Application of Remote Sensing and GIS for the Spatio-Temporal Change Analysis of the Padma River Bank Erosion-Accretion (1991-2018)

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Abstract:The Ganges is one of the major rivers in the world. This South-Asian river reinforces the life and livelihood of thousands of people of Bangladesh and India. There are several names of this system throughout its length. The channel is named the Padma from the Ganges-Brahmaputra confluence near Aricha Ghat up to the Meghna-Dakatia-Padma confluence near Chandpur town. This river system has already faced lots of anthropogenic activities that resulted in environmental, ecological, and social imbalance and this adverse impact will be increased in the near future due to socio-economic and climate change and the rapidly increasing population in the riparian regions. The construction of the Farakka barrage just upstream of the India-Bangladesh border has already been affected adversely to the downstream reach in Bangladesh. The planform shifting of the Padma reach was identified during the period of 28 years (1991-2018) using Landsat images and Geographic Information System (GIS) techniques in nine timelines with an average duration of 3 years each. The total eroded and accreted area, surface area and mean channel width were determined by using GIS. The channel planform analysis identified that the Padma experienced readjustments of the bank lines and behaved relatively straight within the study period. The lost and gained land area was 162 km^2 and 154 km^2 respectively, proving that the total erosion and accretion were almost counterbalanced over that 28 years period.

Keywords: *Planform, Erosion, Accretion, Landsat images, GIS*

1. Introduction

Rivers are extremely susceptible to natural circumstances [1], and alluvial rivers can adapt to the changes caused by natural and anthropogenic activities for spatial as well as temporal scales [2]. Any kind of changes, natural or anthropogenic, can commence the breaking of the dynamic equilibrium state [3]. This contributes to channel instability, resulting in changing of channel form and pattern [4], [5]. The Ganges is one of the largest river systems in the world (total catchment area 1.09 million km^2), originates from the Gangotri glacier of the Himalayas and confluences with the Meghna after coursing 2,526 km crossing over China, Nepal, India, and Bangladesh, making this an ultimate international river. The largest portion (79.1%) of the entire catchment lies in India whereas only 4.3% is within Bangladesh (equivalent to 32% of the total area of Bangladesh) [6].

The density of the population in the river catchment area is about 550 per km^2 [7]. The total harvestable area is about 68 million hectares, of which only 52% area gets rainwater [8]. Thenkabail et al. (2005) [9] showed that almost 24.9% or 33.08 Mha area of the Ganges catchment depended on irrigation.

The Ganges contributes to the foundation of sustainable development in its riparian nations; however, its own flow is going through an unhealthy situation due to the excessive and illegal extraction of water, construction of dams or barrages by the upstream nations, and deforestation. In addition, Moors et al. (2011) [10] have anticipated that the shortage of the availability of flow of water in the catchment area could happen because of climate change. The Ganges delta's distributaries spread over two neighboring countries and have been vulnerable due to the predicted asymmetry caused by different man-made activities and land-use patterns [11].

The Ganges system in Bangladesh, including the Ganges (up to Ganges-Brahmaputra confluence near Aricha ghat) and the Padma (from the Ganges-Brahmaputra confluence near Aricha ghat up to the Meghna-Dakatia-Padma confluence near Chandpur town), is one of the most gigantic rivers in the world and its catchment area catches almost 1,200 mm annual average rainfall [8]. So, it faces very frequent and seasonal floods of immense intensity [12] and almost 80% of the annual total discharge appears during the Monsoon (July–October) [13]. Shifting of the river bank through bed scouring and erosion is very frequent and many believe this has been exaggerated recently due to increased anthropogenic exercises [14]. Although it is reported that the diversion at Farakka results in the scarcity of river flow has increased erosion at the downstream banks [15], the consequence of floods on flow dynamics is to some extent unclear as flooding is also considered one of the leading parameters of bank erosion [16].

Previous studies on the characteristics of the Ganges system have explored sediment transport, erosion, and climatic events [17], [18], sediment characteristics [19], and the evolution of the Ganges–Brahmaputra deltaic system [20]. Others have studied the environmental pollutions near the river bank [8], water resources, and hydrology [21].

Due to the high variation of fluvial inputs in the Ganges and the contemporary interventions, the river course of the Ganges as well as the Padma is changing significantly. Consequently, every year a large area of agricultural lands and homesteads is eroded. In recent decades, to boost the socio-economic condition of the region Bangladesh government has initiated several development projects (i.e. The Padma Multipurpose Bridge Project at Mawa-Zajira point (delineated in Fig. 1(a))) across the Padma River. For this reason, the increasing importance of planform study, erosion mechanism, channel shifting along the Padma (from the Ganges-Brahmaputra confluence near Aricha ghat up to the Meghna-Dakatia-Padma confluence near Chandpur town) lead the authors to investigate this mega river's planform.

