

Changing Pattern of the Downstream of Ganges River Course: A Comparison with Rennell's Map of 1760s

Nusrat Jahan Ety*, Dr. Md. Shahedur Rashid**

* Postgraduate Research Student, Department of Geography and Environment, Jahangirnagar University; e-mail:

nusratjahanety40.geo@gmail.com

** Professor, Department of Geography and Environment, Jahangirnagar University; e-mail: *m.s.rashid@gmail.com*

Abstract- Bangladesh is a land of rivers. Flood and bank erosion since pre historic period had become one of the major aspects of discussion for its direct interaction with physical and socio-cultural environment. As we know regular variation is exposed by this river from upstream to downstream at different reaches in the Ganges River. Ganges River is considered as a frequent bankline migrant and unstable river of the country. This research intends to identify the shifting pattern of the Ganges River courses accordingly using Rennell map in 1760s and Landsat Imageries (MSS-1975; TM-1995, and ETM+ 2015). As Landsat TM band 4 (0.76 - 0.90 μm) is suitable for land-water interfaces separation the Ganges river basin and have been delineated the land and water classification using this band. The size, shape and direction of Ganges River gradually changed over more than 250 years. For that required processing of images like Layer stack, Image Enhancement, Mosaic, Subset Re-Sample and Re-projection changes were done by image processing software ERDAS imagine 2014. To analysis the historical river course shifting of Ganges river on the basis of Rennell's map in 1760s and Landsat imageries have been used various tools of ArcGIS 10.1 and Microsoft Excel 2010 likes georeferencing, digitizing, projection transformation, calculate geometry, layout, pivot table etc. The maximum channel width was 8.2 km in 2015 and minimum channel width was 0.9 km in 1975 in study area. Maximum channel shifted from 1760s to 1975 at the cross section 6 that was shifted in right bank 11014 m and left bank was 14772 m. Minimum channel shifted from 1975 to 1995 at the cross section 5 that was shifted in right bank 610 m and left bank was 61 m. The overall bankline shifted from south to north-eastward. Maximum channel width increased in 2015. Channel width increase day by day. In 1760s Rennell's map, there was no River called as Jamuna which is produced due to Earthquake in 1787 at confluence point of Ganges River that caused dramatically shifting of the channel of old Brahmaputra and as a result, Jamuna spreaded

across the wide area that affected comprehensive changes in physical and human aspects.

Key words: *Rennell's Atlas, Landsat Imageries, ETM+, Ganges River, Bankline, Channel Shifting, Confluence Point, Physical and Human Aspects, Bangladesh.*

1 Introduction

Bangladesh is a land of rivers. More than 700 rivers, with their tributaries and distributaries have criss-crossed the country forming a network of river system (Islam and Rashid, 2011). The Ganges river (Bangladesh part) carries the major flow south-eastward along Indo-Bangladesh border. It continues to flow for about 132 km eastward through Bangladesh and ultimately joins the Brahmaputra or Jamuna. Then it flows for 115 km south-eastward to receive the Meghna further downstream and ultimately discharges into the Bay of Bengal (Rudra, 2014). Its maximum depth is 1,571 feet (479 m) and average depth is 968 feet (295 m) (Wikipedia, 2016). Evaluation of riverbeds increases because of continuous channel fill deposition and responsible for anabranching channel. Main causes are the low water flow. However, comparison of the maps indicates that during the intervening period the river had been consistently migrating northward. Analysis of historical evidence and lithological information (CEGIS, 2004 and Nippon, 2005) shows that materials forming the left bank of the Padma River consist of relatively cohesive and consolidated sediment. Hence, northward migration of the river involves erosion of these sediments at many locations. This is partly due to restraining effects of outcrops of erosion resistant bank materials along the left bank (IRIN, 2008). Regular variation is exposed by this river from upstream to downstream at different reaches in

the Padma River. Padma River is considered as a frequent bankline migrant and unstable river of the country. The rivers also cause of massive suffering to people of Bangladesh. River bank erosion is a serious hazard that directly or indirectly causes the suffering of about one million people annually (Elahi, 1991). A large number of people living in both rural and urban areas become the victims of flooding annually. These two hazards – flooding and river erosion: are major contributors to the process of impoverisation of people in this country. The Padma (The Ganges), the Jamuna and the Meghna, major rivers of Bangladesh, erode several thousand hectares of floodplain, making thousands of people landless and homeless every year (Islam and Rashid, 2011).

2 Aim and objectives of the Research

The aim of the research is to demonstrate the applicability of GIS and Remote Sensing over the historical maps mainly prepared by Major James Rennell in the 1760s (Published 1779) in order to measure of the changing pattern of Ganges River courses (Bangladesh part) in order to assess the causes and impacts of the surrounding conditions on the current environmental features.

In order to fulfill the above aim of the study, the following very specific objectives are important to accomplish the research goals.

- i. To measure the changing pattern of Ganges River courses (Bangladesh part) in comparison with a long period of time (1760s-2015) ;and
- ii. To analyze the bankline shifting pattern of the Ganges river in different years.

3 Data and Methods

To interpret Rennell’s map, historical Landsat imagery (MSS, TM, ETM+) and analysis the features of the old courses of Ganges River in comparison with a long period of time (1760s-2015) for detecting the changes.

3.1 Data

For research work Rennell’s map (1760s) has been collected from SoB (Survey of Bangladesh). There is no ground station to collect LANDSAT data, in Bangladesh. Multi-temporal satellite imagery especially Landsat MSS (1975), Landsat TM (1995), and Landsat ETM+ (2015) have downloaded from the website <http://glovis.usgs.gov> during the dry period. Resolutions of Landsat MSS, TM, and ETM+ are 60m, 30m and 30m respectively. All the imagery are geo-referenced in UTM projection system.

Table 1: The Landsat Imagery MSS, TM and ETM+ Frame Numbers and Meta Data of Study Data

Satellite Sensor	Year	Date	Frame	No. of Band	Data Type	Map Projection
MSS	1975	Mar 17, 1975	137 / 43 137 / 44 138 / 43 148 / 44	4	MSS LIT	WGS_1984_UTM_Zone_46N
TM	1995	Jan 28, 1995	137 / 43 137 / 44 138 / 43	7	TMLIT	WGS_1984_UTM_Zone_46N
ETM+	2015	Mar 08, 2015	137 / 44 138 / 43	11	ETM+LIT	WGS_1984_UTM_Zone_46N

(Source: USGS- Earth Explorer, 2016)

3.2 Methodology

Ganges river basin (Rennell’s Map, Plate no-18) is my study area for its changing behavior due to geographical background. After selecting the study area it is essential to collect data from different sources in order to carry on my research work forward. Remote Sensing data Landsat imageries have been used for detecting changes of Ganges

river basin integrated with GIS. The verified data then processed and analyzed based on the method of examination or analysis. In GIS the analyzed data are presented in the map form (ESRI, 2009). This research intends to identify the shifting pattern of the Ganges River courses accordingly using Rennell map and Landsat Imageries (MSS-1975; TM-1995, and ETM+ 2015). This study also aims to contextualize

spatial-temporal reasons those are working behind the changes and their consequences. Required processing of images like Layer stack, Image Enhancement, Mosaic, Subset Re-Sample and Re-projection changes were done by image processing software ERDAS imagine 2014. To analysis the historical river course shifting of Ganges river on the basis of Rennell's map in 1760s and Landsat imageries have been used various tools of ArcGIS 10.1 and Microsoft Excel 2010 likes georeferencing, digitizing, projection transformation, calculate geometry, layout, pivot table etc. By the applications of the above methods it can be possible to find out the outcome of the research.

4 Delineation of Bankline of Ganges River: Land-Water Classification from 1760s to 2015

To identify the bankline of Ganges River for this research have been used two types of raw data. Those are Rennell's map (Plate No.-18) and Landsat satellite imageries. As Landsat TM Band 4 (0.76 - 0.90 μm) is suitable for land-water interfaces separation, the Ganges river have been delineated using this band. From Landsat MSS, TM and ETM+ single band 4, Land and water are classified and then the interface is marked as the land and water.

