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Monitoring changing course of the river Ganga and land-use dynamicity in Manikchak Diara of Malda district, West Bengal, India, using geospatial tools

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Abstract Dynamicity of the river Ganga introduces significant changes in the land-use character of active alluvial plain of West Bengal, India. The dynamicity of the river Ganga is caused due to continuous sedimentation and formation of char land which frequently changes the flow direction and flow velocity of running water as well as causes the shifting of the bank line due to active bank erosion processes in the upstream of Farakka Barrage. Bank line shifting was estimated with the help of 25 transects since 1973–2011. A large-scale land erosion (38.6 sq. km area) occurred due to the bank line shifting which observed in Godai, Kesharpur, Rambari, Hiranandapur, Mathurapur, Manikchak, Samastipur, Dakshin Chandipur, and Gopalpur mouzas of Manikchak block, whereas deposition (2.4 sq. km area) was found in Chandipur Tofi Narayanpur and Govindapur mouzas. Such erosion and deposition invited a lot of changes in land-use statistics. Land-use–land-cover maps were prepared using supervised image classification techniques and validated through kappa statistics (kappa coefficient 0.803 and 0.892 for the year 1994 and 2016, respectively). Land-use change detection technique was used to identify the transformation of land-use character from one feature to another. This study revealed that a notable area of settlement (5.07 sq. km) and vegetation cover (6.84 sq. km) was converted into water body as a result of bank erosion. Loss of agricultural land and homestead led to the loss of livelihood and introduced internal migration. The observed pattern of river dynamics and the consequent land-use change in the recent decades have shown newer environmental challenges to the coping capabilities of the rural inhabitants.

Keywords Manikchak Diara · Bank erosion · Land use and land cover · Supervised image classification · Kappa coefficient · Change detection

1 Introduction

Soil erodibility and climatic erosivity are the main controlling factors of bank erosion [1–3]. Bank erodibility factors were determined by the engagement of soil characteristics and river regime, e.g., bank height in relation to bankfull depth, bank angle, density of root cover of the plants on the bank, soil stratification and particle size [4].

Channel migration and river bank erosion, a subject of core geomorphology, have been studied by various scholars in last few years [5–9]. Bank erosion of the Ganga is a dynamic phenomenon which occurred due to morphometric change in the upstream of Farakka Barrage up to Rajmahal [10]. River bank line shifting of Ganga at Manikchak Diara adjacent to Malda district in India is studied in this work using geographical information system (GIS) techniques. River dynamics have played a vital role in river draining in Gangetic plain and are particularly severe in the eastern plains from where the most noticeable histories of fluvial dynamics have been marked out [11, 12]. An alluvial rivers such as lower plain of Ganga River is subjected to change its flow path frequently and making a geomorphic instability connected to "geomorphic risk" [13, 14].

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Extreme western portion of Manikchak block of Malda district of West Bengal, India, is highly affected by bank erosion from 1973 to 2011 covering the mouzas (a mouza map is very important as it comprises the boundaries of all land parcels and contains methodically arranged information line the ownership, land use and area details) of Godai, Manikchak, Narayanpur, Gopalpur, Gobindapur, Dharampur, Jot Bhabani, Rambari, Shovanagar, Dergrama, Masahat, etc. The maximum encroachment caused due to bank erosion is around 4500 m. The study revealed that most of the area along the river bank is affected by bank erosion which has brought a tremendous threat to human life and property and terrestrial land as well [15]. The changing river course causes bank erosion which invites a disastrous situation in the region. The bank erosion-induced land destruction and development of new land due to accretion were common phenomena in the Upstream of Farakka Barrage [16]. Both erosion and accretion of land are the normal characteristic features of a major river system [17, 18]. But there will be a chance when the Ganga has gone back to its previous course after reaching the maximum limit of its meander belts. But the specific time for these reversals is very tough to determine [16].

The alternation of land loss and gain is simultaneously entertained by the action of river dynamics [19]. This type of change in terrestrial land directly affects the land use and land cover. Land-use and land-cover (LULC) change detection is very crucial for better understanding the landscape dynamics during a familiar time span for sustainable resource management [20–23]. Remote sensing and GIS (geographical information system) tools and the preparation of LULC mapping have given a fruitful and time-saving way for delineating areas, i.e., vegetation, agricultural land, settlement, water body, within a region [24]. Different kinds of supervised classification methods have been adopted by several scholars for analyzing the LULC change detection [25] throughout the world. The success of these techniques depends on background knowledge and personal experience of user about the study area. This paper is the manifestation of the impact of the river bank erosion-induced land loss and the dynamicity of land use and land cover in the Manikchak Diara, upstream of Farakka Barrage, West Bengal. The river shifting in the area is not just a major engineering problem but also a serious social issue impacting land relocation, population displacement and border disputes. In the present work, the land loss has been estimated since 1973–2011 using remote sensing and geographical information system platform and a land loss vulnerable zonation map was made accordingly. Then, LULC change detection has been made for analyzing the resultant impact of bank erosion on land-cover dynamics. The present study not only identified bank line shifting because of bank erosion, but also prepared vulnerability zones of the concerned region to execute better management options for Manikchak Diara of Gangetic alluvial plains. The main aims of the study are to assess the bank line shifting of river Ganga since 1973–2011, to estimate land loss due to bank erosion, to prepare bank erosion vulnerable zones and to prepare a statistical data base on land-use dynamicity.

2 Study area

Malda district of West Bengal is located in the Indo-Bangladesh border having a total area of about 3733 km^2 (Census, 2001). The district is consisting of 15 blocks. Western side of the district is bounded by the river Ganges where the bank erosion occurs in a frequent manner. The study area, Manikchak block, is located under the Sadar Division of Malda district (Fig. 1) consisting a total population of 2,40,123 (Census 2001). The study area extends from 24°51′N to 25°14′N and 87°46′E to 88°06′E. Manikchak block comprises 11 gram panchayats, 104 villages and 89 mouzas (Fig. 1). The number of female population displaced by bank erosion till 2001 is 17,017 and to that of male population is 18,126 [26, 27], and it is reported that around 750 km^2 land area was lost in last 30 years from Manikchak and Kaliachak blocks. Majority of the population in Manikchak block belongs to Hindu community. Around 49% of the total population engaged in agriculture and belongs to the category of landless laborers. Around 18.5% women population are engaged in agricultural activities which are being affected by bank erosion.

