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Erosional vulnerability and spatio-temporal variability of the Barak River, NE India

Anwarul Alam Laskar[1] and Parag Phukon[2,*]

[1]Indian Statistical Institute, North-East Centre, Tezpur 784 028, India
[2]Department of Geological Sciences, Gauhati University, Guwahati 781 014, India

The alluvial segment of the Barak River within Assam has been studied for a period of 85 years (1918–2003) based on temporal satellite data and Survey of India topomaps. Ten representative reaches with distinctive planform geometry have been delineated in this segment. Overlay analysis of six temporal spatial datasets (1918, 1965, 1975, 1988, 1999 and 2003) reveals that two segments of the river are highly vulnerable to channel migration through the processes of cut-off and bank erosion predominantly effected by toe-cutting and shear failure. Migratory activity index shows cyclic variation for all the representative reaches. Quantitative assessment shows an increasing trend of both erosion and deposition. However, the quantum of deposition is more than erosion over the 85-year period of study.

Keywords: Bank erosion and deposition, Barak River, channel migration, overlay analysis, quantitative assessment.

THE Barak valley in NE India is a distinct entity vis-à-vis the Brahmaputra valley. The Barak river and its tributaries drain a significant part (about 39,390 sq. km) of the summer monsoon-dominated SE Asia, spread over Myanmar, India and Bangladesh. It forms the second largest river system in NE India next to Brahmaputra. Shillong Plateau and the Barail range form a major drainage divide between the two rivers. The alluvial segment of Barak River is well developed in the Cachar and Karimganj districts of Assam and further downstream in Bangladesh. Across its floodplain the river shows different degrees of spatio-temporal variability. However, quantitative assessment of the river variability in space and time in the Barak Valley is almost non-existent, although some snapshots of such a study are available in the Brahmaputra Valley[1–4]. The present study addresses this information gap with emphasis on understanding the river dynamics within the 150 km segment of the Barak River between the Assam–Manipur border and Assam–Bangladesh border (Figure 1). Taking advantage of developments in the field of high-resolution satellite remote sensing and Geographical Information System (GIS), overlay analysis of six temporal datasets spanning 85 years has been carried out. All the datasets were brought

*For correspondence. (e-mail: p_phukon@rediffmail.com)

