Do node points play a role in flood proliferation?

Geomorphologically, the mighty Brahmaputra River system flows over the Quaternary sediments. This is a cause of concern because of its location in an abundant monsoon regime within an active seismogenic volume. Since time immemorial, the Brahmaputra has continued to wreck havoc through repeated floods year after year[1–3]. The flow regime of the Brahmaputra responds to the seasonal rhythms of the monsoon and freeze–thaw cycle of the Himalayan snow[4].

The Brahmaputra valley in Assam represents a tectonosedimentary province, 720 km long and 80–90 km wide with elevation ranging from 120 m at Kobo in the extreme east through 50.5 m at Guwahati to 28.45 m at Dhubri in the extreme west[5,6]. The channel of the river itself occupies about one-tenth of the valley, with over 40% of its area under cultivation. The Brahmaputra valley in Assam is the home of more than 15 million people. In Assam, the river flows in a highly braided channel characterized by numerous mid-channel bars and islands.

Two sets of Survey of India toposheets (1914 and 1975) and a set of Indian Remote Sensing Satellite imagery (IRS-1B, LISS II B/W geocoded data) covering the cloud-free period of 1998 were used for the present study. In order to assess the situation, maps and the imagery were registered and geo-referenced with respect to the Survey of India toposheets. The bank lines were superimposed upon each other and the nature of the channel configuration was measured with the help of digital planimeter. The channel course for the proposed study was divided into ten segments (I–X) at an interval of 15 min east longitude (Figure 1) for quantification of erosion–deposition processes in relation to bank and bars/islands. The areas eroded or added by the river processes within the channel were measured with the help of a digital planimeter through sequential analysis (in km^2). The mean annual rate of erosion was calculated by dividing each area eroded by the corresponding time elapsed between the two sequences. The generated data were also verified with field observations and utilized for the evaluation and interpretation of channel course covering a stretch of 260 km with respect to space and time.

Observation on channel configuration during the period spanning from 1914 to 1998 with regard to the width of the channel revealed a significant change in its behaviour. The width of the braided Brahmaputra River channel, as evidenced from the sequential geomorphologic maps showing that it does not have simple, smooth and parallel banks, varies considerably along its entire length. A recent study[7] has shown that the stretch of the Brahmaputra River within Assam is relatively narrow in at least eight different locations, viz. 90°20′ (Singimari-Ghumari), 90°35′ (Pancharatna-Jogighopa), 91°10′ (Baghmari), 91°40′–91°45′ (Pandu), 92°25′ (Udhantola-Behali), 92°50′–93°0′ (Silghat–Tezpur), 94°20′ (Salmora) and 95°20′ (Laikaghat) east longitude. These positions can be considered as the node points of the river channel. The channel segments just downstream of these node points exhibited considerable widening. These variations in the width might at first seem random, but careful observation indicates that the narrow width or the node points can be explained by either one of two possible ways. First, the narrowness or node points may be present simply because of stability and low erodibility of the bank material. The banklines have been exceptionally stable near Guwahati (91°35′–91°45′E), Jogighopa (90°35′E) and Silghat (92°50′E). Presence of Precambrian gneissic rocks on both sides of

