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Analysis on River Bank Erosion-Accretion and Bar Dynamics Using Multi-Temporal Satellite Images

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Abstract Dudhkumar River flows from upstream of India Border at Bhurungamari to the confluence with Brahmaputra River at Noonkhawa of Kurigram district having a stretch of 64 km in Bangladesh. Due to onrush of water from upstream in monsoon, erosion in Dudhkumar River takes a serious turn, threatening collapse of Sonahat Bridge in Bhurungamari, embankment on its right bank, dykes and several dwelling houses in recent years establishing the river as a destructive one. Thus study aiming at computing the long and short term bank line shifting along the river is of great significance. In this study, images of Landsat MSS and TM acquired from the year 1973 to 2015 have been used to investigate the riverbank migration pattern, accretion-erosion, rate of change of width, sinuosity and island dynamics of Dudhkumar River. For the short term analysis, migration rates are calculated from one Landsat image to the next. For long term analysis, the migration rates are calculated based on the difference between the 1973 image as the reference and subsequent images. From the short-term analysis, the mean erosion and accretion rate have been estimated as 128 m/y and 194 m/y on the left bank, and 141 and 176 m/y on the right bank indicating the accretion rate as greater than the erosion rate. Erosion rate has been found as greater in right bank rather than left bank and accretion rate is much more in left bank than the right bank. Due to high discharge, maximum erosion and accretion have been found as 349 m/y and 410 m/y respectively at left bank in 2013-2015 indicating the bank protection measures vulnerable. Computations on sinuosity of the river Dudhkumar River show that the sinuosity ranges from 1.36 to 1.53 showing significant increase in year 1989, 1997 and 2011 due to active erosion and deposition induced by monsoon flood. Analyses on island dynamics reveal that the island area started increasing after 1973 and maximum island area found in 2001. The analysis divulged that the Dudhkumar River is a highly meandering river with several critical sections where the river has been suffering enormously with erosion problem and shifting.The present study also identifies steadfast evidence on the dynamic fluvio-geomorphology of Dudhkumar River depicting urge for execution of erosion control schemes.

Keywords: *Dudhkumar River, Bankline shifting, Erosion-accretion, Morpho-dynamics, LANDSAT*

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1. Introduction

The country Bangladesh is occupied with a network of about 405 rivers mostly alluvial in nature, spreading all over the country out of which 57 are transboundary [1]. Dudhkumar River, belonging to the Brahmaputra river basin is a transboundary river shared by Bhutan, India and Bangladesh. Bangladesh being the lowermost riparian country, water availability from rivers is very vital for the sustenance of livelihood, planning of new water resources projects including evaluation of existing projects and optimum usage of natural resources. Riverbank erosion is one of the most unpredictable and critical disaster that takes into account the quantity of rainfall, soil structure, river morphology, topography of river and adjacent areas and effect of floods. Alluvial river possesses problems of sediment erosion-deposition attached with it letting Dudhkumar as no exception and leading the problems of flood, erosion and drainage congestion in the Brahmaputra basin as momentous [2]. Riverbank erosion has important implications for short and long term channel adjustment, development of meanders, sediment dynamics of the river catchment, riparian land loss and downstream sedimentation problems [3]. Being alluvial in nature, floodplains of the rivers are predominantly formed of flood-borne sediments while their bank materials consist mostly of fine-grained cohesive sediments [4]. In such alluvial rivers, through continuous erosion accretion processes, the channels frequently change its meandering pattern from reach to reach [5]. On the other hand development works such as, bank protection measures like embankment, dam and bridge may also cause local morphological changes of river affecting the ultimate sediment balance of the river. Thus fluvial channel form and its dynamics over the period of time have been a major interest of study in fluvial geomorphology [6]. Therefore, a better understanding on morphological changes of alluvial rivers, particularly bank shifting, channel migration due to erosion and accretion processes as well as techniques to detect resultant pattern would be useful for effective planning and management of the alluvial environments.

Temporal satellite remote sensing data of a river having unstable banks can be analyzed in GIS for identification of river bank erosion as well as patches of embankment vulnerable to breaching, upholding the remote sensing approach in study of river morphology. Baki et.al. [7] studied on river bank migration and island dynamics of braided Jamuna River using LANDSAT images. Khan et.al. [8] studied on river bank erosion of Jamuna River by using GIS and Remote Sensing Technology. Hossain et al. [9] assessed morphological changes of Ganges River. Afrose et.al [10] analyzed morphological changes of Teesta River. Takagi et.al. [11] analyzed the spatial and temporal changes in the channels of Brahmaputra. Sarker et.al. [12] examined the morphological response of major river systems of Bangladesh due to the Assam earthquake.

No systematic study and research has been done for defining the morphological characteristics of Dudhkumar River, but this river discharge influence the Kurigram district of Bangladesh significantly. Being an important water course for the northern region of Bangladesh, some recent studies have been conducted on the Dudhkumar River. Hossain et.al. [13] conducted an investigation to determine the In-stream Flow Requirement (IFR) of the Dudhkumar River. In this study the author applied three methods of the hydrological approach and according to demand-availabilityscenario the author has considered IFR calculated by mean annual flow method. Asad et al. [14] by using Gumbel's and Powell's method analyzed a flood frequency model. Zaman [15] studied on morphological changes of the Dudhkumar River due to the proposed road bridge at Paikerchara union of Bhurungamari upazila under Kurigram district using HEC-RAS. Due to river bank erosion a large number of people losses their homes, agricultural lands, resources and become homeless resulting in extreme poverty in the country but there is still lack of sufficient erosion management plan. In this study, understanding the predicament of river Dudhkumar in particular, efforts have been ensued to study the bank line shifting, the rate of erosion-accretion and predicting future erosion rate of the river Dudhkumar which may contribute to the development projects and bolstering existing bank protection measures.