The primary focus of this study is to evaluate the dynamics of the planform of the Padma River in Bangladesh.The particular objectives of this study are to:

1. identify the bank line movements of the Padma River
2. estimate the channel patterns through calculating surface area determine the total eroded and accreted land in the river bank within a certain period

2. Study Area

The location of the Ganges–Padma system is situated between 90.49E and 87.42E and 24.34N and 23.20N within Bangladesh. The system within Bangladesh can be split into two different channels [15]. The channel from the downstream of the India-Bangladesh border to the confluence of the Brahmaputra with this channel near Aricha is named the Ganges. Downstream of Aricha, the Ganges channel moves its flow towards south-eastern direction up to the confluence with the Meghna (about 108 km) at Chandpur is named as the Padma (Fig. 1(a)) [22]. The annual average discharge of the Padma is about 30,000 m^3/sec and the bank full discharge is about 75,000 m^3/sec [23]. The Padma is a relatively straight channel as it receives flow from both Ganges and Brahmaputra rivers [24].

The Ganges-Padma channel is important for delta building exercise and land stability [25] as well as navigation, agriculture, fisheries, ecological and environmental balance. For instance, the upstream freshwater flow pushes back the salinity front downstream towards the Bay of Bengal helps to maintain a suitable ecosystem in the south-western part of Bangladesh, which belongs to the largest mangrove forest of the world, the Sundarbans [6], [26], [27]. The Ganges delta is one of the largest fluvial systems in the Himalayan region [28]. So, this system faces extreme variation of both sediment and water discharge between monsoon (May-October) and dry season (November-April) from the upstream due to the monsoon rainfall and the snow melting from the Himalayans, results in high intense floods to Bangladesh. Besides this, the sandy soil of the river bank and the increasing anthropogenic activities are responsible for the frequent bank shifting [24], [29]. This leads to land erosion and population migration in turn.

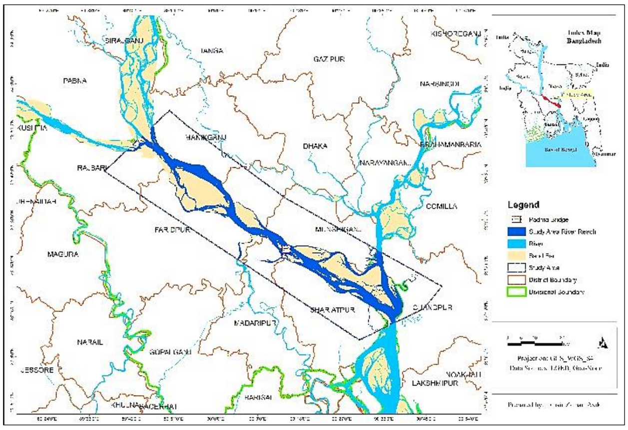

__Fig.1(a).__Location of the Padma river in Bangladesh (from the Ganges-Brahmaputra confluence near Aricha ghat up to the Meghna-Dakatia-Padma confluence near Chandpur town)

__Fig.2(b).__Locations near the river reach [30]

3. Methodology

To quantify channel planform change a GIS-based approach is used to manage historical planform data because it gives flexibility for analyzing data and more accurate results. Aerial photography and cartography are inexpensive and rapid for identification of the channel planform change visually or manually, however, these have limitations to cover a large number of dates effectively and to derive the calculative statistics [31]. A GIS-based method offers the solution of the problems and has significant convenience over the typical manual methods; boundary can be determined and delineated directly from the data source, map projection, and scaling can be estimated digitally, planform displacements can be calculated from the sequential records stored in GIS, statistical data can be exported from GIS and can be used for further analysis using any statistical analysis software and as much as maps can be generated and refined until the desired identification and representation is achieved [32].

Multi-temporal Landsat data has been used to identify the shifting of channel planform from 1991 to 2018 for this study. To estimate the erosion and accretion of the Padma river banks within the period of 28 years (1991-2018), the Landsat images were taken in nine epochs with duration of 3 years each.

In this study, Landsat images were downloaded from the United States Geological Survey (http://glovis.usgs.gov) with a spatial resolution of 30 m. The cloud cover in the available images was figured out visually and 10 images were picked from the available images with no cloud cover over the channel and the nearby areas. All the images were taken during the dry season to avoid the high-water level impacts on the flow dynamics during monsoon as well as get the unclouded images.

The Normalized Difference Water Index (NDWI) threshold method was applied to identify the land-water boundary and to delineate the planforms from the images [33]. The NDWI water index algorithm was produced in the ERDAS Imagine environment by combining the green and mid-infrared bands. The NDWI is perfect for distinguishing between land and water because of the high sensitivity of sediment and green surfaces to the green band (0.52–0.6 µm), a high degree of reflectance by vegetation in the mid-infrared band (1.60–1.70 µm), and a high degree of absorption by water. So, the combination of green and mid-infrared bands is ideal for NDWI. In this study, the NDWI threshold value for differentiating between the boundary of water bodies and non-water body was found 0.30. A precise digitization process has been employed to determine the polygon of bank lines and adjacent chars for each selected year. After that, polygon for two successive years has been intersected by geoprocessing intersection tools to distinguish the difference between land and water bodies for these following years.

