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Assessing the Impact of Riverbank Erosion on Land Use/Land Cover along the Lower Reach of Balasan River, West Bengal

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Abstract: *The present study attempts to assess the impact of riverbank erosion on land use/land cover (LULC) along the lower reach of the Balasan river, West Bengal. Quantification of riverbank erosion followed by bank-line shifting and associated land use/land cover change detection in surrounding flood plain area have been carried out using Landsat 5 TM (1990), Landsat 7 ETM+ (2000), LISS III (2008) and Landsat 8 (2017) in GIS environment. In this regard, a perception study among the flood plain dwellers has also been conducted through in-depth interviews and focus group discussions. The study reveals that riverbank along entire lower reach is unstable due to frequent lateral channel migration although amount of riverbank erosion is highest from Nayabasti up to the confluence where human interference is maximum in terms of restless sand mining and quarrying activities from bed and near bank material. Land use/land cover change detection indicates that area affected by channel shifting and resultant erosion-deposition primarily comprises land under agriculture, settlement and wasteland. Almost 87% of land under agriculture has been reduced whereas almost 145% and 185% of land under wasteland and settlement have been increased over 28 years of period. Submergence of land, deposition of sand over field by flood and associated riverbank erosion and active siltation process by the eroded materials near confluence account for such alteration in land use/land cover pattern. Results indicate that where the amount of riverbank erosion is higher, amount of land conversion under different categories in to river is more prominent.*

Key words: Riverbank erosion, land use/land cover, change detection, Balasan river

Introduction

The role of LULC investigation as a baseline requirement for planning and sustainable management of natural resources within socio-economic and environmental systems is widely accepted and any change in existing LULC pattern acts as one of the most significant drivers for global change affecting climate, bio-geochemical cycles, biodiversity, livelihoods of people (Lambin, 1999; Mishra *et al.*, 2020). Several geo-environmental conditions along with technological, socio-economic and institutional set-up largely influences the LULC of an area (Rai *et al.*, 1994). Flood plains, which serve as primary source of income and provide space for inhabitants are one of the most vulnerable areas subjected to seasonal and periodical modifications by the dynamic nature of river through lateral channel migration driving a change in land use pattern (Hazarika *et al.*, 2015). Effect of such changes becomes a socio-economic hazard to the poor flood plain dwellers. Land lost by riverbank erosion brings change to infrastructure, financial consequences, threatens aquatic habitat and accelerates sedimentation process downstream (Darby and Thorne, 1995) and indeed land lost once in erosion cannot be compensated by the river itself. Several attempts have been made to assess the impact of riverbank erosion on LULC change in terms of agricultural land loss, increase in the amount of wasteland, displacement and relocation of settlement and destruction of forest (Bhunia, 2016; Guite and Bora, 2016; Debnath *et al.*, 2017; Hassan and Mahmud, 2016). Remote sensing and GIS are the most convenient tools for quantifying the amount of riverbank erosion (Chakraborty and Mukhopadhaya, 2015; Das *et al.*, 2014; Thakur *et al.*, 2012; Ghosh, 2007; Sandra and David, 2000) and for assessing land use/ land cover change detection (El-kawy *et al.*, 2011; Dewan and Yamaguchi 2009; Jin-song *et al.*, 2008; Nasihin *et al.*, 2016; Kiran, 2013; Nagaranjan, 2011; Butt *et al.*, 2015; Nie, 2011; Kotoky *et al.*, 2012) because of their repetitive data acquisition, computer association, growing advances in temporal, spatial, spectral resolution and time saving abilities.

After a reconnaissance survey it is evident that extensive extraction of bed and near bank material change the natural form and processes of the river Balasan in North Bengal resulting into channel incision, bank instability with increasing bank heights accounts for wearing away of the exposed bank materials during monsoon high flows. Aggravating river bed, migrating channels and retreating banks pose a serious threat to the riparian population in the Balasan river basin (Dutta, 1995). The previous research works are mainly concentrated on fluvial dynamics, braiding nature, soil loss, causes and rate of riverbank erosion, human intervention in terms of sand mining and quarrying along the river Balasan (Jana and Dutta, 1995; De, 1998; Lama, 2003; Tamang, 2013) but impact of riverbank erosion on LULC has rarely been documented and quantified empirically. Therefore, the present study has been carried out to detect and measure the amount of riverbank erosion and to assess the impact of riverbank erosion on land use/ land cover along the lower reach of the Balasan River.

Study area

Balasan, a major right bank tributary of the River Mahananda, is originated at Lepchajagat at an altitude of 2361 m (27°03´55˝N, 88°14´12˝E). The basin consists of weak weathered rocks like slate and schist in geologically fragile zone of Darjeeling Himalaya. The present study area is confined within 1 km buffer zone from both banks along the lower reach of the Balasan river starting from its debouching point at Dudhiya (26°46´44˝N, 88°14´31˝E; elevation 279 m) to the confluence of the river Mahananda at Noukaghat (26°41´11˝N, 88°23´40˝E; elevation 115 m). The total length of the study area is 24.28 km covering an area of about 57 km^2 (Fig. 1). The present study stretch has been selected for the following reasons:

1. Sudden fall in gradient at Terai plains provides the channel a greater scope for the formation of braiding. The divergent flow due to mid-channel bar formation exerts sheer stress on its bank and inevitably erodes it.
2. Restless extraction of sand and gravel from bed and near bank acts as a major triggering factor for riverbank erosion along the entire lower reach.

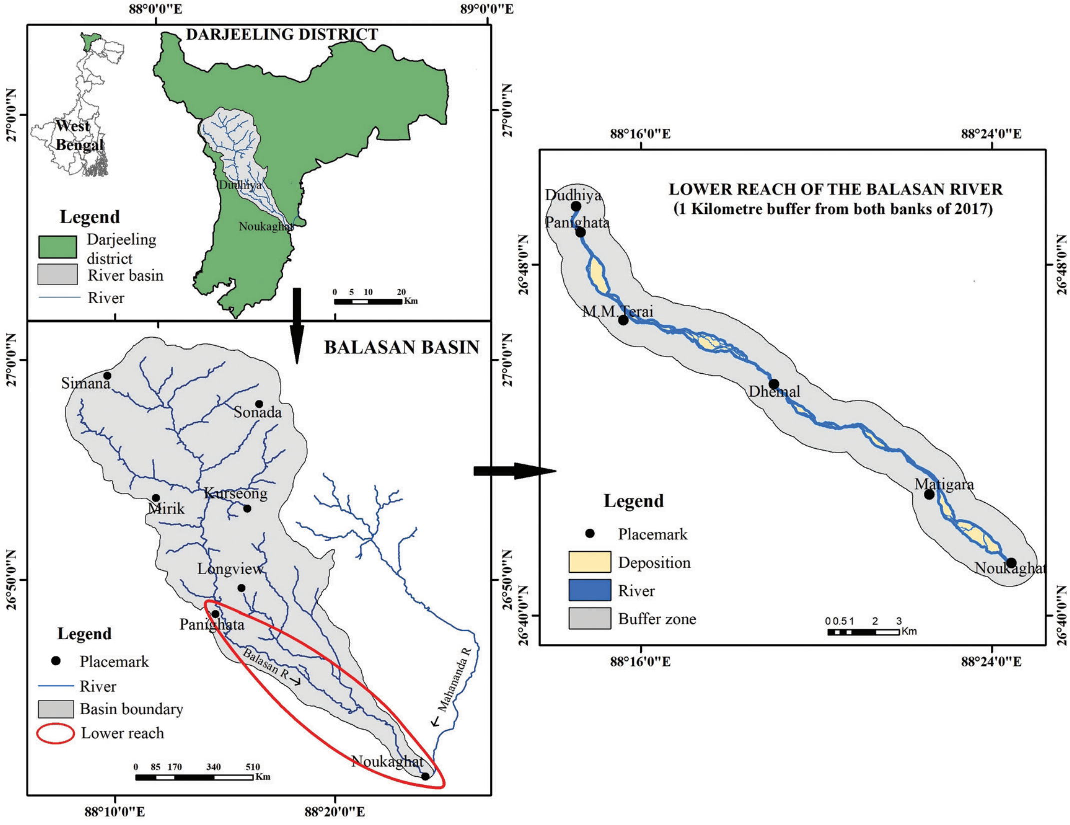


Figure 1. Location map of the study area

Materials and method

Database

Detection and measure of riverbank erosion

The basin boundary has been delineated from ASTER GDEM. Riverbank-lines along the lower reach of the river Balasan, for the years 1990, 2000, 2008 and 2017 have been delineated from various satellite images of post-monsoon season (Table 1), using Arc

