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Morphological analysis and channel shifting of the Fulahar river in Malda district, West Bengal, India using remote sensing and GIS techniques

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Abstract The present study has been carried out to analyse and interpret the morphological changes and channel shifting along the Fulahar river in the Malda district. Fulahar river is one of the most hazardous river zones in the Malda district. The river meets the Ganga river near Manikchak Block and shifts towards the western part of the Malda district. The total length of the river is about 60 km. The study has considered the different parameters like Braiding Index, Sinuosity Index, Channel Index, Valley Index, Hydraulic Sinuosity Index, Topographic Sinuosity Index, Island areas, and river width of the Fulahar river. To detect the river course were used 45 years satellite images for the year of 1973, 1980, 1990, 2001, 2010 and 2018 from Landsat data of USGS. The study is generally based on remote sensing and Geographic Information System methods to elucidate the changes of the river channel and resulting hazard zones of the Malda district. Channel shifting and flooding are the main source of the river bank failure of the Malda district. For the completion of this study, 17 cross-sections were made for calculating the shifting of the total reach of the river from Mihaghat in Harischandrapur II to Paschim Narayanpur in Manikchak C.D. Block of Malda district. Due to the shift of the Fulahar river course, the people of Harischandrapur II, Ratua I, and Manikchak C.D. Block are faced with problems and displaced year by year. The study may help for future management of the area to reduce bank erosion and land loss.

Keywords Morphological changes · Channel shifting · Fulahar river · Remote sensing and GIS

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Introduction

The river becomes an interesting case study when it undergoes several morphological changes longitudinally and transversally, related to various types of hydraulic works, weirs, and embankments over the long periods (Geria et al. 2018). River morphology describes the concept of geographic form, the river channel classification, edges of the river, and geomorphic analysis. River morphology is a significant analysis of the physical principles of hydraulic flow and sediment transport (Chang 2008). A channel pattern is a result of factors such as river discharge, water velocity, thickness, and depth of the channel, which are inter-related to each other (Matsuda 2004). The morphological behaviour and topographical altitude have a vital role to play in the changing nature of the river. Another possible finding is that alternate bars freely move in sinuous channels of low amplitude but can be suppressed in sinuous channels of high amplitude, probably reforming in meanders of very high amplitude, may cause systematic variation inflow and bed topography could affect the migration rates of the river bank (Panda and Bandyopadhyay 2011). Church and Ferguson (2015) observed that the actual relation between discursive characteristics of bed material transport and occurrence of river morphology underline the underlying problems of sediment transport, riparian vegetation, and bar evolution in determining channel form. Guerrero et al. (2013) described a multi-disciplinary and multi-scale approach for the prediction of river future morphology in the perspective of climate change, the intended use of which is the warning of river morphodynamics long term influence on man-made structures and activities over or near the river. The conflux of two channels having distinct flow and sediment discharge regimes comprise difficult erosional and depositional circumstance may cause some changes at the morphology of the channels (Ribeiro et al. 2014). For sustainable river channel management, measurement of magnitudes, and the forthcoming channel change rates are very significant. Lotsari et al. (2015) analysed numerical modelling approaches are available for reach-scale simulation of upcoming river channels and predicted in-channel hydro and morphodynamic changes model. Besides that, the study in the geomorphological form on the variation and monitoring in the rivers should be more significant to interpret the consequence of hydrological implications in fluvial geomorphology. Additionally, in future studies, the role of human activities in river prone areas in hydrological circumstances should be done extensively (Yousefi et al. 2018). The research also focuses on the shifting pattern of the Fulahar River, calculates its morphometric parameters and river channel width, and finds out the associated problems. During the rainy season, the Fulahar river results in floods due to the increased water level, this affects the surrounding area or villages. In present work, we have studied the spatio-temporal shift of the river channel (1973–2018) and hazard zone areas of the Fulahar river in the Malda district using geospatial methods.

Review of literature

The dynamic changes of the river channel are crucial in the study of geomorphology (Yang et al. 2015). The study on the river channel morphology initiated from 1950 onwards and it is assumed as a straight measurement of the river channel (Lane 2000). Channel morphology is classified at a primary level by a basic river typology which illustrates using remotely sensed images, and at a secondary level by an extended river typology that implements information from field investigations (Rinaldi et al. 2016). River shift is strongly influenced by human interference. A combination of human induced activities which causes decline in river levee, high sedimentation rates, and adverse channel gradients, which results in avulsion (Sharma et al. 2010; Heyvaert et al. 2012). Nagata et al. (2000) studied the numerical model experiment of river channel processes with bank erosion. Ramonell et al. (2011) developed a shifting mode of channel pattern with better classification. It has been measured the variation of sinuosity index and radius of curvature (Chakraborty and Mukhopadhyay 2015), and the powerful indication of channel shifting is the wide meander belt (Eardley 1938).

In West Bengal, the Ganga river system has many features such as sediment load, fluctuating discharge, nature of western tributaries, tidal intrusion, underground geology, and the hydraulic gradient (Rudra 2000), and Malda district has an exceptionally high hazard area due to the Ganga river bank erosion and high flood, and the peoples are displaced every year (Iqbal 2010; Laha and Bandyapadhyay 2013; Sahana et al. 2015; Ghosh and Kar 2018). Due to the continuous oscillation of the Ganga river, the peoples faced many difficulties along the lines of Jharkhand and West Bengal, Indo-Bangladesh, and also created a border dispute (Rudra 2010). Mukherjee (2011) describes the people to have moved four to sixteenth times in more than 15 years in newly developed *Chars*. Das and Pal (2016) studied the Kalindri River (a distributary of Fulahar River), pointing out an intricate fabric of channel shift and magnitude of migration in varied reaches. Therefore, to study the channel shift in different years, remote sensing and geographic information system is an essential tool (Yang et al. 1999). Remote sensing and GIS in combination can be used to gain empirical responses to historical and current morphological shifts in river channel problems, which would otherwise be challenging to achieve for time and land coverage purposes. The other benefit of RS and GIS is the use of available, inexpensive, and open-source remote sensing data that allows the rapid identification of morphological changes and how these affect river channels (Langat et al. 2018). The literature cited so far shows that the Ganga river is most hazardous and has affected large parts of land in Malda and also people's living conditions and livelihood. However, none of the studies have been done on Fulahar river, although it plays a significant role in affecting the lives of the people, making them homeless due to morphological changes caused by it. Fulahar river is one of the causative factors of dynamic bank erosion, where peoples are mostly affected every year. It is significant to find out the shifting and change in the river channel and also calculated the morphometric parameters, river channel width, and so on.

