Assessing the Long-Term Planform Dynamics of Ganges-Jamuna Confluence With the Aid of Remote Sensing and GIS

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Abstract

The Ganges-Jamuna-Padma confluence is one of the world's most active confluences. The confluence of two of the world's greatest rivers, the Ganges and the Brahmaputra, makes this a globally significant site. Severe erosion along the banks has been caused by morphological changes in this region. Riverbank erosion is one of Bangladesh's most serious problems, as it necessitates costly intervention. Riverbank erosion in Bangladesh affects millions of people each year as a result of erosion in this confluence zone. As a result, it's critical to comprehend the confluence's morphological changing pattern. This study aims to quantify actual bank shifting around the confluence of the Ganges, Jamuna, and Padma in terms of shifting rate and area during a twenty-five-year period (1990-2015). To conduct this study the collected satellite image were geo-referenced and digitize bank lines from using ArcGIS program. The bank line is the linear structure that divides the river channel's outer border from the flood plains. The distance between the extreme margins of the left and right banks, including mid-channel sandbars, was measured to determine channel width variation. To assess the maturity of change, this time frame is subdivided into five phases, each lasting five years. In addition, the long-term shift from 1972 to 2015 is qualitatively noticeable. This morphological alteration was studied using LANDSAT satellite images. The research gives current and trustworthy information on the Ganga-Jamuna confluence's planform dynamics. This research will be useful in the planning and execution of drainage development plans and erosion control strategies in this critical confluence zone.

1. Introduction

River confluences are important governing points of channel geomorphology (Mosley 1976, Best 1988). Planform shifting is a natural autogenic phenomenon for rivers that occurs as a result of high discharge quantity, large sediment load, stream type (perennial or seasonal), terrain, and anthropology of the regime running through (Roy and Mitra, 2020). One of the world's most serious challenges with alluvial rivers is channel planform dynamics. Natural hazards such as lateral channel transition, floods, bank erosion, and disruption to hydraulic structures, transportation networks, agricultural land, and settlements, are all caused by this. Many water resources experts, engineers, and policymakers rely on a thorough grasp of the historical planform evolution in rivers over time to carry out river management operations (Roy and Sinha, 2018; Majumdar and Mandal, 2020). Tremendous endeavors have been undertaken to investigate channel planform behaviour locally and worldwide over the last three decades (Bora and Goswami, 2021; Hasanuzzaman et al. 2021). Numerous geospatial technology-based studies have been conducted across the world, including in the United States on the four rivers of Olympic National park (East et al., 2017) , Taiwan on the Zhuoshui River and the Gaoping River (Kuo et al., 2017), Italy on the Scrivia river (Mandarino et al., 2020), Germany on the Old Rhine downstream (Arnaud et al., 2015), China on the lower yellow river (Kong et al., 2020; Guo et al., 2021) and the lower jingjiang reach (Yang et al., 2013), India on the Koshi river (Sinha et al., 2014), the Sharda river (Midha and Mathur, 2014), the Dwarkeswar river (Ghosh and Mukhopadhyay, 2021), the middle lower part of ganga (Pal and pani, 2019), and the Ramganga river basin (Agnihotri et al., 2020), and Bangladesh on the lower padma river (Rashid, 2020;

Nawfee et al., 2018; Halder et al., 2021), the rivers in southern estuarine Region (Islam et al., 2018), the Lower Meghna river (Mahmud et al., 2020), Madhumati river (Biswas et al., 2021), the lower Teesta river (Akhter et al., 2019), and the Brahmaputra river (Rashid et al., 2021). Lower sections of rivers regularly change course as a result of tectonic tilting, hydrological variability, and sedimentological readjustments (Agnihotri et al., 2020; Talukdar and Pal, 2017, Talukdar and Pal, 2018, Saha and Pal, 2019, Nawfee et al., 2018, Dewan et al., 2017) and the junction of the Ganga and Jamuna rivers is no exception (Rashid, 2020; Mahmud et al., 2020; Dewan et al., 2017). Any alterations, either natural or anthropogenic, might cause a shift away from dynamic equilibrium (Sinha et al., 2014; Dewan et al., 2017; Rashid et al., 2021; Mahmud et al., 2021). As a result, channel instability may occur, producing changes in channel shape and pattern (Dewan et al., 2017).

Many geomorphologists have observed that channel planform dynamics is a significant issue in Himalayan rivers, which have always switched channel in their lower reaches (Dewan et al., 2017; Rudra, 2010, 2014; Sinha et al., 2014; Gupta et al. 2013). Because of the large area coverage, synoptic view, and frequent data acquisition capability, satellite remote sensing data and historical topographic maps provided an enormous opportunity for fluvial geomorphologists to understand channel planform dynamics, particularly for long and extremely moveable rivers (Gupta et al. 2013). The use of remote sensing and geographic information systems (GIS) to analyse and monitor river erosion and central line movement is becoming more common (Pal and Pani, 2019; Agnihotri et al., 2020; Gupta et al., 2013; Rozo et al., 2014; Ashwini et al., 2020; Jung et al., 2020; Yang et al., 2015). The advent of GIS has improved the researcher's ability to identify planform features like as changes in length, centerline migration, and sinuosity index, among others, by integrating pictures on river planform from various sources. It was discovered that Landsat images may be utilised to categorise river lengths successfully. A research on the examination of meandering and braiding features was recently completed, using the middle-lower portion of the Ganga as the study reach (Pal, 2017). With the aid of Landsat images and streamflow data over a longer period, the Ganga–Padma river system in Bangladesh was studied for planform changes from 1973 to 2011. (Dewan et al., 2017). After examining the Ganga River's erosion–deposition data, it was discovered that during the assessment period, roughly 57 km^2 of land was lost on the right bank and 59 km^2 was deposited on the left bank (Dewan et al., 2017).

According to earlier studies, the Ganga River's morphology changed dramatically after the installation of the Farakka barrier (Aswini et al., 2020; Pal and Pani, 2019; Dewan et al., 2017; Rudra, 2014; Agnihotri et al., 2020; Anand et al., 2018; Sinha and Ghosh, 2012; Raj and Singh, 2020). There have been studies conducted on the upstream and downstream portions of the Farakka barrage on the Ganga River (Rudra, 2014; Agnihotri et al., 2020; Anand et al., 2018; Sinha and Ghosh, 2012; Raj and Singh, 2020). However, there have been no contemporary studies on the morphological alterations of the Ganga-Jamuna River, taking into account both the Ganga river downstream of the Farakka barrier and the Jamuna river confluence. Thus, the current study attempts to identify historical changes in the planform of the Ganga-Jamuna River confluence using dynamic fluvial features obtained from Landsat images taken at various times. This study is being carried out to investigate the planform dynamics of the Ganges-Jamuna confluence zone during 1990-2015 using Landsat sattelite images. The objectives of this study are as follow:

1. To assess the bank shifting near the confluence of the Ganges, Jamuna and Padma rivers in short term and long term basis.
2. To find out the trends on bank line shifting.
3. To quantify the short term and long term erosion and deposition.
4. To determine the variation of river widths in different years.

2. Materials And Methodology

2.1 Study area

The Brahmaputra & Ganges Rivers both originated from glaciers in the Himalayas. The Brahmaputra flows through China, India, and Bangladesh over a length of 2900 km (Islam et al., 1999) and has a drainage area of about 573,500 km^2 of which only 8 percent is inside Bangladesh (Hassan et al., 1999). Whereas the Ganges has a basin area of over 1.1 million km^2 with only 4% of the catchment lying in Bangladesh. The Ganges-Brahmaputra system brought in sediments during the post-pleistocine period that shaped the Bengal deep sea fan (Biswas, 1992). The lower Brahmaputra, prominently known as Jamuna, has a length of 240 km from the point of entry into Bangladesh to its confluence point with the Ganges. It is very dynamic in nature due to its multi-channel split offs around the bars followed by rejoin, giving it a braided shape in the process. Jamuna has an average channel width of about 11 km (Sarkar et al., 2003). In this study, we selected a reach of 60 km from the confluence point to upward. The discharge of Jamuna ranges from 3000 cumec to 100,000 cumec with a bankful discharge of approximately 48000 cumec (Hossain, 1992). The annual monsoon governs the water and sediment discharge of the Jamuna. The flow of Jamuna reaches its peak in July or early August. The catchment has an annual average precipitation of 1900 mm with more than 80% of it occurring during the 5 months of the monsoon (EGIS, 2002). The sandbars of the Jamuna river, locally known as '*Char*' encompass about 1700 square kilometers and are used mainly for rice cultivation by the char dwellers. (EGIS, 1999). The movement of these bars, islands, along with both the banks of Jamuna, is a very common phenomenon, making it harder for the char dwellers to cope with. Sometimes, the bank lines even shift in the range of kilometers per year. In contrast, the Ganges is a meandering river less dynamic than the Jamuna as the bank materials of the Ganges are not homogenous in terms of erodiblity. The Ganges is divided into two reaches owing to its distinct hydrological characteristics. The upper part is from the border of Bangladesh with India to the point of confluence and the lower part is from there to Chandpur, where there is another confluence with Meghna. The length of the upper part is about 87 km while the lower part is about 108 km (Rashid, 1991). The Ganges has an annual average discharge of about 30,000 cumec and a bankfull discharge of about 75000 cumec (FAP24, 1996). The lower part of the Ganges is much straighter than its upper part because of the heavy discharges from two mighty rivers. The Ganges system is very important as it delivers freshwater to the Sundarbans by keeping the salinity front from propagating upward from the sea. The Sundarban is the world's largest mangrove system, having an area of approximately 10,000 square kilometers. So Ganges plays an important role in sustaining the ecosystem of the Sundarban. Like Jamuna, the Ganges also displays great variability in discharge due to heavy rainfall during the monsoon and melted snow from the Himalayans. So, both the riverbanks are prone to bank erosion and migration, which results in land loss and displacement of the population. There is a scarcity of information regarding the number of displaced people due to erosion. However, a study on the resilience and vulnerability of 10 major deltas showed that the number of people displaced per year due to erosion along the river banks of the Ganges delta is higher than 60000 (Bucx et al. 2000). This number is expected to rise due to climate change (Moors et al. 2011).

