American Journal of Climate Change, 2021, 10, 167-184
https://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

Climate Change and Anthropogenic Interferences for the Morphological Changes of the Padma River in Bangladesh

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How to cite this paper: Islam, Md. A., Munir, Md. S., Bashar, Md. A., Sumon, K. A., Kamruzzaman, M., & Mahmud, Y. (2021). Climate Change and Anthropogenic Interferences for the Morphological Changes of the Padma River in Bangladesh. *American Journal of Climate Change*, *10*, 167-184.
https://doi.org/10.4236/ajcc.2021.102008

Received: March 5, 2021
Accepted: May 11, 2021
Published: May 14, 2021

Abstract

This research aims to identify the morphological changes of the Padma River due to the effects of anthropogenic climate change. The morphological changes were measured by aerial satellite images and their historical comparison, terrestrial survey, sedimentation in the riverbed, water flow, water discharge, siltation, and erosion along the river, etc. The Padma River has been analyzed over the period from 1971 to 2020 using multi-temporal Landsat images and long-term water flow data. The climatic parameters data related to temperature and rainfall were collected from 21 metrological stations distributed throughout Bangladesh over a 50-year period (1965-2015) to evaluate the magnitude of these changes statistically and spatially. The Padma, traditionally considered as a dominantly meandering river, is switching over into a braided river due to its highly susceptible nature of erosion and deposition. Results reveal that the tidal range is high during the dry season and increases from upstream to downstream of the river. Climate change may bring changes upstream by changing rainfall intensity, flood severity, and extreme temperature. More inundation can occur due to sedimentation, and more bank erosion can occur at the same time. An exponential increase of morphological activity with increased river flow, water discharge, bank erosion might substantially increase in the future. The changes in the flow introduced by climate change would impact the morphology of the Padma River of Bangladesh during the monsoon. A major change has been observed in the location of the bank and channel, as well as bars, along with their geometry and morphology over time. It is also observed that the bank line is not stable and migrated continuously. The overall width of the Padma River is varied significantly during the last 50 years. Maps and Landsat images represented that the river channel is shifting abnormally. Both climatic parameters and anthropogenic activity play an important role in fish biology and production. From this study, it is hypothesized that this assessment's findings might help understand the overall hydrodynamic and morphological nature of the Padma River. It will suggest possible future developmental works that might be implemented on this river.

Keywords

Climate Change, Anthropogenic, Geomorphology, Morphology, Padma River

1. Introduction

It is widely recognized that Bangladesh is one of the most vulnerable countries to the consequences of global warming and climate change. This is due to its peculiar geographical position, floodplain supremacy, low sea elevation, high population density, high poverty levels, and overwhelming dependency on nature, energy, and services. Intergovernmental Panel on Climate Change (IPCC, 2020) report predicts for South Asia that monsoon rainfall will be higher, resulting in increased flows during the monsoon in the rivers, and sea-level rise. Severe floods, tropical cyclones, storm surges and droughts are likely to become more frequent. Besides these, climate change with higher associated rainfall and relative sea-level rise will likely cause significant changes in sediment and flood regimes. The main issue of climate change particularly changes in precipitation pattern that may affect morphological processes, such as changes in sediment load. The river of Bangladesh is very dynamic as most of Bangladesh has been formed by recent sediments, and rivers are loaded with a huge deposit as well as partly because of the tidal and seasonal variations in river flows and runoff.

Rivers are extremely sensitive to environmental conditions (Eaton et al., 2010; Rozo et al., 2014), and alluvial channels can respond or readjust at a range of rates to the variations caused by water and sediment inputs and human activities. (Hanif et al., 2020; Islam et al., 2017, 2020; Rahman et al., 2016). The Padma River will become a wetland, impacting the navigation, agriculture, fishing, and transportation facilities of the surrounding areas. Finally, it will damage the biodiversity and ecological balance of the southern part of Bangladesh. These problems could be solved only when we will be able to know the actual hydrodynamic and morphological behavior of this river. Therefore, a hydro morphological study of the Padma River is of utmost necessity to identify the hydrodynamic and associated morphological changes of the river.

A small number of research works were noticed on river erosion and their impact on livelihoods in Bangladesh. Some researchers worked on the Brahmaputra, Jamuna, Meghna, and Padma River based on their erosion hazards and their influence on livelihoods and disaster risk reduction strategies on the river-side area (Islam et al., 2017; Rahman et al., 2018). Researchers are especially interested in the Char Janajat region, the site of the latest crossing of the Padma Bridge. As one of the biggest construction projects of Bangladesh, the Padma Bridge will connect the eastern and western parts of the country and shorten travel times between some locations from thirteen hours to three. There are some concerns that erosion could threaten the bridge; however, some researchers claim that once it is completed, it could stabilize the land and decrease erosion.

