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Channel migration and its impact on land use/land cover using RS and GIS: A study on Khowai River of Tripura, North-East India

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ABSTRACT

Channel migration becomes the main characteristic of the Khowai River of Tripura. A study on bank erosion and channel migration of the present course of the Khowai River through the synclinal valley of Atharamura and Baramura Hill Ranges indicates that the area is under active erosion since long back. In this study, the rate of channel migration has been assessed and variation of sinuosity index and radius of curvature have also been calculated. The study of the active channel width and channel position from 1975 to 2014 indicates that a large portion of land along both the banks of the Khowai River has already been eroded away. This work also documented land use changes in its surrounding flood plain area using supervised image classification. Overall accuracy of the land use classification ranges between 88% and 93%. The whole study is being done utilising the remote sensing imagery (2014), SOI topographical map (1975) and GIS technology. The land use classification shows that there is an increase in built up area and decrease in net sown area. The channel migration directly affects the land use and land use change has direct effect on the flood plain dwellers of the study area. All the assessments of this study highlight a significant message of immense vulnerability of Khowai River and also provide news about geomorphological instabilities of the study area.

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1. Introduction

The alluvial nature of the flood plain is valuable and important gift for human society. Floodplains are considered as one of the most endangered area worldwide as they are facing degradation by river regulations and enhanced land use pressure (Hazarika et al., 2015). The river is subjected to erosion and deposition to reach the equilibrium condition. The mapping of changed channel position are important for documenting the erosion hazard and changes in land use/land cover characteristics, as well as for understanding the reasons of those changes.

Riverbank Erosion is an endemic and recurrent natural hazard. When rivers attain the mature stage, they become sluggish and form meander bends. These oscillations cause massive riverbank erosion (Rahman, 2010; Das and Bhowmik, 2013). Lateral migration is a process that can cause catastrophic local or regional changes (Hickin and Nanson, 1984; Thakur et al., 2012), comprehensive effect of such changes become a socio-economic hazard to the flood plain dwellers of the respective river. A number of factors control the lateral migration of river along its pathway such as drainage basin area, topography, vegetation cover, tectonic activity, land use patterns and climatic factors, mainly rainfall and temperature, of that particular region.

Erosion may be caused either by undercutting of the upper bank materials by channels during the high floods producing an overhanging cantilevered block that eventually fails or by oversteepening of bank materials due to migration of the thalweg closer to the bank during the falling stages (Goswami, 2002). Various studies have been carried out for some major rivers with the help of Remote sensing and GIS technique for detecting spatio-temporal changes of river erosion (Nanson and Hickin, 1986; Yang et al., 1999; Bhakal et al., 2005; Kotoky et al., 2005; Kummu et al., 2008; Thakur et al., 2011; Sarma and Acharjee, 2012; Chakraborty and Datta, 2013; Gogoi and Goswami, 2013).

Considering the importance of LULC change on behalf of channel changes, present work tries to relate the condition of those changes using the modern techniques. In this regard, the remotely sensed data have been used, which provides a synoptic view of larger area over different time period and made possible to study the

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LULC in less time and low cost effective manner with better accuracy (Kachhwala, 1985; Rogan and Chen, 2004; Sylla et al., 2012; Boori et al., 2015; Rawat and Kumar, 2015; Hazarika et al., 2015; Jayanth et al., 2016). Several studies have been carried out by many researchers using remote sensing data with GIS technique for multi temporal change analysis of LULC (Ahmed, 2012; Kotoky et al., 2012; Rawat et al., 2013; Yuan et al., 2005; Sun et al., 2009; Jensen, 2005; Lu et al., 2004; Murthy and Rao, 1997). Bank erosion is a natural hazard and this dynamic nature of river changes the LULC of its surrounding basin, which becomes natural phenomena in recent times.

The Khowai River, one of the major rivers of Tripura, is also known as the most disastrous river for its extreme nature, especially during rainy season. The river, after entering into the plain from the higher gradient of Atharamura hill range, spreads its enormous discharge and takes meandering course in the downstream. The Khowai River is characterized by its exceedingly large flow during rainy season, continuous changes in channel morphology, rapid bed aggradation and bank line change. The lateral migration of bank line causes failure of huge fertile land every year. The hills of Tripura are made up of semi-consolidated sedimentary rocks. Due to high precipitation (>2200 mm), steep slope, soft soil cover in the hills and alluvial formation in the valleys, there is high velocity and discharge of water laden with high silt discharge. All these factors result into meandering of the river and cause severe erosion in the concave bends (Deb et al., 2012).

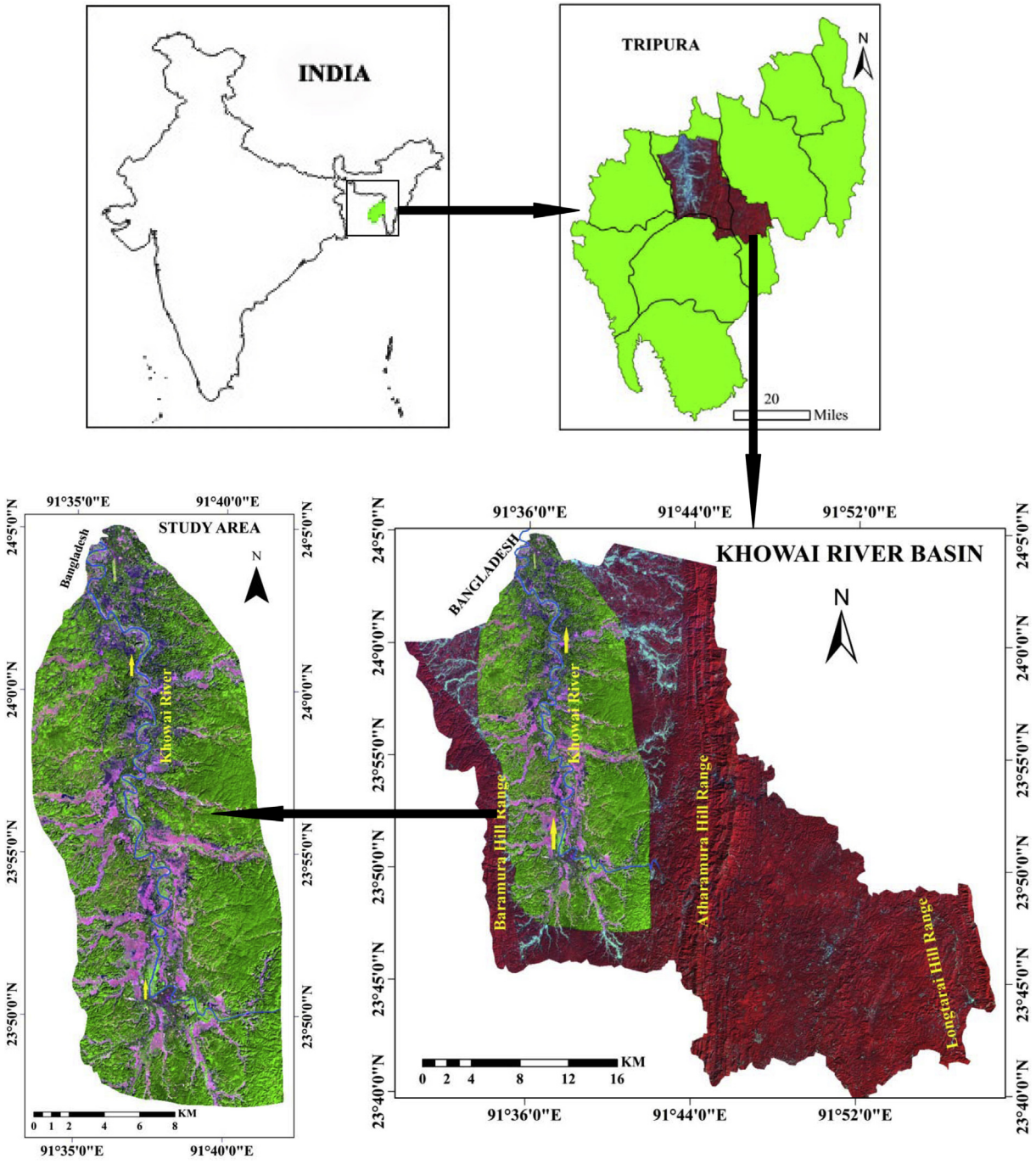


Fig. 1. Location map of the study area.