In fact, Confluence of Ganges, Brahmaputra, Meghna and their tributaries has formed and shaped the deltaic plains of Bangladesh. Two of the major rivers of GBM basin are Ganges and Jamuna (Lower Brahmaputra) meets at a point named Goualondo Ghat situated at Rajbari district of Bangladesh. Ganges and Brahmaputra are two of the world's largest river system with a combined catchment area of 16, 30,700 km^2 of which only 5.23% lies in Bangladesh (JRCB). Usually confluence morphology is dictated by three factors namely discharge and sediment loads at upstream control, junction angle of converging channels and bar formation at the downstream of the confluence (Mosley, 1976). However, Jamuna river avulsed during the 19th century causing the confluence to shift dramatically to north (Rahman et al. 2020). Jamuna is a geomorphologically active braided river where sediment loads are greater than its carrying capacity (Baki, 2012). As a result, sandbars locally known as 'chars' separate flow into multiple channels allowing the river to widen by eroding banks. Dynamics of Ganges-Jamuna confluence is governed by this channel migration (Best, 1997). In contrast, Ganges is an anabranching river (Kleinhans, 2010) with sinuosity ranging from 1.2-1.35 (Dewan, 2017). Eighty percent of the channel's annual discharge volume is drained to Bay of Bengal during the months of monsoon (July-October). This highly seasonal variability of discharge coupled with development activities in the upstream of Ganges have made bank erosion and bed scouring worse in recent times (Sharma et al. 2010). Banks of both Ganges and Jamuna are mostly made up of fine grained clay and silt carried by these rivers (Datta and Subramanian, 1997). From 1973 to 2017 banks of Ganges, Padma(Lower Ganges) & Jamuna have eroded around 1540 km^2 leaving about 1.6 million people homeless (Islam,2017). Significant amount of agricultural land was also lost which has created growing concern about future food security of the country. Several studies have been carried out to understand morphological characteristics of Ganges and Jamuna river. Dewan 2017 et al. used remotely sensed imagery and found that Ganges lost 57 km^2 lands on its right bank while gaining 59 km^2 land on the left bank during 1973-2011. Baki 2012 investigated short and long term erosion- accretion rate of Jamuna River using landsat imagery from 1973-2003.

2.2 Materials and methods

Open-source time series satellite imagery (Landsat) has been used extensively to quantify morphological changes in rivers worldwide. Wong (2020) also used long-term satellite imagery to study bar dynamics of the Amite and Comite Rivers in the USA. However, moderate resolution Landsat images also provide a great scope to quantify riverbank migration. Several studies, including Raj (2020), Agnihotri (2018), investigated the change in morphological parameters over the course of many years. For this study, Landsat imagery from the years 1972-2015 has been selected for analysis. The details of Landsat imageries used in the present study have been presented in the Table 1:

Table 1: Details of the Satellite Images

Year	Date	Satellite data	Image Format	Resolution (in meter)
1972	23-November	Landsat MSS	TIF Format (Geo-referenced)	60
1990	23-December	Landsat 4-5TM	TIF Format (Geo-referenced)	30
1995	16-January	Landsat 4-5TM	TIF Format (Geo-referenced)	30
2000	24-February	Landsat 4-5TM	TIF Format (Geo-referenced)	30
2005	09-December	Landsat 4-5TM	TIF Format (Geo-referenced)	30
2010	08-February	Landsat 4-5TM	TIF Format (Geo-referenced)	30
2015	07-January	Landsat 8OLI	TIF Format (Geo-referenced)	30

To obtain cloud free imagery December to February time frame was selected, as it is the dry season when the river flows with adequate discharge to fill the main channel and yet remains relatively constant on a year-to-year basis (Gupta et al. 2013). Simple pre-processing of satellite datasets was performed for these datasets. Using the layer stack technique in ERDAS software, the satellite images was layered in one file (single layer). As a result of this procedure, a False Color Composite (FCC) image was created. Geometric rectification and subsetting were two important processes in extracting the image of the study region. For the geometric correction of the single-layered picture, the georeferenced toposheet in raster format was utilised as reference data. GCPs were found in both the toposheet and satellite image (2015 image) during geometric rectification. The overall Root Mean Square (RMS) error was assessed to be less than 0.5 pixel in the satellite image. The Auto Sync work station tool in ERDAS Imagine Software was then used to register multitemporal images (1990-2015). The 2015 Landsat 8 image was used as the reference image. The Landsat 4-5TM images were registered and projected to the UTM WGS 1984 datum based on the reference image.

The study area was divided into three segments, namely Ganges, Padma & Jamuna. Each segment was then divided into 13 equal sub segments by 4 km distance for each segment. The total length for each river reaches extending upto 48 km. A total of 39 sections were generated according to the determined 4 km distance. The combine portion of the three big river segments fall under the downward Padma River. Figure 2 showed details of the segments including the different location place and bankline of three rivers for 5 years intervals from 1990 to 2015. Figure 2 shows that the bankline of the Padma River is prone to scatter shifting, which occurs due to the combined flow of the upper river.

2.2 Methods for analyzing bank line shifting and channel width changes:

To analyze the bank line and channel width dynamics, the whole work has been performed in ArcGIS 10.5 software. To perform the analysis, the bank lines were digitized from all geo-referenced images. A bank line is defined as the feature that separates the outer edge of a river channel from the floodplain. All selected satellite images were carefully analyzed for bank lines and boundaries using the software at a scale of 1:50,000. Bankline digitization in a consistent manner is one of the important aspects when changes in the planform, pattern, or position of the channel are being monitored. Digitization of bank lines from satellite images was carried out using ArcGIS software.

The bank line is taken as the linear feature that separates the outer margin of the river channel from the flood plains. Hence, all sand bodies (bed and bar features) visible in an image are considered to be part of the channel except for coarse sediment that is spread over the flood plains during floods that spill over the bank.

Variation of channel width was analyzed by measuring the distance between the extreme edges of the left and right bank, including mid channel sandbars. 39 sections were created at equal distances to evaluate the bank's migratory trend. To quantify the shifting of bank lines, digitised bank lines from two different years were superimposed on one another.

2.3 Method for measuring sinuosity

The degree of meandering in a river channel is determined by river sinuosity. The ratio between the length of the river bed (which is channel length) and the shortest distance of the river bed from beginning to finish is the sinuosity of a river (which is valley length). With more wandering, the sinuosity grows.

$$SI = \frac{AC}{AV} \qquad \text{(Eq. 1) (Brice, 1964)}$$

Where, SI denotes the sinuosity index, while AC and AV are channel length and valley length.

The sinuosity of the river was computed using Eq.(1) after establishing the mid-channel line of river courses using the HWATH's tool, which is also an ArcGIS extension (Garca, 2014).

2.4 Mapping of erosion and deposition

The river channel polygons for the years 1990, 1995, 2000, 2005, 2010 and 2015 have been overlaid. After superimposing these polygons representing river channel erosion and deposition of the research region owing to river course alteration, long and short term changes were estimated for both the left and right banks (Deb and Ferreira, 2015). The river flows from north to south, instead of using the terms left and right banks in the analysis, the terms east and west bank could also be employed. Between 1990-1995, 1990-2000, 1990-2005, 1990-2010, and 1990-2015, the river's erosion and deposition area was retrieved using the overlay tool in ArcGIS 10.6.

The 1972 image was digitised for qualitative examination of very long-term change bank lines and char lands. After that, the most recent image accessible as a base map in ESRI's ArcGIS software was compared.

3. Results

3.1 Dynamics of river width

River width is an important morphological feature that determines the extent of the river. Figure 4 depicts the variations in river width over time and space in all of the branches that converge at the confluence.

Figure 3 depicts the morphological instability of the river, which demonstrates how the breadth of the river fluctuates over time. During this time, Padma's range of variation between maximum and minimum breadth had widened substantially. Jamuna's average width stayed constant from 1990 to 2010, however from 2010 to 2015, it was expanded to 1 kilometre. Throughout the research period, Ganges' maximum and lowest width ranges are very consistent.

The average, maximum, and minimum widths for the Ganges and Padma parts follow a similar trend, as seen in Fig 3. In the case of the Jamuna River, however, no such tendency was seen. Figure 4 depicts the spatial pattern of this shift, which shows that the variance in width change as a function of Padma's distance follows a similar pattern in different years. The Ganges and the Jamuna, on the other hand, do not follow any pattern. The breadth of the Jamuna is rising in the downstream direction. The greatest reduction in width was found along the Ganges part of the confluence at the chainage 0 km stretch at Kushtia Sadar, where the breadth fell by about 3 km between 1995 and 2010. Similarly, between the 1990s and 2000s, the largest width change on the Jamuna stretch was seen at a chainage 12 km portion near Delduar. During this time, the breadth of this stretch narrowed by about 8 kilometres. In the instance of the Padma stretch, the river's breadth rose by roughly 10 kilometres in the part near Faridpur, when the chainage was 24 kilometres.

3.2 Bar Movement & sinuosity:

Extremely dynamic The Ganges-Jamuna confluence shows the net effect of these morphodynamic processes in the form of a southern movement of the confluence point from 1972 to the present. The changing tendency and position of the Jamuna River's widest channel altered over this time period. The broadest channel has a propensity to dominate the right bank of the braidplain in the early stage before lateral migration in the later stage. Multi-channel flow was prevalent around big islands that were forested and therefore established. The confluence's meandering Ganges section likewise exhibits a gradual southerly movement, with bars moving into the confluence zone.

During this time span, the sinuosity of the Ganges section fluctuates from 1.03 to 1.1. Between 1972 and 2015, the sinuosity of the Ganges section reduced. The number of bar spaces has grown qualitatively throughout the years.

3.3 Bank line shifting

Table 2 shows the average bank erosion and accretion rates for the left and right banks of the confluence of the Ganges, Jamuna, and Padma at 5-year intervals. Even though it would be ideal to have annual satellite images, this may not always be possible in practise because Landsat images are taken on a 16-day cycle and a clear Landsat image for the study site at a specific time of year may not always be available because the February images may suffer from partial or major cloud cover in the study area in some years.

