https://doi.org/10.31436/iiumej.v27i3.4347

GIS-Based Geospatial Assessment of Net Land Surface Change for Identifying Erosion-Accretion Hotspots Along the Padma River in Bangladesh

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(Received: 16 April 2026; Accepted: 30 July 2026; Published online: 11 September 2026)

ABSTRACT: Erosion is a continuous natural process that reshapes Earth's surface. It causes geohazards, loss of fertile lands, and has detrimental effects on the environment. This study provides an extensive analysis of erosion and accretion patterns over decades along both banks of the Padma River, the main distributary of the Ganges. Satellite images from Landsat and Sentinel were processed in ArcGIS to extract and compare banklines using a 5 km river-reach framework to identify net land surface change and erosion-accretion hotspots. The temporal scope included both long-term decadal analysis from 1990 to 2020 and recent annual assessment from 2016 to 2022; however, the two periods were interpreted as period-specific estimates rather than statistically tested temporal trends. Results show that erosion dominated accretion across both banks. During 1990-2020, average erosion and accretion rates on the left bank were 464 ha/year and 18 ha/year, respectively, while the corresponding rates on the right bank were 758 ha/year and 285 ha/year, respectively. For the recent 2016-2022 period, the average erosion and accretion rates were 221 ha/year and 177 ha/year on the left bank, and 1035 ha/year and 171 ha/year on the right bank, respectively. These values indicate that the right bank experienced higher erosion activity than the left bank in both the long-term and recent assessment periods. Finally, the 5 km chainage-based hotspots analysis using the net land surface change identified the most critical localized erosion-prone reaches on the right bank within Faridpur, Madaripur, and Shariatpur, while major left-bank erosion hotspots were found within Manikganj, Munshiganj, and Dhaka. These results highlight the importance of priority-based erosion monitoring and riverbank management for industrial site selection, riverbank protection planning, and identifying suitable locations for hydraulic structures along the river.

ABSTRAK: Hakisan adalah proses semula jadi berterusan yang membentuk semula permukaan bumi serta menyebabkan geobahaya, kehilangan tanah subur, dan kesan buruk terhadap alam sekitar. Kajian ini menganalisis corak hakisan dan akresi di kedua-dua tebing Sungai Padma, iaitu cabang utama Sungai Ganges. Imej satelit Landsat dan Sentinel diproses menggunakan ArcGIS bagi mengekstrak serta membandingkan garis tebing berdasarkan rangka kerja rantaian sungai 5 km bagi mengenal pasti perubahan bersih permukaan tanah dan lokasi tumpuan hakisan-akresi. Skop temporal merangkumi analisis dekad jangka panjang dari 1990 hingga 2020 dan penilaian tahunan terkini dari 2016 hingga 2022; namun, kedua-dua tempoh ini ditafsir sebagai anggaran khusus tempoh dan bukan sebagai trend temporal yang diuji secara statistik. Dapatan menunjukkan bahawa hakisan lebih dominan berbanding akresi di kedua-dua tebing. Bagi tempoh 1990-2020, kadar purata hakisan dan akresi di tebing kiri masing-masing ialah 464 ha/tahun dan 18 ha/tahun, manakala di tebing kanan masing-masing ialah 758 ha/tahun dan 285 ha/tahun. Bagi tempoh 2016-2022, kadar purata hakisan dan akresi ialah 221 ha/tahun dan 177 ha/tahun di tebing kiri, serta 1035 ha/tahun dan 171 ha/tahun di tebing kanan. Nilai ini menunjukkan bahawa tebing kanan mengalami aktiviti hakisan yang lebih tinggi berbanding tebing kiri pada kedua-dua tempoh penilaian. Analisis lokasi tumpuan berasaskan rantaian 5 km mengenal pasti kawasan hakisan kritikal di tebing kanan Faridpur, Madaripur, dan Shariatpur, manakala lokasi utama di tebing kiri dikenal pasti Manikganj, Munshiganj, dan Dhaka. Dapatan ini menekankan kepentingan pemantauan hakisan dan pengurusan tebing sungai secara berkeutamaan bagi pemilihan tapak industri, perancangan perlindungan tebing sungai, dan penentuan lokasi struktur hidraulik di sepanjang sungai.

KEYWORDS: *Erosion, Accretion, ArcGIS, Landsat, Sentinel.*

1. INTRODUCTION

Riverbank erosion washes away soil from one side and deposits it on another, eventually reshaping the land. This phenomenon is harmful to the environment in many ways [1]. When the land is eroded, fertile soil and plants are lost, and the quality of the land is reduced [2]. Hence, erosion also destroys habitats for many animals [3]. The eroded soil increases the sediment particles in the water, which increases the turbidity and reduces the light that fish and other aquatic life need to survive [4]. Erosion also forces people to relocate, leaving their homes and livelihoods [5]. This relocation often leads to cutting trees to make new places suitable for living and farming [6]. These changes can create serious pressure on the local ecosystem and natural resources [7]. The occurrence of this riverbank erosion is an unpredictable disaster that occurs frequently within Bangladesh, consequently leading to severe repercussions [8].

