

# Chapter 18

## Shifting of Main Course of River Ganga Within the Reach Bhagalpur to Kahalgaon Using Remote Sensing and GIS



Chandan Raj and Vivekanand Singh

**Abstract** The lateral movement of the river channel within its Khadir over time is a universal phenomenon. Various processes of the fluvial-geomorphological environment, such as frequent occurrence of floods, deposition of sediment, the capture of lower courses of tributaries by the main channel, failure of the bank and avulsion, are predominant factors behind the channel dynamics. In this study, shifting of main course, bank-lines and the variation of the sinuosity index were computed from the year 1973–2018 within the reach Bhagalpur to Kahalgaon, in the state of Bihar, India. The area near both the banks is densely populated and has many important structures. Shifting of river banks put these structures under risk of failure and dwelling area under risk of submergence in flood seasons. It has abandoned its original course and huge sandbars have been formed in the middle of the stream. These sandbars are hindering vessel navigation too. The dynamics of channel adjustment in terms of lateral shifting can be beautifully illustrated by the application of modern geoinformatics tools, i.e., remote sensing and Geographic Information System (GIS). From the study of USGS satellite images using ARC-GIS, it has been found that the main course and bank-line has been shifted significantly during this period. The study of the width of the active channel and the position of main course indicates that both the left and right banks have changed significantly due to the erosion and deposition of sediment during monsoon period of each year. During the period 1973–2018, the river has moved toward its left bank and has become more sinuous in nature. This study highlights a significant message of immense vulnerability of the Ganga river and also points towards its geomorphological instabilities in this reach of the river.

**Keywords** Bankline shifting · Fluvial-geomorphology · Sinuosity Index · Bank-line · Remote sensing and GIS

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## 18.1 Introduction

River channel shifting is very critical among geomorphological and river management problems. Lateral shifting of river is defined as positional change of a river channel due to variations in water and sediment discharge. It is always associated with bank erosion or streambed erosion due to turbulent flow conditions (Yang et al. 1999). Lateral migration of river is a catastrophic local and regional change process (Hickin and Nanson 1984). Dynamic equilibrium of a river can be disturbed by any one of the factors, whether it is natural, anthropogenic or manmade. In order to maintain its equilibrium, river undergo self-adjustment through fluvial processes.

Lateral shifting of river is geomorphological phenomena, and is very burning issue for most of the rivers throughout the world. Detailed study of channel migration is very important for documenting the erosion hazard and changes in planform and land use characteristics, as well as for understanding reasons behind those changes. In recent years, various researchers have studied this phenomenon (Debnath et al. 2017; Dewan et al. 2017; Hossain et al. 2013; Kummur et al. 2008; Nanson and Hickin 1986; Nigam et al. 2016; Thakur 2014). In the present study, the change in the planform of river Ganga has been studied between Bhagalpur and Kahalgaon from the year 1973–2018 using remote sensing and GIS. This stretch of river Ganga is highly affected by problems of flood, erosion and migration of main course (Hazarika et al. 2015; Jayanth et al. 2016; Rawat and Kumar 2015). Remotely sensed data have been used for study, which gives imprint of river channel over area for different time period. This method made possible study of river migration in less time with better accuracy and low-cost effective manner.

The River Ganga is one of the most important religious rivers in India. It is also known for disastrous reasons, especially in monsoon season, when discharge is very high. When it flows through Bihar, India, it is in mature stage. Low bed-slope gradient and decreases in velocity of streamflow cause aggradation in river bed. Aggradation reduces discharge carrying capacity of the river. During the season of high flood, water either overtop banks or its bank fail in action. Soft soil cover, high discharge, low velocity, and water laden with silt, all these factors induce meandering of the river, and causes severe erosion in concave bends (Deb et al. 2012). Huge amount of fertile land lost every year due to shifting of river (Debnath et al. 2017). In the present study area, massive erosion take place every year affecting people living there. Huge amount of agricultural land gets eroded. In this region, areas on the bank of river are highly populated also having many important infrastructures. National Highway No. 80 also get damaged due to flood water. There is need to study the shifting trend over time–space domain and its severity on areas, so that concerned authorities can take preventive steps to minimize disastrous impact. Taking into consideration of earlier studies and severity of channel migration, this study has been aimed to quantify amount of river on spatial and temporal basis.

