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(Research Article)

Post-earthquake Sedimentation Changed the Morphology of the Brahmaputra River

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Abstract

The Eurasian plate is being pushed upwards by the Indian Plate and is moving northeast and uplifting the Himalayan Mountain. Brahmaputra plain is one of most important geological areas, who experienced tectonic evolution, so that area is very seismically unstable. The 1897 and 1950 earthquakes, which had a Richter magnitude of 8.7, were among the worst ever in recorded history. This study primarily focuses on the morphological changes that have taken place in response to the 1950 Great Assam Earthquake's disruption of the fluvial system. We have chosen an area between Pasighat, Bhupen Hazarika, and Bogibeel Bridge for this study. Post-great-Assam-earthquake of 1950 has supplied Around 45 billion m3 of sediments in Brahmaputra River and its tributaries. Due to this riverbed rode by 1.5m at Dibrugarh immediately after the earthquake and thereafter a significant number of debris-silt continued enter to river and riverbed rose by 3m in 1955, ⅓ of Dibrugarh town eroded, and between 1953-2022 approx. 153 Km^2 of areas have been eroded. Fine fraction of sediment (silt and clay) travelled quickly through the system, without disturbing the morphology of the channels, but course fraction (sand) had taken half century to travel through the system and continuous changing the river morphology. During the past century, Brahmaputra River in Assam has expanded from 6-Km to 9-Km, and between 1973 and 2022, it has increased by 0.53-Km. Interpretation based on historical maps suggests that the observed morphological changes of the Brahmaputra River are a continuation of the recent planform evolution of the river which can be observed over 2-3 centuries.

Keywords: Sediment, earthquake, river morphology, Brahmaputra River, remote sensing, and GIS.

1. Introduction

The three main plates-India, Eurasia, and Sunda-converge in north-eastern India and its surrounding areas. Hence, the Eastern Himalayas to the north and the Indo-Burma Ranges to the southeast are the two primary mountain ranges found in the region between 20°-31°N in latitude and 86°-98°E in longitude [1]. One of the most active mountain-building and sediment-transfer systems, the Himalayan Mountains are the tallest and youngest mountains in the world. These processes have persisted uninterrupted during recent geological time and are anticipated to continue in the future [2]. Plate movement and climate interact in a complicated way to produce the inherent instability. Short-term events that are extremely variable in space and time and outperform long-term steady processes by orders of magnitude are overlaid on long-term stable processes [3]. There are two opposing processes at play: (a) fast, systematic mountain construction results from tectonic plate collision, with uplift rates estimated to range from 1 to 5 mm per year, occasionally exceeding 9 to 15 mm [2], and (b) Water movement is the primary force behind the weathering and erosion processes, although glacier and wind transport also play a vital role. The pace of uplift in the Himalayas exceeds the rate of down cutting despite the mountains' incredible rate of erosion [2].

Under the Himalayas, the Indian plate is slowly descending to the north [4-5]. Several studies emphasized the significance of continental collision [6-7]. According on focal mechanism solutions and assessments of borehole breakouts, the current compression is about N-S. Geodetic investigations suggest north-south shortening [8]. A distinctive process of mountain development and erosion results from the collision of the Indian and Eurasian plates. The Himalayas' high mountain range traps monsoon clouds, causing intense rainfall that hastens the erosion of the mountain ranges southern slopes. The bottom layer of plastic is now visible due to deterioration. The mountain range's uplift rates are further accelerated by the plastic layer's exposure. Similar plate collisions elsewhere in the planet produce a plastic layer of rock that persists below the surface. There is a significant relationship between annual

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monsoon precipitation, mean hill slope angle, rate of uplift, and relative stream channel steepness [2, 9]. The sharpest mountain and channel slopes are found in the area of greatest uplift. The largest precipitation occurs here between 1000 and 3000 m height, which causes severe erosion. The extruding channel's process of creating mountains replenishes the sediment loss [10-11].

