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ORIGINAL ARTICLE

Morphological Dynamics of the Jamuna River in Kazipur Subdistrict

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Abstract

This study identifies and evaluates the morphologically changing trend and process–response mechanisms of Jamuna River. The study considers the bank erosion, bank-line shifting, rate of erosion, accretion, sedimentation, course changing directions, changes in river width, fluvial landform dynamics, and floodplain features. The lower Brahmaputra–Jamuna River (named Jamuna River) at Kazipur subdistrict, Sirajganj district in Bangladesh are the study area. Multispectral Landsat satellite imageries of dry seasons were used for time series analyses of time periods (1972–2016) to interpret the chronological changes of morphology. The outcomes obtained from the analyse, support the historical westward channel shifting of the river, alluvial material properties, explicate fluvial processes, discharge anabranch instability, erosion, and morphological responses.

Keywords Braided river · Morphological dynamics · Sedimentation · Erosion and accretion · Sinuosity ratio

1 Introduction

The Brahmaputra–Jamuna River is one of the largest braided river systems in the world (Islam et al. 2017). The river is also extremely unstable (Bhuiyan et al. 2010). Every year it erodes thousand hectares of floodplain (Sarker, et al. 2014). Morphological changes and bank shifting were observed in the agricultural croplands and settlements (Abdulkareem et al. 2018a; Hazarika et al. 2015). Planform development and lateral shifting change the land use pattern, agricultural activities, and people's rehabilitation capacities. This study assesses the current morphological trend, channel flow direction, changes in river width, channel geometry, rate of erosion, accretion, bank-line shifting, and finally morphological dynamics of Jamuna River in Kazipur subdistrict. The research scopes also cover the fluvial landforms, channel geometry, floodplain morphology, fluvial morphodynamics, river basin management, hydrology, and finally socio-economic conditions as well. The study area has been chosen in small-scale due to the lack of sufficient time, satellite image coverage, proper manpower, and financial support.

2 Study Area

This study concentrates on the lower Brahmaputra–Jamuna floodplain drained by multichannel dynamic Jamuna River at Kazipur subdistrict, Sirajganj district in Bangladesh (Fig. 1). Tectonic influence, tributary switching,and catastrophic flood all are being considered as the avulsion of this river (Bristow 1987; Hossain and Paul 2018).

3 Materials and Methods

In this research work, GIS and RS were used to delineate morphological features for proper identification of morphological changes. Dry season Landsat images of 1972 (MSS), 1988 (TM), 2002 (ETM^+), and 2016 ((ETM^+), with WGS (World Geodetic System) projection were downloaded from (USGS) (earthexplorer.usgs.gov) to delineate morphological dynamics.