The monitoring of morphological changes is one of the important studies in geomorphological process analysis. It is also an exciting area of study when associated with anthropogenic activities. In this case, the Padma River was selected as a research location to analyze the morphological changes due to climate change and anthropogenic interferences. Migration of the river through bank erosion and bed scouring is common and is believed, by many, to have been aggravated in recent times in response to increased human activities (Sharma et al., 2010; Afrin et al., 2018). However, the water shortages caused by diversion at Farakka are reported to have increased erosion (CEGIS, 2003; Hossain et al., 2013). The impact of floods on river dynamics remains largely unclear since flooding in the Ganges system is also believed to be one of the major drivers of channel degradation (Jain et al., 2012).

Climate change is now a reality, with the effects already surfacing in many parts of the world. Bangladesh needs to prepare now for adaptation to climate change and safeguard the future well-being of its people. Increased riverbank erosion is likely to displace millions of people who will be forced to migrate, often to slums in cities. Several million people's lives and livelihoods are threatened by floods, floodplain sedimentation, and Riverbank erosion of the Padma River. Thereby, it is now time to assess the impact of climate change on the morphology of the Padma River and the subsequent effects on hilsha fisheries migration routes, and the nation can prepare itself to mitigate the effects.

2. Materials and Methods

The basic method of this study is empirical and the review of works of literature. The geomorphic information was taken using a descriptive approach including a geomorphologic survey of the river bed, changing pattern of the river flow, temperature and rainfall anomalies within the time frame (months and annual). On the other hand, the human interferences are enlisted that are responsible for the change of geomorphology of the Padma River. All available climate parameter data are analyzed using different mapping forms where extreme temperature and precipitation are emphasized with geomorphological characteristics of the rivers and labeled with Q-GIS accordingly.

2.1. Study Area

The Padmariver in Bangladesh lies between longitudes 90.49E and 87.42E and latitudes 24.34N and 23.20N. The study area is in northwestern Bangladesh, located in the channel-bar complex bank of the Padma River, Bangladesh. This river is the one of the major river in Bangladesh started from Rajshahi and connected with Jamuna River at Goalando area. The river bank erosion and regular flood affected much more than other rivers in Bangladesh.

2.2. Data and Methods

The monthly dataset of the minimum and maximum temperatures and rainfall from 21 stations across Bangladesh during the period 1965-2015 that was used and analyzed in this study was given by the Bangladesh Meteorological Department (BMD, 2013). In order to detect any patterns in temperature and rainfall time series results, a linear regression analysis using the least square method was applied and the 95% confidence level was taken as the threshold. The Inverse Distance Weighted (IDW) interpolation technique and geographical information systems (GIS) have been used to map the spatial distribution of temperature and rainfall and their patterns and variability.

This study uses multi-temporal Landsat imageries at a 30 m spatial resolution for fifty years (1971-2020), to monitor long-term changes the river channel morphology of the Padma River. Maps were used to record each Landsat scene to the Bangladesh Transverse Mercator (BTM) system, an area of specific standard UTM (Universal Transverse Mercator) projection. Long term daily water level and discharge data were collected from the Bangladesh Water Development Board (BWDB, 2020). The CEGIS provided data related to human-made riparian structures.

The satellite images make a poor resolution to evaluate the fluvial channel morphology of river systems. For that reason, integrating satellite image and field data may provide a better option for understanding the river morpho-dynamics. The data used in the study were collected during the dry season from the Geological Survey of Bangladesh (GSB). Moreover, data would be more likely to attain the cloud-free condition of Landsat images during the dry season, and other ground conditions were relatively consistent. The behavior of major channel patterns of the river was analyzed from 1971 to 2020.

The satellite imagery results were evaluated to define the relations between riverbank line and bar growth. The images were acquired by Landsat satellites: The Thematic Mapper on Landsat 5, the Enhanced Thematic Mapper Plus on Landsat 7, and the Operational Land Imager on Landsat 8. They include shortwave infrared, near infrared and visible light to highlight differences between land and water. Q-GIS and Adobe illustrator graphical software were used for image processing and interpretation. Geomorphic maps were prepared from each digitally classified image showing river channels, sand bars, and riverbank lines, etc. Finally, a spatial superimposition of each classified image's bank line between three years was carried out by using the GIS techniques to generate a map showing the changes in detection of fluvial channel dynamics.

2.3. Software Used for Mapping

Using Q-GIS software and its extensions were used to evaluate the left and right banks' positional changes and curvature, mean channel width, and total channel surface area. Using GIS overlay techniques; two temporally succeeding bank lines were compared in order to calculate the bank line movement of each segment over the epoch. Using GIS tools, the total channel area for each measurement period, including the area occupied by mid-channel sandbars was assessed by dissolving the polygons representing the sandbars. The GIS then calculated the area of the overall channel polygon for each reach. The river width was taken as the distance between the extreme right and left banks and, therefore, included any mid-channel bars' width. The width of the river at the start of the segment was then measured, and the mean channel width for each reach was calculated from the sum of the appropriate widths.