The Assam plain, often referred to as the Brahmaputra plain, is one of India's most important geological areas. The Assam plain experienced tectonic evolution in two separate phases. It changed into a composite shelf-slope-basinal system with a passive border layout between the Early Cretaceous and the End of the Oligocene [12]. However, because to compressive tectonic stresses, several parts of the mega basin saw divergent evolutionary patterns during the post-Oligocene period. Brahmaputra plain is the easternmost outcrop of the Indian plate, where, according to plate tectonics, it is sub-ducting beneath the Eurasian Plate and creating a subduction zone [13]. The Tethys geo-incline, which is positioned between the Indian and Eurasian plates and is rising higher at a pace of 4 cm per year, was forced upward by the Indian Plate as it shifted to the northeast and gave rise to the Himalayan Mountain ranges. Due to the Himalayan Mountain ranges bordering its north, northeast, and eastern sides, and the Brahmaputra plain has a unique geomorphological landscape with valleys and fragmented mountains [14-16]. Essentially, the Brahmaputra plain was created and continues to be created by the erosive products of the southern Himalayan banks [17]. Now, the Brahmaputra serves as a conduit for the waste materials to be transported to the Bay of Bengal. The Brahmaputra serves as a fantastic transportation route for sediment and water, among other things [18].

1.1 Earthquakes: Frequent earthquakes of significant size accompany the formation of Himalayan mountains, which have an effect on local life. The main fault lines of the Himalayas are followed by significant earthquakes and areas of high seismic risk [19]. India's eastern region has had some of the strongest earthquakes ever recorded [20]. Several significant earthquakes have occurred in the tectonically active Himalayan Mountain area during the past century, including the following: 1897-Shillong [21], 1905-Kangra [22], 1934-Bihar and Nepal [23], 1950-Assam [24], 2005-Kashmir [25], 2015-Inda and Nepal [26], and 2021-Assam [27]. Being one of the seismically active areas of the globe, the North-Eastern region, which includes Assam, is vulnerable to earthquakes, floods, landslides, cyclones, and occasionally droughts. The Brahmaputra River flows almost parallel to the MBT (major boundary thrust) / HFT (Himalayan frontal thrust) in the Brahmaputra valley before turning at 90° E longitude to run parallel to the Dhubri/Jamuna fault [28].

A very seismically unstable region is made up of the Brahmaputra valley and its neighboring hills. The earthquakes in 1897 and 1950, which had a Richter magnitude of 8.7, were among the worst ever seen in recorded history [29-31]. The epicenter of the 1950 Great Assam Earthquake was at the India-China border at latitude 28.6° N and longitude 96.5° E, 14 Km under the Earth's surface [32]. The Subansiri, Dibang, and Dihang rivers had their courses momentarily obstructed by large landslides that were brought on by the 1950 earthquake on the Himalayan foothills [33]. These dams eventually burst, unleashing a huge amount of ponded water that triggered devastating floods downstream after several days [34]. The earthquake devastated 70 villages and claimed 780 lives. Around 66% of Assam was badly damaged by the earthquake and the ensuing floods [35-38].

The Great Assam Earthquake of 1950 had a considerable influence on the upper Brahmaputra in Assam, whereas the earthquake of 1897 altered the terrain of the lower Brahmaputra [39]. The riverbed in Dibrugarh and farther downstream raised by 1.5 m as a result of these earthquakes [40]. This resulted in erosion in the downstream area and an increase in the frequency of floods. Then, there is no longer a tendency for the Brahmaputra River to erode or flood due to earthquakes. However, inside the valley reach, the Brahmaputra River has a propensity to migrate southward, and active bank erosion is typically seen [41].

1.2 Landslides: Massive landslides in the hills occurred in conjunction with the earthquakes in 1897 and 1950 [42-43]. Over 20% of Assam was affected by the catastrophic landslides, and forty-five billion m^3 of landslide debris was thought to have been produced [32, 44]. It is more than thirty-four thousand times more than the Brahmaputra River's annual suspended sediment loads (0.0013 billion m^3 per year) [43, 45-46]. The major tributaries of the Brahmaputra River were momentarily diverted due to extensive landslides on the Himalayan Mountains [47-48]. Due to the failure of multiple dams, the downstream of the Brahmaputra River experienced catastrophic floods and due to this flood, it has received substantial amounts of water and sediments [49-50].