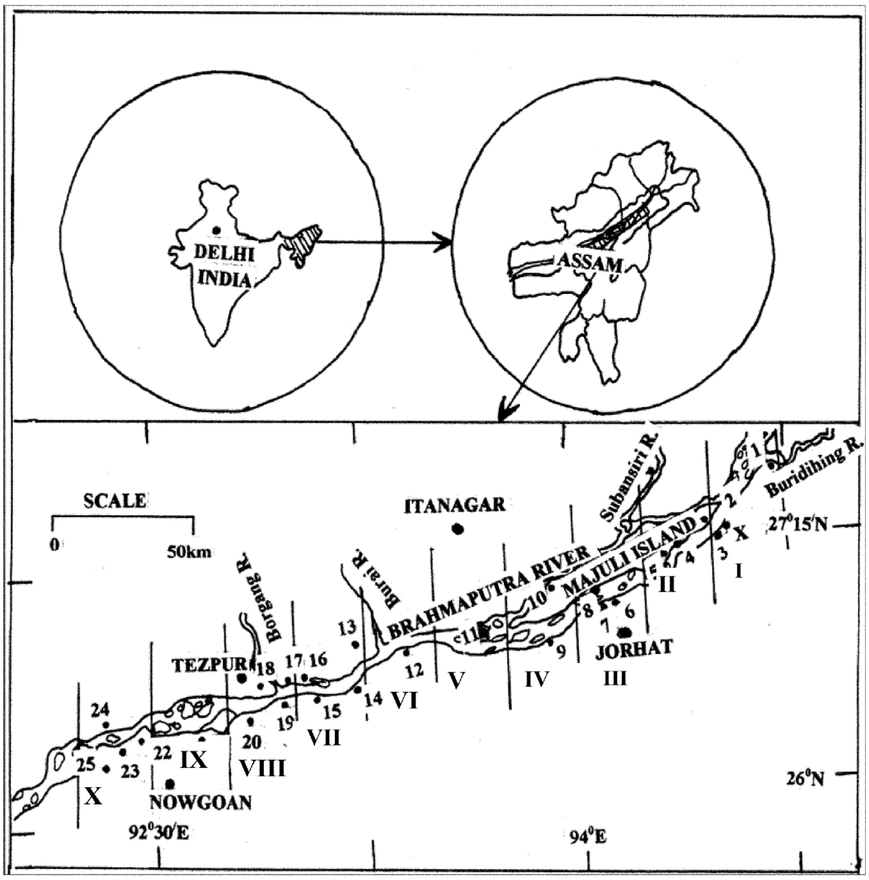
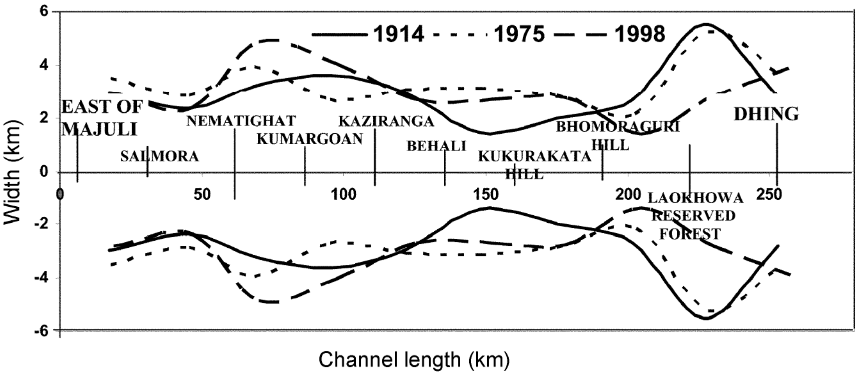


Figure 1. Location map of the study area. 1, Panidihing Reserve Forests; 2, Dishang Mukh; 3, Dikhow Mukh; 4, Bokajan Bil; 5, Borkoba Bil; 6, Nematighat; 7, Kakila Mukh; 8, Nayagaon; 9, Shikarighat; 10, Kumargaon; 11, Pichala Chapari; 12, Kaziranga; 13, Behali; 14, Dhansiri Mukh; 15, Dipholu Mukh; 16, Vishwanath; 17, Kamahaya Hill; 18, Kukurakata Hill; 19, Bhomoraguri Hill; 20, Jor Bil; 21, Laokhowa Reserve Forests; 22, Vahantola; 23, Dhing; 24, Orang Reserve Forests, and 25, Halaukunda Bil.

the bank might have resulted in stability of the banklines at these locations[8]. The other node points were formed due to the presence of cohesive clays, which had not allowed the river to migrate as freely as in the other places. Field observation around Salmora area has revealed a similar situation, where the banks composed of relatively stable, fine-grained sediments offer significant resistance to the connected flow regime[4,9].