1.1. Study Area

Dudhkumar River is located in the north-east corner of the North-West region of Bangladesh originating in the Himalayan foot hills in Bhutan and flowing through south-easterly direction from the foot hills through India to its outfall into the Brahmaputra River in Bangladesh [1]. The river enters in Bangladesh near Shilkhuri of Bhurungamari Upazila in Kurigram district [15]. The river possesses a length of 220 km having the catchment as around 5,800 km^2 out of which about 240 km^2 is within Bangladesh. About 96% of the catchment area lies outside Bangladesh[16]. In Bangladesh the river travels a distance of about 51 km having average slope of 10 cm/km in the south south-easterly direction to meet with the Brahmaputra River at Noonkhawa. Within Bangladesh, there are several small rivers that drain into the Dudhkumar River, notably Satkuradara, Phulkumarriver, Giraikhal, Dikdaridara and Santashikhal [14].

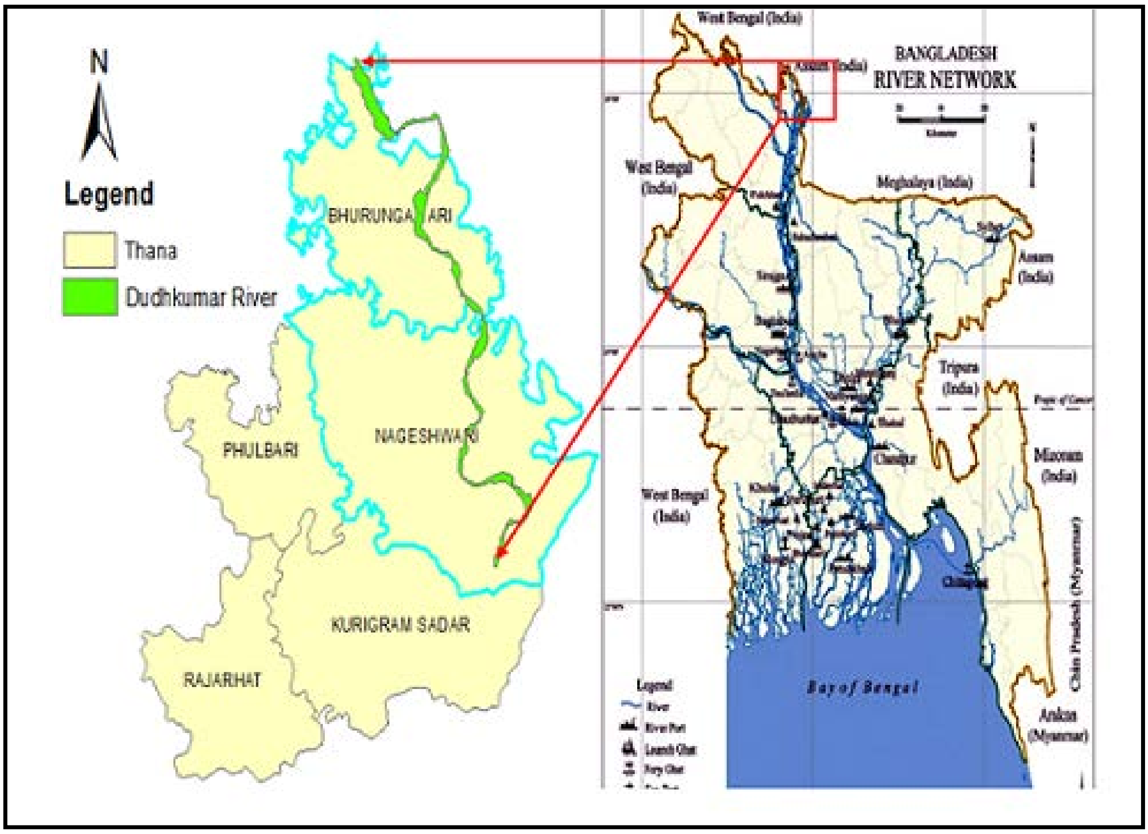


Figure 1. Map of the study area showing Dudhkumar river

Dudhkumar is a semi braided river and morphologically highly dynamic. Being a semi braided river, it is associated with the development of loops. Sometimes channels move quite fast and consequent abandonment of meander loop through cut off. Such natural cut off can occur frequently within 1-2 years [17]. The sediment size, d_{50}, at Pateswari and Tangonmari have been found as 0.21 mm and 0.16 mm respectively [17]. The. Average cross sectional area of the river is about 1506 m^2 [1]. Average width of the river at high and low water level is about 284.24m and 225.34m respectively [1]. This high slope makes Dudhkumar a flashy type during monsoon when onrush of surface runoff cause flooding to the flood plain of the river causing bank erosion and destruction of houses and settlement of the people living on the river banks. For the present study, full reach of Dudhkumar having length of 64 km has been considered. A map of the study area focusing the catchment of Dudhkumar river is shown in Figure 1.

3. Methodology

To conduct the analyses, Landsat satellite images are collected from USGS earth explorer website covering the whole of Dudhkumar River in Bangladesh from the year 1973 to 2015. All the images were collected during the dry season (January to March) except the year 1997 image which was acquired in early November as during dry season, vegetation cover and other ground conditions, particularly the water level, are relatively consistent from year to year which is essential for assessing the inter-year change of erosion and accretion of the River. In addition, during dry season the chances of getting a relatively cloud free atmosphere is a bit higher and the planform generally shows the boundary and pattern of channels within the braid belt clearly. Based on available flow data, time from November to May have been considered as the low flow month and June to October as the high flow month. Initially, each image was projected onto a plane, rotated, rescaled, and geo-referenced using a 1997 Landsat image mosaic of Bangladesh which itself was geo-referenced using SPOT photo maps of 1:5000 scale and produced from multi-spectral SPOT images. The geo-referencing of a satellite image consists of identifying ground control points (GCPs) on the image that correspond to GCPs on the 1997 image mosaic. Each raw satellite image was re-sampled using the nearest neighbor algorithm, and transformed into the WGS 1984 UTM zone 45N projection and coordinate system of the following specifications (ISPAN, 1992): (1) Ellipsoid = Everest 1830, (2) Projection = Transverse Mercator, (3) Central meridian = 900E, (4) False easting = 500,000 m, and (5) False northing = 2,000,000 m. After geometric correction, each satellite image was classified to different land use types using an un-supervised, statistical classification technique, an artificial neural network, that group pixels into distinguishable classes. Three broad land cover classes are identified: water, sand and land (including cultivated/vegetated land). Lastly, from each digitally classified image a map is produced showing river channels, sandbars and a land use class that includes all cultivated and vegetated areas[18] using the available images during the dry season of 1973, 1987, 1989, 1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013 & 2015. To quantify changes in river bank locations that have occurred between any two images using Arc View, a total of 80 cross-sections at 0.5 km intervals along the 51 km long study reach of the Dudhkumar River were drawn and coordinates of all intersection points between the bank lines and cross-section lines determined Figure 2.