Table 1
Parameters of the selected reaches of the Khowai River, 2014.

Parameters	Reach-1	Reach-2	Reach-3	Reach-4	Reach-5
Areal extent	Chakmaghat barrage to Teliamura	Teliamura to Madhya Kalyanpur	Madhya Kalyanpur to Dwarikapur	Dwarikapur to Sonatala	Sonatala to Khowai
Reach length (km)	11.01	10.91	11.04	11.86	11.04
Sinuosity	1.41	1.45	1.85	1.69	1.77
Channel type	Alluvial	Alluvial	Alluvial	Alluvial	Alluvial
Dominant bed material	Sand & pebbles	Sand	Sand	Sand	Sand
Morphological Appearance	Sinuous	Sinuous	Meander	Meander	Meander
Total catchment area (km^2)	1328				
Annual Rainfall (mm)	1873.6				
Avg. Annual Discharge (Cumec)	143.29				

Source: Computed by the authors.

Table 2
Detail dataset of the study.

Data	Path/ Row	Resolution/ SCALE	Year	Source
Topographical Map		1:50,000	1974–1975	Survey of India
Landsat MSS	136/044	60	1975	USGS[a]
Landsat TM	136/044	30	2014	USGS[a]

[a]USGS: United states Geological Survey.

Table 3
Description of the Land use/cover classification in the study.

Land Use Classes	Description
Dense forest	Deep forest where human interaction not existing
Open forest	Scattered forest including degraded forest, plantation where human interaction presented
Cultivated land	Area where crops are harvested
Settlement	Areas under rural build up area and 'tong' house including home stead area
Water body	Open water features such as rivers, natural lake etc
Barren land	Surface without vegetation

2. Study area

Originating from the Longtarai hill range (at 228 m altitude) the River Khowai becomes antecedent in character as it maintains its course across the Atharamura hill range and flows northwards throughout the synclinal valley located between Atharamura and Baramura hill ranges in the east and west respectively for a distance of 133 km and enters into Bangladesh (at 26 m altitude). After flowing for a distance of 89 km through Bangladesh, the Khowai River has its confluence with the River Kushiyara, a tributary to the River Meghna. The basin area extends from 23°40′ to 24°5′30″ N. latitude and 91°30′ to 91°55′50″ E. Longitude within the Dhalai and Khowai districts of Tripura, covering an area of 1328 km^2 (Fig. 1).

The study area is located in a neotectonic zone. The Khowai River catchment falls under the Surma, Tipam, Dupitilla and alluvium formation. Anticlinal hill range and Synclinal valley with flood plain are the dominant physiographic divisions of the area. The area experiences tropical monsoon climate. Temperature ranges between 9 °C and 35 °C and average monsoon rainfall is about 2487.77 mm. During rainy season, the river is characterised by very high discharge (average monsoon discharge is about 488 cumec) and becomes very turbulent at the time of its peak flow (maximum average velocity 1.09 m/s). The river has significant fluvio-geomorphic character like abandoned tracts and processes such as shifting and river capture. The steep slopes of the river banks, ranging from 60° to 90°, comprise of fine grained, sandy, silty and clay deposit of varying meters in thickness. The vegetation mainly found in the river bank is bamboo and shrubs.

For the present purpose only 56 km length of the Khowai River, *i.e.*, in upstream from Chakmaghat barrage (Teliamura) up to Khowai Town, near Bangladesh border, has been considered which has again been divided into 5 reaches for detail study (Table 1). The geographical bound of the area is 23°50′ N–24°04′ N latitude and 91°42′ E–91°35′ E longitude.

3. Methodology and database

3.1. Database preparation

The authors have identified channel migration by using SOI topographical map (1975), and satellite imagery (2014, Landsat

TM, Landsat MSS), with the help of Remote Sensing and GIS technique. GIS techniques are effective and accurate tool of quantifying channel changes both at medium term and short term scales (Winterbottom, 2000). For identifying bank line migration and LULC change of the study area, the SOI topographical map and Remote sensing imagery have been used. The details of the dataset are utilised in this study are presented in the Table 2.

This work adopts three regularly use sophisticated software Geomatica 2012 for channel migration, ARCGIS 10.1 for LULC analysis and ERDAS 9.1 for radiometric correction of the image. The datasets are imported in Geomatica 2012, geo-referenced using

