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Channel dynamics associated with land use/cover change in Ganges river, India, 1989–2010

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Abstract Shifting river courses and braiding in large rivers are part and parcel in fluvial morphology. The study aims at probing the changes of the Ganges river courses with accompanying land use/land cover characteristics. Here the changes that took place over a period ranging a couple of decades were recorded using multi-temporal Landsat 4–5 Thematic Mapper data. Meander geometry was precisely estimated. River course change pattern along with the changes in land use/land cover were studied over the period of 21 years (1989–2010). Results showed 0.14 km bank erosion and 0.85 km valley area was prone to erosion during the entire study period. The study exhibited the active channel area decreased by 22.88 km^2 (0.33 % of the original river course) from 1989 to 2010. Land use characteristics showed settlement and plantation with settlement and crop lands were increased, whereas agricultural land was decreased in the study area. The overall kappa statistics were recorded as more than 0.84 during the study period. Rivers tend to maintain its high volume flow by eschewing additional silt load through bank overflow, called flash flooding; which is a natural process for any river to maintain the health of its thalweg.

Keywords River course dynamic · Channel morphology · Land use/land cover change · Multi-temporal satellite data

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1 Introduction

Floodplains are deliberated to seasonal and periodical alterations as a result of lateral and vertical agility of rivers pouring a conversion in the land use/land cover pattern [1]. The river Ganges (the largest river in India) is considered by its extremely bulky flow, huge amount of sediment load, incessant modification in channel morphology, rapid bed aggradations and bank line downturn and erosion in the state of Bihar, India [2]. Furthermore, the tangential changes in channels cause degradation along the banks in each year [3]. River Ganges is famed for its high sand content, frequent floods, inimitable channel characteristics [4, 5]. River bank erosion, low gradient in the lower reaches, high sediment load and anthropogenic causes have caused large channel shifts and morphological changes of Ganges river course. Meandering rivers are highly non-linear dynamic systems, which produce complex and fascinating planimetric patterns. River channel changes, such as bank erosion, down cutting and bank accretion, are natural processes for an alluvial river [6, 7]. Moreover, the Ganges is predominantly a braided river and bank erosion strongly associated with the development and migration of meander bends [8]. The consequential channel changes caused diverse environmental and socioeconomic cost in terms of steering, flood hazards, trouncing of riparian land and infrastructure and the amendment of aquatic and riparian ecosystems.

Changes in river course may alter the land use/land cover (LULC) characteristics in its surrounding areas. Channel stability is often threatened [9, 10]; however, it may be due to morphological adjustments to accommodate the range of flows and sediment loads from upstream [11, 12]. LULC changes due to river dynamics may escorts to the socio-economic discrepancy by plummeting crop yield, infrastructure damage and escape a pawmarks in the livelihoods of the poor inhabitant in the society [13, 14]. Globally, several studies in this regard have been conducted for ascertaining channel changes [1, 15–18]. The employ of remotely sensed data in recognize is the trends of river channel and as source of input data to determine river behaviour study has became popular in recent years [19, 20]. The satellite data has made available the information on the channel formation of the river system on recurring basis edifying much obligatory data on the transforms in river morphology [21, 22], and its sway on the LULC characteristics.

The Ganges river has been causing an assortment of annihilation by lateral movement and widespread flooding in North Bihar, particularly in southern part of Vaishali district of Bihar (India) [23]. As its waters carry heavy silt load and the river has a steep gradient, the river has a tendency to move sideways. In order to control flood in north-Bihar and shifting nature of its course, anti-erosion work at Rustampur, Jafarabad–Jahangirpur and Jafrabad–Sukumarpur village (on left bank of right channel) in Raghopur Diara (Vaishali district) along river Ganga have constructed. Understanding the nature of river course and its surrounding land cover characteristics of the river Ganges is imperative way by physical processes [24, 25]. Therefore, the present study aims at probing the changes and river courses with accompanying land use/land cover, taking a major river of India—the River Ganges using multi-temporal satellite data and Geographic Information System (GIS). To the best of our knowledge, this is the first study to understand the river dynamic of the River Ganges (middle Gangetic plain) and associated LULC characteristics of the study area.

2 Materials and methodology

The study area is extended between 25°39′22″N–25°27′44″N latitude and 85°12′07″E–85°43′37″E longitude, spreads in southern parts of Vaishali district of Bihar, India (Fig. 1), covered approximately 586 km^2. The catchments practice heavy rainfall during the monsoon season (annual average rainfall 1200–1400 mm) ensuing in superfluous surface runoff overwhelming vast area in the plains used mainly for agrarian tenacities. The study area is characterized by 232,909 populations, having approximately 397 per km^2 population density [26]. The rivers are flashy in character and recognized to people of this region for bed aggradation. The Raghopur block in Vaishali district situated between two streams of the Ganges river, submerged by water due to flood by the Ganges. In this process of shifting, it has created numerous chaurs (saucer like depressions) and mauns (deep horse- shoe shaped water bodies formed due to avulsions/cut-offs) in the basin [23]. The morphology of the area has been shaped mainly by Ganges river which is the lowest and youngest geomorphic unit, emerges from river bed. Quaternary alluvial deposit consisting of alternate layers of sand, silt, clay and gravel with calcareous concretions forms prolific unconfined and confined aquifer system in the study area [27]. Annual flood is causing damages and changes the LULC pattern of the study area in each year during monsoon season.

