

ANALYSIS OF MORPHOLOGICAL CHANGING SCENARIO OF RIVER JAMUNA, WEST BENGAL, INDIA

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Abstract

Jamuna is one of the distributary river of India which belongs to the Gangetic Delta region located in the eastern part of India and originates from the Bhagirathi River and flows into Ichhamati River. But at present the Jamuna River is continuously drying up and its flow is gradually slowing down. In this study, the morphological changes of the river from 1977 to 2020 are described through change detection technique. Topographical map (US Army, 1955), USGS satellite images of different years (1977, 2000) and google satellite image (2020) have been used for that. Again for the convenience of the discussion the river has been divided into three segments. A comparison of the course of the river in 2020 with respect to the course of the river in 2000 has been made to determine how much the river course has been damaged by humans. A large part of the river course has been occupied by man for his own needs i.e. cultivation, settlement, fisheries and even plantation of trees. Here, it shown that the course of the river has been progressively narrowed and damaged by human activities. All work was done using RS and GIS platform with GIS software.

Keywords: River delineation, plan form pattern, channel width, long profile, human activities

JEL classification: Q25, R14, Y10, Y91
pp. 115-134

1. Introduction

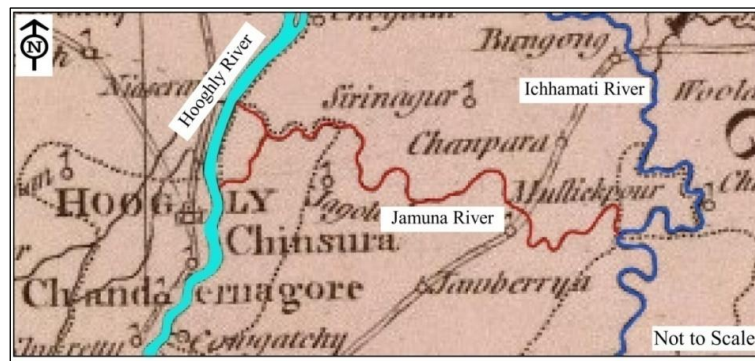
Water resources are the key to human survival and development, and even water is an integral part of natural ecosystem. However, due to rapid population growth, economic development and expansion of urbanization, the amount of water resources worldwide is declining at an increasing rate (Wang et al., 2020). One of the most important part of this water resource is the river, which is inextricably linked with human civilization. A river is usually a natural stream of fresh water, which flows primarily towards the ocean, lake or some other river (Maurya et al., 2016). In some times, a river dries up before it reaches the end of its course. River bank erosion is a natural geological process (Nath et al., 2013). Rivers are an essential element of human existence that has been slowly evolving since human evolution (Panda et al., 2011).

To describe how a river changes its shape and direction over time, river morphology is a field of science in which sedimentation and erosion processes in a river mainly change the river's form and cross section (Change, 1988). The science of carving out landforms by river action is called river morphology (Wilson et al., 2021). River course change is a natural phenomenon that usually occurs due to flooding in river (Mahmood et al., 2015). Generally, the river flows from its source to mouth according to slope of land, but it never takes any short path (Pan, 2013).

The course of the river was changed at different times and various factors involved with it have been pointed out in different research papers such as Dey et al., 2018, Bandyopadhyay et al., 2013, Ety et al., 2017, Mondal et al., 2018, Biswas et al., 2018 and Chauniyal et al., 2018.

One of the riverine states of India is West Bengal, which was an integral part of east Bengal before independence. Jamuna was one of the important rivers of Bengal. Once (last half of the twelfth century), this river was described in verses 33 and 34 of the “*Pavandoot Kavya*” of Raja Lakshman Sen’s poet Dhoi. Even Rennell’s map of the Ganges-Brahmaputra delta published by the British Government in 1779 clearly showed the location of the river Jamuna, and at that time the river was fully alive. Almost a century after Rennell’s map, Hunter (1875) described the location and depth of the river in his book namely ‘*A Statistical Account of Bengal*’ (Rudra, 2008) (Figure 1).

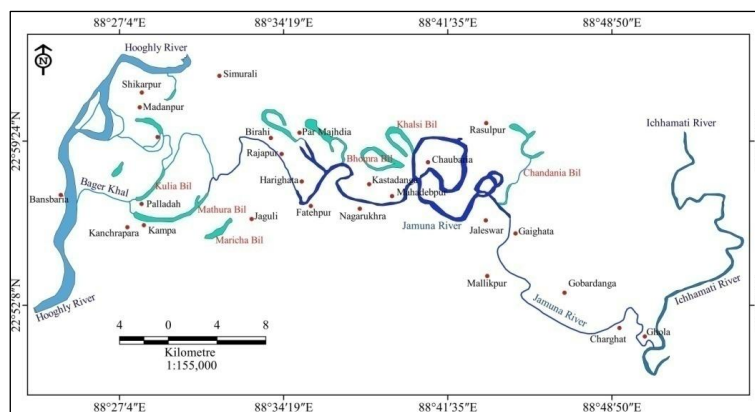
Figure 1: Jamuna River, 1786



Source: A map of Bengal, Bahar, Oude and Allahabad with part of Agra and Delhi Exhibiting the Course of the Ganges from Hurdwar to the sea by James Rennell, 1786

The Jamuna River is a distributary of Hooghly River. It originates from Tribeni then flows to south-east and joins with Ichhamati River near Tipi village which belongs to Swarupnagar tehsil of North 24 Parganas district. According to the topographical map (1955), Hooghly River and Jamuna River were connected with each other through Bager Khal and Mathura Bil, so that the water of Hooghly River could freely flow into Jamuna River. Not only Mathura Bil, but there were many lakes (meander cut of Hooghly River) in the vicinity with which the Jamuna River was connected (Figure 2).

Figure 2: Jamuna River with its surrounding water bodies and places, 1955



Source: Topographical Maps (Sheet no. NF 45-3, NF 45-4, NF 45-7 and NF 45-8), US Army Map, 1955

The water flow of Jamuna River has been affected by some other reasons, e.g., due to deposition of sediments in the river bed and thus depth of river bed decreases. The highest river bed of Jamuna exists at Birohi and the Hooghly River flows westwards over time. Only Bager Khal is the source of water from Hooghly River to Jamuna River (Biswas, 2001). But after some time people built their settlements in the adjacent area of Bager Khal and Mathura Bil. As a result, the Bager Khal continues to be damaged by human activities. It is currently associated with the city’s drainage system, but it is completely isolated from the Mathura Bil and Jamuna River. Due to this reason the source of water in the Jamuna River is now only rain water, as a result of which the river course has changed.

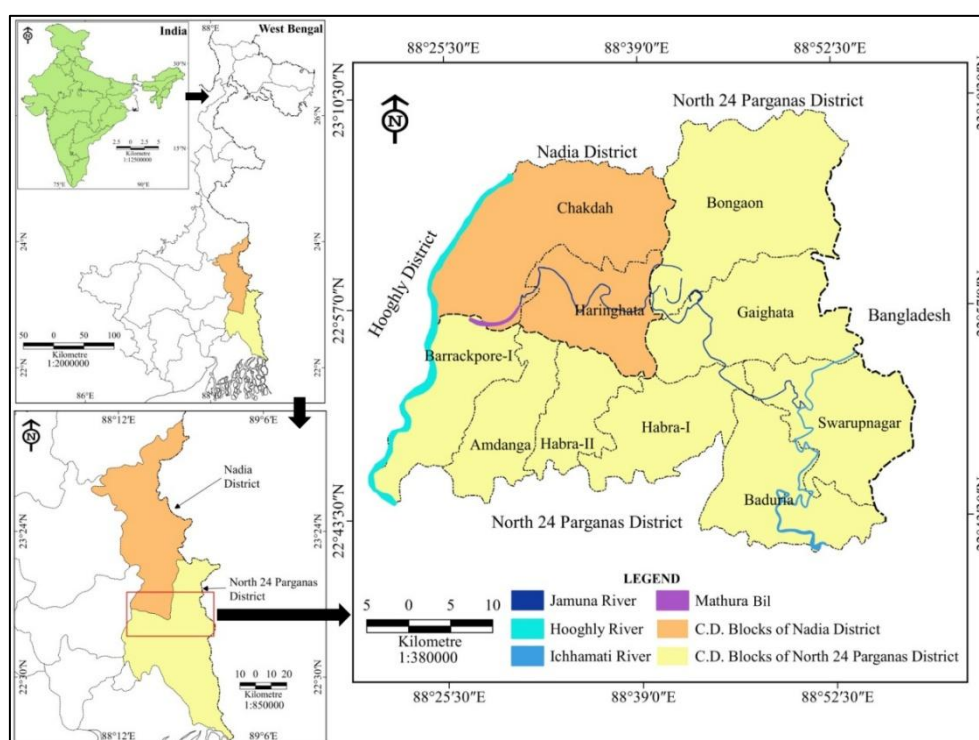
2. Objectives

Objectives of the present study are assessing the changing channel morphology of Jamuna River and to analyze the situation of the river course area.