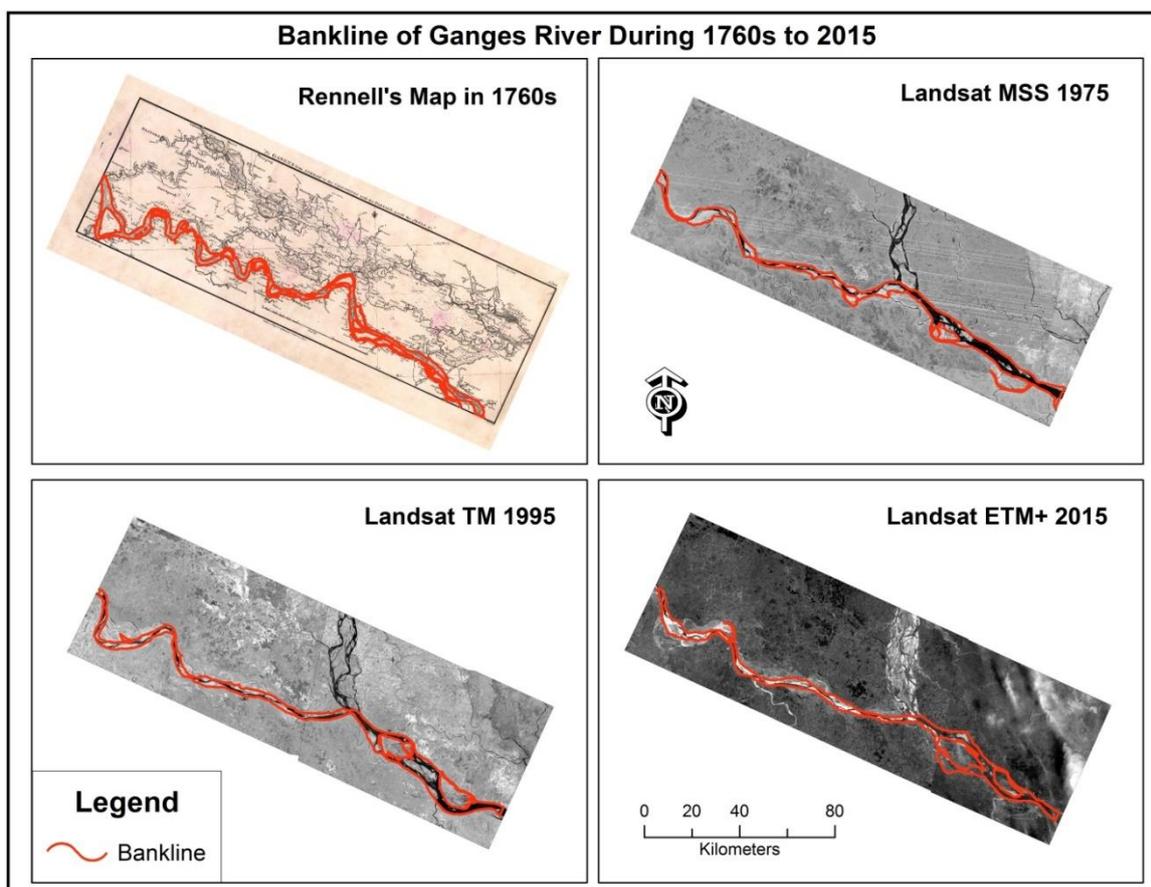


Figure 1: Delineation of Bankline of Ganges River: Land-Water from 1760s to 2015

(Source: Based on Rennell's map in 1760s and Landsat imageries, Compiled by Author, 2016)

5 River Course Shifting

The dynamic physical processes of rivers, including the movement of water, sediment and wood, cause the river channel in some areas to move, or "migrate," over time. This is a natural process in response to gravity and topography and allows the river to release energy and distribute its sediment load. Migration processes include bank erosion and deposition. The area within which a river channel is likely to

move over a period of time is referred to as the channel migration zone (CMZ) (Department of Ecology, 2015). The river Ganges is characterized by changes in its course over historical time scales, particularly in its seaward reaches before it enters the Bay of Bengal (Gupta, 2012). River course line shifting mainly depends on hydrological and morphological characteristics. Such as water level, water discharge, soil condition, erosion and deposition. Padma River

is a meander river. In meander river lateral erosion occurs. It is the causes of river bank shifting.

The three major Himalayan Rivers, the Ganga, Brahmaputra and Indus, are the most sediment laden in the world (Milliman and Meade, 1983); they carry 1.8 Gtonnes yr⁻¹ of suspended sediment which about 9% of the total annual load carried from the continents to the oceans worldwide (Meybeck, 1976; Hasnain and Thayyen, 1999). The River Ganga itself carries a sediment load of 300-500 million tonnes yr⁻¹ measured in downstream at Hardinge Bridge (Sarker, 2004). The river system is about 1.4 km to 2 km wide at its narrowest points in the study area and varies from 10 km to 13 km wide at its widest sections. The channel bars are also about 0.7 km to 1.5 km wide and sometimes even larger. The channel pattern of the river is mainly meandering with anabranching pattern (multiple channels) within some reaches (Gupta, 2012).

River bank erosion and lateral migration are chronic problems both upstream and downstream of the Hardinge Bridge (Sarker, 2004) along most of the 195 km length of the river being studied. The upstream length of the river in the study area is about 62 km north of the Hardinge Bridge and the downstream length of the river in the study area is around 133 km from Hardinge Bridge in Bangladesh. Lateral migration results in loss of villages and towns and loss of agricultural land as the river flows through one of the most densely

populated regions of the world. The lateral migration of the river has been observed to be from west to east upstream of the barrage and from east to west downstream of the barrage (Gupta, 2012). In the recent past, bank erosion and the rate of change has increased resulting in a loss of agricultural land of about 3 km² to 3.5 km² annually upstream in the study area (Chattopadhyay, 2003). The total loss of land between 1980 and 1999, in downstream of the Hardinge Bridge (in Bangladesh) was 126.5 km² (Sarker, 2004).

6 Spatial and Temporal Dynamics of Bankline

Padma River is one of the most river bank eroded river in Bangladesh. Continuous shifting of the thalweg from one position to another has been occurred within bankline. Observation of satellite images for 1760s, 1975, 1995, 2015 years are usually used compare the channel shifting from Surdah to Calligonga at the different reaches. To easy the measurement of bankline shifting the study area are divided into six cross sections. Those are XS-1, XS-2, XS-3, XS-4, XS-5, and XS-6.

7 Shifting Pattern of Ganges River from 1760s to 2015

Rennell's map (1760s), Landsat MSS (60 m) data of 1975, Landsat TM (30 m) data of 1995 and Landsat ETM+ (30 m) 2015 were used to generate digital database of different time period, analysis of shifting nature of Padma river of Bangladesh.