2.1 Data used

For a period of 22 years (1989–2010) satellite data was used with an integrated approach of remote sensing and GIS for delineating the spatio-temporal dynamics of river course and land use/land cover changes of its surrounding. In the present study multi-temporal satellite data of Landsat-Thematic Mapper (TM) (path/row: 141/42) was used. Observance a common projection lessens the error that ensues due to temporal changes The TM data of Jan 24, 1989, Feb 04, 1999, Feb 12, 2005 and 11th February, 2010 were acquired from the Earth Explorer of U.S. Geological Survey (http://earthexplorer.usgs.gov/). As the volume of water changes with the season on the river course; therefore, all the satellite data were collected for the same month for better estimation. Ancillary data like Survey of India (SOI) topographical maps on 1:50,000 scale and ground truth information are also used to register the image.

2.2 Pre-processing of data

All the satellite data were geo-referenced based on Universal Transverse Mercator (UTM) projection system with World Geodetic System (WGS) datum and North 45 zone. The image processing operation was performed though ERDAS Imagine v9.0 software. The second order polynomial transformation with nearest neighbor resampling technique has been espoused, having a root mean square error (RMSE) of the transformation 0.16 was attained (<1 pixel error). SPSS v10.0 is used for statistical analysis.

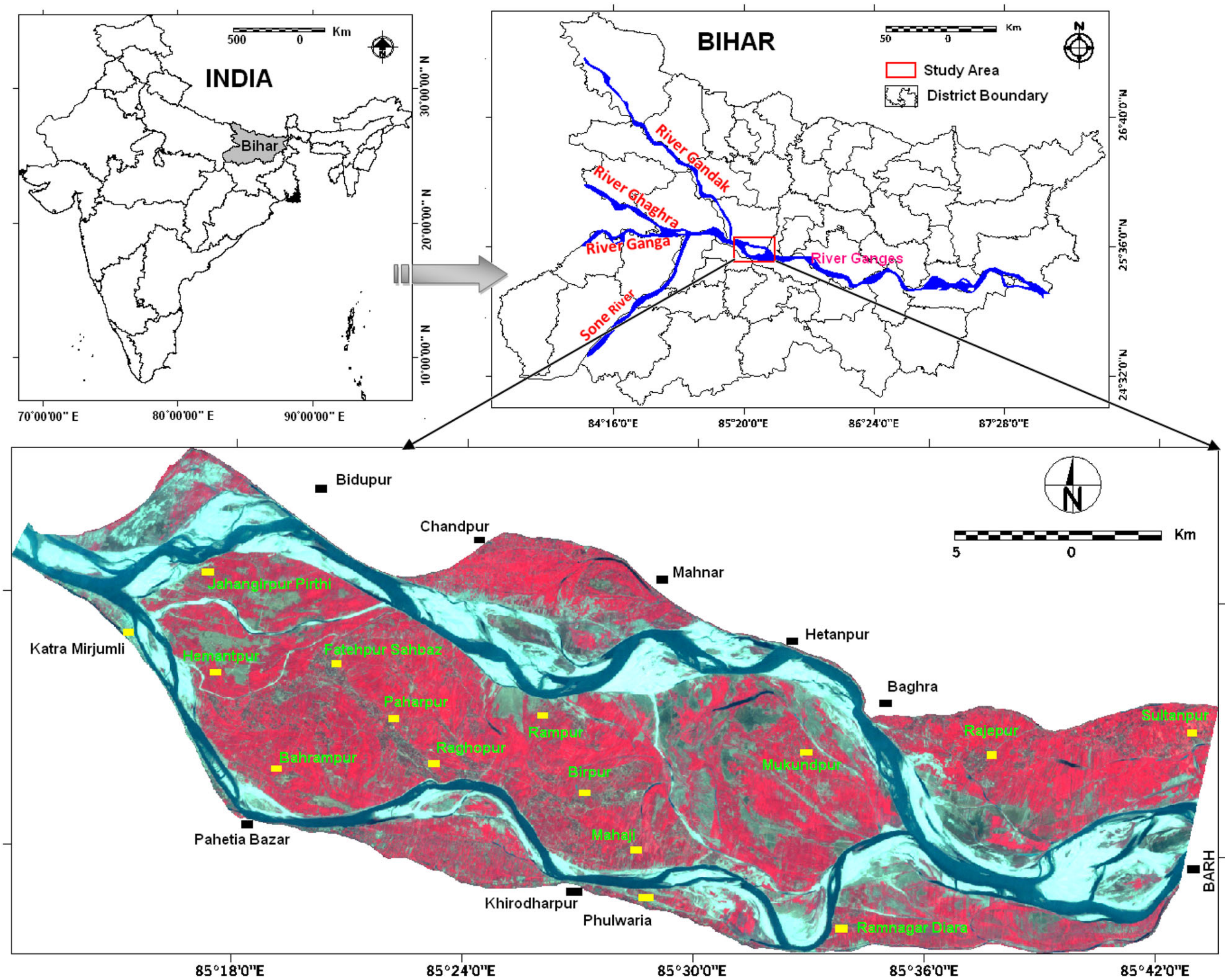

Fig. 1 Location map of the study area

2.3 Delineation of Channel boundary and calculation of meandering geometry

Yao et al. [28] method has been adopted to delineate the channel boundary from the Landsat Thematic Mapper (TM) images. The edge of the river channel was defined as an elongated area in which stream flow occurred with adequate frequency, energy, and duration to daunt the existence of vegetation [29]. Generally, reflection of waterbody is high in the optical/visible region of electromagnetic spectrum; however, clearer water has low reflectance than turbid water. In the Near IR and Mid-IR spectral regions water progressively absorbs the light creating it darker; however, this is reliant upon water depth and wavelength (http://igett.delmar.edu/Resources/Remote%20Sensing%20Technology%20Training/Landsat_bands-sm.pdf). In false colour composite (FCC) image of Landsat TM, the combination of spectral band 1 (0.45–0.52 μm), band 4 (0.76–0.90 μm) and band 7 (2.08–2.35 μm) usually used for detection of water body. Consequently, the ratio between band 4 and band 5 of TM data was used to heighten the water body. Water body has looked as dark tone. Because, the water body is strong absorber in near IR region (band4); and the higher reflectance is found in band 5 (1.55–1.75 μm). It can be useful for discriminating water bodies from land. Continuous polygons were created to represent the stream channel in each year using the image (map) data through the GIS software. On screen digitizing method was adopted to digitize the polygons at a scale of 1:5000, and methodological reliability was sustained by having a single operator to execute all polygons.

In the present study, meandering geometry, like meander length (M_L), meander width (M_W), meander ratio ($M_R = M_W/M_L$, [30]), sinuosity index (i.e., the ratio of the length along the channel to the direct axial length of the river [31] and braiding index (i.e., ratio between the total length of bars and the length of the reach, Brice's [32] were calculated from the multi-temporal satellite data. Rivers having a sinuosity of 1.5 or greater refers meandering, and any division between straight and meandering is arbitrary [33]. Brice's [32] used a sinuosity of 1.3. The changes in active channel area (sq. km.) were calculated as the differences between new area and original area divided by original area. Consequently, a measure of bank erosion were estimated as the distance between new bank line and old bank line and standardized by channel width. The ratio between average channel width and average valley width was calculated to understand the valley prone to channel erosion in the study site. For digitization of river course and geometrical calculation ArcGIS software v9.0 were used.

2.4 Classification of satellite data