The GIS-based approach provides great flexibility in the management of the data, extracted from the images. This method gives an inexpensive way to analyze the planform changes as the images are available free to the communities.The GIS-based method may not be as accurate as the manual method to some extent but increase the efficiency of a huge number of data analysis within a very short period of time.

4. Results and Discussion

The Padma River gets the discharge from the Ganges as well as the relatively high sediment containing water from the Brahmaputra and this may lead the frequent shifting of this channel duringthe study period (1991-2018), and the shifting of the bank line is dispersed along the length of the channel. This phenomenon was also noticed by Rob (1997) [34].

Near Faridpur, Naria and Kalma (shown in Fig. 1(b)), the widening of the channel is remarkably noticeable (Fig. 2-12) because there exist large sand bars in the middle of the channel. Sharma (2005) [35] identified almost same kind of channel widening throughout the Brahmaputra River reach in Assam. On the contrary, near Charbhadrasan and above Harirampur (shown in Fig. 1(b)), relative narrowing of the channel is identified during the study period (1991-2018) (Fig. 2-12). Rahman and Alam (1980) [36] also observed this along with the Ganges reach. The composition of bank materials and the riparian vegetation may be responsible for the narrowing of the channel [37]. The extinction of anabranches might be another driving parameter of the channel narrowing [38] which is frequent in the Padma (Fig. 2-12) due to regular bank line shifting.

Temporal variation of the surface area of the reach is shown in Fig. 13. Variation of the surface area ranges from 1450 km^2 to1900 km^2 over the study period of 28 years (1991-2018) (Fig. 13). The surface area change has been considered at the surface of the river. From the rate of change of the surface area per year over the study period shown that both erosion and accretion occurred significantly on an average along the river bank (Fig. 14).