3. Area of study

The area of study is the River Jamuna course which belongs to Ichhamati - Vidyadhari river basin and it is lying between $22^{\circ}57'15.76''$ N to $22^{\circ}50'32.36''$ N and $88^{\circ}30'40.83''$ E to $88^{\circ}50'30.70''$ E. The source of River Jamuna is Hooghly River and its mouth is Ichhamati River. The river flows through the Chakdah and Haringhata C.D. Blocks (Community Development Block) of Nadia district and the Bongaon, Gaighata, Habra-I, Baduria and Swarupnagar C.D. Blocks of North Twenty Four Parganas district in West Bengal. The total river length is 66.64 km (from the end of Mathura Bil to Ichhamati River). From the mean sea level the average elevation of the area is 10 metre (Banerjee et al., 2014) (Figure 3).

Figure 3: Map of the Study Area



Source: District Census Handbook (North 24 Parganas and Nadia), Census of India, 2011 and Google Satellite Map, 2020

4. Database and Methodology

For the identification of Jamuna River course topographical maps were used. The topographical maps were prepared by the U.S. Army, Washington, D.C., compiled in 1955 from Survey of India. Satellite data from USGS Earth Explorer is also used to interpret the Jamuna River course for the years of 1977 and 2000. In the present study, google satellite image (2020) has been also used for better delineation of the river course. The details of data used during the analysis are given in the Table 1.

Table 1. Details of Satellite Images

Satellite	Path/row	Projection	Layers	Date of acquisition	Spatial resolution
Landsat 1-5 MSS	148/044	UTM-WGS84	4	9 th February 1977	60 m
Landsat 7 ETM+	138/044	UTM-WGS84	8	17 th November 2000	30 m

Source: United States Geological Survey (USGS) Earth Explorer

For the purpose of image processing, GIS software has been used in this study. The Landsat satellite images which has spatial resolution 60 and 30 metre and the all bands were included in the analysis.

At first, the four Survey of India topographical maps (Table 2) were georeference and mosaic in WGS84/UTM45N projection through the georeferencer option. Then the river has been digitized through the add vector layer option in GIS software. Two satellite images, which were downloaded from website of USGS and using GIS software for the pre-processing such as georeferencing, layer stacking, geometric correction and radiometric correction. Thereafter, Jamuna River has been digitized from Landsat satellite images. Again the River has been also digitized using in the GIS software with the help of google satellite image to monitor the current status of the river channel.

Table 2. Details of Topographical Maps

Topographical Map No	Year	Scale	Source
NF 45-3			
NF 45-4	1955	1:2,50,000	Prepared by the Army Map Service (NSS & H) Corps of Engineers, U.S. Army, Washington
NF 45-7			
NF 45-8			

Source: Topographical Maps, U.S. Army map, 1955

The SRTM (Shuttle Radar Topography Mission) DEM (Table 3) was downloaded from USGS Earth Explorer to draw long profile of the River Jamuna and then a vector file along the middle of the river section was digitized and overlapped on the DEM file. Through the GIS software then taken one point at intervals of 2000 metre along the middle of the river (total 34 points from the end of Mathura Bil to Ichhamati River) and subsequently determined the height of the location of each point from the DEM file.

Table 3. Details of SRTM DEM

Entity ID	Acquisition Date	Updated Publication Date	Resolution
SRTM1N23E088V3	11 th February 2000	02th January 2015	1-ARC

Source: United States Geological Survey (USGS) Earth Explorer

Due to connection between Jamuna River and Mathura Bil, in this study end of the Mathura Bil to mouth of Jamuna River has considered as the area of discussion. After that, for the better delineation of the river channel, the total river has been divided into three segments, respectively,

- Segment-1: from the end of the Mathura Bil to Nagarukhra,
- Segment-2: from Nagarukhra to Gaighata and
- Segment-3: from Gaighata to the mouth (Ichhamati River) of the river.

To establishing the geomorphological river types, Sinuosity Index has been used. For the calculation of the Sinuosity Index, Schumm's model (1963) has been applied.

5. Result and Discussion

5.1. Delineation of Jamuna river bank lines

For delineation of the river bank lines Landsat images of 1977, 2000 and also google satellite image (2020) have been used. Due to calculate the length of left side bank, right side bank and centre line of the river the digitization method has been applied with the help of GIS software. Total length of Jamuna River is 66.63 km from end of Mathura Bil to mouth of Jamuna River at Tipi village. Segment wise river lengths are described in Table 4.

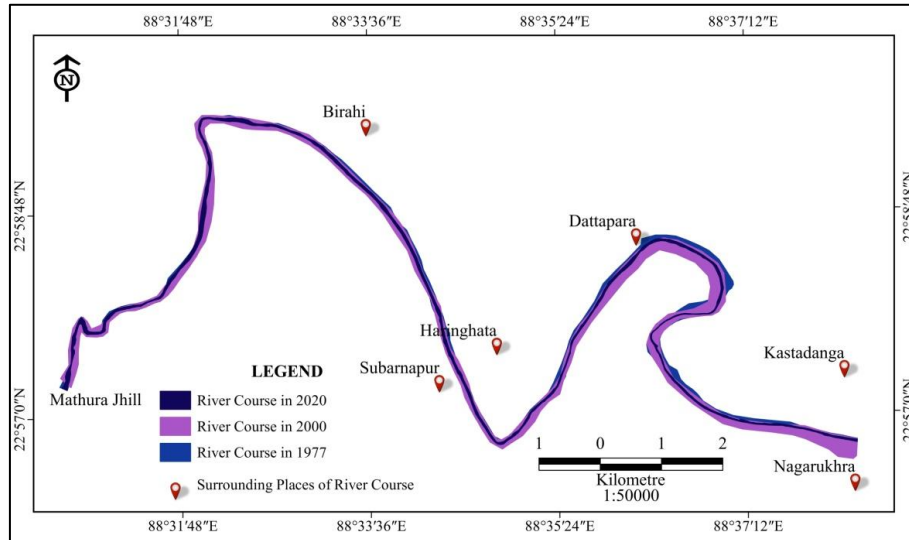
In segment-2, the river flow path has changed a lot, meaning that the river has become much narrower than before and it has become isolated from many of the surrounding bils (Figure 5). Even in segment-1 and segment-3, the flow of the river has also changed (Figure 4 and 6).