In Manikchak block of Malda district, 15 mouzas were getting affected by river bank erosion since 1978 where 3330 families were affected by land loss. At present, the bank erosion is being found in some selected mouzas of Narayanpur, Balutola, Gopalpur, Dharampur, Dakshin Chandipur, etc. The emerged char land on the river bed is also getting affected in the present day and inviting the loss of vegetable and agricultural land in Manikchak [15]. In the study area, bank erosion occurs twice in a year. One occurs in pre-flood period, and another one is in post-flood period. Pre-flood situation causes a high pressure of increasing water on the bank walls. In post-flood situation, the stagnated water seeps as groundwater through weak and porous soil in the left bank and finally weakens and dissects the bank deep rooted. So, after the recession of flood water, left bank collapses in chunks [28].

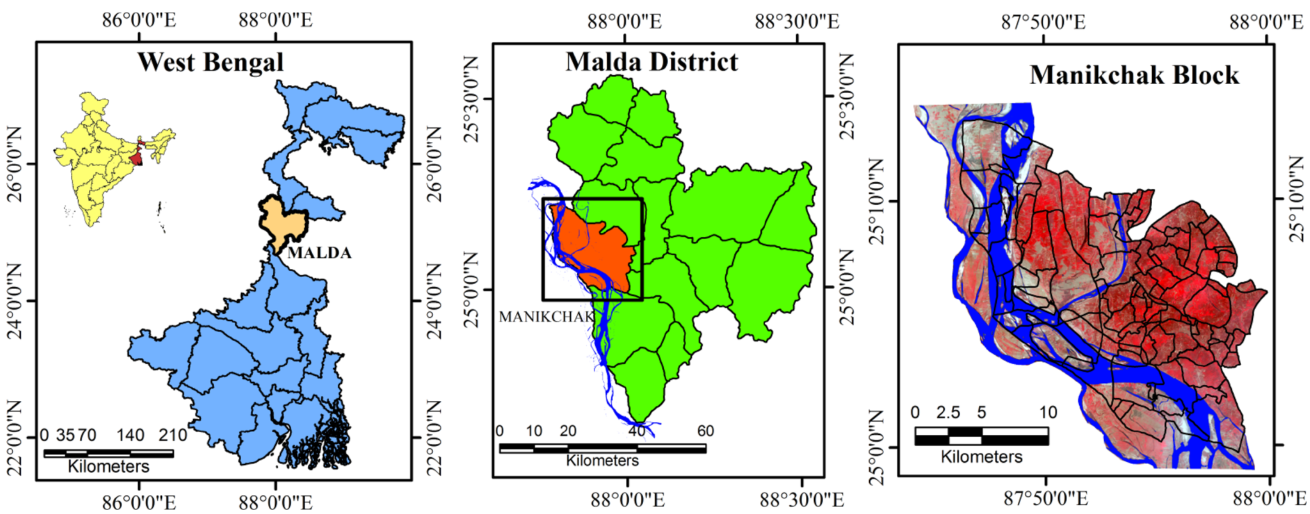


Fig. 1 Location map of the study area

3 Database and methodology

3.1 Database preparation

Satellite data were used in the study to assess land loss and prepare LULC map. LULC map was validated by ground truth using global positioning system (GPS). Satellite images of Landsat MSS (Multispectral Scanner System) for the year of 1973, Landsat TM 5 (Thematic Mapper) for the year of 1996, 2011 and Landsat OLI (Operational Land Imager) for the year of 2016 have been downloaded from USGS Earth Explorer Web site. Google earth image of 2016 was also used to clearly identify some land-use features. Topographic sheet (72-O/11 of 1974) was collected form survey of India and used to digitize river layer. The mouza map of Manikchak block was imported from BLRO (Block Land Records Office, Manikchak) office.

3.2 Assessment of the shifting course of the river

From the satellite imagery, the river course of 1973 and 2011 was digitized and then overlaid them as one over another. Thus, the displacement of the river bank line (left bank) was assessed. It is very important to know the direction of the shifting course of a channel for assessing the vulnerability zonation in connection with land loss.

3.3 Estimation of land loss and preparation of land loss zonation map

A detailed analysis on the shifting of the river course Ganga adjacent to Malda district was made with the help of raster layer acquiring from Landsat images on ARC GIS environment (software version 10.1). Landsat MSS of 1973 was digitized, and then, the mouza map was also digitized corresponding to the study area. The digitized mouza map was overlaid on the digitized classified map of 1973 to assess the actual area under land and water at mouza level. The same process continued for the year 2011 on Landsat TM 5. Finally, the changes in the areal extent of the land were estimated considering the mouza from the images of 1973 and 2011. On the basis of estimated land loss, a bank erosion vulnerable zonation map was prepared and it was classified into high, medium and low vulnerable zones. Such classification was made on the basis of the amount of land loss, and three zones were segregated by equal interval method. Bandyopadhyay [29] documented the necessity of vulnerability zonation caused by bank erosion in the case management. Mouza-wise land gain was also calculated to understand the land-use dynamics.

3.4 Method for land-use classification and accuracy assessment

In the present study, pixel-wise signatures were collected and stored in signature files. The digital numbers (DNs) of each pixel then converted to radiance values [30, 31]. Object-based classification was used for differentiating land features [32, 33]. To work out LULC classification, supervised classification method and maximum likelihood algorithm were applied using ERDAS Imagine 9.2 Software and suitable sensing data (digital number) were used accordingly. Vegetation, seasonal agricultural land, permanent agricultural land, built-up land, water body, wetted area and fallow land were classified in the LULC. Different types of features were identified from the signature collection from ground truth as well as Google earth image. Here vegetation class implies not only the typical forest region, but also considered orchard and plantation according to the need of the study. Chakraborty et al. [34], Pal and Ziaul [35] also used same approach for classifying vegetation. Seasonal agricultural land was identified by comparing pre- and post-monsoon NDVI images of particular time frame following the threshold used by Saha and Pal [36]. The supervised classification method is based on the probability that a pixel belongs to a particular class. The basic theory assumes that these probabilities are equal for all classes where input bands have normal distributions. However, this method needs long time of computation, which relies heavily on a normal distribution of the data in each input band and tends to over-classify signatures with relatively large values in the covariance matrix. It requires the least computational time among other supervised methods and the pixels that should not be classified without class variability. Based on the ground truth, the misclassified areas were corrected using recode option in ERDAS Imagine. The error matrix and kappa statistics methods were used to assess the mapping accuracy.