### 18.2 Study Area

The Ganga River reach between Bhagalpur to Kahalgaon has been considered, which is lying in Bihar, India. The study area has been shown in Fig. 18.1. Bhagalpur is the district town of Bihar State, is located in the middle of eastern part of the state. The area of the district is 2569 km<sup>2</sup>, having population of 3,037,766 (Census 2011). River Ganga flow through middle of the district. This district is home to the Vikramshila Gangatic Dolphin Wildlife Sanctuary, which is 50 km in length. This study is based on channel shifting due to bank erosion of Ganga River. So, the study area comprises only river part and area near its bank affected by erosion hazards. The geographical extent of study area is from 25°12' N to 25°19' N and 87°01' E to 87°14' E, with an area of about 314 km<sup>2</sup>.

Ganga river enters the study area in Bhagalpur and ends at Kahalgaon, after flowing about 38 km in length. In this stretch, river is continuously changing its planform because it is in mature stage and plain is formed by loose alluvium. This

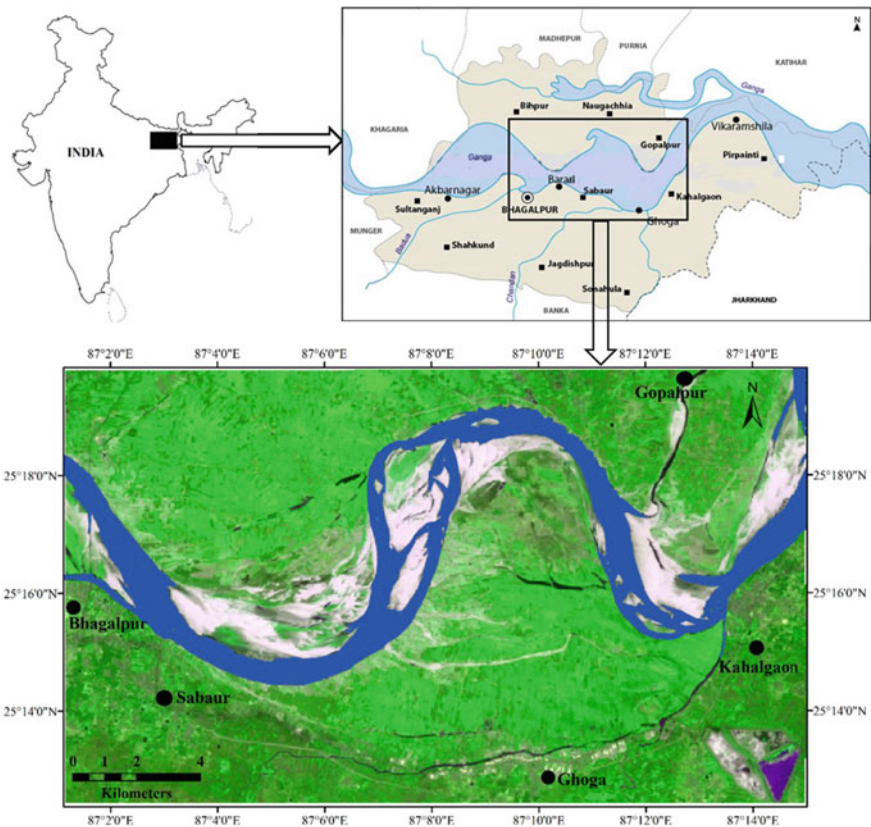


Fig. 18.1 Study area (Ganga river)

loose and unconsolidated soil stratum is highly vulnerable to erosion. The direction of flow is from west to east. Many islands and sandbars are also formed in this stretch, some of them are old and some are newly formed. Old and vegetated islands are called 'Diara' in local language where agricultural activities are performed in lean period.