Study area

The Fulahar is an important river of Malda extends about 60 km. It is a main flow of the river Mahananda. The river flows through Bihar and enter in the district near Mihaghat of Harishchandrapur-II (25°32′ N and 87°37′ E) and merges with Ganga at Manikchak (25°08′ N and 87°48′ E). The Mahananda river divided into two channels in Barsoi of Bihar district. Out of its two branches the western branch flows through the Bihar and Malda district of West Bengal by the name of Phulhar or Fulohar or Fulhar or Fulahar (Rudra 2010). The river Fulahar discharge into the Ganga river at Manikchak block in Malda district (Fig. 1). Mostly the Tal and Diara region with alluvium of two different ages (e.g. Pleistocene and Tertiary). This region consists of layers of clay and sand. It originated in the age of Ramayana, the great Hindu epic, and takes off from old Mahananda or Mara Mahananda near Bagjob and entered into the district (Saha 2012). Buchanan Hamilton (1810) considered that Fulahar river lying over the Tal region within the district which was merely a branch of the Ganga. During the Nababi period (in the seventeenth century), it is known as Kalindri, after this century it renamed as Fulahar (field survey by the local people). As per the census of India 2011, the total population of the study area (Manikchak, Harishchandrapur-II and Ratua-I) is 796,546 persons. At present, the Fulahar meet the Ganga at West Narayanpur of Manikchak block. The main tributaries of this river system are Kankhar, Katiganj, Kalkos, Kankhor, Maria-kankhar, Kalikosi and Chitolia etc. For contributing the massive turbulence into the river, not only the Ganga herself rather the Fulahar individually acts as one of the causative factors of dynamic bank erosion in Malda district. Nowadays, the river Fulahar does not show a successive change in its course. The river move laterally in its channel bed. Occasionally, it moves two or three km towards the right bank side and at times moves towards the left bank side. During the summer month, the river water gets reduced; however, in monsoon the water level increases. The river experiences a prolonged flood in July, August and September every year. The western part of the Malda district receives floodwater from the neighbouring country of Nepal and the state of Bihar through a vast network of the river.

Database and methodology

The data has been collected from the United States Geological Survey (USGS) Earth Explorer, Google Earth, Survey of India (SOI), District Census Handbook, Human Development Report, and Department of Science and Technology and Public Health and Engineering Department (Govt. of West Bengal). In the present study, from 1973 to 2018, Landsat satellite data used to show the actual changes and channel migration of the Fulahar river course. The satellite images of data such as Landsat 1 and 3 data of Multi-Spectral Scanner (MSS), Landsat 5 data of Thematic Mapper (TM), Landsat 7 data of Enhanced Thematic Mapper (ETM) and Landsat 8 data of Operational Land Imager and Thermal Infrared Sensor (OLI-TIRS) along with the topographical sheet (Table 1).The projection covers Universal Transverse Mercator (UTM) with 45 zone datum and also used the World Geodetic System (WGS) 84 in the geospatial data. The rectified of the images and subset of the study area using the Erdas Imagine 2014 software. The spatial resolution was 30 and 60 m of the satellite images. After finalising all the processes, we modified the False Colour Composite and also extracted the river body through ArcGIS 10.3.1. After that, retrieve form of the river body; the study area was digitized and saved in a personal geo-database in ArcGIS 10.3.1

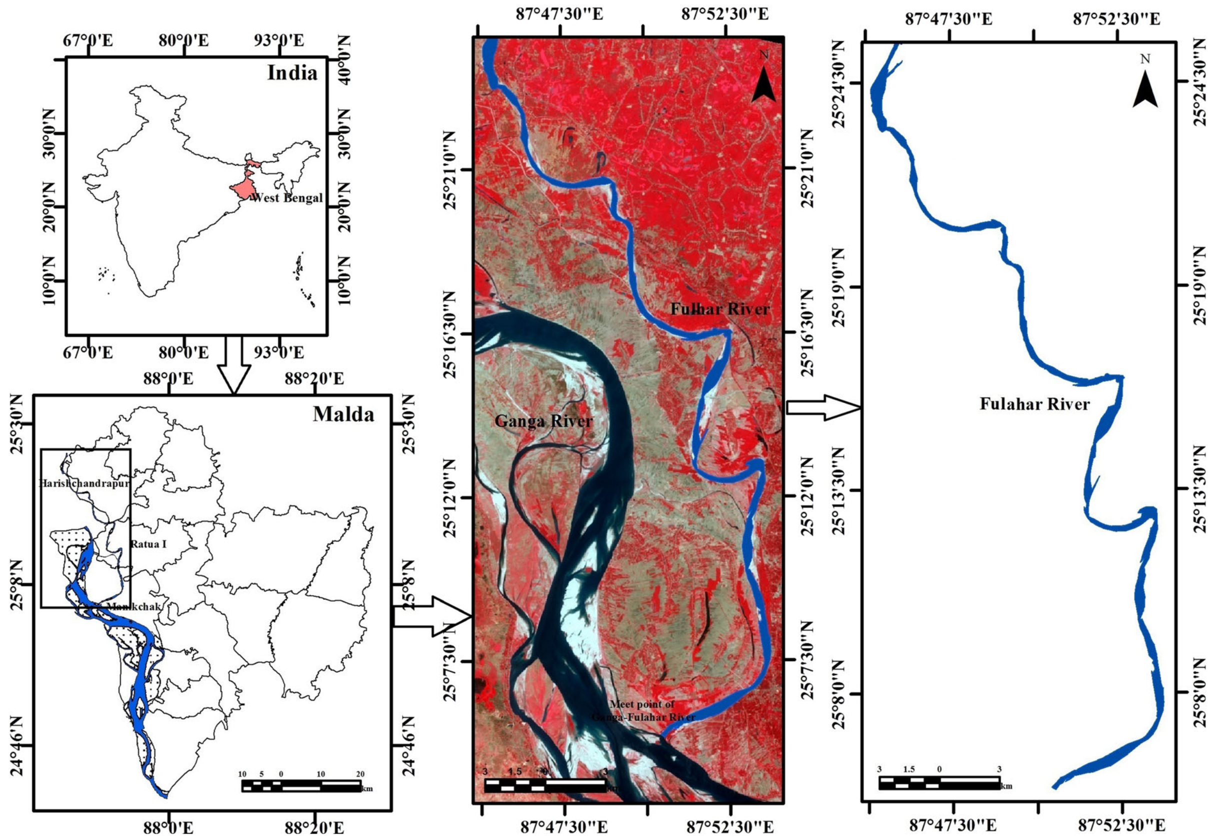

Fig. 1 Location map of the study area

Table 1 The details of datasets used in this study

Satellite	Sensor	Path/Row	Date of acquisition	Spatial resolution(m)	Source
Landsat 1	MSS	149/43	22.02.1973	60	USGS
Landsat 3	MSS	149/43	17.01.1980	60	USGS
Landsat 5	TM	139/43	06.02.1990	30	USGS
Landsat 7	ETM +	139/43	27.01.2001	30	USGS
Landsat 5	TM	139/43	02.04.2010	30	USGS
Landsat 8	OLI-TIRS	139/43	24.04.2018	30	USGS

software. Seventeen fixed cross-sections were formed with mention to 1973 and 2018, given base and present scenario of Fulahar river. The cross-sections were prepared unequal distances from the north–south direction, providing more concern to morphometric fluctuations of the river. These cross-sections are marked based on the visual inquiry of temporal river course pattern, more significant morphometric changes, and the massive fluctuation in a river bank. Along those cross-sections, the stretch from right to the left bank of the river has been measured using the measurement tool in ArcGIS 10.3.1 software and described fruitfully. Another is that the block boundaries of the study area were collected from the Malda district census handbook and digitized by the ArcGIS 10.3.1 software and also identified the risky villages due to river course shifting.