3. Results and Discussion

3.1. Trends of Rainfall and Temperature

The spatial pattern of rainfall and temperature trend from 1965 to 2015 is shown in Figure 1, which was developed for the 21 weather stations using measured trend statistics. As shown in Figure 1(a) the spatial trend of rainfall demonstrates a regional disparity as well as variations in rainfall in Bangladesh. The upward trend in annual rainfall was highest (10 to 13.14 mm per year) in the hill districts, located in the southeastern part of Bangladesh, when comparing the districts. However, at the stations of Rajshahi, Bogra, Ishurdi, Dhaka, Faridpur, Comilla, Shatkhira and Barishal, a negative pattern of annual rainfall was found

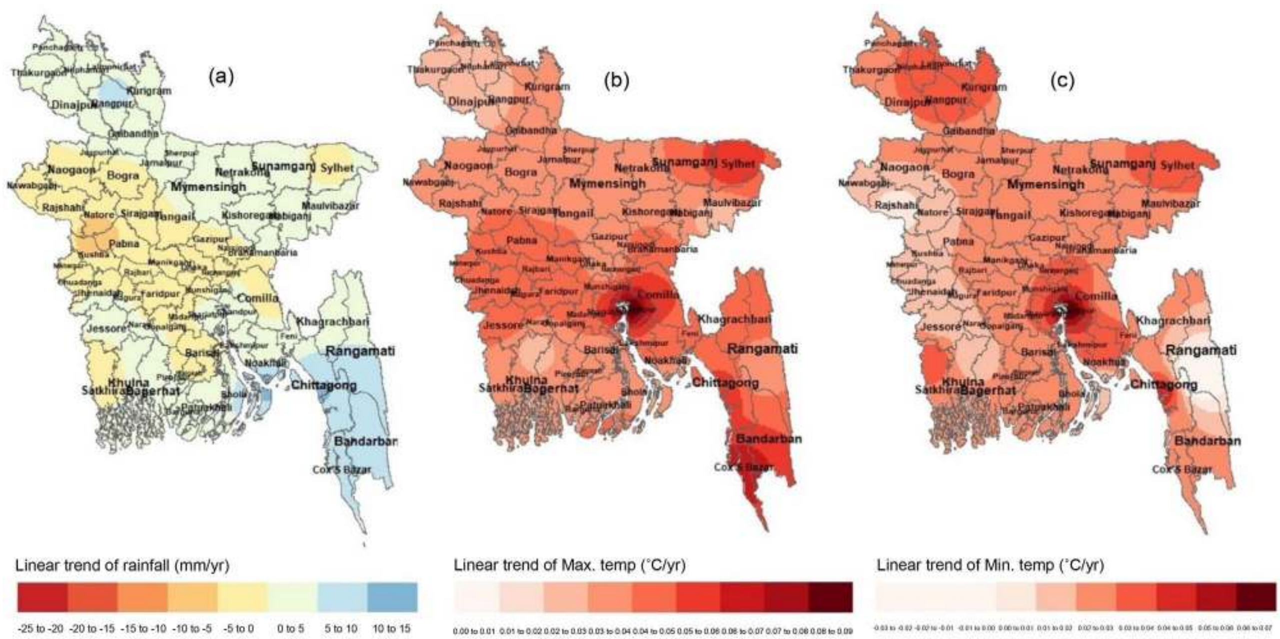

Figure 1. Trends of annual (a) rainfall (mm per year), (b) mean maximum temperature (˚C per year) and (c) mean minimum temperature (˚C per year) from 1965 to 2015.

(−0.30 to −7.93 mm per year). Although the results of the present study align with those of Shahid (2010), in which annual rainfall in Bangladesh was a positive trend. Shahid (2010) found a significant upward trend in the western part of annual rainfall; however, a significant upward trend was mostly observed in the south-eastern and north-western parts of Bangladesh in the present study. Low rainfall in the northwestern, western, central, and central southern parts has been reported in the last decade and high rainfall in the south-eastern and northeastern parts has been recorded (BMD, 2013).

As seen in **Figure 1(b)** and **Figure 1(c)**, all of the weather stations presented a positive trend, except at the Rangamati station for the mean minimum temperature. The mean maximum and minimum temperature spatial pattern indicates an upward trend of 0.02˚C to 0.09˚C and 0.001˚C to 0.07˚C per year, respectively, across the region, while an exceptionally high trend was noticed at Chandpur station for the mean maximum and minimum temperature. Pursuant to **Figure 1(b)** and **Figure 1(c)**, it can be said that the northern, northwestern, southern, southeastern and to some extent, central parts of the country are warming at an alarming rate. This may be linked to the impact of global warming and climate change.

It has been observed that in the last 50 years' time scale, the annual mean maximum and minimum temperature has increased by nearly (range of 1 - 4.50˚C) and (range of 0.05 - 3.50˚C), respectively. The increasing trend was reported by Keka et al. (2013) and Nasher and Uddin (2015). Global average air temperature has increased by nearly 1.70˚C over the past century (Collins et al., 2013). The change in air temperature generally changes water temperature. However, the secondary data of this study revealed that the mean annual air temperature of Bangladesh has increased, which perhaps indicated that the surface water temperature of fish habitats has also increased.