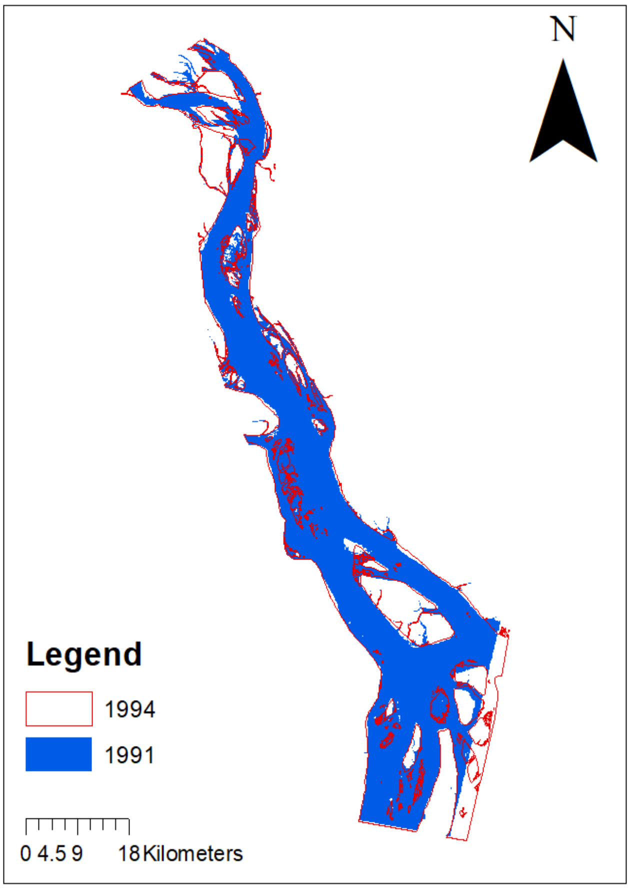

Fig.2.*Planform changes at river bank (1991-1994)*

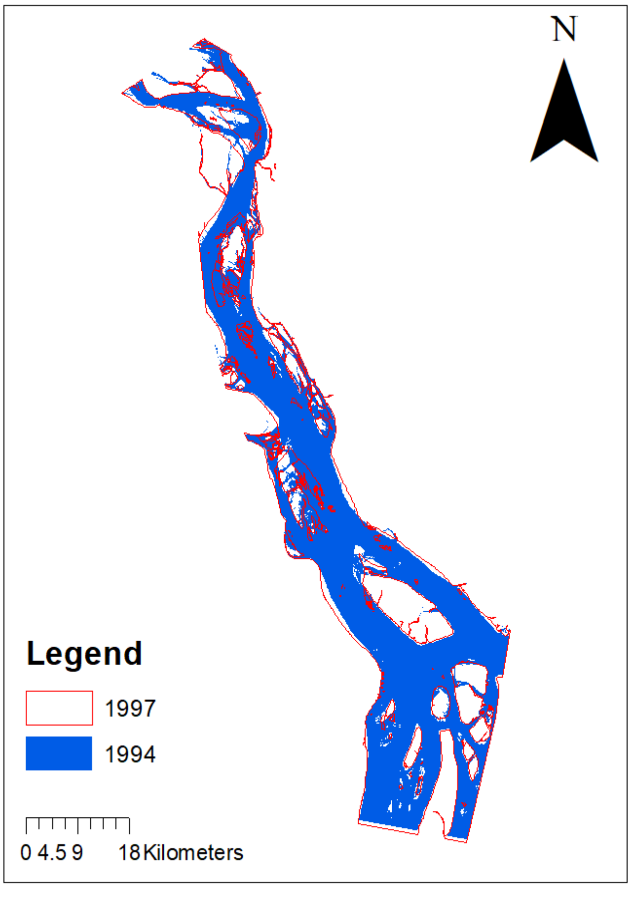

Fig.3.*Planform changes at river bank (1994-1997)*

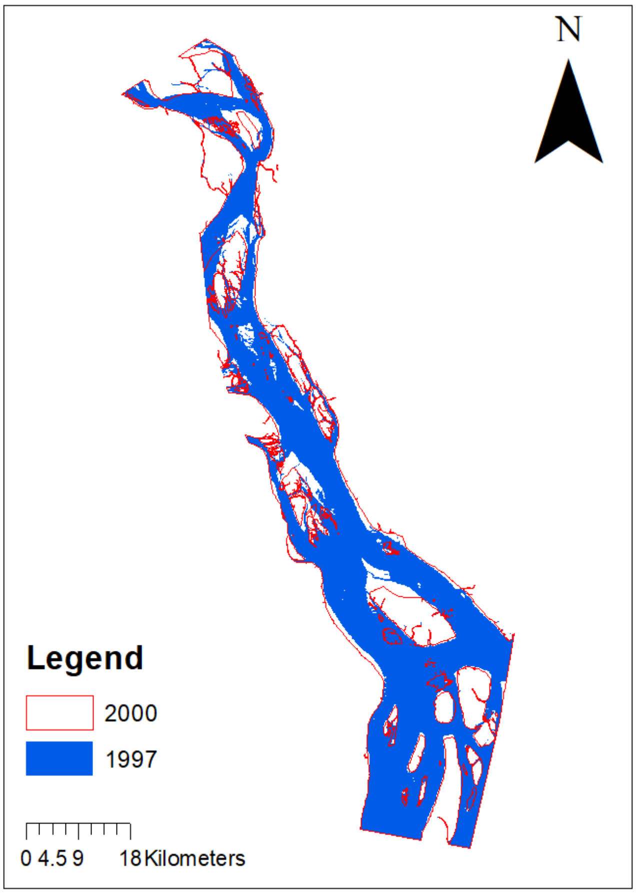

Fig.4.Planform changes at river bank (1997-2000)

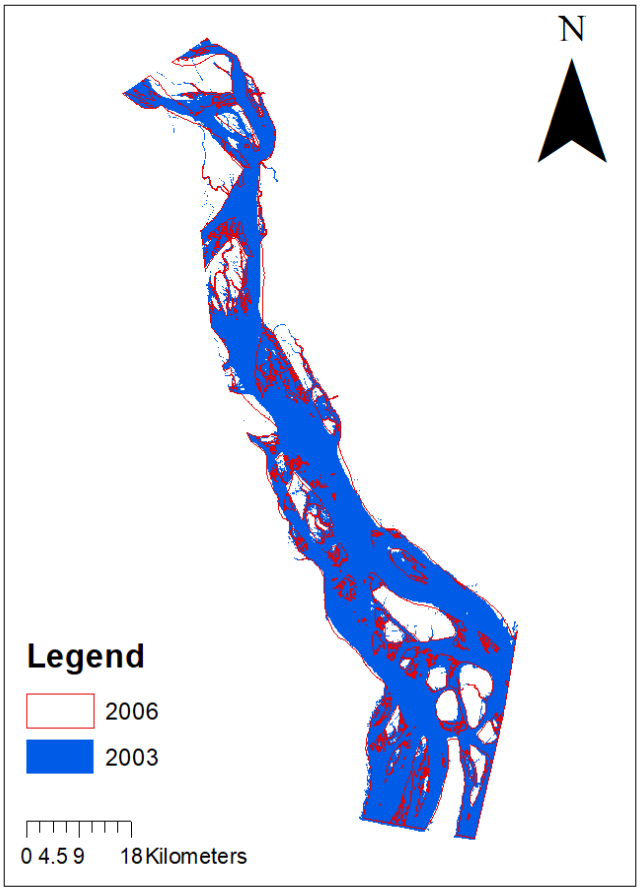

Fig.6.Planform changes at river bank (2003-2006)