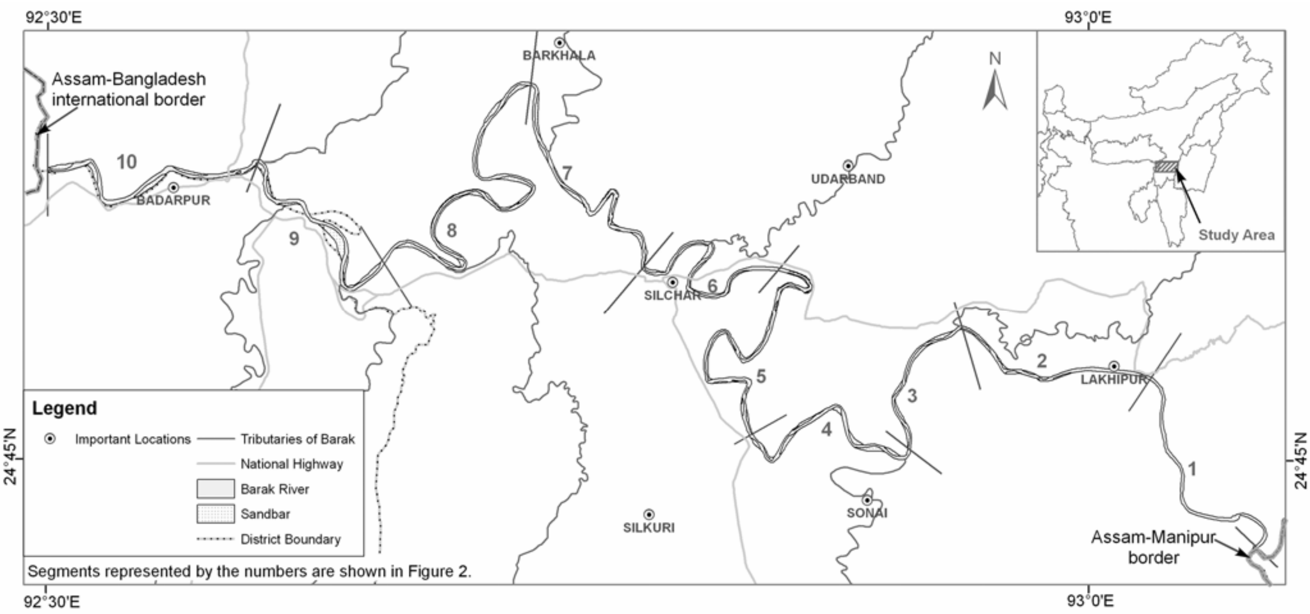

Figure 1. Location map of the study area of the Barak River.

Table 1. Details of the spatial database

Type of data	Year of survey/ date of acquisition	Scale/resolution	Index/path–row
Survey of India toposheets	1912–1928	1 : 63,360	$83^D/9$, $83^D/10$, $83^D/13$, $83^D/14$, $83^H/1$
	1963–1971	1 : 50,000	$83^D/9$, $83^D/10$, $83^D/13$, $83^D/14$, $83^H/1$, $83^H/2$
Satellite images			
IRS 1D LISS-III	24 March 2003	23.5 m	Path-112, row-55
IRS 1D PAN	27 February 2003	5.8 m	Path-112, row-55
Landsat ETM+	19 December 1999	30 m (multispectral)	
		15 m (panchromatic)	Path-136, row-43
Landsat TM (multispectral)	10 November 1988	30 m	Path-136, row-43
Landsat MSS	26 March 1975	70 m	Path-146, row-43

into a common spatial reference system (LCC projection and WGS 84 datum) for this analysis (Table 1).

The channel segment within the study area represents a typical meandering pattern[5], with an overall sinuosity index of 2.2. Within the 150 km segment, 10 representative reaches are identified based on morphology and trend of the channel (Figure 2)[6,7]. It is observed that the reaches which encounter Neogene bedrocks across anticlines show consistency of sinuosity index with an average value of 1.4 and standard deviation of 0.02. By contrast, the typical alluvial segments show significant temporal variation in sinuosity index ranging from 1.2 to 2.6, having a mean of 1.8 with a standard deviation of 0.5. Based on meander–loop axis orientation and radius of curvature, four basic meander types have been identified along the river, namely, simple symmetric, compound-symmetric, simple-asymmetric and compound-asymmetric[8]. On an average the planform parameters of these meanders show greater variability in the synclinal reaches and remain unchanged where they encounter bedrocks across anticlines (Figure 3). The overall temporal variation in the sinuosity index measured for the whole study area shows a decreasing trend (Figure 4), which can be attributed to the channel shortening through cut-off processes. Study of the channel width for three different years, viz. 1918, 1965 and 2003 shows that there is an increase in channel width in the lower reaches during the period 1918–1965, whereas during the period 1965–2003, it shows a decrease in the channel width all through, except a 30-km segment in the lower reaches where the width remains the same (Figure 5).

Channel migration is the process of a river channel moving across or within its valley, which may vary from gradual lateral movement of meander to abrupt shifting of a channel to a new course through avulsion, cut-off, etc. Channel migration is most likely to occur in the area of deposition, particularly along the transition from the zone of sediment transport to the zone of deposition[9]. The Barak River within its alluvial reaches of Assam shows evidence of lateral movement, whereas some of its tributaries show both vertical and lateral movement. Overlay analysis of six temporal datasets (1918, 1965, 1975, 1988, 1999 and 2003) shows that the major processes involved in channel migration are meander growth and meander bend migration, channel cut-off and bank line retreat, with the cut-off processes being predominant. There were as many as nine major cut-offs during the period 1918–2003, of which seven are between 1918 and 1965 and two occurred between 1988 and 1999. A notable recent example is the Dungripar cut-off of 1992, which led to the shortening of the channel by 9 km (Figure 6).