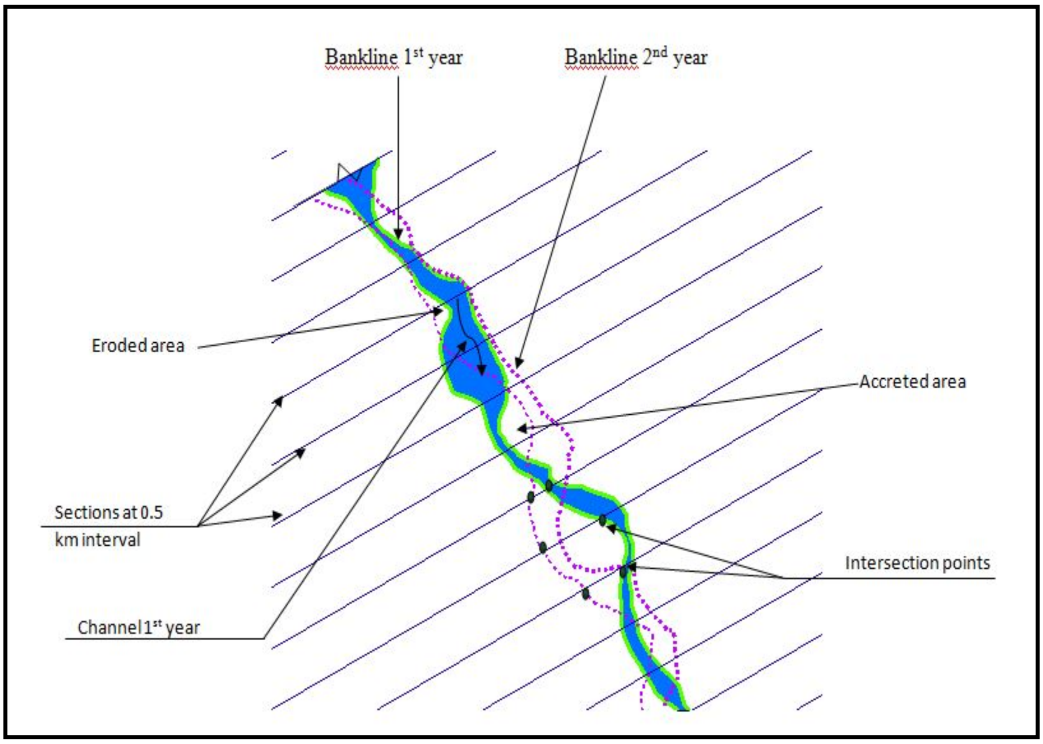


Figure 2. A schematic diagram showing how shifting of the riverbanks from 1987 to 1989 was computed. Sections are taken at 0.5 km intervals along the 51 km valley length of the Dudhkumar River

Usually, the sections used to measure the bank lines shifting are set to be at 90° to the axis of the channel [7]. However, for a channel undergoing meandering and erosion, the channel tends to change its flow direction frequently year after year, and so it will be difficult to use sections at 90° to the axis of the channel to predict the bank line shifting [7]. In other words, for the Dudhkumar River subjected to frequent and significant erosion/accretion, if we were to set the cross-sections at 90° to the axis of the channel, the locations of the cross-sections would shift from year to year. To avoid such a problem, we set the river cross-sections at 90° to the valley direction. By so doing, based on changes to the cross-sections detected from the satellite images, we would be able to consistently track temporal changes to left and the right bank lines.

3. Analyses and Results

3.1. Analysis on Flow of Dudhkumar River

The discharge and water level data of Dudhkumar River at the Pateswari gauging station was collected from Bangladesh Water Development Board (BWDB). The water level in the river was very low in late February, March and April; very high in June to October where water level varies from 20.00 m PWD to 33.42 m PWD [19]. Hydrology of the catchment area of Dudhkumar river is mainly governed by rainfall runoff and cross boundary flows through the river. The mean annual rainfall gradually decreases from 3000 mm in the north to 1800 mm in the south, with an average annual rainfall of 2700 m [20]. From available record and data it is found that flows in the Dudhkumar river at Pateswari during the dry season (November to May) comes down to an average of 159 m^3/s and during the monsoon season (June to October) the average flow is about 897 m^3/s. Based on the data available from BWDB, the maximum and minimum discharge is found to be 9250 m^3/s and 52.30 m^3/s that occurred on 6th October, 1968 and 18thApril, 1992 respectively. Flow and stage discharge hydrographs of Dudhkumar river at Pateswari for the period of 1968 to 2007 have been shown in Figure 3.

3.2. Analysis on bank Line Shifting of Study Reach

To get an overall picture of the erosion and accretion patterns of Dudhkumar River over two time periods, 1973-1987 (14 years) and 1973-2015 (43 years), the maps of riverbank erosion and accretion are overlapped in Arc GIS. Next, the rates of bank movement as a function of distance along the river for both the left and the right banks for both time periods are plotted in Figure 4 (a) and Figure 4 (b) respectively. These figures show a considerable movement of the bank lines resulted from accretion indicating riverward movement of banks as well as erosion which depicts the landward movement of the banks for both the time periods. For the short term analysis between 1973 and 1987, bankline shifting rates varied from less than a m per year to several hundred meters per year, as is evident in high standard deviations shown in Table 2. For 1973 to 1987, maximum accretion and erosion rate in left bank were 260 m/y in Bhurungamari and 200 m/y in Pateswari sub-district respectively, while the corresponding rates for the right bank were 180 m/y and 200 m/y respectively in Pateswari. On a whole, right bank of the Dudhkumar River has experienced more accretion rather than erosion highlighting the existence of bank protection measures. For the long term analysis between 1973 to 2015, bankline shifting rates varied below more or less hundred meter per year, as is evident in lower standard deviations. For the time range, maximum accretion and erosion rate in left bank were 100m/y and 40 m/y in downstream reach while the corresponding rates for the right bank were 45 m/y and 100 m/y respectively at downstream of Dudhkumar river. Figure 4(a) also shows that accretion occurred in large areas, especially at the upstream reach of the river at 7 km from the upstream point along the left bank where as considerable erosion at left bank occurred at 29km from upstream. In case of right bank both the maximum erosion and accretion occurred at 29 km from upstream. During the long term period raging from year 1973 to 2015, both the maximum accretion occurred at 28.5 km from upstream and erosion at 23 km from the upstream point in case of left bank. On the right bank, almost the full reach. Accretion appeared in small areas upto 28 km from the upstream on the right bank which could be because of the building of erosion control structures.