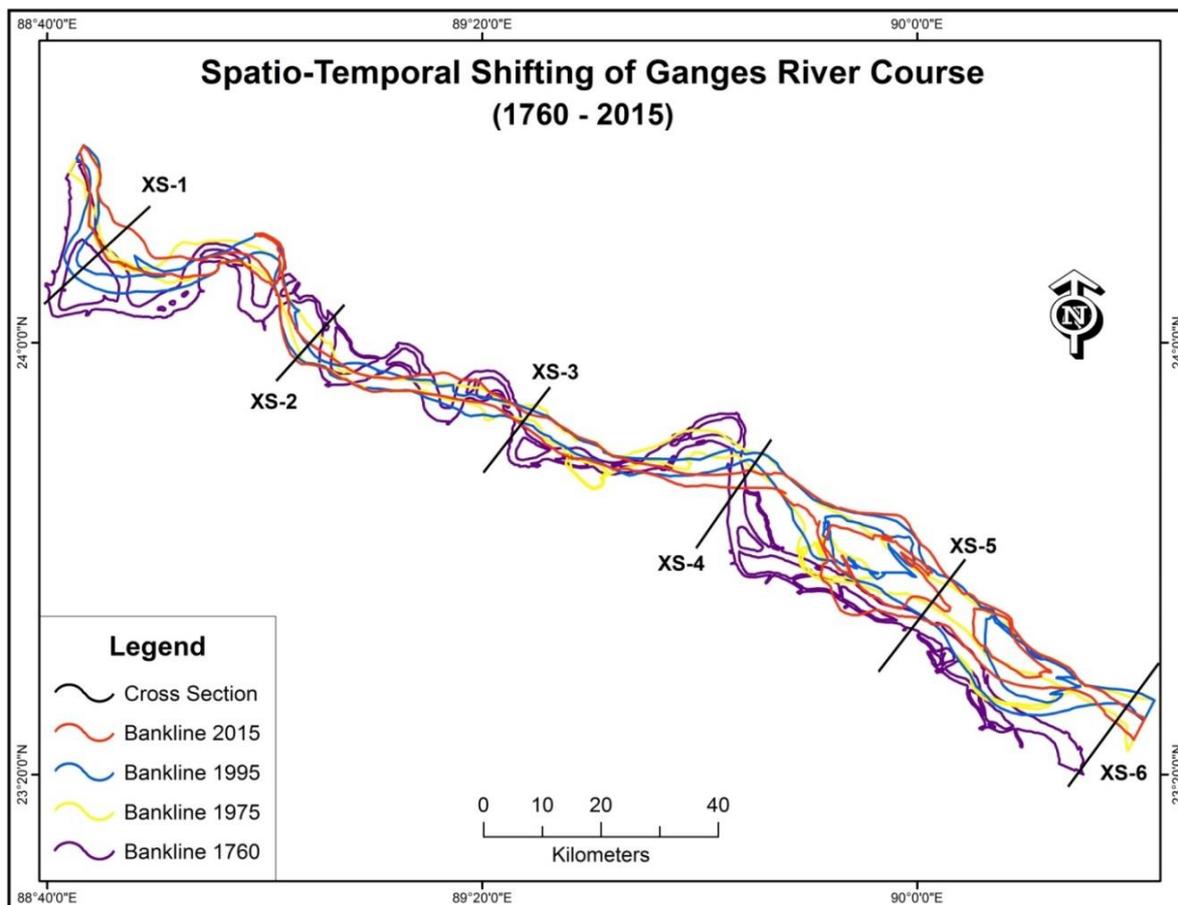


Figure 2: River width of different cross sections in 1760s to 2015
 (Source: Based on Rennell's map in 1760s and Landsat imageries, Compiled by Author, 2016)

From the above map it can be said that Ganges river course line is gradually losing its land from southwest to northeast direction. River course line maximum shifted in 1760s to 1975 at the cross section 2 in right bank that was 45734 meter. In left bank maximum channel shifted in cross section 6. It was 14772 meter. In 1760s to 1975 the river course shifted to more in right bank. From 1995 to 2015 the course line of Padma river both bank (left and right) are shifted from north west to south east direction. In 1995 at the cross section 1 river width increased in both bank by erosion. In 1760s to 2015 river course line shifted south direction to north east direction. River course line migrated to north east direction at the cross section 1. Right bank shifted 11856 meters and left bank shifted 12556 meters. Minimum shifted in cross section 6 from 1760s to 2015. In 1760s the meander pattern of Padma River was which showed in Rennell's map but at the present time the Padma river almost straight river.

7.1 Bankline Shifting from 1760s-1975 of the Study Reach

To analysis of bankline shifting of Padma River from 1760s to 1975 have taken six cross section that represent the Padma river continuously change its plan form through shifting of channel. It also indicates the erosion and accretion level at different cross section.

From the figure it is clear that river bankline is not same in every cross section. There was a change in every cross section spatially and temporally.

In 1760s at the cross section 1 river bankline is wide is more than 1975. Right bank of the river in 1975 accretion is more. Cross section 2 river course line 1760s was down side than 1975. In cross section 2 river shifted to north east from 1760s to 1975.

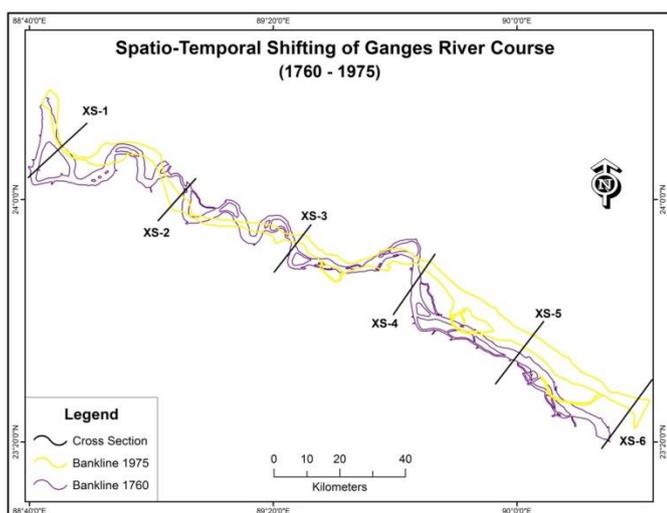


Figure 8.16: Bankline shifting of the Padma river from 1760s to 1975

(Source: Based on Rennell's map in 1760s and Landsat imageries, Compiled by Author, 2016)

At the cross section 3 depositional works is stronger than erosion. River shifted to south west. At the cross section 4, it is the most changeable point. At this cross section huge amount deposition occurred in right bank and erosion in left bank of the river. From cross section 4 to 5 river shifted to north east direction. From cross section 5 to 6 river courses shifted to north east direction. Erosion occurred more in left bank and deposition occurred in right bank (Figure 3)

At the cross section 1 river width was 1.57 km and 0.93 km approximately in 1760s and 1975. In 1760s and 1975 river width was 2.69 km and 4.36 km at the cross section 2. At the cross section 3 river width was 2.7 km and 3.03 km approximately in 1760s and 1975. Cross section 5 river width was 2.66 km and 4.53 km in orderly 1760s and 1975 (Table 2).

Table 2: Width variation different cross sections from 1760s to 1975

Cross Section	River Width 1760s (km)	River Width 1975 (km)	Right Bank (m)	Left Bank (m)	Direction of Migration
XS-1	1.57	0.93	11950.37	305.51	North-east
XS-2	2.69	4.36	-45734	-4080.86	South-west
XS-3	2.7	3.03	3590	3796.93	North ward
XS-4	4.67	2.85	9404.28	4827.38	North ward
XS-5	2.66	4.53	4925.35	6701.66	North-east
XS-6		4.35	11014.39	14772.89	North-east

(Source: Based on Rennell's map in 1760s and Landsat imageries, Compiled by Author, 2016)

In this place river is more extend in 1975. Bankline more shifted in cross section 4. In this place river shifted to right bank 9404 m and left bank 4827 m from 1760s to 1975.

Cross section width variation from 1760s to 1975 shows that more width in 1760s than 1975. At the cross section 1 and 3 channel width was less difference from 1760s to 1975. At the cross section 4 show maximum variations. In 1975 deposition is more occurred here. So channel width was decreased (Figure 4).

On the basis of cross section channel migration is more occurred in cross section 2. In cross section 2 channels shifted to right direction that was 457334 meter (Figure 5).

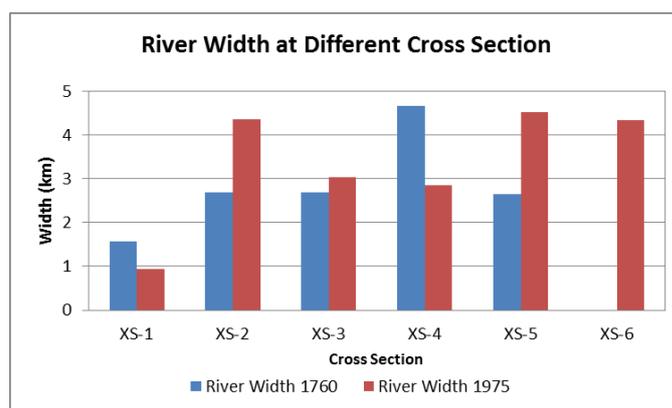


Figure 4: Bank width variation from 1760s to 1975

(Source: Author, 2016)

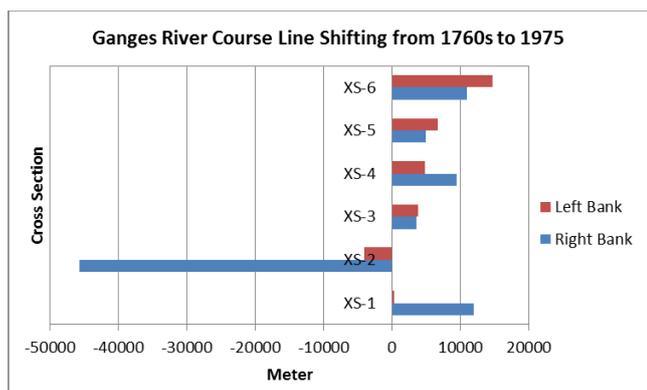


Figure 5: River Course Line Shifting from 1760s to 1975
(Source: Author, 2016)

River course line maximum shifted in 1760s to 1975 at the cross section 2 in right bank that was 45734 meter. In left bank maximum channel shifted in cross section 6. It was 14772 meter. In 1760s to 1975 the river course shifted to more in right bank (Table 2). Overall river course line migration to north east.