The assessment of supervised classification accuracy of 1994 and 2016 images was made to determine the quality of information derived from the data. For delineating the change detection of classified image, the accuracy assessment must have done for individual classification within an image [36]. Totally, 225 sample sites from Google earth and ground truth were selected for an accuracy assessment. The percentage of overall accuracy [35] was calculated using the following formula:

$$\text{Overall accuracy} = \frac{\text{Total number of cotrrect samples}}{\text{Total number of samples}} \times 100\% \quad (1)$$

Kappa coefficient (K) is a measure of agreement between predefined producer ratings and user assigned ratings. The calculation of kappa statistic k is as follows:

$$K = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} (X_{i+} * X_{+i})}{N^2 - \sum_{i=1}^{r} (X_{i+} * X_{+i})} \quad (2)$$

where N is the total number of pixels; r is a number of rows in the matrix; X_{ii} is the number of observation in row i and column i and x_{i+} and x_{+i} are the marginal totals for row i and column i, respectively.

Monserud and Leemans [37] suggested that 'K' values of < 0.4 represent poor or very poor type of classification, values from 0.4 to 0.55 represent fair, values from 0.55 to 0.7 represent good one, values from 0.7 to 0.85 represent very good agreement, and values higher than 0.85 represent excellent result among images.

3.5 Land-use and land-cover change detection

For performing land-use and land-cover change detection, a post-classified detection method was employed. A pixel-based comparison was used to produce a changing information on pixel basis and thus interpret the changes more efficiently taking the advantage of "conversion" information. Classified image pairs of two different dates of data were compared using cross-tabulation in order to determine qualitative and quantitative aspects of the decadal changes from 1990 to 2010. A change matrix [38] was produced with the help of ArcGis 10.1 software. Quantitative areal data of the overall land-use and land-cover changes as well as gains and losses in each category between 1994 and 2016 were then compiled. Bank erosion-induced LULC transformation in erosion vulnerable mouzas was emphasized in this study through a sequential methodology (Fig. 2).

4 Result

Erosion and deposition are a natural process in the playfield of active alluvial Gangetic plain. But, the rate of these processes varies from one fluvial environment to another one. Shifting of the river Ganga in Manikchak Diara is a common phenomenon along the left bank as the topographic expression of Ganga from Rajmahal to the vicinity of Panchanandapur area is such that the bed level from right to left bank has a transverse slope toward left bank [39]. Besides, the study area is situated at the convex part of the channel flow; thus, the general tendency of shifting of the river is in the leftward and erodes significantly in the left bank. The changing course of the river in Manikchak Diara was quantified (Table 1), and it was found that the river encroached toward the lands noticeably along the left bank since 1973–2011.

4.1 Measurement of bank line shifting

To assess the shifting bank line of the river Ganga, 25 transects were studied and it was found that the north-western part of Bhutni Char and the southern part of Manikchak Ghat are attributed with severe river erosion. Maximum shifting (Table 1) occurred along the cross sections A, B and C (4.3 km, 3.5 km and 2.8 km) in the northern part and along the cross sections T, X and Y (2.2, 2.27 and 2.26 km) in the southern part of Manikchak Diara toward left bank (eastward direction). The basins of northeastern India were tilted south-eastward direction due to the independent tectonic movement of Indian plate [40, 41]. Pronounced right-hand shifting observed along the cross sections L, M and N (Fig. 3). The concave portion of a river always has a chance to store some amount of deposition [42, 43]. Thus, a bank line shifting causes a joint action of erosion and deposition and makes significant river dynamicity [19].

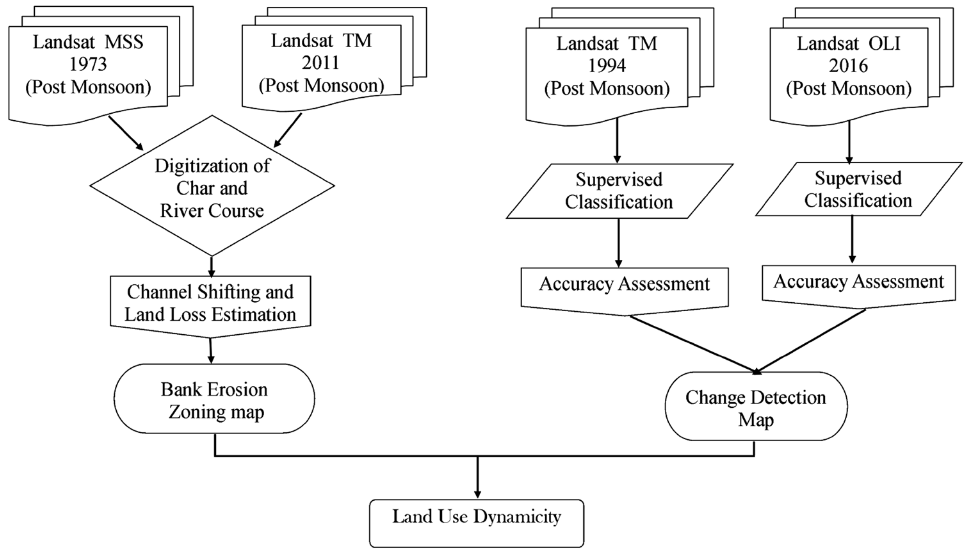


Fig. 2 Workflow of the methodology

Table 1 Shift of bank line from 1973 to 2011

Point	Distance (m)	Direction
A	4334.086668	Left
B	4324.736579	Left
C	3568.658641	Left
D	2816.168455	Left
E	2325.439163	Left
F	2198.759767	Left
G	1844.1122	Left
H	1776.992112	Left
I	1064.742491	Left
J	767.553728	Left
K	366.793903	Left
L	1004.996436	Right
M	944.687361	Right
N	271.546223	Right
O	244.888662	Left
P	736.408062	Left
Q	1032.966411	Left
R	1533.688333	Left
S	1910.312139	Left
T	2201.551764	Left
U	2047.443162	Left
V	1626.444133	Left
W	1871.87424	Left
X	2274.365375	Left
Y	2260.006065	Left