LULC characteristics of the study area were delineated based on supervised classification method with maximum likelihood algorithm [34]. A total of fifty training sites were selected. SOI topographical sheets, historical census map (Census of India 1980) of the study areas, cautious investigation of satellite image, Google Earth image, and native knowledge about the area and variations over time were employed for conveying LULC classes. Using the training sets, different spectral signatures for each class were extended and estimated using separability analysis to assess the expected error in the classification for different attribute combinations [35]. Employing a separability cell array, various spectral signatures in each class were combined collectively [36] which then was expected to evince better accuracy in the final image classification. A resultant thematic map of LULC comprises settlement (areas under urban and rural built-up), plantation with settlement (mixed areas under urban and rural built-up with vegetation cover), weeds/grass (areas dominated by vegetated sandbars and grazing land), surface water body (open water features such as rivers, streams, lakes and reservoirs), sand (dry and wet sand areas), sparse vegetation (agricultural plantations like orchards), crop land (areas under cultivation), agricultural fallow land (single crop dominated areas including current fallow areas) and moist fallow (low lying areas saturated with moisture and covered with aquatic vegetation) were generated for each individual layer.

To execute accuracy assessment of digital classification, an error matrix table was imitative that represents a square array of numbers laid out in rows and columns (Table 7), expresses the number of sample unit (e.g. clusters of pixel) consigned to a particular class relative to the concrete category as verified in the field [37]. Stratified random sampling was assumed in the accuracy assessment by considering 50 sample points for each land cover class. The point distributions were prepared in proportion to the field distributions of the classes, often based on highly subjective interpretations [38]. Earlier report [39, 40] also suggested the accuracy for classes using significantly fewer than 50 reference sample points. Two different measures were derived from the values in an error matrix: user's and producer's accuracy [41, 42]. Kappa coefficient is also calculated to measure of map accuracy [43, 44]. The USGS projected an accuracy level of 85 % as the minimum constraint for LULC mapping with Landsat data [45].

2.5 River course change detection

To delineate the dynamic changes of river course in different time intervals, overlaying operation was performed. The difference, intersection and union techniques were used to club the depositional [after shoreline (Input layer)—before shoreline (Difference layer)] and erosional [before shoreline (Input layer)—after shoreline (Difference layer)] area from temporal river course vector database. Conversely, the after and before temporal river course vector layer were merged together spatially and non-spatially to build one common portion vector layer insisted overlay or intersect area only. Furthermore, union operations were conducted by merging all these layers and separated by attribute assigned text, like deposition, erosion, and intersect area.

2.6 Change detection analysis of land use/land cover map

The LULC images resulting from the supervised classification method were employed to examine and distinguish the changes in land cover classes during different time intervals. In this model, image differencing technique was employed to delineate the changes between before and after image [46]. For the LULC images, changes in nine land cover classes were detected. The altered region and unchanged region is established by choosing the appropriate threshold values of gray levels in the difference image [47]. The gray value of the difference image illustrates the changes of corresponding pixels of two images.

3 Results and discussion

During the period between 1989 and 2010, the channel of the Ganges river course extended, constricted and attuned its configuration in response to episodes of high and low flow. Analysis of the study segment shows that the actual path length of the channel flows was 94.93 km in 1989, 86.95 km in 1999, 80.21 in 2005 and 84.64 km in 2010. The observed length exhibits a decreasing trend during the period between 1989 and 2010. In contrast to the upper, lower reaches of the river Ganges illustrated dawdling and incessant migration of its banks by progressive fluctuating of its meander curves. The overall average meander width (M_w) showed increasing in trend from 1989 to 2010 (Table 1). Leopold and Wolman [48] also observed progressive fluctuating of meander bends is an inherent possessions of a meandering alluvial river by virtue of which it inclines to preserve symmetry in energy circulation. During monsoon season throughout high phases of flow the river meanders are ruptured by chute waterways in various river reaches that join the two adjoining bends of a meander. This causes dispersal of water in various reaches and sediment distribution nearby the confluence point [49].