2. Study Area

The Brahmaputra River rises from Mount Kailash, which is located at a height of 5,300 meters (amsl). It has traversed 2,880 Km in total (1,625 Km in China, 918 Km in India, and 337 Km in Bangladesh) before draining into the Bay of Bengal through the river Padma [51]. The river descends from its initial height in the High Himalaya extremely quickly when it reaches Arunachal Pradesh (India) until ultimately emerging in the lowlands, where it is known as Siang. The Brahmaputra valley in Assam is roughly 670 Km long and 35-80 Km wide [52]. It is bordered by the Himalayan Mountain ranges in the north, the Patkai hill ranges in the east, the lower (Assam) hill ranges in the south, and the plains of Bangladesh in the west.

The Brahmaputra River slopes down from 1.63 m / Km in the Kailash range to roughly 0.1 m / Km in Assam (Figure 1). The slope flattening causes a rapid dip in velocity, which causes the river to dump massive amounts of silt and other material gathered from mountainous terrains on the riverbed, raising its level [53]. The sedimentation rises in the summer when soil erodes from glacier melt [54-55]. Sedimentation occurs as a result of the lower sediment carrying capacity caused by the decrease in flow velocity [56]. The risk of floods and overtopped embankments was raised by increasing sedimentation in the river profile [57]. As a result, embankments are weakened and more vulnerable to collapsing [58]. Longitudinal profile of the Brahmaputra River is shown in Figure 1.

Study area fall between three bridge locations (Ranaghat Bridge, Pasighat; Bhupen Hazarika Bridge, Tinsukia; and Bogibeel Bridge, Dibrugarh). Location map of the study area is shown in Figure 2. The Brahmaputra valley contains a broad range of geological features. It is close to the Himalayan Mountain range's sharp turn [59]. As a result, the Brahmaputra valley features extensive expanses of sedimentary deposits that were generated during the Pleistocene and more recent eras, around 2 million years ago, as a result of the immense geostatic strain on the continent during the building of the Himalayas. It is a 720 Km long and 80 Km broad tectono-sedimentary basin covered with 200-300 m thick pebble, sand, and clay alluvium that was recently deposited [60]. The basin is covered by highly fresh and unweathered sedimentary layers, and the river transports mostly fine sand and silt and very little clay [61]. The many sandbars of all sizes and forms, locally referred to as Chars, that grow on the sandy substrate of the braided channel are a defining characteristic of the riverine scenery of the Brahmaputra [62-63]. While being primarily transient, some of these chars are more or less permanent, covered with fertile soil that supports towns, plants, and agriculture [64-65].