Table 4. Location and Length of the Segments

Segments	Start to end location	Length (in Km.)
1	End of Mathura Bil to Nagarukhra	25.26
2	Nagarukhra to Gaighata	17.77
3	Gaighata to the mouth (Ichhamati River) of the river	23.60

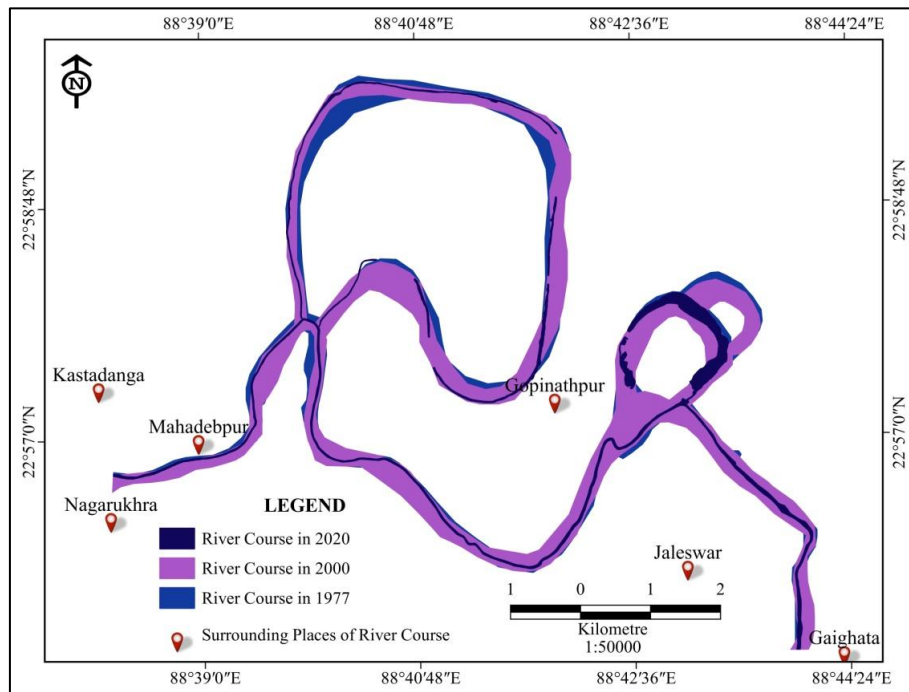
Source: Computed by the Authors using GIS software

Figure 4: Segment-1



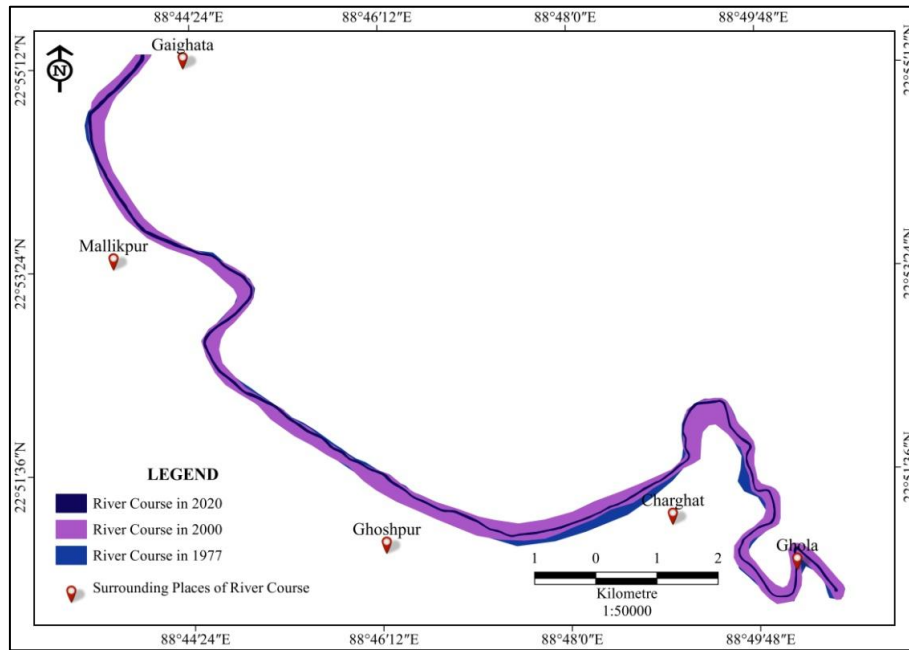
Source: USGS Landsat Satellite Images (1977, 2000) and Google Satellite Data (2020)

Figure 5: Segment-2



Source: USGS Landsat Satellite Images (1977, 2000) and Google Satellite Data (2020)

Figure 6: Segment-3



Source: USGS Landsat Satellite Images (1977, 2000) and Google Satellite Data (2020)

5.2. Channel pattern of the Jamuna River

Generally channel pattern of river described as three types respectively straight, meandering or braided. In maximum cases rivers turned from straight to meandering or meandering to braided channel pattern on its course. The ratio of channel length and valley length is called sinuosity ratio, through which the straight channel and meandering channel of a river can understand (Schumm, 1963).

According to Leopold and Wolman (1957), a sinuosity ratio of 1.5 is considered to differentiate sinuous from meandering. If the value of sinuosity index is below 1.5 then the channel is straight or sinuous and again the value of sinuosity index is above 1.5 then the channel belongs to meandering channel.

Here, Sinuosity Ratio of Schumm (1963) has been used in this study.

$$\text{Channel Sinuosity} = O_L/E_L$$

Where, O_L = observed (actual) path of a stream, E_L = expected straight path of a stream. The map is shown the enumeration of segment wise sinuosity ratio (Figure 7).

From 1977 to 2020, the sinuosity ratio of Jamuna River has significantly changed. During this time period sinuosity ratio has recorded as 2.31 (1977), 2.25 (2000) and 1.84 (2020) (Table 5). The value of sinuosity ratio of Jamuna River is lowest in the year of 2020.

Table 5. Sinuosity Ratio of the Jamuna River

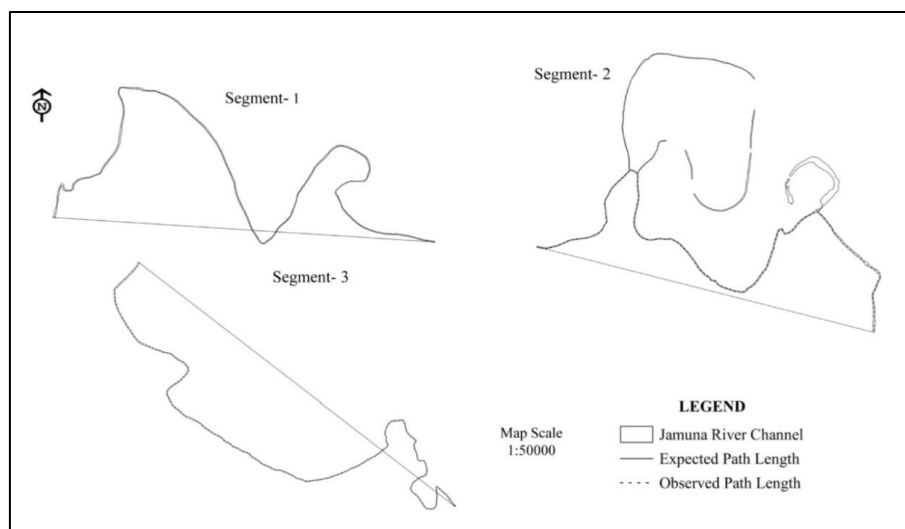
Year	Observed Length (OL) in Km.	Expected Length (EL) in Km.	Sinuosity Ratio
1977	83.8633	36.2559	2.31
2000	81.9315	36.2987	2.25
2020	66.6353	36.1589	1.84

Source: Computed by the Authors

Again, the Jamuna River has been divided into three segments and thus several changes can be observed segment-wise value of sinuosity ratio. In segment-1 the value of sinuosity ratios are 1.94 (1977), 2.45 (2000) and 1.95 (2020). In segment -2 values of sinuosity ratio also changed respectively 3.58 (1977), 2.41 (2000) and 1.76 (2020). These values in segment-3 are 1.56 (1977), 1.55 (2000) and 1.65 (2022) (Table 6).

Overall, it can be seen that the value of sinuosity ratio in segment -2 has decreased in year of 2020 (1.76). So it is clear that from 1977 to 2020 in these three segments this river belongs to meandering form and the River Jamuna is classified as meandering river.