3.2. Impact of Temperature Anomalies on Fisheries

The frequencies and intensities of extreme climate events are likely to have a major impact on future fisheries production. The effects of temperature variation could be negative or positive, depending on the severity and extremity of the shift in the climatic elements. Fisheries are particularly vulnerable because aquatic habitats directly absorbed and store part of the solar heat energy; most fish species are cold-blooded. Most of the Physico-chemical parameters and the quality of water bodies interact with the water temperature. Elevated temperatures positively alter the breathing rates, feed consumption, enzyme activities, oxygen consumption, and feed metabolism (Smith, 1989), thereby affecting fish growth. An increase in water temperature will exacerbate these situations with a resultant decrease in the fish population.

3.3. Morphological Changes Detection of Padma River over Time

The Landsat satellite images were used to show the changes in the Padma River channel dynamics over the three decades. It indicates that the Padma River became a more sinuous character over time. It signifies that the Padma River becomes meander to semi braided river in nature. It showed that the erosion of the bank line was increased significantly and changes in river channel dynamics (**Figure 2**). Channel area has been dramatically changed for the rapid sedimentation in the right (west) bank rather than left (east) bank due to the sinuosity ratio increased in the right channel. It reveals that the lateral erosion has been increased because of the high rate of sedimentation over the 50-year time periods.

In recent years, Padma's erosion rates have decreased. Erosion slowed as the meandering bends disappeared due to sedimentation-when the water flows across the land instead of following the curve of the river. But that does not mean the area is free from erosion. Any disturbance in the ecosystem, such as floods, landslides, or construction, could influence the morphology of the river.

3.4. Water Flow of the Padma River

The flow of water in the Padma is much better than that of previous years, all because of the sudden rise of water level in September and October last year, according to the Hydrology Department, a wing of the Ministry of Water Resources (Daily Star, January 01, 2020). The Padma is flowing above 1 lakh to 1.4 lakh cusec at the Hardinge bridge point in 2019 although the water level was 80 to 90 thousand cusecs in 2018. This is the highest ever water level in the Padma during the dry season, and the water level increased in September and October last year due to the sudden flood.

Figure 2. Comparison of Landsat satellite images of Padma River from 1988 to 2018.

The water flow of the selected locations of the river is shown in **Table 1**, based on BWDB (2020).

The Padma River has a mean flow of around 30,000 m^3/s, full bank flow about 76,000 m^3/s, and transport roughly 1×10^9 t/year of sediment, making it one of the largest rivers in the world (McLean et al., 2012). Physiographically, the study area occupies the Ganges River Floodplain. Geologically, the area is situated in the north-northwestern part of the Bengal Basin.

The Padma enters in Bangladesh from India at Nawabganj district and flows about 110 km along with the international border of Bangladesh and India occupying the territory of both countries. The length of the river downstream of this reach flowing inside Bangladesh up to the confluence with the Jamuna River is 130 km. Changes in river flow will likely cause river morphology changes, particularly in sensitive systems, which include fine-grained alluvial streams. The potential impacts of increased discharge have channel enlargement and incision, a tendency toward either higher sinuosity single channels or braided patterns, increased bank erosion, and more rapid channel migration. High massive floods will result in sudden changes to channel characteristics that may trigger greater long-term instability of rivers. Increased frequency of massive floods will tend to keep rivers in a modified and unstable state. Decreased discharge often results in channel shrinkage, vegetation encroachment into the channel, sedimentation inside channels, and channel pattern change toward more stable, single-channel patterns. There may be reductions in the stability of the valley walls in entrenched or confined valleys and, hence, increases in the rate of erosion caused by a greater tendency for streams to erode the valley walls. Increased valley-side erosion will increase sediment delivery to the streams with consequences for stream morphology.

3.5. Rainfall Caused Geomorphological Changes of Padma River

Rainfall intensity is a major factor in controlling such phenomena as flooding, soil erosion rates, and mass movements (Sidle & Dhakal, 2002). There is some evidence that rainfall events in several countries have become more intense during recent warm decades. Examples are known from the United States (Karl & Knight, 1998; Kunkel, 2003), Australia (Suppiah & Hennessy, 1998), Japan (Iwashima & Yamamoto, 1993), South Africa (Mason et al., 1999), and Europe (Forland et al., 1998). In the United Kingdom, there has been an upward trend

Table 1. Point wise water flow of Padmariver in Bangladesh.

Location	District	Min	Max
Pakshi, Ishwardi	Pabna	6.24 mPWD	15.19 mPWD
Debagram, Golando	Rajbari	2.57 mPWD	10.21 mPWD
Baghra, Sreenagar	Munshiganj	3.50 mPWD	7.58 mPWD
Kedarpur, Naria	Sariotpur	2.48 mPWD	5.94 mPWD

Source: BWDB (2020).

in the most massive winter rainfall events (Osborn et al., 2000).