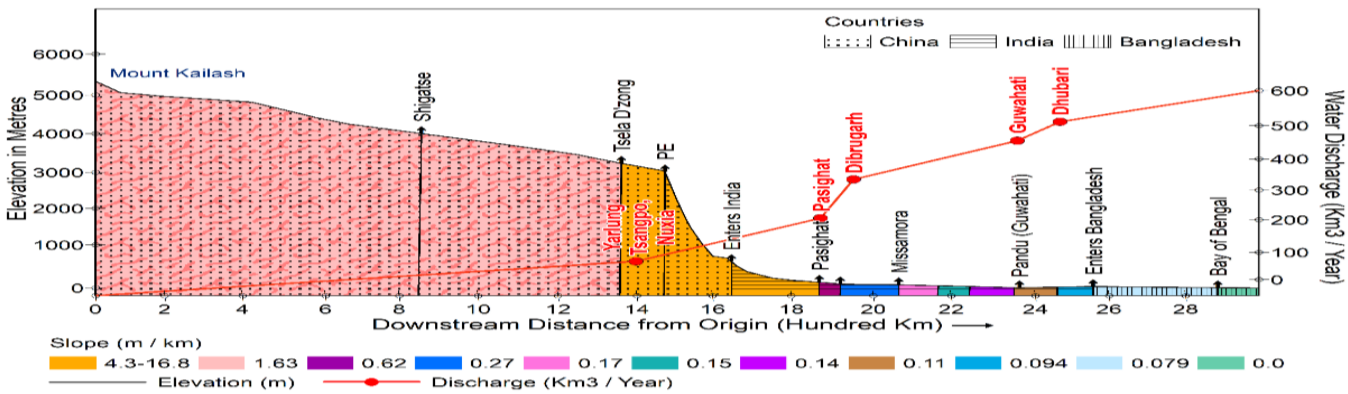

Figure 1. Longitudinal profile of the Brahmaputra River

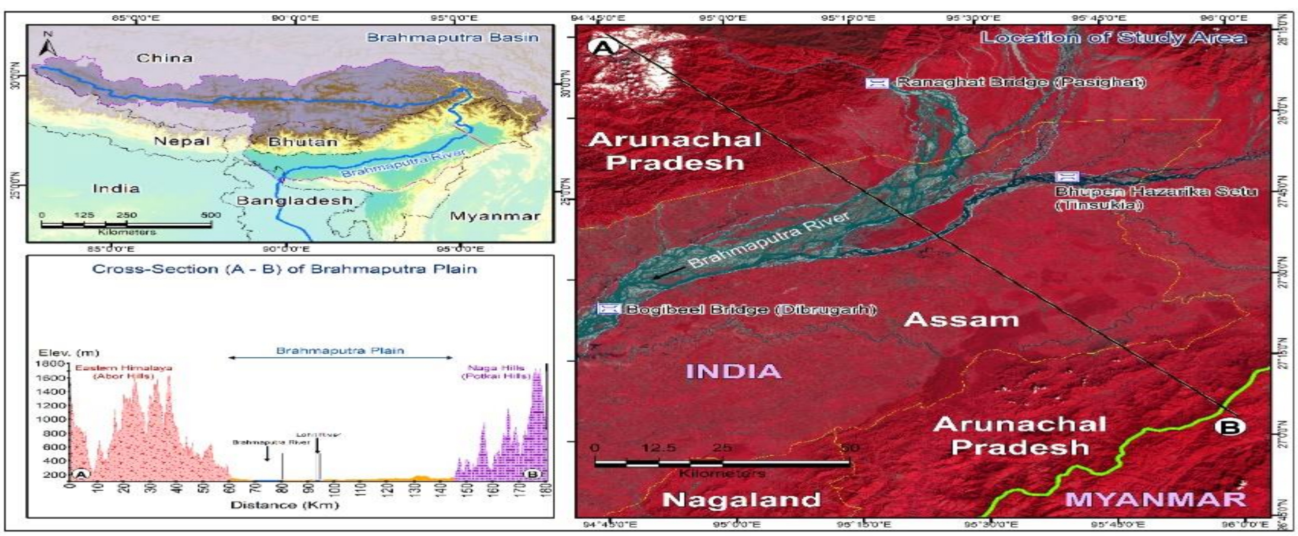

Figure 2. Location map of the study area

3. Data Used and Methodology

Landsat series satellite imageries with 30 m spatial resolution from 1973 to 2022 have been used to measure the river width at prefix 684 cross-sections. Shuttle Radar Topography Mission (SRTM) DEM data of Brahmaputra basin (0.5 million Km^2) with 30 m spatial resolution has been used for delineation of basin boundary, sub-basin boundary, and detailed drainage network. Observed water level (WL) data for 23 gauge station of Brahmaputra River in Assam have been collected from Water Resource Department (WRD), Assam between 2010 and 2017. The WL data from 2018 to present

(2023) have been downloaded from Central Water Commission (CWC) at https://ffs.tamcnhp.com/. The year wise highest and lowest water level of Brahmaputra River at Dibrugarh (gauge site: stone spur no 5) from 1913 to 2022 have been collected from Water Resource Department (WRD) of Dibrugarh, Assam. These data have been used to analyze the post-earthquake water level change in Dibrugarh; and therefore, sedimentation changed the morphology of the Brahmaputra River. Discharge data of Brahmaputra River are restricted and not available to the general public in India, so Authors have used various published literatures such as [66-71], and unpublished consultancy report such as [72] to analyze the discharge data of the Brahmaputra River. Sediment data is also restricted and not available to the general public, so subsequently, Authors have used various literatures such as [56, 73-76] to analyze the sedimentation data of Brahmaputra River.