7.2 Bankline Shifting from 1975- 1995 of the Study Reach

Padma river’s shape, position change and channel shifted from 1975 to 1995 at different cross section is measured and represented in the present study. Specific trend of movement can observe from the position of bankline. Variation of the bankline at the cross section 1, here accretion is occurred more in 1995. Its means less amount of erosion occurred at

that cross section in right bank and deposition occurred in left bank (Figure 6). At the cross section 2 river width decreased causes of left bank deposition. Cross section 3 and 4 a little amount of channel shifted. Here erosional and depositional activities were very low.

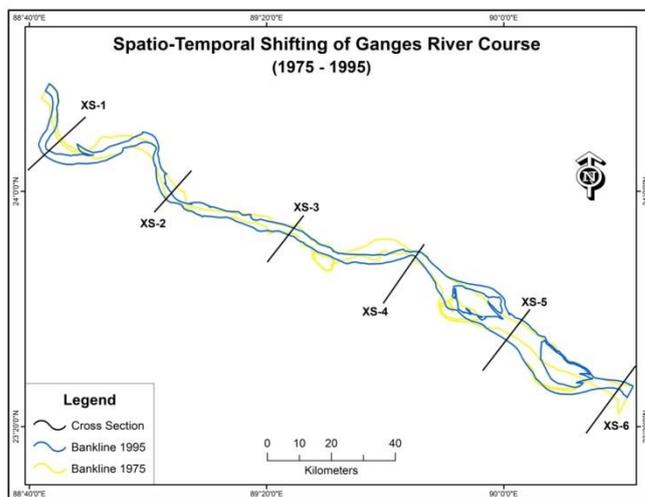


Figure 8.19: Bankline shifting of the Padma River from 1975 to 1995

(Source: Based on Rennell’s map in 1760s and Landsat imageries, Compiled by Author, 2016)

At the cross section 4 a little amount of variation is also shown that is erosion. In 1995 a huge amount of erosion occurred at the cross section 5. Erosion is more occurred in left bank of Padma River. At the cross section 6, accretions are more occurred in the right bank of the river (Table 3).

Table 3: Bankline shifting from 1975 to 1995

Cross Section	River Width 1975 (km)	River Width 1995 (km)	Right Bank (m)	Left Bank (m)	Direction of Migration
XS-1	0.93	1.92	-6124.3	-5201.33	South-west
XS-2	4.36	2.52	-567.4	-2382.57	South-west
XS-3	3.03	2.67	-692.9	-1087.77	South-west
XS-4	2.85	1.89	-1018.11	31.76	North-east
XS-5	4.53	7.66	-2154.73	1010.16	South ward
XS-6	4.35	2.66	2086.32	1011.16	North ward

(Source: Based on Rennell’s map in 1760s and Landsat imageries, Compiled by Author, 2016)

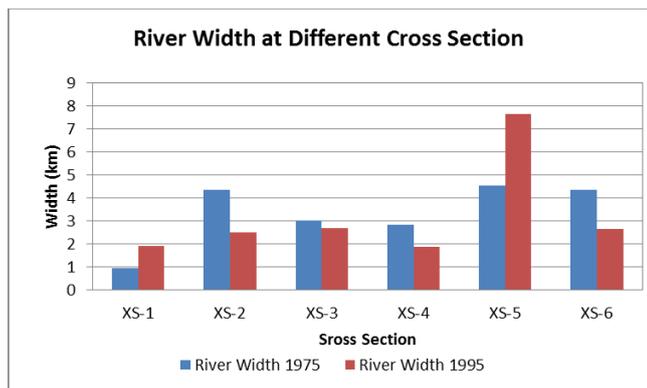


Figure 7: Channel width variation from 1975 to 1995
(Source: Author, 2016)

River width varies from one cross section to another cross section and that indicate the changes of channel. River width was increased in 1995 at the cross section 1. Here channel width was 0.93 km in 1975 that increased in 1995 was 1.92 km. At the cross section 2 river width was decreased because accretion is present here. Here channel width was in 1975 and 1995 approximately 4.36 km and 2.52 km. At the cross section 3 and 4 a little amount of channel variation are shown in right and left bank. In 1975 channel width was 4.53 km which was increased 4.66 km in 1995 at the cross section 5. Here a great amount of erosion occurred. At the cross section 6, in 1975 the channel width was 4.35 km and it was decreased in 1995 that was 2.66 km (Figure 7).

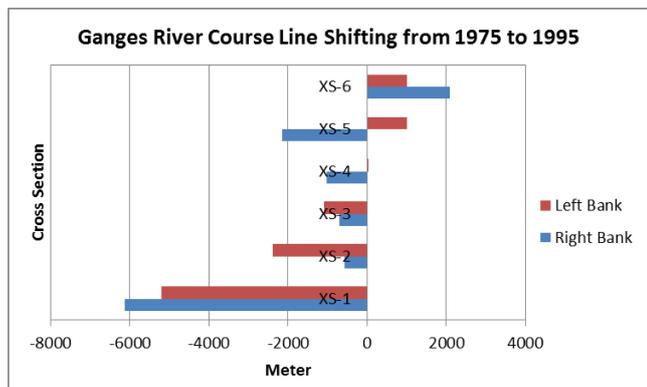


Figure 8: River Course Line Shifting from 1975 to 1995
(Source: Author, 2016)

Table 4: Channel width variation from 1995 to 2015

Cross Section	River Width 1995 (km)	River Width 2015 (km)	Right Bank (m)	Left Bank (m)	Direction of Migration
XS-1	1.92	5.58	6188.81	9788.31	North-east
XS-2	2.52	3.43	-508.1	440.2	South-west
XS-3	2.67	2.17	-345.63	-861.51	South ward
XS-4	1.89	4.51	-5036.93	-3417.28	South ward

Bankline shifting of study area has been measured through cross-section method for better understanding of the shifting pattern scenario in Ganges River. From the above map it can be said that Ganges river course line is gradually losing its land from southwest to northeast direction.

7.3 Bankline Shifting from 1995-2015 of the Study Reach

The bankline of Padma river 1995 to 2015 how much shifted and channel change are shown by map. Hydro-logical and morphological components and its characteristics is responsible for channel migration. At the cross section 1, bankline in 2015 has been changed due to erosion on right bank and deposition in left bank. Here in 1995 river channel width was narrow than 2015. Comparatively at the cross section 2, river channel width increase a small amount in 2015 than 1995 due to erosion (Figure 9).

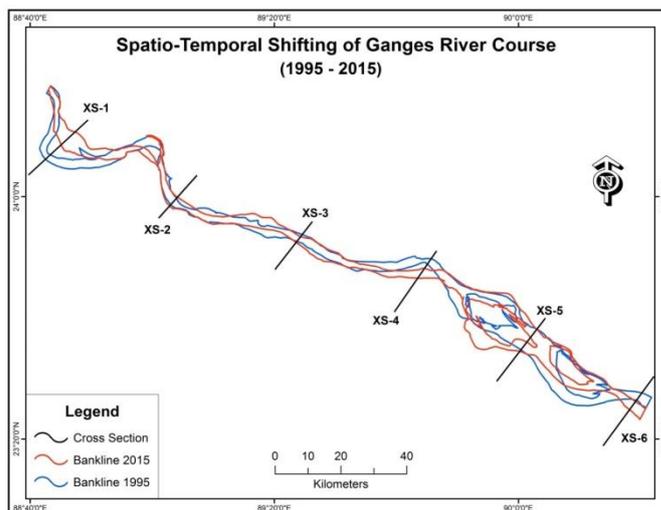


Figure 8.22: Bankline shifting of Padma River from 1995 to 2015

(Source: Based on Rennell's map in 1760s and Landsat imageries, Compiled by Author, 2016)

Bankline has been changed a vast amount in 2015 at the cross section 4 than 1995. Here in 1995 the channel was narrow. But in 2015 channel were width due to erosion on right bank (Figure 9).