Table 2: Short term analysis of Mean Erosion & Accretion Rate (Ganges, Jamuna & Padma segment)

	Ganges Segment				Jamuna Segment				Padma Segment			
	Left Bank Shifting (m/yr)		Right Bank Shifting (m/yr)		Left Bank Shifting (m/yr)		Right Bank Shifting (m/yr)		Left Bank Shifting (m/yr)		Right Bank Shifting (m/yr)	
Year	Erosion	Accretion	Erosion	Accretion	Erosion	Accretion	Erosion	Accretion	Erosion	Accretion	Erosion	Accretion
1990-1995	48.58	100.6	105.4	152.16	164.66	244.30	372.46	411.16	281.06	114.51	604.78	145.79
1995-2000	30.56	65.28	190.4	189.4	230.40	115.63	150.61	133.11	268.56	305.72	135.53	157.23
2000-2005	64.85	99.65	82.40	56.56	122.91	263.04	263.14	154.77	182.22	869.83	69.43	171.48
2005-2010	72.36	121.03	60.92	107.30	120.97	63.44	85.27	290.79	140.19	219.54	211.19	270.42
2010-2015	106.6	124.28	89.46	64.96	69.62	114.78	180.99	115.47	279.85	9.85	308.21	9.38

The left bank of the Ganges has a mean short-term erosion rate of 64.5 m/y, whereas the right bank has a rate of 105.2 m/y. The left bank of the Jamuna has a mean short-term erosion rate of 141.23 m/y, whereas the right bank has a rate of 210 m/y. Padma's mean short-term erosion rate is 240.4 m/y on the left bank, and 281.1 m/y on the right bank. The mean accretion rates for the Ganges, Jamuna, and Padma rivers on the left bank are 115.4 m/y, 239.1 m/y, and 303.2 m/y, respectively, whereas the right banks are 133.6 m/y, 220.6 m/y, and 152.2 m/y. Between 2005 and 2010, the Ganges had maximum erosion of 297.2 m/y and maximum accretion of 473.9 m/yr (1995-2000). The highest erosion and accretion rates on the right bank of the Ganges are 664.544 m/yr (1995-2000) and 445.4 m/yr (2005-2010), respectively. The highest erosion and accretion rates on the left bank of the Jamuna are 652.6807 m/yr (1995-2000) and 969.2 m/yr (1990-1995), respectively. The highest erosion and accretion rates on the right bank of the Jamuna are 815 m/yr (2000-2005) and 782.9 m/yr (1990-1995), respectively. The highest erosion and accretion rates on the left bank of the Padma are 781 m/yr (1990-1995) and 1756 m/yr (2000-2005), respectively. The highest erosion and accretion rates on the right bank of the Padma are 1118 m/yr (1990-1995) and 727 m/yr (2005-2010), respectively. Table 2 demonstrates that erosion has grown along the left bank of the Ganges portion throughout the research period, but erosion has decreased along the left bank of the Padma section till 2010. In compared to the preceding five years, erosion rose by over 100% from 2010 to 2015. During the research period, erosion on the left bank of the Jamuna has decreased. The right banks of the Ganges, Jamuna, and Padma segments, on the other hand, have seen a very uneven erosional pattern.

The Padma segment's left bank has the most erratic accretion propensity. In comparison to the preceding five years, the accretion tendency increased nearly thrice between 2000 and 2005. However, Padma section showed a relatively low mean accretion of 9.85 m/yr during the previous 5 years of study. Between 2005 and 2010, accretion on the left bank of the Jamuna fell dramatically. Throughout the study period, the left bank of the Ganges exhibits an almost consistent rate of accretion. However, no regular pattern of accretion was seen on the right bank of any segments.

The right bank of the Ganges is very unstable and shows continuous movement throughout the confluence zone, as illustrated in Figure 6 from a short term examination of the Ganges part of the confluence region. However, channel shifting may be seen in the upstream area of the confluence zone on the left bank of the Ganges. The left bank of the Ganges remained relatively steady around the site of confluence.

Jamuna's short-term alterations are depicted in Figure 7. The upstream portion of the confluence zone is more mobile than the zone at the site of confluence in the event of left bank movement, as seen in the diagram. The right bank of the Jamuna River follows a similar pattern.

Data from the Padma section during a 5-year period reveals that the downstream portion of the right bank is unstable, with irregular movement, but the area near the confluence is less mobile. The left bank of the Padma, on the other hand, is relatively stable near the confluence, but the downstream part has a larger changing propensity, as seen in Figure 8.

For the Ganges, Padma, and Jamuna portions, long-term changes in the confluence region are also examined. This study gives a clear picture of these rivers' changing tendencies. Figure 9 clearly indicates that, with the exception of the yatra, the main pattern of the left bank of the Ganges is one of deposition throughout the year 1990-2005.

The rate of deposition, on the other hand, has steadily reduced over time. The standard deviation of erosion has remained relatively consistent, implying homogeneous erosion in all portions of the confluence zone along the Ganges. However, between 1990 and 2000, the standard deviation for deposition instances was greater, which might indicate a lack of uniformity in deposition along the sections. Deposition occurred on the right bank of the Ganges between 1990 and 2000, however the bank quickly became prone to erosion and has continued to do so in recent years.

In the long term, the mean erosion and deposition tendency in the left bank of the Jamuna has stayed comparable, although there has been a depositional trend in recent years, as seen in Figure 10. On the other hand, In the long run, the right bank of the Jamuna is exhibiting erosional characteristics.

Figure 11 reveals that Long Term bank shifting trend has showed mostly erosional tendency in both the banks of Padma.

It can be seen from the Figure 12 that during the five year span from 1990 to 1995 the confluence zone showed erosional tendency in the lower portion of Jamuna at Shivalaya. Areas like Dohar, During this time, Charbhadrashan, Rajbari sadar, and Pabna sadar all experienced significant erosion. With the exception of the Dohar region, this erosional trend continued for the following five years. During this time, Dohar did not experience any severe erosion. As illustrated in Figure 13, the erosional tendency on the right banks of the Jamuna and Padma Rivers was less severe from 2000 to 2010. During this time, the right bank of the Padma River saw considerable accretion. However, the riverbanks of the Padma River in Dohar have been severely eroded in recent years. The erosional tendency can be ascribed to the creation of sand bars in rivers; as a result, flow is directed towards the rivers' banks, producing erosion. Table 3 summarises the findings of the study.

Table 3: Short & Long term analysis of Erosion & Acretion in terms of area

Short Term			Long Term		
Year	Erosion (sq km)	Deposition (sq km)	Year	Erosion (sq km)	Deposition (sq km)
1990-1995	269.19	174.16	1990-1995	269.19	174.16
1995-2000	194.09	126.72	1990-2000	376.33	214.43
2000-2005	172.03	110.92	1990-2005	409.85	212.17
2005-2010	109.67	173.61	1990-2010	370.53	239.66
2010-2015	201.23	38.05	1990-2015	487.89	173.28

Table 3 shows that during the course of 25 years, the confluence zone lost 487.89 sq km of area while gaining just 173.28 sq km. It can also be noted that erosional tendency has been on the decline in the short term between 1990 and 2010. However, between 2010 and 2015, the degraded area nearly doubled in contrast to the previous five years. Meanwhile, there is no discernible pattern in the deposition tendency.

4. Discussion

For investigating the bankline movement of the Ganga-Jamuna River, the accuracy of the coarser resolution Landsat-MSS (80 m) data should be lower than the higher resolution Landsat TM and OLI (30

m) data. Several studies have reported on the effective use of density slicing of Landsat-OLI, TM, or MSS data to define water bodies, although without comparing the two types of Landsat data quantitatively. According to Mohajane et al. (2018), TM and OLI digital data are generally more helpful than MSS data in mapping homogenous, near-urban land covers, but they may be less effective in mapping heterogeneous urban areas than MSS data. In other words, TM data may not necessarily be more valuable than MSS data, according to Mohajane et al. (2018). There have also been successful investigations of MSS data-based multi-spectral classifications of water borders (Bhaskaran et al. 2010).

Ganga-Jamuna's mean channel width is around 11 km, which is significantly larger than the resolution of Landsat satellite data, particularly Landsat-TM and OLI. The radiometric values of pixels depicting river banks and water regions ought to be sufficiently homogenous, and the investigation must be suitable for detecting Ganga-Jamuna backline movement. This is due in part to the fact that the Ganga-Jamuna is a very active river, and the shift in the bankline between certain processed Landsat photos should be apparent. The accuracy of identifying differences between two pictures might be somewhere between the resolution of the satellite data, such as between 30 and 80 m, or better.

The erosion and accretion rates vary considerably throughout the river, and they appear to be impacted by the river's meandering feature and flow direction, according to early analyses of overlay maps of bank movement and bank movement as a function of distance during 1990–2015. The magnitude of accretion on the left bank has typically been greater than the magnitude of erosion on the right bank, and their rates have only slightly changed from 1990 to 2015, as predicted. Between 1990 and 2015, the left bank had more accretion than erosion, resulting in lower net movement rates than the right bank, which is in line with earlier research by Sarif et al. (2021).

The mean erosion and accretion rates estimated from the short-term analysis, where the migration rate is determined based on short-term changes between six accessible consecutive pictures, are 227 and 271 m/y on the left bank and 187 and 148 m/y on the right bank. In contrast, for the long-term analysis, the average erosion and accretion rates are 90 and 104 m/y on the left bank, 75 and 50 m/y on the right bank, respectively, which are identical with the work of Pal and Pani (2019) and Sarif et al. (2021). The right bank experienced more severe erosion, resulting in a quicker migration rate than the left bank, which experienced both erosion and accretion, resulting in relatively modest net movement rates (Sarif et al., 2021). The Ganga-Jamuna River's average short and long-term migration findings show a particularly dynamic form of erosion and accretion processes that contribute to channel shifting, as seen by its high short-term range of erosion and accretion rates. Because, Klaassen and Masselink (1992) found that bank erosion in curved channels occurred at rates ranging from 0 to 500 m/y, with a maximum of around 1000 m/y, and that it occurred mostly at 90 degrees to the major flow direction (in the eastewest direction). However, between 1990 and 2015, the right bank's declining erosion and accretion patterns were more constant than the left bank's.

