HYDROLOGICAL IMPACT OF EARTHQUAKES ON THE BRAHMAPUTRA RIVER REGIME, ASSAM: A STUDY IN EXPLORING SOME EVIDENCES

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ABSTRACT: The Brahmaputra basin in North East India constitutes an extremely unstable seismic region of the world. The impact of the major earthquakes on the regime of the river with its host of tributaries and the large number of water bodies (wetlands) strewn over the flood plains is no doubt very significant. However, no serious efforts have so far been made to collate and sieve through the pile of scientific data and observations available so far relating to the effects of major earthquakes vis-à-vis the regime of rivers and morphology and behaviour of channels. Tectonics and denudation of the Himalayas and alluviation of the Brahmaputra Valley in Assam are concomitant phenomena (Goswami, 1985). There appears to be phases of rapid aggradation of the Brahmaputra channel associated with earthquakes followed by relatively slower removal of accumulated debris over longer time periods. Major earthquake episodes of Assam appear to be separated by a period of seismic quiescence.

In the present paper an attempt is made to present a comprehensive and coherent report on the hydrologic and geomorphic impact of the last two major earthquakes of this region viz. 1897 and 1950, based on examination and analysis of data and information available in published research, official reports and other documents. These earthquakes caused extensive landslips and rock-falls on hillslopes, subsidence and fissuring of ground in the valley, and changes in the course and configuration of the rivers. The effects of the earthquakes are discussed here under six different categories viz. (i) landslides on the hillslopes including blockage of river courses (ii) flash floods due to sudden bursting of landslide-induced temporary dams (iii) raising of river beds due to heavy siltation, fissuring and sand venting (iv) subsidence/elevation of existing river and lake bottoms and margins and creation of new water bodies and waterfalls due to faulting. Several examples are cited to illustrate each of the categories mentioned.

INTRODUCTION

The Brahmaputra is a major river system of the world that extends over a drainage area of 580,000 km² million hectares of which 50.5% lies in China, 33.6% in India, 7.8% in Bhutan and 8.1% in Bangladesh (Fig.1). The Eastern Himalayan watershed of the Brahmaputra including its valley in Assam constitutes an extremely unstable seismic region. The geologic and tectonic framework of the region has considerable impact on the hydrologic as well as fluvio-geomorphic regime of the river and its host of tributaries. Besides there are a large number of static water bodies strewn all over the flood plain.

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areas which are also significantly affected by neotectonism. There is an imperative need to examine thoroughly the impact of major earthquake episodes on the long term hydrological and morphological character of rivers and wetlands of the region. This will help in understanding the natural systems better and in evolving appropriate strategies for sustainable development of water resources and management of natural hazards.

In this paper an attempt is made to examine and interpret some of the available data and observations pertaining to geology, tectonics, hydrology and fluvial geomorphology of the Brahmaputra river system in order to highlight the nature and intensity of impact of the last two earthquakes i.e. 1897 and 1950, on the flow regime and morphological character of the river. The effects of the earthquakes are discussed under six different categories: (i) Landslides and blockage of river courses (ii) flash floods due to dam bursting (iii) raising of river bed due to siltation, fissuring and sand-venting (iv) drastic bank erosion (v) dramatic channel changes and (vi) subsidence or elevation of river beds, lake bottoms etc. or creation of new water bodies due to faulting. To understand the long term hydrological impact of the earthquakes, especially that of 1950, an analysis of low water levels of the Brahmaputra from 1913 to the present, specific discharge hydrographs and sediment rating curves at different periods is carried out. Besides, sediment load budgets based on sequential channel cross sections are used for the purpose.