The Padma River is one of the major rivers in Bangladesh and is morphologically highly dynamic, which makes it susceptible to erosion of the riverbanks and channel shifting [9]. Owing to its intensive channel shifting and incessant bank erosion, the river is known as ‘Sharbagrashi’, which means ‘disastrous’ in English [10]. There are two main causes of riverbank erosion: natural factors and anthropogenic (human) activities [11]. Natural factors include water discharge, runoff events, active tectonics, sediment supply, and climate change, whereas anthropogenic activities include land cover change, construction of hydraulic structures on the riverbed, and illegal sand mining, all of which accelerate riverbank erosion and channel shifting of the Padma River [11]. Three mechanisms primarily cause riverbank erosion: mass failure, fluvial entrainment, and subaerial weakening and weathering [12].

The left bank, which is located north of the bridge location, shows a certain level of resistance to erosion over considerable stretches owing to the presence of clay soils, whereas significant fluctuations in erosion and deposition patterns are observed along the right bank, which predominantly comprises fine-grained soils with no cohesive arrangement [13]. The outer bank of the flanking meandering channel is typically prone to riverbank erosion, and the erosion rate and erosion pattern are greatly influenced by the characteristics of bank materials [14]. The Padma and the Lower Meghna are alluvial rivers that are predominantly formed of sediments related to floods, while the bank materials mostly consist of sediments that are fine-grained and cohesive in nature [15]. These alluvial rivers are prone to frequent channel changes from reach to reach, owing to the continuous process of erosion and accretion [13]. Planform change has increased the sinuosity ratio and braiding index, clearly indicating differences in erosion along the river [16]. Hence, riverbank erosion in the Padma River is considered a perennial problem, resulting in the loss of a huge amount of landmass, settlements, and

https://doi.org/10.31436/iiumej.v27i3.4347

livelihoods [17]. For decades, the Padma River's complex geography has caused it to meander, twist, and weave in zigzag patterns, leading to intense erosion and accretion that displace farmlands, houses, and even lives [10]. As a result, thousands of floodplain dwellers lose their land due to this riverbank erosion, rendering them homeless and landless [6]. The effects of riverbank erosion are particularly severe in the areas of Harirampur, Tongibari, Faridpur Sadar, Char Vodrasion, Dohar, Mawa Ghat, and Shiv Ghat [18].

These landless people are often left with no alternative but to settle on newly accreting char land, which leads to the development of a social and economic char environment [6]. Deforestation and forced habitation by displaced people in reserve forests result in ecological deterioration, as well as shortages of fuelwood and fodder in the area [19]. Therefore, similar to drought risk, erosion-accretion hotspots worsen livelihood and flood hazards by making displaced populations more vulnerable and decreasing ecological resilience through unplanned land-use change [20]. Owing to the socio-economic importance of the river and the development of the Padma Bridge that connects the country's capital and northern parts with its southern parts, the Padma River is very important today [21]. Therefore, timely intervention is necessary to control and manage riverbank erosion in the Padma River [22]. To identify the vulnerable zones, regular erosion-accretion analysis is crucial, and it is also necessary to monitor how the river channel changes over time [23]. Such information is important for planning protective measures such as riverbank protection works, relocation and rehabilitation of local people, risk analysis and mitigation, and land-use management. Since unplanned land-use change increases the Flood Risk Index (FRI), the identification of erosion–accretion hotspots of the Padma River could represent priority zones for flood-risk reduction and resource allocation [24]. Proper monitoring and early action can reduce land loss, protect biodiversity, and support the livelihoods of people living along the river [25].

However, earlier studies did not always quantify erosion at smaller intervals, which would help identify specific locations susceptible to erosion. Furthermore, precise data comparing the net change in land surface area between the left and right banks due to erosion and accretion are lacking. Therefore, the objective of this study is to estimate erosion and accretion along both banks of the river to make a comparison of the left and right banks of the Padma River and then identify erosion- and accretion-prone hotspots within the districts along the river at smaller intervals of 5 km in terms of net land surface change.

2. METHODS

2.1. Study Area

The Padma River gets its name from the Ganges River system, which originates from the Gangotri Glacier of the Himalayas, runs through India, and meets the Brahmaputra River of Bangladesh at Aricha, which then merges with the Upper Meghna River at Chandpur [26]. The length of the Padma River is about 120 km, and its width varies from 4 km to 8 km along its reach [27]. The Padma River is located between latitude 23°53'-23°8'N and longitude 89°38'-90°45'E and flows through the districts of Rajbari, Faridpur, Madaripur, Shariatpur, Chandpur, Munshiganj, Dhaka, and Manikganj, as shown in Fig. 1.