The rivers are constantly transferring water and sediment loads downstream. The Ganga, like other tropical rivers, has certain distinctive fluvio-geomorphological features. Because more than 80% of yearly flow passes during the monsoon months, the hydrograph of the Ganga as measured and depicted is significantly skewed. In September 1998, the maximum peak discharge at Farakka was around 76456 m3/s (Rudra, 2010). The lean season discharge drops to less than 1557 m3/s, prompting tensions between India and Bangladesh over water sharing (Rudra, 2010). Many scientists have calculated the amount of suspended silt transported by the river each year. Rudra claims it to be 736 million tonnes (2010). Explaining the sediment budget of the Ganga–Brahmaputra system, Wasson (2003) determined that Himalayan tributaries provide more than 90% of the sediment load in the Ganga, whereas peninsular tributaries contribute less than 10%. Human interaction in the fluvial regime disrupts dynamic equilibrium, and altering course processes are either slowed or hastened. Therefore, the long-term migration rate for both banks is lower than the short-term counterpart, owing to human interventions such as the development of bank protective mechanisms (Rudra, 2014). Human interventions on the Ganga-Jamuna River over the last 50 years have included: (1) On April 21, 1975, a large barrage at Farakka was opened. It is near the point where the river's main flow reaches Bangladesh, while the tributary Hooghly (also named as Bhagirathi) flows through West Bengal towards Kolkata. (2) Kanpur has the Lav Khush Barrage over the Ganges River, and (3) Tehri Dam was built on the Bhagirathi River, a tributary of the Ganges. It's 1.5 kilometres downstream of Ganesh Prayag, where Bhilangana and Bhagirathi converge. After Devprayag, Bhagirathi was renamed Ganges, and Bansagar Dam was constructed on the Sone River, a tributary of the Ganges, for irrigation and hydropower, (5) the construction of a number of bank protection structures since the early 1960s, such as the Sirajganj town protection work, which began during the British period and was strengthened in 1964 with brick mattressing, which was washed away in 1969; (6) In 1994–1998, the Jamuna Bridge Guide Bund (3.2 km on both banks) and Bhuapur Hard Point (5 km upstream of the Jamuna Bridge) were built. (7) In 1996–1998, the Sirajganj Hard Point, which included the groyne with the revetment, was built as part of the River Bank Protection Project (RBPP). (8) Under the FAP 21/22 programme, revetment test structures at Bahadurabad and Ghutail, as well as a groyne test structure at Kamarjani, were erected in 1996–1997; and (9) the BWDB sponsored Kalitola and Sailabari Groynes were built in 1980 and 1978, respectively.

The variation in river width between 1990 and 2015 is analogous to that reported by Gupta et al. (2013) and Gupta (2012), who found that the river widened from 1990 to 2015 but then stayed constant. The breadth of a river will often expand under the impact of erosion and shrink under the effect of accretion if the discharge rate does not change significantly. However, assuming that both the sediment load and the discharge rate stay constant, a common morphological feature of rivers is that as river width grows, erosion rates should decrease since river flow velocity decreases, and vice versa. In the same way, as a river narrows, the rate of accretion should accelerate.

For the short-term study, changes in the right (left) bank's erosion (accretion) rate follow the general morphological pattern of river bank migration, but not so for the right (left) bank's accretion (erosion) rate. When the left (right) bank undergoes accretion (erosion), the basic morphological characteristic of river movement appears to apply, but not when the left (right) bank undergoes erosion (accretion). Only the right bank erosion rate and the left bank accretion rate obey this concept, owing to complexities created by the intricate interactions of both erosion and accretion processes, as well as the Jamuna River's meandering characteristic ((Bomer et al., 2020).

For the long-term analysis, the observed erosion rate for the right bank and accretion rate for the left partly follow the general morphological principle of river migration, i.e., as a river widens, erosion rates generally decrease because the velocity of river flow decreases, and vice versa, assuming that both the sediment load and the discharge rate remain roughly unchanged. Because of its braided, meandering, or anastomosing characteristics, the Jamuna River has problems (for example, unanticipated shifts in bank erosion or accretion may occur) (Sarker et al., 2014; Best et al., 2007; Richardson and Thorne, 2001).

Instead of island migration, due to the shifting of sediment loads produced by each flood, some islands may vanish or new islands may develop after a flood. According to Sarker et al. (2014), about 68 percent of the islands are under the age of six years, or have lasted between one and six years. According to a frequency analysis of changes in the number of islands in relation to their size in hectares (ha) within the Jamuna River, islands larger than 150 ha are clearly more stable (fewer temporal changes in size, shape, and location) than small islands smaller than 50 ha, which tend to be very unstable and subject to fairly major changes as observed in this 1990–2015 study period.

5. Conclusion

From the analysis, it can be seen that the Ganges-Jamuna confluence has undergone significant changes over the past few decades. In this paper, these changes are quantified in terms of river width change, bank line shifting & area of erosion or deposition. It is noted that the maximum width of the Ganges section is 4078.10 m, observed during the year 1995. Similarly, the maximum width of the Jamuna & Padma section was 13925 m & 22479.88 m consecutively observed during the year 2015. The maximum bank line shifting in the left bank of the Ganges segment is 473.92 m/yr observed near Pabna Sadar at chainage 16 km during 1995–2000. Likewise, the maximum bank line shifting in the right bank of the Ganges segment is 394.83m/yr observed near Kumarkhali at chainage 4 km during 2005–2010. In the case of the Jamuna segment, the maximum left bank line shifting is 959.30 m/yr observed near Tangail at chainage 8 km during 1990–1995. Similarly, maximum right bank line shifting is 975.12 m/yr observed at chainage 36 km during 1990–1995. The Padma segment also shows significant migration with a maximum left bank shifting of 1756 m/yr being observed at chainage 48 km near Dohar during 2000–2005. The maximum right bank shifting of the Padma segment is 1502.99 m/yr being noted at chainage 44 km near Sadarpur during 1990–1995. In terms of area, the confluence zone is losing land at an alarming rate. It is observed that, confluence zone has lost 201.23 sq km. of land during 2010–2015; in the same period, the zone has gained only 38.05 sq km. area. This means a net decrease of 163.18 sq km took place during the last 5 years. This may occur due to the various anthropogenic activities in this region.

Huge sediment deposition boosts attached bar and island bar, where agricultural farmland, plant cover, and population agglomeration grew, according to this research paper. Due to repeated morphological changes, socioeconomic condition has deteriorated. Several built barrages and dams are thought to be a key source of morphological changes in the river's downstream. This structural structure alters river morphology by introducing island bars, connected bars, multichannel, increased sedimentation, and a reduction in water discharge flow velocity. The agriculture system and river aquatic ecology are greatly influenced by various morphological characteristics generated by morphological changes. In addition to the study areas, there are some policy implications and management strategies. Any unplanned artificial constructions, like dams and bridges, can have a negative influence on flow velocity and direction, causing massive sedimentation, bank-line shifting, and bank narrowing, among other things. To reduce climatic impacts, the government and other nonprofit organizations should focus on minimizing the vulnerability of multiple fluvial hazards by stabilizing their banks through numerous restoration mechanisms such as riparian buffer zones, embankment flood protection systems, waste dumping processes, and toxic materials.