XS-5	7.66	8.21	-609.56	-61.38	South-west
XS-6	2.66	2.98	-3467.93	-3139.14	South-west

(Source: Based on Rennell’s map in 1760s and Landsat imageries, Compiled by Author, 2016)

The bankline width in 1995 was 7.66 km that increased was 8.21 km in 2015 at the cross section 5. At the cross section 6, channel width increased a little amount in 2015 that was 2.98 km and 2.66 km was in 1995 (Table 4).

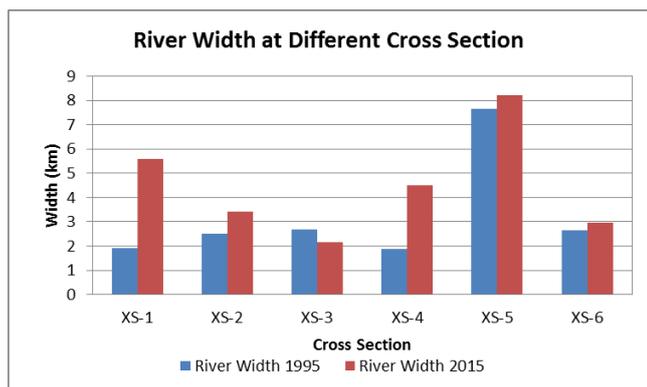


Figure 10: Channel width variation from 1995 to 2015
(Source: Author, 2016)

At the cross section 1, channel width in 1995 was 1.92 km and 5.58 km was in 2015. At the cross section 2, channel width increased a little amount on left bank. Here channel width was 2.52 km in 1995 and in 2015 was 3.43 km (Figure 10).

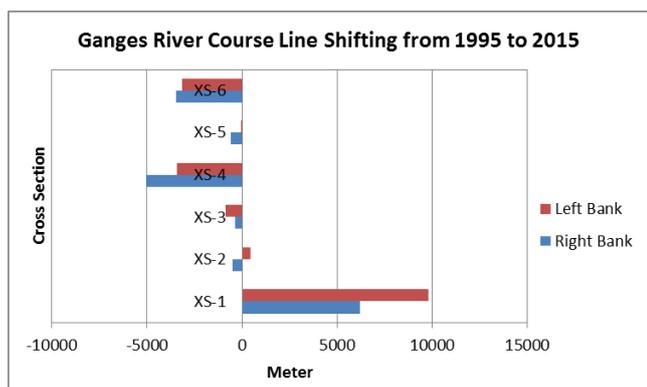


Figure 11: River Course Line shifting from 1995 to 2015
(Source: Author, 2016)

From the above map it can be said that Ganges river course line is gradually losing its land from northeast to southwest direction. From 1995 to 2015 the course line of Padma river both bank (left and right) are shifted from north west to south east direction. At the cross section 1 river width increased in both bank by erosion.

7.4 Bankline Shifting from 1760s-2015 of the Study Reach

The channel of the Padma River undergoes changes in response to morphological variation. The river exhibits temporal changes in bankline setting as well as channel configuration. Unique channel characteristics can observe through the spatio-temporal dynamics of the study reach. The bankline of Padma River more than 250 years from 1760s to 2015 have shown (Figure 12).

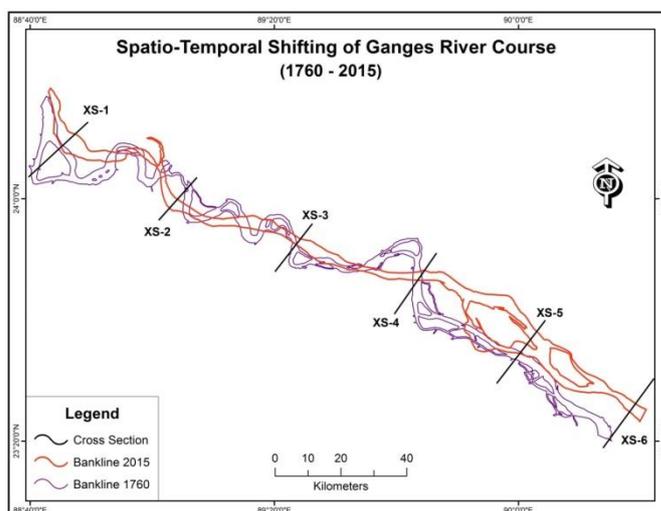


Figure 8.25: Bankline variation from 1760s to 2015

(Source: Based on Rennell’s map in 1760s and Landsat imageries, Compiled by Author, 2016)

The migration of the Padma River shows that the mitting point of the rivers has been changed into different direction into different cross section. The main channel shifted one place to another place day by day.

Bankline of 1760s has been changed in 2015 due to vast erosion on the left bank and deposited in right bank at cross section 1 (Figure 12). At the cross section 2 right bank were eroded in 2015 and accorded in left bank. Bankline of 1760s at the cross section 3 both side of the bank were eroded a vast area in 2015. Bankline 1760s has been change in 2015 due to erosion on left bank at the cross section 4. From the figure changing nature of river pattern, its direction and bankline

shifting can observe (Figure 12). In 1760s the Padma river was meander pattern which showed in Rennell’s map but at the present time the Padma river almost straight river.

Because of changing nature of river channel its width varied from 1760s to 2015. River width was 1.57 km in 1760s and 5.58 km in 2015 at the cross section 1. It means width increases in 2015 than 1760s. At the cross section 2 channel

width was 2.69 km in 1760s and 3.43 km in 2010 that’s means channel width increased in 2015 than 1760s. Again channel width decreased in 2015 at the cross section 3. Here channel width was 2.7 km in 1760s and 2.17 km in 2015. At the cross section 4 channel width was 4.67 km in 1760s and 4.51 km in 2015. That means channel width decreases in 2015 than 1760s (Table 5).

Table 5: Channel width variation 1760s to 2015

Cross Section	River Width 1760s (km)	River Width 2015 (km)	Right Bank (m)	Left Bank (m)	Direction of Migration
XS-1	1.57	5.58	11856.54	4881.24	North-east
XS-2	2.69	3.43	-6648.82	-5982.43	South-west
XS-3	2.7	2.17	2529.33	1973.17	North-east
XS-4	4.67	4.51	2561.71	1508.18	North ward
XS-5	2.66	8.21	2228.13	7736.33	North-east
XS-6		2.98	10221.93	12556.2	North-east

(Source: Based on Rennell’s map in 1760s and Landsat imageries, Compiled by Author, 2016)

Distance within right and left bank of the study reach has occurred at different cross section. Maximum width changes have taken place at cross section 1. River width has decreased in 2015 only for cross section 3 and 4 than 1760s. But at the others cross section width enlarged in 2015 than 1760s. Change of the channel width variation at all the cross section (Figure 13).

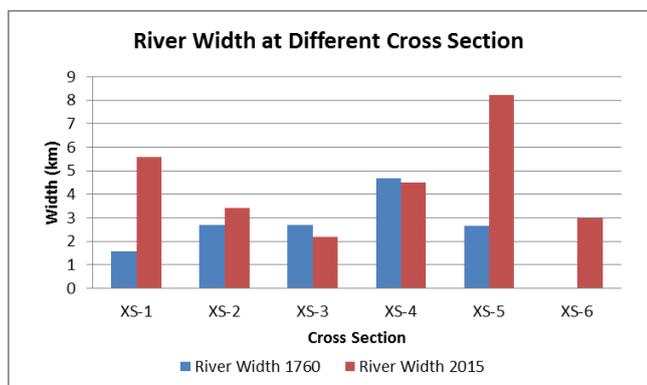


Figure 13: Channel width variation from 1760s to 2015.
(Source: Author, 2016)

In 1760s to 2015 river course line shifted south direction to north east direction. At the cross section 1 river course line migrate north east direction.