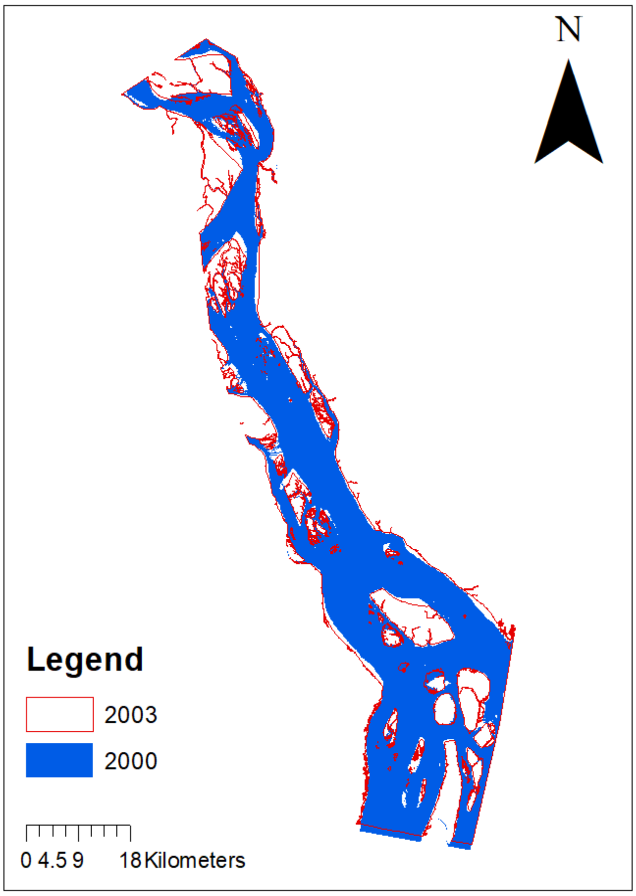

Fig.5.Planform changes at river bank (2000-2003)

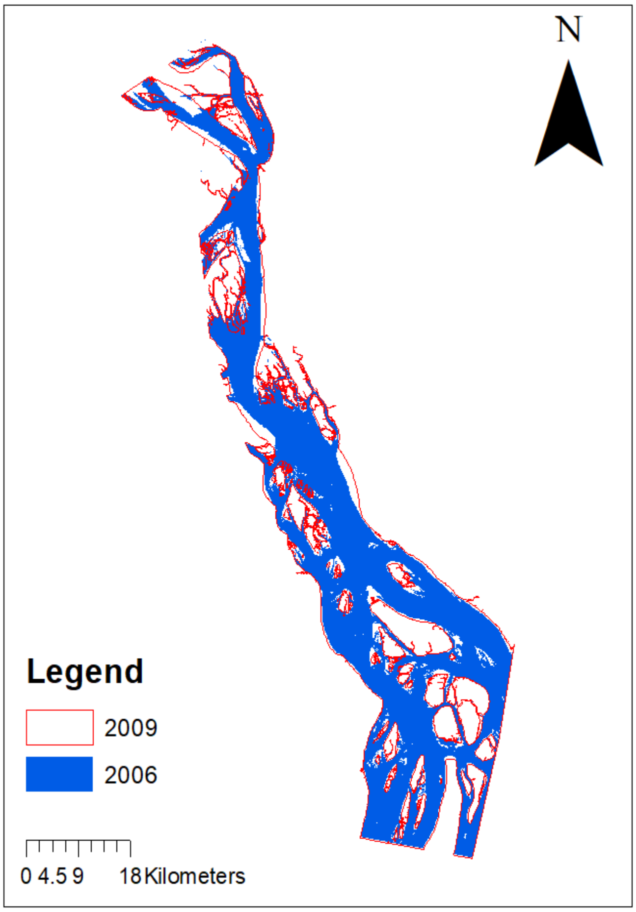

Fig.7.Planform changes at river bank (2006-2009)

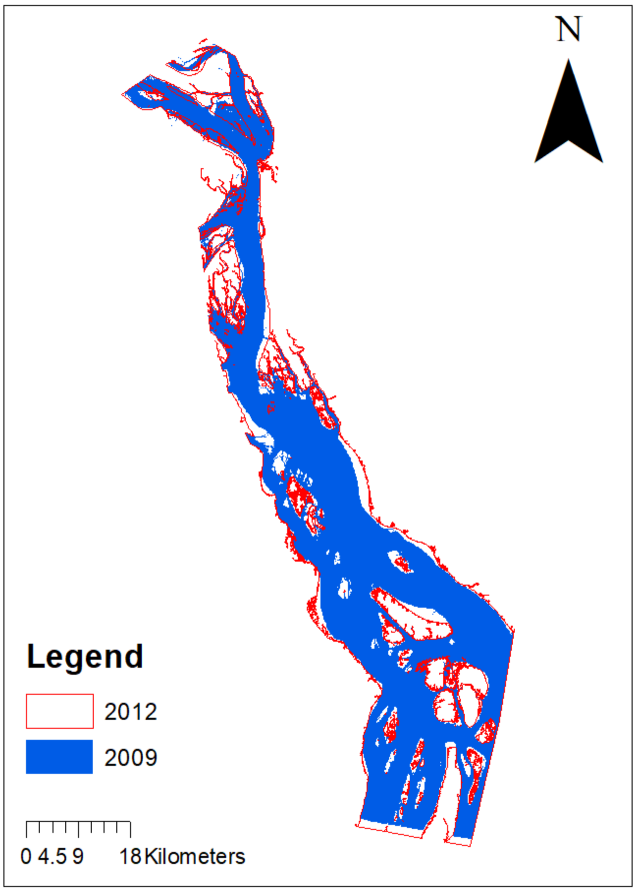

Fig.8.Planform changes at river bank (2009-2012)