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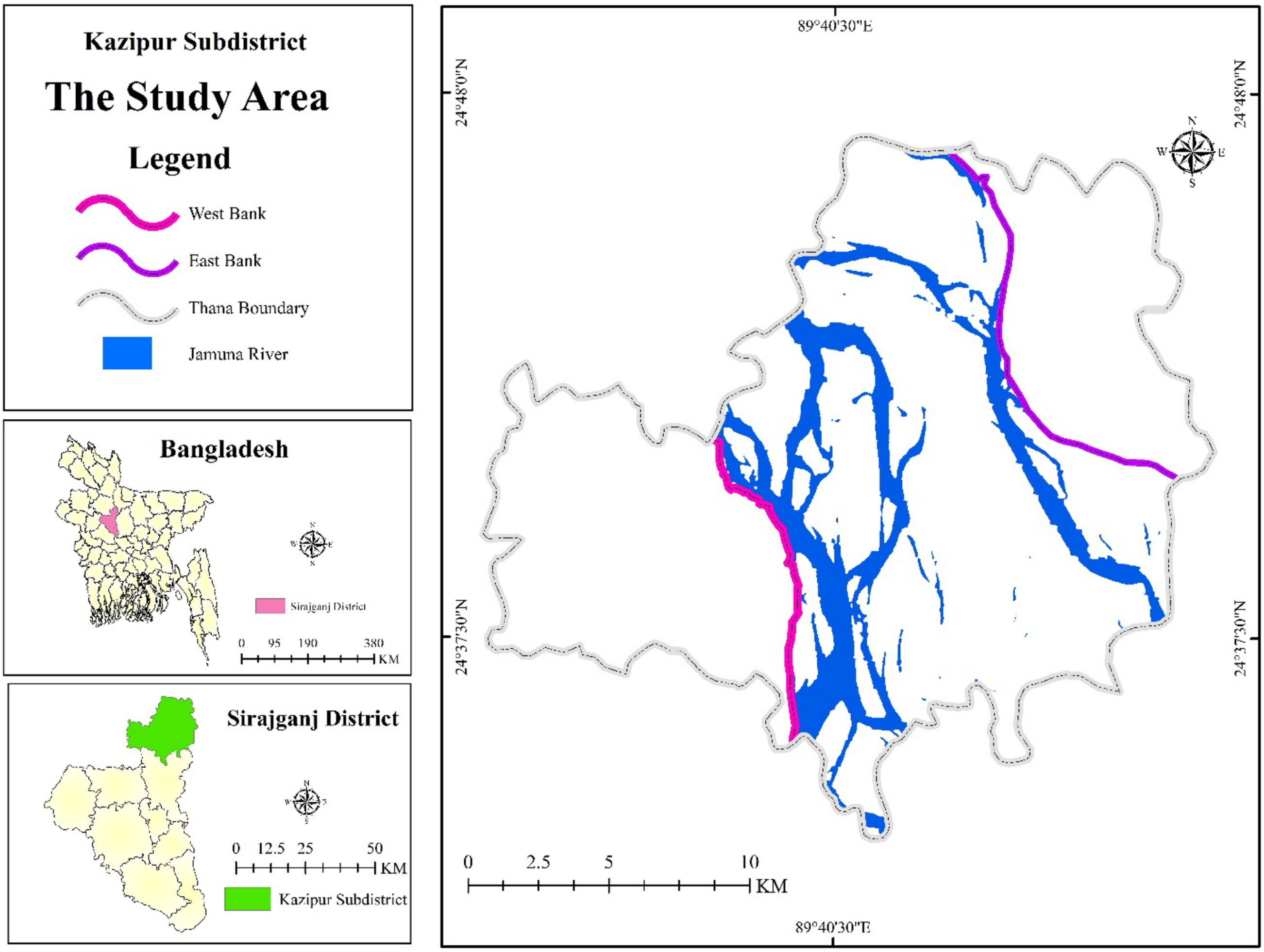

Fig. 1 Geographical extent of study area

3.1 Satellite Image Processing

The projections from the Landsat images were first imported for geo-referencing. BTM (Bangladesh Transverse Mercator) projection was transformed from WGS (World Geodetic System) projection and then the error that occurs due to temporal changes was minimized. Generally, Landsat imageries for the dry season were analyzed to avoid cloud cover (Rai et al. 2017). The channel length, channel width average of four segments, valley length, thalweg length, and bank lines in the years 1972, 1988, 2002, and 2016 are delineated with RS techniques.

3.2 Morphometric Parameters and Morphological Change Detection

Bank-line shifting record for the analysis of mainland floodplain aggression, sinuosity measurement, erosion and accretion were measured. The whole dataset are integrated into GIS environment to assess the morphological dynamics (Abdulkareem et al. 2018b). For analysis of the changes in channel width, study area segments (A–D) with equidistant sections were calculated by an automated process in Arc GIS 10.3. Bank-line shifting was measured for different study periods using overlay techniques. The shifting of the banks is considered 'positive' (+) and channel narrowing is considered as a negative (−) change (Hazarika et al. 2015). The intersecting banks were vectorized as polygons for erosion and deposition. Sinuosity (S) is the "channel thalweg length (LC) divided by valley length (LV) between two points", S = LC/LV (Leopold and Wolman 1960). According to Schumm (1963), "Sinuosity ratio is the ratio between stream length (SL) and valley length (LV)", S = CL/ML.