Morphometric parameters (sinuosity index, topographical sinuosity index, hydraulic sinuosity index, and braiding index) and island areas were measured significantly in this study. The individual parameters of the river based on remote sensing and GIS are

Table 2 Details of the study area

Name of the river	Fulahar
Entry point	Mihaghat in Harishchandrapur II (25°32′ N, 87°37′ E)
End point	Paschim Narayanpur meeting Ganga river in Manikchak (25°08′ N, 87°48′ E)
Total length	60 km
Runs through the blocks	Harishchandrapur II, Ratua I and Manikchak

Source: Census of India, 2011 and Google Earth

measured and described in this study fruitfully. It has been applied in geomorphological studies with numeric calculation. Leopold et al. (1964), Mueller (1968), Friend and Sinha (1993) described the sinuosity index of river channels. Therefore, the sinuosity index can be measured with the following formula:

$$\text{Sinuosity Index (SI)} = L_{cmax}/L_R \quad (1)$$

where L_{cmax} is the length of the mid-channel for the same reach, and L_R is the total length of the channel belt reach measured along a straight path.

$$\text{Channel Index } (C_I) = C_L/A_L \quad (2)$$

where C_I is the Channel Index, C_L is the length of the channel, A_L is the Air Length between the source and mouth of the river.

$$\text{Valley Index } (V_I) = V_L/A_L \quad (3)$$

where V_I is the Valley Index, V_L is the length of the valley, A_L is the Air Length between the source and mouth of the river.

$$\text{Hydraulic Sinuosity Index } (H_{SI}) = \% \text{ equivalent of } (C_I - V_I)/(C_I - 1) \quad (4)$$

where H_{IS} is the Hydraulic Sinuosity Index or percentage departure from a straight line course due to hydraulic factors, C_I is the Channel Index, V_I is the Valley Index.

$$\text{Topographic Sinuosity Index } (T_{SI}) = \% \text{ equivalent of } (V_I - 1)/(C_I - 1) \quad (5)$$

where T_{SI} is the Topographic Sinuosity Index or percentage of streams departure from a straight course due to topographic interferences, C_I is the Channel Index, V_I is the Valley Index.

Brice (1960) used the Braiding Index (BI) parameters to measure the whole extent of bank length, where the length of the bars or islands has considerably higher than width. Therefore, the absolute length of the bank will be almost by doubling the length of bars or the islands.

$$\text{Braiding Index (BI)} = 2(\Sigma L_i)/L_r \quad (6)$$

where ΣL_i is the length of total bars or islands in the reach, L_r is the mid-length measured between the banks of the channel belt.

Results and discussion

Detection of change in Fulahar river morphometry with time

1973 Fulahar river reach

The river course has been digitized from the corrected Landsat 1 MSS data of February 22, 1973. The present river course appears from Mihaghat in Harishchandrapur-II to Paschim Narayanpur of Manikchak and joins the Ganga river (Table 2). The total area of the river was 11.711 km^2. The sinuosity index for the entire river reach was 1.704. The channel Index and valley index was 1.67 and 1.74. And the topographic sinuosity index and hydraulic sinuosity index were mainly 91.75 per cent and 8.25 per cent. At that time, there were very few river islands in the river reach. The total area of the river island area was 2.0517 km^2, and the river width was minimal. The braiding index of the river reach was 0.318 (Table 3).

1980 Fulahar river reach

The river reach was identified and analyzed from the rectified Landsat 3 MSS data of January 17, 1980. In 1980, the total area of Fulahar river in the Malda district was measured as 16.815 km^2. It has increased by 5.10 km^2 from the preceding years. The sinuosity

Table 3 Morphometric parameters of the study area

Year	1973	1980	1990	2001	2010	2018
Braiding index	0.318	0.316	0.591	0.780	0.872	1.028
Sinuosity index	1.704	1.487	1.420	1.450	1.60	1.56
Channel index	1.740	1.552	1.584	1.624	1.619	1.604
Valley index	1.679	1.536	1.548	1.528	1.580	1.521
Hydraulic sinuosity index	8.248	2.899	6.162	15.326	6.318	13.660
Topographic sinuosity Index	91.751	97.100	93.838	84.674	93.681	86.339
Island area(sq. kms)	2.015	2.826	3.780	4.139	5.635	5.705

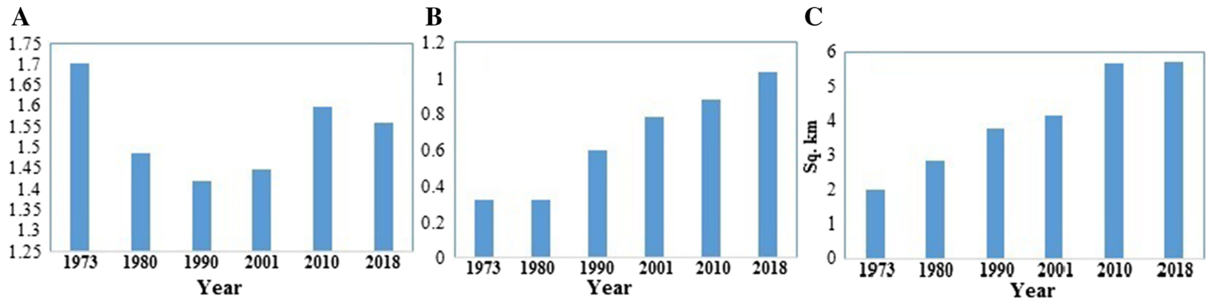

Fig. 2 **a** Sinousity Index, **b** Braiding Index, **c** Island Area (sq. kms)

index of the entire river reach was 1.487, which has decreased; similarly, the channel Index and valley Index of the river fell as per the previous year from 1.74 to 1.55 and 1.67 to 1.53 respectively. The topographic sinuosity index has increased from 91.75 to 97.10 per cent, and the hydraulic sinuosity index has decreased from 8.25 percent to 2.90 per cent. During this year, the river showed a sinuous pattern. The total area of river islands was 2.826 km^2, which has increased from previous years. Finally, the braiding index of the river reach was 0.316.

1990 Fulahar river reach

The Fulahar river course has been taken from the corrected Landsat 5 TM data of November 21, 1990. The total study area covered 16.374 km^2. The entire river area reach has decreased from 1980 to 1990. In this year, the sinuosity Index, channel index, and valley index of the river are 1.42, 1.58 and 1.54 respectively. The topographic sinuosity index and hydraulic sinuosity index were 93.84 per cent and 6.16 per cent, respectively. The degree of sinuosity of the river was a sinuous type. The braiding index of the river was 0.591. The braided index of the river has increased from the preceding years by 0.275. The total island area of the river was measured as 3.780 km^2, which has increased significantly more than the previous year.

2001 Fulahar river reach

The river has been digitized from the rectified Landsat 7 ETM + satellite image of October 26, 2001. The sinuosity index of the river was 1.450, which has been increased from the past years; likewise, valley index has also reduced from 1.54 to 1.52, but the channel index has increased from 1.58 to 1.62. And topographic sinuosity index was 84.67 per cent while the hydraulic sinuosity index was 15.33 per cent which has increased due to heavy flood recorded in 1998 and 1999. The total river area was 20,234 sq. km. The braiding index of the river was 0.780, which has increased in order. The island area has also been increased from the previous year. The total island area covered 4.139 km^2.