4. Result and Discussion

4.1 Sediment transport: The Brahmaputra River in South Asia carries one of the largest sediment loads in the world, and the dynamics of sediment movement have a profound influence on the region [56]. Since it is a marker of the erosional and depositional processes that affect the topography of the basin, hence sediment movement plays an important role in river systems [73, 77]. As the Brahmaputra River data are restricted and not available to the general public in India, the following proposals for measuring sediment data are made: (a) Measurements must be made during the new project to determine the amount of silt that may be dredged, (b) Suspended silt, which is measured at several locations and may be collected during the flood season, and (c) The amount of transported sediment that may be used for land reclamation (building up char land) is rather little. During the rainy season (May-to-October), the Brahmaputra River conveys more than 95% of the annual suspended sediment load at Pandu [50, 76]. Almost 95% of the load is carried by the typical annual sediment supply at Pancharatna near Goalpara, which corresponds to a 2-year return time [74]. When the Brahmaputra River enters the Himalayan Mountain plain, its sediment output rises [75].

4.2 River discharges and water volume: The Brahmaputra Basin encircles a 0.58 million Km^2 area before it enters to Bangladesh [78]. With an average annual flow of about 20,000 m^3/s in India, the Brahmaputra ranks 22^{nd} in terms of drainage area and is the fourth-largest river in the world in terms of mean discharge [79-81]. Extreme seasonal variations in flow, as well as yearly variations in the highest discharges and total water supply, are all characteristics of the Brahmaputra River [82-83]. The yearly monsoon flow is around 80% of what occurs from May to October (5 months). The Brahmaputra River's first measuring station was built in India at Tuting (2 Km upstream of Passighat) on the Siang River [84]. Table 1 provides the average annual discharge at various locations along the Yarlung Tsangpo, Siang, Brahmaputra, and Jamuna Rivers, which indicates that the river flows are increasing in a downstream direction. During summer floods, flash flooding occurs in the majority of the Himalayas' main streams [85-87].

Table 1. Average annual discharge at various sites on the Yarlung Tsangpo, Siang, Brahmaputra, and Jamuna River

S. No	Stretch	Observation site	Average annual discharge (m^3/s)	Ref.
1	Yarlung Tsangpo	Nuxia	1,021.06	[71]
2	Yarlung Tsangpo	Point leaving China	4,309.36 / 2,476.53	[70] / [69]
3	Siang	Pasighat	5,869.48	[68]
4	Brahmaputra	Majuli	8,828.01	[67]
5	Brahmaputra	Bhurbandha	11,591.51	[72]
6	Brahmaputra	Pandu	16,682.52 / 19,830.00	[72] / [66]
6A	Brahmaputra	Pandu	1757.00 (Min: Feb 1963)	[72]
6B	Brahmaputra	Pandu	72,779.00 (Max. Aug 1962)	[72]
7	Brahmaputra	Jogighopa	17,030.27	[72]
8	Jamuna	Bahadurabad	19,199.96	[67]

4.3 Post-earthquake water level rise at Dibrugarh: Fans and avulsions happen as a result of a decrease in the gradient of the channel and the aggravation of the floodplain caused by the accumulation of bedload and suspended load. The majority of avulsion activities are related to rivers with significant sediment loads and low gradients, such the Brahmaputra River, particularly its northern tributaries [88-89].