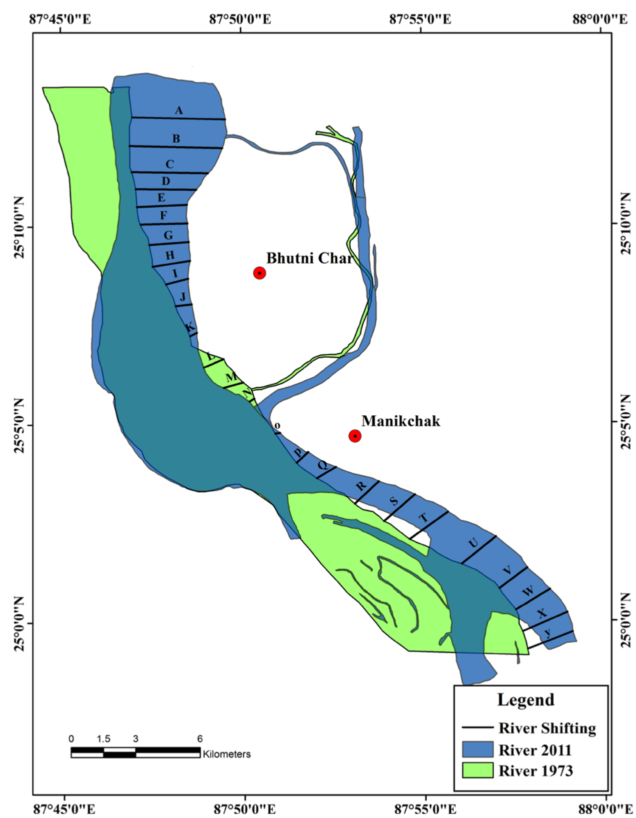


Fig. 3 Bank line shifting of river Ganga along Manikchak block

4.2 Land loss vulnerability assessment

Since 1973–2011, the assessment on the terrestrial land loss (Table 2) at mouza level showed that mouzas like Godai, Dergrama, Rambari, Shovanagar, Hiranandapur, Masahat, Samastipur, Shovapur, Mirpur, Rahimpur and Gopalpur were being inundated totally (Fig. 4) and were experienced with extensive land loss. Three mouzas are

Table 2 Mouza-level distribution of the land area in 1973 and 2011

JL no.	Name of mouza	Area (sq. m)	Land area (sq. m)		Land change (sq. m)
			1994	2016	
1	Godai	14,476,137.81	11,929,163.27	7,988,079.538	− 3,941,083.736
2	Kesharpur	6,673,182.395	6,673,182.395	4,307,607.051	− 2,365,575.344
4	Chandipur mal	18,815,290.57	18,815,290.57	16,985,776.19	− 1,829,514.387
8	Suksena	3,440,935.99	3,440,935.99	1,927,789.888	− 1,513,146.103
9	Dergrama	873,997.8867	873,997.8867	728,584.6103	− 145,413.2764
10	Rambari	7,229,363.404	5,737,620.098	3,662,340.904	− 2,075,279.194
11	Shovanagar	1,165,296.53	1,165,296.53	116,242.5511	− 1,049,053.979
12	Hiranandapur	4,879,323.774	3,667,303.326	3,262,408.088	− 404,895.2378
13	Masahat	2,430,630.398	1,384,376.121	382,951.107	− 1,001,425.014
15	Bagdukra	4,985,597.694	3,079,173.849	3,118,131.601	38,957.75224
16	Samastipur	2,432,146.076	1,486,840.269	761,159.4124	− 725,680.8564
17	Shovapur	16,862,685.01	221,985.9034	15,637,877.76	15,415,891.85
18	Chandipur Tofi	2,793,738.618	2,010,579.969	2,245,727.396	235,147.4271
19	Dakshin Chandipur	6,394,839.254	4,854,715.979	4,527,090.597	− 327,625.3812
20	Duarni Tofi	5,727,625.06	5,005,865.604	3,557,404.328	− 1,448,461.276
21	Paschim Narayanpur	6,394,839.254	1,732,829.136	1,731,040.615	− 1788.520823
22	Narayanpur	10,505,358.74	7,071,173.46	7,477,702.2	406,528.7402
23	Ugritola	2,584,322.934	2,584,322.934	2,584,322.934	0
24	Karia Sultanpuur	1,138,207.239	1,138,207.239	1,138,207.239	0
25	Kamalpur	2,862,286.148	2,862,286.148	2,862,286.148	0
26	Mathurapur	3,719,286.224	3,719,286.224	3,713,554.201	− 5732.02273
27	Gashigown	851,362.137	851,362.137	851,362.137	0
82	Jot Bhabani	1,692,446.127	1,692,446.127	1,349,031.524	− 343,414.6035
83	Dharampur	6,706,434.146	6,706,434.146	2,295,883.681	− 4,410,550.465
84	Manikchak	11,284,029.78	11,259,955.56	5,360,200.341	− 5,899,755.217
85	Raniganj	454,570.5863	46,602.78207	0.000257	− 46,602.78181
86	Govindapur	1,174,436.126	439,263.0127	1,111,939.177	672,676.1647
87	Rustampur	5,829,323.203	3,690,984.986	5,394,469.322	1,703,484.336
88	Mirpur	3,119,949.299	3,119,949.299	692,750.1938	− 2,427,199.105
89	Rahimpur	3,010,620.93	3,010,620.93	3,010,620.93	0
90	Gopalpur	12,487,211.5	12,487,211.5	3,846,641.603	− 8,640,569.895

registered with high erosion, 9 mouzas are experienced with moderate erosion process, and 8 mouzas are dominated by low amount land loss. Severe land loss was found at Gopalpur, Manikchak, Dharampur, Godai, Mirpur, Rambari followed by Duarni Tofi and Shovanagar. Hiranandapur, Chandipur and Raniganj had faced a little amount of land erosion (Fig. 5). Northwestern portion of Manikchak block is highly affected by bank erosion followed by the mouzas of Rambari, Godai, Masahat, Dergrama, Shovanagar, etc. The lower most part of the Manikchak block is also affected severely by bank erosion process (Fig. 6). Chandipur mouza has gained a slice of land due to deposition of sediments. But, the overall study depicted that most of the area along the river bank is affected by bank erosion process due to the shifting course of the river eastward. The middle most part of the Manikchak block is least affected by erosion process because of the presence of the Bhutni Char which changed the direction of the main flow of the river Ganga. Presently, the western part of the Bhutni Char adjacent is affected by river erosion process due to direct impact of main flow [15, 44].

4.3 Accuracy assessment of LULC

The accuracy assessment for LULC of 2016 was performed by field data, and also Google earth historic image was used for validating the LULC map of 1994 (Fig. 7). The overall accuracy (Eq. 1) for the year 1994 and 2016 is 84.74% and 93.23%, respectively. The kappa coefficients (Eq. 2) for the year 1994 and 2016 maps were 0.803 and 0.892, respectively.