2010 Fulahar river reach

Here, the river reach has been analysed and digitized from the Landsat 5 TM satellite imagery of April 2, 2010. The sinuosity index of the river was 1.60. The

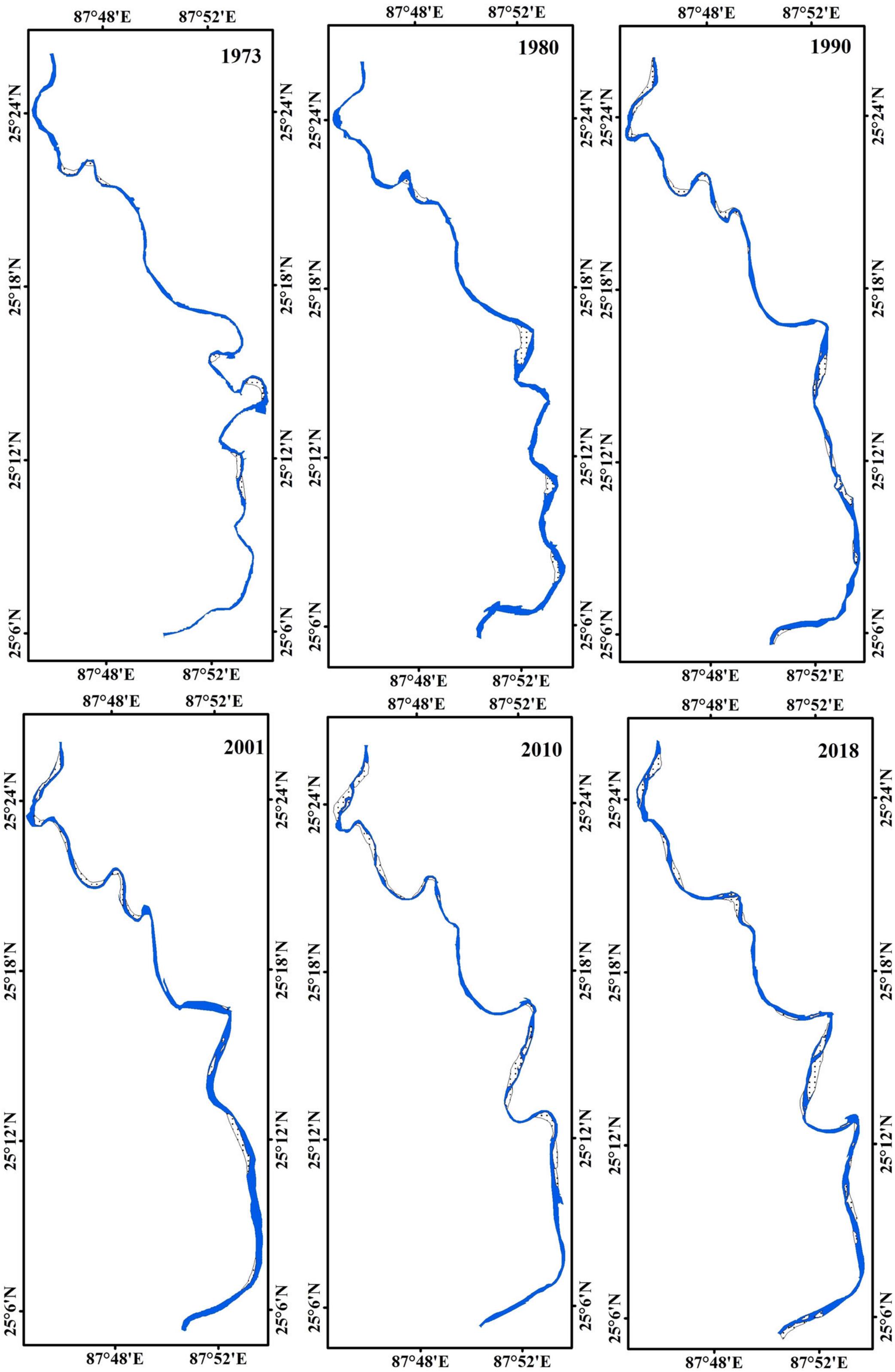

Fig. 3 Spatio-temporal shift of the Fulahar river from 1973–2018

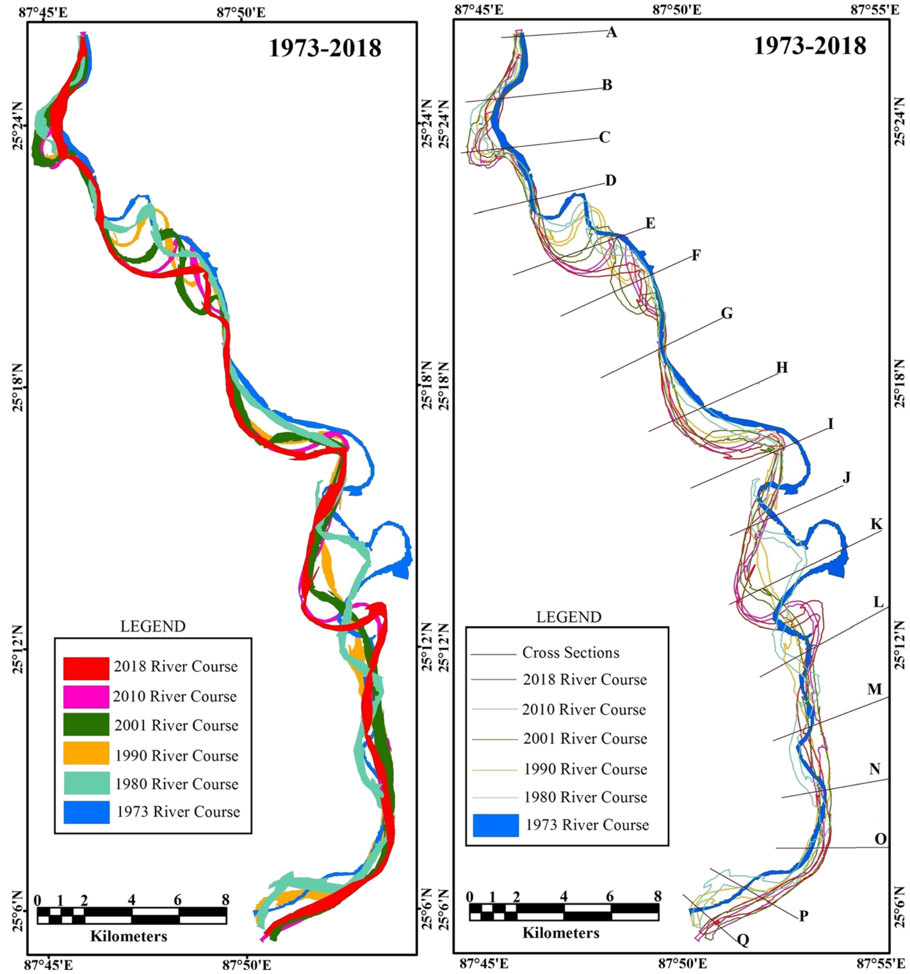

Fig. 4 Measuring temporal shift of the Fulahar river along each cross-sections

sinuosity Index and channel index of the river have increased, but valley index has decreased as per the previous year. The topographic sinuosity index and hydraulic sinuosity Index were 93.68 per cent and 6.32 per cent respectively. From 2001 to 2010, the river course had shifted towards the western part. The braiding index of the river was 0.872. Therefore, the braiding index of the river has increased from 2001 to 2010. The island area has covered by 5.635 km^2, which rose from the preceding year.