There are various reasons to expect increases in extreme precipitation if and when significant warming occurs. There will be more moisture in the atmosphere, and there is likely to be greater thermodynamic instability (Kunkel, 2003). Some dry regions will suffer particularly large diminutions in soil moisture levels (Wetherald & Manabe, 2002) and annual runoff (sometimes 60 percent or more). The sensitivity of runoff to precipitation changes is complex, but relatively small rainfall changes can cause proportionally larger changes in the runoff in some environments. As rainfall amounts decrease, the proportion that is lost to streamflow through evapotranspiration increases. On the other hand, a research group reported that the high rainfall marked the lowest fish production due to floods (Olaoye et al., 2010).

Therefore, the rivers are susceptible to changes in parameters like flood flow, sediment load, and base level. The river may take long periods for adjustment in fluvial processes and morphological forms against the changes.

3.6. Comparison of Satellite Images of Padma River

The extreme erosion patterns have two leading causes. First, the Padma is a natural, free-flowing river with little bank protection, other than some occasional sandbags to protect buildings. Second, the bank sits on a large sand bed that can be eroded quickly. Like parents measuring a child's height, scientists measure erosion on the Padma River by noting differences in its width, depth, shape, and overall appearance. These natural-color satellite images show the changes to the shape and width of the Padma since 1971, and each twist and zigzag tells a different geologic story about the river. All images were acquired in January and February, during the dry season.

Based on the observed images of the river, the Padma shows the greater spatial extent of the channel widening at Hardinge Bridge. Within 240 km reach of the Jamuna, neither the alignment nor the spatial extent has differed distinctly for climate change conditions. Abrupt shifting of the channels from one bank to another bank is not seen. However, there are some sporadic locations where noticeable change is seen. More straightening at the downstream portion of the river is observed due to climate change conditions. At upstream of the proposed Padma Bridge, increased bed erosion has been found.

3.7. Channel Shifting

River morphology and channel shifting are primarily determined by the topography, channel material, water flow, and sediment from the surrounding basin. Historical evidence and current understanding of fluvial geomorphologic processes indicate that rivers are highly responsive to changes in these processes. Quantitative analyses of channel shifting positions demonstrate that west side migration has occurred in the Padma River (**Table 2**). This is due to the right bank (west) between 1977 and 2000 that has not balanced by the left bank (east) between

Table 2. The distribution of westward channel shifting of the Padma River (Islam, 2016).

Duration	Right bank (west)	Left bank (east)	Central line
Since 1977	2 - 3	−2	−0.5
1977-1989	3	1	1
1989-2000	6	−1	−1

Note: Data are in kilometers, and a minus sign denotes eastward shifting.

1977 and 2000. The changes in trend line can be ascribed mostly due to a switch in the direction of the right (west) bank migration: before 1977, this was advancing direction eastwards at a slower rate than the east (left) bank was retreating to produce eastward movement and narrowing the channel.

Conversely, since 1977, the right bank has been retreating at a higher rate than that of the left bank, producing westward movement and accelerated widening channels in recent decades. The findings show that the river moves from the east to westward. It is complex because of its topography, exhibiting morphological characteristics attributed to neo-tectonics, fluvial processes, and sedimentation associated with the right bank distributors. The future study requires predicting precisely morphological changes and its trend line position in the Padma River. The channel shifting of the Padma River was obtained during the time periods of 1977 to 2000 (23 years) (Islam, 2016).

During the 1977s, the bank line movement was relatively slow. To get a clear picture and compare the changes of the bank line of Padma River using the GIS superimposed have shown on the 1977-1989 and 1989-2000 satellite images, different rates of bank erosion were detected in the periods1977 to 2000. The bank line shifting was identified significantly at the upstream side, which occurred in the westward direction of the Padma River. In contrast, minor eastward shifting of the bank line was observed in the lower part of the Pakshi area in northwestern Bangladesh (**Figure 3**). From the overall observation of channel, shifting indicates that the channel shifting at the upper middle part of Padma River (Rajshahi district) showed westward shifting of bank line while the lower part (Pabna district) of the river shifted in an eastward direction from 1977 to 2000 time periods. The width of the Padma River almost doubles in (1989-2000) compared to (1977-1989). The satellite images show that the Padma River's overall width has increased from around 4 km to 6 km during the last 23 years. Mid channel bar like Gargari is eroded mostly and shifted its original position. The bank migration was prominent in those areas. The previous results of Talukder and Islam (2006), and Uddin (1973) supported this finding. From the above discussion, it is clear that the Padma River bank is very much unstable and changes its banks often frequently.