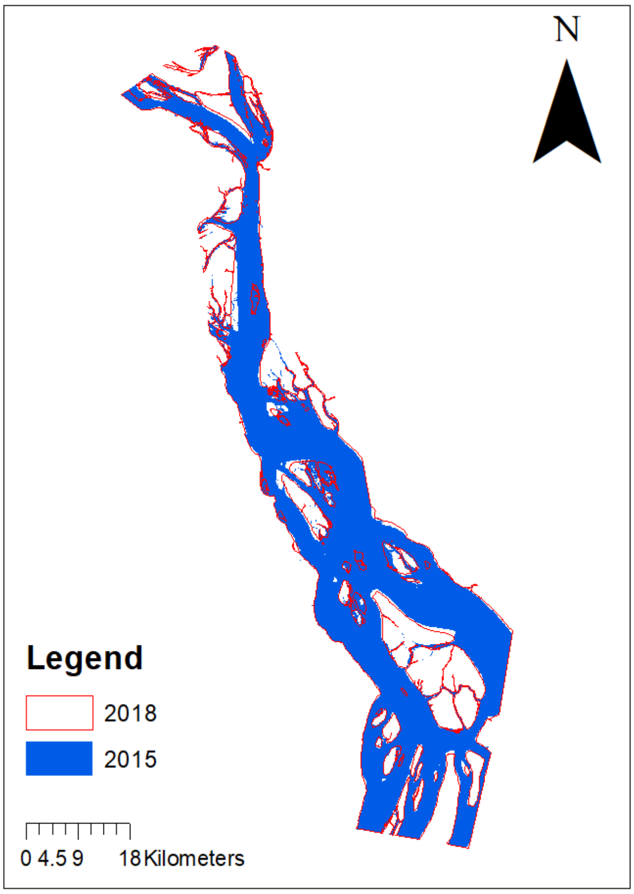

Fig.10.Planform changes at river bank (2015-2018)

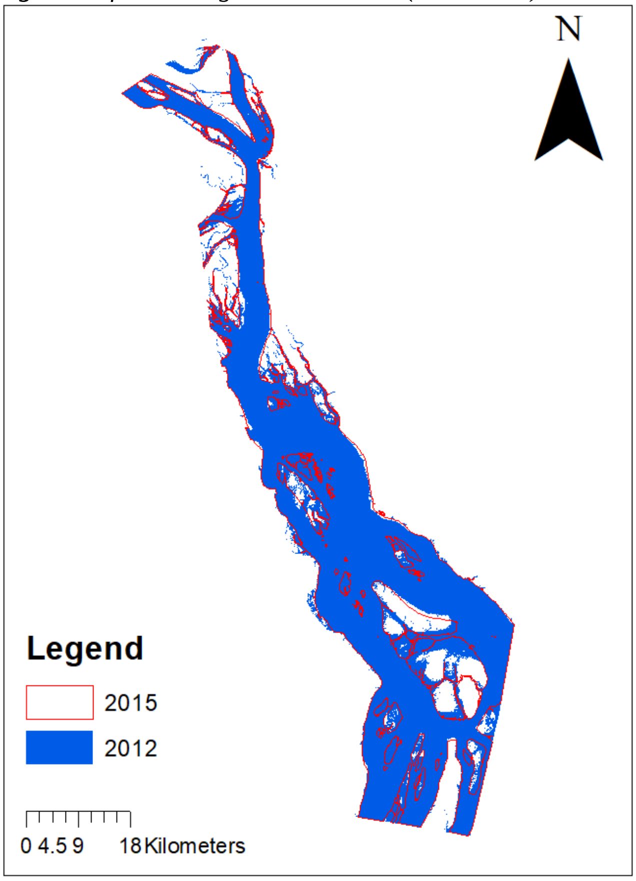

Fig.9.Planform changes at river bank (2012-2015)