The lowest value of sinuosity index (SI) was recorded as 1.30 during 2010 and the highest value was documented as 1.58 in 1989. The reduction in SI because of meander cutoffs has caused in river curbing. Hazarika et al. [50] stated river straightening to upsurge in the bed material burden along with coarser sediments. Between 1989 and 1999, the channel continued to enlarge. Mean channel length increased by 3.95 km, and the mean channel width increased by 1.46 km. Differences in mean channel length between 1989 and 2010 were statistically significant ($p < 0.0001$). The analysis shows that braiding index was 1.42 in 1989; however, it has been observed that the braiding index is increased. Differences in mean channel width between 1989 and 2010 were also showed statistically significant ($p < 0.0001$). The braiding index was 1.74, 1.96 and 2.15 in 1999, 2005 and 2010 respectively which indicated that river is braided nature. The sinuosity index and braiding index at different time intervals is represented in Fig. 2. The result of our analysis reveals clearly braided course and quite sinuous pattern. Lewis and Lewin, [51] attributed neck cut-off is a flood plain feature of a meandering river where the whole meander loop is abandoned.

During the study period (1989–2010), the bank erosion was measured as 0.14 km and the per cent of the valley prone to channel erosion was estimated as 0.85 km. During 1999 and 2005, the valley prone to channel erosion was calculated as 0.89 %, whereas the bank erosion was measured as 0.08 km (Table 4). From 2005 to 2010, the estimated bank erosion was 0.02 km and 0.69 % of the valley was prone to channel erosion.

3.1 River course change analysis

The river course of the study area has been categorized into three classes, namely river sand and weeds/grass. The light

Table 1 Descriptive characteristics of meander length (M_L), width (M_w) and ratio (M_R) in the study area

Meander characteristics	Mean	SE	Median	SD	Kurtosis	Skewness
1989						
M_L	9.82	1.11	10.79	2.94	−.146	−0.27
M_w	3.29	0.41	3.26	1.09	−0.89	0.009
M_R	3.01	0.12	3.06	0.31	−1.22	−0.21
SI	1.58					
BI	1.42					
1999						
M_L	11.64	2.11	10.9	4.22	0.49	0.88
M_w	3.82	0.85	3.68	1.69	−0.11	0.43
M_R	3.27	0.57	2.89	1.13	3.20	1.69
SI	1.47					
BI	1.74					
2005						
M_L	12.61	1.82	12.31	4.81	−1.29	−0.19
M_w	4.08	0.54	3.5	1.43	2.07	0.10
M_R	3.06	0.14	3.20	0.37	0.14	−0.55
SI	1.31					
BI	1.96					
2010						
M_L	13.77	1.65	14.20	3.70	−1.69	0.15
M_w	4.75	0.53	4.46	1.20	1.03	1.05
M_R	2.97	0.41	2.74	0.92	4.18	2.01
SI	1.30					
BI	2.15					