2018 Fulahar river reach

The river has been digitized from the Landsat 8 OLIS image of April 12, 2018, covered by 15.658 km^2. In 2018, the sinuosity index of the river was 1.562. The channel index and valley index of the river were recorded as 1.60 and 1.50, which decreased from the preceding years. The degree of sinuosity index is a meandering type. The topographic sinuosity index and hydraulic sinuosity index of the river were 86.33 per cent and 13.67 per cent. From 1973 to 2018, after the cross-section analysis of the river, the majority part has changed, respectively. The river reach near Maniknagar, Kamalpur, Dakshin Bhakuria, Uttar Bhakuria, and Narayanpur has shifted very much. The braiding index of the river has increased from the earlier analysis. The island area was 5.705 km^2 which has also increased.

Therefore, sinuosity deals with the river channel patterns and the sinuosity values greater than 1.5 are characteristics of the meandering type. It is also

Table 4 Temporal shift of the river along each cross section

Cross-sections	River shifts in metres											
	1973–1980		1980–1990		1990–2001		2001–2010		2010–2018		1973–2018	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
A	204.74	212.92	− 78.45	− 8.79	32.09	− 41.36	− 88.62	− 2.14	24.29	− 3.42	93.95	157.18
B	570.84	603.42	− 171.5	− 291.04	49.22	− 224.29	− 319.54	62.73	198.45	− 146.46	327.47	− 0.092
C	707.78	653	581.34	831.71	285	37.48	− 191.07	− 87.61	− 933.71	− 1031.8	449.35	402.76
D	45.85	90.94	− 90.41	6.78	112.13	− 56.41	− 185.79	− 4.03	− 24.55	− 59.45	− 142.69	− 22.16
E	1066.4	1085.3	− 322.88	− 449.1	302.15	− 362.83	171.42	262.54	73.57	89.78	2878.64	2931.21
F	245.29	136.79	− 142.73	− 41.81	1560.87	1372.68	− 859.83	− 697.13	− 391.74	− 345.89	411.88	424.63
G	15.39	− 118.96	33.5	85.26	1.34	− 26.71	− 6.24	− 27.19	− 1.35	− 15.15	42.02	− 102.73
H	203.07	91.26	783.22	892.28	191.04	− 29.65	109.45	139.68	61.93	123.67	1348.72	1217.25
I	881.79	759.41	− 37.83	65.85	160.33	− 102.55	− 270.47	− 97.19	174.93	70.62	908.61	699.16
J	908.73	800.53	30.25	− 5.35	27.87	− 271.2	− 596.96	− 91.14	701.71	773.91	1071.6	1203.78
K	2298.6	2014.87	1282.43	1531.16	738.09	530.78	609.53	919.79	− 95.02	− 116.52	4830.52	4882.68
L	972.59	755.92	57.35	− 287.17	− 765.8	− 381.16	− 308.65	− 278.69	− 23.59	− 147.43	− 68.37	− 338.51
M	738.04	340.04	− 684.81	− 697.62	− 38.79	10.66	13.29	31.81	386.61	677.48	414.34	362.45
N	609.66	258.68	− 537.93	− 424.05	119.64	− 33.29	102.91	353.91	− 155.34	− 125.65	138.92	56.59
O	− 73.6	− 170.66	126.04	9.67	− 485.73	− 359.84	− 237.37	− 52.13	32.89	− 19.88	− 637.78	− 592.84
P	1139.2	− 38.5	− 1115	− 857.26	− 991.07	− 384.57	52.82	208.49	110.08	− 182.58	− 803.93	− 1253.5
Q	128.15	− 111.54	188.22	318	− 1126.78	− 1172.1	− 109.95	− 138.37	170.02	241.64	− 750.33	− 753.74

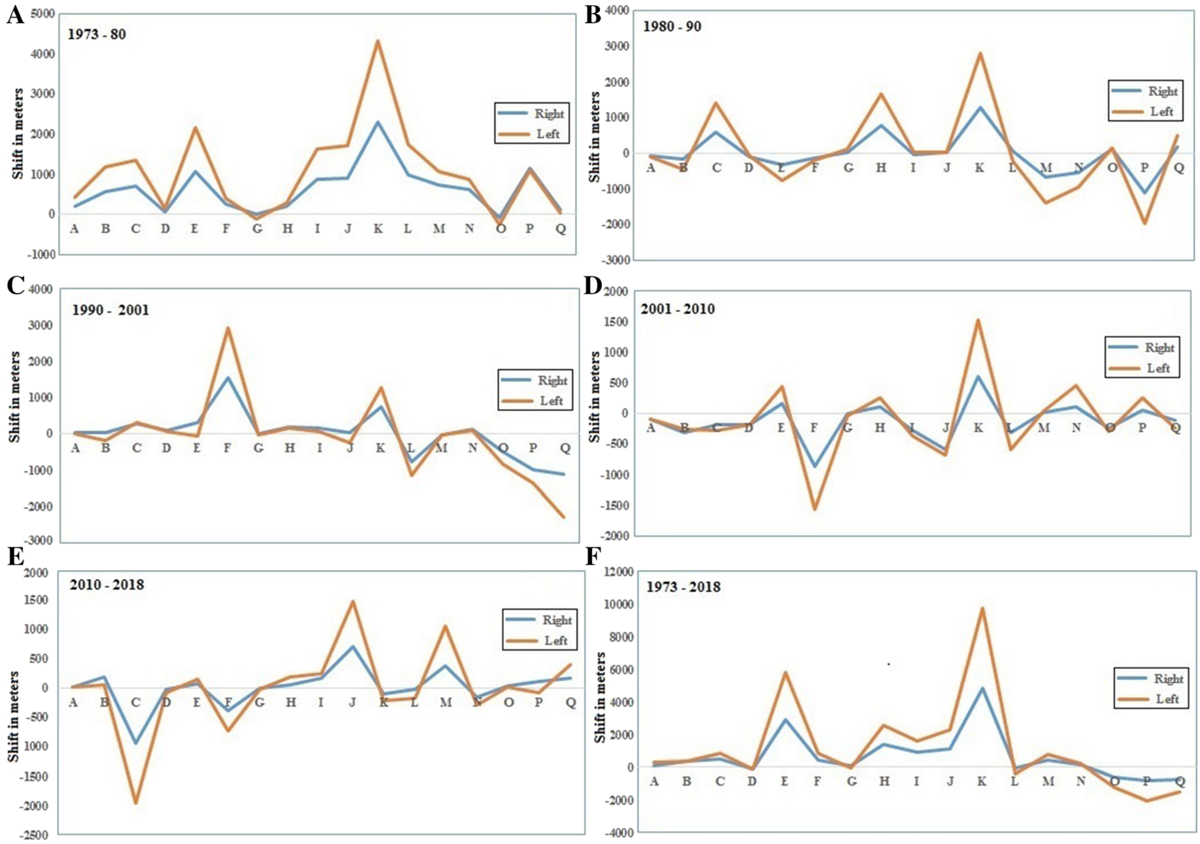

Fig. 5 Bank wise migration of the river along each cross-sections. **a** 1973–1980, **b** 1980–1990, **c** 1990–2001, **d** 2001–2010, **e** 2010–2018, **f** 1973–2018