Meander bend migration in the Barak River is a complex phenomenon with more than one migration style existing in a single meander. Most of the meanders show irregular movements and the individual meanders show a combination of more than one style of meander movement (Figure 7), viz. extension, translation, rotation, enlargement and complex[4,10]. Migratory activity index (MAI), which is a standardized function of both length and time[11], is computed for the 10 representative reaches. It is calculated using the following formula

$$\mathrm{MAI} = \left(\sum A_{\mathrm{avg}} / L_{t_1}\right) \times (\text{month m}^{-1}),$$

where A_{avg} is the average area of each polygon encompassed by midlines of successive periods and L_{t_1} is the length of the channel at time t_1.

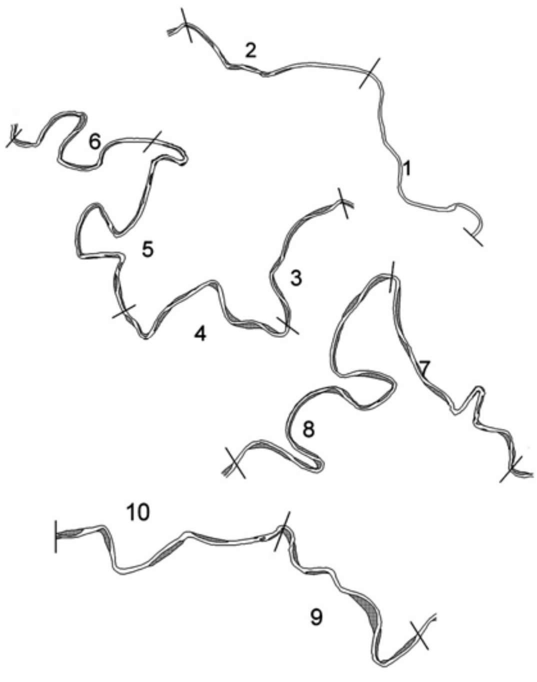

Figure 2. Representative reaches of the Barak River within the study area.

For determining MAI, midlines of each period are digitized and overlay of midlines of each of the successive periods is done to measure the area of polygons encompassed by the migration of the channel during the respective time-periods. Average migration per month was computed by dividing the area of the polygons by the number of months required for the migration. Further, to compare the migration indices of the reaches of different lengths, the migration is standardized as a function of length by dividing the sum of the average area for each polygon within a given reach by the length of the channel at the beginning of the period (t_1).

It is observed that for most of the segments MAI values show a cyclic variation with an increasing trend followed by a general decrease and then increasing again (Figure 8). It is also observed that the average MAI values for segments 3, 4, 5, 8 and 9, which are within the synclinal areas, are higher. Meander loop orientation of the Barak River shows that the preferred direction is N–S to NNE–SSW, which is also the direction of the prevailing tectonic fabric of the area.

Channel migration zone (CMZ) for the Barak River within the area is identified following a composite approach. CMZs or erodible river corridors are the areas which are affected by the movement of the river channel across its valley. The CMZs are the areas where the active channel of a stream is prone to movement over time. Channel migration is usually found along a small percentage of the entire network length of the stream. CMZs are also known as 'flood hazard' or 'floodway fringe' areas and are generally considered to be spatially equivalent to the 100-year floodplain, i.e. the floodplain area subject to a 1% or greater chance of flooding in any given year[12–15]. From the overlay of six temporal datasets (1818–2003), CMZs are delineated through identification of the active migration zone, active floodplains and palaeo floodplains. Active floodplains represent alluvial plain adjacent to the active channel with recurrent flood inundation and are dotted with cut-off meanders (locally known as anua), whereas the palaeo floodplains are at a slightly higher topographic level and are characterized by overlapping sets of meander scars which are well discernible from the satellite imagery. It is observed that the CMZ is restricted where the river passes through bedrocks and becomes wide in the alluvial reaches. Four segments with well-developed CMZs are – Banskandi to Kashipur, Ramnagar to Masimpur, Barjatrapur to Badarpur and downstream of Srigauri (Figure 9). It is also observed that there is no preferential direction of channel movement.