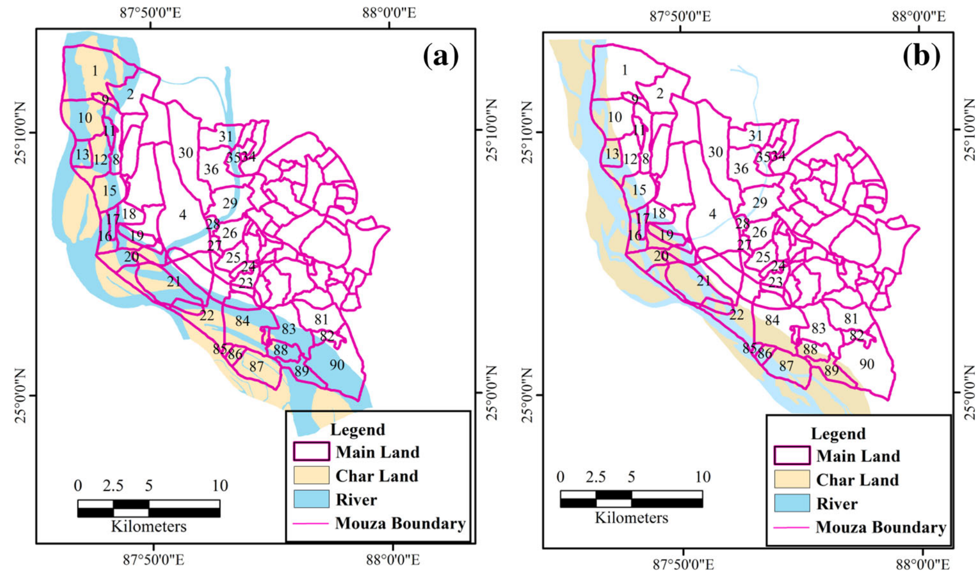


Fig. 4 Overlaying of mouza map of Manikchak block on river Ganga for the year **a** 1973 **b** 2011

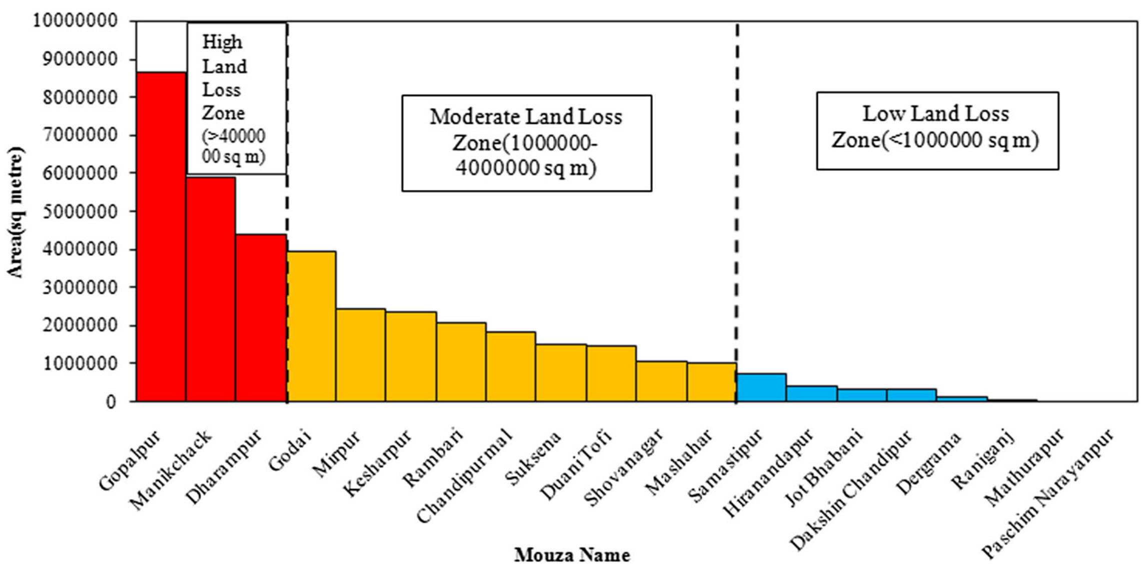


Fig. 5 Mouza-wise bank erosion-affected area of Manikchak block

4.4 Transformation of LULC change in relation to bank erosion

In 1994, 17.55% (54.98 sq. km), 27.38% (85.77 sq. km), 19.17% (49.26 sq. km), 2.69% (6.91 sq. km), 21.60% (55.53 sq. km), 11.25% (28.92 sq. km) and 12.36% (31.77 sq. km) area of Manikchak Diara were covered by settlement, vegetation, water body, wetted area, agricultural land, seasonal agricultural land and fallow land, respectively. A noticeable changed in LULC observed as a result of continuous shifting of the river course, construction and destruction of the char land (Lahiri-Dutta [45] defined char lands as the islands formed in major river systems particularly in the flat deltaic plains such as those in the Bengal delta in eastern India and Bangladesh), and erosion of the main land [10]. In 2016, 9.45% (29.59 sq. km), 22.20% (69.52 sq. km), 18.06% (56.58 sq. km), 0.27% (.85 sq. km), 20.75% (65.01 sq. km), 22.53% (70.57 sq. km) and 6.70% (21.01 sq. km) areas were experienced with settlement, vegetation, water body, wetted area, agricultural land, seasonal agricultural land and fallow land, respectively. It was found that settlement, vegetation cover and agricultural land areas were seriously damaged in the erosion-affected mouzas of Dharampur, Manikchak and Gopalpur (Fig. 8). Agricultural lands and settlement areas were being converted into water body in erosion vulnerable mouzas of Gadai, Kesharpur, Dharampur, Manikchak, Chandipur mal, Rambari, Masahat, etc., since 1994. The river water