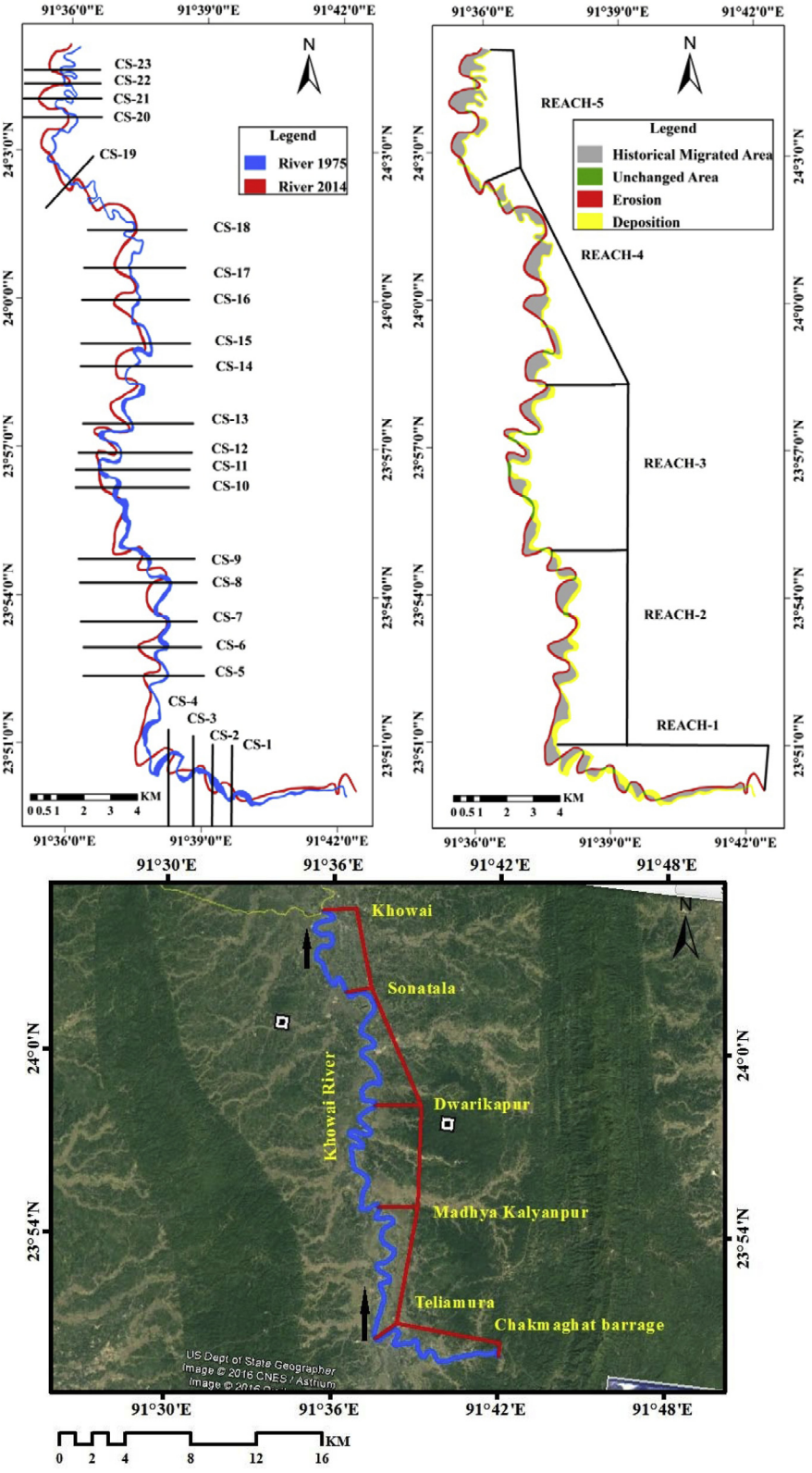


Fig. 2. Cross section sites and Segment/Reach-wise division of the Khowai River.

following steps – Projection Type: Universal Transverse Mercator (UTM), Earth Model: D076, Spheroid Name: WGS 84, Datum Name: WGS 84, UTM Zone: 46, UTM Row: Q. The datasets again imported in the Arc GIS 10.1 for supervised classification. Apart from better classification and accuracy assessment, ERDAS 9.1 has been used for radiometric correction. Stretch, Image filtering and different band combinations are utilised for supervised classification.

3.2. Channel change detection and analysis

The entire river from Chakmaghat up to Khowai (near Bangladesh border) was divided into 5 reaches and 23 reference sites were selected for cross sections. Methods of reach-wise bank line change were almost identical with the previous work of Chakraborty and Mukhopadhyay, 2015; Das et al., 2014. Each cross section was numbered from upstream towards downstream. Table 1 shows the identification of various reaches of the river. For identifying the scenario of the river and its characteristics channel width, total amount of shifting, sinuosity index, radius of curvature, area of erosion, deposition, unchanged area and historical migrated area were measured and studied reach-wise along the cross sections.

For detection of widening of channel, change of direction of the meander and radius of curvature, cross section wise study is applied whereas reach wise study applied for calculating sinusity index and capturing of total area by the river. The river bank-line was identified and delineated from the topographical sheet and satellite image of 1975 and 2014 respectively. The identified river bank lines for both the left and right banks were digitized using Geomatica 2012 software. Then the polygon vector lines were overlaid and quantified an overall migration of the channel extract from this overlaid map. Erosion, deposition, unchanged and historical migrated areas were being calculated using attribute manager for each reach. Section-wise channel widening and direction of migration at each particular place were calculated from the respective maps (earlier map 1975 and recent map 2014).

Sinuosity (S) deals with the meandering nature of the river. It is the ratio between actual length and the straight length of the river.

$$\text{Channel sinuosity} = \frac{\text{OL}}{\text{EL}} \qquad (\text{Schumm, 1963})$$

where OL = observed (actual) path of a stream.EL = expected straight path of a stream.

The sinuosity indices of the entire five reaches were calculated for the years 1975 and 2014. According to sinuosity index, channels can be classified into three classes: straight (SI < 1.05), sinuous (SI 1.05–1.5), and meandering (SI > 1.5).

Meander belt is the evaluation of the meandering curvature and its nature of lateral migration.

$$Cw = \frac{2w\psi}{(lu + ld)} \qquad (\text{Howard, 1992})$$

where, Cw = Curvature, W = Channel width, ψ = the angular change in direction at the meander), lu and ld = the distance to the adjacent upstream and downstream nodes.

3.3. Land use/land cover change detection and analysis

For analysis of LULC change the existing landscape of the study area were classified into seven classes, determined by adopting the land sat image and topographical map – i) Open forest ii) Dense forest iii) Settlement iv) Barren land v) Sand bar vi) Water bodies vii) Cultivated land. The details description of the Land use/Land Cover classes is given in the Table 3.

The work applied supervised classification method with maximum likelihood algorithm in the Arc GIS 10.1 software and it is a very common and extensively used method for determination of the LULC classes throughout the world (Butt et al., 2015; Iqbal and Khan, 2014). The creating signatures are used to classify the images using a maximum likelihood algorithm which classifies the pixels based on the maximum probability of belonging to a particular class. Recoding was done for misclassified pixels. Careful examination of topographical map, satellite image, Google earth image and field verification were adopted for ground truth verification of classified image.

Accuracy assessment is the process of quantifying and checking the validity of the classified image and most essential for a proficient land use/cover analysis (Mosammam et al., 2016). Accuracy assessment of each map was applied with taking 420 random

Table 4
Migration of Khowai River during 1975–2014.

Station	Direction	Migration (m) [Base year 1975]
CS-1	Northward	394.42
CS-2	Southward	145.02
CS-3	Northward	215.11
CS-4	Northward	83.29
CS-5	Westward	488.32
CS-6	Westward	724.62
CS-7	Eastward	271.41
CS-8	Westward	473.72
CS-9	Eastward	216.57
CS-10	Eastward	376.54
CS-11	Westward	411.33
CS-12	Westward	567.31
CS-13	Eastward	209.59
CS-14	Westward	531.57
CS-15	Eastward	61.64
CS-16	Westward	531.34
CS-17	Westward	219.66
CS-18	Eastward	375.33
CS-19	Westward	250.37
CS-20	Westward	14.86
CS-21	Westward	260.28
CS-22	Westward	617.63
CS-23	Eastward	533.48

Source: Calculated by the authors from the 1975 Topo. sheet and 2014 LANDSAT imagery.

Table 5
Variation of active channel width during 1975 and 2014.

Station	1975	2014	Change in total width (m)
CS-1	49.79	60.41	10.62
CS-2	44.92	70.93	26.01
CS-3	66.54	73.23	6.69
CS-4	35.58	63.6	28.02
CS-5	45.26	74.15	28.89
CS-6	62.66	76.13	13.47
CS-7	88.55	120.4	31.85
CS-8	91	75.24	−15.76
CS-9	49.54	96.36	46.82
CS-10	38.07	96.35	58.28
CS-11	99.98	104	4.02
CS-12	49.47	105	55.53
CS-13	97.11	85.9	−11.21
CS-14	18.2	60.29	42.09
CS-15	65.89	84.85	18.96
CS-16	70.2	94.39	24.19
CS-17	48.52	80.8	32.28
CS-18	54.54	27.83	−26.71
CS-19	52.12	79.2	27.08
CS-20	58.73	90.7	31.97
CS-21	48.85	60.2	11.35
CS-22	38.7	87.9	49.2
CS-23	52.49	80.99	28.5

Source: Calculated by the authors from the 1975 topo. sheet and 2014 LANDSAT imagery.

points, called reference points in Arc Map 10.1. A minimum of 30 points for each class and more than 250 for a whole map is required for identifying a valid accuracy assessment map (Congalton and Green, 1999). Combine table was created with combination of these reference points and the classified map. From this combine table, confusion matrix table was established using the pivot table tool box. Confusion matrix table is relationship between the classified map and the reference data summarized in an error matrix (Jensen, 2005) and used for calculating the reliability between controller and explainer (Gerard et al., 2010). Omission percent, Commission percent, Producers accuracy and User's accuracy were calculated applying this matrix table exporting in MS Excel. Overall accuracy, Kappa coefficient was measured with the help of this calculated data. Kappa coefficient always ranges between 0 and 1. The area of each map and increasing and decreasing percentage were also extracted from each classified image. For identifying the conversion of land use/cover from 1975 to 2014 'from-to' map was applied using the ArcMap10.1.In order to identify the land use/land cover pattern within the historical migrated area the channel plan form of 1975 and 2014 were overlaid on the LULC maps of 1975 and 2014.