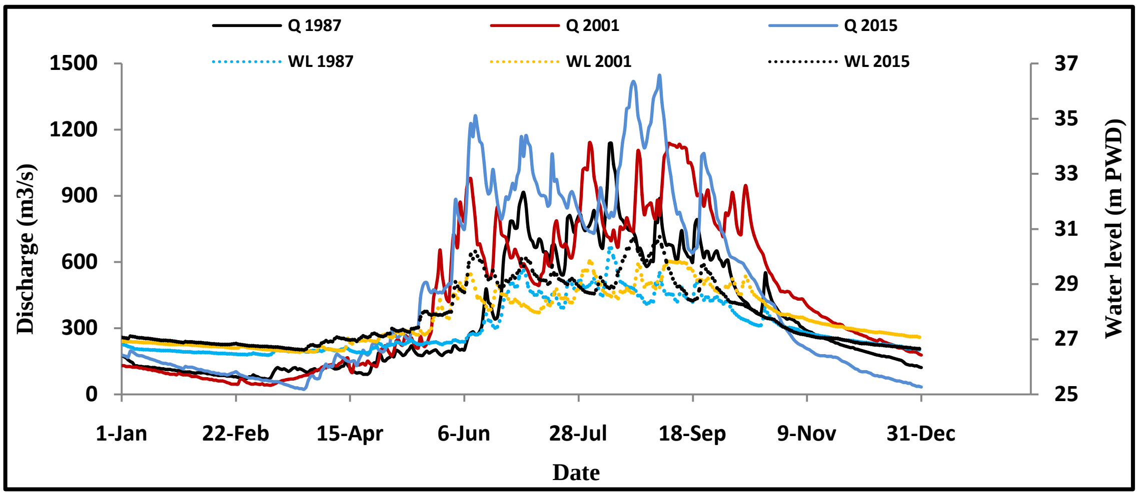
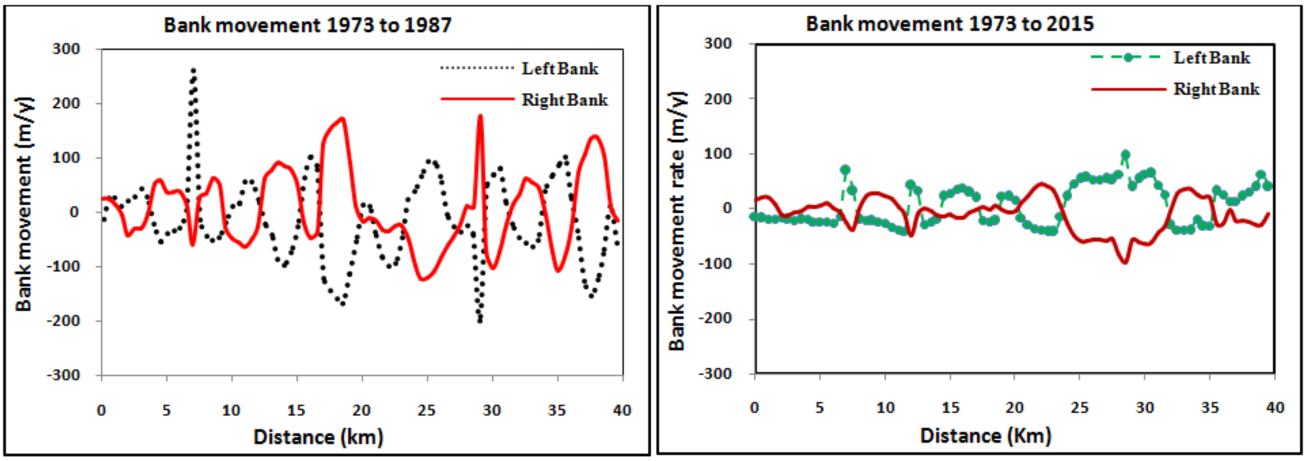


Figure 3. Variation in flow and water level at Pateswari of Dudhkumar River



(a) (b)

Figure 4. Bank movement rate along the Dudhkumar River (length means distance from the northern most point of the river) for both the left and the right banks, between (a) 1973 and 1987, and (b) 1973 and 2015

3.3. Short-Term, Inter-Annual Changes to River Banks

The average bank erosion and accretion rates for the left and the right banks of the Dudhkumar River at inter-annual intervals (2 years) are listed in columns 1-4 of Table 1. Even though it will be ideal to have regular satellite images acquired on an annual basis but may not always be possible in practice. The mean short-term erosion rate on the left bank is 128 m/y and that on the right bank is 141 m/y (Table 2) and the mean short-term accretion rate on the left bank is 194 m/y and that on the right bank is 176 m/y. The maximum erosion rate recorded in the left bank of about 349 m/y occurred between 2013 and 2015, while in the right bank the maximum erosion rate of about 263 m/y occurred between 1999 and 2001. The range of erosion rate (maximum-minimum) in the left bank is 300 m/y while that of the right bank is 308 m/y (Table 2). The corresponding mean (range) of accretion rate on the left bank is 194 (357 m/y) and that on the right bank is 176 (250 m/y). Therefore, the left bank experienced a net accretion of about 66 m and higher range of accretion (357 m/y) than erosion rates (300 m/y), while the right bank experienced a net accretion of about 35 m, but range of erosion (308 m/y) is higher than accretion rates (250 m/y). In the left bank the maximum accretion rate of 410 m/y recorded occurred between 2013 and 2015, while in right bank the maximum accretion rate recorded was 318 m/y that occurred between 1993 and 1995. Figure 5a and Figure 5b depict the short-term bank migration due to erosion-accretion in Dudhkumar River. For short-term changes, the correlation between bank erosion/accretion rates and annual discharges varies from about 0.15 to 0.57 as shown in Figure 6.