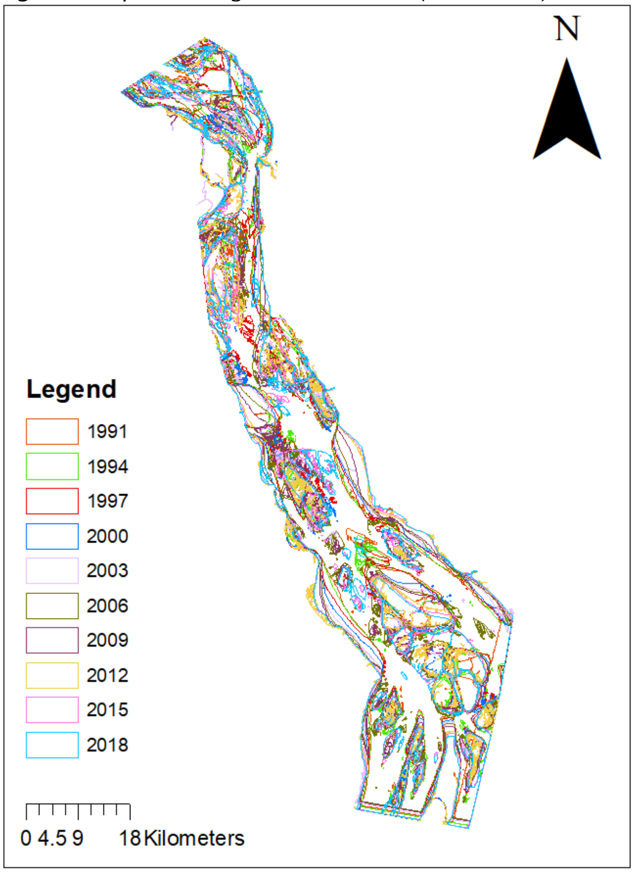

Fig.11.Planform changes at river bank from 1991-2018 at three years interval

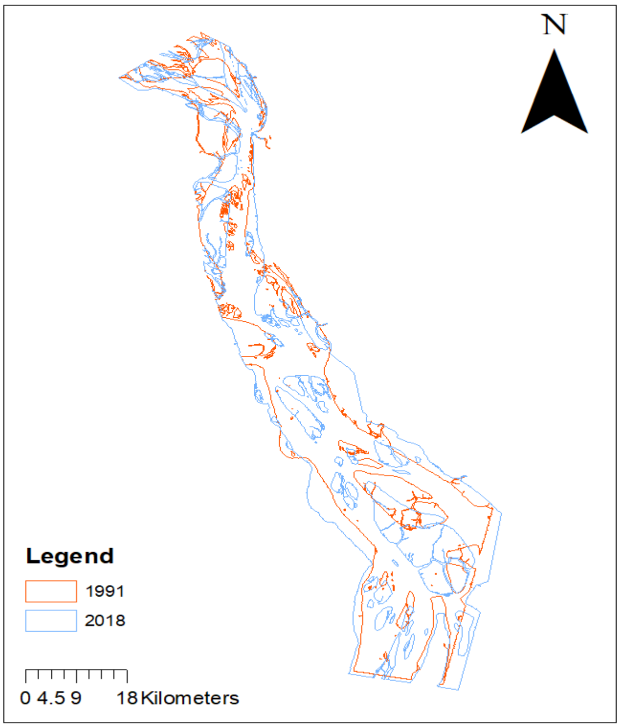

Fig.12.Planform changes at river bank for the last 28 years (1991-2018)

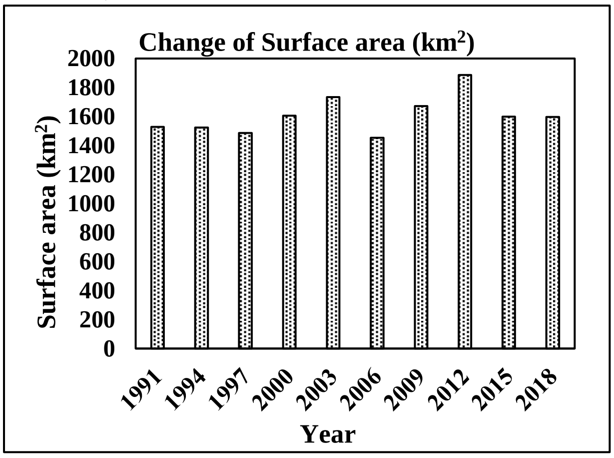

Fig.13.Temporal variation of surface area of river reach (1991-2018)

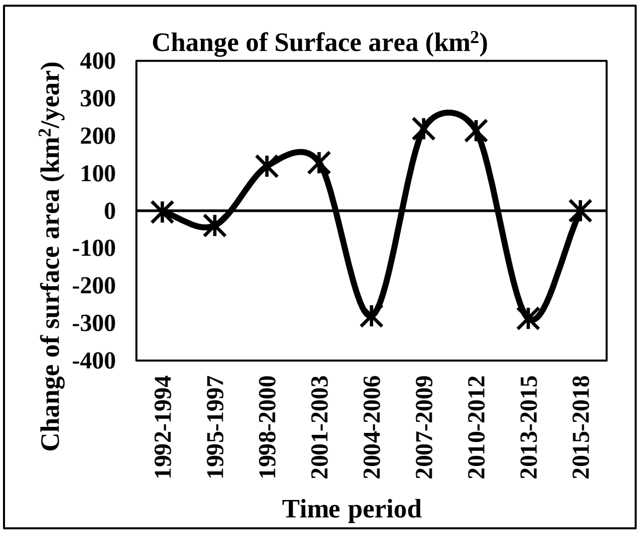

Fig.14.Temporal variation of rate of change of surface area of river reach (1991-2018)

The Padma has been roughly straight during the study period (Fig. 15). This was also observed by Rahman and Alam (1980) [34] and Rob (1997) [36]. Average width of the river reach indicates (Fig. 15) almost straight tendency up to the year 2015 meaning that average width was almost stable in that time, but after 2015, some instability has been found (Fig. 15). Although average width of the river reaches shows relative stability but there exists local instability because of localized river bank erosion and accretion.