### **18.3 Erosion in Study Area**

The river Ganga shows dynamic nature of its river course almost every year. This dynamic nature is due to natural factors like discharge, soil characteristics, topography, geological characteristics etc., and also due to man-made factors like construction of barrages, deforestation etc. This stretch of river face river bank failure almost every year. In Gopalpur, dozen of houses had disappeared in 72 h only in year 2018. In this stretch of river, bank erosion occurs firstly due to high pressure of water on bank wall, and secondly due to submerged and stagnated water seepage as groundwater. It weakens porous soil profile and dissects the bank deep root. And as result after recession of flood bank collapses (Keshkar et al. 1996).

### **18.4 Social and Economic Aspect of River Bank-Line Shifting**

River bank shifting has also led to administrative problems. Villages situated on the bank of river lost its boundary due to erosion. This has also become a matter of local dispute. People from affected area shift to nearby village, increasing administrative problems. They lost their agricultural land and became landless and without livelihood. They demand for their re-allocation/ rehabilitation from government. Government has to go through long procedure for their rehabilitation. People search their shelter themselves, and often take shelter on road side making huts. It results in high rate of road accidents. The neo- refugees like situation prevail with many social problems. Poverty and local conflicts increase crime. A social grouping and conflicts between victims and non-victims get started. Geomorphological process of river comes with many unseen problems directly associated with our life.

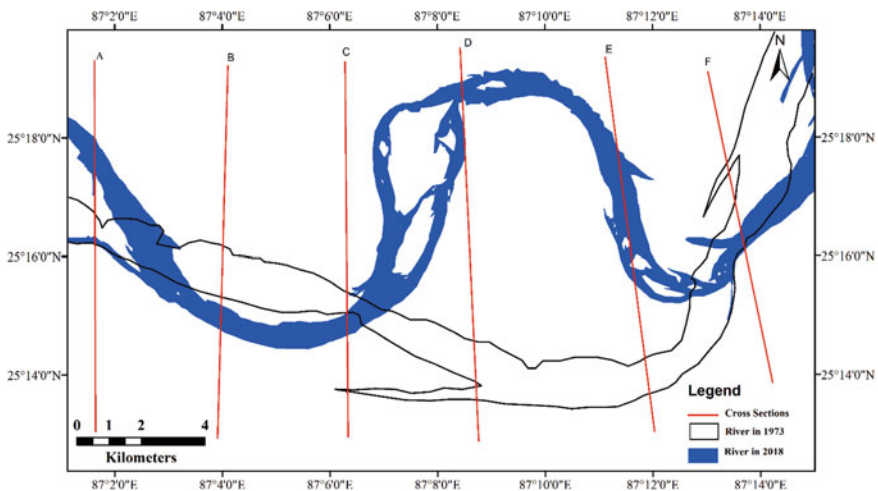
### **18.5 Methodology**

Satellite imagery gives an imprint of a river. Thus, remote sensing and GIS technique is very suitable for this study. ArcGIS and its extensions have been used for the

study, which is highly sophisticated software for analysis of mapped information, and provides infrastructure for managing geographical information.

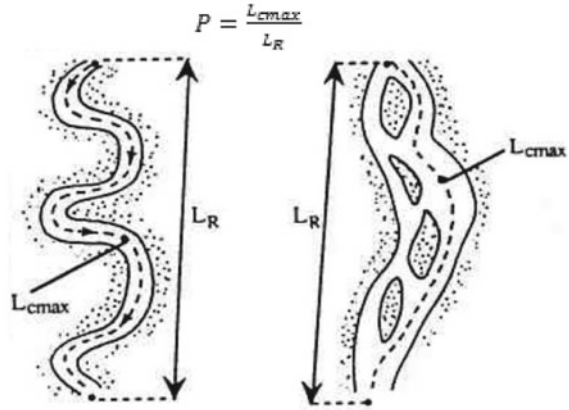
In this study, shifting of bank-line and sinuosity have been computed and analyzed. Landsat scenes have been taken from 1973 to 2018 at the interval of every fifth year. All these data were collected from USGS site (<http://earthexplorer.usgs.gov/>). Selection of images is based on cloud cover and its availability. Here only dry season images (i.e. January to March) have been used as water level remain normal and sky are mostly cloud free in this period. These selected images are processed for distortion and rectified as per requirement. Finally, each image has been clipped for the getting study reach. Clear boundary between land and water is required for study of river planform. For extraction of river boundary several methods are described in previous studies. Some are manually done, and in some work, it has been extracted automatically using GIS software. Previous record showed that automated result is unreliable because it is based on reflectance of riverine features (Dewan et al. 2017). Different features having similar reflectance give errors in result. Thus, manual digitization of river boundary is more accurate process (Gupta et al. 2013; Yang et al. 1999). In this study, manual digitization of river boundary has been used. Multispectral data comprising of band combination 4-5-3 clearly distinguishes land and water boundary. During digitization of the river bank, similar zooming level of 1:100,000 has been kept for consistency in method because scale is an important factor in analysis of channel boundary (Tiegs and Pohl 2005). A georeferenced spatial dataset representing river boundary was finally obtained for each year of study.