Declarations

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Figures

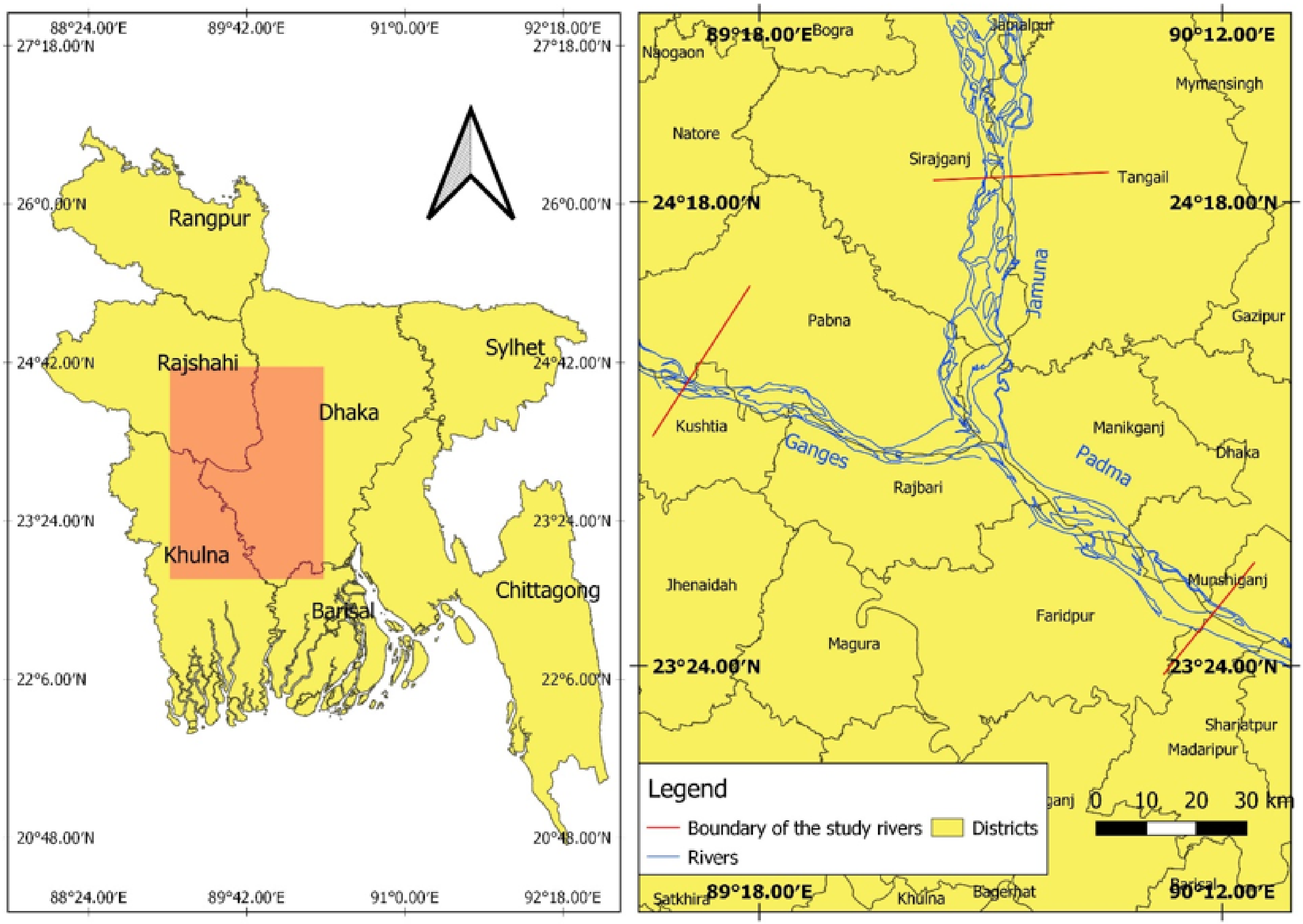

Figure 1

Study Area – Ganges-Jamuna Confluence

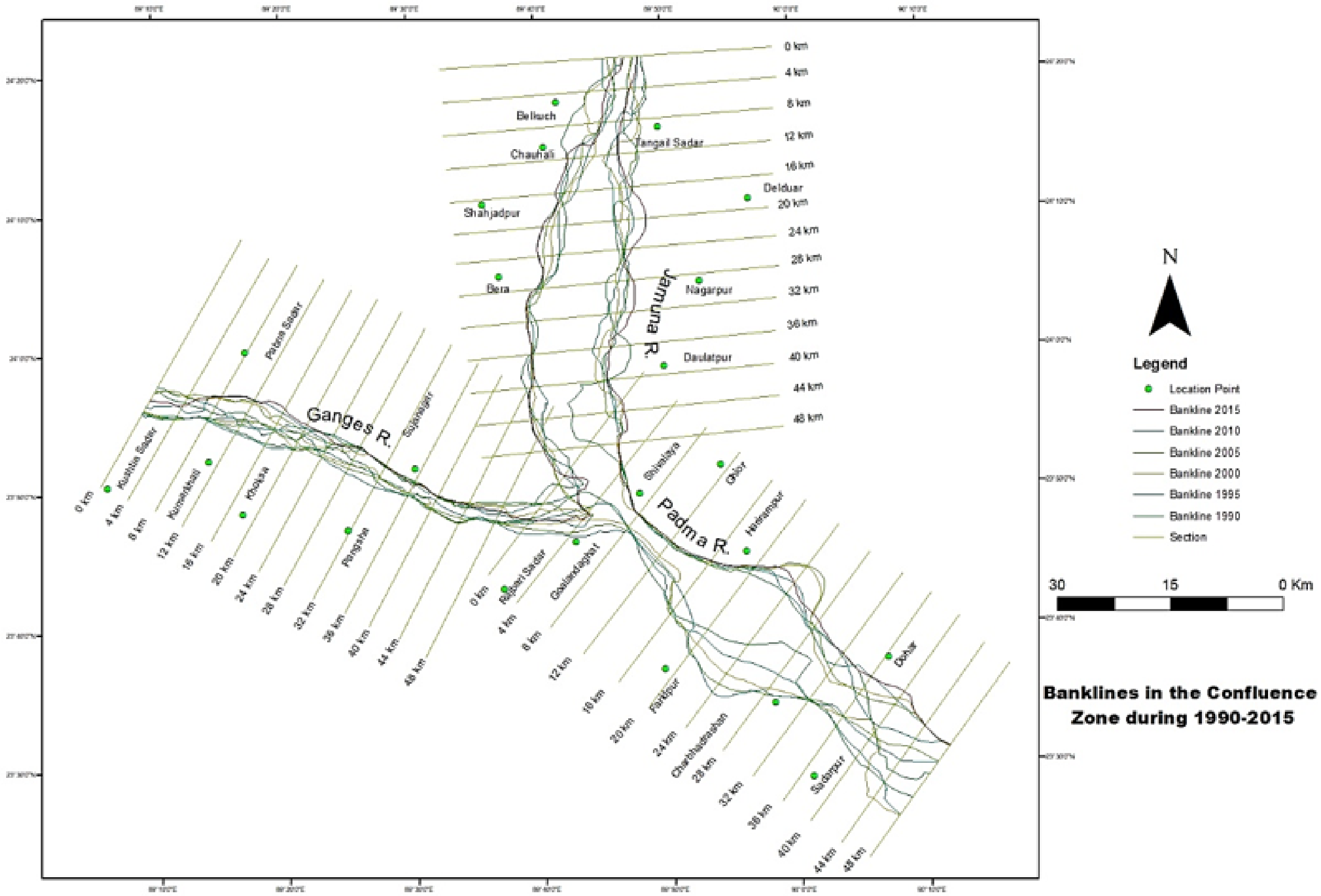

Figure 2

Sections taken for analysis along Ganges-Jamuna Confluence

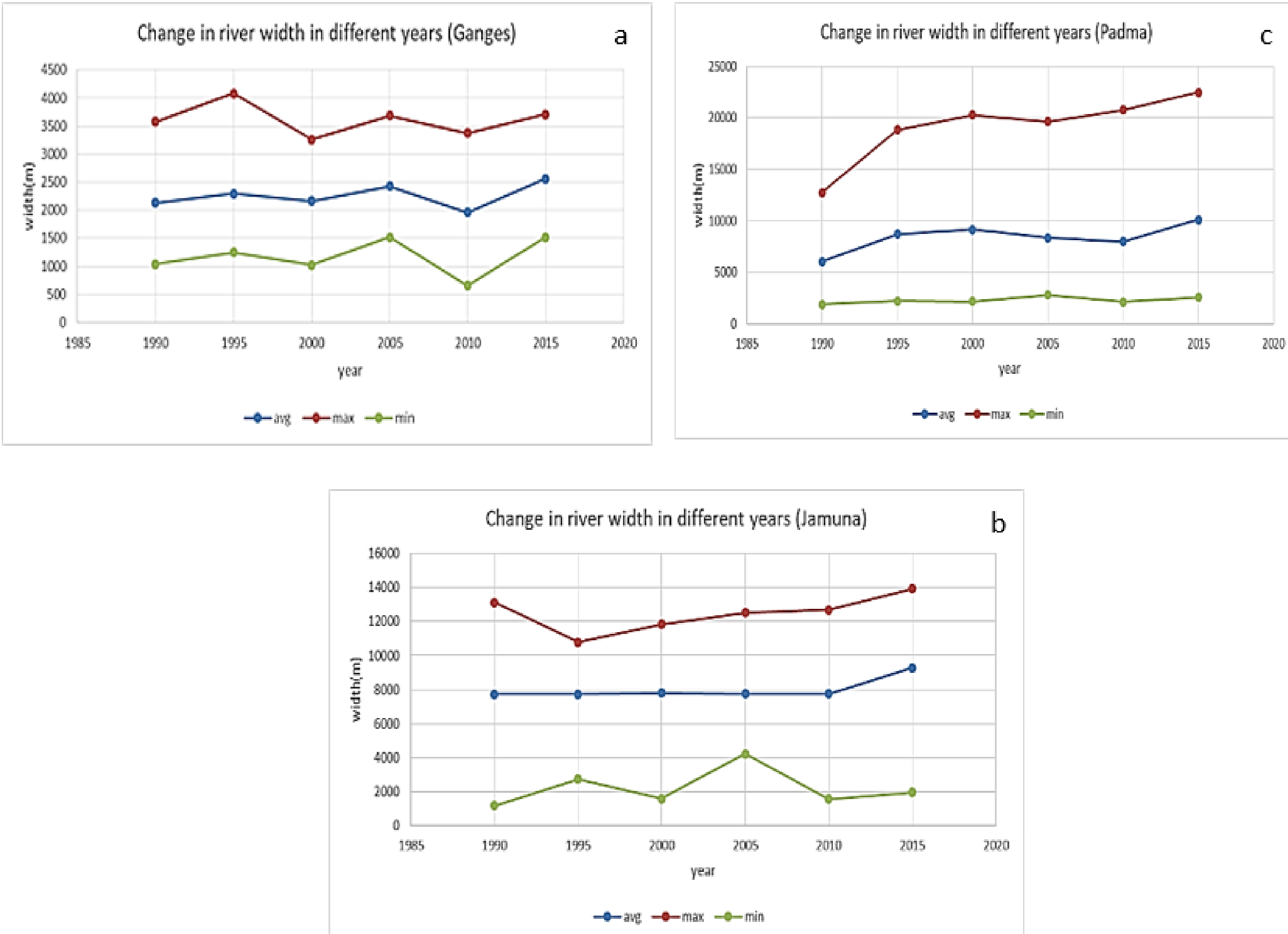

Figure 3

Changes in river width from 1990-2015 (a) Ganges (b) Jamuna and (c) Padma

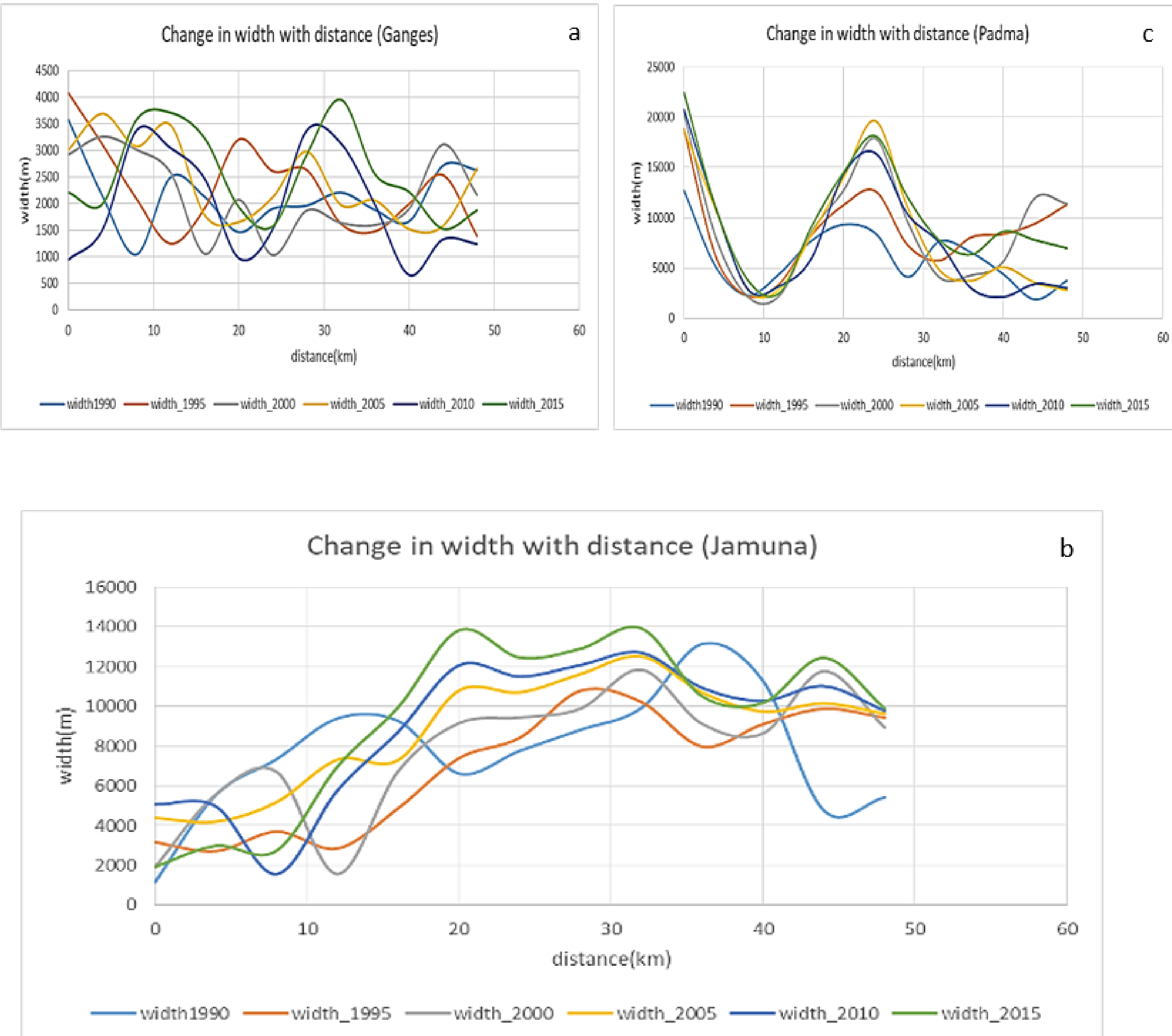

Figure 4

Variation of River width according to distance from 1990-2015 (a) Ganges (b) Jamuna and (c) Padma