4. Results and discussion

Based on the channel plan form change and land use classification, results of the study are presented into two parts – channel migration and adjustment of land use associated with land use change.

4.1. Channel migration and widening

Lateral channel erosion is one of the significant characteristics of the alluvial river which is mainly observed in the middle course and lead to the widening of the channel. So, in order to know the erosion process (vertical or lateral) and morphological characteristics of the bank, determination of the channel width was carried out from two maps of different years. The bank erosion frequency of the river is higher after monsoon, when there is sharp decrease in rainfall intensity. This is due to the recession of water level causing disequilibrium between the water level and river bank and resulting in the loss of soil cohesive strength which leads to bank erosion. Non-cohesive bank material i.e., sand leads to maximum erosion which ultimately leads to widening of the Channel (Bhowmik and Das (Pan), 2014). In the present study, active widening and radius of curvature of the Khowai River has been measured at 23 sites across the river and along with reach wise channel migration has been evaluated from 1975 to 2014 (Fig. 2). It was found that the river Khowai has been migrated vigorously towards both the banks (Table 4). The highest erosion took place in the left bank near cross section-6 (724.62 m) whereas in the right bank it was near cross section-23 (533.88 m). Table 5 shows the segment-wise change of active channel width, which is documented at every point of cross section. It indicates that the lateral erosion is highly predominant in the Khowai River.

4.2. Radius of curvature

In contrast to sine waves, the loops of a meandering stream are more nearly circular and the radius of the loop is considered to be the straight line perpendicular to the down-valley axis intersecting the sinuous axis at the apex (Deb et al., 2012). Fig. 3 shows the variation of radius of curvature during the study periods 1975 and 2014 and it was found that the maximum radius of curvature was 600 m at CS-18 in 2014 and the minimum was 111.11 m at CS-19 in 1975. At CS-10 and CS-17 the river was in sinuous during 1975 but it became meandering in 2014, whereas, at CS-11 and CS-21 the river was meandering in nature during 1975 but became straight during 2014. Therefore, this variation signifies a change in meander geometry of the Khowai River during the study period (1975–2014).

4.3 Area captured by the river

Riverbank failure processes and erosion are complex events caused by the interplay of several factors including river discharge,

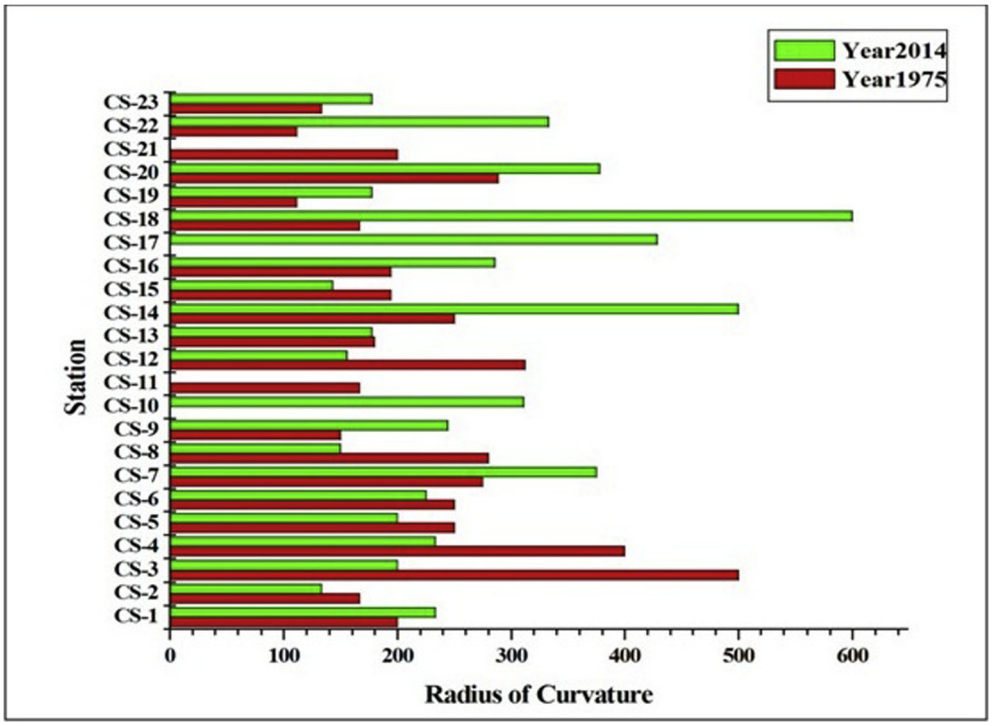


Fig. 3. Variation in radius of curvature of the Khowai River during 1975 and 2014.

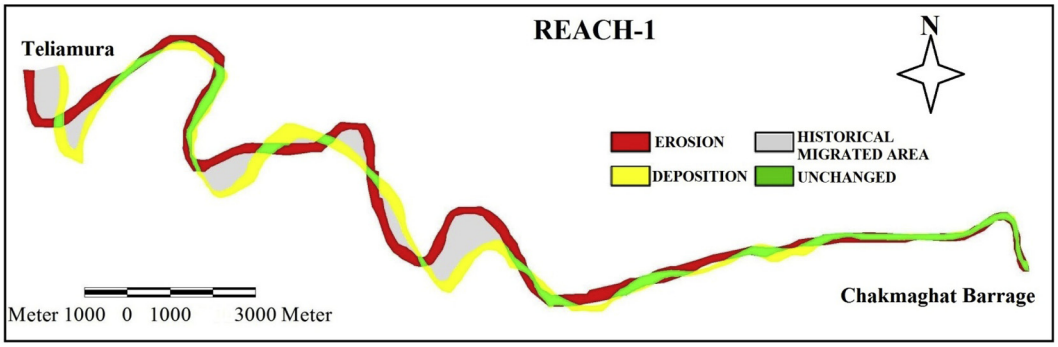


Fig. 4. Status of the area captured by the River Khowai in Reach 1 during the study period 1975–2014.

flow, bank lithology, stratigraphy and inclination, channel geometry, as well as anthropogenic activities (e.g. navigation). However, bank erosion primarily depends upon the soil type and river discharge rate (Youdeowei, 1997). Erosivity depends on the nature and amount of flow and discharge and velocity together play important role to bank collapse (Majumdar and Das (Pan), 2014). So, in the hilly river, discharge associated with high steep gradient leads to the high percentage of erosion. River erodes one side of the bank and the eroded particles are deposited in the opposite bank, it is the natural character of the river. In the meandering river, due to the presence of loose bank material, lateral erosion predominant and consequently the river erodes deposits and migrates for a long distance. In that period of migration, some unchanged/unaltered portions remain which cannot be eroded due to the existence of