River-bank erosion is the result of a complex set of interactions between hydraulic action of the river and nature of the bank materials. Bank erosion takes place by hydraulic action on the bank materials and mass failure under gravity followed by removal of the failed materials[16,17]. In this study a quantitative assessment has been

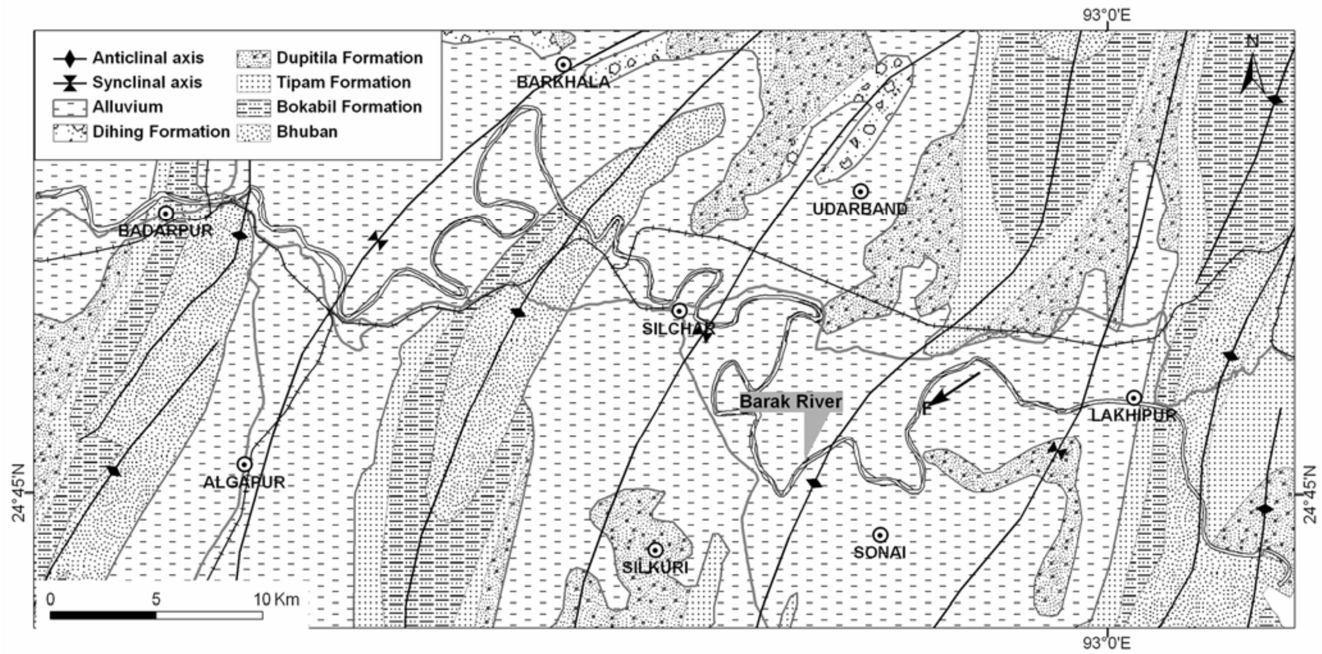

Figure 3. Geological map of the study area (modified after Das Gupta and Biswas[18]) showing planview morphology of Barak river segments across anticlines and synclines.

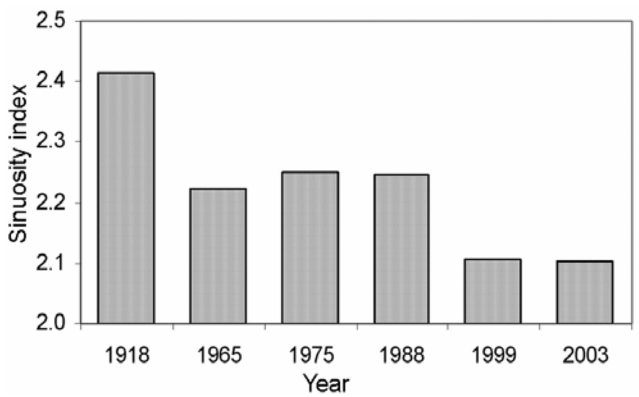

Figure 4. Temporal variation of sinuosity index of the Barak River.