Figure 7: Sample map of computation of segment wise river sinuosity



Source: Prepared by the Authors

Table 6. Segment Wise Sinuosity Ratio of the Jamuna River

S	Name of the Segments	Year 1977			Year 2000			Year 2020		
		OL (km)	EL (km)	SR	OL (km)	EL (km)	SR	OL (km)	EL (km)	SR
1	End of Mathura Bil to Nagarukhra	25.13	12.98	1.94	24.68	12.96	2.45	25.26	12.97	1.95
2	Nagarukhra to Gaighata	36.22	10.11	3.58	34.78	10.09	2.41	17.76	10.09	1.76
3	Gaighata to Mouth (Ichhamati River)	22.50	14.42	1.56	22.46	14.44	1.55	23.60	14.33	1.65

Note: S. = Segments, OL= Observed Length in Km., EL= Expected Length in Km., SI= Sinuosity Ratio. Source: Computed by the Authors

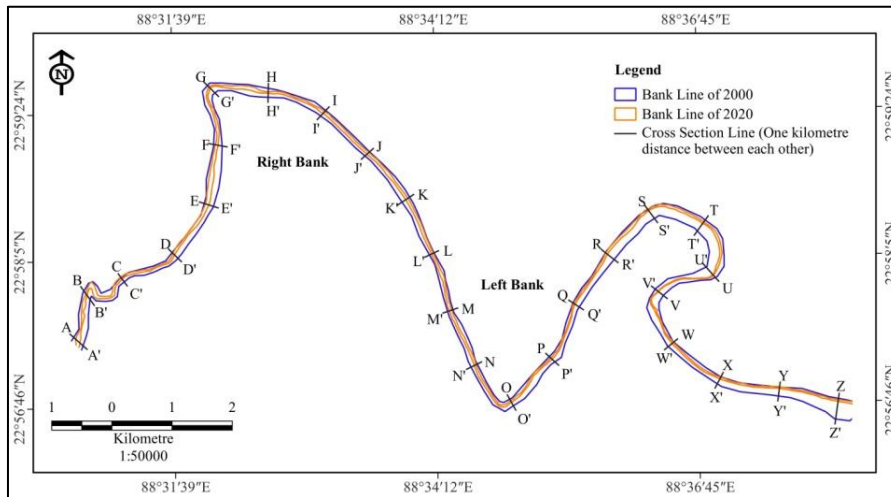
5.3. Main course shifting of the River Jamuna

The change of the course of river Jamuna has been determined on the basis of the river course of 2020. Each segment is divided into many parts in accordance with one kilometre and cross section line is drawn like segment-1 has 26 lines, segment-2 has 34 lines and segment-3 has 25 lines. River course data of the years of 1977, 2000 and 2020 have been used in GIS software to show river course shifting. The maps of segment wise River course shifting are shown in figure 8, 9 and 10 and the outcome data are given in table 7, 8 and 9.

5.3.1. Segment-1

In 1977, there are only three parts in segment-1 where the shifting of the river bank is slightly outward, respectively AA', TT' and VV'. Again in 2000, three parts in segment-1 have also shifted outward such as CC', SS' and YY' (Figure 8). In this segment it shows that only 4 of 6 parts (cross section lines) changes are near the left side bank and only 2 parts changes (TT' and VV') are near the right side bank of the river (Table 7). From 1977 to 2020, maximum shifting of the river bank is occurred in inward at segment-1.

Figure 8: Main Course Shifting of Jamuna River in Segment-1

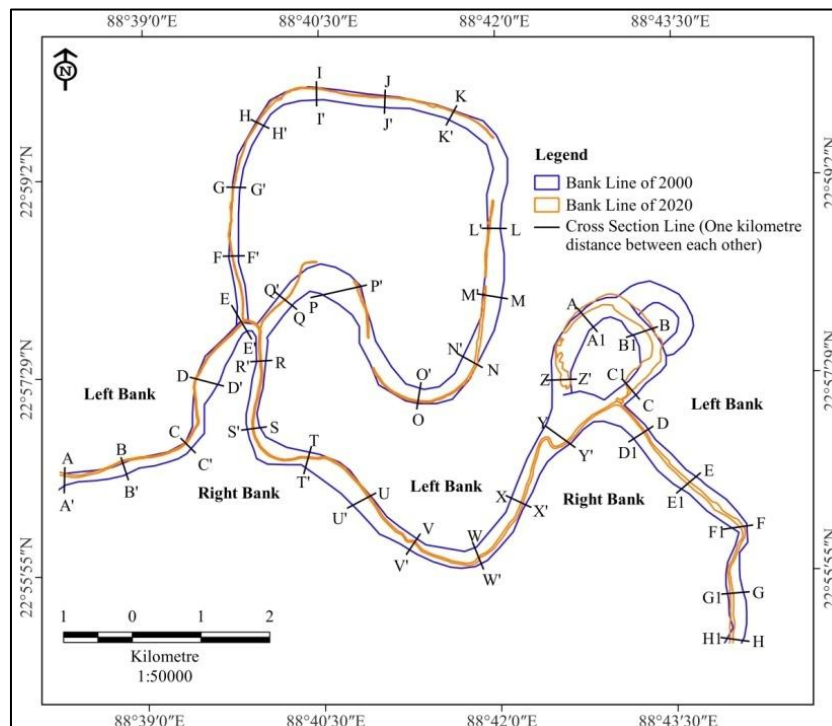


Source: Landsat Satellite Imagery (ETM+ data) 17th Nov., 2000 and Google Satellite Image, 2020

5.3.2. Segment-2

From table 8, it is observed that in the year of 1977 only 4 of 34 parts (cross section lines) where river bank moved outward. The parts are OO', ZZ', BB1 and CC1. Remaining parts are indicated the inward shifting of river bank. Again in the year of 2020, 8 parts (AA', BB', CC', DD', NN', AA1, BB1 and CC1) are detected outward river bank shifting and rest of these parts are detected the inward shifting of river bank (Figure 9). Only BB1 and CC1 parts are recorded as outward movement of the river bank during 1977 to 2020.

Figure 9: Main Course Shifting of Jamuna River in Segment-2

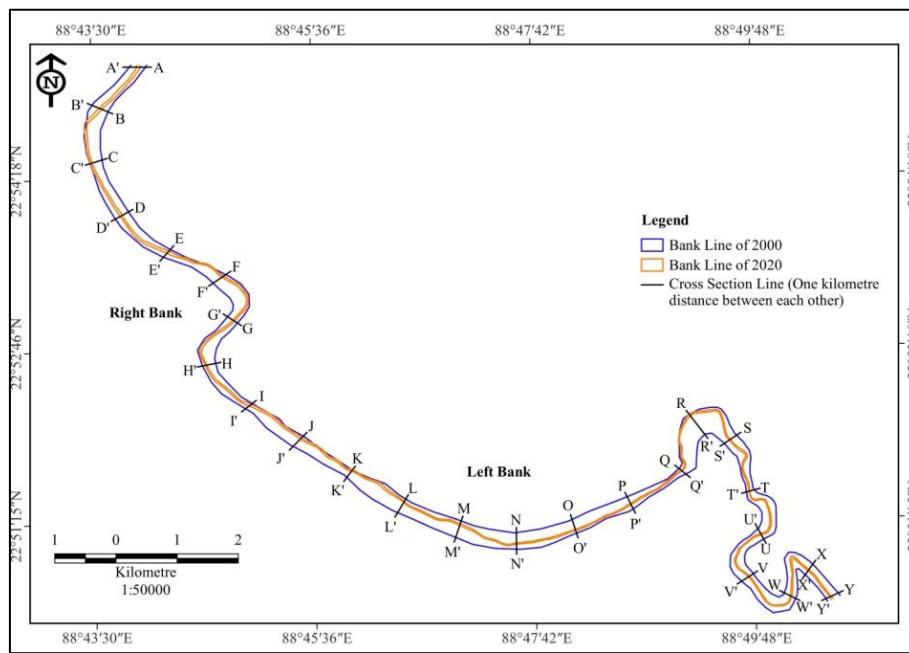


Source: Landsat Satellite Imagery (ETM+ data) 17th Nov, 2000 and Google Satellite Image, 2020

5.3.3. Segment-3

On the other hand in 1977 in segment-3 three parts of the river bank have changed outward like DD', EE' and VV'. Again in year of 2000, two outward change of river bank have been occurred these are KK' and RR' (Figure 10 and Table 9).