Table 1. The inter-annual short-term and long-term riverbank migration rates (erosion and accretion) of the left and right banks of Dudhkumar River

Year	Short-term riverbank migration				Year	Long-term riverbank migration			
	Left bank shifting average rate (m/y)		Right bank shifting average rate (m/y)			Left bank shifting average rate (m/y)		Right bank shifting average rate (m/y)	
	Erosion	Accretion	Erosion	Accretion		Erosion	Accretion	Erosion	Accretion
Column	1	2	3	4		5	6	7	8
73-87	66	53	48	68	**73-87**	66	53	48	68
87-89	120	247	101	140	**73-91**	44	48	43	46
89-91	99	323	215	154	**73-95**	37	43	44	31
91-93	126	143	356	207	**73-99**	32	34	35	31
93-95	49	101	151	318	**73-03**	30	32	29	25
95-97	174	199	168	219	**73-07**	24	39	30	24
97-99	235	239	126	246	**73-11**	24	36	28	20
99-01	100	210	263	254	**73-15**	26	41	29	19
01-03	104	353	82	93					
03-05	133	170	120	149					
05-07	109	195	78	167					
07-09	99	75	127	184					
09-11	81	87	119	141					
11-13	82	102	103	195					
13-15	349	410	58	104					

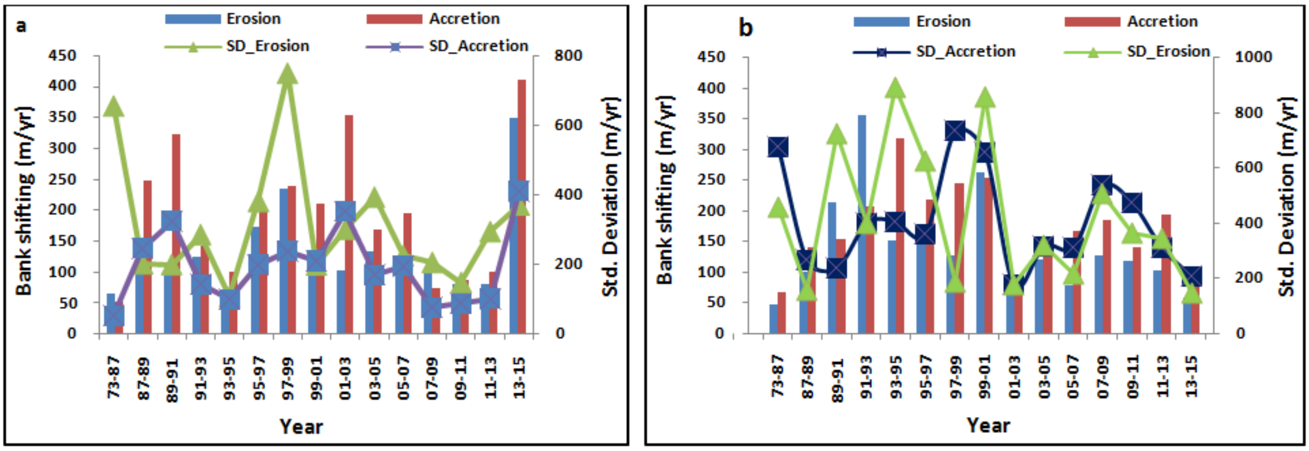


Figure 5. Short-term bank migration due to erosion-accretion in Dudhkumar River (a) left bank (b) right bank

