire reach of the basin. On entering Assam, the gradient of the river is reduced at a rate of 13 cm/km which results in the deposition of sediments in the form of both suspended and dissolved form. The river is meandering in nature leading to change in the course of the river. The river along with its tributaries is also responsible for the formation of the Brahmaputra valley. It ultimately debouches itself into the Bay of Bengal where the gradient is lowest. Thus, sediments in the Brahmaputra river are generally derived from the tertiary Himalayan region and they are also derived from its numerous north and south bank tributaries.

Modes of sediment transport

Sediments are transported by the river in various forms whereas these distinctions are to some extent arbitrary. It generally includes: Suspended load, Bed load, Dissolved load and Wash load. Those materials which are in suspension by upward flux of turbulence generated at the bed of the channel and they move through the channel in water column. The size and concentration of suspended- sediment typically varies logarithmically with height above the bed. Coarse sand is highly concentrated near the bed and declines with height at a faster rate than the fine sand (Hickin, 1995). It generally consists of smaller particles of clay, silt and fine sands.The bed loads are those which move along the bed of the channel. These loads are mainly sand and gravel, and are kept in motion (rolling and sliding) by shear stress acting at the boundary (Hickin, 1995). Dissolved load are those materials which are completely dissolved in water flowing through a channel. It doesn't depend on forces in the flow to keep it in water column. Dissolved load is very important to geomorphologists concerned with sediment budgets at a basin scale and with regional denudation rates (Hickin, 1995).

Wash load is a part of suspended load and it does not rely on the force of mechanical turbulence generated by flowing water. It is so fine that it is kept in suspension by thermal molecular agitation. It is a component of the particulate that is washed through the river system. Wash load tends to be uniformly distributed throughout the water column. It does not vary with height above the bed (Hickin, 1995).

Sediment types of the Brahmaputra river

A comprehensive analysis was carried out on the temporal variation and distribution of the sediment types over the 16-year period. The results of this analysis have been presented graphically to illustrate trends and fluctuations in sediment composition across the years.

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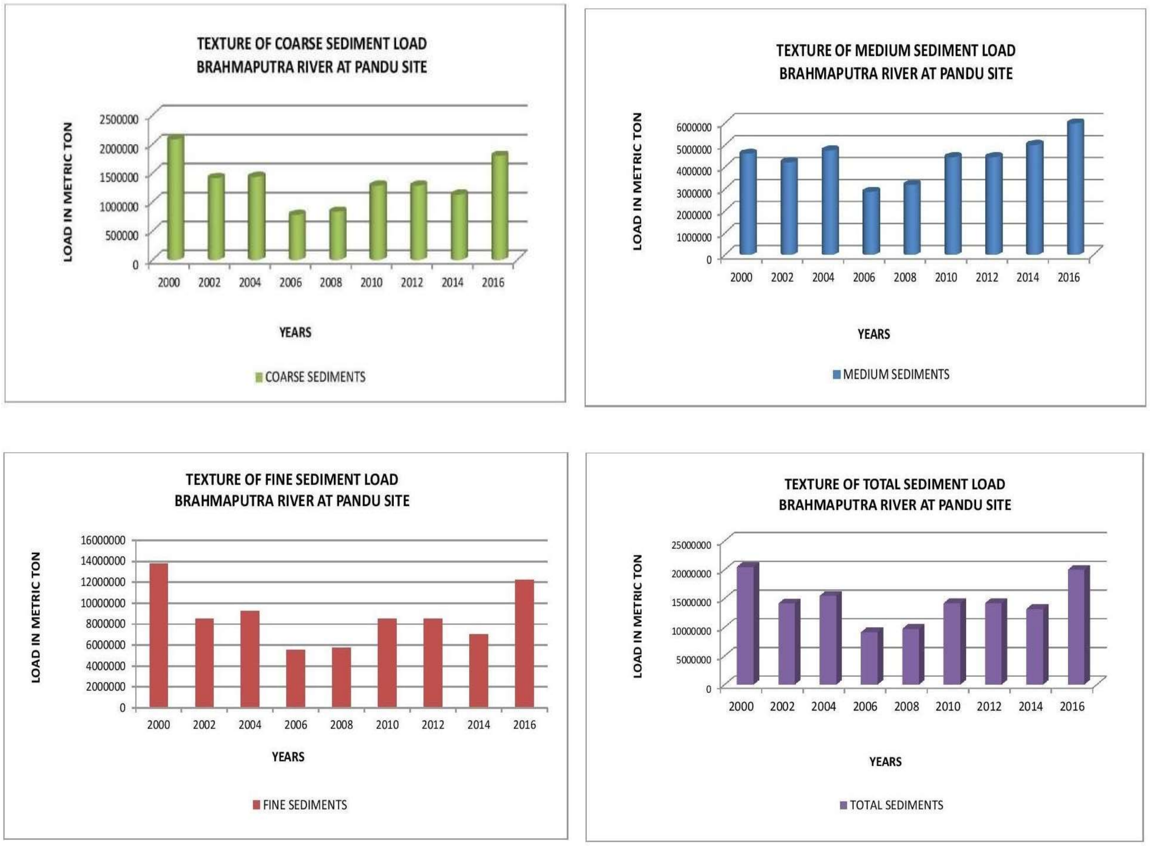