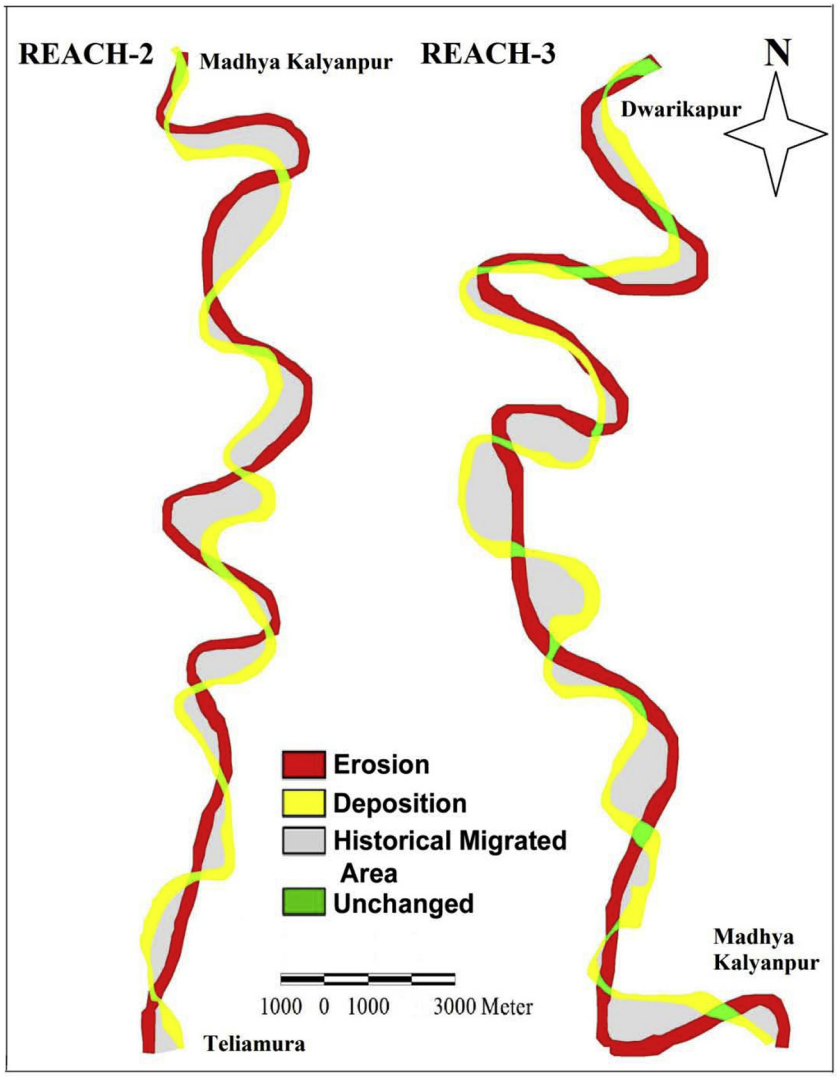


Fig. 5. Area captured by the River Khowai in Reach 2 and 3 during the study period 1975–2014.

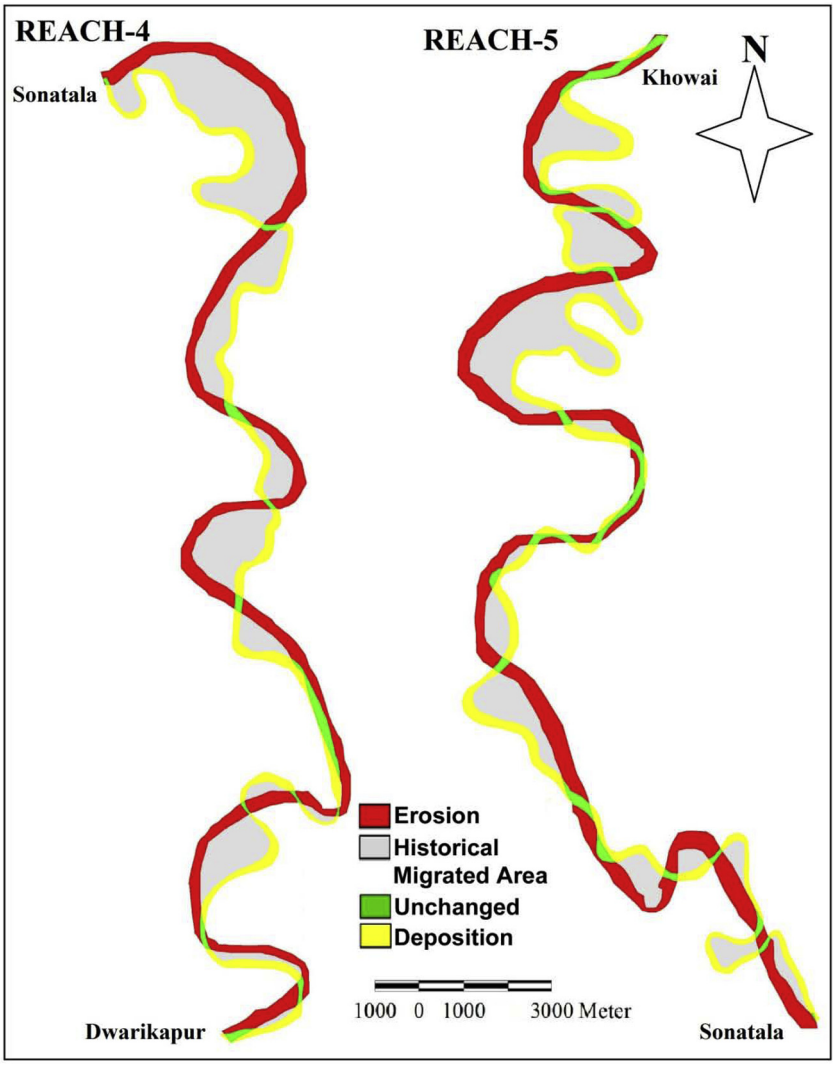


Fig. 6. Area captured by the River Khowai in Reach 4 and 5 during the study period 1975–2014.

hard rock and/or riparian vegetation cover. Based on the application of modern technique, the whole area drained by the River Khowai can be grouped into four classes, area under erosion, area under deposition, area remained unchanged and migrated area. Reach-wise grouping of this drained area gives significant information about the status of fluvial erosion and deposition of a particular region. As Reach 1 is in the upper part of the river, the existing position leads to less shifting of the river in between Chakmaghat Barrage and Teliamura (Fig. 4). The erosive power of the river channel mainly depends on the nature and amount of flow. The River Khowai receives average annual rainfall of 1873.6 mm among which more than 75% occurs during the monsoon season. The intense rainfall during this season accelerates the velocity as well as discharge of the river. According to the CWC (Central Water Commission) data the average annual discharge of the river Khowai is 143.29 Cumec of which more than 70% is observed during the monsoon season. On the other hand, the kinetic energy of the river water, released from the Chakmaghat Barrage, attack the concave banks, especially during rainy season and consequently bank erosion prevails in downstream in all the Reaches (Figs. 5 and 6). Although most part of the Khowai River bank is well guarded by several bank protection revetments and flood protection embankment, but tendency of erosional activities may become vigorous along the unprotected banks. Instead of riparian forest cover and protection of revetments, sometimes both the banks of the Khowai River faces several hazards in the form of bank erosion, prominently avulsion and capturing of the lower course of the tributary streams, e.g. capture of Moharchara, Lalchara etc by the Khowai River has been identified in 2014. Figs. 4–6 provide a prominent picture of channel migration from Chakmaghat barrage (Teliamura) up to Khowai (Bangladesh border). In Reach-4, as historical migration area is quite more (855.16 acre) than other reaches, so the area under erosion also becomes more (556.36 acre) between Dwarikapur and Sonatala (Fig. 7). All the Reaches are primarily consisted of non-cohesive sands and unscientific land use change. In fact, during field survey, it was observed that erosional activities, complex river dynamics and annual flood in the lower course may lead to sudden avulsion of the Khowai River.