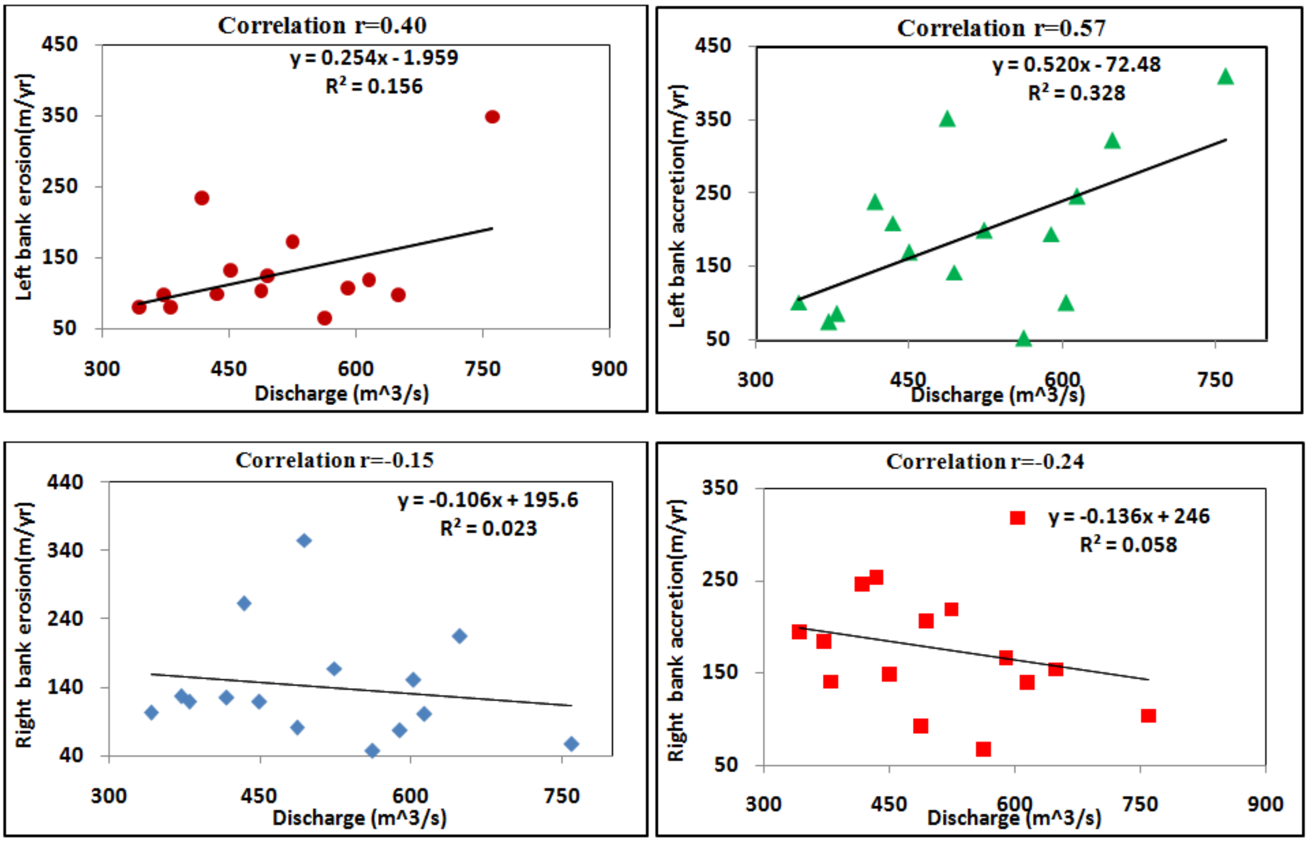


Figure 6. The short-term regression relationships between annual discharge and banks erosion/accretion rates (a) left bank erosion, (b) left bank accretion, (c) right bank erosion, (d) right bank accretion

Table 2. Summary statistics of inter-annual short-term and long-term riverbank migration rates (erosion and accretion) of the left and right banks of the Dudhkumar River

	Short-term riverbank migration				Long-term riverbank migration			
	Left bank shifting average rate (m/y)		Right bank shifting average rate (m/y)		Left bank shifting average rate (m/y)		Right bank shifting average rate (m/y)	
	Erosion	Accretion	Erosion	Accretion	Erosion	Accretion	Erosion	Accretion
Column	1	2	3	4	5	6	7	8
Mean	128	194	141	176	35	41	36	33
Standard Deviation	74	104	80	65	14	7	8	16
CV	0.58	0.54	0.57	0.37	0.40	0.17	0.22	0.48
Range	300	357	308	250	42	52	20	49
$r^{(i,j)a}$	$0.65^{1,2}$	$-0.16^{1,3}$	$0.52^{3,4}$	$-0.27^{2,4}$	$0.83^{5,6}$	$0.88^{5,7}$	$0.87^{7,8}$	$0.82^{6,8}$

$r^{(i,j)a}$ = Correlation between columns i and j.

3.4. Long-Term Changes to River Banks

The long-term bank erosion and accretion rates of Dudhkumar for its left and right banks are listed in columns 5-8 of Table 1. The mean (range) erosion rates of the left bank is 35 (42) m/y, while that of the right bank is 36 (20) m/y, respectively (Table 2). As expected, the long-term erosion rate is considerably less than that of the short-term erosion rate for both banks are 35 and 36 m/y shown in Table 2, Similarly, the mean long-term accretion rate for both banks over 43 years are 41 and 33 m/y, respectively, which are considerably less than the short-term accretion rate for left and right banks (194 and 176 m/y). For long-term changes, the correlation between bank erosion/accretion rates and annual discharges varied between 0.01 and 0.44 which are weaker than the corresponding correlations of short-term changes. From a long-term perspective, because of averaging the effects of erosion deposition, the overall bank line shifting rates tend to decrease as the time span considered increases, even though from year to year, annual rates of erosion and accretion can vary significantly partly because of the climatic and hydrologic variability of the Dudhkumar River.