made of the bank-line migration of the Barak River for the reaches within Assam using six temporal datasets spanning 85 years, viz. 1918, 1965, 1975, 1988, 1999 and 2003. The bank-line migration was measured by overlay analysis of bank lines of two successive periods (Figure 10). Since the bank area eroded or deposited is dependent on the length of the bank line and also on the time period considered, it is standardized with respect to the length of bank line and time. During 1918–1965, total deposited area exceeded total eroded area, with a net construction of 1.82 km^2. The rates of erosion and deposition were 2,747 and 3,134 $m^2\ km^{-1}\ year^{-1}$ respectively. During the next period (1965–1975) total bank erosion exceeded total bank deposition, with a net loss of 2.14 km^2 and the erosion and deposition rates were 7,595 and 6,036 $m^2\ km^{-1}\ year^{-1}$ respectively. During 1975–1988, there was a net loss of 1.82 km^2 as erosion exceeded deposition and the rates of erosion and deposition were 4,303 and 3,294 $m^2\ km^{-1}\ year^{-1}$ respectively. The period 1988–1999 showed a net construction of 3.19 km^2 with the rates of erosion and deposition being 2,413 and 4,534 $m^2\ km^{-1}\ year^{-1}$ respectively. The last period of observation (1999–2003) shows a net construction of 2.78 km^2, with rates of erosion and deposition of the order of 7,168 and 12,525 $m^2\ km^{-1}\ year^{-1}$ respectively. Total bank area eroded and deposited during 1918–1965 was highest, but the highest rate of erosion was during 1965–1975 and that of deposition was during 1999–2003 (Figure 11). There is a net reduction in the area of river spread narrowing down the channel from 1918 to 2003.

Continuous plots of erosion and deposition against length of the channel for different time-periods show the nature of erosion and areas vulnerable to erosion. The period between 1918 and 1965 shows both erosion and deposition of the order of 4000 m^2 in a few individual segments. The most affected areas during that period were Katakhal, Krishnapur, Baghpur, Dungripar, Banskandi and Singirband. During 1965–1975 the most affected areas were Sangjurai, Baghpur and Dungripar, while during 1975–1988 the most affected areas were Sialtek, Krishnapur and Baghpur. The next period (1988–1999) shows maximum effect in Katakhal, Krishnapur, Sonabarighat and Dungripar. Between 1999 and 2003 a significant effect of erosion is observed all along the length of the channel, without dominance in a particular stretch. Bank erosion of the river takes place either simultaneously or

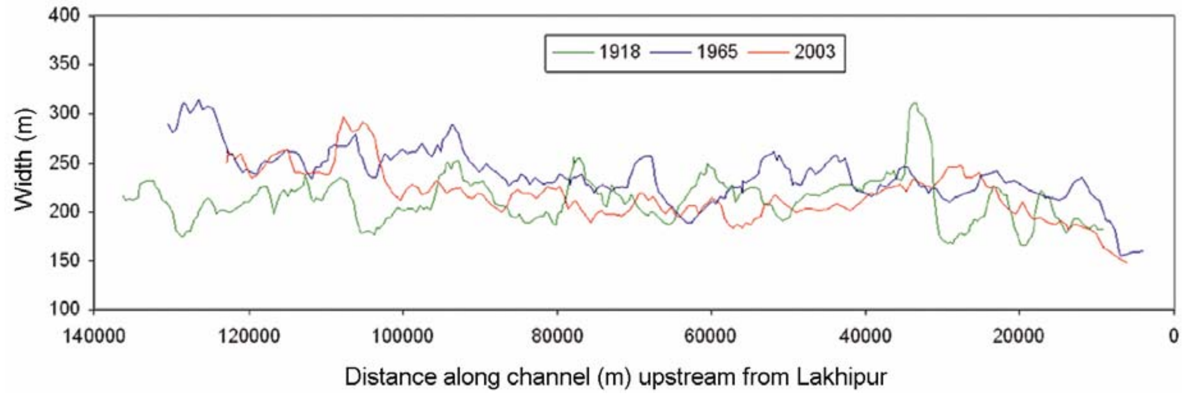

Figure 5. Variation of average channel width along the length at three different times.