4.4 Sinuosity index

Meandering is a natural geomorphic feature in rivers which results in gradual migration of the river's course and erosion of the banks (Ayman and Ahmed, 2009). Historical analysis of meander bends reveals the fact that meandering tendencies of the Khowai River has been reduced than the earlier times. During 1975 the Khowai River was flowing through highly meandering channel but

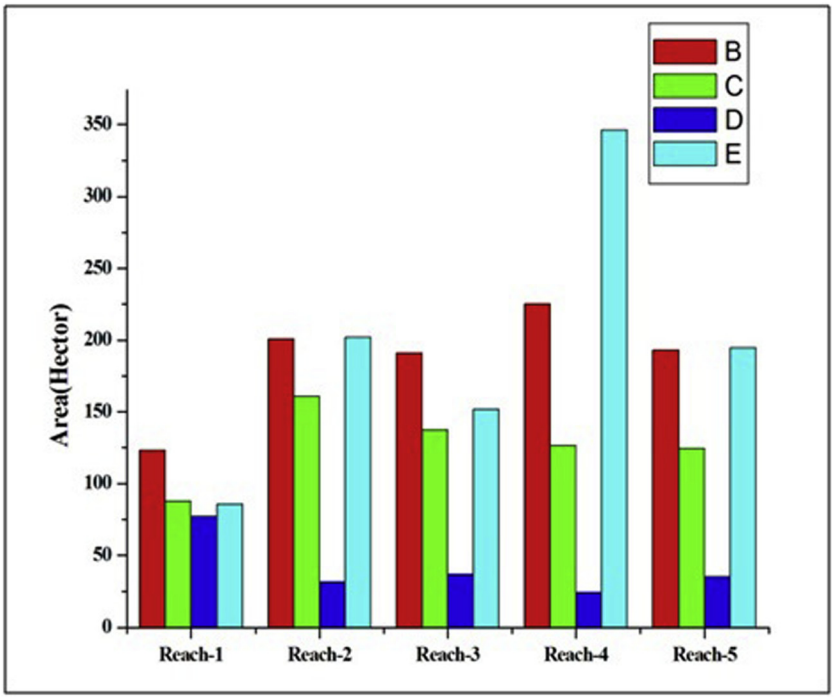


Fig. 7. Reach-wise area captured by the river during 1975–2014 timeframe. B = erosion, C = deposition, D = unchanged, E = historical migrated area.

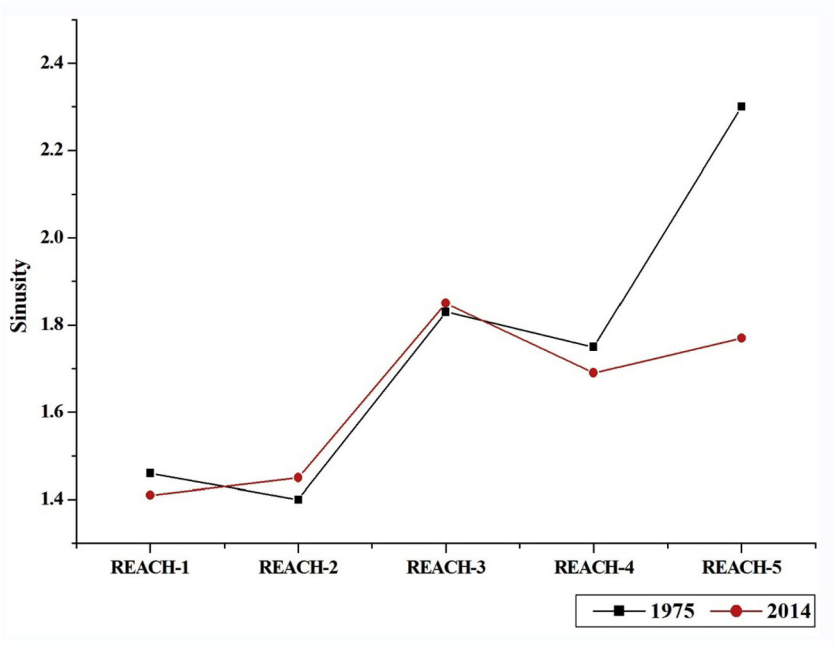


Fig. 8. Variation in sinuosity index of the Khowai River (1975–2014).

Table 6
Classification of accuracy of the Supervised Classification and Kappa Co-efficient for 1975.

LULC classes	Ground truth percent	Commission percentage	Omission percentage	Producer's accuracy	User's accuracy
Dense forest	17.86	0	0	100	100
Open forest	17.41	0	0	100	100
Cultivated land	27.68	38.71	5	95	61.29
Water body	17.41	0	2.5	97.5	100
Settlement	17.86	0	0	100	100
Barren land	1.79	50	8	8	50
Overall Accuracy (%)	88.39				
Kappa Coefficient	0.86				

Table 7
Classification of accuracy of the Supervised Classification and Kappa Co-efficient for 2014.

LULC classes	Ground truth percent	Comision percentage	Omision percentage	Producers accuracy	Users accuracy
Dense forest	16.81	0	0	100	100
Open forest	16.81	0	0	100	100
Cultivated land	17.23	17.07	24.44	75.56	82.93
Water body	17.63	26.19	0	100	95.24
Settlement	17.23	2.44	20.51	79.49	75.61
Barren land	14.29	0	0	100	100
Overall Accuracy (%)	92				
Kappa Coefficient	0.91				

Table 8
Land use/Land cover classes of the study area in 1975 and 2014.

LULC Classes	1975		2014		Change b/w 1975 & 2014		Rate of change	
	Area in km^2	% of Area	Area in km^2	% of Area	km^2	%	Km^2	%
Dense forest	38.51	11.23	64	18.66	25.49	66.19	2.12	7.43
Open forest	128.17	37.37	117.38	34.23	−10.79	−8.42	−0.9	−3.14
Cultivated land	139.55	40.69	133.2	38.84	−6.35	−4.55	−0.53	−1.84
Settlement	13.72	1.69	14.07	4.10	0.35	2.55	0.03	2.41
Water body	19.33	5.64	2.23	0.65	−17.1	−88.46	−1.43	−4.39
Barren land	3.65	1.06	11.34	3.30	7.69	210.28	0.64	2.25
Total	342.93	100	342.93	100	–	–	–	–