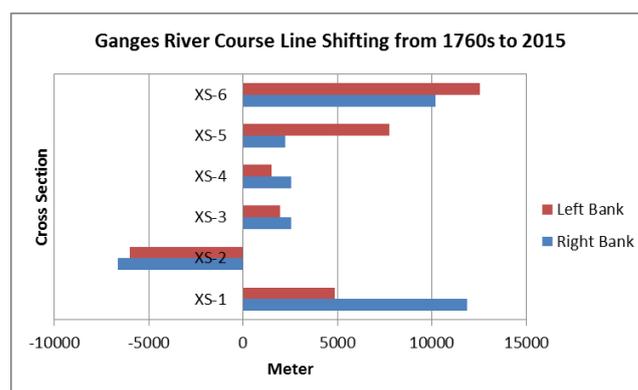


Figure 14: River Course Line shifting from 1760s to 2015
(Source: Author, 2016)

Right bank shifted 11856 meters and left bank shifted 12556 meters. Minimum shifted in cross section 6 from 1760s to 2015 (Figure 14).

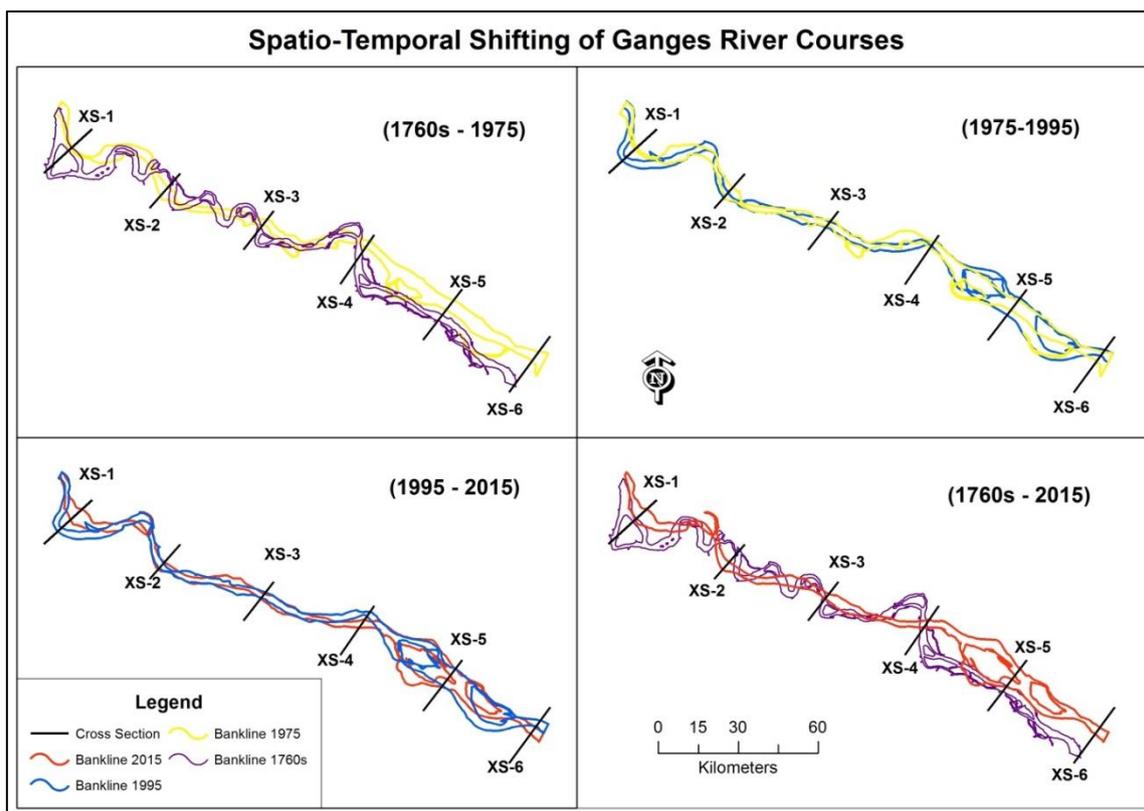


Figure 15: River width of different cross sections in 1760s to 2015

(Source: Based on Rennell's map in 1760s and Landsat imageries, Compiled by Author, 2016)

8 Statistical Analysis of River Width in Different Years

Table 6: Channel width variation of different cross sections from 1760s to 2015

Cross Section	River Width 1760s (km)	River Width 1975 (km)	River Width 1995 (km)	River Width 2015 (km)
XS-1	1.57	0.93	1.92	5.58
XS-2	2.69	4.36	2.52	3.43
XS-3	2.7	3.03	2.67	2.17
XS-4	4.67	2.85	1.89	4.51
XS-5	2.66	4.53	7.66	8.21
XS-6	-----	4.35	2.66	2.98
Maximum	4.67	4.53	7.66	8.21
Minimum	1.57	0.93	1.89	2.17
Mean	2.86	3.34	3.22	4.48
Median	2.69	3.69	2.59	3.97
Variance	1.26	1.92	4.86	4.76
Standard Deviation	1.12	1.39	2.20	2.18
Skewness	1.12	-1.17	2.31	1.05
Kurtosis	2.68	0.93	5.48	0.84

(Source: Based on Rennell's map in 1760s and Landsat imageries, Analysis by Author, 2016)

Due to erosion, accretion and channel migration on the bank of Padma this river considered as meander pattern. Meander Rivers are characterized rapid rates of channel migration temporally. Satellite images provide a comprehensive spatial

and temporal analysis and coverage of channel change, related hydraulic process in large meander rivers. Study reach of the Padma river change along the cross section at different time.

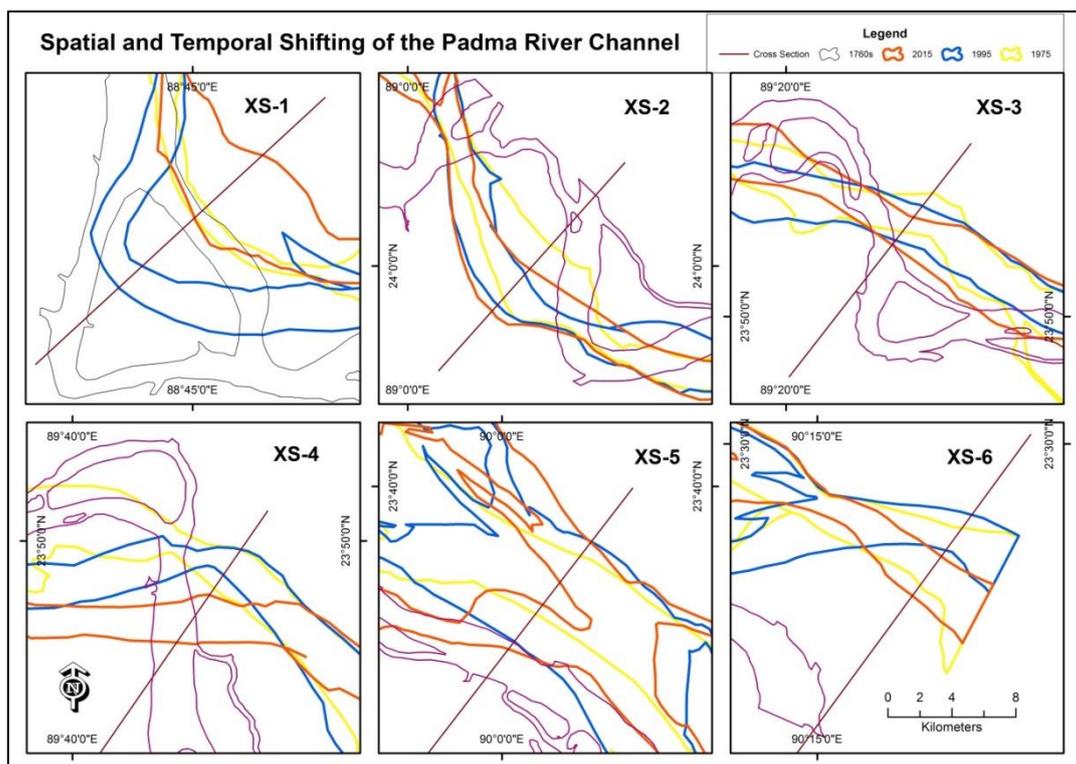


Figure 16: Spatial and Temporal variation of channel pattern in different cross sections from 1760s to 2015
 (Source: Based on Rennell's map and Landsat imageries, Compiled by Author, 2016)

River channel has changed in a particular time at different cross section. Due to natural processes bank erosion, down cutting and bank accretion an alluvial river has changed. Cross sectional river width varies from 1760s to 2015 (Table 6). In contrast with location and time, descriptive statistics provide information about the variability of the total data. Table 6 can be analyzed by two ways. One is straight down analysis and another is parallel analysis. Straight down analysis indicate the spatial changes of the river bank. Alternatively parallel analysis of the table clearly point toward the temporal shifting of river.