In order to calculate amount of bank-line and centerline shifting, fixed cross sections have been drawn which is shown in Fig. 18.2. Bank-lines for two successive



**Fig. 18.2** Cross sections across Ganga for measuring temporal (1973–2018) shift along each cross section

**Fig. 18.3** Sinuosity (Source Friend and Sinha (1993))



years i.e. 1973–1975, 1975–1980 and so on have been overlaid and compared to calculate amount of shift.

A sign convention has been adopted to study bank-line shifting. Left bank shifting towards left direction (i.e. erosion) is marked with positive sign, whereas left bank shifting towards right direction (i.e. accretion) is marked with negative sign. Similarly, right bank shifting towards right (i.e. erosion) is marked with positive and right bank shifting toward left (i.e. accretion) is marked with negative sign.

Sinuosity is the measure of deviation of flow path from a straight path. Many researchers have defined it in different ways. This study adopted sinuosity defined by Friend and Sinha (1993). It is defined as “Ratio of mid-channel length of widest channel ( $L_{cmax}$ ) to overall length of channel belt reach measured along a straight line ( $L_R$ )”. Figure 18.3 shows the  $L_{cmax}$  and  $L_R$  in meander and braided rivers (Friend and Sinha 1993). Sinuous,  $P$  is given as:

$$P = \frac{L_{cmax}}{L_R}$$

## 18.6 Results and Discussions

Regular shifting of the river Ganga has been analyzed at different sections along the river between Bhagalpur and Kahalgaon. The river has meandered in this reach and hence sinuosity has also been measured and analyzed.

Shifting of the left bank along selected cross sections (A, B, C, D, E, and F) have been shown in Fig. 18.4 a and b for each interval of time. In the year 1973, the river was flowing almost straight from CS (Cross Section) A to E. Left bank start eroding and continuously goes on shifting northward from year 1973 to 1995, which can

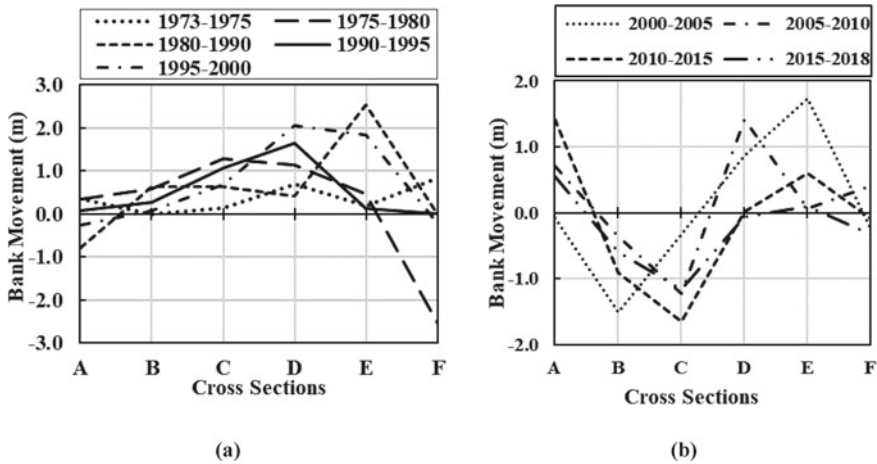


Fig. 18.4 Left bankline shifting along cross sections, 1973–1995 (a); 2000–2018 (b)

be clearly seen in Fig. 18.4 a. During the years 2000 to 2018, southward shifting (i.e. accretion) of the left bank-line was observed at cross sections CS-A to CS-D. However, the stretch beyond CS-D to CS-F continues shifting northward. Further erosion of left bank between the CS-D and CS-E has been restricted from the year 2005 onwards due to construction of left bank protection.