Figure 2: Figure showing texture of course, medium, fine and total sediment load of the Brahmaputra river at Pandu site

The above graphs depict the texture and quantity of different types of sediment loads—coarse, medium, fine, and total—in the Brahmaputra River at the Pandu site across a 16-year period from 2000 to 2016. Each graph shows notable temporal variations in sediment load, reflecting fluctuations in river dynamics, catchment erosion, rainfall patterns, and possibly human activities like deforestation or land use changes. The coarse sediment load (top-left graph) shows a sharp decline from 2000 to 2002, followed by a consistent but relatively lower volume across the years, with slight rises in 2010 and 2014, indicating a major reduction in coarse material transport after 2000. The medium sediment load (top-right graph) exhibits more stability over time, with moderately high and consistent values in 2000, 2002, 2004, and 2006, a noticeable dip in 2008, and then a gradual rise, peaking significantly in 2016. This suggests a steady presence of medium particles and possibly improved sediment retention or re-mobilization in later years. The fine sediment load (bottom-left graph) shows a major drop from 2000 to 2006, followed by fluctuations and a notable recovery by 2016. The extremely high value in 2000 compared to subsequent years indicates a possible extreme event or higher erosion rates during that period. Finally, the total sediment load (bottom-right graph) mirrors the combined trends of the other three graphs, starting at a high in 2000, dropping sharply in 2004 and 2006, then recovering gradually with peaks in 2012 and 2016.

These overall patterns highlight that sediment transport in the Brahmaputra River at Pandu is highly dynamic and governed by several factors such as rainfall, upstream land use, slope stability, and hydrological variations. The distinctly high loads in 2000 across all sediment types may indicate an extreme climatic or erosional event in that year. Conversely, the mid-period decline suggests either reduced sediment supply or trapping due to upstream interventions like dams or afforestation. The resurgence in sediment loads post-2010, particularly in 2016, may reflect increased monsoonal runoff, catchment degradation, or flood events. The above data underlines the importance of continuous sediment monitoring, as these changes