3.3 Satellite Image Classification for Resource Assessment and Morphological Dynamics

The river area of multichannel braided Jamuna is classified into three major classes: waterbodies, barren sandy bar, and vegetated bar with unsupervised classification using ERDAS Imagine 14. The waterbodies comprised of river channel, cut off channel, backswamp, and wetland; vegetated char comprised of agriculture land, homestead vegetation, and bushes area; barren sandy bar comprised of sandy area and newly accreted bar land. These three major classes are representatives of the actual landscape.

4 Results and Discussion

4.1 Change in River Width

In this study, cross-sectional width was measured for the changes in width from Landsat images (Fig. 2). The cross-sectional width measurement results reveal that the average width has been declined progressively from 11,664.07 m in 1972 to 11,551.73 m in 2016 (Table 1). Rate of widening between 1972 and 1988 (~72.32 m y^{-1}) was extremely high. After 1988, it lessened steadily, averaging only ~45.34 m y^{-1} up to 2016. The widening was not consistent; rather, it was irregular in nature.

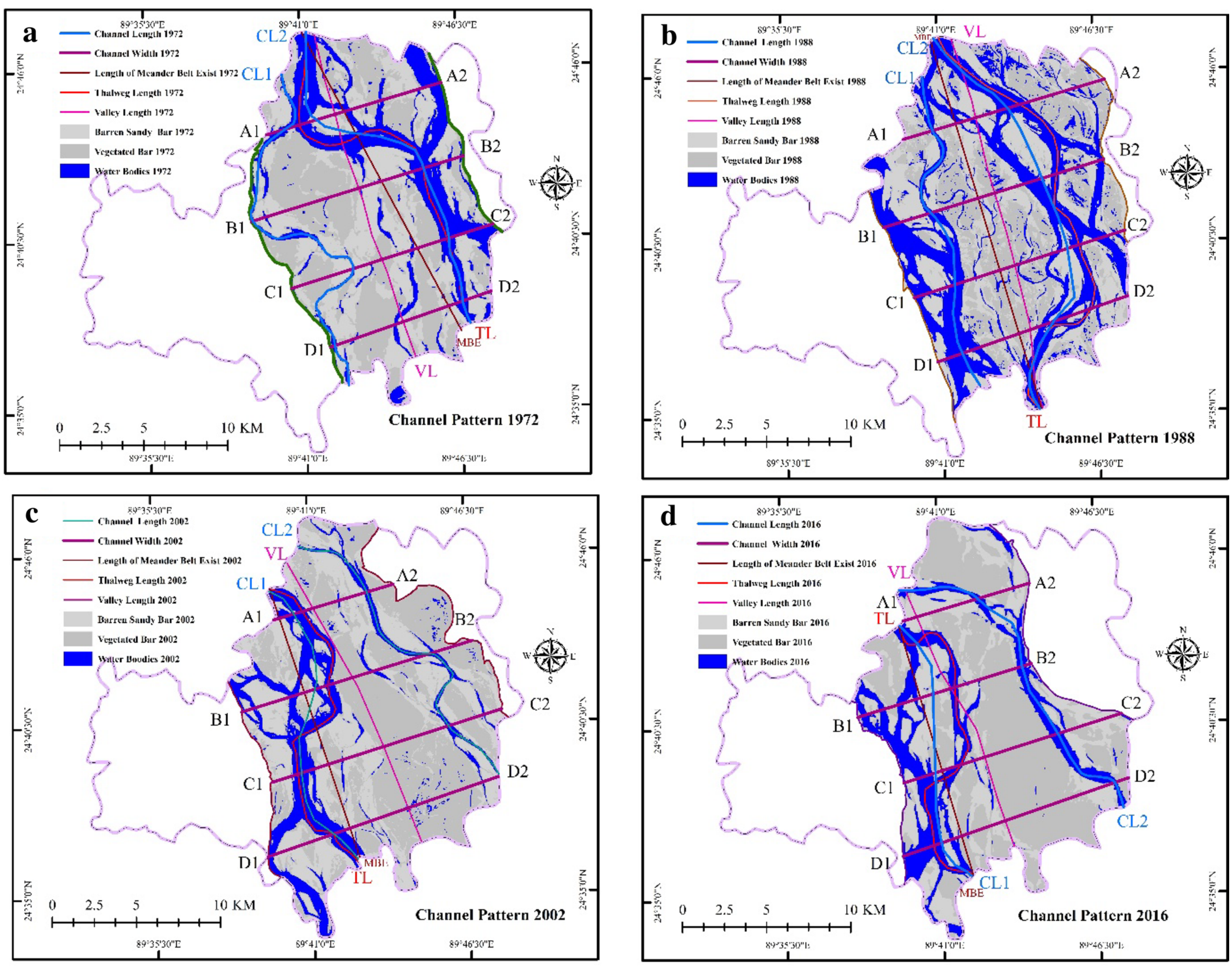

Fig. 2 Fluvial landforms, channel geometry, and channel pattern variables; (**a**) 1972, (**b**) 1988, (**c**) 2002, and (**d**) 2016

Table 1 Channel geometry, sinuosity index, and channel pattern analysis from 1972 to 2016

Parameter and sinuosity index (SI)		Year			
		1972	1988	2002	2016
Cross-sectional width (m)	A1–A2	10,822.7	12,464.4	7394.76	7791.64
	B1–B2	13,182.9	13,716.5	14,311.5	10,765.6
	C1–C2	12,554.7	13,148.8	14,303.3	13,519.3
	D1–D2	10,096	11,955.4	14,482.3	14,130.4
	Average width	11,664.08	12,821.28	12,622.97	11,551.74