Table 1. Satellite imageries used for the present study

Date	Satellite	Co-ordinates/ path / row	Resolution	Source	Purpose
17.10.2017 17.10.2017	ASTER GDEM V2	26.5, 88.5 27.5, 88.5	30 m	USGS	Basin delineation
05.11.1990	Landsat 5 TM	139 / 41	30 m	USGS	Measurement of riverbank-line shifting and LULC mapping
26.12.2000	Landsat 7 ETM+	139 / 41	30 m	USGS	
30.10.2008 17.12.2008 17.12.2008	Resourcesat-2 LISS-III	107 / 53 107 / 52 107 / 52	23.5 m	ISRO	
11.11.2017				Google Earth	
01.12.2017	Landsat 8 OLI	139 / 41	30 m	USGS	

GIS 10.3 software. Those bank-lines have been superimposed to determine the amount of bank-line shifting for both left and right bank, changes in channel width across the 10 cross sections. The major affected sites by riverbank erosion during 1990-2017, have been selected for cross sections. Total bank-line shifting for the period of 1990-2017 has been presented in terms of progression and retrogression (Bandyopadhyay and De, 2017) which indicates direction of shifting for both banks individually. Progression indicates advancement of bank-line towards river with accretion where retrogression reveals step back of bank-line towards land and erosion.

Land use/land cover change detection

PREPARATION OF LAND USE/LAND COVER MAPS

Four LULC maps have been prepared with the help of aforementioned satellite imageries (Table 1) using ERDAS Imagine 9.1 platform. Layer stacking, image enhancement, selection of different band combination, sub-setting of 1 km buffer zone has been followed as image pre-processing prior to change detection (Rawat and Kumar, 2015). For each predetermined land use/land cover class (Table 2), training samples have been selected by delimiting polygons around representative sites. Maximum likelihood algorithm has been used for supervised classification (Castellana *et al.*, 2007). The misclassified classes (Lu and Weng, 2005) have been corrected using 'recode' option in ERDAS 9.1 as post-classification refinement, based on visual interpretation and local knowledge.

ACCURACY ASSESSMENT

Accuracy assessment is essential to assess the quality of information derived from data. Anderson *et al.* (1976) recommend the standard accuracy for LULC mapping as 85-90%. Total of 253 points have been selected throughout the study area in Arc GIS 10.3 based on ground truth data and visual interpretation. Google earth image and field verification using GPS GARMIN 72 has been adopted as reference data. The comparison between reference data and classified data has been carried out statistically using error matrix table (Lillesand, 2004). Producer's accuracy, user's accuracy, overall accuracy and Kappa co-efficient have been calculated

Table 2. Description of land use/land cover classes mapped in the study area

Land use/land cover classes	Description
Sparse vegetation	Small number of trees spread over a large area
Forest	A large tract of land covered with trees and underbrush
Tea garden	Land where tea plants are grown
Agricultural land	Land is used for agriculture
Wasteland	Land is remained uncultivated for more than 5 years
Culturable wasteland	Land is arable but not taken up for cultivation or any other use
Settlement	Inhabited place where people live
River	Lower reach of the river Balasan
Deposition	All types of deposition by river

by exporting this error matrix in MS Excel.

DETECTION OF LAND-USE/LAND-COVER CHANGES

Post-classification comparison technique has been applied in order to detect, identify and measure the nature and areal extent of change, acquired from different land use/land cover map at different time scale (Rawat *et al.*, 2013). Data regarding LULC from classified image pairs of two different time periods have been compared using cross-tabulation change matrix table to determine qualitative and quantitative aspects of change. After that 'from-to' map has been also generated to show spatial pattern of change.

Perception study

Due to the limitations of secondary data, in-depth interview and Focus Group Discussion (FGD) have been conducted during field survey in December 2017 to March 2018 to know the perception of local inhabitants regarding the impact of riverbank erosion on LULC along the lower reach of the river Balasan within 1 km buffer from both banks. 20 in-depth interviews, 2 at each of 10 erosion-affected sites were conducted through an unstructured questionnaire. On the other hand, five FGDs, (consisting of five members in each group) have been conducted in five major affected sites of past and present to supplement the findings of in-depth interview. Purposive sampling technique has been adopted to select the respondents in the age group of 45 and above drawn from prominent elders, community leaders,

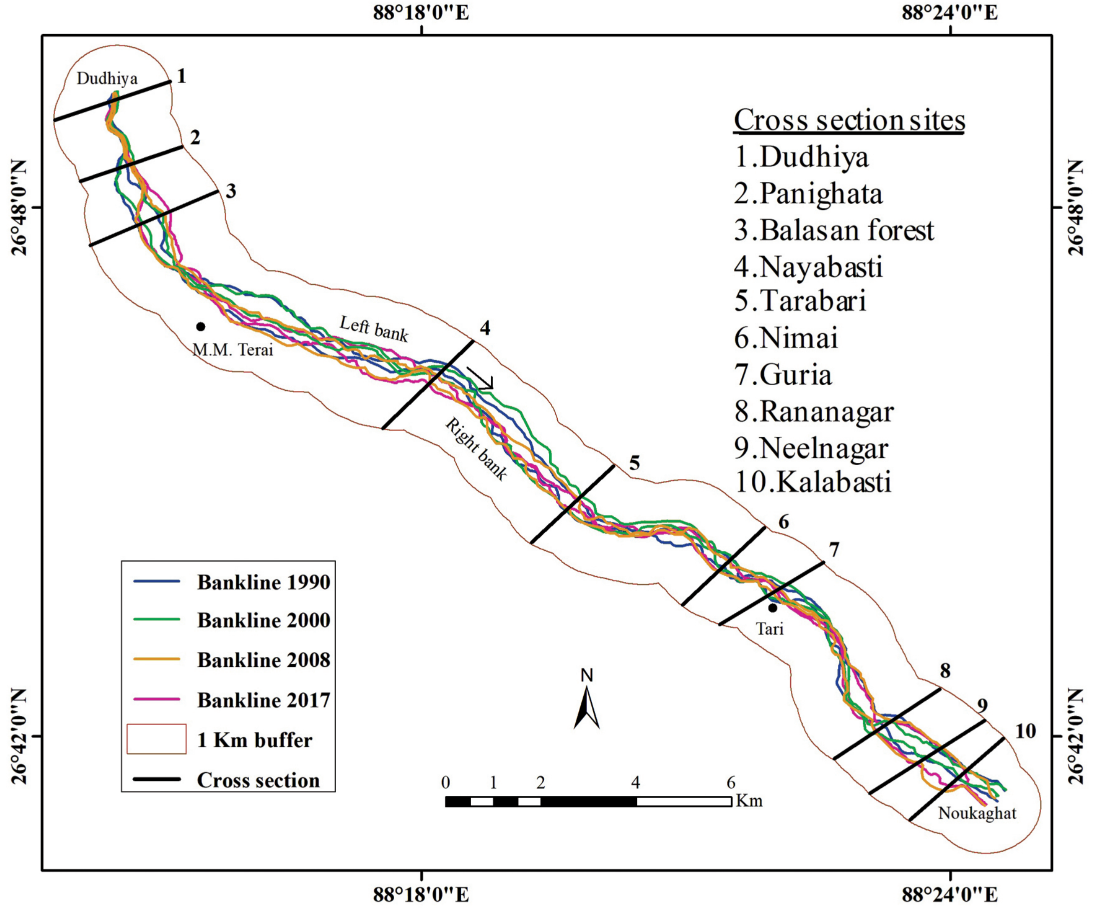


Figure 2. Bank-line shifting along the lower reach of the Balasan River (1990-2017)

teachers and government officials of the area both for in-depth interviews and FGDs. Care has been taken to cover the same proportion of the respondents from the aforementioned groups. Opinions of the respondents have been converted into percentage, tabulations were done and analysis has been made to draw the conclusion.