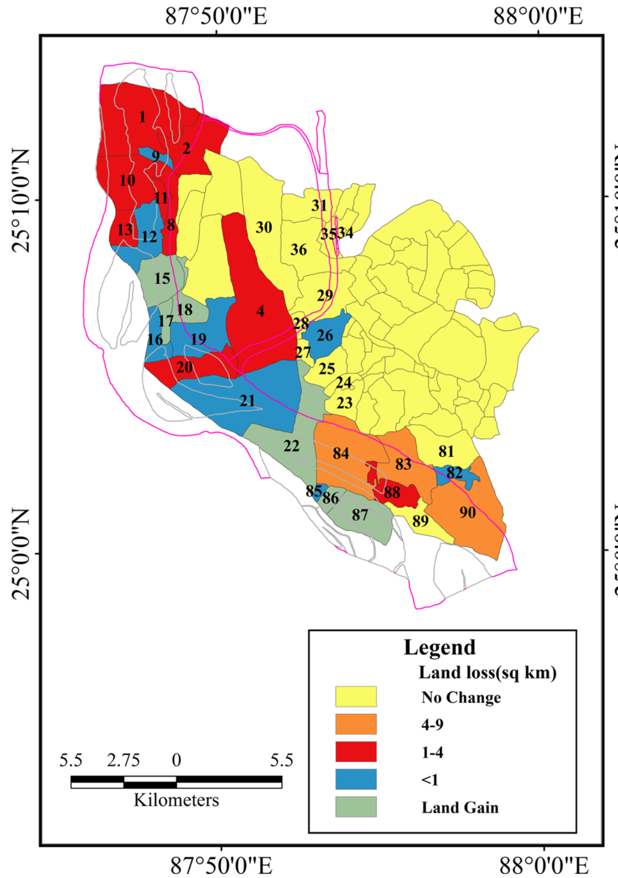


Fig. 6 Vulnerable zonation map based on mouza-wise land loss

occupied the agricultural land, vegetation cover, seasonal agricultural land and fallow land till 2016 in erosion-prone mouzas of Dharampur, Manikchak, Mirpur, Suksena, Duarni Tofi, Shovanagar, Masahat, etc. (Fig. 8).

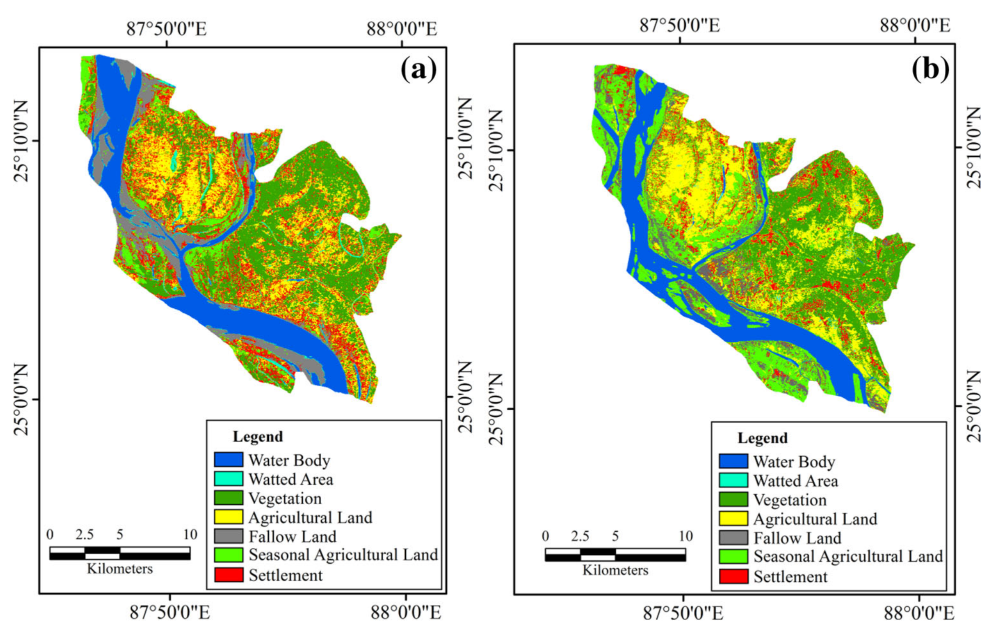
4.4.1 Transformed LULC area in high bank erosion zone

In highland loss zone settlement, wetted area and agricultural land were converted into water body (Fig. 9). Transformed LULC [46–49] was studied in high erosion zone and found that a vast area of land was inundated. The river bank erosion have converted the agricultural land and settlement into water body and as a result of which the human livelihood got affected severely. Gopalpur, Manikchak and Dharampur mouzas faced high amount of terrestrial land loss. Areas of settlement, vegetation, agricultural land and fallow land were decreased from 1994 to 2016 (Table 3), while water body and seasonal agricultural land were increased in the high erosion zone (Fig. 9a). Around 11.51 sq. km area was dominated by water body in Manikchak block in 1994, but in 2016 it was increased to 13.66 sq. km. Since 1994–2016, fluvial dynamics destroyed settlement area (0.93 sq. km), vegetation cover (0.33 sq. km), wetted area (0.13 sq. km), agricultural land (0.62 sq. km), seasonal agricultural land (0.36 sq. km) and fallow land (1.06 sq. km) in the entire high erosion zone (Table 3).

4.4.2 Transformed LULC area in moderate bank erosion zone

Moderate amount (1–4 sq. km) of land loss was observed in 9 mouzas, i.e., Godai, Mirpur, Kesharpur, Rampur, Chandipur mal, Suksena, Duarni Tofi, Shovanagar and Mashar. Settlement, vegetation and wetted areas were converted into water body, agricultural land, seasonal agricultural land and fallow land in this zone (Fig. 9b). Since 1994–2016, 1.08 sq. km of settlement area, 0.88 sq. km of