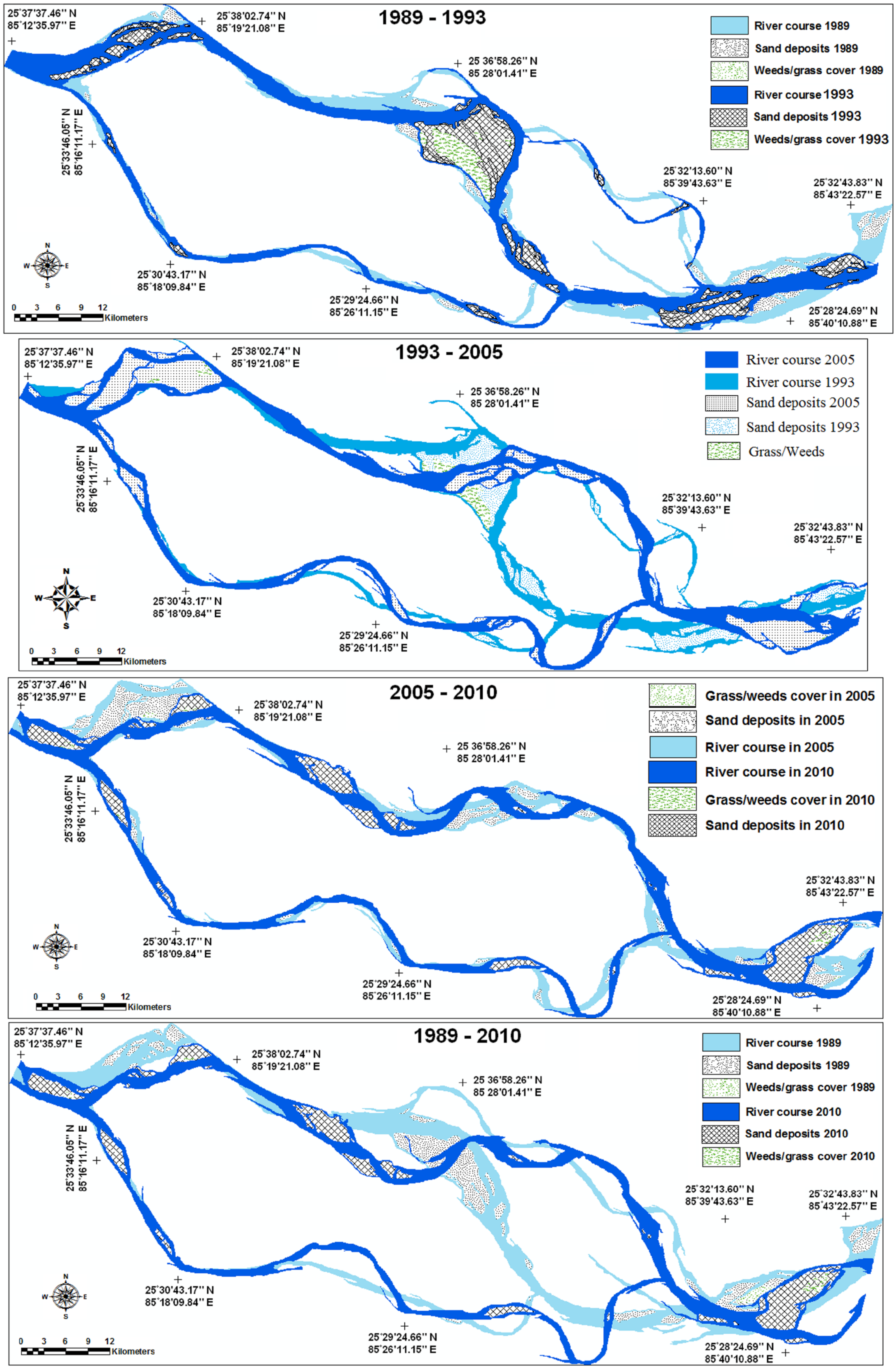

Fig. 2 River course change analysis of the Ganges river in the study area in different time intervals (1989–2010)

'blue' colour in the map represents the previous year river course in the study site, while the 'deep blue' colour in the map represent the current year river course. The area and per cent of each individual category was estimated (Table 2), and the results revealed that maximum area of river (68.61 km^2) was covered in 1989 and the minimum area is covered by the river in 2010 (91.49 km^2). The active channel course of the river Ganges has shown to be decreasing during the entire study period (0.22 km^2 of the original active channel area). Furthermore the maximum deposition of sand was documented in between 1995 and 2005 (0.24 km^2 of the original active channel area). 0.78 km^2 area has been changed by weed/grass of the original active channel area. The river course of Ganges is experiencing both the erosion and deposition during the studied interval. River course change analysis (erosion and deposition mapping) study revealed that the central-eastern part of the course is highly eroding in nature, while the sediment deposition is found in the extreme eastern and northwest part of the course (Fig. 2). Many sites along the study reaches have suffered from channel shifts as a result of erosion that endangered nearby settlements and infrastructure.

The changes in sinuosity, channel length, channel area, and the overall channel shift trends were analyzed during this period. The channel length gradually increased and the braided index gradually increased during this period. However, the channel dynamics revealed a gradual reduction of river course from 1989 (68.61 km^2) to 2010 (91.49 km^2) that due to the deposition of sand on the river course.

Between 1989 and 1999, the channel area decreased by 3.22 km^2. The deposition of sand (7.37 km^2) was increased and weed/grass (0.33 km^2) covered area was decreased during this period (Table 3). During the period between 1999 and 2005, the channel area decreased by 0.57 km^2 and sand covered area increased by 1.01 km^2 and weed/-grass covered area decreased by 0.17 km^2. However, during 2005 and 2010, the channel area further decreased by 19.09 km^2 and sand covered area was decreased by 0.22 km^2 and weed/grass (0.04 km^2) covered area was increased. During the entire time span of this research (1989–2010), the study reach exhibited the active channel area decreased by 22.88 km^2 (0.33 % of the original river course), 8.60 km^2 area (0.36 % of the original river course) increased by the deposition of sand and 0.20 km^2 (0.66 % of the original river course) area by weed/grass (Table 4). The downstream of the river displayed greater erosional rates than the upstream reaches (Fig. 2). This may be because of the concave bank erosion by the river in the downstream reaches and the progression of confluence movement which subjugated the river progressions throughout the whole study period. However, the observed facts of channel course shift and confluence migration designated that rivers have been dynamic and aggressively varying the floodplain features.

3.2 Dynamics of land use/land cover characteristics

Quantitative information of the nature and trend of LULC change deliver the elementary picture of apparent feature of erosional and depositional characteristics of river Ganges. The LULC analysis for the year 1989 showed 51.99 % area of the study site is covered by crop land and agricultural land. The area of surface water body is covered by 12.55 % and sand by 11.06 %. 3.55 % area is covered with settlement and plantation with settlement area covered by (Table 5). The classified result for 1999 also showed that maximum portion of the study area was covered with crop and agricultural land (47.79 %). Sparse vegetation dominated land extended over 11.08 %, while sand and surface water body occupied by 22.76 % in 1999. In case of deposition, it was most apparent in the LULC class of surface water bodies suggesting movement of the active channel. The analysis results of LULC in 2005 portrayed 21.59 % area covered by agricultural land and the area dominated with crop land was 27.60 %. In 2010, the crop land and agricultural land was occupied by 30.55 and 19.61 % respectively. The area of sparse vegetation was 13.56 %. Settlement area in 2010 increased to a total of 6.65 % of the valley area, which was nearly double the value of 3.55 % from 1989 (Fig. 3 and Table 5). In 1989, 0.31 % (182.25 ha) area was occupied by settlement, while in 2010, it was increased by 0.99 % (579.51 ha). Though, the figure is small in terms of area, but in terms of socio-economic stress the impact is noteworthy as its lead to loss