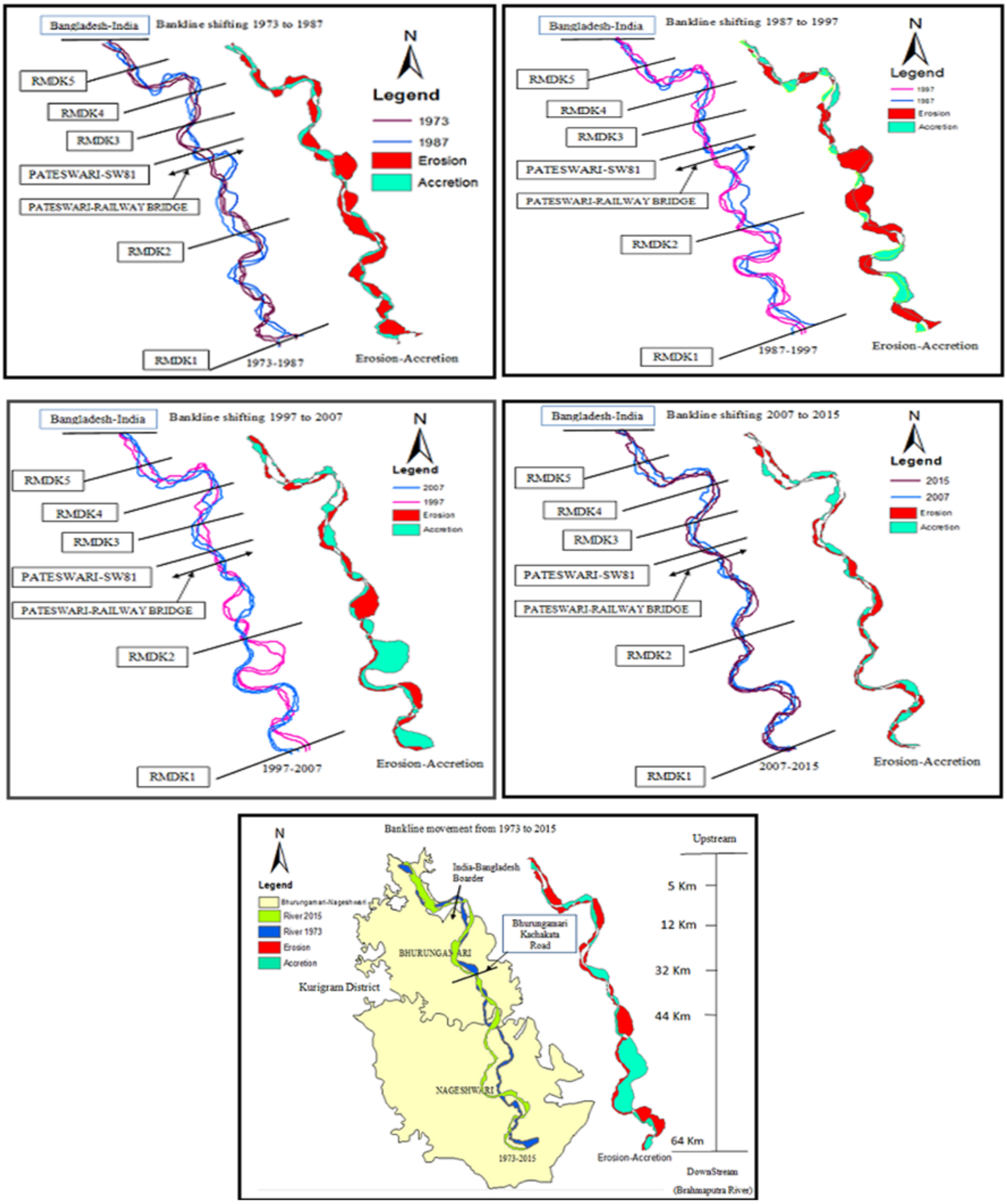


Figure 7. River bank shifting along the Dudhkumar River for different time ranges

Table 3. Erosion-accretion along the Dudhkumar River for four study periods

Duration	Location	Erosion		Accretion	
		Total (ha)	Rate (ha/yr)	Total (ha)	Rate (ha/yr)
1973-1987 (14 years)	Left Bank	2248	160.57	1146	81.86
	Right Bank	1395	99.64	1991	142.21
1987-1997 (10 years)	Left Bank	2295	229.50	1103	110.30
	Right Bank	2084	208.40	941	94.10
1997-2007 (10 years)	Left Bank	1408	140.80	2440	244
	Right Bank	2213	221.30	1442	144.20
2007-2015 (8 years)	Left Bank	816	102	752	94
	Right Bank	941	117.63	687	85.88

3.5. Area of Erosion and Accretion

Area of riverbank changes of the Dudhkumar due to erosion and accretion for 1973 to 2015 are presented in Table 3 and Figure 7, respectively. Figure 7 shows a high spatial variability of erosion and accretion on both sides of the riverbank. From Table 4, it can be seen that erosion rate (ha/y) gradually increased from 1973-2007 and then decreased during 2007-2015 on the left and right bank. It also seen that maximum erosion occur at left bank rather than right bank (2295 ha and 2213 ha). During 1987-1997 erosion rate maximum (229.5 ha/yr) at left bank and 1997-2007 erosion rate maximum (221.3 ha/yr) at right bank but maximum accreted area (rate) found 2440 ha (244 ha/yr) in 1997-2007 at left bank. So, left bank faced greater erosion-accretion rather than right bank.

3.6. Riverbank Shifting Verses River Width

Over 43 years (1973-2015), the average width of the Dudhkumar River was about 595 m, and the minimum (maximum) width was 87(4520) m in 2001 (1991) (Table 4). The rate of change of the river width peaked in about 1993 (Figure 8a). From the short-term analysis, the average ratio of erosion and accretion rates to the river width is 0.22, 0.33 at the left bank and 0.24, 0.30 at the right bank, respectively. From the long-term analysis, the average ratio of erosion and accretion rates to the river width is 0.059, 0.065 at the left bank and 0.06, 0.055 at the right bank, respectively. Again because of the time averaging effect, the ratios for the long-term analysis are smaller than that of short-term analysis.

Table 4. Changes in the Dudhkumar River channel width for 1973-2015

Year	Maximum width (m)	Minimum width (m)	Average width (m)
1973	3005	117	458
1987	2738	91	532
1989	1374	115	377
1991	1968	87	332
1993	3918	500	883
1995	2129	100	477
1997	2266	108	517
1999	2579	164	674
2001	4520	104	752
2003	1807	118	509
2005	3620	110	586
2007	2155	88	478
2009	3517	139	621
2011	2990	90	688
2013	3401	143	737
2015	1792	116	727