Fig. 7 LULC map of Manikchak block for the year **a** 1994 and **b** 2016



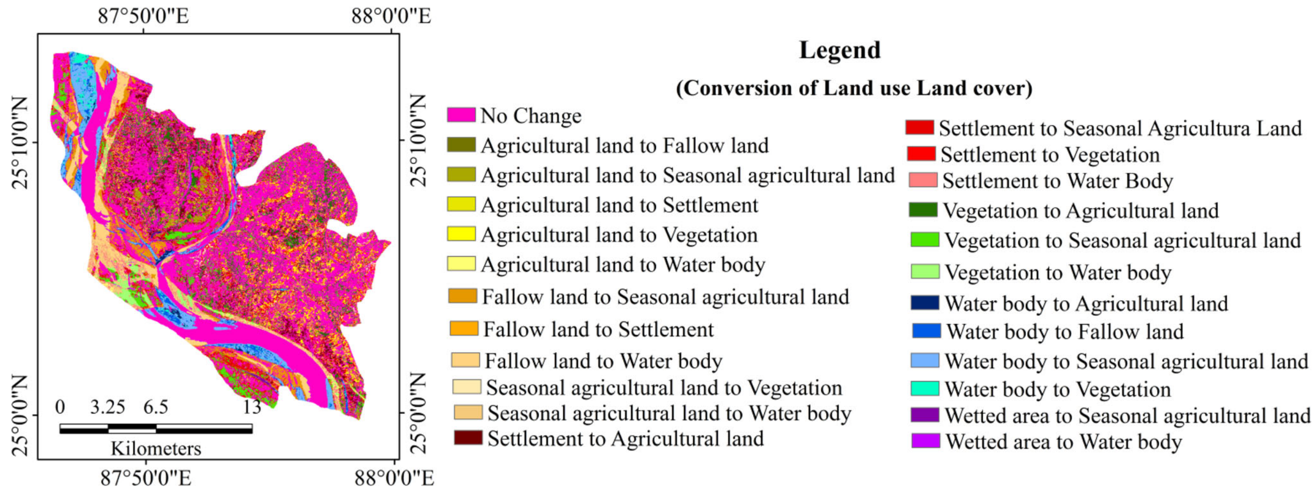


Fig. 8 Transformed LULC map of Manikchak block since 1994–2016

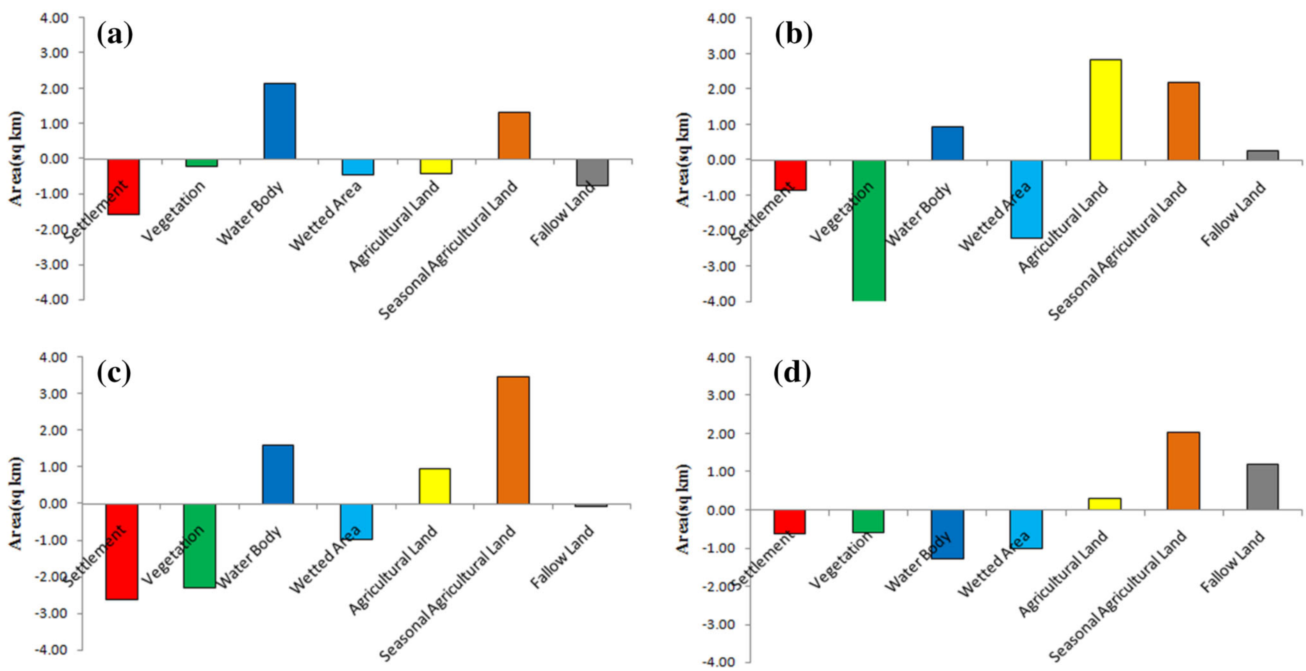


Fig. 9 Vulnerability zone-wise change detection statistics of LULC since 1994–2016 **a** highland loss zone, **b** moderate land loss zone, **c** lowland loss zone and **d** land gained zone

vegetation cover, 1.45 sq. km of agricultural land, 1.39 sq. km of seasonal agricultural land and 0.81 sq. km of fallow land were being replaced by water body (Table 4).

4.4.3 Transformed LULC area in low erosion zone

Samastipur, Hiranandapur, Jot Bhabani, Dakshin Chandipur, Dergrama, Raniganj, Mathurapur, Paschim Narayanpur were included in low erosion zone. Settlement, vegetation and wetted areas were decreased in terms of area, but water body and seasonal agricultural lands were increased in this zone (Fig. 9c). The field investigation revealed that the population of this area focused mainly on seasonal agriculture practises due to the bank erosion in monsoon and post-monsoon season. Since 1994–2016, water body engulfed 1.01 sq. km of the settlement area, 1.48 sq. km of vegetation cover, 0.28 sq. km of wetted area, 0.43 sq. km of agricultural land, 0.90 sq. km of seasonal agricultural land and 1.25 sq. km of fallow land (Table 5). Besides, the fallow land and vegetation cover were affected due to severe river bank erosion.

Table 3 Transformed area of different LULC features in high erosion zone

High erosion zone affected JL. No.: 83, 84, 90 (area in sq. km)

LULC change matrix	Settlement	Vegetation	Water body	Wetted area	Agricultural land	Seasonal agricultural land	Fallow land	1994
Settlement	0.37	0.41	0.93	0.01	0.60	0.29	0.30	2.92
Vegetation	0.22	0.45	0.33	0.00	0.68	0.42	0.18	2.28
Water body	0.15	0.08	10.24	0.01	0.01	0.31	0.72	11.51
Wetted area	0.02	0.01	0.13	0.00	0.13	0.15	0.07	0.51
Agricultural land	0.40	0.78	0.62	0.01	1.16	0.80	0.29	4.06
Seasonal agricultural land	0.10	0.21	0.36	0.01	0.53	0.51	0.08	1.80
Fallow land	0.07	0.13	1.06	0.03	0.52	0.62	0.12	2.54
2016	1.33	2.07	13.66	0.06	3.63	3.10	1.76	

Table 4 Transformed area of different LULC features in moderate erosion zone

Moderate erosion zone affected JL. No.: 1, 2, 4, 8, 10, 11, 13, 20, 88 (area in sq. km)

LULC change matrix	Settlement	Vegetation	Water body	Wetted area	Agricultural land	Seasonal agricultural land	Fallow land	1994
Settlement	0.70	0.15	1.08	0.01	2.09	1.35	0.73	6.11
Vegetation	0.58	0.27	0.88	0.01	1.16	1.82	0.56	5.27
Water body	1.74	0.02	4.95	0.00	0.64	3.28	1.34	13.19
Wetted area	0.10	0.04	0.52	0.02	0.64	0.77	0.19	2.28
Agricultural land	0.53	0.18	1.49	0.02	4.10	0.82	0.19	7.33
Seasonal agricultural land	0.81	0.26	1.39	0.00	0.70	4.45	3.13	10.74
Fallow land	0.79	0.04	3.81	0.01	0.81	0.42	1.32	7.19
2016	5.25	0.96	14.12	0.07	10.15	12.91	7.44	