Length (m)	Channel length	22,544.5	25,735.9	18,417.9	16,354.7
	Thalweg length	24,340.3	28,519.8	21,077.8	20,798
	Valley length	20,109.8	22,681.8	18,450.9	16,617.5
	Length of mender belt exist	20,126.4	22,749	16,815.5	15,389.6
Sinuosity index (S.I)	S.I (Leopold and Wolman 1960)	1.21	1.26	1.142	1.252
	S.I (Schumm 1963)	1.12	1.13	0.998	0.984
	S.I (Brice 1964)	1.12	1.13	1.1	1.06
	Average S.I	1.15	1.17	1.08	1.09
Channel pattern	Leopold and Wolman (1960)	Sinuous	Sinuous	Sinuous	Sinuous
	Schumm (1963)	Sinuous	Sinuous	Straight	Straight
	Brice (1964)	Sinuous	Sinuous	Sinuous	Sinuous

4.2 Changing Trends of Sinuosity

The channel pattern was measured from sinuosity ratio. The sinuosity ratio is presented in Table 1. The average sinuosity (after Leopold and Wolman 1960; Schumm 1963; Brice 1964) demonstrates a dwindling tendency from 1.15 in 1972 to 1.09 in 2016. Increasing trend of accretion reaches during recent decades is the major indicator of morphological changes.

4.3 Bank-Line Shifting

Bank-line shifting was not uniform in 1972–2016 (Fig. 3 and Table 2). The mean shifting in the east bank for the period 1972–1988 was 0.55 km, whereas a shifting of about 0.77 km is recorded for the west bank. However, the mean shift in the east bank and the west bank for the period 1988–2002 is 1.40 km and 1.01 km, respectively. The reach shows that the highest mobility was in the upstream in the east bank and downstream in the west bank. The upper reach segment (A1–A2) reveals the highest mobility for east bank and segment (D1–D2) for the west bank. Both the banks migrated ~ 1.9 km towards west in 1972–2016, which is the highest. In comparison to the upper, lower streams exhibit steady and continuous migration.