Table 2 Identifying of various features in the river course at different time intervals

Features of river course	1989 (km^2)	Percent	1999 (km^2)	Percent	2005 (km^2)	Percent	2010 (km^2)	Percent
River	68.61	75.24	71.83	70.62	72.40	70.21	91.49	74.70
Sand	21.67	23.76	29.04	28.55	30.05	29.14	30.27	24.72
Weeds/grass	0.91	1.00	0.84	0.83	0.67	0.65	0.71	0.58

Table 3 Change area of matrix of river course of the original active channel area during the period between 1989 and 2010

Features of river course	Area in km^2			
	1989–1999	1999–2005	2005–2010	1989–2010
Active channel (river)	0.05	0.01	0.26	0.33
Sand	0.34	0.03	0.01	0.40
Weeds/grass	−0.08	−0.20	0.06	−0.22

Table 4 Analysis of the geometry of river course in the study area

Period	Bank erosion (in km)	% of the valley prone to channel erosion
1989–1999	0.05	0.82
1999–2005	0.08	0.89
2005–2010	0.02	0.69
1989–2010	0.14	0.85

Table 5 Land use/land cover characteristics in study area during the period between 1989 and 2010

Land use/land cover class	1989		1999		2005		2010	
	Area (in ha)	Percent	Area (in ha)	Percent	Area (in ha)	Percent	Area (in ha)	Percent
Settlement	182.25	0.31	362.34	0.62	385.56	0.66	579.51	0.99
Plantation with settlement	1897.11	3.24	1970.07	3.36	2700.18	4.60	3319.20	5.66
Weeds/grass	4784.23	8.16	4235.93	7.22	3818.16	6.51	2582.82	4.40
Surface water body	7362.08	12.55	5664.60	9.66	5369.48	9.16	5253.53	8.96
Sand	6485.42	11.06	7683.10	13.10	6982.29	11.91	5571.00	9.50
Sparse vegetation	2283.08	3.89	6495.91	11.08	6457.24	11.01	7950.82	13.56
Crop land	12,432.06	21.20	13,909.23	23.72	16,182.99	27.60	17,912.53	30.55
Agricultural land	18,053.82	30.79	14,113.98	24.07	12,662.70	21.59	11,500.16	19.61
Moist fallow	5161.82	8.80	4206.71	7.17	4083.27	6.96	3972.30	6.77

of homestead. Hazarika et al. [50] suggested that damage of farm coupled with livelihood clues to internal migration in the floodplains in India. Consequently, Hutton and Mutton and Haque [52] reported that socio-economic insolvency and relegation is the providence of the shifts persuaded by river bank erosion. However, our study recommended that erosion and deposition by the river Ganges also affected the settlement areas in the floodplains, specifying a population growth in the floodplains.

In the overall framework of this work, the LULC classes, like settlement, plantation with settlement, sparse vegetation and crop land were increased during the period between 1989 and 2010 (Fig. 4). Agricultural land, sand, weeds/grass and moist fallow cover area were decreased in the study site. Higher deposition was perceived in agricultural areas followed by weeds/grass and moist fallow areas. It may be due to the increase inhabitants, the proportion of crop land is increased, whereas, proportion of agricultural land is decreased.

During the study period, settlement and plantation with settlement and crop land were increased, whereas agricultural land followed by weeds/grass and moist fallow were decreased (Table 6). It may be due to the increase in agriculture land has been in seek of new agriculture sites and has indicated crop intensification. Alternatively, the expansion of vegetation with settlement indicated that the density of population in the study area was increased. The area covered with sparse vegetation was also increased. Results also showed weed/grass and moist fallow covered area were decreased.

Table 7 showed the overall accuracies for digital classified images were 86.00, 88.00, 88.00, and 90.00 % for 1989, 1999, 2005 and 2010, respectively. The overall kappa statistics were 0.87 in 1989, 0.84 in 1999, 0.86 in 2005 and 0.88 in 2010, respectively.

Consecutively, to observe the change in land cover over the studied period (1989–2010), a change area matrix table was generated. A remarkable decrease of % of surface water body, weeds/grass, moist fallow and agricultural land were realized for the entire study period. Moreover, the per cent of area under settlement, plantation with settlement, sparse vegetation, sand and crop lands were increased in the study area. Some information was obtained between 1999 and 2005 to be erroneous, such as moist