Several Himalayan Rivers exhibit fast channel avulsion in the lower catchments despite having extremely large sediment loads and a substantial gradient reduction after crossing the Mountains [90-92]. Around 45 billion m^3 of silt were supplied to the Brahmaputra River and its tributaries in the Brahmaputra basin by the great Assam earthquake of 1950 [32, 43, 46]. This caused the river's flow to change close to Dibrugarh town [45] At Dibrugarh, the riverbed rose 1.5 m immediately after the earthquake, and in the weeks, months, and years that followed, a significant number of debris and silt continued to enter the Brahmaputra River [32]. As a result, the river regime at Dibrugarh changed in 1955 when the riverbed there rose by more than 3 m [34]. Following that, the Brahmaputra continued to erode the land in and around the town of Dibrugarh on the southern bank of Upper Assam [93]. The earthquake completely changed the face of the historic city of Dibrugarh. The town's overall area was eroded by around one-third. The river Brahmaputra eroded around 153 Km^2 of land in the Dibrugarh area between 1953 and 2021 [94]. The historic low water and high flood changes at Dibrugarh is shown in Figure 3 [95].

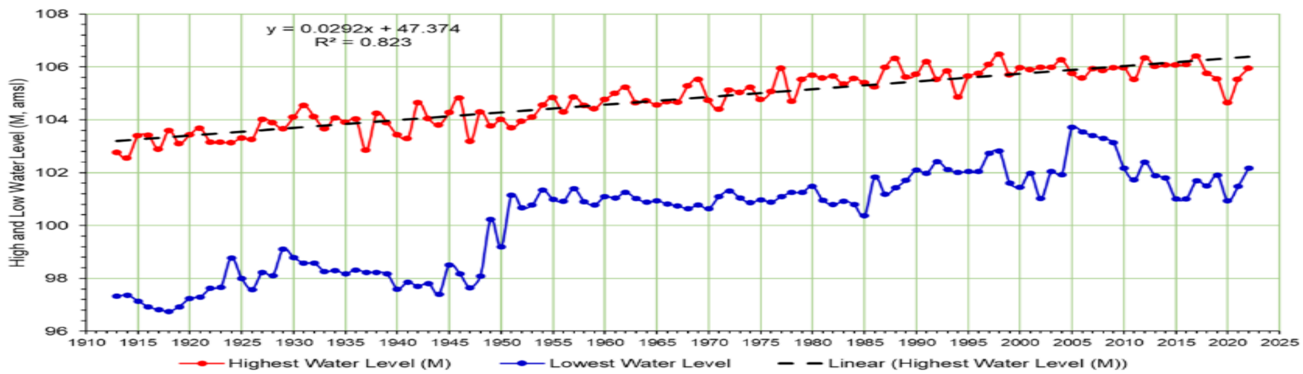

Figure 3. Low water and high flood level changes at Dibrugarh, Assam

4.4 Variation in width of the Brahmaputra River: The Brahmaputra, one of the greatest alluvial rivers and a braided river, has a river channel that ranges in length from 1.1 Km to 18.6 Km [96]. By their very nature, braided rivers are less stable than meandering rivers [97]. The river braiding inside the river profile are subject to frequent and unpredictably changing modifications. During hydrological events, certain river braids may be abandoned, and other ones may be generated or combined [98-99]. This indicates that significant amounts of sediment are scoured, produced, and mobilized by internal erosion and deposition processes inside the braided river profile [100-103]. An area along the outer banks of a braided river channel has significant rates of erosion and deposition, which leads to unstable banks and an elevated risk of floods [104-106]. Due to the fact that most banks in Assam are made of silt and sand, they do not create identifiable hard points that would otherwise be difficult to erode. Key planform characteristics of the Brahmaputra River in Assam and Bangladesh is given in Table 2. It is unfortunate that there are no maps or photographs of the Brahmaputra from before 1950 to demonstrate the spatial enlargement of the river. Nevertheless, there is data from 1973 to 2022 that can validate this [51, 112].