Fig. 16 demonstrates the comparison of both erosion and accretion within the study period in the river reach. Erosion was significantly great in the period of 2006 to 2012 (Fig. 16) and accretion was great within the period of 2013 to 2015 (Fig. 16). From calculation, the average erosion rate was estimated 54 km^2/year and the average accretion rate was estimated 51 km^2/year within the study period.

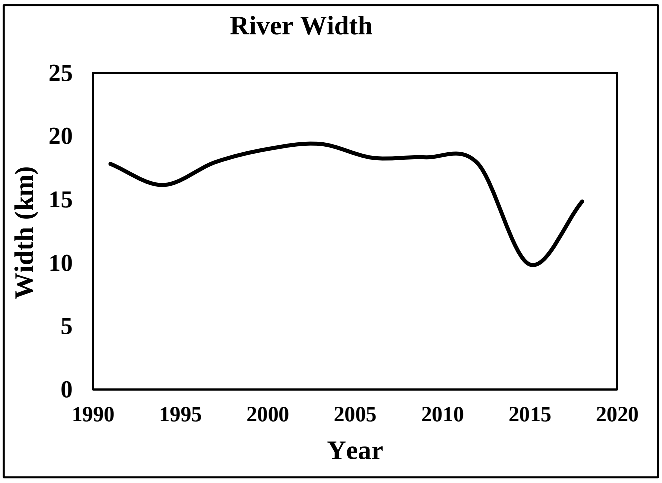

Fig.15.Temporal change of river width (1991-2018)

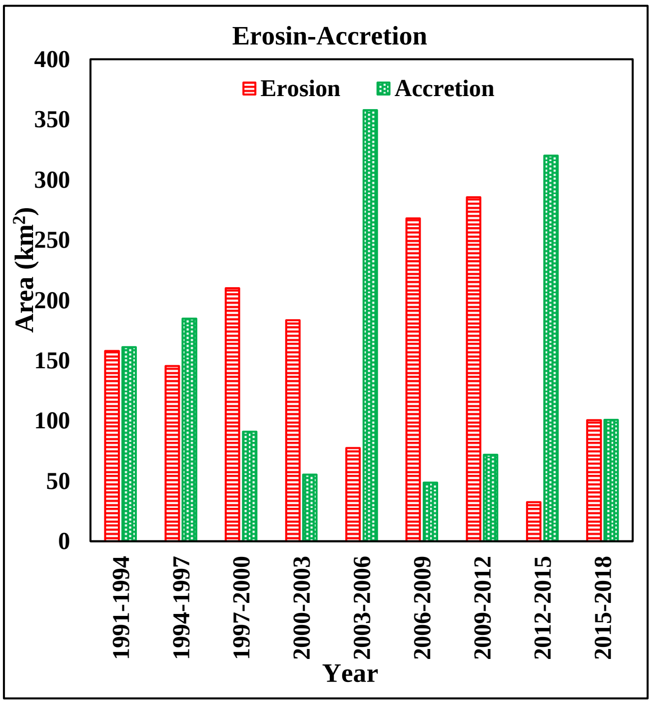

Fig.16.Comparison between erosion and accretion at the river reach during 1991-2018

5. Conclusion

This study has quantified the 108 km long channel planform of the Padma River by using Landsat images of 28 years (1991-2018) and a spatial geospatial technique in GIS. A land-water separation index named NDWI has been used to determine the river boundary from multi-temporal Landsat data. Besides the computation of the erosion and accretion volume and planform movement, this study has also delineated the channel pattern by estimating river width and area by using GIS.

It is very much clear from the planform shifting maps that the Padma experienced readjustments of the bank lines for the 28 years (1991-2018). The river also shows a relatively straight channel over the period comparing to the upstream meandering Ganges River. It also demonstrated that in total 162 km^2 area has been eroded, however, 154 km^2 areas has been accreted, proving the erosion and accretion has almost counterbalanced over the 28 years investigated here.

The analysis of this study has provided some significant information regarding the better understanding of the planform characteristics of the Padma River, which will assist the local leaders and planners to take any kind of development projects, both structural and non-structural, in the study area. To be much more specific, this study will help the local authorities to estimate the potential loss of the productive land and the potential shifting of the land due to the planform movement.

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