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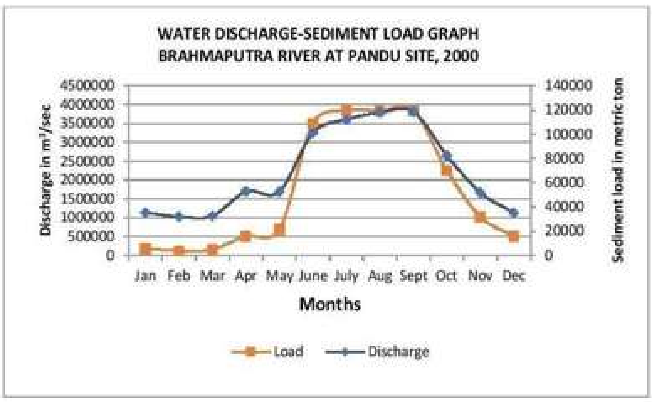
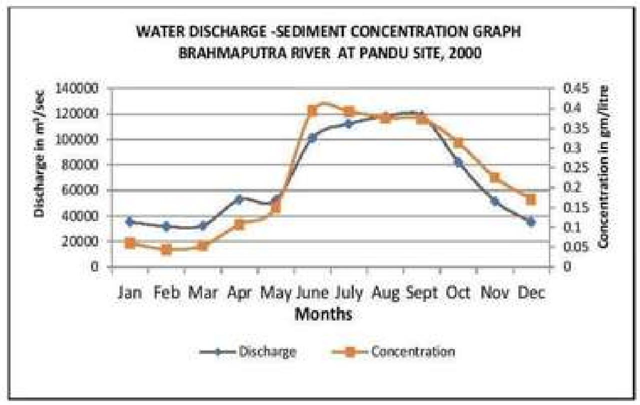
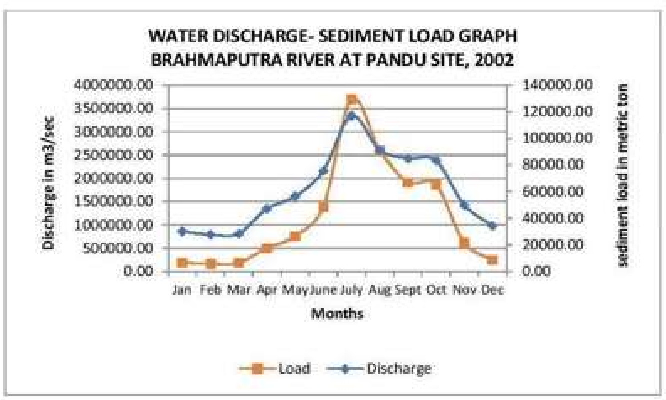
have significant implications for river morphology, flood management, reservoir siltation, and aquatic ecology in the region

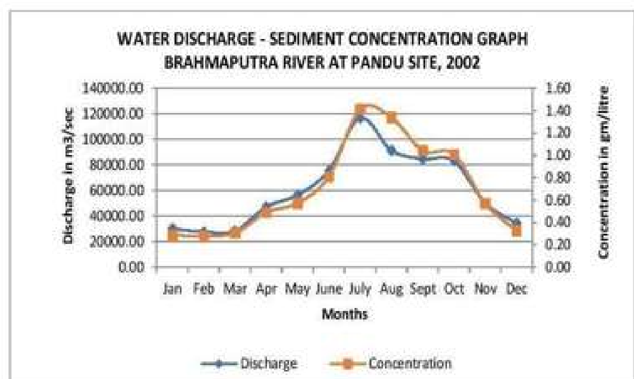
Sedimentation record of the Brahmaputra river

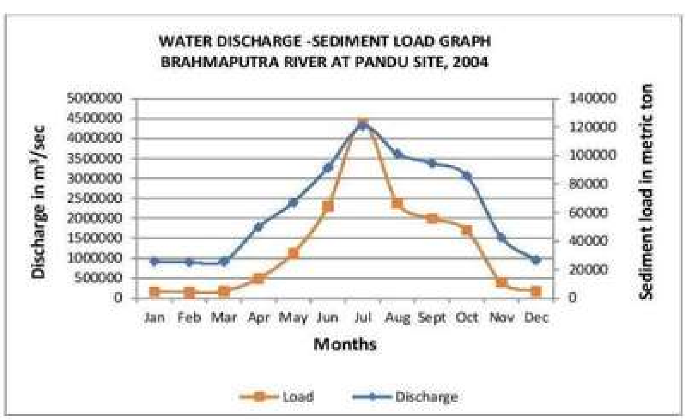
The analysis of water discharge and sediment characteristics reveals a pronounced seasonal variability that is closely linked to the South Asian monsoon cycle. The graphical data presented comprising discharge vs. sediment load and discharge vs. sediment concentration plots—clearly depicts this seasonal rhythm, highlighting the dynamic nature of river flow and its sediment transport behavior across different hydrological years. The data are collected from secondary sources and are very much useful for understanding sediment behavior for effective river basin management, especially in flood prone areas.