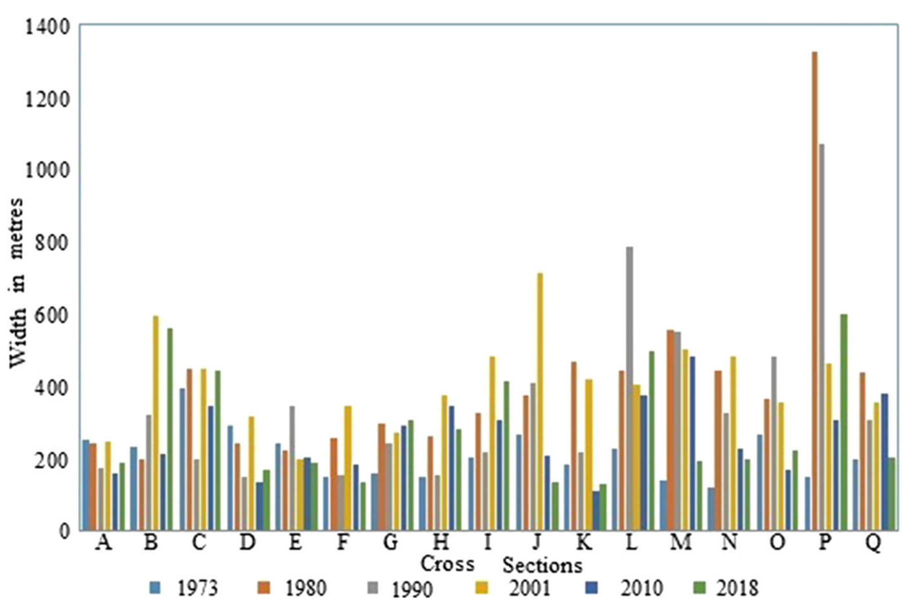

Fig. 6 Temporal change of river width at various cross-sections

Table 5 Changes of river width along each cross section

Cross-sections	River width in metres					
	1973	1980	1990	2001	2010	2018
A	250.12	241.93	172.28	245.74	159.17	186.89
B	230.27	197.95	317.5	595.01	212.91	557.83
C	393.96	448.77	198.4	445.91	342.45	440.56
D	287.27	242.17	144.97	313.52	131.85	166.74
E	238.45	219.53	345.76	194.98	202.09	185.88
F	146.43	254.94	154.02	342.21	179.53	133.69
G	157.96	292.32	240.56	268.61	289.54	302.72
H	148.1	259.9	150.85	371.54	341.32	279.58
I	201.63	323.97	217.3	480	306.76	411.08
J	264.7	372.89	408.48	710.54	204.72	132.51
K	181.97	465.59	216.86	419.21	108.32	129.82
L	224.69	441.18	785.71	401.06	370.98	494.83
M	137.87	553.87	548.63	499.17	480.65	189.77
N	116.1	440.07	326.19	479.13	228.13	198.43
O	266.15	363.2	479.57	353.67	168.44	221.21
P	149.29	1327.04	1068.41	461.91	306.22	598.89
Q	195.86	435.57	305.82	351.1	379.49	202.27

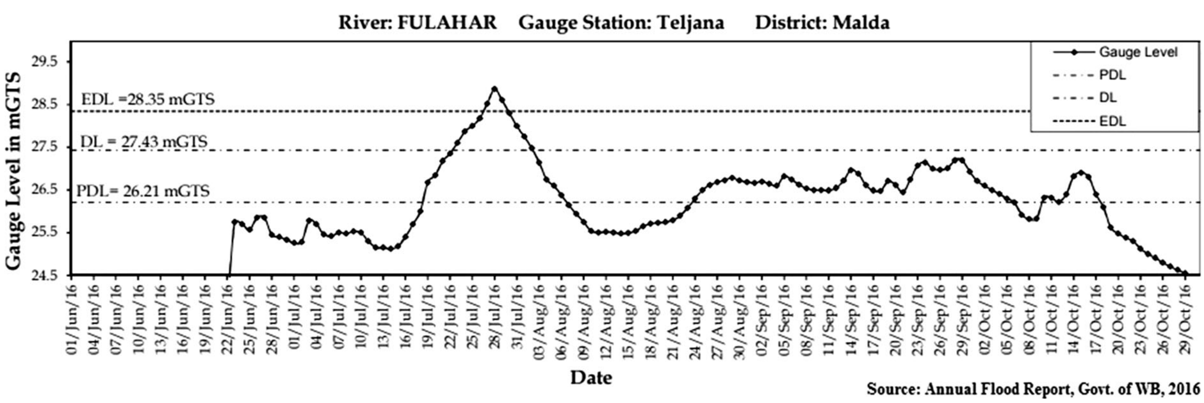

Fig. 7 Frequency of Flood during Monsoon, 2016

significant to say that, sinuosity indices evaluate the hydrological or topographical factors of the river. The channel sinuosity is an important parameter used in the morphological studies to differentiate between the several types of terrain and to ascertain the degree of the establishment made by the drainage line in the area of influence. Mueller (1968) has introduced sinuosity indices in which gives importance to channel and surface configuration making the sinuous bends of the river. In the present study, the role of hydraulic sinuosity and topographic sinuosity index are the two important tools for the study of the regional landforms and hydrology. The hydraulic sinuosity index has increased constantly in 2001 after the two massive floods. Therefore, the river has developed flood plains in general. The low percentage of hydraulic sinuosity index indirectly suggests that the meandering rivers do not belong to the initial denudation cycle. As the river progresses in the cycle of erosion, the topographic sinuosity is high during the youth stage and hydraulic sinuosity is negligible; on the other hand, hydraulic sinuosity is high during the old stage after the most of the topographic sinuosity has been reduced. Therefore, the Fulahar river in the Malda district flows from the