4.4 Quantification of Erosion and Accretion

The erosive nature of this river impacts on mainland floodplain (Fig. 3). Mainland floodplain erosion and accretion and their rate along the river banks are shown in Table 3. The results reveal that about 2632.66 ha mainland floodplain of the study area was eroded, where 895.26 ha was lost along the left (east) bank and 1737.40 ha along the right (west) bank in 1972–1988. The rate of right (west) bank erosion (108.59 ha y^{-1}) was comparatively higher than left (east) bank erosion (55.95 ha y^{-1}) during the same period. On the other hand, only 43.76 ha of new land was accreted along the left (east) bank. The highest rate of accretion in the left (east) bank between 1972 and 1988 was 2.73 ha y^{-1}. The loss (382.324 ha) of land along the left (east) bank is inconsistent with the fact that the left (east) bank is formed in sediments considered as younger, more sandy, and less consolidated than those in the right (west) bank loss (194.77 ha) during 2002–2016. The rate of erosion in the east and west bank was 27.31 ha y^{-1} and 13.91 ha y^{-1}, respectively, during the same period. About 3971.19 ha of floodplain was eroded between 1972 and 2016, located along the right (west) bank. This reveals that during the study period, the river consumed 3971.19 ha of precious floodplain land because of riverbank erosion. On the other hand, 3969.38 ha of floodplain was accreted during the same period.

4.5 Fluvial Landform Dynamics

Fluvial landforms are classified into three distinctive classes: waterbodies, vegetated bar, and barren sandy bar (Fig. 2) and their area measurement results were represented in the Table 4. The result shows that the waterbodies reduced from 5166.36 ha in 1972 to 4300.43 ha in 2016, vegetated bar irregularly increased from 9503.64 ha in 1972 to 11,822 ha in 2016, and barren bar declined