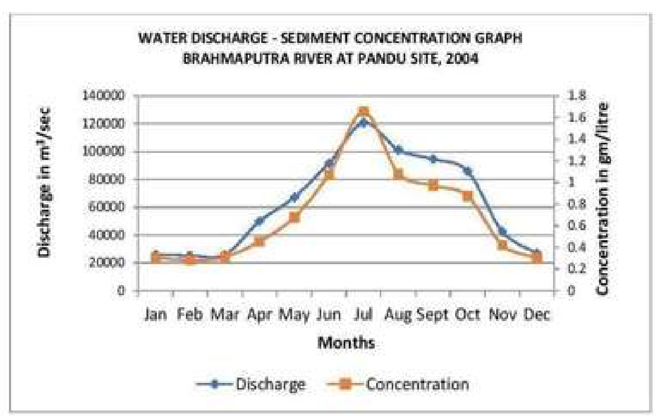










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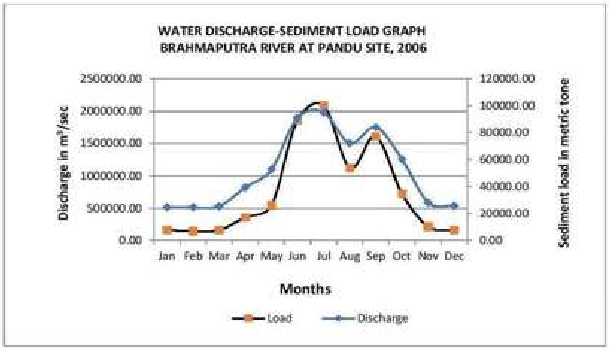