From the straight down analysis of the table it is clear that channel width varies at different scale among different cross section at a particular year. This straight down analysis indicate the spatial changes of the river bank. In 1760s, 1.57 km was lowest width distance at the cross section 1 and 4.67 km was the highest width cross section 4 (Table 6). The mean width of all cross sectional values in 1760s was 2.86 km and median was 2.69 km. Values are normally distributer away from the mean within a 1.12 standard deviation. It indicates the average deviations from the mean. The overall variance of the values is 1.26 (Figure 17). The skewness coefficient was 1.12 that indicates the distribution is not symmetric. Because

it is positive. The kurtosis was 2.68 that indicate it is positive (Figure 17). Its means the distribution has sharp peak with long tails.

In 1975 the minimum river width was 0.93 km at the cross section 2 and maximum width was 4.53 km cross section 5. Mean width of all cross section was 3.34 km and median was 3.69 km. Values are normally distributer away from the mean within a 1.39 standard deviation. It indicates the average deviations from the mean. The overall variance of the values is 1.92 (Figure 17). The skewness was -1.17 and this negative skewness indicates the distribution is not symmetric. The kurtosis of all values channel width in 1975 was 0.93 that is positive. It means the distribution has sharp peak with long tails (Figure 17).

Again in 1995, 1.89 km was lowest width distance at the cross section 4 and 7.66 km was the highest width cross section 5 (Figure 17). The mean width of all cross sectional values in 1995 was 3.22 km and median was 2.59 km. Values are normally distributer away from the mean within a 2.20 standard deviation. It indicates the average deviations from the mean. The overall variance of the values is 4.86 (Figure 17). The skewness coefficient was 2.31 which is positive that

indicate the distribution is symmetric. The kurtosis was 5.48 that indicate it is positive. Its means the distribution has sharp peak with long tails (Figure 17).

Again in 2015 minimum river width was 2.17 km at the cross section 3 and maximum width was 8.21 km cross section 5. Mean width of all cross section was 4.48 km and median was 3.97 km (Figure 17).

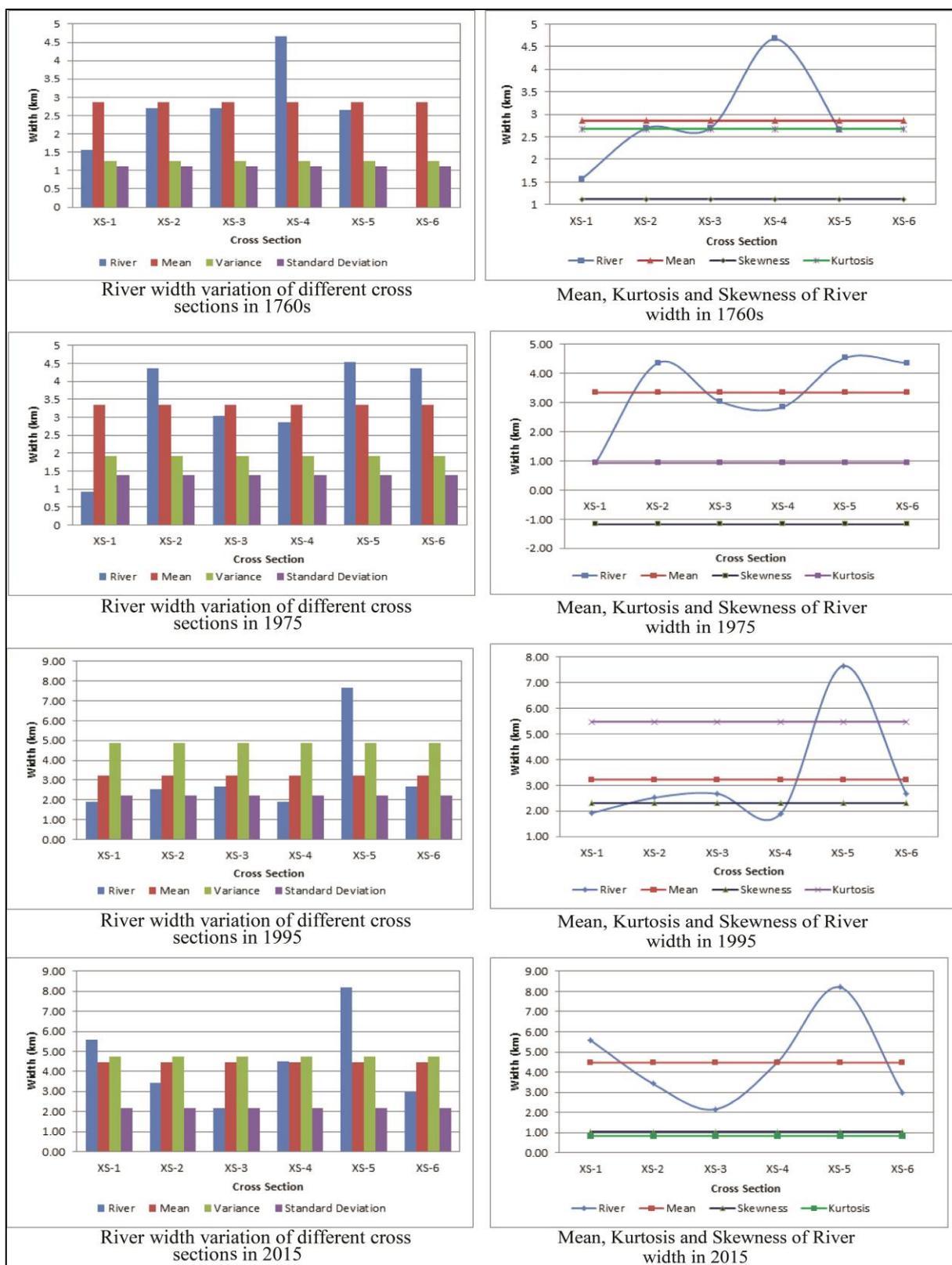


Figure 17: River width variation, Mean, Kurtosis and Skewness of different cross section from 1760s to 2015
(Source: Based on Rennell's map and Landsat imageries, Analysis by Author, 2016)

Values are normally distributed away from the mean within a 2.18 standard deviation. It indicates the average deviations from the mean. The overall variance of the values is 4.76 (Table 6). The skewness was 1.05 and this positive skewness indicates the distribution is not symmetric distribution. The kurtosis of all values channel width in 2015 was 0.84 that are positive. It means the distribution has sharp peak with long tails (Figure 17).

On the other hand, parallel analysis of table clearly point toward the temporal changes of river. River width varies

naturally according to time. Parallel analysis of the table 6 shows that channel width varies among different years at a same cross section. In 1760s, 1975, 1995, and 2015 river width changes accordingly 3.91 km, 2.76 km, 3.38 km, 3.99 km, 7.18 km, and 7.38 km at the cross section 1 (Table 6). From the bar chart it is clearly represented that rivers maximum width was in 2015 and minimum width was in 1975 (Figure 18).