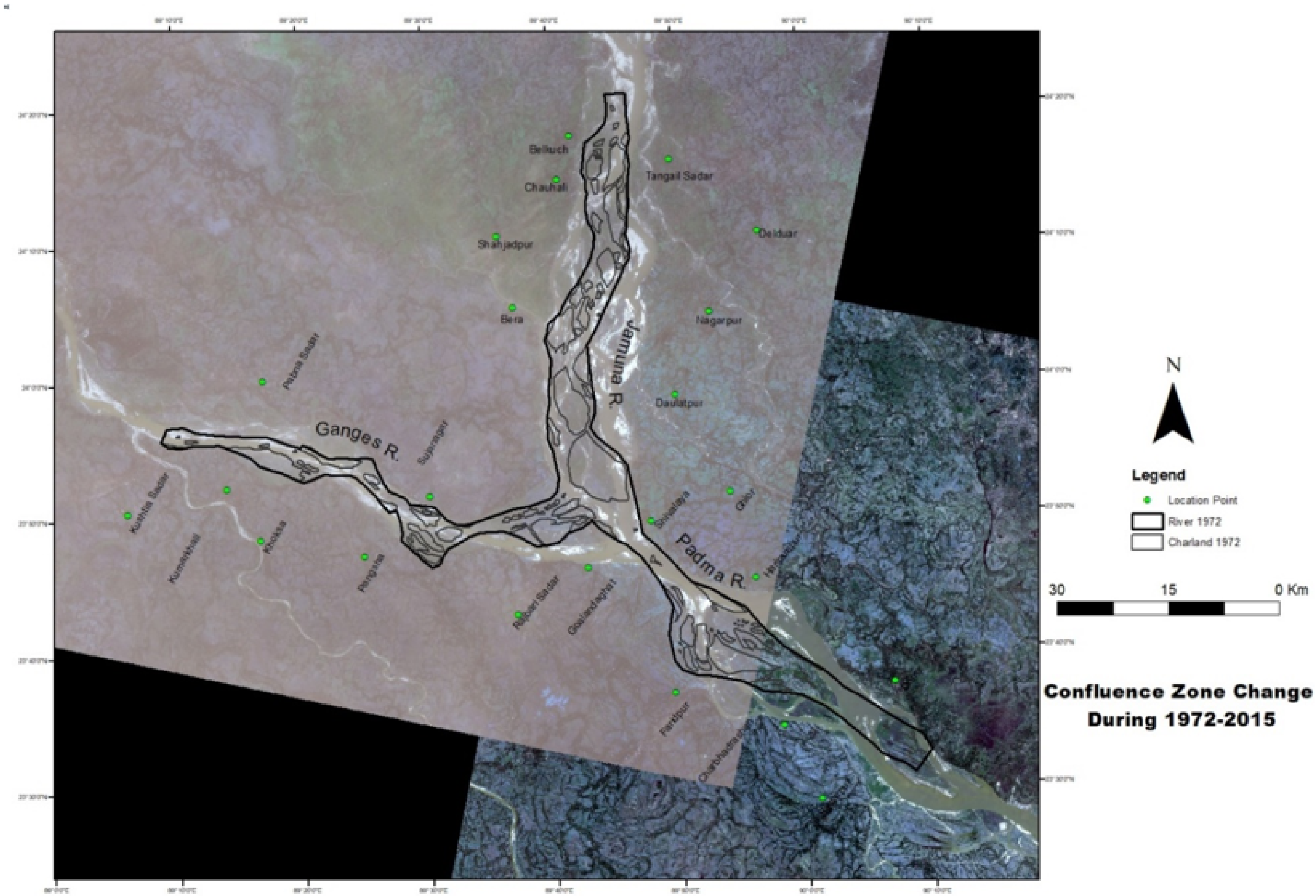

Figure 5

Evolution of Ganges Jamuna confluence from 1972 to 2015

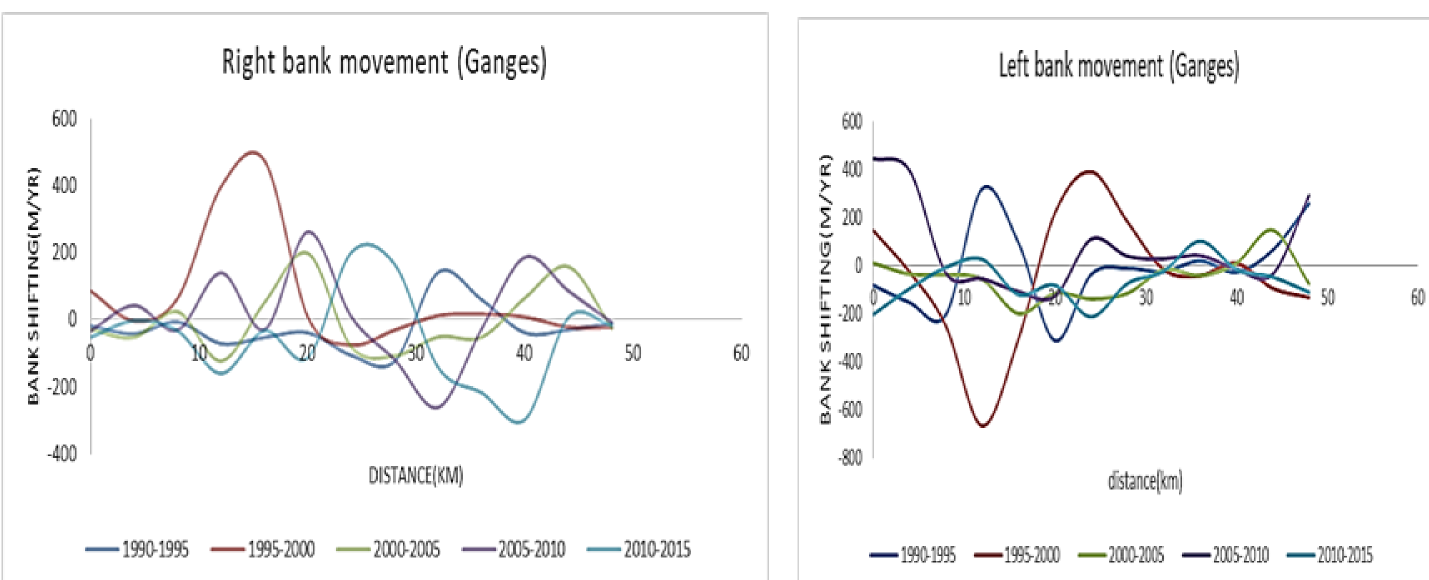

Figure 6

Bank movement of left & right banks of Ganges Section in the Confluence region

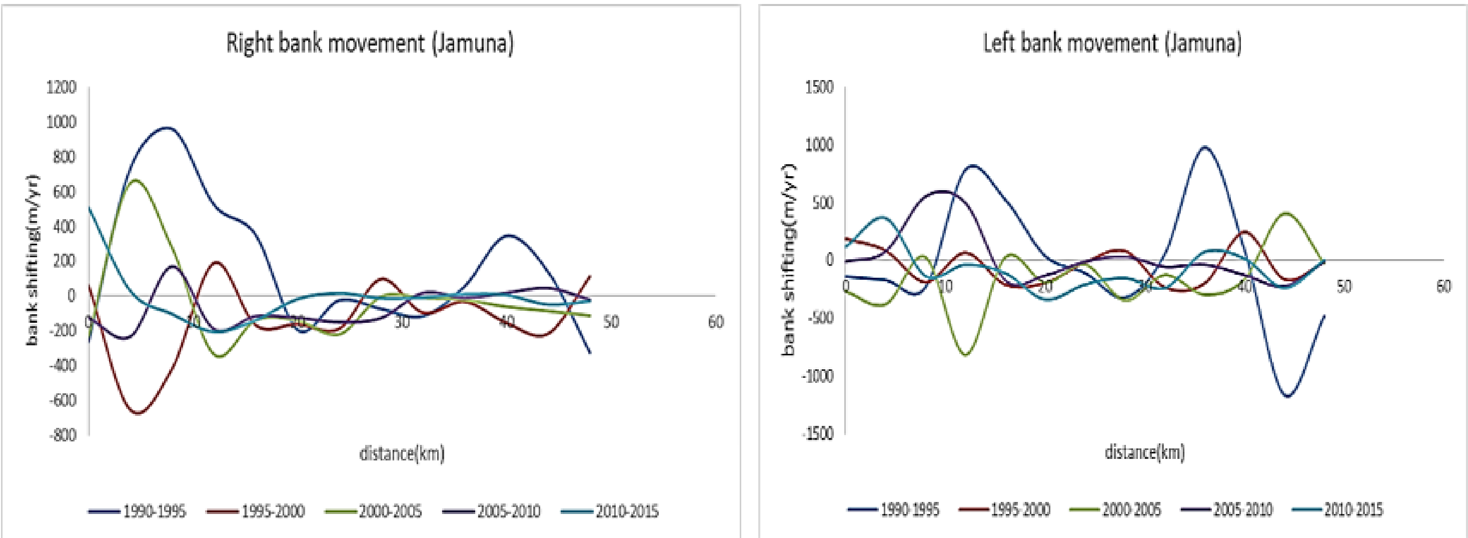

Figure 7

Bank movement of left & right banks of Jamuna Section in the Confluence region

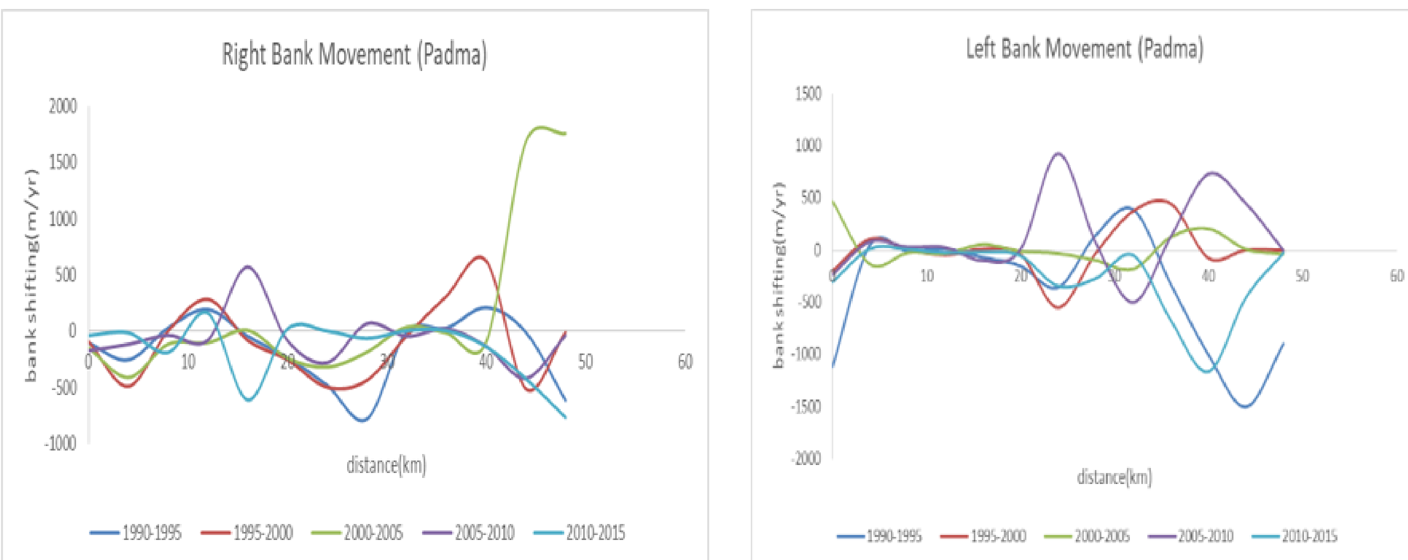