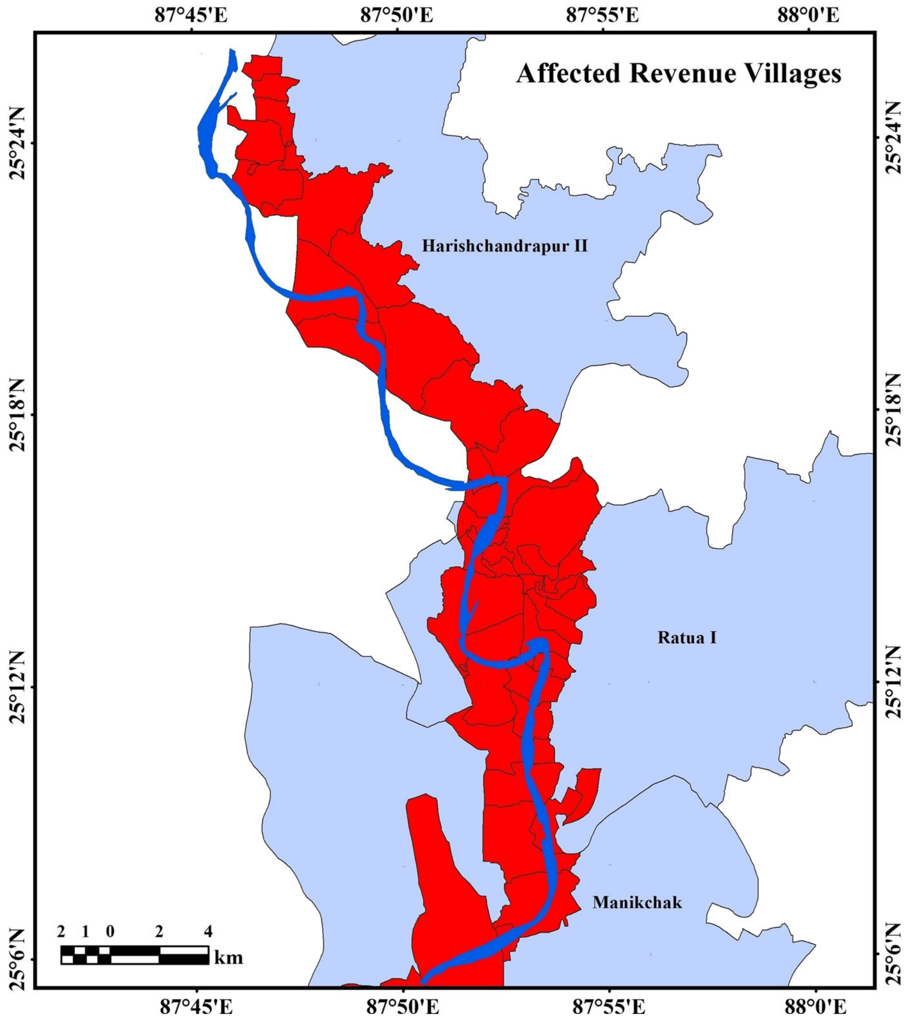

Fig. 8 Affected revenue villages due to river course shifting

Table 6 Details information about affected blocks by Fulahar River

Criteria	Harishchandrapur II	Ratua I	Manikchak
Total area (sq. km)	217.20	230.53	251.53
Affected area (sq. km)	64.71	49.54	45.92
% of affected area to total area (sq. km)	29.79	21.49	18.26
Number of affected revenue villages	14	14	7
Number of un- inhabited villages	0	2	1
Total affected population	63,311	39,437	19,198
% of affected population to total population	25.19	14.32	7.12

Source: Analysis based on Block wise Land use map prepared by Geo-informatics and Remote Sensing Cell, Department of Science and Technology, Govt. of West Bengal, Kolkata and District Census Handbook (2011) youth to the mature stage of the cycle of erosion. Thus, the graphical representations (Fig. 2) clearly show that the river's sinuosity index and braiding index increased considerably. The continuouss increase in the island areas resulted in the increased braiding index (Table 3). The river width increased considerably due to the sedimentation increase, the height of the river bed and the water level. It is due to the monsoonal flood discharge, high flash flood magnitude, thalweg, lateral migration, and the changing river course or bank failure are common phenomena in the Fulahar river. It is more significant that flooding is one of the main reasons for the course shift in the Fulahar river of Malda district.

Temporal shifts of the Fulahar river

For the temporal shifts of the Fulahar river, 17 cross-sections have been made along the river. The cross-sections of the Fulahar river made covering entire the study area which has been calculated left and right bank of the river in meters (Fig. 3, Table 4). The three blocks are mainly affected across the cross-section near Harishchandrapur-II, Ratua-I and Manikchak. From 1973 to 1980, the maximum shift was at cross-section K and E, which has about 2298.6 and 1066.4 m on the right bank and 2014.87 and 1085.3 m on the left bank side of the river. The cross-section comes under the Uttar Bhakuria, Dakshin Bhakuria, Maniknagar and Dwitiya Balupur villages, which has most affected villages from. During 1980–1990, the shift is widespread at cross-section K, 1282.43 near the left and 1531.16 m near the right bank of the river. From 1990 to 2001, a maximum number of eroded comes under Uttar Bhakuria, Kamalpur and Maniknagar villages. And cross-section at F has largest part as 1560.87 and 1372.68 m at the right and left bank of the river. From the period of 2001 to 2010, the highest shift under only the part of the Uttar Bhakuria. From 2010 to 2018, the highest shift due to erosion and flooding near Sambalpur, Bajitpur, Nandanpur-Gopalpur, and Bishnupur-Lakshmipur. During the period of 1973 to 2018 (45 years), the maximum migration of the cross-section was at K, E, H and J which both left and the right bank has shifted respectively (Fig. 4). The overall shift of the river course time span from 1973 to 2018, shows that the highest portion of the shift was at cross-section K about 4.8 km both the bank of the river. The maximum range of erosion has cross-section at K, E, H, I, J, O, P and Q than others. So, there are two portion of the river where channel shifting is most frequent i.e. D, E and F and I, J, K and L (Fig. 5). Due to the shift of Fulahar river Uttar Bhakuria, Dakshin Bhakuria, Maniknagar, Bishnupur-Lakshipur and Dwitiyo Bhagalpur are the most hazardous parts in the study area. Therefore, because of every year flooding and erosion, the left and right bank of the Fulahar river has shift vastly.

River width

The flood changes varied morphological aspects and widening the course of the river. Floods are a crucial role play to increase the river width channel and high mobilization of channel sediments and erosion of the river bank in meandering reaches (Yousefi et al. 2018;

Table 7 Block wise affected Gram Panchayets

Sl. No	C. D. blocks	Name of the affected gram panchayets	Name of the affected revenue villages
1	Harishchandrapur-II	Islampur, Daulat Nagar and Bhaluka	Sahara Bahara, Maharapara, Talbha Kuria, Bhuna, Nawapara, DigriInlis, Khopakati, Uttar Bhakuria, Dakshin Bhakuria, Daulat Nagar, Mihaghat, Fatepur, Parbhaluka and Bhaluka
2	Ratua-I	Mahanandatola, Debipur, Kahala and Belaimari	Kamalpur, Maniknagar, Udaypur, Dwitiya Balupur, Ramnagar, Kotoali, Sambalpur, Bajitpur, Balupur, Nandanpur, Gopalpur, Surjapur, Bishnupur, Lakshmipur, Shibpur and Narottampur
3	Manikchak	Mathurapur, Uttar Chandipur, Dakshin Chandipur and Nazirpur	Chandipurmal, DuaniTafir, Bahadurpur, Narayanpur, Talim Nagar, Mahabbatpur, Jitmanpur and Nazirpur

Source: District Human Development Report: Malda, 2007 and Public Health and Engineering Department, Govt. of W.B, 2014

Table 8 Year-wise water level of Fulahar river in Malda district

Gauge point	Extreme Danger Level (mts)	Highest danger level reached in the year (mts)								
		2010	2011	2012	2013	2014	2015	2016	2017	2018
Teljana	28.35	28.5	28.46	27.92	28.94	28.65	27.35	27.01	28.90	27.55