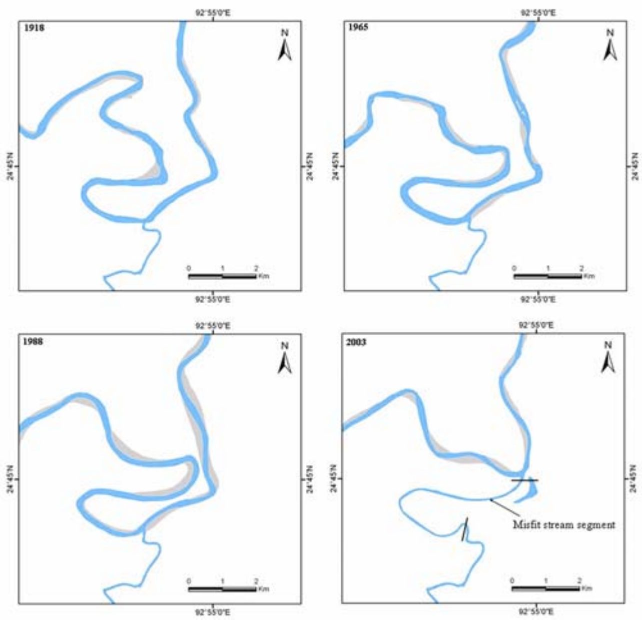

Figure 6. Progressive change and cut-off of the meander at Dungripar leading to the development of misfit stream and ox-bow lake.

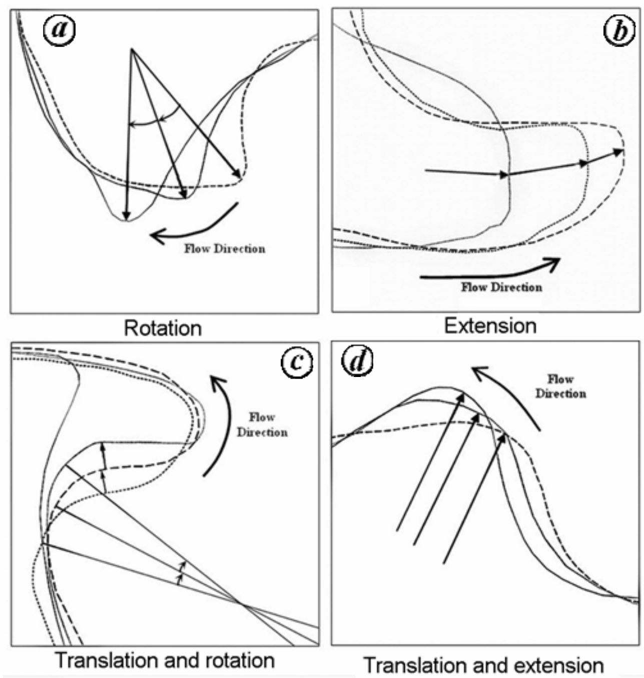

Figure 7. Styles of change of meander bends: examples from the Barak River.

intermittently through removal of soil particles from the surface of the bank, sequential failure of a single reach of bank material due to seepage or undercutting by the river, followed by shear failure of the bank materials. The river is vulnerable to bank erosion along the alluvial reaches, and it remains stable in the bedrock segments. Based on overlay analysis of temporal datasets, the two most vulnerable reaches are found to be Banskandi–Dungripar–Sonabarighat–Baghpur–Krishnapur–Berenga and Phulbari–Katakhal–Kalinagar–Sialtek–Panchgram (Figure 10).