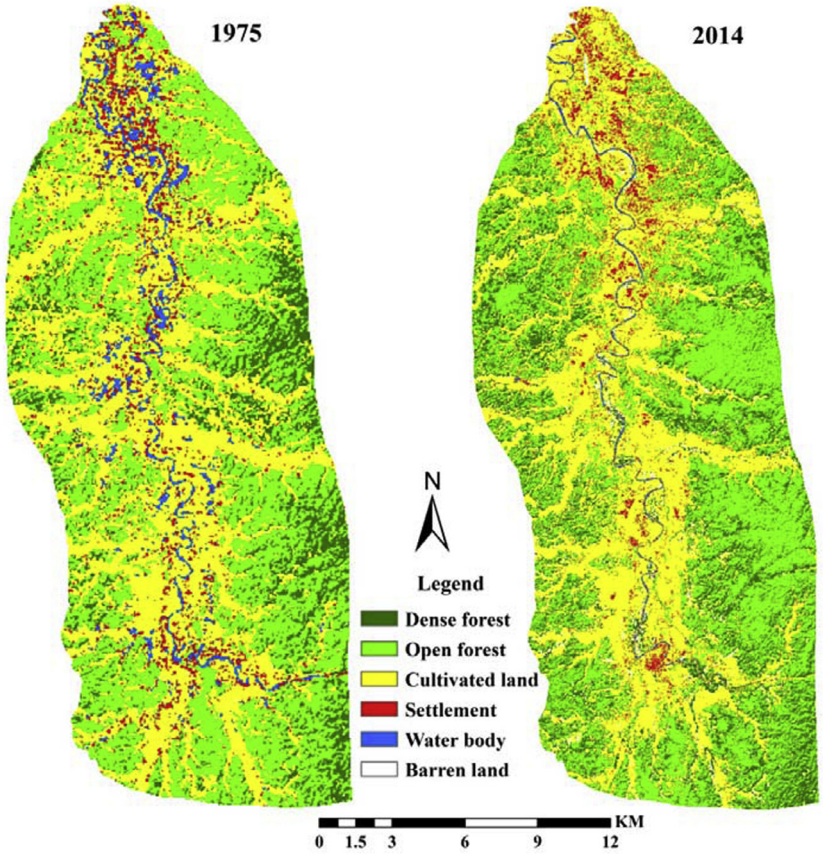


Fig. 9. Land use/Land cover map of the study area for 1975 and 2014.

after that period, it started to straighten its course through releasing meander necks/cut offs (Fig. 8).

Reach-wise sinuosity calculation (Schumm, 1977) for the entire Indian segment of the Khowai River has been recorded as 1.46, 1.40, 1.83, 1.75 and 2.30 during 1975 and 1.41, 1.45, 1.85, 1.69 and 1.77 during 2014. It implies that the river is steadily losing its meandering character and is transforming into a sinuous course.

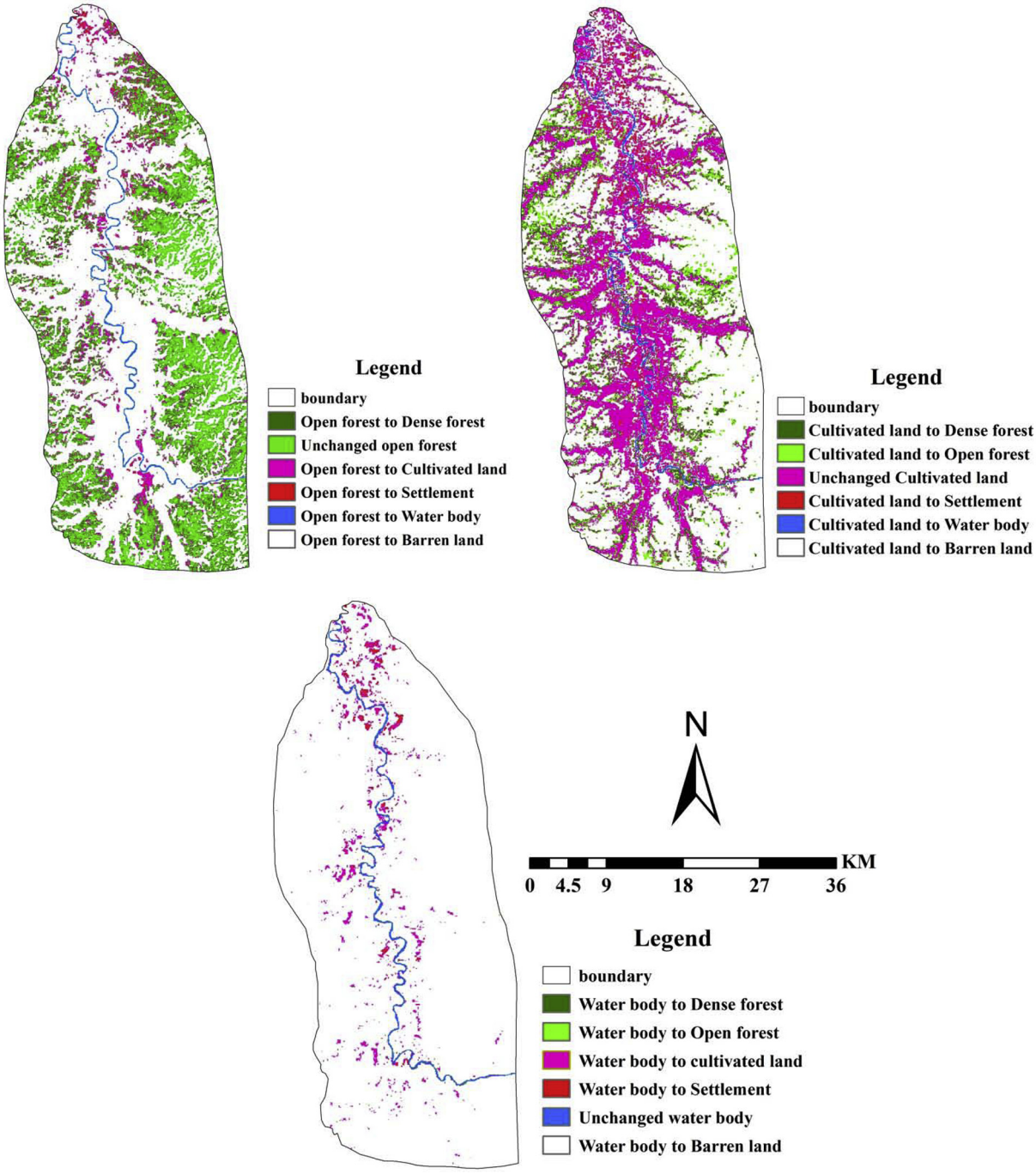


Fig. 10. 'From-to' change map of the Study area 1975–2014. (A) Cultivated land to other land use/land cover category (B) Open forest to other land use/land cover category (C) Water body to other land use/land cover category.

4.5. Accuracy assessment of the Land use/cover map

Error matrices applied for detection of producer's accuracy, user's accuracy, overall accuracy and kappa statistics for both the images. For the 1975 land use map, accuracy assessment result shows the overall accuracy of 88.39% and kappa coefficient of 0.86 (Tables 6 and 7). The land use classes quite always classified as accurately (Landis and Koch, 1977; Sun et al., 2009). In the classified map of 1975, producer's and user's accuracy is above 90% for all the classes except for barren land.

The cultivated land percentage and barren land percentage show confused because of its mixed pixels between these two classes. For the 2014 land use map accuracy assessment result shows the overall accuracy of 92% and kappa coefficient of 0.91. In case of the classified map of 2014, Producer's accuracy and User's accuracy is above 95% for all land use classes, except for cultivated land and settlement. The cultivated land percentage and settlement percentage show confusion because of having mixed pixels between these two classes with water body.

4.6. Adjustment of LULC with bank erosion

The LULC map of 1975 and 2014 presented in this study highlighted distinct features of the Khowai flood plain. Here the

Table 9
Converted area (km^2) under land use/land cover change from 1975 to 2014.