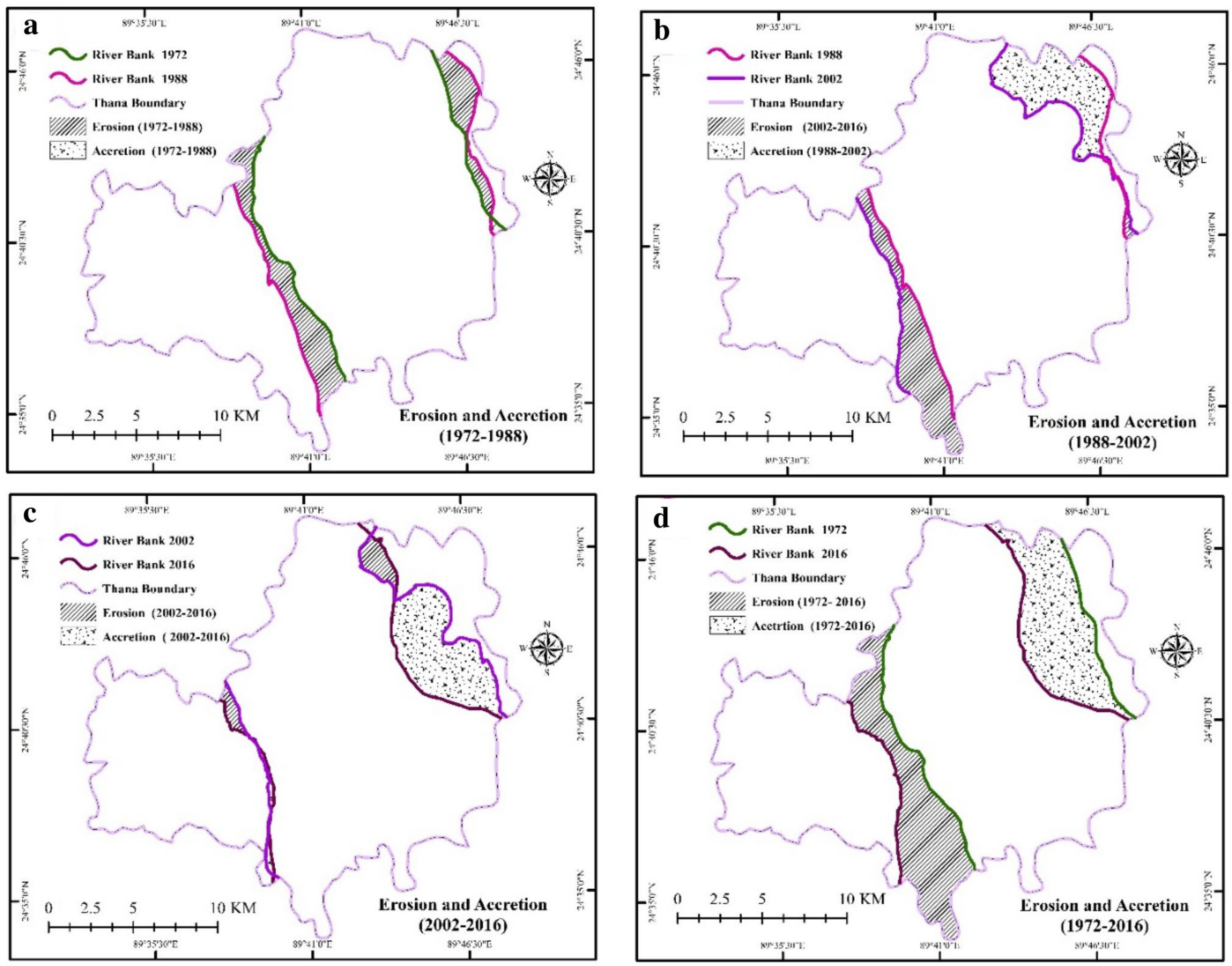

Fig. 3 Changes of flow directions, rate of erosion and accretion along the banks; (**a**) 1972 and 1988, (**b**) 1988 and 2002, (**c**) 2002 and 2016, and (**d**) 1972 and 2016

Table 2 Bank-line shifting trends

Cross-section	East bank shifting (m)				West bank shifting (m)			
	1972–1988	1988–2002	2002–2016	1972–2016	1972–1988	1988–2002	2002–2016	1972–2016
A1–A2	1641.74	5069.65	396.89	3031.06	0.00	0.00	0.00	0.00
B1–B2	229.33	140.95	4390.08	4301.69	304.25	735.99	844.14	1884.39
C1–C2	315.30	384.43	639.16	570.00	909.35	770.10	144.81	1534.60
D1–D2	0.00	0.00	0.00	0.00	1859.36	2526.97	351.96	4034.40
Mean (m)	546.59	1398.76	1356.53	1975.69	768.24	1008.26	335.23	1863.35
Mean (km)	0.55	1.40	1.36	1.98	0.77	1.01	0.34	1.86

unpredictably from 7146.36 ha in 1972 to 5546.72 ha in 2016. Fluvial landform dynamics were analyzed through overlay techniques (Fig. 4) and their results are shown in Table 4. Analysis results revealed that the area of waterbodies was highly increased of 2917.41 ha in 1972–1988 and declined of 3821.78 ha during 1988–2002. This outcome indicated high flood water discharge in 1988 and low water discharge, high sedimentation, and low water velocity in the period of 1988–2002. During 1972–2016, waterbodies were decreased of 865.93 ha, vegetated bar were increased as 2318.36 ha and barren bar were decreased of 1599.64 ha.

Table 3 Rate of erosion, accretion, and along the riverbanks during the period of 1972–2016

Erosion and accretion (ha)/erosion and accretion rate (ha y^{-1})	Period			
	1972–1988	1988–2002	2002–2016	1972–2016
West bank erosion	1737.405	2189.31	194.774	3971.19
East bank erosion	895.2635	86.8597	382.324	0
West bank accretion	0	0	150.293	0
East bank accretion	43.75603	2381.01	2909.06	3969.38
West bank erosion rate	108.5878	156.3793	13.9124	90.2543
East bank erosion rate	55.9540	6.2043	27.3089	0.0000
West bank accretion rate	0	0	10.7352	0
East bank accretion rate	2.7348	170.0721	207.7900	90.2132

Table 4 Fluvial landform class, areas, and their changing trends

Year/period	Fluvial landforms		
	Waterbodies (Ha)	Vegetated bar (Ha)	Barren bar (Ha)
1972	5166.36	9503.64	7146.36
1988	8083.8	8083.8	7850.8
2002	4261.99	4261.99	4261.99
2016	4300.43	11,822	5546.72
1972–1988	2917.41	− 1419.87	704.43
1988–2002	− 3821.78	− 3821.78	− 3588.8
2002–2016	38.44	7560.01	1284.73
1972–2016	− 865.93	2318.36	− 1599.64

(−) Sign indicates decrease and (+) sign indicates increase (during the period)

4.6 Rate of Sediment Deposition

The sedimentation area was high (19,899.99 ha) in the year 2002 and lowest in 1972 (16,650 ha). Moreover, sedimentation of the river has been showing irregular increasing trends (Table 5).