The present study shows a description and quantitative assessment of the fluvial dynamics of the Barak River, including channel morphology, channel migration and bank erosion and deposition for the stretch within Assam. In this study erosion and deposition are considered in terms of lateral bank migration, which is computed through overlay analysis of multitemporal datasets rather than sediment volume. In the case of the Barak River, the channel shifting has been largely affected by lateral bank erosion and simultaneous deposition. The gauge records have not been considered here. However, there is no fluvial significance along the study area of the river to suggest major channel shifting due to floods, except affecting the cut-off as in the case of the Dungripar meander. The following inferences can be made based on the present study.

- The Barak River is a typical meandering river within the study stretch flowing east to west and cutting across the general structural trend of the fold belt. It

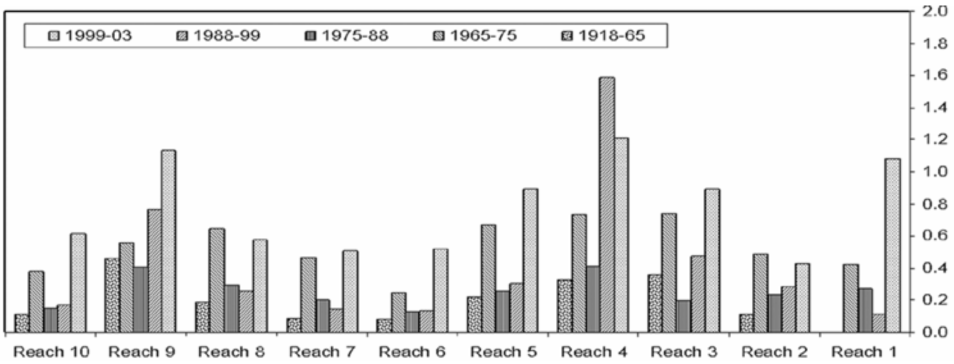

Figure 8. Temporal variation of migratory activity index for different reaches of the Barak River.

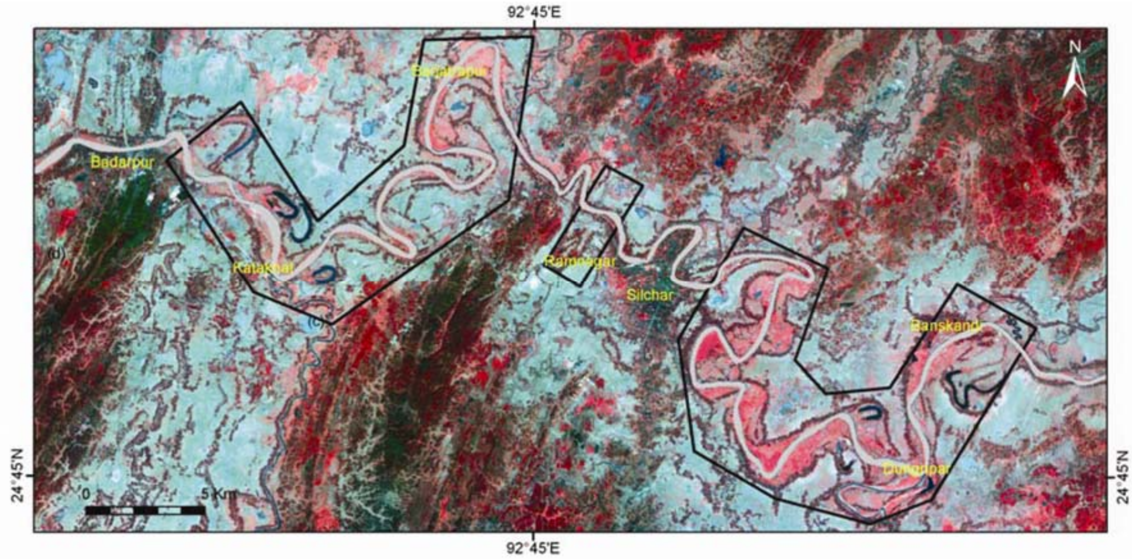

Figure 9. Channel migration zones of the Barak River.