GEO-ENVIRONMENTAL SETTING

The geo-environmental setting of the Eastern Himalayas is characterised by four topographic units each having a unique set of geologic and structural characteristics (Fig.2). Rising progressively to the north above the Brahmaputra plain, these units are:
(i) Sub-Himalayas (average elevation 1000 m), (ii) Middle Himalayas (average elevation 4000 m), (iii) Greater Himalayas (average elevation 6000 m), and (iv) Trans-Himalayas (average elevation 4500 m). The Sub-Himalayas consist mainly of Tertiary sandstones and are conspicuous by the presence of many raised, relatively young terraces (Gansser, 1964). Such terraces comprising pebbles, cobbles and boulders of gneisses, quartzites, granites and sandstones occur in successive elevations up to 300 m above the Brahmaputra plain. The Sub Himalayas, also called Siwaliks, supposedly belong to the mollasse facies of the Middle Miocene-Pliocene age. The Middle Himalayas are underlain by lower Gondwana (Paleozoic) deposits comprising shales, slates, and phyllites interjected and overlain by a thick horizon of basaltic rocks called Abor volcanics. To the north, these are succeeded by a belt of highly metamorphosed schist, quartzites and dolomites. The Greater Himalayas consist primarily of granites and gneisses with some sedimentary sequences in between. Structurally this region is very complex with a series of overthrusts, nappes and recumbent folds. Lying further to the north, the Trans-Himalayas of Tibet consist of highly fossiliferous sedimentary formations of Palaeozoic to Eocene Age (Wadia, 1968). At the structural band in the extreme east, the Himalayan ranges swerve to the south and eventually merge with the Patkai-Naga ranges bordering the Brahmaputra Valley at the east and southeast. An enormous thickness (2500 m) of boulders, cobbles and pebbles of Pliocene age are exposed in the north eastern part of the valley. These conglomerates are supposed to have been deposited in a rapidly sinking basin floor along basement faults. The eastern hill ranges are crisscrossed by a large number of active fault planes, evidence of high tectonic instability of the region.
The highland to the south of the Brahmaputra valley comprising the Meghalaya Plateau and the Mikir Hills forms a part of the stable Indian peninsular block of Precambrian age. The Brahmaputra valley in Assam is underlain by recent alluvium approximately 200-300 m thick consisting of clay, silt, sand and pebbles and boulders (Geological Survey of India, 1977). According to Murthy (1968), the Brahmaputra valley in Assam has evolved into its present configuration during the last two million years of Pleistocene and Recent times.

The present tectonic framework of northeast India is the result of the regional north-northeast ward drift of the Indian plate along with westward overriding of the Burmese plate (Das, 1992). Several authors (Nandy, 1980, 2001; Verma and Krishna Kumar, 1987; Evans, 1964; Das, 1992) have discussed the tectonic framework of the northeastern region and its relation to structural features and geological processes. The Assam basin is bounded by extensive thrusts. The Main Boundary Thrust (MBT) lies in the north, the Mishmi thrust towards northeast and the Naga thrust in the east-south east. In the south it is formed by the Cambrian formations, to the south of which runs the Dauki fault. The MBT separates the Sub-Himalayan formations from the Gondowanas of the Middle Himalayas. Due to the migration towards each other of the thrust belts in Naga hills and the Himalayan region, the upper Assam region has been compressed in the northwest-south east direction. The crustal shortening due to this in the Naga hills was between 150-300 Km and in the eastern Himalayas between 300-600 Km (Evans, 1964). The lineament map of the region based on the analysis of satellite imagery indicates the seismo-tectonic significance of these features in the context of northeast India.

Recent geophysical enquiries have revealed that the Precambrian basement of the Brahmaputra valley that supports the thick pile of sediments is crisscrossed with fractures along which various blocks rise and fall at different rates. It is also known that of the major tributaries of the Brahmaputra, the Subansiri basin is sinking simultaneously with sedimentation, the Jia Bharali basin lies in a graben and the Manas basin is controlled by tectonic and erosional scarps in the Sub-Himalayas. The Brahmaputra valley is characterised by a large number of palaeo-channels that are easily identifiable on satellite imageries (Goswami, 1996).

**THE BRAHMAPUTRA RIVER REGIME**

The hydrologic regime of the Brahmaputra River responds to the seasonal rhythm of the monsoons and the freeze-thaw cycle of the Himalayan snow. The river originates in a great glacier mass in the Kailash range of Himalayas south of lake Gunkuyd in southwest Tibet at an elevation of 5300 m and flows through China, India and Bangladesh for total distance of 2880 km before emptying into the Bay of Bengal through a joint channel with the Ganga. In Tibet, the river known here as the Tsangpo, flows eastward for about 1100 Km along the bottom of a longitudinal graben parallel to and about160 km north of the Himalayas. At the extreme eastern end of its course in Tibet, the Tsangpo suddenly enters a deep narrow gorge at Pe(3500 m) and skirting around the Namcha Barwa peak(7755 m) continues southward cutting across the Himalayan ranges. The gradient of the river in the gorge section ranges from about 4.3 to 16.8 m/Km, whereas after emerging from the gorge its gradient near Dibrugarh is only 0.09 to 0.17 m/km. In Assam the Brahmaputra flows through a uniquely braided
channel characterised by numerous sand bars and islands, high and variable flow pattern and excessive rates of sediment transport and sedimentation (Goswami, 1998).