5 Findings

The main emphasis of the study was detecting the sequential morphological changes of Jamuna River using a time series imageries of past 44 years. The average width in the study area reduced to 112.34 m and the rate of narrowing was ~ 2.55 m y^{-1} during the past 44 years (1972–2016). Sedimentation increases attached bar and decreases the average width of this river. The attached bar is not stable and its behavior is very unpredictable. The upper reach segment (A1–A2) showed the highest mobility for east bank and segment (D1–D2) for west bank. Both the banks migrated ~ 1.9 km towards west in 1972–2016. This result indicates the trends of erosion along the west bank. The channel patterns of this river straight to sinuous trends which is measured by applying sinuosity index of Leopold and Wolman (1960), Schumm (1963) and Brice (1964) during the study period 1972–2016. The average sinuosity indicates a decreasing trend from 1.15 in 1972 to 1.09 in 2016. Analysis results also reveal that, more sedimentation, low discharge, and water velocity accelerated bend development of this river which is a clear indication of the changes of river morphology. About 10.95% (3971.19 ha) of floodplain was eroded out of 36,259.3 ha of total area between 1972 and 2016, and located along the west bank. Westward river bank shifting and bend development are responsible for this fluvial hazards. Moreover, 10.947% (3969.38 ha) of accretion floodplain was located along the east bank of this river during the same study period. Sediment deposition and low water velocity accelerated for accretion of floodplain or attached bar development in the east bank. Approximately, 6.394% (2318.36 ha) vegetated bar was increased, 4.41% (1599.64 ha) barren bar was lessened, and 2.389% (865.93 ha) waterbodies were reduced, respectively, out of total area.

6 Concluding Remarks

The Jamuna River has a diverse morphological characteristics. The changing flow pattern directions, bank shifting, bar development, migration, erosion and accretion are the natural processes as a braided river and sometimes changes by external human forces. This research paper indicates that huge sediment deposition increases attached bar and island bar, where agricultural cropland, vegetation cover, and population agglomeration increased. Socio-economic status broken down due to frequent different morphological changes. Bangabandhu Jamuna Multipurpose Bridge; constructed in 1998 considered as a major cause of morphological changes in the downstream of the river. This structural construction changes the river morphology by creating island bars, attached bars, multichannels, more sedimentation, and decreases the flow velocity of water discharge. Various morphological features created by morphological changes have a great influence on the agriculture system and river aquatic