The movements of the left and right banks of the Padma River are shown in **Figure 3**. The left bank shows a great deal of movement between locations 10 and 40 km, which is not reflected by the right bank. Within the 120 to 200 km,

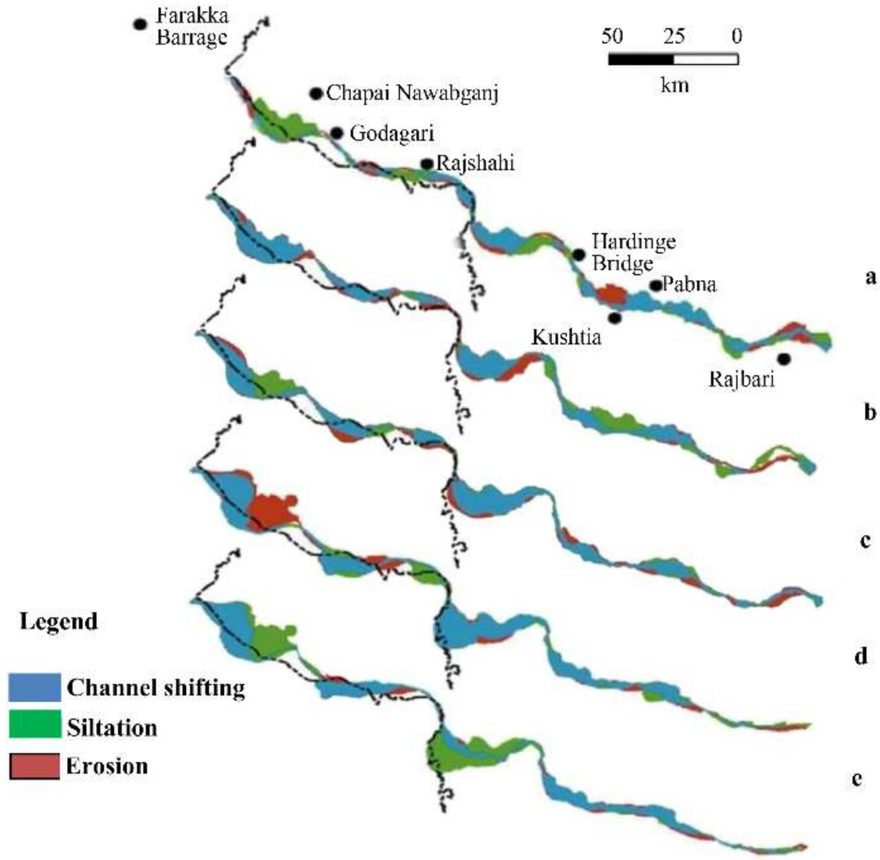

Figure 3. Year wise comparison of spatial patterns of siltation and erosion of the Padma River. The letters of ride sides showed different durations; (a) denotes 1971-1980; (b) denotes 1981-1990; (c) denotes 1991-2000; (d) denotes 2001-2010 and (e) denotes 2010-2020.

both banks show a similar degree of movement. The maximum left bank erosion occurred in 1981-1990 and 2001-2010, where eroded distances are 34 and 27 km. The number of periods during which the siltation rate exceeds erosion at five on the right bank, compared to another time during which the channel narrows. During the first three periods (1971-2000), the reverse two durations (2001-2010 and 2011-2020) exceeded along the left bank with an earlier pattern of excess siltation. In 1981-1990 the highest siltation was observed, where 70 sq. km/yr, while in 2001-2010, the most increased erosion occurred (212 sq. km/yr). An average of 7.98 sq km/yr of land was accreted along the left bank over the 40 years, compared to 5.2 sq. km/yr of erosion. Overall, a total of 190 sq. km of land was eroded along the left bank compared with 230 sq. km of accretion.

The channel shifting reveals that during the last 50 years, about 66 sq. km of land has been gained along the left bank of the Padma. The right bank of the Padma is more prone to erosion than accretion. Except for the first period (1971-1980) and last (2011-2020) epochs, right bank erosion exceeded accretion.

The erosion, siltation, and channel shifting can affect fish populations by covering the spawning sites with silt or deep, slow water or blocking access to upstream spawning grounds. These remarkable changes have led to spawning habitat siltation and probably restrict access to spawning grounds for some species. However, where spawning habitat is limiting, the modified river morphology may affect fish populations. Observations of extensive sediment accumulation behind the Hardinge Bridge support the hypothesis that over a long period can significantly change the river's morphology.

3.8. Impact of Climate Change on Riverbank Erosion and Deposition

Riverbank erosion is increased by climate change. Bank erosion has also risen at some of the locations of the Padma River. As the Padma could accommodate the increment of flow by increasing its conveyance area, the bed erosion of the Padma increment is quite high. Increment of water flow due to climate change has been reflected in bed erosion and deposition changes. The higher amount of flow would cause higher bed erosion at some of the locations. At downstream getting eroded materials, deposition is also observed, which can be visualized in the Padma River case, shown in bed level contour (**Figure 3**). However, an increase in bed erosion at a location upstream of the Pakshey Bridge area has not been found much but upstream of the Padma Bridge (under construction) has been found significant for climate change conditions in comparison to an existing condition.

The geomorphic information will be taken using a descriptive approach, including a geomorphologic survey of the river bed, changing pattern of the river flow, temperature, and rainfall anomalies within the time frame (months and annual). In this regard, the Padma River (based on water flow path) was illustrated in **Figure 4**.