Non-uniformity in the variation of width between two successive periods, i.e. 1914–75 and 1975–98 (Figure 2) can clearly be attributed from a study within the proposed reach. Throughout the segments under study the mean width of the channel was 5.9 km in 1914, which increased to 6.5 km in 1975 and became 6.9 km in 1998. This increasing trend clearly attributed to its relationship with the generation and migration behaviour of constricted regions (node points) and relative rate of erosion–deposition processes within the stretch under study. The geomorphologic development within the studied reach manifested two node points in 1914, while it increased by one in the later period with shift in their positions. The available information till 1914, showed two prominent nodal portions/points within the studied reach, one almost in and around Salmora area and other around Behali. Just after crossing Salmora the river expands its width gradually to about 8.5 km and continues almost for 100 km till the development of another node point near Behali, exhibiting a channel width of 7 km. After crossing the node point around Behali the channel gradually widens in the downstream direction up to a maximum of 11 km near Laokhowa Reserve Forests. After crossing the Laokhowa Reserve Forests, the channel of the river again shrinks and starts forming another node point near Dhing. The picture in the later period as observed from the Survey of India toposheets (1975) reveals a significant change in the width of the river from Neematighat to Kaziranga area and generation of another node point around Kumargaon. After crossing Kumargaon the river continues to flow with an average width of 7 km till the Bhomoraguri Hills and generates another node point near there. Thereafter, the river bulges out in a gradual manner. The present-day scenario, as evidenced from the 1998 IRS imagery, has demonstrated somewhat different behaviour than the period till 1975. The river channel widens abruptly after the node point at Salmora and attains a maximum width of 9.5 km. Thereafter, the channel shrinks by about 3 km and flows till Kukurakata Hill and generates another node point near Bhomoraguri Hills. After crossing the Bhomoraguri Hills, the channel gradually widens for another 2–3 km, resulting in maximum width of the channel (about 8.5–9 km). It is interesting to note that the position of the node around Salmora did not change during the entire study period. Ground observation along the channel around Salmora area helps to explain its semi-permanent nature in the light of the existence of clayey material, which offers significant resistance to the erosive power of the connected flow regime[10] (D. Bezbaruah, unpublished). Since the banks are relatively stable in this area, the river scours deeper or undercut of the channel becomes active to accommodate flood discharge and the scoured material causes a local sharp increase in transported load. Therefore, just downstream of the node point around Nematighat–Kumargaon area, the river tends to be wider and shoaler. Here the current velocities diminish, causing an increase in sediment load to drop out and form islands or chars. The formation of chars causes a decrease in cross-sectional area, and the river cuts its bank laterally to maintain a proper cross-sectional area that is in equilibrium with the discharge. Thus constriction of the channel by comparatively rigid clay materials at Salmora area accounts for extensive bank erosion and variation in width along the proposed reach of the Brahmaputra River channel. These types of node points are described as relatively stable[9] and do not move on short-term basis (50–100 years). Downstream of node point at Salmora, lateral bank movement is highly exaggerated and extensive local cutting is pronounced causing significant erosion at Neematighat and Kaziranga areas. In the Salmora area bank materials are composed of cohesive clay materials and it is characterized by the dominant association of kaolinitic and illite group of minerals[11]. Moreover, field evidence around Salmara area shows protruding nature of Older Alluvium towards the river channel, which offers significant resistance to the flow regime of the Brahmaputra[9,12]. Here banklines take a somewhat concave shape and the presence of thick, cohesive clay–silt layer at a depth of 4–6 m from the surface was observed. In this area the bankline appears to have been stable for the last 76 years (1917–2001) and the rate of erosion was significantly low (0.58 km^2)[7]. Another type of node point is related directly to the formation of islands or chars, which reduces the cross-sectional area and the river accordingly reciprocates in relation to its volume of water by widening at the points where the islands develop. This condition also helps in the formation of node points both below and above the areas of char formation, independent of the bank materials in question. However, the width below this node point is solely dependent on discharge and local increase in sediment load in relation to variable hydraulic conditions as may be expected in a braided river like the mighty Brahmaputra. This phenomenon is clearly observed near Nematighat and Laokhowa Reserve Forests, just after the Salmora and Bhomoraguri node points within the studied reach[7,10].