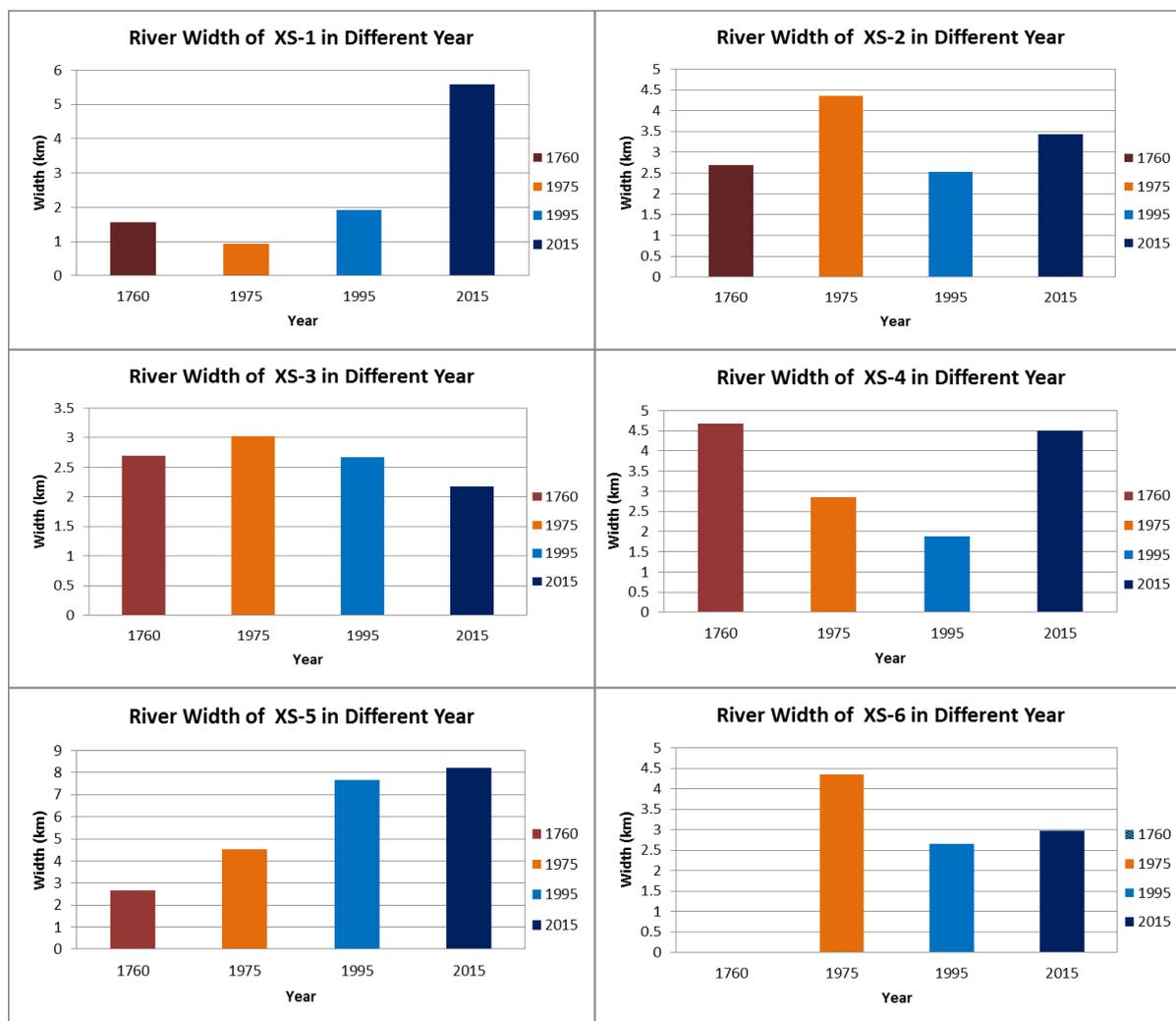


Figure 18: Channel width variation of different cross sections from 1760s to 2015

(Source: Based on Rennell's map and Landsat imageries, Analysis by Author, 2016)

Again at cross section 2 in 1760s, 1975, 1995, and 2015 river width changes from approximately 2.69 km, 4.36 km, 2.52 km, and 3.43 km. The minimum width was 2.52 km in 1995 and maximum width was 4.36 km in 1975 (Figure 6). These results give an idea about temporal changes of river width cross section 2.

Once more in 1760s, 1975, 1995, and 2015 river width was respectively 2.7 km, 3.03 km, 2.67 km, and 2.17 km at the cross section 3 (Table 6). Here minimum width of the channel was 2.67 km in 1995 and maximum width was 3.03 km in 1975. From the bar chart it is identify that gradually decrease

the channel from 1975 to 2015. This increasing pattern means deposition occurred here very much (Figure 18).

At cross section 4 in 1760s, 1975, 1995, and 2015 river width changes from approximately 4.69 km, 2.85 km, 1.89 km, and 4.51 km. The minimum width was 1.89 km in 1995 and maximum width was 4.69 km in 1760s (Figure 18). Once more in 1760s, 1975, 1995, and 2015 river width was

respectively 2.66 km, 4.53 km, 7.66 km, and 8.21 km at the cross section 5 (Table 6). Here minimum width of the channel was 2.66 km in 1760s and maximum width was 8.21 km in 2015. Again at cross section 6 in 1760s, 1975, 1995, and 2015 river width changes from approximately 0 km, 4.35 km, 2.66 km, and 2.98 km. The minimum width was probably 0 km in 1760s and maximum width was 4.35 km in 1975 (Figure 18). From 1760s 1975 the channel shifted north ward.

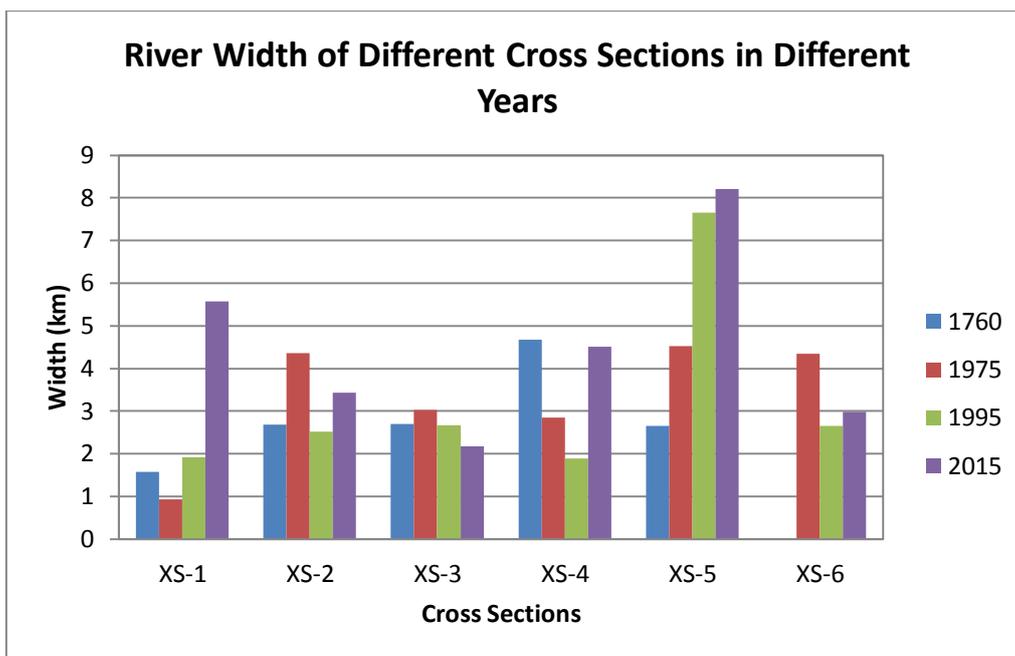


Figure 19: River width variation of different cross sections in different years
(Source: Based on Rennell's map and Landsat imageries, Analysis by Author, 2016)

Maximum channel width increased in 2015 in cross section 1 and cross section 5. Channel width increased day by day.

9 Conclusion

Erosion and accretion process are the common phenomena of the river area including Ganges River. It has been observed that, due to the hydrological processes, morphology of the river area has been continuously changing its position, configuration, shape and size eventually. Flood and bank erosion since pre historic period had become one of the major aspects of discussion for its direct interaction with physical and socio-cultural environment. Bank erosion is in facts are very common phenomena since more than 250 years in Ganges River and surroundings environment. In every year

the large numbers of local inhabitants are being severely affected due to bank erosion, particularly along the river bed of the Ganga in the present study area. Ganges River gradually changed over more than 250 years and the bankline shifted from south to north-eastward. Maximum channel width increased in 2015. Channel width increased day by day. In 1760s Rennell's map, there was no River called as Jamuna. Earthquake in 1787 changed the current (line) of Brahmaputra which created Jamuna River. The (water) flow has gradually decreased to old line as Brahmaputra has started to flow by the former Genai river line. As a direct impact of this, source of mouth of Shitolokkha emitting from Brahmaputra is gradually drying.

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Authors

Nusrat Jahan Ety

Postgraduate Research Student,
Department of Geography and Environment,
Jahangirnagar University,
Savar, Dhaka, Bangladesh.
E-mail: nusratjahanety40.geo@gmail.com

Dr. Md. Shahedur Rashid

Professor,
Department of Geography and Environment,
Jahangirnagar University;
Savar, Dhaka, Bangladesh
E-mail: m.s.rashid@gmail.com