Figure 18.5 a and b shows the shifting of right bank along predefined cross sections. Right bank has shifted northward due to accretion in the stretch CS-A to CS-E in duration 1973–1995. Further, it has shifted southward due to erosion between CS-B to CS-C after 2000. However, stretch CS-C to CS-E continues shifting northward due to accretion. In a whole, it is observed that right bank has shifted northward

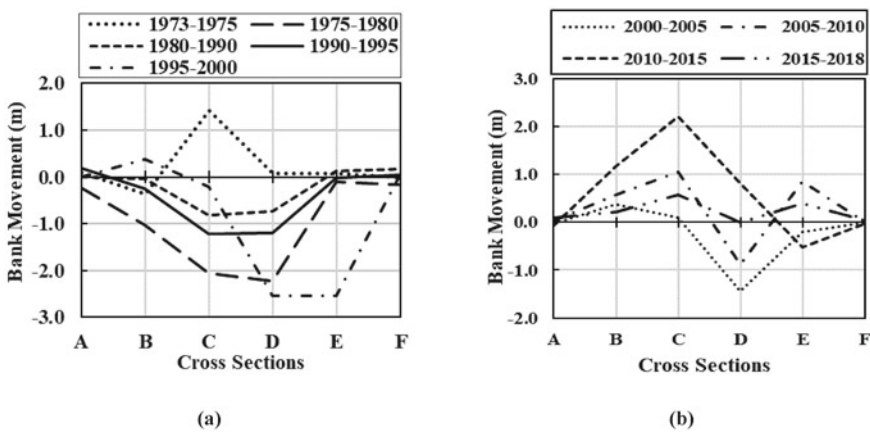


Fig. 18.5 Right bankline shifting along cross sections, 1973–1995 (a); 2000–2018 (b)

as a result of accretion. This accretion formed the vast attached bar and some narrow stream. These bars get vegetated along time and people started agricultural activities in the lean period. Analysis of shifting of the both bank-lines revealed that river has undergone drastic change in its planform. People living in the areas close to both banks are affected every year due to these shifting. Their agricultural land and dwelling areas disappeared because of erosion.

Table 18.1 presents temporal variation of left and right bank-lines in terms of erosion and accretion from 1973 to 2018 with an interval of every 5 years. Amount of per year shifting has been shown. It can be seen that the Left bank undergone more shifting compared to right bank and it is continuous. However, the left bank shows less accretion compared to right bank. Right bank faces more accretion than left bank of the river.

Sinuosity is an important parameter after bank-line shifting to describe planform change of a river. Temporal change of morphological parameters width of the river and sinuosity is presented in Table 18.2. It has been calculated from historical maps between year 1973–2018.

Result shows mean width of the river undergoes moderate change in the study reach from year 1973 to 2018. It varies from maximum 2.05 km in 1975 to 1.19 km in 1980. There is abrupt increase in river width from 1973 (1.47 km) to 1975 (2.05 km). This abrupt change may be due to blockage of flow after commissioning of Farakka Barrage in year 1975. River Ganga flowing in alluvium plain, is in mature stage in this stretch. Erosion is easy because of loose alluvial soil. Hence river goes on continuous expansion and contraction. The river is facing erosion at one bank and accretion at the other so its gross width is increased without showing major variation in waterway width. Overall width of the river is in increasing trend with minor variation.