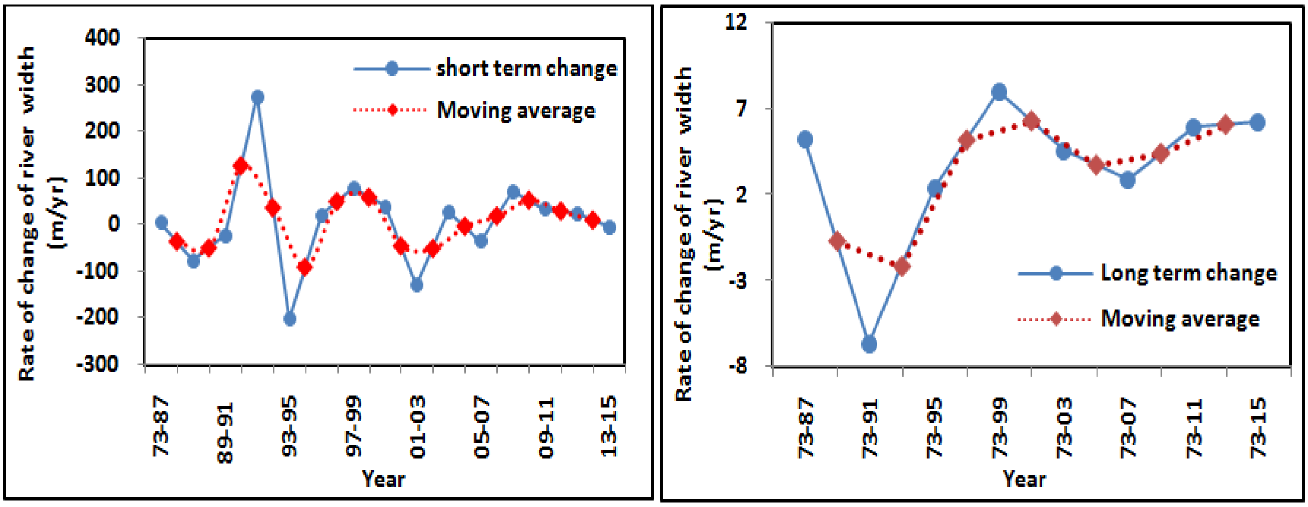


Figure 8. Change of width of Dudhkumar River (a) short term (b) Long term

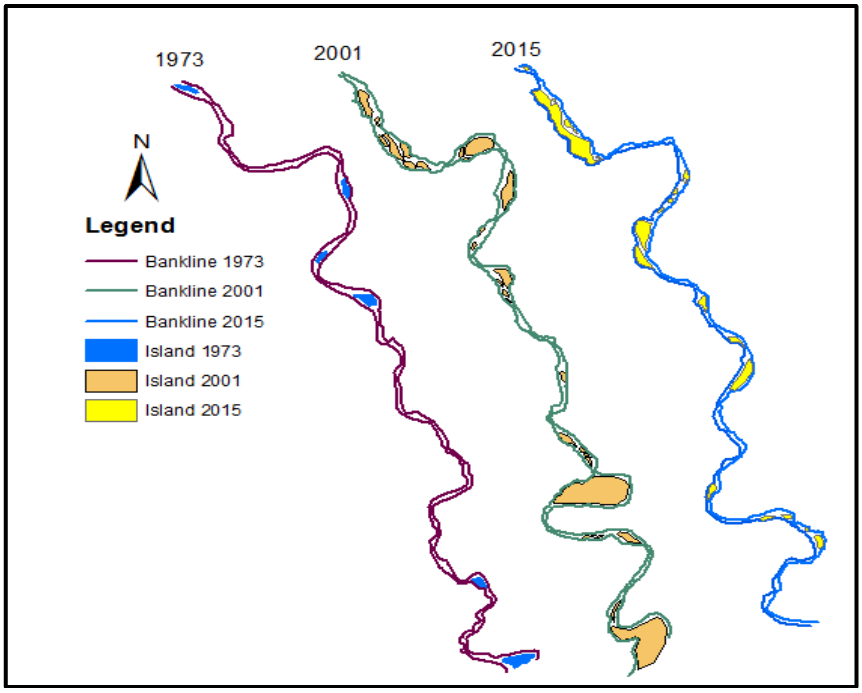


Figure 9. Island shifting at 1973, 2001 and 2015

3.7. Island Dynamics

An island is any kind of landmass within a river that sits above water. Sand or other sediment can build in a portion of the river by currents when the river level is high. During the dry season, these can be exposed above the surface. Ana branching in any river system occurs where a river is divided by islands [21]. The Dudhkumar River in the influence of small and large islands. Table-6 represents the change of island area from 1973 to 2015. It is seen that the island area started increasing after 1973, maximum area found in 2001, about 1637 ha and 28 number of island exists. It is seen that the island area at 1973 fully shifted in 2001 and 2015. Maximum number of island found at upstream (at Bhurungamari Upazila).

Table 5. Changes of island from 1973 to 2015

Year	Total Water Surface (ha)	Islands (char) Area (ha)	Islands area over total water surface
1973	1814	218	6
1987	2319	735	19
1989	1730	289	20
1991	1446	197	15
1993	2372	731	22
1995	2108	665	17
1997	2315	587	20
1999	3106	963	25
2001	3612	1637	28
2003	2158	390	16
2005	2469	694	19
2007	2038	538	17
2009	2379	638	12
2011	2780	1055	17
2013	3010	1018	16
2015	2356	760	19

4. Conclusion

The present work using remote sensing and GIS based approach with multi-date satellite data has revealed sharp changes in fluvial land form in recent years resulting in considerable inhabited land loss. It is observed that in general the river has eroded both the banks throughout its course except at a few sites where banks are well defined as the river is constricted due to presence of dykes at some places of right bank. River adjustment processes that affected fluvial system of the river Dudhkumar include forcing functions like channel degradation and aggradations, lateral river migration, widening or narrowing, avulsion, changes in the quantity and character of the sediment load at spatial and temporal scale, intensely powerful monsoon regime, recurring earthquakes and adverse impact of anthropogenic factors. This study has proved the utility and application of satellite remote sensing which allows a retrospective, synoptic viewing of large regions and so provides the opportunity for a spatially and temporally detailed assessment of changes in river channel erosion/deposition. This study has further demonstrated how the use of GIS has been expedient in organization of geo-spatial databases and facilitation of channel position mapping and measurement. The Dudhkumar is a meandering River with many oxbow bends. Over the years, under the combined impact of erosion, accretion, and human interventions, the Dudhkumar River within Bangladesh has experienced significant hydro-morphological changes. Through the analysis of fifteen satellite images of Landsat MSS and TM collected between 1973 and 2015, below are the conclusions on the short-term and the long-term riverbank migrations of Dudhkumar River in Bangladesh. From the short-term analysis, the mean erosion and accretion rates estimated are 128 and 194 m/y on the left bank, and 141 and 176 m/y on the right bank. From the long-term analysis, the average erosion and accretion rates are 35 and 41 m/y on the left bank, 36 and 33 m/y on the right bank. The migration results of both banks indicate a very dynamic form of erosion and accretion processes leading to channel shifting in the Dudhkumar River. The right bank experienced more erosion than the left bank; and the long term migration rate is smaller than the short-term counterpart for both banks probably because of human interventions such as construction of bank protection structures and the time averaging effect of erosion and accretion. The average erosion rate estimated from Landsat images over 43 years for the short and long-terms analysis of the Dudhkumar River are 135 m/y and 36 m/y, respectively, which are much higher than the bank erosion rate of 18 m/y estimated from the global erosion relationship of Van de Wiel (2003), probably because of its highly erodible bank materials. The long-term shifting of river banks due to erosion/accretion and the rate of change of channel width (widening/narrowing) may not necessarily follow the general morphological principle of river migration. For the short-term, only erosion rate for the right bank and accretion rate for the left bank follow this principle. The present study identified locations affected by of bank erosion accretion and the bankline shifting and indicated the urgent need to protect the river banks employing afforestation measures and other strategies. Therefore, it is necessary to incorporate geomorphic changes in formulating flood management programmes.

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