Table 2. Key planform characteristics of the Brahmaputra River

Planform characteristics	Brahmaputra, Assam	Brahmaputra (Jamuna), Bangladesh
Braid plain width / river width (Km)	6.05 (1912-1928)	6.03 (1830)
	9.01 (2006)	12.04 (2013)
	9.43 (2022)	-
Braiding index (-)	2 - 9	2 - 5
Braided bars (ha)	66,000	-

Throughout a season (and a year), changes in second and third-order channels happen quickly; these channels also grow continuously from erosion and deposition. The breadth of the first order channel has grown over time (Table 2) [107-112]. During the previous century, the Brahmaputra's total braided width through Assam has expanded from 6 Km to 9 Km, and between 1973 and 2022, it has increased by 0.53. In Bangladesh, the river's width has increased from 6 Km to 12 Km during the past 200 years. Because to bank erosion, the braided Brahmaputra River in Assam has been spreading continuously, including agricultural area into the river's profile [113].

The great Assam earthquake of 1950, which registered an 8.7 on the Richter scale, may have contributed to the increases in river width [24]. In the Himalayas, this earthquake caused extensive landslides [42-43]. After the earthquake, the Himalayan slopes became barren, and the combination of loose debris and barren slopes added 45 billion m^3 of silt to the river system in this area of heavy rainfall, which eventually clogged the Brahmaputra bed [43, 45-46]. Channel capacity has decreased as a result of the floodplain aggradation's inability to keep up with it. The great Assam earthquake of 1950 caused a tremendous quantity of silt to be deposited on the bank of the Brahmaputra River, raising it by nearly 3 metres in Dibrugarh. This is evidenced by a dramatic rise in the low-water level of the Brahmaputra River at Dibrugarh [32, 34, 93]. After 1950, the river's shallowing caused it to widen in order to handle its normal flow. After this event, river morphology underwent significant modification.

5. Conclusions

The study focused on post-earthquake morphological changes and their causes. Available literature and unpublished consultancy reports were reviewed; Landsat satellite imagery from 1973 to 2022, as well as water discharge data, sediment data, and water level data at Dibrugarh from 1903 to 2022 were analyzed. The study started by gathering data from secondary sources about the immediate aftereffects of the 1950 Assam earthquake and the resulting modifications to the tributaries and channel of the Brahmaputra River in India. We have chosen an area between three bridges viz. Ranaghat Bridge, Pasighat; Bhupen Hazarika Bridge, Tinsukia; and Bogibeel Bridge, Dibrugarh. It was established that the great Assam earthquake of 1950 caused massive landslides in the Himalayas that totaled 45 billion cubic meters of sediments. The Brahmaputra River and its many tributaries in the Brahmaputra plain received a significant amount of the silt produced by the landslides. These sediments' final resting place was undoubtedly the Bay of Bengal, even if some of the material was planned for long-term storage in Assam's floodplains and flood basins. According to recent reports and sediment transport theory, the fine fraction of the sediment added to the river system (silt and clay) made up a wash load that quickly moved through the system without strongly interacting with the morphology of the bed, instead being transported to the Bay of Bengal, or deposited in the flood basins. The coarser portion of the sediment (sand), which was flowing as bed material load, however, appears from historical accounts to have moved downstream considerably more slowly because transit rather than supply was constrained.

The Brahmaputra River and its tributaries have received about 45 billion m^3 of silt since the 1950 Great Assam Earthquake. Owing to the fact that the riverbed in Dibrugarh rose by 1.5 meters immediately after the earthquake and then climbed by 3 meters in 1955 as a result of a substantial number of debris and silt entering the river, about 153 Km^2 of land have been lost to erosion between 1953 and 2022. As this coarser material traveled from Assam to the Bay of Bengal, it appears to have formed a sediment wave or pulse that disturbed the bed and caused changes in the channel morphology in each reach sequentially over a period of about 73 years. This sediment wave or pulse also appears to have continuously changed the river's morphology. The Brahmaputra River in Assam has grown from 6 Km to 9 Km during the last century, and between 1973 and 2022 it has grown by 0.53 Km. Historical map interpretation leads to the conclusion that the Brahmaputra River's observable morphological changes are a continuation of the river's recent planform evolution, which may be seen over a period of two to three centuries.

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