The Brahmaputra carries a mean annual flood discharge of 48,160 m$^3$ s$^{-1}$ and sediment load of 400 million metric tons at Pandu (Assam). It is ranked fourth among the largest rivers of the world with an average annual discharge of 19830 m$^3$s$^{-1}$. The rates of discharge per unit drainage area (or yield) of the Brahmaputra basin rivers are also among the highest in the world. The yield of the Brahmaputra from the catchment above Pandu, Assam, is 0.0306 m$^3$s$^{-1}$km$^{-2}$. The high rates of yield for some of the tributaries of the Brahmaputra such as the Subansiri(0.076 m$^3$s$^{-1}$km$^{-2}$)the Jia Bharali(0.086 m$^3$s$^{-1}$km$^{-2}$) and the Manas(0.023 m$^3$s$^{-1}$km$^{-2}$) are very significant compared to those of other major rivers of the world. A large number of tributaries, some of which are Trans-Himalayan, join the Brahmaputra in Assam. High monsoonal rainfall in the upper catchments and the steep gradient of the rivers are considered to be the major factors responsible for the high rates of unit discharge which in turn help generate the high sediment yield from the basin and contribute significantly towards causing drainage congestion in the valley.

EFFECTS OF 1897 AND 1950 EARTHQUAKES ON THE BRAHMAPUTRA RIVER

The Brahmaputra valley and its adjoining highlands comprise one of the most active seismic regions of the world. Earthquakes are rather frequent in this region. The earthquakes of 1897 and 1950, each of Richter magnitude 8.7, are among the most severe ones in recorded history. Table 1 lists the earthquakes of magnitude 7.0 or above that have occurred in the region since 1897.

Table 1: Earthquakes of magnitude 7.0 or above that have occurred in Northeastern India and adjoining regions since 1897.

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Date</th>
<th>Epicentral Area</th>
<th>Lat(ºN)</th>
<th>Long(ºE)</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12/06/1897</td>
<td>Shillong, Meghalaya</td>
<td>26º00'</td>
<td>91º00'</td>
<td>8.7</td>
</tr>
<tr>
<td>2</td>
<td>31/08/1906</td>
<td>India-Burma border</td>
<td>27º00'</td>
<td>97º00'</td>
<td>7.0</td>
</tr>
<tr>
<td>3</td>
<td>12/12/1908</td>
<td>Kachin, Burma</td>
<td>26º30'</td>
<td>97º00'</td>
<td>7.0</td>
</tr>
<tr>
<td>4</td>
<td>09/09/1923</td>
<td>Jankaria, Meghalaya</td>
<td>25º12'</td>
<td>91º00'</td>
<td>7.0</td>
</tr>
<tr>
<td>5</td>
<td>02/07/1930</td>
<td>Dhubri, Assam</td>
<td>25º30'</td>
<td>90º00'</td>
<td>7.1</td>
</tr>
<tr>
<td>6</td>
<td>27/01/1931</td>
<td>Kachin, Burma</td>
<td>25º36'</td>
<td>96º48'</td>
<td>7.6</td>
</tr>
<tr>
<td>7</td>
<td>04/08/1932</td>
<td>India-Burma border</td>
<td>26º00'</td>
<td>95º30'</td>
<td>7.0</td>
</tr>
<tr>
<td>8</td>
<td>23/10/1943</td>
<td>Hojai, Assam</td>
<td>26º00'</td>
<td>93º00'</td>
<td>7.2</td>
</tr>
<tr>
<td>9</td>
<td>29/07/1947</td>
<td>Tammu, Arunachal Pradesh</td>
<td>28º30'</td>
<td>94º00'</td>
<td>7.8</td>
</tr>
<tr>
<td>10</td>
<td>15/08/1950</td>
<td>India-Burma-China border</td>
<td>28º30'</td>
<td>96º30'</td>
<td>8.7</td>
</tr>
<tr>
<td>11</td>
<td>06/08/1988</td>
<td>Manipur-Burma border</td>
<td>25º14'</td>
<td>95º12'</td>
<td>7.2</td>
</tr>
</tbody>
</table>

The number of earthquakes of different magnitude ranges during the periods 1897
to 1952 and 1953 to 1992 are presented in Table 2.

Table 2: Number of earthquakes in different magnitude ranges in the Himalayas and northeast India during the period 1897 to 1952 and 1953 to 1992

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>1897-1952</th>
<th>1953-1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>M&gt;7.5</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>7.5&gt;M&gt;7.0</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>7.0&gt;M&gt;6.5</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>21</td>
</tr>
</tbody>
</table>

Source: Gupta(1997)

It shows that during the period 1897-1992 as many as 65 earthquakes of magnitude higher than 6.5 have occurred in the region (Gupta, 1997). Khattri and Wyss(1978) analysed the seismic data of the region for the last 150 years and came to the conclusion that each of the major earthquakes is preceded by a period of seismic quiescence. The earthquakes of 1897 and 1950 were found to have such periods lasting 28 and 30 years respectively.