Figure 8

Bank movement of left & right banks of Padma Section in the Confluence region

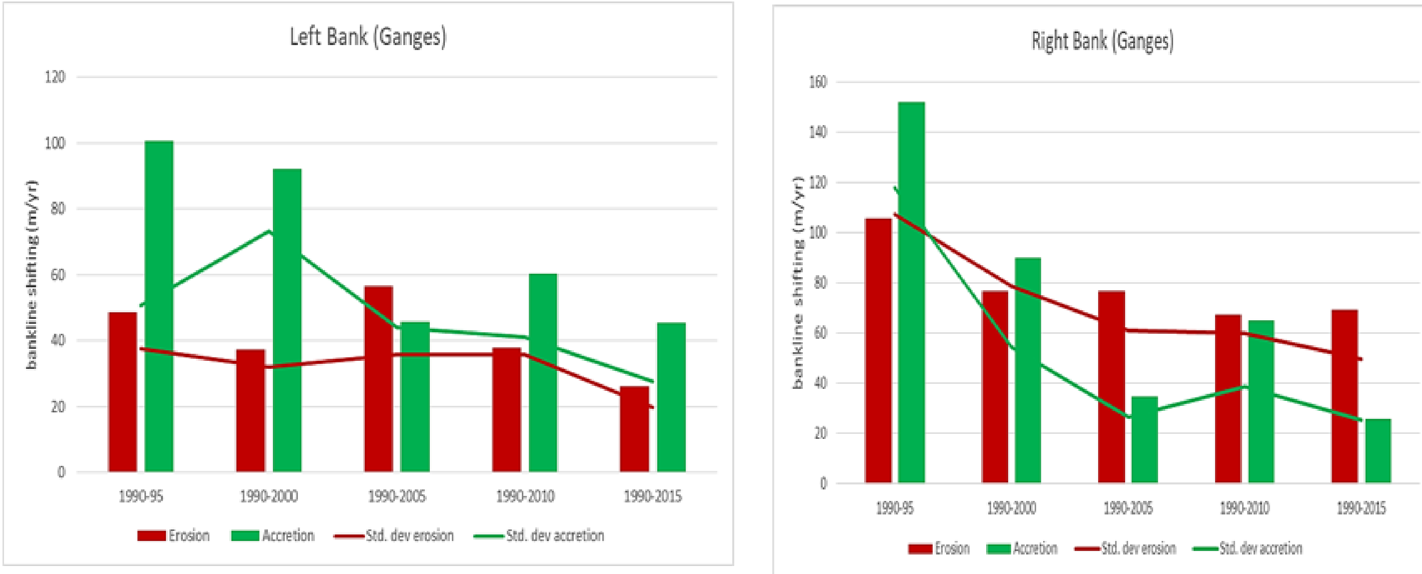

Figure 9

Long term changes to erosion and accretion rates along the left and right banks of the Ganges, (1990-2015)

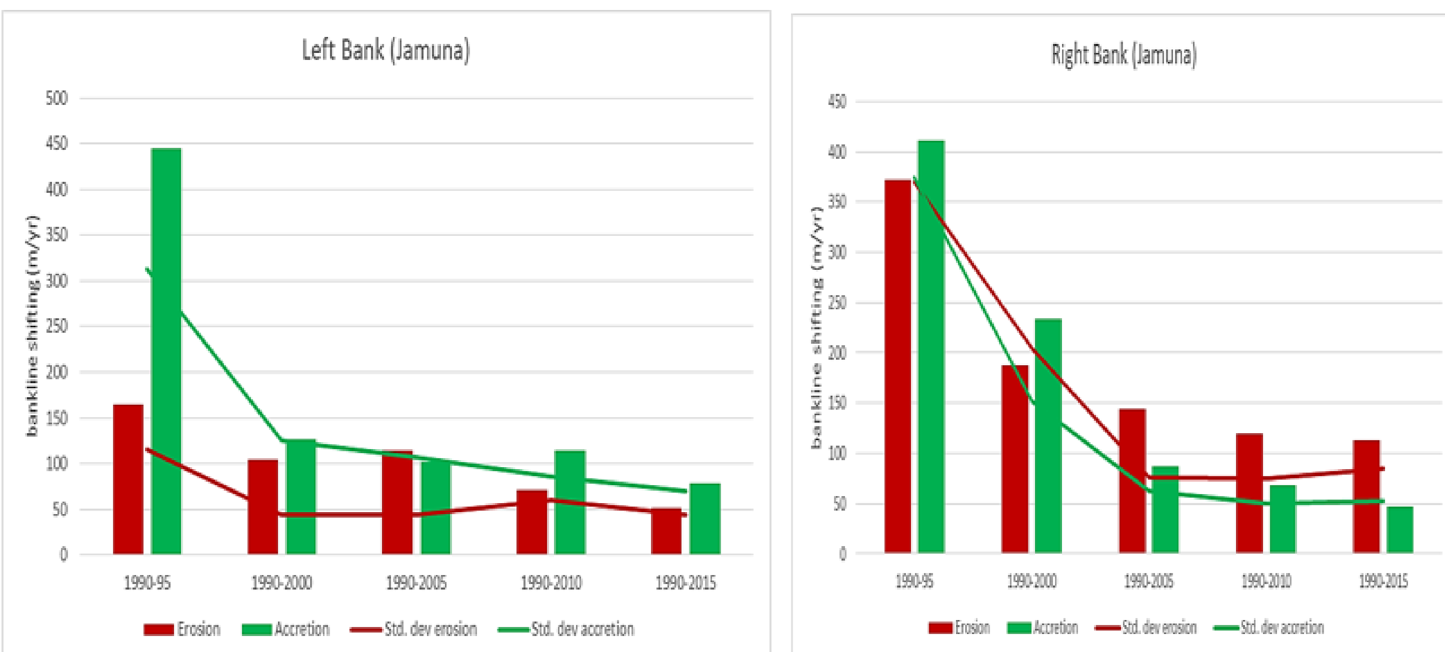

Figure 10

Long term changes to erosion and accretion rates along the left and right banks of the Jamuna, (1990-2015)