Results and Discussion

Detection and measure of riverbank erosion along the lower reach of Balasan (1990-2017)

Amount of bank-line shifting and change in channel width

From Balasan forest up to the confluence, river bank-line is unstable and associated with a remarkably higher amount of shifting than average whereas Dudhiya, Panighata near debouching point always experienced a lower amount of shifting. During 1990-2000 maximum bank line shifting was observed at Rananagar including both left (202.46 m) and right (117.98 m) bank higher than average shifting of about 68.87 m and 66.75 m for left and right bank respectively while the lowest shifting was found at Panighata of about 9.31 m (left bank) and 6.23 m (right bank). Overall bank-line shifting tendency has been noticed towards left bank followed by a noticeable amount of shifting at Guria (98.48 m), Nayabasti (95.71 m) and Tarabari (96.84 m). During next nine years tendency of bank-line shifting remained intense towards left bank although highest bank-line shifting is observed along the right bank at Kalabasti of

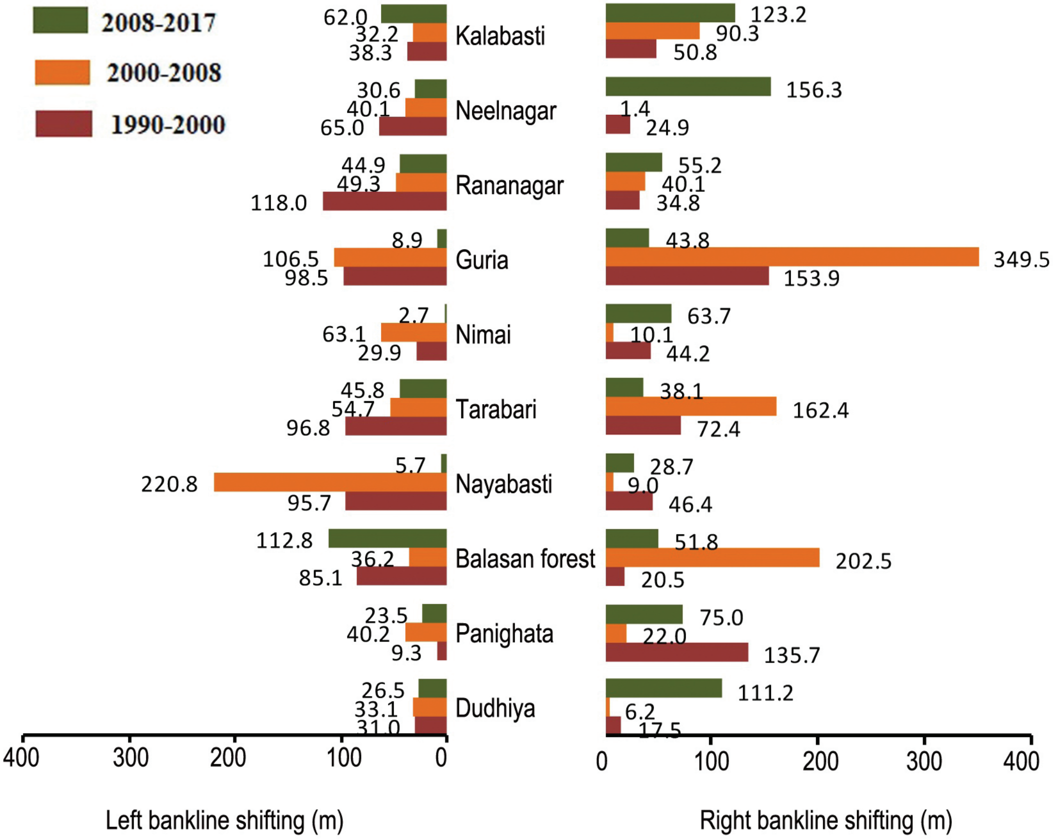


Figure 3. Amount of left and right bank-line shifting along the lower reach of the Balasan river (1990– 2017)

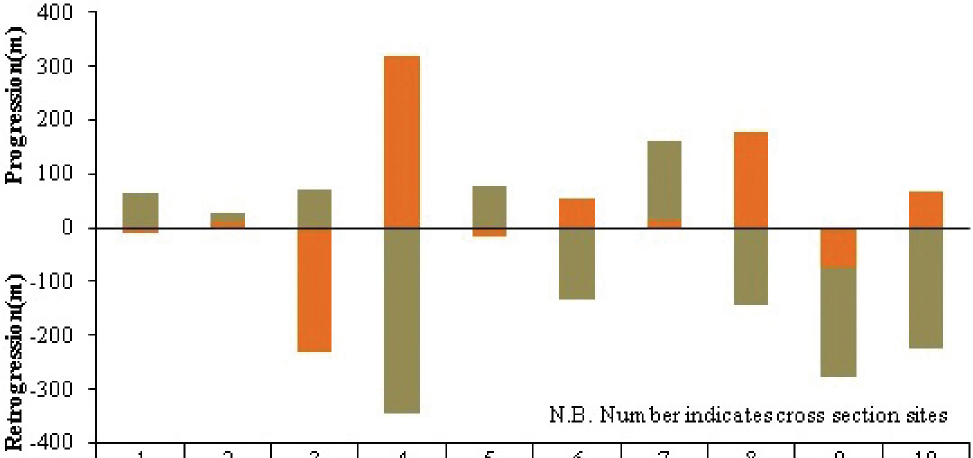
about 349.51 m with marked variation from average right bank-line shifting of 98.21 m. Maximum left bank line shifting is found at Nayabasti of about 220.84 m. Guria is another important erosion affected site experienced bank-line shifting of 106.49 m along left bank. On the other hand, lowest bank line shifting of 9 m (right bank) is observed at Dudhiya. During the recent 10 years, bank line shifting has been reduced compared to previous years. Maximum and minimum bank-line shifting is noticed at Guria (156.31 m) and Nimai (1.43 m) along right and left bank respectively. At Balasan forest bank line shifting is observed noticeably high of about 112.78 m along its left bank followed by Kalabasti of about 123.19 m, Neelnagar of about 90.32 m along right bank. Shifting tendency has been changed towards right bank than left bank and shifting is higher than previous years at Dudhiya and Panighata along both banks. On an average amount of bank-line shifting is higher during 2000-2008 compared to other periods (Fig. 2 and 3).

Bank-line shifting directly affects the channel width, which is a significant indicator for evaluating erosion and deposition. From Table 3 it is found that at Dudhiya and Panighata, channel width has been decreasing during last 28 years, while at Balasan forest channel width has increased from 446.31 m (1990) to 570 m (2017). During first 11 years (1990–2000) maximum channel width increased by 121.17 m at Guria. In next 9 years, the river Balasan experienced both increasing and decreasing trend in channel width followed by maximum increase of about 158.65 m at Kalabasti near the confluence. From 2008-2017, river width has been increased at Nayabasti (from 210.31 m to 366.3 m) followed by a reduction of 105.97 m at Rananagar. At a glance, river width is unstable along the whole lower reach, especially from Balasan forest up to the confluence due to gradual shifting of bank-line.