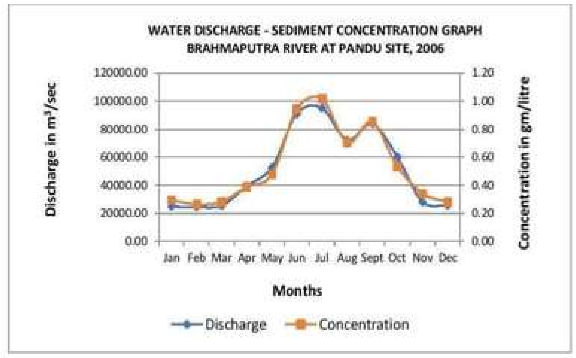

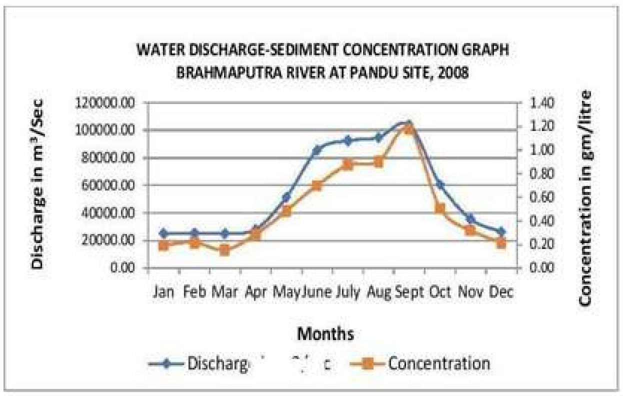

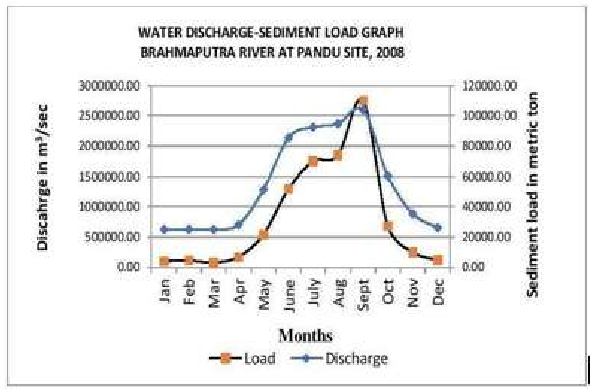

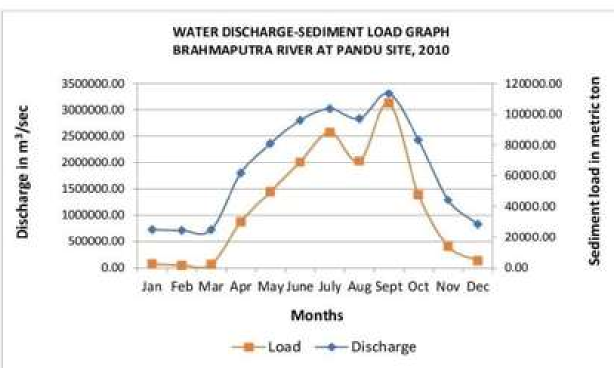

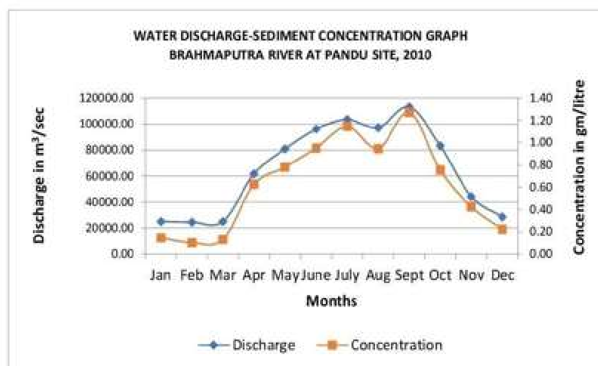

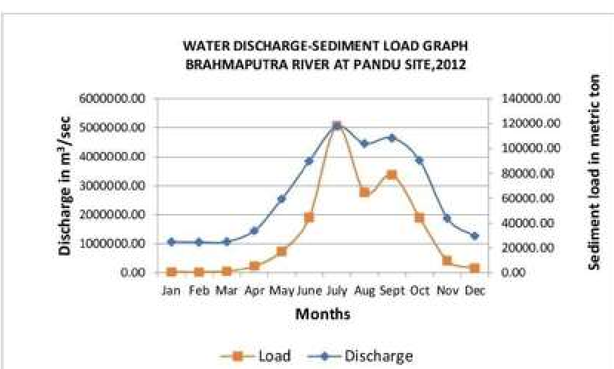

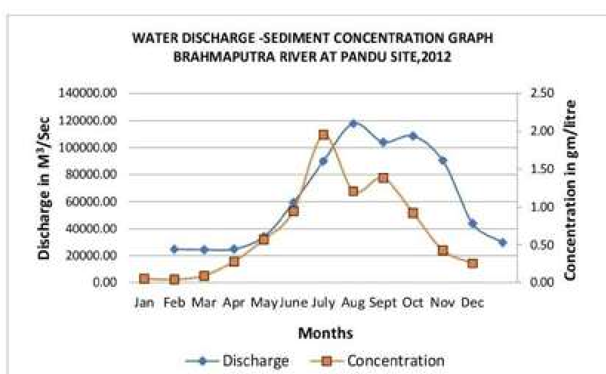


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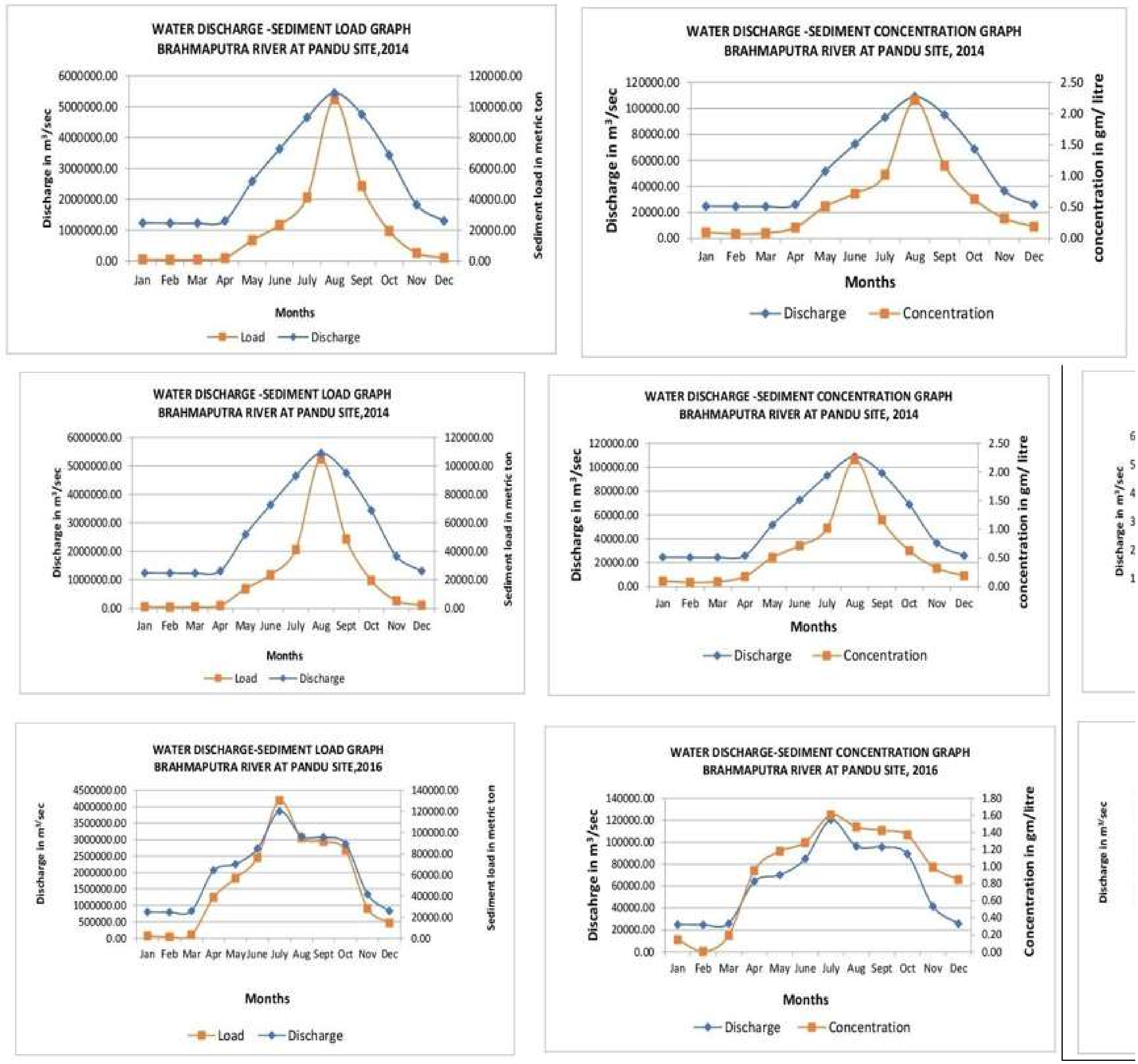

Figure 3: Figures showing water discharge trends, sediment load pattern and sediment concentration for the years 2000 to 2016

Water discharge trends

Across all years, the Brahmaputra River at Pandu displays a seasonal monsoonal pattern. Discharge begins to increase in April, peaks in June–August, and declines steadily until December. This confirms the strong influence of Southwest

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Monsoon rainfall and glacial meltwater. In 2000, discharge sharply rises in May and sustains high flow through September, indicating a prolonged monsoon period. This is consistent with later years (e.g., 2002, 2004, 2006, 2008), which also show strong peak discharges during the same months. Years like 2014 and 2016 show relatively lower discharge peaks, suggesting weaker monsoons or reduced upstream inputs.

Sediment load pattern

Sediment load follows a similar seasonal trend, with major increases during May to September. In 2000, the sediment load closely mirrors the discharge curve, with a high peak from June to September, suggesting a strong erosion response in the upstream catchment. The highest sediment loads are seen in flood-prone years like 2004 and 2008, where the river mobilized vast quantities of silt and debris, likely due to heavy rainfall and landslides. The load curve in 2000 is smoother than some subsequent years but still significant, reflecting stable sediment supply under intense flow. In recent years (2014–2016), although discharge was lower, sediment loads remained substantial, indicating sediment availability from degraded upstream landscapes.