Figure 10: Main Course Shifting of Jamuna River in Segment-3



Source: Landsat Satellite Imagery (ETM+ data) 17th Nov, 2000 and Google Satellite Image, 2020

From 1977 to 2020, it is clear that outward shifting of river bank is observed in each segment. Even in the year of 1977 rightward movement of river is more active than leftward movement but in 2000 this river movement is totally changed and the movement form rightward to leftward. According to the data analysis tables it is observed that inward shifting of the river bank is very high in every segment. Due to this type of changes river width of Jamuna River is gradually decreased from 1977 to 2020.

Table 7. Bank wise river shifting along the cross section line between 1977 and 2000 with respect to Year 2020 (Segment-1)

L. N.	C. S. L.	Year of 1977					Year of 2000				
		L.R.B.	D.	R.R.B.	D.	R.S.	L.R.B.	D.	R.R.B.	D.	R.S.
1	AA'	0.38	L.	20.48	L.	Outward	47.8	R.	68.49	L.	Inward
2	BB'	21.51	R.	64.65	L.	Inward	50.82	R.	86.31	L.	Inward
3	CC'	28.89	R.	37.75	L.	Inward	10.82	L.	55.4	L.	Outward
4	DD'	6.36	R.	21.96	L.	Inward	19.64	R.	79.09	L.	Inward
5	EE'	3.43	R.	43.9	L.	Inward	20.42	R.	81.88	L.	Inward
6	FF'	13.82	R.	36.14	L.	Inward	30.61	R.	70.8	L.	Inward
7	GG'	8.2	R.	43.2	L.	Inward	33.44	R.	111.44	L.	Inward
8	HH'	27.9	R.	14.88	L.	Inward	55.18	R.	67.57	L.	Inward
9	II'	27.68	R.	39.78	L.	Inward	24.42	R.	56.8	L.	Inward
10	JJ'	49.1	R.	32.18	L.	Inward	14.87	R.	44.37	L.	Inward
11	KK'	64.92	R.	30.34	L.	Inward	34.77	R.	74.2	L.	Inward

L. N.	C. S. L.	Year of 1977					Year of 2000				
		L.R.B.	D.	R.R.B.	D.	R.S.	L.R.B.	D.	R.R.B.	D.	R.S.
12	LL'	43.59	R.	27.28	L.	Inward	14.26	R.	37.11	L.	Inward
13	MM'	55.92	R.	25.34	L.	Inward	21	R.	31.68	L.	Inward
14	NN'	21.48	R.	52.08	L.	Inward	21.99	R.	58.24	L.	Inward
15	OO'	23.25	R.	43.69	L.	Inward	28.03	R.	66	L.	Inward
16	PP'	32.23	R.	20.57	L.	Inward	31.86	R.	61.87	L.	Inward
17	QQ'	38.78	R.	68.97	L.	Inward	15.4	R.	85.86	L.	Inward
18	RR'	68.86	R.	38.71	L.	Inward	8.82	R.	139.54	L.	Inward
19	SS'	107.59	R.	44.23	L.	Inward	10.14	L.	162.25	L.	Outward
20	TT'	116.55	R.	9.74	R.	Outward	37.91	R.	152.14	L.	Inward
21	UU'	15.15	R.	199.84	L.	Inward	45.18	R.	164.84	L.	Inward
22	VV'	99.89	R.	8.01	R.	Outward	103.14	R.	58.25	L.	Inward
23	WW'	108.02	R.	19.19	L.	Inward	6.39	R.	79.13	L.	Inward
24	XX'	46.51	R.	57.57	L.	Inward	6.71	R.	93.32	L.	Inward
25	YY'	43.53	R.	55.81	L.	Inward	4.01	L.	129.76	L.	Outward
26	ZZ'	29.02	R.	131.72	L.	Inward	17.33	R.	297.8	L.	Inward

Note: L.N. = Location Number, C.S.L. = Cross Section Line, L.R.B. = Left River Bank, D. = Direction, R.R.B. = Right River Bank, R.S. = River Shifting, L. = Left, R. = Right
Source: Computed by the Authors using GIS software

Table 8. Bank wise river shifting along the cross section line between 1977 and 2000 with respect to Year 2020 (Segment-2)

L. N.	C. S. L.	Year of 1977					Year of 2000				
		L.R.B.	D.	R.R.B.	D.	R.S.	L.R.B.	D.	R.R.B.	D.	R.S.
1	AA'	25.11	R.	84.81	L.	Inward	0.39	R.	144.13	L.	Outward
2	BB'	37.08	R.	75.25	L.	Inward	37.74	L.	185.97	L.	Outward
3	CC'	68.84	R.	62.42	L.	Inward	2.4	L.	105.24	L.	Outward
4	DD'	55.4	R.	36.62	L.	Inward	7.19	L.	316.63	L.	Outward
5	EE'	135.04	R.	153.51	L.	Inward	137.49	R.	126.86	L.	Inward
6	FF'	5.41	R.	154.47	L.	Inward	44.42	R.	83.31	L.	Inward
7	GG'	21.64	R.	167.47	L.	Inward	6.8	R.	95.32	L.	Inward
8	HH'	1.2	R.	342.97	L.	Inward	16.7	R.	92.06	L.	Inward
9	II'	62.3	R.	316.69	L.	Inward	6.99	R.	160.48	L.	Inward
10	JJ'	64.51	R.	90.92	L.	Inward	14.69	R.	145.19	L.	Inward
11	KK'	47.65	R.	166.24	L.	Inward	14.09	R.	126.09	L.	Inward

L. N.	C. S. L.	Year of 1977					Year of 2000				
		L.R.B.	D.	R.R.B.	D.	R.S.	L.R.B.	D.	R.R.B.	D.	R.S.
12	LL'	148.41	R.	81.34	L.	Inward	148.94	R.	14	L.	Inward
13	MM'	200.85	R.	42.96	L.	Inward	235.77	R.	23.45	L.	Inward
14	NN'	34.46	R.	134.42	L.	Inward	3.45	L.	190.88	L.	Outward
15	OO'	44.67	L.	268.99	L.	Outward	24.72	R.	179.79	L.	Inward
16	PP'	327.26	R.	34.45	L.	Inward	507.23	R.	33.07	L.	Inward
17	QQ'	121.01	R.	53.39	L.	Inward	127.99	R.	93.48	L.	Inward
18	RR'	85.36	R.	192.82	L.	Inward	65.82	R.	45.54	L.	Inward
19	SS'	90.8	R.	64.61	L.	Inward	92.37	R.	74.76	L.	Inward
20	TT'	61.93	R.	116.49	L.	Inward	69.73	R.	141.97	L.	Inward
21	UU'	40.26	R.	182.68	L.	Inward	15.64	R.	250.86	L.	Inward
22	VV'	66.71	R.	89.27	L.	Inward	47.32	R.	121.98	L.	Inward
23	WW'	14.38	R.	67	L.	Inward	143.09	R.	79.34	L.	Inward
24	XX'	29.8	R.	85.15	L.	Inward	153.59	R.	42.24	L.	Inward
25	YY'	328.5	R.	99.88	L.	Inward	382.53	R.	33.42	L.	Inward
26	ZZ'	109.97	L.	33.78	R.	Outward	123.86	R.	12.95	L.	Inward
27	AA1	22.71	R.	38.95	L.	Inward	39.75	L.	239.22	L.	Outward
28	BB1	54.46	L.	32.57	R.	Outward	27.86	L.	191.06	L.	Outward
29	CC1	67.48	L.	23.93	R.	Outward	87.75	L.	35.65	R.	Outward
30	DD1	34.68	R.	72.84	L.	Inward	52.18	R.	171.81	L.	Inward
31	EE1	39.89	R.	45.75	L.	Inward	119.07	R.	114.52	L.	Inward
32	FF1	76.24	R.	96.31	L.	Inward	50.74	R.	112.93	L.	Inward
33	GG1	64.61	R.	30.39	L.	Inward	152.31	R.	35.83	L.	Inward
34	HH1	63.02	R.	31.51	L.	Inward	140.42	R.	41.63	L.	Inward