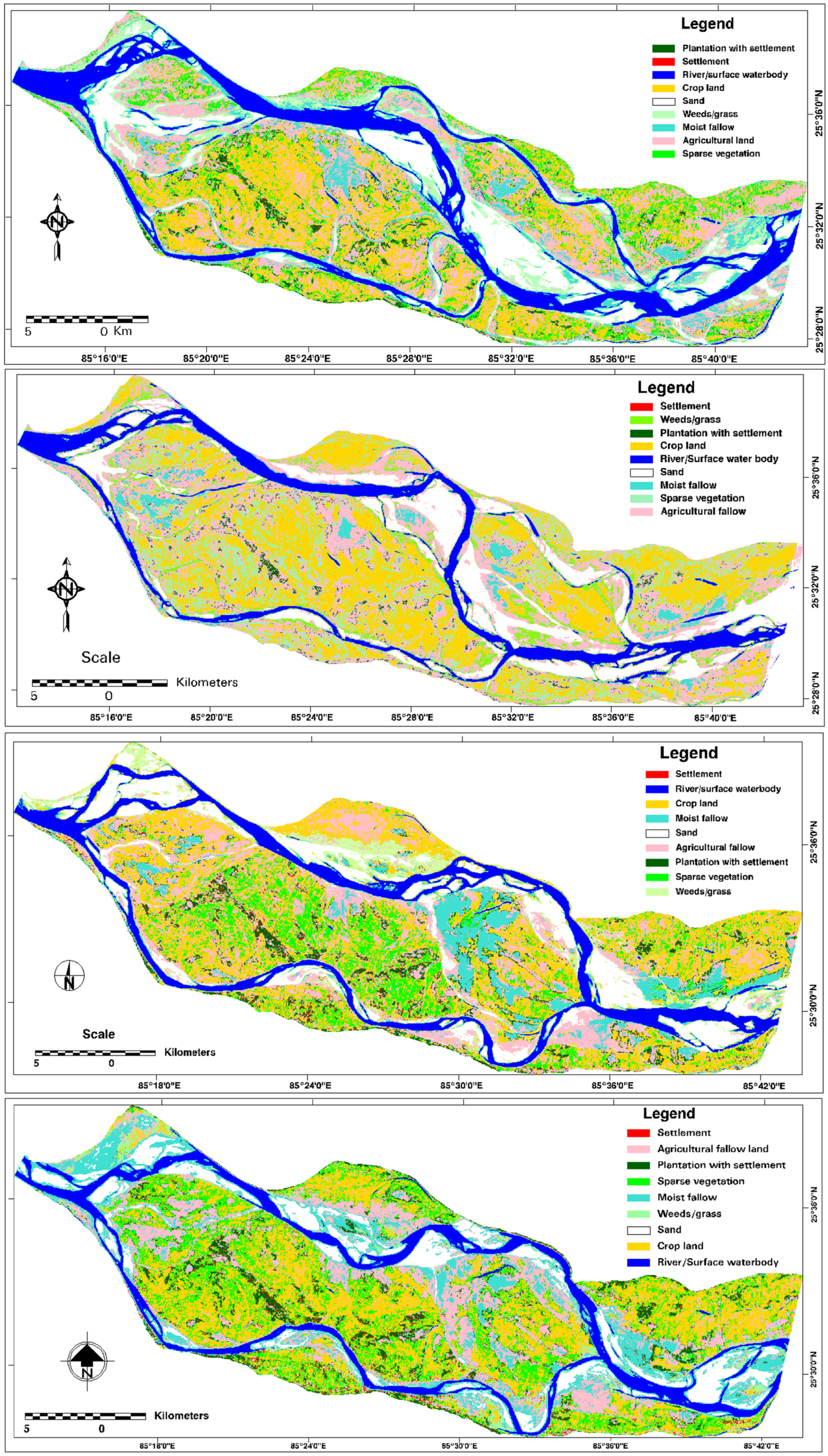

Fig. 3 Land use/land cover characteristics of study area at different time intervals (1989–2010)

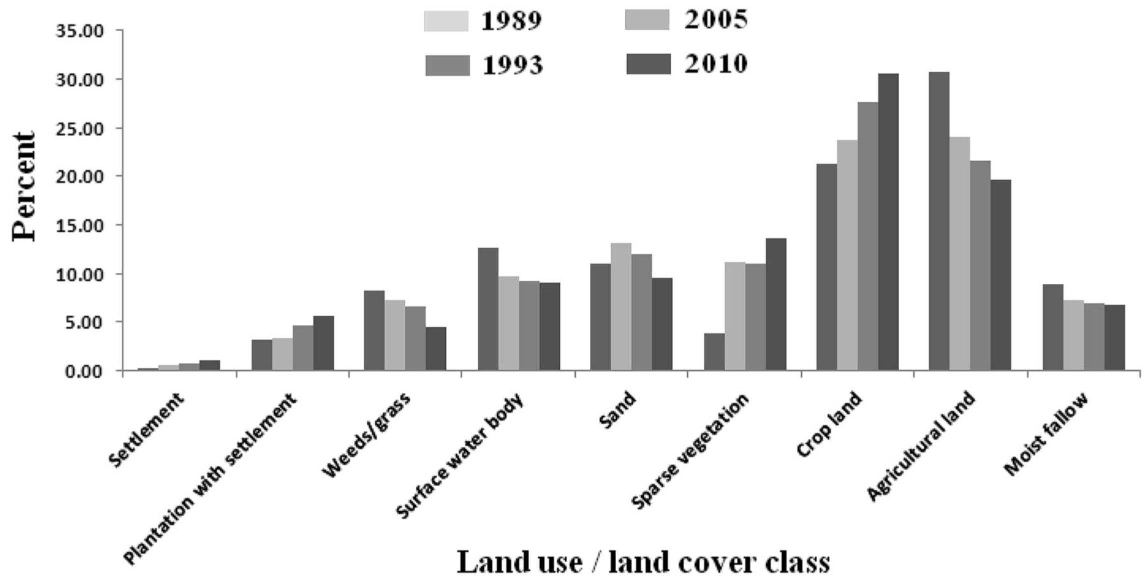

Fig. 4 Distribution of land use/land cover classes during the period between 1989 and 2010

Table 6 Areal changes of land use/land cover characteristics in study area from 1989 to 2010

Land use/land cover class	Area in km^2			
	1989–1999	1999–2005	2005–2010	1989–2010
Settlement	−180.09	−23.22	−193.95	−397.26
Plantation with settlement	−72.96	−730.11	−619.02	−1422.09
Weeds/grass	548.30	417.77	1235.34	2201.41
Surface water body	1697.48	295.12	115.95	2108.55
Sand	−1197.68	700.81	1411.29	914.42
Sparse vegetation	−4212.83	38.67	−1493.58	−5667.74
Crop land	−1477.17	−2273.76	−1729.54	−5480.47
Agricultural land	3939.84	1451.28	1162.54	6553.66
Moist fallow	955.11	123.44	110.97	1189.52

fallow land and the sand areas were transformed into surface water body. It may be due to imprecise analysis during the expurgation of signature classes.