Source: District Disaster Management Section, Malda

Fig. 9 **a** Fulahar river showing bank erosion, (source: field survey, 2017), **b** affected area along the Fulahar river, (source: field survey, 2017)

Schumm and Lichty 1963). Therefore, continually floods and bank erosion results in channel widening and changes the channel pattern of the Fulahar river (Fig. 3). The lateral shift of the Fulahar river course has been measured from the year of 1973–2018. A total of 17 cross-sections have been drawn to detect the changes in the river width. It has clear to depict that the majority portion of the river shifted in the middle portion of the study area. Table 5 shows that the river width is generally changing in higher magnitudes over time. From 1973 to 2018, river width has experienced higher at P, B and L, measured as 449.6 m, 327.56 m and 270.14 m (Fig. 6). It is also significant to describe that river discharge has directly linked to rainfall intensity and flooding. Therefore, flooding is one of the crucial role plays to the Fulahar river discharge. Bhuna, Nawapara, Shibpur, Bishnupur Lakshmipur Surjapur, Mathurapur, Ghansigan and Bahadurpur are the most apparent villages where the river width much in the consecutive years. Because of excessive sedimentation and formation of the bars, the river width of those areas has also expanded over the years. It may signify that the river experiences continued flood in the month of July, August and September almost every year (Fig. 7). The river width has also enlarged because of the increasing number of islands and braidedness.

Hazard zone areas of the Fulahar river

The Fulahar river enter Mihaghat of Harishchandrapur-II C.D. block, it flows towards southern direction and meet the Ganga river in Paschim Narayanpur of Manikchak C.D. block of Malda district. The river runs through North western and western part of the district mainly Harishchandrapur-II, Ratua-I and Manikchak C.D. blocks. Due to the Fulahar River, these three blocks are affected by the erosion and deposition of its left and right bank during several years. The shifting characteristics of the river is escalating in every year and affecting more than 160 sq. km areas under the villages of Harishchandrapur-II, Ratua-I and Manikchak blocks. Within these blocks, the percentage of affected area to total area is high in Harishchandrapur-II block. In the block, 29.79 sq. km areas are affected in respect of total area

(21.49 sq. km in Ratua-I and 18.26 sq. km in Manikchak respectively). Among the affected blocks, 35 revenue villages are severe affected while 3 revenue villages are uninhabited (Table 6). Most of the population of Harishchandrapur-II block (25.19 percentage of population in respect of total population of the block) are affecting by the Fulahar river bank erosion and flooding in every year. 14 revenue villages of Islampur, Daulat Nagar and Bhaluka gram panchayets of Harishchandrapur-II block are severely affected by the natural or man-made hazards (Fig. 8). In every year, Mahanandatola and Belaimari gram panchayets of Ratua-I block one more affected than its other affected gram panchayets of Debipur and Kahala. On the other hand, Dakshin Chandipur gram panchayet of Manikchak block is more affected remaining other gram panchayets such as Narayanpur, Uttar Chandipur and Nazirpur (Table 7).

The river bank erosion and flooding are most hazardous phenomena in the study area. During 1998 and 1999, there was a massive flood in the Malda district. In 1998, 198 villages and 200,000 persons were affected in Ratua-I C.D. block, 99 villages and 140,000 persons were affected in Manikchak block, and 74 villages and 75,000 persons were affected in Harishchandrapur-II C.D block. Again in 1999, 218 villages and 90,000 persons in Harishchandrapur-II C.D block, 413 villages and 128,135 persons were affected in Manikchak C.D block, and 81 villages and 80,000 persons in Ratua-I were affected due to flood (DHDR 2007). So, most of the parts were devastated due to back to back floods in the study area. After that, no heavy flood occurred, but due to continuous increase in the water level of the Fulahar river most villages suffer from the flood every year (Table 8). The northern and middle part of the mainstream reflects its frequent shifting pattern than other parts (Fig. 4). The shifting pattern and flooding cause several damage along with the riverine villages of these blocks (Fig. 9). Due to the shifting nature of the river, the agricultural lands along both the bank areas (right and left) have become a barren land for excess siltation of sand. Primary economic activities, cultivation, fishing, agricultural practice and cropping pattern of agricultural land have been changed at an extreme rate. Sometimes the agricultural land becomes a barren land due to the siltation of sand by flooding. The villagers loss their homeland, local rural infrastructure and services and also struggle for their survivals with the selected natural hazards.

Conclusion

The left bank erosion of the Ganga river has the harshest type of hazardous in West Bengal and also experiencing flood problems every years. The main reason of flood in Ganga basin due to the impediment of flow in tributaries, the high stage in monsoon season, heavy precipitation for a long duration, the meandering of the river, poor maintenance of flood control structure, etc. Laha and Bandyapadhyay (2013) studied the upstream of Farakka barrage to Rajmahal area is the source of that hazardous which morphometric changes over a period of time. Most of the scholars studied the Ganga river bank erosion and its impact on socio-economic condition (Banerjee and Chakravarty 1983; Banerjee 1999; Parua 1999; Rudra 2004, 2010) but few studies were related to Fulahar river bank, which has one of the hazardous riverine regions in the Malda district. Some of the previous work showed that the morphological changes and channel shifting, as well as the vulnerability zones of the Ganga River particularly in the Diara (Laha and Bandyapadhyay 2013; Mukherjee and Pal 2018) but they avoided the part of Fulahar river changes which has also three hazardous blocks (Harishchandrapur-II, Ratua-I and Manikchak) in the Malda district. The present study has described the measuring of different morphometric parameters (braiding index, sinuosity index, hydraulic sinuosity index and topographic sinuosity index), river width and island areas with the help of remote sensing and GIS techniques. The sinuosity index of the river has little bit decreased as compare to previous years but the braiding index of the river to shows the increased by 0.71, and the island areas has increased by 3.69 km^2. It is also significant to describe that aggradation and degradation are mainly influenced by river discharge, sediment low, river morphology, shifting the channel banks and human involvements. The present study analysed 45 years of satellite imageries data collected from United State Geological Survey (USGS) and prepared a different year of river shifting maps to show it fruitfully. In this study, 17 cross-sections were made across the Fulahar river from Mihaghat to Paschim Narayanpur and calculated the channel shifting and width of the river where most of the area is increased within a certain period of time. It has been observed that water level of the Fulahar river is high at the period of time from last week of July to first week of September. This indicates that dominant flood discharge of Mahananda flows mainly through the Fulahar to outfall into the Ganga river near Manikchak while bifurcated Mahananda receiving much less flow from its main course. Due to the reason of the left bank of Fulahar river near Harishchandrapur II block of Malda district has become more vulnerable either overtopping or breaching. Therefore, due to flood hazards and bank erosion, we find out the affected villages and analysed the hazard zone areas in Harishchandrapur-II, Ratua-I and Manikchak block of Malda district. This study has analysed the temporal shift of the river and hazardous areas which gives us future alertness in the study area. It has also shown that the high-risk areas and also can be helpful to future management and planning for stopping river bank erosion, economic loss and land loss, etc.

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