Note: L.N. = Location Number, C.S.L. = Cross Section Line, L.R.B. = Left River Bank, D. = Direction, R.R.B. = Right River Bank, R.S. = River Shifting, L. = Left, R. = Right

Source: Computed by the Authors using GIS software

Table 9. Bank wise river shifting along the cross section line between 1977 and 2000 with respect to Year 2020 (Segment-3)

L. N.	C. S. L.	Year of 1977					Year of 2000				
		L.R.B.	D.	R.R.B.	D.	R. S.	L.R.B.	D.	R.R.B.	D.	R.S.
1	AA'	51.42	R.	30.64	L.	Inward	92.13	R.	116.45	L.	Inward
2	BB'	62.59	R.	31.28	L.	Inward	107.44	R.	130.17	L.	Inward
3	CC'	47.08	R.	20.56	L.	Inward	168.79	R.	6.53	L.	Inward
4	DD'	23.92	R.	0.26	R.	Outward	113.14	R.	91.2	L.	Inward
5	EE'	0.35	L.	61.23	L.	Outward	34.98	R.	85.32	L.	Inward
6	FF'	24.75	R.	123.17	L.	Inward	42.88	R.	174.49	L.	Inward

L. N.	C. S. L.	Year of 1977					Year of 2000				
		L.R.B.	D.	R.R.B.	D.	R. S.	L.R.B.	D.	R.R.B.	D.	R.S.
7	GG'	39.84	R.	99.98	L.	Inward	59.8	R.	100.9	L.	Inward
8	HH'	61.89	R.	35.73	L.	Inward	148.73	R.	50.1	L.	Inward
9	II'	46.6	R.	65.53	L.	Inward	21.82	R.	72.98	L.	Inward
10	JJ'	53.9	R.	98.09	L.	Inward	34.92	R.	164.42	L.	Inward
11	KK'	27.08	R.	143.67	L.	Inward	6.56	L.	127.87	L.	Outward
12	LL'	46.89	R.	129.2	L.	Inward	46.13	R.	194.96	L.	Inward
13	MM'	31.96	R.	200.86	L.	Inward	46.09	R.	205.91	L.	Inward
14	NN'	26.68	R.	167.15	L.	Inward	168.8	R.	81.82	L.	Inward
15	OO'	18.28	R.	186.59	L.	Inward	170.83	R.	45.46	L.	Inward
16	PP'	31.36	R.	181.65	L.	Inward	122.94	R.	74.49	L.	Inward
17	QQ'	70.04	R.	34.69	L.	Inward	47.19	R.	83.45	L.	Inward
18	RR'	2	R.	346.1	L.	Inward	2.81	L.	377.97	L.	Outward
19	SS'	89.78	R.	89.17	L.	Inward	126.32	R.	98.73	L.	Inward
20	TT'	25.43	R.	193.69	L.	Inward	80.99	R.	39.89	L.	Inward
21	UU'	85.84	R.	46.07	L.	Inward	81.82	R.	94.99	L.	Inward
22	VV'	1.28	L.	148.92	L.	Outward	71.96	R.	133.51	L.	Inward
23	WW'	68.64	R.	51.58	L.	Inward	110.74	R.	71.52	L.	Inward
24	XX'	75.12	R.	107.48	L.	Inward	110	R.	80.19	L.	Inward
25	YY'	52.96	R.	120	L.	Inward	126.62	R.	67.58	L.	Inward

Note: L.N. = Location Number, C.S.L. = Cross Section Line, L.R.B. = Left River Bank, D. = Direction, R.R.B. = Right River Bank, R.S. = River Shifting, L. = Left, R. = Right
Source: Computed by the Authors using GIS software

5.4. Changing channel width of Jamuna River

Three satellite images have been used of the years from 1977 to 2000 and google satellite image (2020) has been also used for drawn the river bank line using GIS software. After that the river divided into three segments and also the segments were divided into several parts by cross section line. Then computed the value of river bank width which is represented in table and also graphical form. After the analyzed of the data it reveals that

- In the duration of 1977 to 2020 so many changes have been occurred in each segments of the River Jamuna. Value of the river width is comparatively decreased with respect to previous value of river width.
- Again, it is observed that the width of the river was greater in 2000 than 1977 in most places. But from 2000 to 2020 it is declined almost everywhere.

On the basis of cross section line which is drawn on the river bank, in segment-1 the year wise river widths (Table 10) were 3181.73 metre (1977), 4007.23 metre (2000) and 933.46 metre (2020). Again in segment-2 year wise widths (Table 11) of the river were 7197.02 metre (1977), 7901.63 metre (2000) and 1254.72 metre (2020). After that in segment-3 the river width (Table 12) is also totally decreased such as 4486.17 metre (1977), 5599.71 metre (2000) and 706.50 metre (2020).

Due to lack of natural water sources the Jamuna River bank has changed at a very rapid rate. Spatial data helps to obtain temporal information by which the nature of changes in the course of Jamuna River can be easily understood. Segment wise nature of change of Jamuna River course and its statistical analysis is given below in the form of table (Table 13).

Table 10. Channel Width of Jamuna River in Segment-1

Location No.	Cross Section Line	Channel Width of River (in Metre)		
		Year 1977	Year 2000	Year 2020
1	AA'	112.34	207.87	92.31
2	BB'	124.65	175.58	38.09
3	CC'	108.31	85.10	41.62
4	DD'	65.32	135.47	37.26
5	EE'	108.67	161.99	61.12
6	FF'	93.46	144.19	43.78
7	GG'	82.43	176.02	30.97
8	HH'	69.65	148.54	26.39
9	II'	109.63	123.91	43.02
10	JJ'	124.48	102.22	43.14
11	KK'	136.76	150.35	41.33
12	LL'	101.57	82.53	31.32
13	MM'	120.90	92.99	40.72
14	NN'	105.55	113.26	32.53
15	OO'	97.09	125.45	31.1
16	PP'	86.48	127.41	33.52
17	QQ'	130.46	124.04	22.86
18	RR'	136.92	181.95	33.62
19	SS'	183.42	184.46	31.88
20	TT'	141.09	224.29	34.45
21	UU'	235.82	230.47	20.44
22	VV'	100.80	169.40	8.33
23	WW'	156.39	115.48	29.63
24	XX'	133.40	128.81	29.32
25	YY'	123.97	149.36	23.85
26	ZZ'	192.17	346.09	30.86
Total Channel Width of the River		3181.73	4007.23	933.46

Source: Computed by the Authors using GIS Software

Table 11. Channel Width of Jamuna River in Segment-2

Location No.	Cross Section Line	Channel Width of River (in Metre)		
		Year 1977	Year 2000	Year 2020
1	AA'	146.84	181.13	37.37
2	BB'	133.08	169.54	21.33
3	CC'	149.15	120.9	18.07