Table 5 Transformed area of different LULC features low erosion

Low erosion zone affected JL. No.: 9, 12, 16, 19, 21, 26, 82, 85 (area in sq. km)

LULC change matrix	Settlement	Vegetation	Water body	Wetted area	Agricultural land	Seasonal agricultural land	Fallow land	1994
Settlement	0.57	0.53	1.01	0.02	1.03	1.41	0.71	5.27
Vegetation	0.96	1.87	1.48	0.00	0.80	1.66	0.94	7.73
Water body	0.24	0.68	3.60	0.00	0.25	1.78	0.80	7.34
Wetted area	0.02	0.30	0.28	0.01	0.06	0.24	0.12	1.03
Agricultural land	0.32	0.34	0.43	0.00	0.45	0.47	0.19	2.21
Seasonal agricultural land	0.33	1.69	0.90	0.00	0.34	1.24	0.77	5.28
Fallow land	0.20	0.02	1.25	0.00	0.22	1.94	0.92	4.54
2016	2.65	5.41	8.95	0.04	3.16	8.75	4.45	

4.4.4 Transformed LULC area in land gained zone

Formation of new char land and destruction of the same are common phenomena in the active Gangetic plain of Manikchak Diara due to an alternation process of deposition and it was noticed that the loss of main land and char land have given birth to the development of new char land in the upstream of Farakka Barrage. In the land gain zone, 6 mouzas such as Bagdukra, Shovapur, Chandipur Tafir, Narayanpur, Gobindapur and Rustampur were characterized by the deposition of sediments and formation of char land (Fig. 5; Table 3). Settlement, vegetation, water body, wetted areas were being reduced, while the area of seasonal agricultural land as well as fallow land was enlarged noticeably (Fig. 9d). The seasonal agricultural practices were being adopted by the local people to maintain their livelihood. In this zone, 7.69 sq. km areal extent of water body was converted into settlement (0.58 sq. km), vegetation cover (0.71 sq. km), agricultural land (0.09 sq. km), seasonal agricultural land (0.69 sq. km) and fallow land (0.43 sq. km) since 1994–2016 (Table 6). This situation proved the dynamicity of land-use character may be caused due to quasi-natural fluvial processes.

5 Discussion

The Ganga River has changed its course toward Dharampur, Manikchak, Gopalpur mouzas of Manikchak block since 1973–2011. The maximum rate of shifting (4.33 km) has been found in Godai mouza followed by Chandipur, Rambari, Samastipur, Duarni Tofi mouzas. Consequently, 0.43 sq. km of agricultural land out of total 4.06 sq. km, 0.21 sq. km of vegetation out of total 2.81 sq. km, 1.59 sq. km of settlement out of total 2.92 sq. km have been submerged under the river which indicates this region experienced high bank erosion [15, 50] because of the construction of Farakka Barrage [51] and location of the Rajmahal hill on the another side of the Manikchak block [52]. This river bank erosion and shifting of the river have affected not only the river morphology [10] but also the socioeconomic condition [53]. Sinha et al. [54] studied on damage caused by the shifting of the river Kosi and found that the river shifted 150 km at western direction and a huge amount of property have destructed due to the shifting of river Kosi. The assessment of shifting character of river Ganga and associated land loss were finely documented by Mandal et al. [15]. Due to bank erosion-induced land loss, changes were found in land-use and land-cover character in Manikchak block. Khan et al. [55] investigated the combined effects of land use changes and natural disasters in the southwest coastal area of Bangladesh. River shifting accelerates the process of short-term land-use dynamism which has been clearly depicted in the Result section.

Pal and Talukdar [56] studied on Punarbhaba River and found that shifting of Punarbhaba River caused rapidly land-use dynamics. In short time period, new land-use types were formed on that basin. Maiti et al. and Reddy et al. worked on the Ghatshila and Kanchinegalur River basin, respectively, and found that how river shifting rapidly transformed its own basin's land-use pattern to new pattern and experienced a huge damage [57, 58].

Therefore, this microscale study on the impact of river shifting on land-use dynamics has noteworthy significance, because this study helps planners to execute the management plan to reduce the damage. Vulnerability zone identification is the important work which helps planners to identify the region where attention is more needed and even planners can use protective plan how the bank erosion can be reduced. Therefore, this study plays a valuable role.

Table 6 Transformed area of different LULC features in land gained zone

Land gained JL. No.: 15, 17, 18, 22, 86, 87 (area in sq. km)

LULC change matrix	Settlement	Vegetation	Water body	Wetted area	Agricultural land	Seasonal agricultural land	Fallow land	1994
Settlement	0.47	0.17	0.28	0.00	0.47	1.22	0.92	3.53
Vegetation	0.36	0.19	0.13	0.01	0.39	1.11	0.65	2.83
Water body	0.58	0.71	5.19	0.00	0.09	0.69	0.43	7.69
Wetted area	0.26	0.07	0.24	0.01	0.10	0.29	0.09	1.05
Agricultural land	0.19	0.07	0.04	0.00	0.25	0.47	0.29	1.32
Seasonal agricultural land	0.85	1.01	0.20	0.00	0.25	1.18	0.71	4.20
Fallow land	0.19	0.02	0.31	0.00	0.09	1.27	1.04	2.92
2016	2.90	2.24	6.39	0.03	1.63	6.23	4.12	

6 Conclusion

The study area of Manikchak Diara of Malda district, West Bengal, is dominated by agricultural practices. Changing course of the river Ganga and shifting of the bank line at an average of 1.85 km toward left bank have aggravated the problems of land loss and frequent transformation of land-use character. Bank line shifting of Ganga River in western side promotes a severe bank erosion and land loss (38.6 sq. km area) in the eastern part of Manikchak block. The human settlement of 5.07 sq.km area was badly affected by leftward shifting of the river Ganga which directly affected the socioeconomic status of the local people. Most of the settlements were shifted landward caused due to bank erosion process and directly enforce the people of Manikchak to practice seasonal agriculture in newly developed char land. The river bank erosion converted the settlement area of 14.3 sq. km, vegetation area of 15.28 sq. km, agricultural land area of 13.6 sq. km into seasonal agricultural land area, fallow land and water body partially. It is clear from the study that natural phenomena like river shifting induced bank erosion leave a deep imprint upon the land-cover character and manipulates the mind setup of people of Manikchak block to changing their land-use pattern.

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