The Padma is one of the major rivers of Bangladesh, and satellite imagery shows that it has been growing in size, transforming in shape, and changing in location for at least the past 50 years. Every year, hundreds (sometimes thousands) of hectares of land erode and fall into the Padma River. The extreme erosion patterns have two leading causes. First, the Padma is a natural, free-flowing river with little bank protection, other than some occasional sandbags to protect buildings. Second, the bank sits on a large sand bed that can be eroded quickly.

The Padma is a typical meandering river with high dynamics in nature. The morphological change is comparatively high because of the alteration of the fluvial flow regime of the river. The satellite images show that the island area on the right bank of the river channel is increased due to the high rate of sedimentation. In the last 50 years, the Padma River has shifted dramatically from east to west, considerably near the Rajshahi district. This situation is alarming due to bank erosion in the west bank rather than the east bank of the Padma River.

3.9. Impact of Climate Change on Water Flow of Padma River

The impact of increased flooding of the country, like other rivers, the Padma River has positive or negative depending on the severity. The floods experienced in many parts of Bangladesh in the rainy season and the devastating effect are

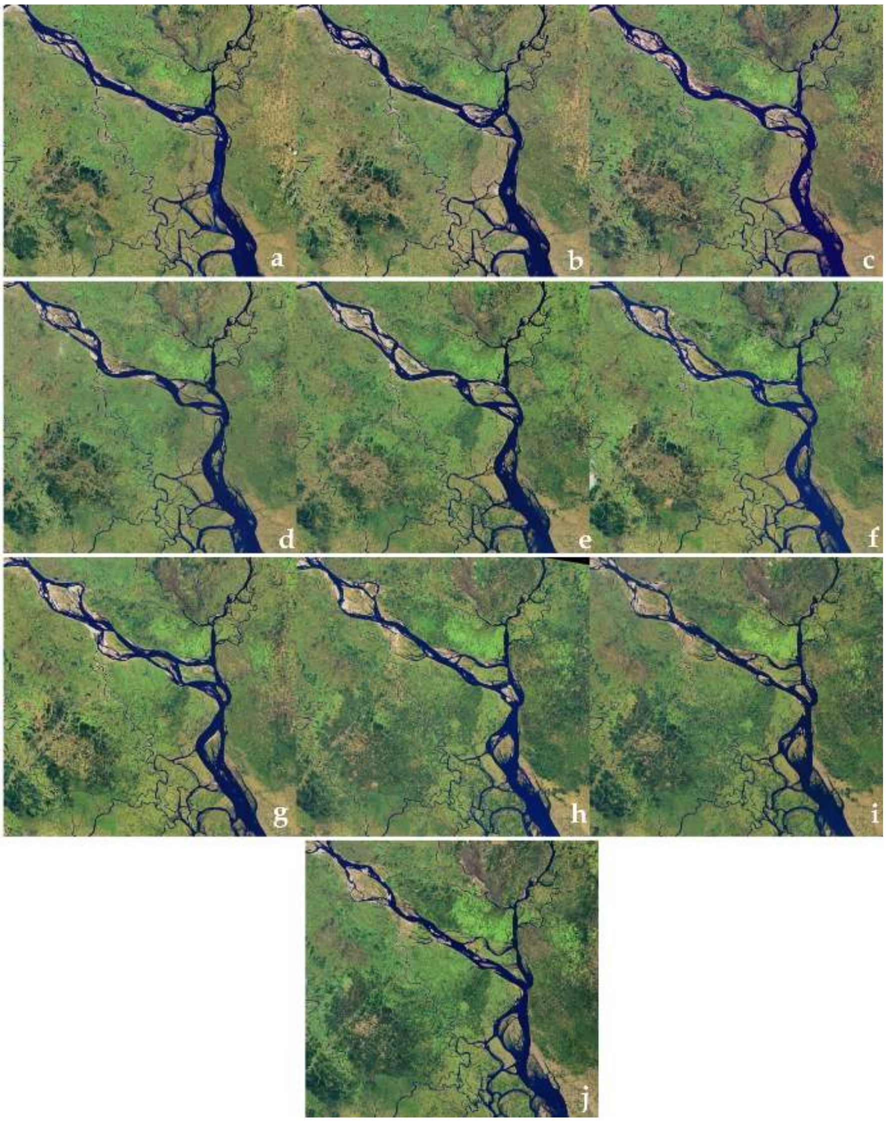

Figure 4. Geomorphic Variations of the Padma River in Bangladesh-focusing water flow. Years are marked using letters where (a) for 1971; (b) for 1975; (c) for 1980; (d) for 1985; (e) for 1990; (f) for 1995; (g) for 2000; (h) for 2005; (i) for 2012; and (j) for 2020.

attributable to climate change. There are indications that the country should prepare for hard times ahead. The relief of this historical flood and huge economic loss should be explored to create awareness of climate change dangers and the need for mitigation and adaptive measures. The impacts could also be positive. Increased rainfall and flooding will lead to the inundation of the adjacent land areas, which will benefit fisheries. It expands the littoral zones and increases the diversity of the fish movement, breeding, and rearing of the juveniles. Erosion of coastal zones, siltation of breeding and feeding sites, displacement of fish to new habitats often caused by excessive floods are detrimental to fisheries.