Study showed that sinuosity had changed considerably over time between Bhagalpur and Kahalgaon. Figure 18.6 shows the time interval wise sinuosity and it is in increasing trend from 1.20 (1973) to 1.66 (2018) in the study reach. This increase

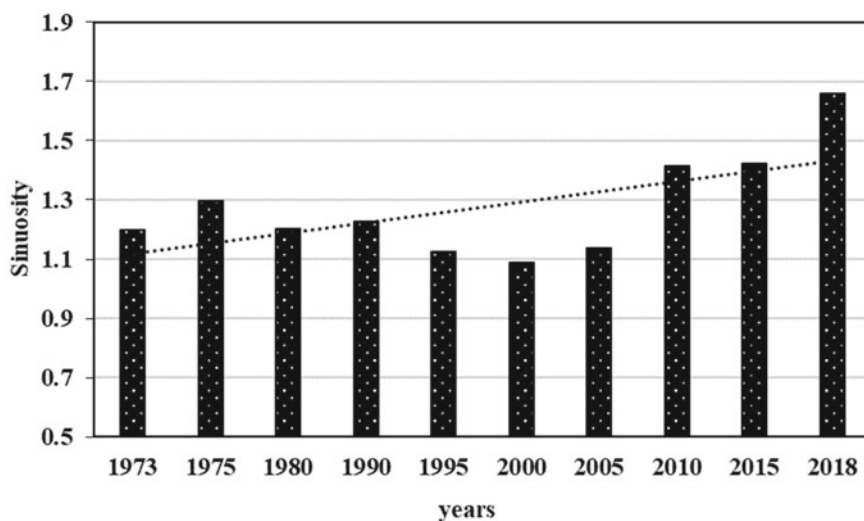
**Table 18.1** Temporal variation of left and right bankline shifting

Time period	Left bank-line shifting		Right bank-line shifting	
	Erosion (m y <sup>-1</sup> )	Accretion (m y <sup>-1</sup> )	Erosion (m y <sup>-1</sup> )	Accretion (m y <sup>-1</sup> )
1973–1975	220.28	0	209.86	181.02
1975–1980	152.59	505.30	0	193.87
1980–1990	104.89	79.26	14.72	53.05
1990–1995	127.80	0	23.52	134.30
1995–2000	233.06	47.66	29.49	352.35
2000–2005	259.20	107.63	46.61	83.47
2005–2010	130.10	157.76	124.96	88.50
2010–2015	136.05	177.05	278.65	41.47
2015–2018	108.47	178.56	87.01	0



**Table 18.2** Temporal change of width and sinuosity

Year	Mean channel width (Km)	% Change in mean channel width	Sinuosity	% Change in sinuosity
1973	1.47		1.20	
1975	2.05	39.8	1.30	8.06
1980	1.19	-41.9	1.20	-7.22
1990	1.49	25.1	1.23	2.19
1995	1.60	7.5	1.13	-8.39
2000	1.20	-24.9	1.09	-3.24
2005	1.07	-11.1	1.14	4.52
2010	1.52	41.8	1.41	24.16
2015	2.02	33.0	1.42	0.55
2018	1.76	-12.7	1.66	16.76

**Fig. 18.6** Change in sinuosity

may be due to blocking of sediment by Farakka barrage. The result showed decrease in the sinuosity from 1990 to 2000. This decrease may be contributed to process of meandering when river length shortens before changing course from one side to the other side. However, it showed increasing trend (Fig. 18.6). In general increase in sinuosity is associated with increase in bank erosion, because it causes decrease in streamflow velocity. This decrease in streamflow velocity is combined action of low river bed gradient, siltation and backwater effect after construction of barrage. This particular reach of the Ganga had sinuosity ranged between 1.13 (1995) to 1.66

(2018). Between years 1973–2018, overall sinuosity of the River Ganga study reach had increased, which resulted in an increase on overall length of 9.70 km study reach.

## 18.7 Conclusions

Under the combined action of erosion, accretion and human interventions, the River Ganga had experienced significant morphological change. Accurate quantification of this change is a challenging task. To detect long-term morphological change through remote sensing is a practical approach. In this study, shifting of river has been calculated and analyzed using multiple Landsat images of the Ganga from Bhagalpur to Kahalgaon for the of period 1973–2018. Figure 18.2 also shows complete shifting of the river in this period within study area. During this study period, the river has migrated towards the north by maximum of 9.5 km. Massive erosion has completely changed planform of the river. About 8174 hectares of land has been lost in this study area only in the period of study. Almost Straight River has completely become sinuous. Its sinuosity has increased from 1.20 (1973) to 1.66 (2018). Formation of bars is also seen in the study reach.

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