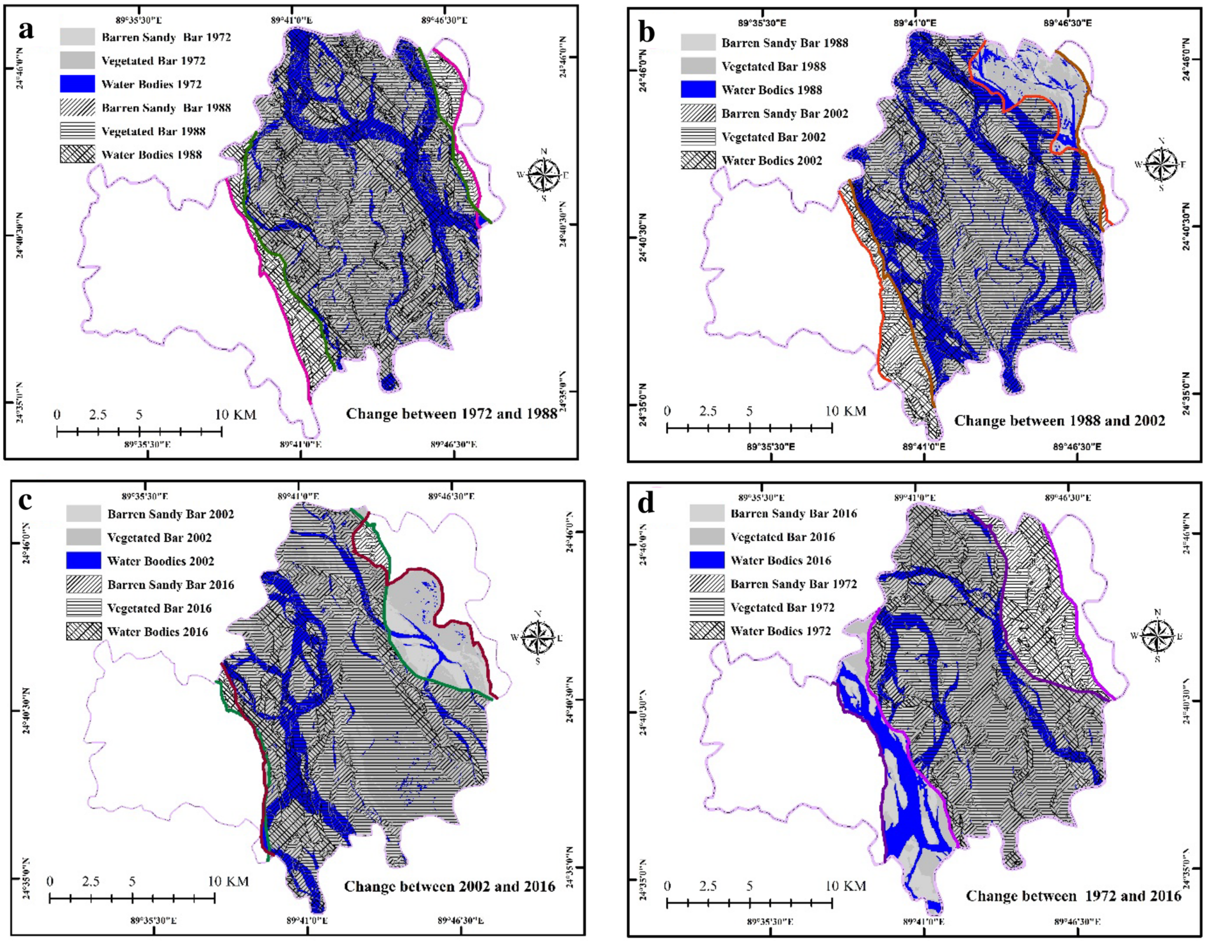

Fig. 4 Morphological dynamics of fluvial landforms; (**a**) 1972–1988, (**b**) 1988–2002, (**c**) 2002–2016, and (**d**) 1972–2016

Table 5 Rate of sediment deposition

Sedimentation scenario	Year	Area (ha)/(ha y^{-1})
Sediment deposition (ha)	1972	16,650
	1988	15,934.56
	2002	19,899.99
	2016	17,368.72
Change sedimentation (ha)	1972–1988	− 715.44
	1988–2002	3965.43
	2002–2016	− 2531.27
	1972–2016	718.72
Rate of sedimentation (ha y^{-1})	1972–1988	− 44.72
	1988–2002	283.25
	2002–2016	− 180.81
	1972–2016	16.33

(−) Sign indicates decrease and (+) sign indicates increase (during the period)

ecosystem. There are some policy implications and management strategies adjoining the research scopes. Any kind of unplanned manmade structures such as dams, bridges, may have adverse impacts on the flow velocity, direction and may cause a huge sedimentation, bank-line shifting, bank narrowing and so on. The government and other nonprofit organizations should emphasze on reducing vulnerability of various fluvial hazards by stabilizing its banks through various restoration processes like creating riparian buffer zones, embankment flood protection system, reducing waste dumping processes, and toxic materials to reduce climatic impacts.

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