Insufficient water flow in the river basins causes spawning and primary production, thereby affecting fish production. Water flow also depends on the geomorphology and discharge of water in the river. Ultimately, the geomorphology of a river directly affects the habitat for fishes. A decreasing trend in *T. ilisha* catch has been reported at the Indus River at Sindh of Pakistan, and a major factor affecting the fishery was a low flow of freshwater to the sea, which directly affects the natural migration of the species (Panhwar & Liu, 2013).

3.10. Impact of Anthropogenic Activities on River Morphology and Fisheries

Water flow and sedimentation of a river are controlled not only by climatic parameters but also by man-made activities. River channel modifications like bridge, dam, and embankment constructions are responsible for water abstraction. Anthropogenic climate change impacts on river channel systems result from the direct effects of rising temperature trends and indirectly influences the hydrological cycle, leading to change in rainfall patterns and evapotranspiration rates. The construction of dams and other water regulatory structures have a significant impact on fish migration and their population (Galib et al., 2018). Such man-made activities like obstruction in spawning routes can affect the natural phenomenon for fishes like-spawning and recruitment processes (Lucas & Baras, 2001).

Based upon the secondary data, the declining trend of hilsa fishery in the inland waters, particularly from the river Padma in Bangladesh, has also been reported (Haldar & Amin, 2005). Both habitats and fish species can badly be affected by water regulatory structures (Mohsin et al., 2009; Samad et al., 2010). Various anthropogenic activities increased siltation and rising of the river basins disturbed, displaced, or even destroyed the migratory routes as well as spawning grounds of hilsa (Miah, 2015).

4. Conclusion

Bangladesh is recognized worldwide as one of the most vulnerable countries to the impacts of climate change. Serious floods, tropical cyclones, storm surges, and droughts are likely to become more frequent. Apart from these, climate change with higher associated rainfall and extreme temperature will likely cause significant changes in sediment and flood regimes. The changes in flood regime due to changes in precipitation patterns may affect the Padma River morphology. Precipitation anomalies also cause changing the load of sediment. Thus, the river may take long periods for adjustment in fluvial processes and morphological forms against the changes. Since too much rainfall reduces fish production due to over flooding, which also affects fish species' migratory behavior, the Government and respective authority should include sluice gates, spillways, etc. to help stop over flooding.

In analyzing the temperature over Bangladesh, a general increasing trend has been noticed. The mean maximum and minimum temperature spatial pattern indicates an upward trend of 0.02˚C to 0.09˚C and 0.001˚C to 0.07˚C per year, respectively, across the region, while an exceptionally high trend was noticed at Chandpur station near the Padma River for the mean maximum and minimum temperature. An upward trend in annual rainfall was highest (+10 mm per year) in the hill districts, located in the southeastern part of Bangladesh. However, at the stations of Rajshahi, Bogra, Ishurdi, Dhaka, Faridpur, Comilla, Shatkhira and Barishal, a negative pattern of annual rainfall was found (−0.30 to −7.93 mm per year). There is increasing concern over the consequences of climate change for fisheries production all over the country. The fisheries of the Padma River are influenced by changes in hydrographic and meteorological variables, such as temperature, rainfall, and severe climate events.

Anthropogenic activities have significantly affected morphological changes. In this case, vertical and horizontal changes over six months in the selected segment of the Padma River valley have been triggered by mining activities. However, an anthropogenic activity can typically lead to faster morphodynamic changes than natural processes, such as erosion or sedimentation. Besides, aerial mapping is beneficial for monitoring rapid morphodynamic changes due to anthropogenic processes. If the sand mining continues in the depleted location, riverbank failure could occur because of unstable river valley slopes. This study aims to explore the change of fluvial channel dynamics and the shifting of the Padma River channel.

The research studied to present an indication regarding the influence of climate change on the river morphological behavior of the Padma River system. The work has been done with some limited data to indicate and shed light on further research and study in this river. Geomorphology and climate change are strongly interrelated in fish production and must be addressed jointly. Further studies on fishery and biology of the stocks in the context of environmental changes in the Padma River are also recommended.

Acknowledgements

A research grant funded the research from the BFRI (Bangladesh Fisheries Research Institute) under the project entitled "Strengthening of Hilsa Research in Riverine Station, Chandpur Project"; Project Code: 224069100. Thanks to Professor Dr. Md. Yeamin Hossain, Dr. AKM Shakur Ahmed and Dr. Mohammad Ashraful Alam who helped with their constructive comments and suggestions during the annual workshop and in every step of the research works, and to the postgraduate students during field observation and data acquisition.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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