Past flood events and braiding nature of the channel are mainly responsible for lateral

Table 3. Change in channel width along the lower reach of the river Balasan during 1990–2017 (in metres)

Cross section	Channel width				Net changes in channel width		
	1990	2000	2008	2017	1990–2000	2000–2008	2008–2017
1	148.1	132.48	116.50	98.85	–15.62	–15.98	–17.65
2	96.4	86.77	76.30	73.85	–9.63	–10.47	–2.45
3	446.31	406.98	526.29	570.00	–39.33	119.31	43.71
4	192.44	233.36	210.31	366.30	40.92	–23.05	155.99
5	307.61	375.24	309.70	298.70	67.63	–65.54	11
6	221.31	314.19	262.91	241.20	92.88	–51.28	–21.71
7	179.19	300.36	184.61	132.90	121.17	–115.75	–51.71
8	361.31	392.52	355.37	249.40	31.21	–37.15	–105.97
9	294.62	323.6	459.70	374.10	28.98	136.1	–85.6
10	284.19	225.51	384.16	340.84	–58.68	158.65	–43.32



	1	2	3	4	5	6	7	8	9	10
🟫 Right bank	65.65	15.14	70.93	-344.2	78.13	-134.9	148.04	-144.7	-204.1	-225.6
🟧 Left bank	-10.83	11.33	-230.2	319.3	-15.85	53.34	13.75	177.85	-73.71	66.68

Figure 4. Total amount of retrogression and progression due to bank-line shifting along the lower reach of the river Balasan in metre (1990-2017)

channel migration and widening of channel width. Catastrophic flood in 1998 created a single new flood channel up to 350 m wide (Lama, 2003). Abrupt fall in gradient at debouching point and consequent channel incompetency provide a typical braided pattern to entire lower reach resulting into channel avulsion or non-systematic migration with several ephemeral bar formation and frequent flow diversion.

Amount of erosion and deposition

Frequent bank-line shifting results into both erosion and accretion along the lower reach of the river Balasan. From figure 4, maximum retrogression (indicating erosion) is observed at Nayabasti (344.19 m), followed by Nimai (134.9 m), Rananagar (144.7 m), Neelnagar (204.1 m), Kalabasti (225.6 m) along right bank and minimum at Dudhiya (10.83 m) along left bank.

Area near the debouching point is less prone to erosion due to cohesive bank material, which acts against sheer stress of channel flow eliminating the chances of lateral erosion. On the other hand, area from Balasan forest up to the confluence is more prone to erosion along its right bank which could be attributed to recurrent past flood events of the year 1991, 1993, 1998, 2000, 2004, 2007 and 2011 during the study period. Flood has a tremendous capacity to erode riverbanks by huge amount of energy engulfed within floodwater. In the peak flood flow of 1991 and 1992 there was remarkable bank erosion in the lower section of the river (De, 1998). Therefore, seasonal variability in discharge and velocity also triggers riverbank erosion. Sudden reduction in discharge after a peak flow during monsoon affects soil cohesiveness, which leads to bank erosion. On the other hand, scouring effect is enhanced by the sheer stress exerted by high flow velocity of moving fluid during peak flood period. However, presently riverbank erosion is mainly human induced in the form of bed material and near bank sediment extraction after getting government lease in 1980. Prolonged extraction on channel bed causes bed erosion, channel incision and flow

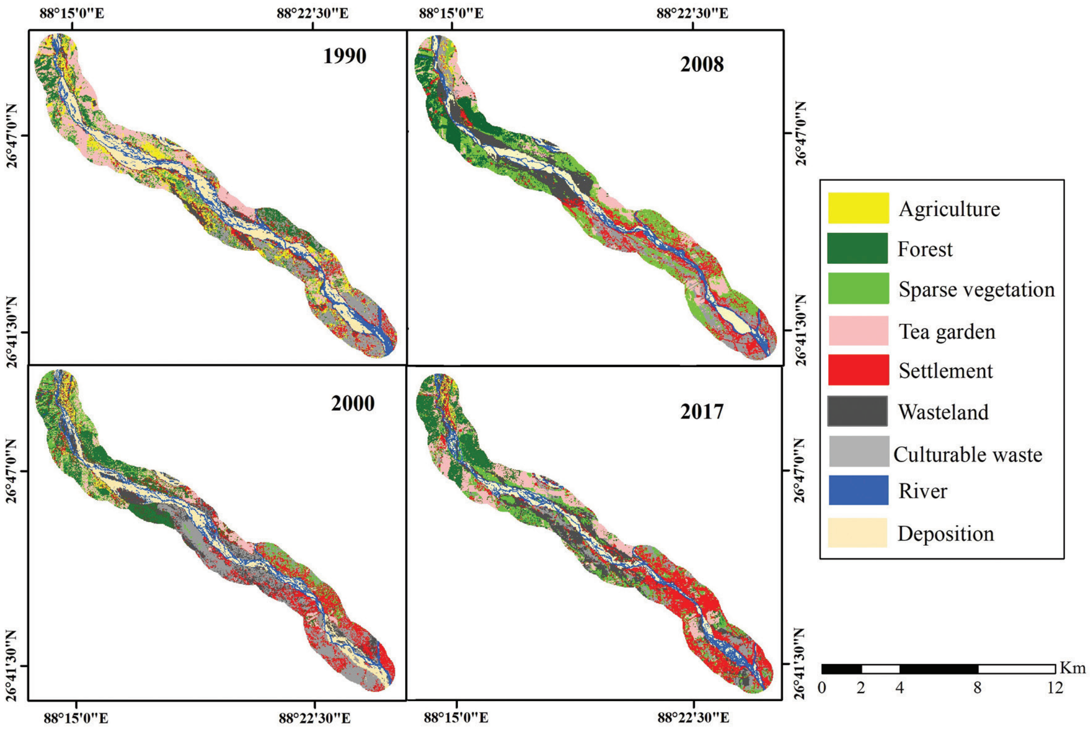


Figure 5. Land use/land cover map along the lower reach of the Balasan river within 1 km buffer from both banks of 2017 during 1990, 2000, 2008 and 2017.

diversion. During rainy season due to increase in discharge and velocity, large boulders and gravels are mostly extracted from near bank results into shifting of maximum depth towards bank which exerts sheer stress on bank failure.

LULC status

Four land use/land cover maps covering nine classes have been prepared using Landsat and Resourcesat data of different periods having different resolutions as mentioned in Table 1. The classes are agriculture, forest, sparse vegetation, tea garden, settlement, wasteland, culturable wasteland, sediment deposition and river of the year 1990, 2000, 2008 and 2017 (Fig. 5). Overall accuracy of the classified maps for the year 1990, 2000, 2008 and 2017 are 91.7%, 91.3%, 94.86% and 93.28% respectively.