Sediment Concentration Behavior

Sediment concentration indicates the amount of sediment carried per unit of water. In 2000, the concentration curve aligns well with discharge from May to September, peaking during the high-flow season and declining afterward. Notably, concentration remains above 0.4 g/l during monsoon months, showing that the river remained sediment-rich. In later years like 2006, 2010, the concentration sometimes peaks earlier than discharge, hinting at the first flush of sediments during early monsoon rains. From 2014 onwards, the concentration remains high even at lower discharges, possibly indicating increased surface erosion or anthropogenic disturbances such as mining and deforestation.

Year wise observations

Year	Peak discharge	Peak sediment load	Peak sediment concentration	Key observations
2000	June-September	High	~0.45 g/l	Strong monsoon, prolonged high flow
2002	July	Moderate	~0.7 g/l	Good sediment- discharge sync
2004	August	Very high	High	Likely flood year
2006	July	Moderate	Early peak	Sediment flushed before discharge
2008	August	Very high	High	Twin peak; extreme sediment
2010	July	High	Early	Complex sediment response
2012	July	Low	Elevated	High concentration despite low flow
2014	August	Moderate	High	Sharp load peak
2016	August	Moderate	High	Stable flow, sediment- rich water

Source: Computed by the researcher

Based on the comprehensive visual data analysis of water discharge, sediment load, and sediment concentration for the Brahmaputra River at Pandu site over the span of 2000 to 2016, a detailed comparison reveals both consistent seasonal trends and marked interannual variations. Throughout all years, a distinct monsoonal influence governs the hydrological and sediment dynamics, with discharge, load, and concentration rising steadily from March or April, peaking between June and August, and tapering off toward November–December. However, the magnitude, rate of increase, duration of

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peak, and the alignment between discharge and sediment behavior vary significantly across years, reflecting changes in monsoonal intensity, upstream land use, glacial contributions, and watershed conditions.

In the year 2000, discharge steadily increased from April, peaked during June–September, and closely mirrored the rise in sediment load and concentration, both of which also maintained elevated levels during the peak flow period. This year exhibited a textbook monsoon response with moderate concentration (~0.45 g/l), indicating stable catchment behavior. Moving to 2002, the discharge was slightly higher and displayed a sharper rise from May, leading to a substantial increase in sediment load by July. Notably, sediment concentration peaked beyond 1.5 g/l, higher than in 2000, suggesting either greater sediment availability or erosive monsoon rains. By 2004, a flood-prone year, the system registered a steep surge in both discharge and sediment load during June and July. The sediment concentration exceeded 1.6 g/l, the highest among early years, and indicated extreme sediment mobilization, potentially from landslides or extensive bank erosion during floods.

In 2006, a more balanced pattern emerged, where discharge and load both rose in tandem but without sharp spikes, suggesting relatively uniform rainfall or moderated upstream contributions. Concentration remained below 1.2 g/l, showing less intense sediment flow. Contrastingly, 2008 displayed a dual peak in discharge and sediment load, indicating a possible bimodal rainfall distribution or multiple sediment source activations. This year was characterized by very high load values and moderate-to-high sediment concentrations. By 2010, discharge once again rose rapidly and was accompanied by sharp increases in sediment load, maintaining high values between June and September. Interestingly, sediment concentration remained relatively consistent (~1.2–1.4 g/l), suggesting steady sediment supply during continuous high flows.

The year 2012 showed a significant discharge peak, and unlike 2008, had a single, sharper crest in both discharge and sediment load curves. The concentration also rose considerably, peaking above 1.8 g/l, one of the highest in the time series. This year likely saw concentrated sediment delivery during a short, intense monsoon burst. 2014, however, marked a major deviation from the previous years. While discharge was noticeably lower, sediment concentration remained surprisingly high (up to 2.5 g/l), indicating catchment degradation, surface erosion, or anthropogenic factors such as land clearance. The sediment load remained moderate, but the elevated concentration despite reduced flow indicates a troubling sediment-to-water ratio. This pattern is repeated in 2016, where although discharge was modest, sediment concentration sustained a high range, confirming continued instability in sediment supply mechanisms.