Oldham (1899), who traced the origin of the 1897 earthquake to numerous foci associated with fault planes covering a large area of the Meghalaya plateau, made some interesting observations about the geomorphic and hydrological impact of the disturbance. These include extensive landslips and rock falls on hillslopes, subsidence and fissuring of grounds in the valley, changes in the course and configuration of channels, and flow and sediment transport characteristics of the river and many of its tributaries. At certain places river-beds and tanks were arched up or filled with sand spouted through fissures and vents. At others, the slopes of the stream beds were reversed creating pools of water. Landslips and rockfalls were widespread on the hillslopes. In the Chedrang valley, a fault-scarp running parallel to the river for about 20 km with vertical throws up to 11 m was detected. Several waterfalls and as many as 30 pools were created in the river. Subsidence of the ground near the Brahmaputra river created a number of depressed areas now occupied by swamps. In some areas existing wetlands (beels) were made shallower, as it happened in the case of the Kapla beel of Sarukhetri area where the bed was raised by several meters. In the Kulsi river, severe floods after the earthquake led to aggradation of the river bed thereby changing the river from one with deep pools to one with a shallow sandy bed. The bed-level of the river was reported to have gone up by more than three meters due to which several tributaries had been blocked leading thereby to inundation of adjoining areas. The Chandubi beel now covered with visible remnants of submerged vegetation bears clear testimony to the impact of the earthquake on the Kulsi river system. The navigability of the Chowlikhoa river was greatly affected due to rising of the river bed. Aggradation of the river-beds was also reported in case of many other rivers like Pagladiya, Borolia, Barnadi, Manas, Kaldiya etc. The Singra river in Barpeta district had undergone a bedlevel elevation of about five meters. The bed of the Brahmaputra at Goalpara was reported to have risen by about 2.5 meters after the
earthquake. Occurrence of flood almost immediately after the tremor was reported in many areas like Nalbari, Dalgaon, Bholabari etc. Sand-venting through fissures and fractures was widespread especially in riverine areas. Goswami(1986) identified Quaternary landforms in the alluvial tract of Upper Assam bounded by scarps that were affected or reactivated by the 1897 and 1950 earthquakes. Molnar(1987) discussed the distribution of intensity associated with the great 1897 Assam earthquake and bounds on the extent of the rupture zone.

Poddar(1952) provides an useful account of the 1950 Assam earthquake that was epicentered at a place called Rima on the tri-junction of India, Burma and China. Garg(1953) discussed the effects of this earthquake on the topography and regimes of rivers of North East India and damages caused to roads. Gee (1953) and Ramesh and Gadagkar(1990) described the changes in the river courses in the Upper Assam area as a result of the earthquake. Poddar(1952) reported that as a result of tremors, extensive landslides occurred in the Himalayan slopes temporarily blocking the courses of the Subansiri, the Debang and the Dihang. Bursting of these dams after several days released an enormous amount of ponded water producing devastating floods downstream. It was reported that a large amount of the sediment generated by the landslides was brought to the river raising its bed considerably. At several places the channels of the Brahmaputra river were choked with sediments released from fissuring and squeezing of the soft levee areas. Rivers like the Subansiri and several of its tributaries changed their courses at different places and formed new channels. At many places subsidence of the ground occurred along with fissuring which resulted in drainage congestion and water logging.

HYDROLOGICAL IMPACT OF EARTHQUAKES

Major seismic events have considerable impact on regimes of rivers. These effects can be both primary and secondary. However, on a long term basis the secondary effects like landslides, erosion, sedimentation, morphological changes etc. may bring about significant changes affecting geometry and behaviour of channels, flooding characteristics and erosion potential. The response of the fluvial system to the disturbance caused by a seismic event varies according to the geophysical and environmental setting unique to it and the intensity, duration and distribution of the concerned events. Some of the evidences that can be obtained from the analysis of hydrological and fluvo-geomorphic records are discussed here in the context of the 1950 earthquake.