Results from classified maps indicated that in 1990 area under tea garden covered highest proportion of land of about 20.01%, followed by culturable wasteland 17.21%, deposition 16.08%, agricultural land 9.87%, forest 9.43%, river 9.41%, and settlement 7.2%. In 2000, about 2.47% and 8.39% of the area was covered by agricultural land and tea garden against 9.87% and 20.01% area in 1990 respectively showed a decrease in area under cultivated land and tea garden (Table 4). On the other hand, area under culturable waste, wasteland, forest and settlement increased up to 2.78 km^2, 3.93 km^2, 2.38 km^2 and 3.69 km^2 from 1990 to 2000 (Fig. 6). Results from the classified image of 2008 illustrate that more than 25% of the area was covered by culturable waste and wasteland collectively, whereas agriculture shared only 0.99% of land out of total land cover. Settlement covered 13.55%, forest occupied 10.34%, while tea garden covered 9.76%

Table 4. Area under different land use/land cover classes along the lower reach of the river Balasan within 1 km buffer from both banks of 2017 during 1990–2017

LULC classes	1990		2000		2008		2017	
	Area(km^2)	Area (%)	Area(km^2)	Area (%)	Area(km^2)	Area (%)	Area(km^2)	Area (%)
Agriculture	5.67	9.87	1.42	2.47	0.57	0.99	0.74	1.29
Culturable waste	9.89	17.21	12.67	22.05	7.99	13.90	6.12	10.65
Forest	5.42	9.43	7.80	13.58	5.94	10.34	6.54	11.39
River	5.41	9.41	4.36	7.59	4.17	7.25	4.74	8.25
Deposition	9.24	16.08	7.37	12.82	5.25	9.14	4.17	7.25
Settlement	4.14	7.20	7.83	13.63	7.79	13.55	11.84	20.61
Sparse vegetation	2.88	5.01	3.95	6.87	12.72	22.14	6.87	11.95
Tea garden	11.50	20.01	4.82	8.39	5.61	9.76	8.18	14.23
Wasteland	3.32	5.77	7.25	12.62	7.43	12.92	8.27	14.40
Total land	**57.47**	100	**57.47**	100	**57.47**	100	**57.47**	100

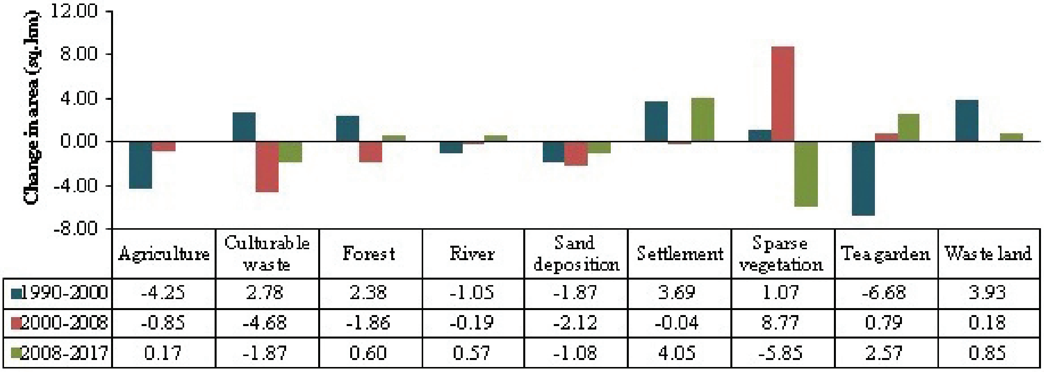
area. In 2017, the area under agriculture and tea garden has increased and covered 15.52% collectively. Area under settlement was also increased by 7.06% during 2008-2017 (Table 4).

Land use/land cover change matrix

To detect, identify and measure the nature and areal extent of change, LULC change matrix has been prepared for the periods 1990-2000, 2000-2008 and 2008-2017 shown in Table from 5-7. The values shown in bold letters indicates no change in LULC categories.

LULC CHANGE OVER 1990–2000

For the period 1990-2000 major change was observed under agricultural land, which reduced by 4.25 km^2, almost 75% of land out of total agricultural land in 1990. Most



	Agriculture	Culturable waste	Forest	River	Sand deposition	Settlement	Sparse vegetation	Tea garden	Waste land
🟦1990-2000	-4.25	2.78	2.38	-1.05	-1.87	3.69	1.07	-6.68	3.93
🟥2000-2008	-0.85	-4.68	-1.86	-0.19	-2.12	-0.04	8.77	0.79	0.18
🟩2008-2017	0.17	-1.87	0.60	0.57	-1.08	4.05	-5.85	2.57	0.85

Figure 6. Net change in the area under different land use/land cover classes along the lower reach of the river Balasan within 1 km buffer from both banks of 2017 during 1990– 2017.

Table 5. Land use/land cover change matrix for the period 1990–2000 (km^2)

LULC classes		2000									
		Agriculture	Culturable waste	Forest	River	Deposition	Settlement	Sparse vegetation	Tea garden	Wasteland	Grand Total 1990
1990	Agriculture	**0.52**	1.67	0.69	0.09	0.07	0.97	0.44	0.47	0.74	5.67
	Culturable waste	0.04	**5.05**	0.19	0.08	0.21	2.82	0.35	0.12	1.03	9.89
	Forest	0.10	1.17	**1.79**	0.11	0.05	0.81	0.70	0.33	0.36	5.42
	River	0.06	0.54	0.04	**1.71**	2.11	0.18	0.02	0.00	0.75	5.41
	Deposition	0.02	0.72	0.03	1.93	**4.52**	0.08	0.00	0.00	1.94	9.24
	Settlement	0.13	1.33	0.18	0.14	0.14	**1.37**	0.20	0.10	0.55	4.14
	Sparse vegetation	0.13	0.59	0.84	0.03	0.03	0.39	**0.22**	0.34	0.28	2.88
	Tea garden	0.29	0.47	3.92	0.07	0.02	0.89	1.96	**3.41**	0.47	11.50
	Wasteland	0.12	1.16	0.11	0.21	0.22	0.28	0.05	0.05	**1.12**	3.32
	Grand Total 2000	1.42	12.67	7.80	4.36	7.37	7.83	3.95	4.82	7.25	57.47

of the area under agriculture at Panighata, Nayabasti, Balasan forest, Tarabari, Tari changed to waste (0.7 km^2) and culturable waste (1.67 km^2) land which is collectively more than 42% out of total agricultural land in 1990. 2.82 km^2 area of land transformed from culturable waste to settlement mainly at Nayabasti-I, Nayabasti-II, Nayabasti-III, Dhemal followed by a remarkable overall increase up to 89 % (3.69 km^2) area against the total land under settlement in 1990. A great extent of land, 1.94 km^2, under wasteland has been emerged from previously deposited area (Table 5).

LULC CHANGE OVER 2000–2008

Within 2000-2008 area under sparse vegetation increased up to 8.77 km^2 and most of the land changed from culturable waste (3.39 km^2). Culturable waste and permanent wasteland have been found at some patches beside riverbank, used neither for agriculture, tea garden nor for settlement. Agricultural land again decreased by 0.85 km^2 which is almost 60% out of total agricultural land in 2000 followed by 0.55 km^2 of land change to culturable waste and wasteland collectively. Almost 23% (2.90 km^2) out of total culturable wasteland in 2000 changed to settlement.

During these 9 years period, area under almost in every category had a negative growth, except wasteland, tea garden and sparse vegetation due to recurrent flood events (Table 6).

LULC CHANGE OVER 2008-2017

During 2008–2017, area under settlement followed the same increasing trend as before. Almost 52% of the total land under settlement in 2008, changed mainly from culturable wasteland (2.97 km^2) and sparse vegetation (3.05 km^2). Agricultural land increased at a negligible amount, among which 0.17 km^2 mainly changed from culturable wasteland (0.27 km^2). On the other hand, area under sparse vegetation followed a negative growth of about 5.85 km^2 of area, among which 3.05 km^2 changed to settlement. Area under tea

Table 6. Land use/land cover change matrix for the period 2000–2008 (km^2)

LULC classes		2008									
		Agriculture	Culturable waste	Forest	River	Deposition	Settlement	Sparse vegetation	Tea garden	Wasteland	Grand Total 2000
2000	Agriculture	**0.18**	0.36	0.12	0.04	0.02	0.08	0.35	0.06	0.19	1.42
	Culturable waste	0.06	**3.71**	0.02	0.21	0.29	2.90	3.39	0.59	1.51	12.67
	Forest	0.09	0.11	**3.66**	0.03	0.01	0.34	2.12	0.64	0.81	7.80
	River	0.02	0.24	0.07	**1.29**	1.23	0.50	0.22	0.02	0.79	4.36
	Deposition	0.01	0.17	0.00	2.11	**3.14**	0.52	0.07	0.00	1.33	7.37
	Settlement	0.05	2.08	0.21	0.09	0.04	**1.82**	2.41	0.87	0.26	7.83
	Sparse vegetation	0.05	0.10	0.90	0.02	0.00	0.36	**1.18**	1.21	0.12	3.95
	Tea garden	0.03	0.14	0.88	0.01	0.00	0.08	1.59	**1.98**	0.11	4.82
	Wasteland	0.09	1.08	0.08	0.37	0.51	1.19	1.39	0.24	**2.30**	7.25
	Grand Total 2008	0.57	7.99	5.94	4.17	5.25	7.79	12.72	5.61	7.43	57.47

garden is increased up to 2.57 km^2. About 4.02 km^2 changed from forest and sparse vegetation collectively (Table 7).