Finally, 2016 showed moderate discharge peaking in July–August, but like 2014 and 2016, sediment concentration reached above 1.6 g/l, despite an otherwise average monsoon profile. This continuation of high concentration values amidst normal or slightly subdued discharge indicates a possible long-term increase in sediment vulnerability across the basin—likely caused by deforestation, unregulated construction, and upstream soil loosening. The sediment load did not reach the levels seen in 2004 or 2008, but the concentration trends are indicative of worsening sediment-water dynamics.

While 2000–2010 reflects a typical hydrological regime with discharge and sediment load moving in tandem, post-2010 years increasingly show decoupling, especially between discharge and concentration. The peak concentration values after 2012 consistently remain high, pointing to intensified catchment degradation. The earlier years, particularly 2000, 2002, and 2006, exhibited more synchronized and stable behavior, where peak flows corresponded with expected sediment loads and moderate concentrations. Years like 2004, 2008, and 2012 were marked by extreme hydrological or sediment events. Conversely, 2014–2016 highlight a shift toward high sediment concentrations even during moderate flows, suggesting that the sediment regime of the Brahmaputra at Pandu is not only driven by monsoon variability but increasingly by land-use change, soil vulnerability, and anthropogenic pressures. This evolving pattern necessitates urgent attention for integrated sediment and watershed management practices to restore hydrological balance and mitigate risks associated with sediment overloading in the Brahmaputra basin.

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Conclusion

The Brahmaputra River, one of the major transboundary rivers of South Asia, exhibits a highly dynamic and complex sedimentary regime, shaped by its unique geomorphological and climatic conditions. Originating from the Chemayungdung glacier in the Tibetan plateau, the river carries an enormous sediment load, largely due to the steep gradients in its upper reaches and the fragile, erosion-prone geological formations along its course. The diverse lithological composition of the river basin, including metamorphic, igneous, and ophiolitic rocks, contributes significantly to the variability in sediment texture, composition, and transport dynamics.

The findings of the study underscore the critical importance of understanding sediment characteristics such as texture (fine, medium, and coarse), load, concentration, and seasonal behavior to better manage the Brahmaputra's complex hydrology and its impacts on downstream regions. The sediment data collected from the Central Water Commission (CWC) at the Pandu monitoring site between 2000 and 2016 revealed significant temporal fluctuations in sediment load and concentration. These variations are primarily influenced by seasonal monsoonal rainfall, upstream erosion, anthropogenic activities, and natural factors such as landslides and glacial melt.

The analysis shows that while the overall discharge and sediment load fluctuated year by year, the sediment concentration remained significantly high, especially during the monsoon months. This persistence of high concentration even during low discharge years from 2014 onwards indicates a steady supply of sediment, possibly due to increased deforestation, land use change, and surface erosion in the upper catchments. Such anthropogenic pressures are increasingly becoming key contributors to sediment dynamics, often overshadowing natural climatic controls.

The study of sediment types indicates that fine sediments, which are more susceptible to erosion and transport, are dominant in the Brahmaputra basin. These sediments, due to their small particle size, remain in suspension for long periods and are transported over vast distances. In contrast, coarse sediments are typically deposited near the riverbed and transported during high-energy flow conditions. This differentiation is essential in understanding the sedimentation patterns and their implications for river morphology, floodplain dynamics, and infrastructure planning along the riverbanks. The river's meandering nature further adds to the unpredictability of sediment deposition and erosion patterns, making it imperative to carry out continuous monitoring and adaptive management.

The Brahmaputra River's sediment regime is influenced by a delicate interplay of natural and human-induced factors. Understanding this regime through systematic data collection and analysis provides invaluable insights for flood prediction, erosion control, land use planning, and sustainable water resource management. This study not only contributes to the academic understanding of sediment dynamics but also serves as a guiding framework for regional planners, environmentalists, and policymakers working toward the sustainable management of one of Asia's most sediment-rich river systems.

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