Figure?????? Variation in average width of the Brahmaputra River channel within the studied stretch.

The lateral migration of node points within the studied reach has also been

Table 1. Erosion and deposition activities at different sectors

Sector	Erosion (km^2)		Deposition (km^2)		Net erosion (km^2)	Erosion rate (km^2/yr)
	1914–75	1975–98	1914–75	1975–98		
I	35.77	2.00	–	31.75	–6.02	0.45
II	29.82	2.57	0.47	27.45	–4.47	0.38
III	37.67	10.73	–	10.32	–38.08	0.57
IV	61.65	43.67	–	2.30	–103.04	1.25
V	–	27.30	43.75	13.62	+30.07	0.32
VI	28.09	79.72	33.79	10.05	–63.97	1.28
VII	31.49	1.70	01.15	11.45	–20.66	0.39
VIII	0.63	0.50	9.07	23.34	+31.28	0.01
IX	53.55	21.45	–	3.45	–71.55	0.89
X	52.70	33.87	9.10	01.35	–76.12	1.03

Negative sign indicates degradation (erosion) and positive sign indicates aggradations (deposition).

observed. Throughout the period under study the position of the node around Salmora was relatively stable. However, the nodes as observed near Behali with reference to 1914 SOI toposheet shifted back and forth for about 40 km towards Kaziranga–Kumargaon areas as revealed from the base map of 1975 under study, but the base map of 1998 showed a downstream motion of 90 km, presently located near Bhomoraguri Hills. This observation has significant bearing on the differential hydrodynamic behaviour of the braided Brahmaputra River channel. Within the limitation of poorly understood hydraulic conditions with many variables, it may be attributed that owing to the development of local areas of slack current rapid deposition of bed load occurs in areas just after the semi-permanent Salmora node points. The channel accordingly attains a tendency to widen at this point, and the islands are formed. This condition will cause the formation of another node point below this wider area. This might be the most plausible explanation in the development of node point near Behali below the semi-permanent Salmora node point, independent of the bank materials under question. It is clear from the study that the node points developed in this process, however, are not stable and moved according to the existing hydrodynamic conditions in relation to sediment load of the river. The migrating behaviour of node points as observed during period till 1998 towards Kumargaon–Kaziranga and Bhomoraguri Hills also supports our contention. It is also clear from an earlier study (D. Bezbaruah, unpublished) that the area exhibited a depositional episode near Kumargaon–Kaziranga areas till 1975. However, the area near Behali suffers significant erosion for both the periods under study. Again just after the Kukurakata Hills the channel exhibited differential rate of erosion on both the sides[10] (D. Bezbaruah, unpublished) and attained a maximum width up to 11 km. To have a clear idea an attempt has been made to analyse the erosion–deposition processes within the reach under study for the successive periods (Table 1).

The study has showed prevalence of extensive net-erosion activity around sectors III and IV (Neematighat–Sikarighat, 141.12 km^2), VI (Kaziranga 63.97 km^2), IX (Laokhowa Reserve Forests, 71.55 km^2) and X (Orang Reserve Forests, 76.12 km^2). The annual rates of erosion within these areas are 1.82, 1.28, 0.89 and 1.03 km^2/yr. It is clear from the observations that all these areas with significant erosion activities are located just below the node points around Salmora, Behali and Bhomoraguri areas. In a recent study it has been reported clearly that the around Rahmaira area, Dibrugarh District, Assam suffered extensive bank erosion (132.70 m/yr) just after the Laikaghat node point[7], with southern shift in the bankline up to 4116 m.

In the flood plain of the Brahmaputra there is constant exchange of sediments between the flood plain and the channel. At any point sediment input is from the suspended and bed load of the upstream reach of the river, tributaries, bank and bar erosion within the area. To have an idea about the quantitative relation between bank erosion and sand bar growth which in turn helps in the formation of node points, volume of sediment is calculated based on the planimetric measurement of channel migration, bar and bank height. To translate the planimetric area to volume of sediment requires estimation of the height of the area deposited or eroded. It is assumed that each aerial measurement represented an entire column of sediment from the channel bed[13].