Table 6. Land use/land cover change matrix for the period 2000–2008 (km^2)

LULC classes		2008									
		Agriculture	Culturable waste	Forest	River	Deposition	Settlement	Sparse vegetation	Tea garden	Wasteland	Grand Total 2000
2000	Agriculture	**0.18**	0.36	0.12	0.04	0.02	0.08	0.35	0.06	0.19	1.42
	Culturable waste	0.06	**3.71**	0.02	0.21	0.29	2.90	3.39	0.59	1.51	12.67
	Forest	0.09	0.11	**3.66**	0.03	0.01	0.34	2.12	0.64	0.81	7.80
	River	0.02	0.24	0.07	**1.29**	1.23	0.50	0.22	0.02	0.79	4.36
	Deposition	0.01	0.17	0.00	2.11	**3.14**	0.52	0.07	0.00	1.33	7.37
	Settlement	0.05	2.08	0.21	0.09	0.04	**1.82**	2.41	0.87	0.26	7.83
	Sparse vegetation	0.05	0.10	0.90	0.02	0.00	0.36	**1.18**	1.21	0.12	3.95
	Tea garden	0.03	0.14	0.88	0.01	0.00	0.08	1.59	**1.98**	0.11	4.82
	Wasteland	0.09	1.08	0.08	0.37	0.51	1.19	1.39	0.24	**2.30**	7.25
	Grand Total 2008	0.57	7.99	5.94	4.17	5.25	7.79	12.72	5.61	7.43	57.47

Table 7. Land use/land cover change matrix for the period 2008–2017 (in km^2)

	LULC classes	**2017**									
		Agriculture	Culturable waste	Forest	River	Deposition	Settlement	Sparse vegetation	Tea garden	Wasteland	Grand Total 2008
2008	Agriculture	**0.14**	0.03	0.11	0.01	0.00	0.09	0.06	0.08	0.05	0.57
	Culturable waste	0.27	**1.72**	0.10	0.04	0.03	2.97	1.12	0.28	1.45	7.99
	Forest	0.02	0.15	**3.54**	0.02	0.00	0.13	0.36	1.69	0.01	5.94
	River	0.03	0.07	0.02	**1.83**	1.21	0.61	0.09	0.01	0.31	4.17
	Deposition	0.04	0.04	0.00	2.09	**2.21**	0.31	0.05	0.00	0.49	5.25
	Settlement	0.04	0.78	0.38	0.19	0.25	**3.88**	0.64	0.16	1.49	7.79
	Sparse vegetation	0.07	2.02	0.96	0.04	0.06	3.05	**2.33**	2.72	1.48	12.72
	Tea garden	0.03	0.38	1.21	0.00	0.01	0.42	0.68	**2.77**	0.12	5.61
	Wasteland	0.09	0.94	0.22	0.52	0.39	0.37	1.55	0.47	**2.88**	7.43
	Grand Total 2008	0.74	6.12	6.54	4.74	4.17	11.84	6.87	8.18	8.27	0.57

OVERALL CHANGE (1992–2017)

From the following change matrix in table 8, major changes in different land use/land cover during these 28 years of period have

Table 8. Land use/ land cover change matrix of the study area in km^2 (1990-2017)

	LULC classes	**2017**									
		Agriculture	Culturable waste	Forest	River	Deposition	Settlement	Sparse vegetation	Tea garden	Wasteland	Grand Total 1990
1990	Agriculture	**0.25**	0.79	0.30	0.09	0.07	1.23	0.88	1.09	0.98	5.67
	Culturable waste	0.02	**2.54**	0.10	0.12	0.05	3.94	1.38	0.27	1.45	9.89
	Forest	0.05	0.79	**1.92**	0.03	0.01	1.09	0.77	0.43	0.33	5.42
	River	0.08	0.22	0.03	**1.78**	1.16	0.95	0.36	0.04	0.80	5.41
	Deposition	0.05	0.14	0.03	2.33	**2.62**	1.25	0.78	0.02	2.01	9.24
	Settlement	0.05	0.44	0.08	0.15	0.06	**1.88**	0.55	0.21	0.73	4.14
	Sparse vegetation	0.06	0.41	0.60	0.02	0.01	0.34	**0.48**	0.66	0.31	2.88
	Tea garden	0.09	0.56	3.42	0.03	0.01	0.47	1.27	**5.35**	0.30	11.50
	Wasteland	0.09	0.23	0.06	0.19	0.17	0.69	0.41	0.10	**1.36**	3.32
	Grand Total 2008	0.74	6.12	6.54	4.74	4.17	11.84	6.87	8.18	8.27	57.47
	Net Change	-4.93	-3.77	1.12	-0.67	-5.08	7.70	3.99	-3.32	4.96	

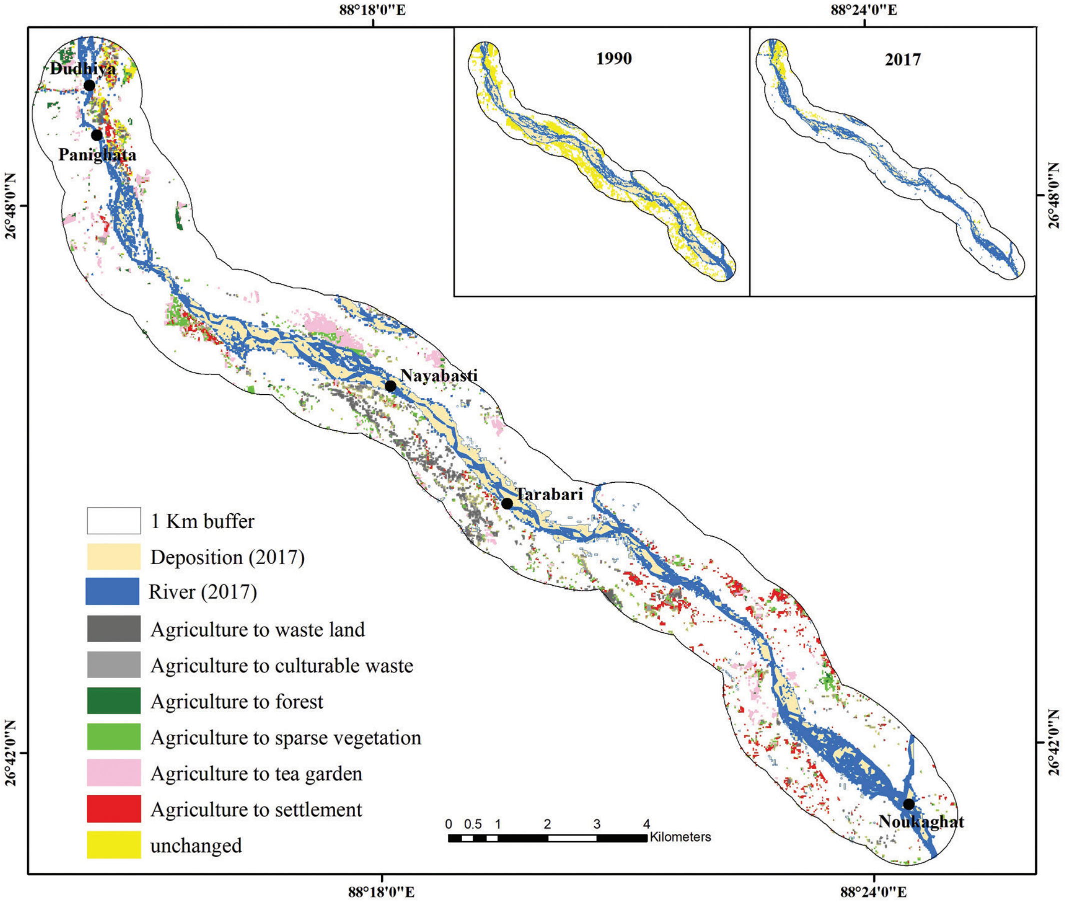


Figure 7. From-to' map showing changes in agricultural land to other land use/land cover along the lower reach of the river Balasan within 1 km buffer from both banks during 1990-2017 (agricultural land in 1990 and 2017 inset)