Location No.	Cross Section Line	Channel Width of River (in Metre)		
		Year 1977	Year 2000	Year 2020
4	DD'	111.45	328.74	19.47
5	EE'	307.14	284.51	20.11
6	FF'	171.16	139	11.46
7	GG'	198.03	111.81	9.73
8	HH'	355.51	119.95	11.09
9	II'	391.5	180.86	13.19
10	JJ'	166.84	170.47	11.66
11	KK'	224.39	150.76	10.76
12	LL'	249.28	181.53	19.66
13	MM'	258.71	272.25	13.92
14	NN'	217.2	235.28	48.01
15	OO''	242.95	223.08	19.51
16	PP'	387.96	568.48	26.66
17	QQ'	186.33	232.61	11.65
18	RR'	300.32	134.63	23.4
19	SS'	175.52	187.95	20.51
20	TT'	199.07	233.23	21.21
21	UU'	247.74	290.73	24.71
22	VV'	176.5	191.83	22.02
23	WW'	111.57	249.46	28.39
24	XX'	145.19	227.38	30.71
25	YY'	458.93	446.34	30.7
26	ZZ'	212.52	273.39	136.24
27	AA1	142.73	279.93	81.67
28	BB1	149.78	288.73	127.79
29	CC1	214.21	223.02	171.61
30	DD1	135.86	251.53	27.86
31	EE1	131.68	278.76	45.9
32	FF1	221.24	215.65	51.33
33	GG1	138.16	231.14	43.11
34	HH1	138.48	227.03	43.91
Total Channel Width of the River		7197.02	7901.63	1254.72

Source: Computed by the Authors using GIS Software

Table 12. Channel Width of Jamuna River in Segment-3

Location No.	Cross Section Line	Channel Width of River (in Metre)		
		Year 1977	Year 2000	Year 2020
1	AA'	136.68	265.32	55.66
2	BB'	133.21	281	43.79
3	CC'	95.32	203.64	28.52
4	DD'	63.91	243.2	39.77
5	EE'	107.23	168.84	48.37
6	FF'	177.46	248.85	31.45
7	GG'	169.03	190.57	30.63
8	HH'	120.47	222.44	23.24
9	II'	150.65	138.87	43.63
10	JJ'	187.31	234.6	35.13
11	KK'	193.59	146.96	25.38
12	LL'	265.07	258.45	17.84
13	MM'	213.3	283.14	31.67
14	NN'	222.52	270.48	20.19
15	OO'	237.78	235.04	18.39
16	PP'	118.15	221.34	24.54
17	QQ'	383.18	143.29	12.91
18	RR'	195.09	409.38	34.45
19	SS'	236.37	240.4	16.97
20	TT'	156.5	137.94	16.03
21	UU'	166.13	195.32	19.83
22	VV'	142.53	225.91	19.33
23	WW'	205.73	206.4	23.65
24	XX'	213.83	209.85	20.42
25	YY'	195.13	218.48	24.71
Total Channel Width of the River		4486.17	5599.71	706.5

Source: Computed by the Authors using GIS Software

From the tables 10, 11 and 12, it is cleared that the width of River Jamuna has decreased a lot with time. However, looking at the value of segment wise skewness in each year, it can be said that the distribution is the totally right skewed direction and the distribution is purely asymmetrical (Table 13). The kurtosis values in 2000 were 4.59 (segment-1), 5.28 (segment-2), and 3.26 (segment-3). In 2020, the kurtosis value was 7.61, indicating a leptokurtic distribution. On the other hand other values of kurtosis belong to platykurtic distribution.

Table 13. Table for Segment wise Statistical Analysis of Jamuna River Width

Segments	Segment-1			Segment-2			Segment-3		
	1977	2000	2020	1977	2000	2020	1977	2000	2020
Maximum	235.82	346.09	92.31	458.93	568.48	171.61	383.18	409.38	55.66
Minimum	65.32	82.53	8.33	111.45	111.81	9.73	63.91	137.94	12.91
Mean	122.37	154.12	35.90	211.68	232.40	36.90	179.45	223.99	28.26
Median	116.62	146.37	33.03	192.18	227.21	22.71	177.46	222.44	24.71
Standard Deviation	37.12	54.57	14.80	85.04	89.11	37.21	63.55	56.82	10.87
Skewness	1.25	1.71	2.10	1.27	1.81	2.45	1.07	1.05	0.88
Kurtosis	2.28	4.59	7.61	1.16	5.28	5.70	2.93	3.26	0.11

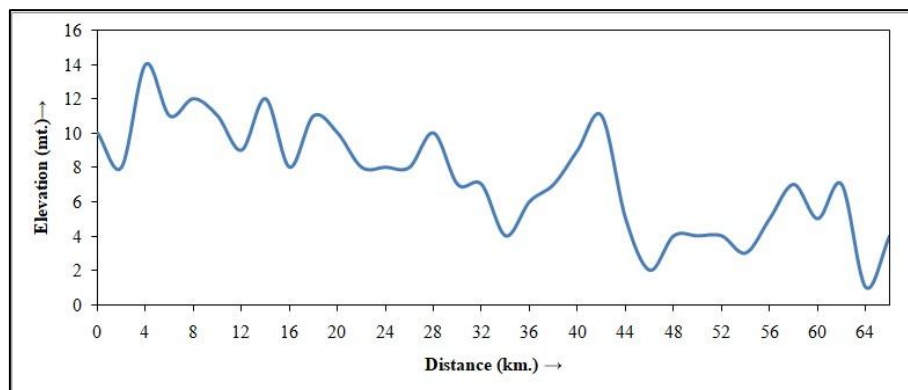
Source: Computed by the Authors

5.5. Longitudinal Profile of Jamuna River

The long profile from the source of the river to the estuary (mouth) helps in understanding the gradient of a particular river. It is very easy to show the whole channel of a river. It also shows how a river loses its land height as it flows from its source to its estuary (mouth).

The following is a picture of the river profile of the River Jamuna (Figure 11). The source of which is very difficult to find at present, so the long profile of the River Jamuna from end of *Mathura Bil* (Mathura Lake) to Ichhamati River has been drawn for the convenience of discussion. Observing the long profile of the river and the land topography of the local area, it is clear that the river has flowed through the plains crossing slight ups and downs in its course.

Figure 11: Longitudinal Profile of the Jamuna River from end of the Mathura Bil to Ichhamati River



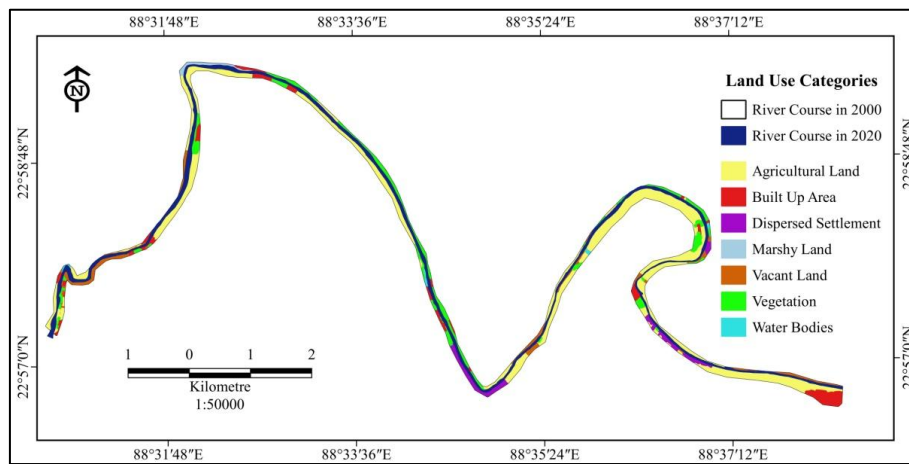
Source: SRTM DEM data

5.6. Present status of Jamuna River course

5.6.1. Segment-1

In 2000, the area of river course from *Mathura Bil* to Nagarukhra was 3.618 Sq. Km. Later in the year of 2020, the course of the River Jamuna changed a lot. Humanitarian activities are mainly responsible for this. Because people on both sides of the river are using it for their own needs, e.g. 45.82% of the total land use of the river course is for agricultural purposes, 8.63% is built up area, 3.94% is dispersed settlement, 11.04% is forest, 1.24% is wetland, 5.7% is vacant land and 0.47% is being used as other water reservoirs. In a word, only 24.20% of the total river course is in the form of flowing water bodies (Figure 12 and Table 14).