Following Dunne *et al.*[13], net erosion or deposition along the bank, and difference in volume of sediment storage in the bar for each segment covering different periods were calculated (Table 2). Unlike the meandering river, where erosion along one bank corresponds to deposition on the opposite, in the braided Brahmaputra River channel either erosion or deposition predominates within the same segment. During the period 1914–75 largest volume of bank sediments was eroded away from the bank near Laokhowa–Orang Reserve Forests just after the semi-permanent Behali node point. However, in the later period during 1975–98, the picture changed with shifting of the node point in the downstream direction for a distance of about 50 km and erosion became predominant near Dhing attributing to the impact of node point on the erosion activity. The area around Neematighat–Kaziranga just below the Salmara node point suffered significant bank erosion. During this period total volume of bank sediments that suffered bank erosion within sectors III–VI was 1019.89×10^6 m^3, which was almost seven times more than the bar deposition activities (142.98×10^6 m^3). The erosion activity changed during the later period (1975–98) and river architects itself with the formation of bars or islands in relation to existing hydrodynamic behaviour within the channel. However, the erosion

Table 2. Volume of bank and bar sediments eroded or deposited within the studied stretch

	Period 1914–75		Period 1975–98	
Sector/name	Bank net erosion/ deposition (10^6 m^3)	Bar net erosion/ deposition (10^6 m^3)	Bank net erosion/ deposition (10^6 m^3)	Bar net erosion/ deposition (10^6 m^3)
I: Panidihing	–399.51	+535.62	–62.79	–355.80
II: Bokajan	–358.63	–5.73	+78.37	–123.03
III: Neematighat	–568.65	+148.02	–29.83	+242.86
IV: Sikarighat	+280.16	–332.69	–743.39	+798.54
V: Pichala Chapori	–142.98	+85.54	–670.18	–180.09
VI: Kaziranga	–588.42	+242.11	+10.27	+108.50
VII: Behali	–414.43	+325.50	–275.32	+108.69
VIII: Bhomoraguri	+44.95	–278.96	+63.45	–1.74
IX: Laokhowa Reserve Forests	+304.38	–248.77	+70.24	–517.76
X: Orang Resrve Forests	–749.62	+198.44	–273.38	+171.45
Total	–2592.77	+669.07	–1525.60	+242.63

Positive sign before numerals denotes deposition and negative sign before numerals denotes erosion.

activity predominated over the depositional activity. The total bank net erosion and deposition during 1914–75 and 1975–98 were 2592.77×10^6 and 1525.60×10^6 m^3 respectively. The corresponding total bar net erosion and deposition were 669.07 and 242.63×10^6 m^3 respectively. It can be concluded that the node points played a positive role in geomorphological development of the 260 km reach of the Brahmaputra River channel under study.

The channel reach under study manifests a significant change in its geomorphologic behaviour. Throughout the stretch there appear two nodal points/ portions in 1914 base maps, while it increases by another as revealed from later period of observations (1975–98). The semi-permanent node point around Salmora area bears a close relationship with the existing sediments/soil characteristics of the riverbank. The node points around Behali and Bhomoraguri Hills confirm their genesis in relation to the char-forming processes and exhibited a transitory nature. It can be established from the study that the mechanism, generation and migration of node points bear a close relationship with the active erosion processes of the braided Brahmaputra River channel. It is expected that such type of studies may be able to provide a better understanding in channel mitigation and management approaches and will help in optimizing the flood management and mitigation studies. Moreover, construction of bridges over the Brahmaputra (till now two and one under process) might have imposed a situation similar to the node points and its potential implication to flood proliferation with time cannot be ruled out. It is therefore highly essential to undertake concerted efforts to correlate site-specific geomorphological attributes with other hydrological aspects towards formulation of effective flood management practices of this mighty Brahmaputra river.

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