been identified, such as —

i) The major affected area was agriculture. Only 0.25 km^2 (4%) remained unchanged and almost 87% area reduced out of total agricultural land (5.67 km^2) in 1990. From agricultural land 1.23 km^2 converted into settlement, 1.09 km^2 to tea garden, 0.98 km^2 to wasteland and 0.79 km^2 to culturable wasteland. Transformation of cultivable land into wasteland is due to recurrent flood events in the year 1968, 1978, 1993, 2000, 2003 and 2007. Submergence of land and large-scale deposition of sand in field due to flood and associated riverbank erosion is the main reason behind reduction of agricultural land and conversion into infertile depositional land, remained as waste and culturable wasteland at places like Panighata, Nayabasti, Balasan forest, Tarabari, Tari (Fig. 7 and Plate 1).

ii) The concerned area under the settlement changed by 0.15 km^2, 0.55 km^2, and 0.73 km^2 to river, sparse vegetation and wasteland respectively. 28.26 % of land out of total land under settlement in 1990 changed to wasteland and culturable wasteland collectively. After losing fertile land hundreds of households shifted from riverbank side and some of them left the place in search of another livelihood remaining the area as wasteland (Fig. 8). Dwelling houses have been shifted by 100 m from the riverbank-line along left

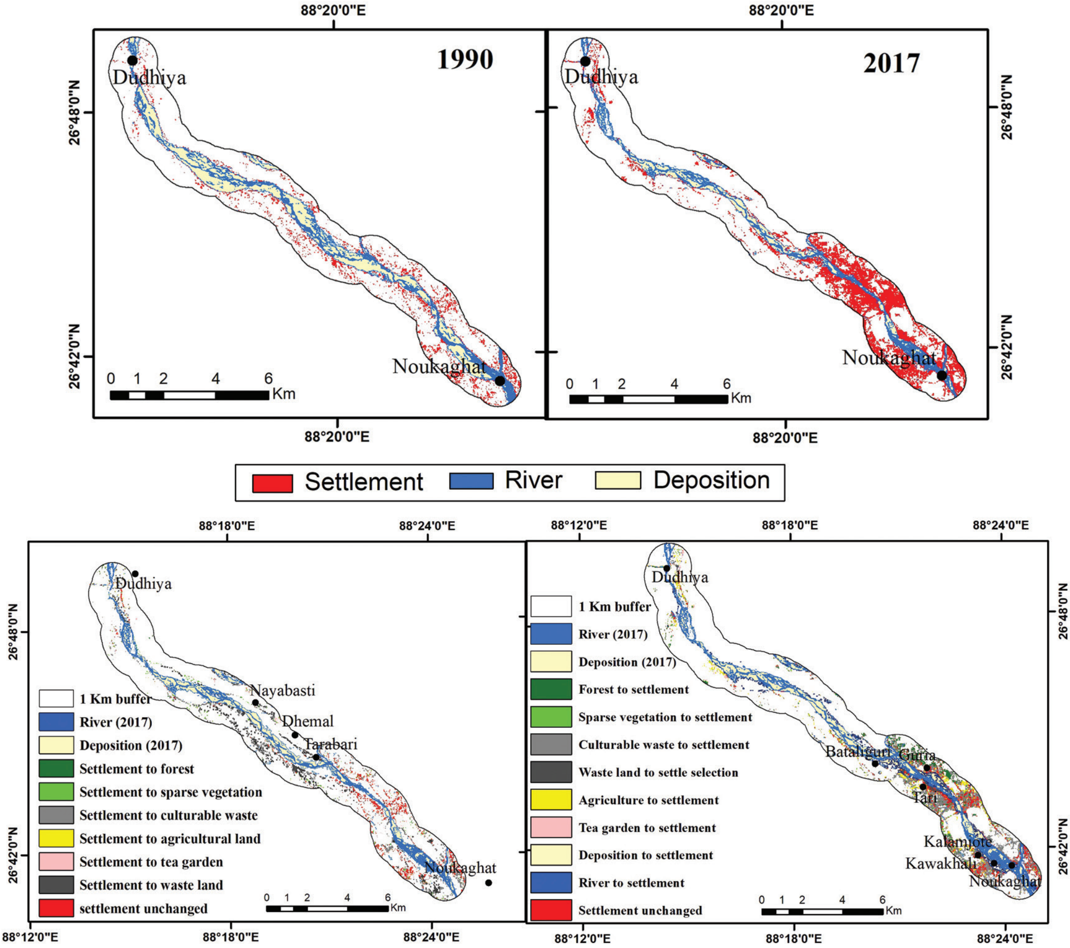


Figure 8. Area under settlement in 1990 (A), in 2017 (B), 'from-to' map showing changes from settlement to other LULC (C) and from other LULC to Settlement (D) along the lower reach of the river Balasan within 1 km buffer from both banks during 1990–2017

bank at Nayabasti and Tarabari. However, surprisingly almost 186% of land (7.70 km^2 against 4.14 km^2 in 1990) increased under settlement among which 1.23 km^2, 3.94 km^2, 1.09 km^2, and 1.25 km^2 area converted from agricultural land, culturable waste, forest and deposition. Emergence of new settlements on the land beside riverbank and even on river bed near confluence specially at Nimai, Guria, Kalabasti, Rananagar, Neelnagar, Noukaghat, Kolughat because of active siltation process by the eroded materials (Fig. 8, Plate 1). Most of the settlements are temporary and inhabitants are engaged into sand mining and quarrying activity in the river Balasan. Rapid urbanization in and around Siliguri municipality triggers this situation. Noukaghat, the confluence point between the river Mahananda and Balasan is situated only about 9.5 km away from Siliguri Municipality.

iii) The maximum amount of land under tea gardens of about 5.35 km^2 (47%) remained unchanged. Due to safe and distant position riverbank erosion could hardly affect area under tea garden except some patches along the left bank near Gouri (Plate 1). Instead, 3.32 km^2 area reduced under tea gardens.