Figure 12: Land Use Categories in Segment- 1



Source: Google Satellite Image, 2020

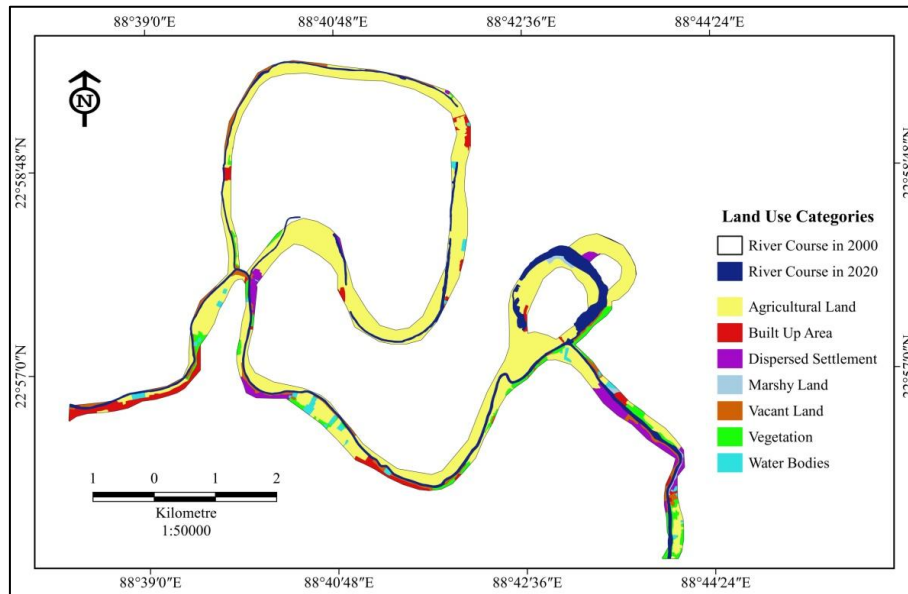
Table 14. Land Use Categories in Segment-1

Serial Number	Land Use Categories	Area in Sq. Km.
1	Agricultural Land	1.6578
2	Built Up Area	0.2845
3	Dispersed Settlement	0.143
4	Forest	0.4011
5	Marshy Land	0.0451
6	Vacant Land	0.2056
7	Water Bodies	0.0175
Total		2.7546

Source: Computed by Authors using Google Satellite Image, 2020

5.6.2. Segment-2

In this segment, the river course has been changed largely from Nagarukhra to Gaighata. In the year of 2000, the river course was very wide (8.5364 Sq.Km.) but now most of the area of river course has been converted into different types of human activities such as agricultural land (65.45%), built up area (5.14%), dispersed settlement (4.01%), forest cover (4.66%), marshy land (0.64%), vacant land (4.62%) and water bodies (1.97%). In 2020, the River Jamuna course area is gradually decreased and amount is 1.661 Sq. Km. which is 13.51% of total river course area in 2000 (Figure 13 and Table 15).

Figure 13: Land Use Categories in Segment- 2

Source: Google Satellite Image, 2020

Table 15. Land Use Categories in Segment-2

Serial Number	Land Use Categories	Area in Sq.Km.
1	Agricultural Land	5.6514
2	Built Up Area	0.4435
3	Dispersed Settlement	0.3461
4	Forest	0.4024
5	Marshy Land	0.0555
6	Vacant Land	0.3992
7	Water Bodies	0.1703
	Total	7.4684

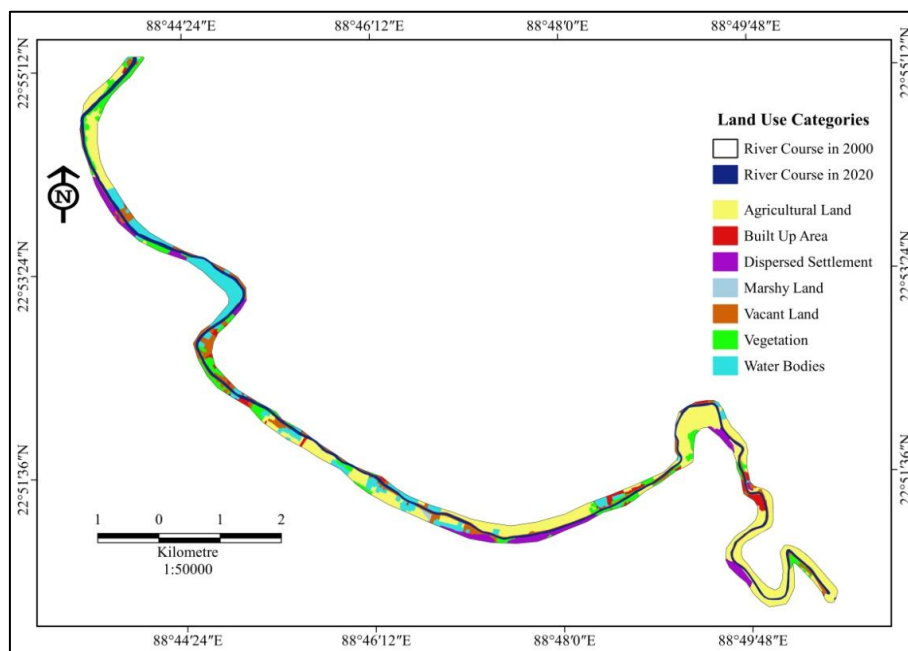
Source: Computed by Authors using Google Satellite Image, 2020

5.6.3. Segment-3

From Gaighata to river mouth, the river course has also changed. Most of the river course area have been encroached by the agricultural land (43.29%), built up area (3.42%), dispersed settlement (7.04%), forest cover (10.40%), marshy land (0.35%), vacant land (10.12%), water bodies (6.37%) and other type of water bodies (6.47%) which is used in fisheries purpose. Here, present river course area is 12.55% of the total course area in 2000 (Figure 14 and Table 16).

As per the above discussion it is clear that, the river course area has changed a lot due to different types of human activities. As a result the condition of the river is extremely bad and now it has turned into a dying river whose water source is completely closed and the natural course is also being affected by other activities.

Figure 14: Land Use Categories in Segment-3



Source: Google Satellite Image, 2020

Table 16. Land Use Categories in Segment-3

Serial Number	Land Use Categories	Area in Sq.Km.
1	Agricultural Land	2.1604
2	Built Up Area	0.1707
3	Dispersed Settlement	0.3512
4	Forest	0.5192
5	Marshy Land	0.0173
6	Vacant Land	0.5049
7	Water Bodies	0.3179
8	Water Bodies (Fisheries)	0.3227
	Total	4.3643

Source: Computed by Authors using Google Satellite Image, 2020

6. Conclusion

In this study, the variations in the Jamuna River’s course are shown using several remote sensing techniques and GIS. This demonstrates that the river’s source has over time become blocked due to lack of flowing water throughout the year. As a result comparing the course of the river in 1955 with the course of the river in 1977 and 2000 shows many changes. Even the course of the river in 2020 has also changed significantly. However, in this case by analyzing the google satellite map (2020), it can be understood that human activities are also one of the main reason for changing the course of the river. Because the course area of the River Jamuna is being affected by this activity and people are occupying the course area of the river illegally for their own purpose (e.g. agricultural land, settlement etc.) which is reducing the course area of the river. As a result the river is going to lose its existence. It is possible to state that this issue have some solutions like,

- Re-linking of Jamuna River with Bhagirathi River.
- Excavating the channel of river and making it deeper.

- Government intervention is needed so that the common people cannot enter the river course area arbitrarily and cannot easily use the area for their own activities.
- All categories of people who are directly engaged with Jamuna River like fisherman, farmer etc. should keep their own interests in mind and try to maintain the normal flow of the river.

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