Water level is a parameter commonly measured in rivers. Unlike the data-base on the discharge or sediment load, that of water level is normally quite long in case of moderate to large rivers. Besides, water level is much easier to estimate even without any technical device. Almost instantaneous observation of water levels during the earthquake, as recorded in reports, help in understanding nature and intensity of its impact on the fluvial system. Oldham (1899) reports that river gauge at Guwahati showed a height of 50.13 m above msl at 7 am on 12th June, 1897- the day of the great earthquake. But at 6 pm, i.e. 3.5 hours after the earthquake, the water level was 52.50 m. Next morning it sunk to 51.93 m at 7 am, on 14th to 50.97 m and on 15th to 50.37 m. Garg(1953) also reported rising of water levels in the Brahmaputra river after the earthquake of August 15, 1950. An examination of the low water levels
of the Brahmaputra river at Dibrugarh recorded since 1913 reveals very clearly the effect of the 1950 earthquake on the stage hydrograph (Fig. 3), indicating aggradation of the river bed through accelerated sedimentation triggered by the earthquake. Before 1950 the Brahmaputra rarely used to cross the danger level at Dibrugarh. It exceeded the danger level only in 1931, 1938, 1942 and 1946 and the duration was only for two days. But since 1954, the river rises above the danger level more than once every year and remains above the danger level for 15 to 20 days or more.

The effect of the earthquake on the river regime is also reflected on the graph showing specific discharge against water level (Fig. 4). The rising trend observed on the graph after 1955 and its decline since 1970 may be related to the response of the channel to the rapid sedimentation caused by the earthquake followed by slower removal of bottom sediments in subsequent years.

An examination of the sediment discharge data for the Brahmaputra river at Pandu indicated that the rate of sediment transport was exceedingly high in the years immediately following the earthquake of 1950. For example, the mean annual suspended load during 1955-60 was 91.47 ha.m. as against 17.10 ha.m. during 1966-69 and 8.96 ha.m. during 1971-76. The denudation rate of the catchments was estimated to be 1.57 mm/year from 1955 to 1979 as against 0.73 mm/year from 1971 to 79 indicating a much higher denudation rate during 1955-71.

Estimation of storage and removal of sediments in the channel using sediment budget method based on the continuity equation for sediment transport and by end
area method using sequential channel cross-sections indicates that the period 1957-71 shows much higher rate of aggradation of the river bed compared to 1971-77 which can be attributed to the impact of the earthquake (Goswami, 1985). The rate of bankline shift is also found to be very high following the earthquake. In Assam, the bank erosion of the Brahmaputra assumed alarming proportion during the years following the earthquake. Several flourishing towns like Dibrugarh and Palashbari have lost considerable part of their land area due to erosion by the river. The reduction in the conveyance capacity of the Brahmaputra following aggradation of its bed as a result of the earthquake led to intensification of the erosion hazard as well as flood potential of the river. A similar scenario has evolved in case of many of its tributaries. The impact of human induced factors like deforestation, encroachment, improper and adhoc strategies for control etc. has further aggravated the hazard potential in recent times.

The relationship between flow and sediment load in the river as expressed in the sediment rating curve is indicative of the variability in the pattern of sediment transport caused due to seismic disturbances. For the Brahmaputra river at Pandu separate rating curves were developed for each period of different sediment transport rate: 1955-60, 1971-76 and 1977-79(Fig. 5). To compare the sediment rating curves for the different periods, an analysis of variance test for equality of regression coefficients was conducted. The test suggests that the difference in the regression coefficients is statistically significant at the 5% level. The slope of the rating curve is steeper during the period 1955-60 when the sediment transport rate was higher compared to the one for the period 1971-76(Goswami, 1985).

![Fig-5. Sediment Rating Curve of the Brahmaputra at pandu for (a) 1955-60 (b) 1971-76](image-url)
CONCLUSION

High intensity seismic events have considerable impact on the fluvial regime of the Brahmaputra river. There appears to be phases of rapid aggradation associated with earthquakes followed by periods of relatively slower removal. Variations in gauge height for specific discharges at Pandu may indicate such a pattern with aggradation during the period 1955-63. The period of rapid aggradation may be associated with the great earthquake of 1950 which generated a large debris load for the river. Thus recurring tectonic disturbances in the region seem to have pronounced effects on channel configuration leading to intensification of flood and erosion hazards of the river in the valley region. The hydrograph of lowest annual water level of the river at Dibrugarh indicates the sudden raising of the water level after 1950 indicating aggradation of the river bed due to accelerated sedimentation caused by the 1950 earthquake. Sediment rating curves developed for different periods also indicate the change in the pattern of sediment transport due to the seismic event. Sediment budget based on measured suspended load and also sequential channel cross-sections provide another two methods for estimating the impact of earthquake on the hydrologic regime of the river.

Analysis of the available scientific data clearly indicates that neotectonism of the Brahmaputra valley and its surrounding highlands of Eastern Himalayas have pronounced effects on the flooding, sediment transport and depositional characteristics of the river and its tributaries.

REFERENCES

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