Table 9. Amount of riverbank-line shifting and conversion of different land use/land cover into river and deposition in m^2 along the lower reach of river Balasan (1990-2017)

Amount of river bank line shifting (m)		Conversion of different LULC into river and deposition between every consecutive cross-section area (m2)									
CS sites	Type of shifting	Amount of shifting (m)	Area between CS	Type of land conversion	Agriculture	Forest	Sparse vegetation	Tea garden	Wasteland	Culturable wasteland	Settlement
1	Retrogression	–10.8	1 & 2	River	2634.2	2647.3	1738.0	–	1289.2	1717.5	3121.2
	Progression	-		Deposition	-	-	-	-	-	-	-
2	Retrogression	-	2 & 3	River	8157.5	4407.9	2412.0	-	14333.8	3085.1	6763.1
	Progression	11.3		Deposition	1146.7	2233.2	709.3	-	1661.3	2704.1	59.4
3	Retrogression	–522.1	3 & 4	River	51220.7	3468.7	8170.0	12305.6	55064.5	12986.2	31030.9
	Progression	-		Deposition	43971.6	1316.0	3711.1	4035.1	67728.9	1747.3	18193.7
4	Retrogression	–462.3	4 & 5	River	7790.7	4661.3	272.3	-	21515.2	8922.3	21762.9
	Progression	324.3		Deposition	15848.3	1681.3	1246.5	-	54322.6	17368.4	20597.4
5	Retrogression	–221.2	5 & 6	River	7864.7	9827.6	1445.5	7367.7	25516.1	13908.7	28266.8
	Progression	-		Deposition	4399.5	5935.0	294.3	291.3	24237.7	4587.6	12002.9
6	Retrogression	–287.9	6 & 7	River	13.1	-	-	-	3885.6	279.4	1402.9
	Progression	53.3		Deposition	58.8	-	-	-	998.0	239.3	221.5
7	Retrogression	-	7 & 8	River	1257.8	429.7	-	157.6	20795.1	8027.8	20567.3
	Progression	13.6		Deposition	3434.0	1980.5	1049.8	5975.9	12279.5	11544.8	4631.9
8	Retrogression	–346.1	8 & 9	River	631.1	-	-	-	8538.4	5322.3	11263.3
	Progression	184.7		Deposition	577.8	713.3	-	-	0.6642	5827.3	2187.1
9	Retrogression	–396.0	9 & 10	River	857.7	-	-	41.4	5084.7	3258.1	22269
	Progression	-		Deposition	-	-	-	-	-	269.3	-
10	Retrogression	–358.7									
	Progression	71.0									

Building construction in place of tea gardens is responsible for such reduction. 3.42 km^2, 1.27 km^2, 0.47 km^2 area got changed from tea garden to forest, sparse vegetation and settlement respectively.

iv) About 5.5%, 1.4%, 63.2% of land under forest changed to agricultural land, settlement and tea gardens respectively. Human encroachment toward inland from the riverbank and resettlement of economic activities by deforestation indirectly affect the forest cover (Dumriguri, Dhemal).

Comparison between amount of riverbank-line shifting and LULC change

To understand the impact of riverbank erosion on land use/ land cover more precisely table 9 has been generated comparing the amount of riverbank-line shifting across every cross

Table 10. Perception of the flood plain dwellers regarding impact of riverbank erosion on land use/land cover along the lower reach of the river Balasan (1990-2017)

1.Type of affected land (1990-2017)				
In-depth interview			Focus Group Discussion	
Type of land	% of respondents	Total	% of participants	Total
Agricultural field	45	100	48	100
Dwelling house	35		40	
Tea garden	20		12	
2. Amount of agricultural land loss (1990-2017)				
In-depth interview			Focus Group Discussion	
Amount of land (acre)	% of respondents	Total	% of participants	Total
<20	40	100	36	100
20-40	50		48	
>40	10		16	
3. Shifting of housing from riverbank (1990-2017)				
In-depth interview			Focus Group Discussion	
Shifting in metre	% of respondents	Total	% of participants	Total
<25	40	100	40	100
25-50	30		32	
50-75	20		16	
>75	10		12	
4. Number of damaged house due to flood and riverbank erosion (1990-2017)				
In-depth interview			Focus Group Discussion	
Number of damaged houses	% of respondents	Total	% of participants	Total
<20	10	100	12	100
20-40	20		20	
40-60	40		44	
>60	30		24	
5. Present use of land beside riverbank				
In-depth interview			Focus Group Discussion	
Factors	% of respondents	Total	% of participants	Total
Settlement	60	100	56	100
Agriculture	10		12	
Wasteland/ no use	30		32	

section with the amount of different land use/land cover converted into river and deposition within the area between every successive cross section in the present study area. It is clear from the table that higher the amount of retrogression of bank-line more the conversion of land to river. Cross-section 3, 4, 5 experienced a higher amount

Plate 1: Impact of riverbank erosion on various land use/land cover along the lower reach of the river Balasan within 1 km buffer from both banks: (A) present agricultural practice near Dudhiya bridge, (B) wasteland at Panighata, (C) Damage of tea garden at Gouri, (D) vulnerable condition of riverbank at Nimai, (E) Sedimentation at Kalabasti near confluence, (F) Settlement over flood plain at Noukaghat.

of retrogression of 522.08 m, 462.32 m, and 221.5 m respectively which indicates erosion. Similarly, the area under agriculture, tea gardens, settlement between corresponding cross sections also converted to river at a greater extent. The same thing happens in the cross section 8, 9, 10 near confluence.

Perception of local inhabitants

Along with analysis of multi-dated satellite images in GIS environment, a field-based detailed perception study among the local inhabitants in the form of in-depth interview and FGD has been conducted to know the impact of riverbank erosion on present day land use/land cover pattern in the concerned study area. Table 10 depicts that 45% of respondents during in-depth interviews opined that agricultural land is the major affected area under riverbank erosion and 30% of respondents during in-depth interviews and 32% participants during FGDs opined that there is presence of wasteland beside riverbank used as fertile land for agriculture earlier. Among the respondents, 40% respondents between Nayabasti and Tarabari possess the opinion that on an average less than 8 hectares of land, 10% have the opinion that more than 16 hectares of land has destroyed due to bank erosion at Nayabasti-1 (32 hectare), Nayabasti-2 (26 hectare), Tarabari (6 hectare). Fifty percent of respondents in lower stretch stated that 8-16 hectare of agricultural land had been lost at Panighata (12 hectare), Dudhiya (8 hectare), whereas 16% of participants during FDGs opined that more than 16 hectares of land lost by bank erosion and flood during 28 years of period. During opinion survey 10% of respondents stated that dwelling houses have been shifted more than 75 m, especially at Nayabasti- 1, 2, 3 and Tarabari. Severe riverbank erosion also damaged number of houses. 40% and 30% of respondents during in-depth interviews stated that 40 to even more than 60 houses had been washed away at Rananagar (75) and Neelnagar (50), while 24% and 44% of participants during FGD revealed that more than 60 and 40-60 numbers of houses had been damaged at Nayabasti- 1, 2, 3 and Tarabari. Only 12% of the participants in focus group discussion supported that due to riverbank erosion area under tea gardens has been reduced.

Conclusion

This study assessed the impact of riverbank erosion on land use/land cover along the lower reach of the river Balasan. The result reveals that riverbank erosion is mostly predominant from Nayabasti to Guria where human interference is maximum in terms of sand mining quarrying activities. This process will be continued until the fluvial processes are active and human interventions are continued. Local people also possess the opinion that any change in river dynamics and flow regime effectively alternates the land use/land cover pattern over flood plain. Agricultural land has been identified as the major affected area with remarkable decrease of almost 87% during 1990–2017 out of total agricultural land in 1990. Most of the land under agriculture decreased either by submergence of land or large-scale deposition of sand over field turning it into wasteland which was extensively used as a fertile land earlier, especially at Panighata, Nayabasti, Dhemal, Tarabari, Bataliguri, Lalsara Chhat, Neelnagar and Rananagar with major cultivated crops like paddy, maize, wheat, sesame. After losing the fertile land people left the place remaining the land under settlement as wasteland too. Due to lack of proper initiative for land reclamation, the area under wasteland is increasing day by day. On the other hand, new settlements are emerging downstream due to active siltation process. Since most of the inhabitants are Bangladeshi migrants and engaged in sand mining and quarrying activities, they choose to settle along the riverbank or near the confluence for nearness of extraction sites. Urban sprawl and continuous expansion of Siliguri municipality also trigger this situation. Thus, forced migration, changes in livelihood pattern could affect the social and demographic structure through deterioration in infrastructural facilities and living standard, emergence of crimes and illegal activities. Therefore, changes in land use/land cover pattern in association with riverbank erosion could be utilised as an indicator of evaluating socio-economic impact of fluvial hazards and prerequisite for mitigation of such hazards with proper implementation of flood plain management programme.

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