	Area (km^2)	% of area
Conversion of Open forest		
Open forest to dense forest	18.68	13.65
Open forest to open forest (no change)	80.62	58.91
Open forest to cultivated land	24.03	17.56
Open forest to Settlement	9.96	7.28
Open forest to water body	0.06	0.04
Open forest to barren land	1.5	1.10
Conversion of Cultivated land		
Cultivated land to dense forest	13.86	8.84
Cultivated land to open forest	23.32	14.87
Cultivated land to cultivated land (no change)	94.75	60.43
Cultivated land to settlement	15.97	10.18
Cultivated land to water body	1.29	0.82
Cultivated land to Barren land	7.61	4.85
Conversion of Water body		
Water body to dense forest	0.55	3.77
Water body to open forest	0.26	1.78
Water body to cultivated land	9.65	66.23
Water body to Settlement	2.7	18.53
Water body to Water body (no change)	0.74	5.08
Water body to Barren land	0.67	4.57

dynamic nature of the river has changed the land use type of its flood plain area significantly, which falls under historical migrated area. In the overall context in 1975 about 11.22%, 37.37%, 40.69%, 1.68%, 5.63%, and 1.06% area were covered by dense forest, open forest, cultivated land, settlement, water body and barren land respectively, whereas in 2014 these areas were changed into 18.66%, 34.23%, 38.84%, 4.10%, 0.65% and 3.30% respectively (Table 8).

As it is clear that the area under settlement has been increased by 2.55%, besides this, the bank erosion also intends to capture the nearby settlements located along the Khowai River. The classification map (Fig. 9) shows that cultivated land area is dominant land use type of the study area but in this time period from 1975 to 2014 the percentage has gradually been decreased by 4.55% due to bank erosion of the river.

The 'from-to' map (Fig. 10A) of cultivated land analyses that the maximum cultivated land occupied by settlement and open forest. While on the other hand, the 'from-to' map (Fig. 10B) focuses the conversion of open forest, which has decreased by 8.42% from 1975. Here the map analyses the proportion of open forest transferred into cultivated land and settlement. River shifting also affect water body of the study area, which has decreased by 88% from earlier period. People tend to convert water bodies into agricultural land and settlement as per their necessity (Fig. 10C). Over population associated with channel migration had lead to the conversion of open forest and cultivated land into other land use type. The study shows that 58.91% open forest remains unchanged whereas open forest has been converted into 17.56%, 13.65% and 7.28% cultivated land, dense forest and settled area respectively. In case of cultivated land 60.43% area remains unchanged whereas cultivated land has been converted into 14.87%, 10.18%, 8.84% and 4.85% open forest, settled area, dense forest and barren land respectively. On the other hand, incase of water bodies 5.08% remains unchanged whereas water bodies have been converted into 66.23%, 18.53%, 4.57%, 3.77% and 1.78% cultivated land, settled area, barren land, dense forest and open forest respectively. Conversion of these land use/land cover types, especially in the flood plain area, is mainly affected by the channel migration and increased population (Table 9).

The adjustment of land use in the flood plain area of the River Khowai is distinctively a highlighting fact. Settlement and cultivated land have been eroded away and converted into depositional land which was again used for both cultivation and settlement purposes. But some portions remain as barren land due to the presence of high percentage of sand, which cannot be used either for cultivation or for settlement. In the study area the river has mostly eroded the cultivated land which is more than 2 km^2, whereas it becomes less than 2 km^2 when deposition took place in the opposite bank. Another most identical affected land use type is settled area, which has been eroded for more than 1.5 km^2 area, whereas

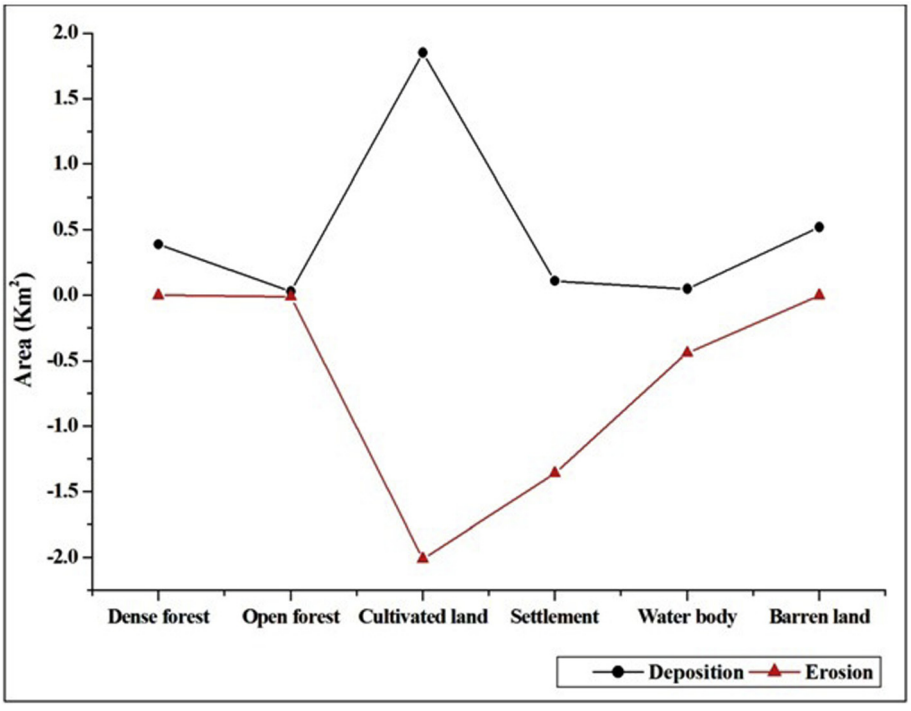


Fig. 11. Adjustment of the area of different land use/land cover in the flood plain of the study area.

in the opposite bank the deposited area becomes less than 0.5 km^2. River Khowai has eroded away about 0.5 km^2 water body of the study area, which now occupies only 0.20 km^2 area of the deposited land of the opposite bank (Fig. 11).

The socio-economic impact of this type of change is very much significant. Due to the erosion of the settled area the people had to migrate to another place, as well as, they had to change their livelihood pattern also for loss of agricultural land. Consequently, the socio-cultural environment of the study area had also been modified. On the other hand, due to the shrinkage of swampy area i.e., shallow water zone in the flood plain area, adverse impact had been felt on the ecological system of the study area.

5. Conclusion

Present study has proved the utility and application of remote sensing and GIS technology and provided a detailed assessment of spatial and temporal changes in river channel processes and adjustment of LULC types of the study area. The past and present data analyses indicate that the River Khowai has changed its channel from highly meandering (SI = 2.30) to sinuous (SI = 1.41) and modified its flood plain land use/land cover significantly. The analysis of cross sections at 23 sites across the past and present Khowai River reveals the endangered condition of the nearby settlements and infrastructures due to high bank erosion. Therefore, there is need of an in-depth study of interaction of geo-tectonic activities, geological characteristics and fluvial regime to understand the complex physical processes and to suggest a fruitful management for the river interventions.

The study evaluates the effective land use study with reference to dynamic change of the channel from 0.7 km to 0.02 km in the vulnerable places. Therefore, it will be very much helpful to establish certain plans for upcoming future to mitigate the hazards and to minimize human intervention to the natural flow of the river and ensuring the growth of riparian vegetation so that the ecological and biological diversity of the flood plan area will be more prosperous and healthy than before.

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