4 Conclusion

In the present study river dynamics along with LULC in an active floodplain of the river Ganges (middle Gangetic plain) was studied. Channel relocation and lateral erosion are two of the most communal geomorphic changes in the rivers of Ganga [53, 54]. The river morphology and LULC is thornily interrelated, the increased human interferences are a probable agent of changing a threatened ecosystem. Both the left and right bank along the study reaches has erosion from channel shifts as a result of erosion that threatened adjacent settlements and infrastructure in the left bank. The maximum continuous movement and excessive sedimentation of the river has been observed towards, the right side from 1989 to 2010. It is found that all together the river has eroded both the banks through its course. The results also demonstrated that the changing rate of braiding index is more than sinuosity ratio, designates the meandering commotion of the river decreases, thus subsidising more sediment into the river. As the river is perennial and snowmelt system with predictable seasonal peaks, therefore planting could take place after spring peak flows to reduce the erosion along the river bank.

Modification in LULC pattern in connotation with river dynamics can be efficiently employed as a pointer of appraising socio-economic influence of riverine menaces on human beings. If the analysis is executed with a higher spatial resolution satellite data these signs could be applied to evaluate socio-economic influence at micro scales. These have instigated a number of problems like soil aggradations in the upper part and siltation, river bank

Table 7 Error matrix/accuracy assessment for thematic classified images for different land use/land covers during different periods

Class name	Reference total	Classified total	Number correct	Producers accuracy (%)	Users accuracy (%)	Kappa statistics (%)
Year 1989						
Settlement	5	5	4	80.00	80.00	0.78
Plantation with settlement	6	6	6	100.00	100.00	1.00
Weeds/grass	4	6	4	100.00	66.67	0.64
Surface water body	4	5	4	100.00	80.00	0.78
Sand	5	5	4	80.00	80.00	0.78
Sparse vegetation	6	5	5	83.33	100.00	1.00
Crop land	5	6	5	100.00	83.33	0.82
Agricultural land	7	6	5	71.43	83.33	0.81
Moist fallow	8	6	6	75.00	100.00	1.00
Totals	50	50	43			
Overall classification accuracy = 86.00 %						
Overall kappa statistics = 0.8423						
Year 1999						
Settlement	6	5	5	83.33	100.00	1.00
Plantation with settlement	7	6	6	85.71	100.00	1.00
Weeds/grass	5	6	5	100.00	83.33	0.81
Surface water body	4	5	4	100.00	80.00	0.78
Sand	7	5	5	71.43	100.00	1.00
Sparse vegetation	5	5	5	100.00	100.00	1.00
Crop land	4	6	4	100.00	66.67	0.64
Agricultural land	6	6	5	83.33	83.33	0.81
Moist fallow	6	6	5	83.33	83.33	0.81
Totals	50	50	44			
Overall classification accuracy = 88.00 %						
Overall kappa statistics = 0.8650						
Year 2005						
Settlement	3	3	2	66.67	66.67	0.65
Plantation with settlement	7	6	6	85.71	100.00	1.00
Weeds/grass	5	4	4	80.00	100.00	1.00
Surface water body	4	3	3	75.00	100.00	1.00
Sand	2	3	2	100.00	66.67	0.65
Sparse vegetation	5	6	5	100.00	83.33	0.81
Crop land	8	6	6	75.00	100.00	1.00
Agricultural land	13	15	13	100.00	86.67	0.82
Moist fallow	3	4	3	100.00	75.00	0.73
Totals	50	50	44			
Overall classification accuracy = 88.00 %						
Overall kappa statistics = 0.8589						
Year 2010						
Settlement	4	3	3	75.00	100.00	1.00
Plantation with settlement	6	6	5	83.33	83.33	0.81
Weeds/grass	5	4	4	80.00	100.00	1.00
Surface water body	3	3	3	100.00	100.00	0.78
Sand	3	3	3	100.00	100.00	1.00
Sparse vegetation	5	6	5	100.00	83.33	0.81
Crop land	8	6	6	75.00	100.00	1.00

Table 7 continued

Class name	Reference total	Classified total	Number correct	Producers accuracy (%)	Users accuracy (%)	Kappa statistics (%)
Agricultural land	13	15	13	100.00	86.67	0.82
Moist fallow	3	4	3	100.00	75.00	0.73
Totals	50	50	45			
Overall classification accuracy = 90.00 %						
Overall kappa statistics = 0.8826						

erosion in the downstream portion. The reaches have been lined up with respect to the land area misplaced in 21 years. As the Ganges is relatively active in terms of its rates of erosion/channel migration; therefore, in-depth study of collaboration of geological activities conjunctively with fluvial regime in the region required to comprehend the multifaceted physical processes.

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