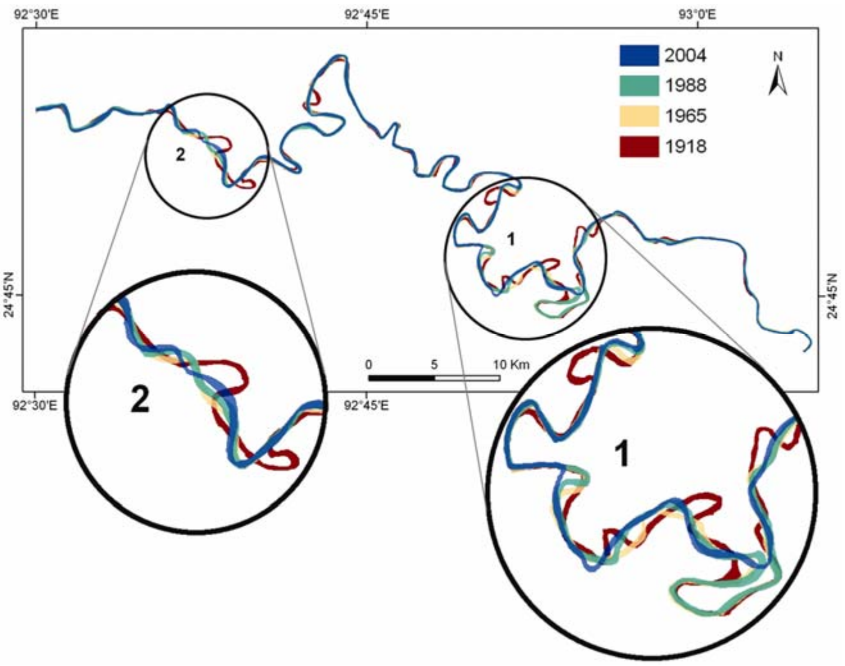

Figure 10. Overlay of four temporal datasets showing variability of Barak River during 1918–2004. The highlighted segments at 1 and 2 are the most vulnerable sites for bankline migration.

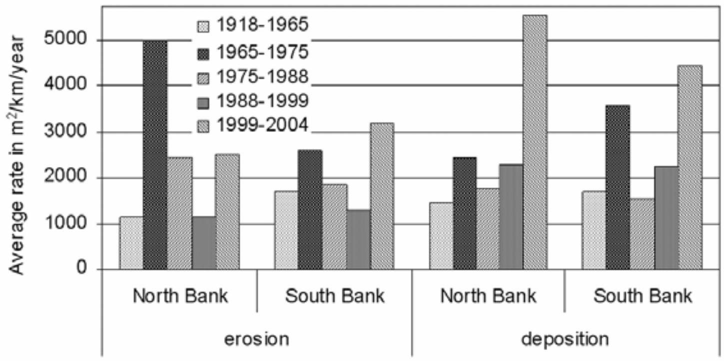

Figure 11. Average rate of bank erosion and deposition along both northern and southern bank of Barak River segment between Assam–Manipur border and Assam–Bangladesh border during 1918–2004.

behaves as an alluvial channel in the synclinal part, while in areas where the river cuts across the anticlines of Tripura–Cachar–Mizoram foreland fold belt, it becomes a bedrock channel.

- Based on the nature and trend of the channel, the river in the study area can be divided into 10 representative reaches which have different morphological characters.
- The river is highly vulnerable to shifting, particularly in the alluvial stretch and the major processes involved are meander bend migration and cut-off, with cut-off being the most prominent.
- Nine major cut-offs occurred in the study area during 1918–2003, of which seven are between 1918 and 1965, whereas two are between 1988 and 1999. The Dungripar cut-off is the most recent (1992) event which led to shortening of the river channel by nine kilometers.
- Meander bend migration in the Barak River is a complex phenomenon, with more than one migration style existing in a single meander. There is also change in the migration style for a single meander during different periods.
- Four CMZs are delineated based on a composite approach; they occupy synclinal valleys filled up by the alluvium. However, there is no preferential direction of channel migration.
- Two segments of the river vulnerable to bank-line migration are: Banskandi–Dungripar–Sonabarighat–Baghpur–Krishnapur–Berenga and Phulbari–Katakhal–kalinagar–Sialtek–Panchgram.

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