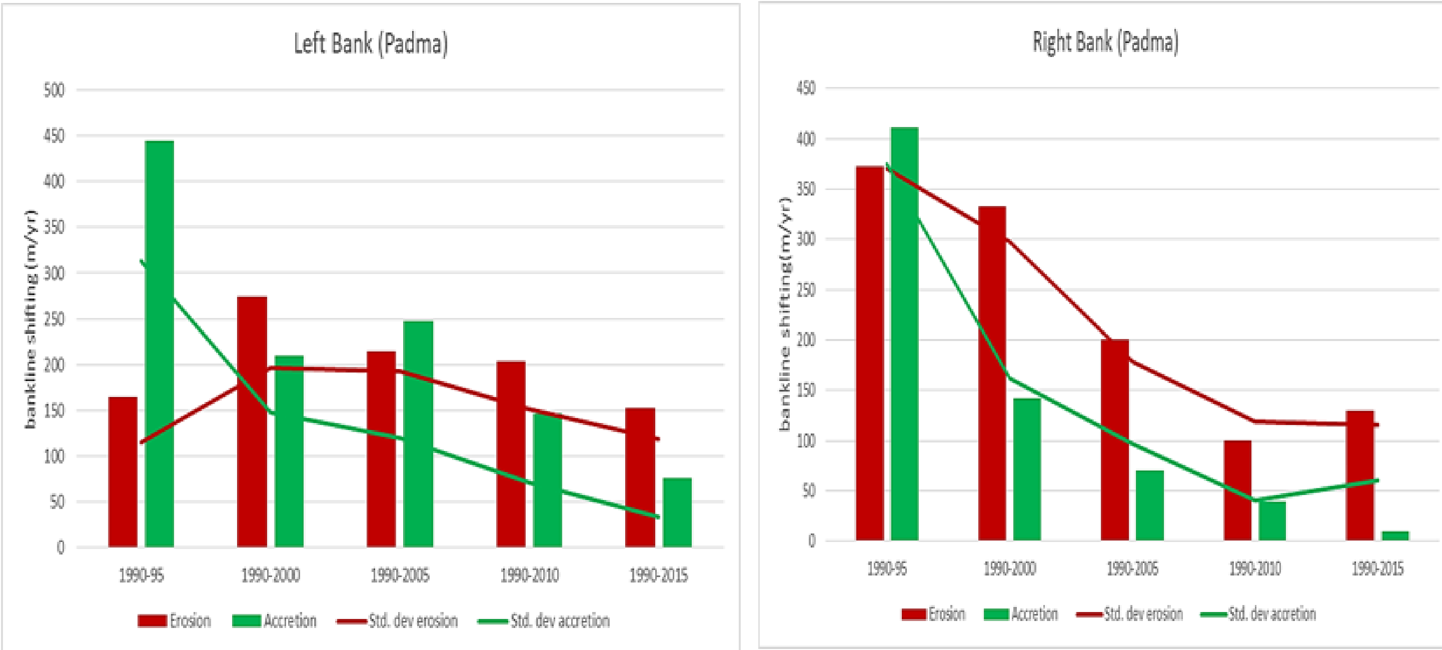

Figure 11

Long term changes to erosion and accretion rates along the left and right banks of the Padma, (1990-2015)

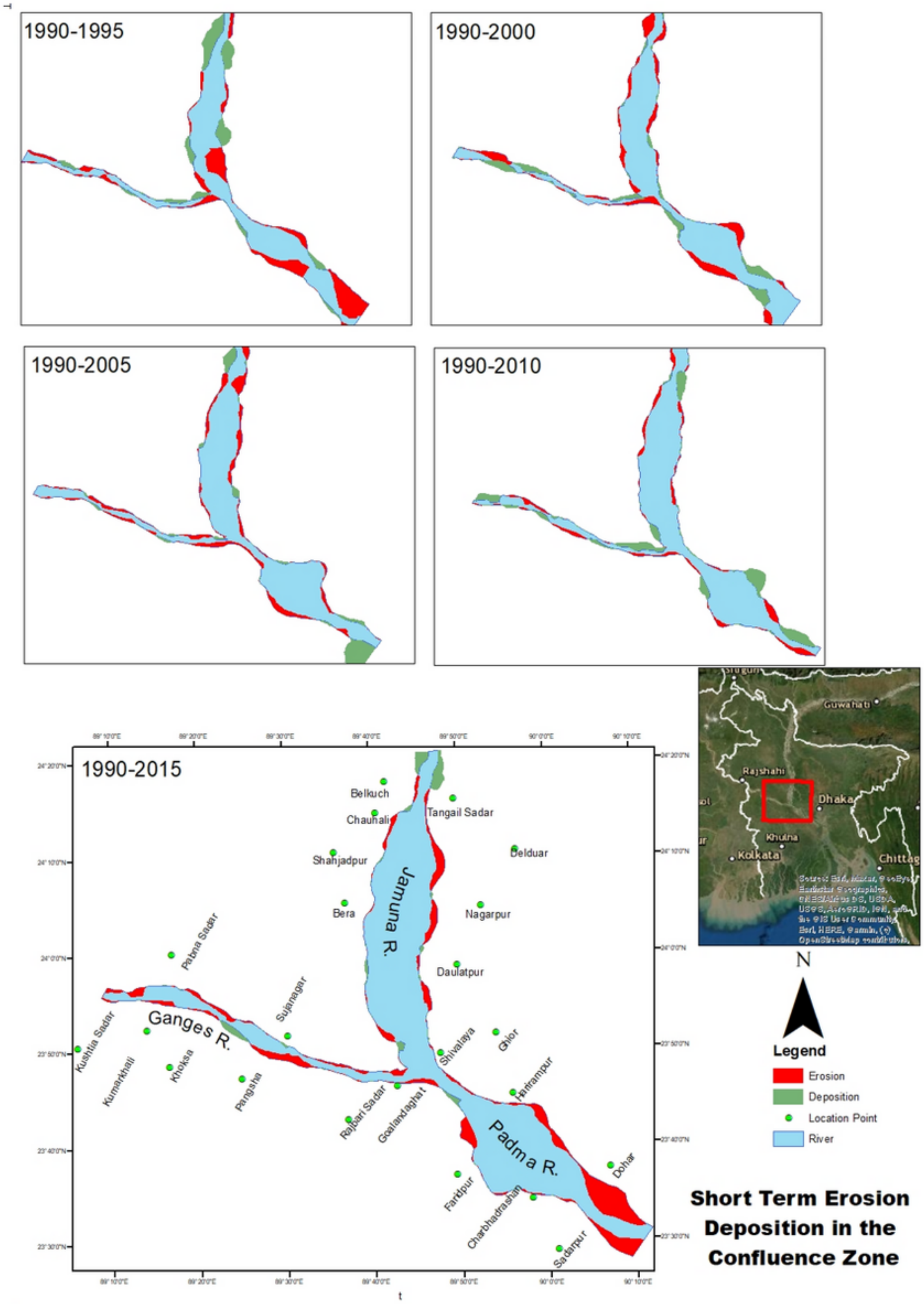

Figure 12

Short Term Erosion & Deposition in the Ganges Jamuna Confluence zone

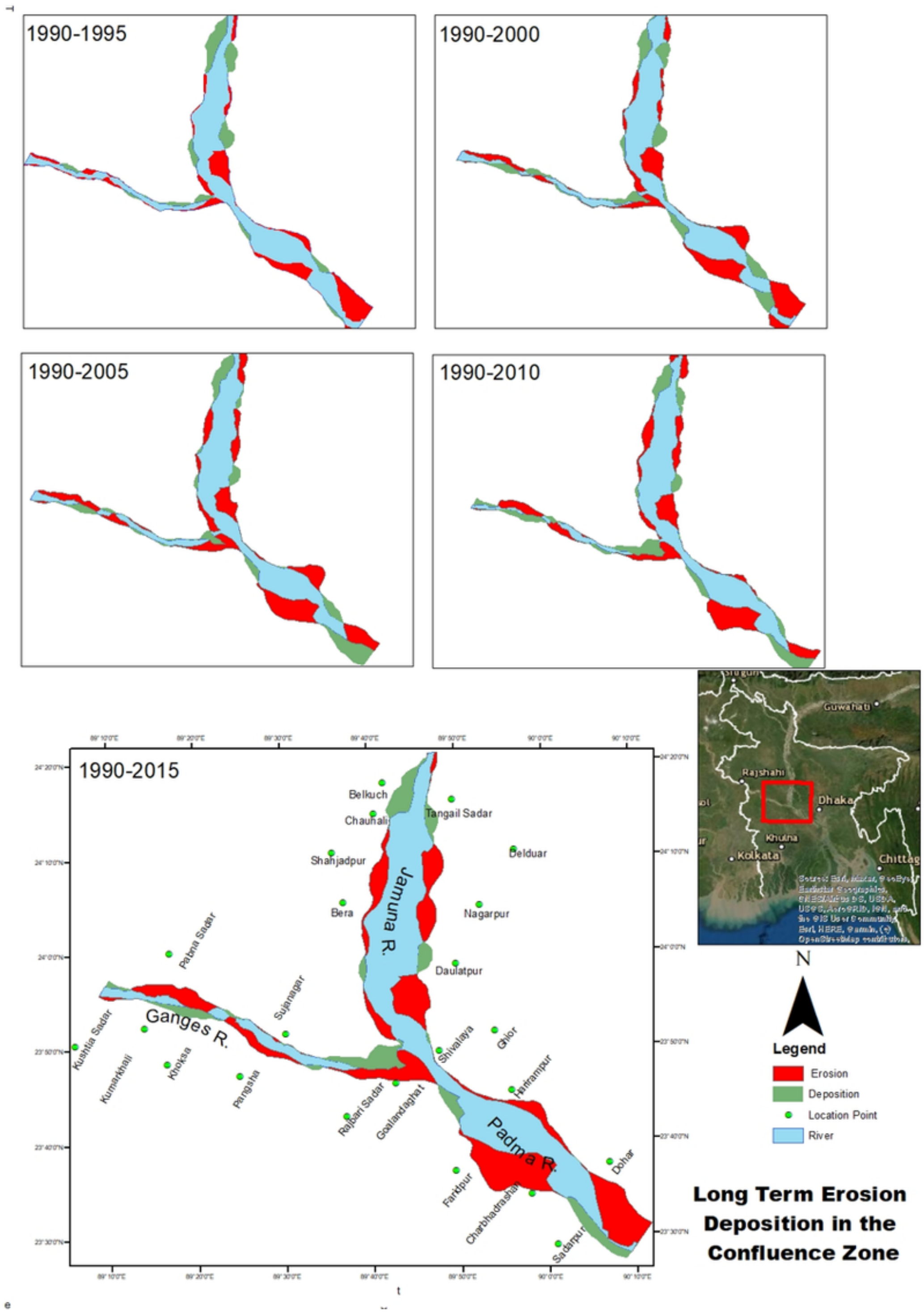

Figure 13

Long Term Erosion & Deposition in the Ganges Jamuna Confluence zone