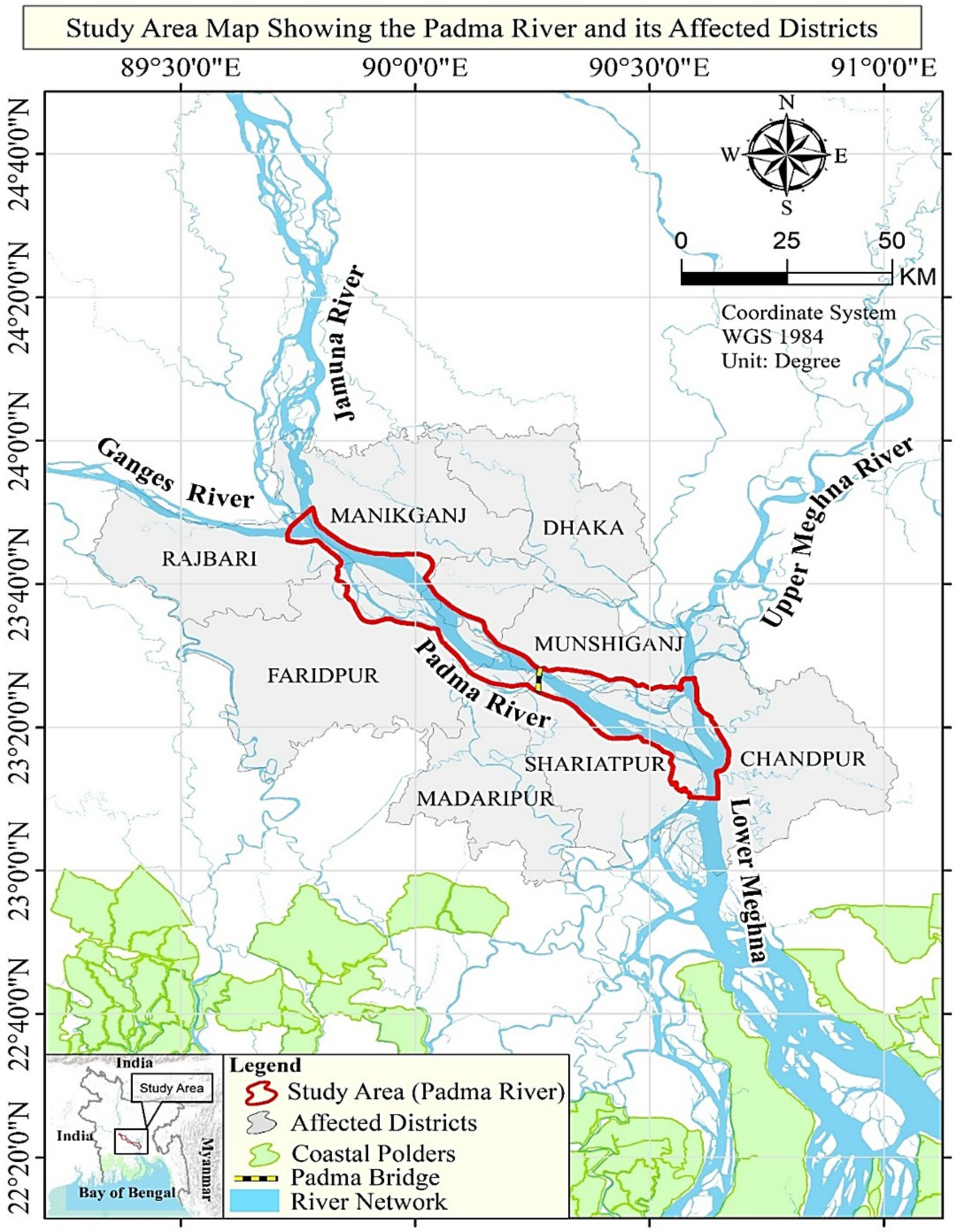

Figure 1. Study area map showing the Padma River.

2.2. Collection of Data and Image Preprocessing

To assess the erosion-accretion pattern along the Padma River, multi-temporal satellite images were collected for the years 1990, 2000, 2010, and 2016-2022. Landsat-5 TM imagery was used for 1990, Landsat-7 ETM+ imagery was used for 2000 and 2010, and Sentinel-2 MSI imagery was used for the annual analysis from 2016 to 2022. All images were selected from the dry season, mainly November to March, to reduce the influence of monsoon flooding, temporary inundation, and seasonal water-level variation on riverbank identification. Images with minimum cloud cover over the Padma River reaches were selected to ensure clear visualization of the river channel and adjacent floodplain areas.

Before bankline delineation, several preprocessing steps were performed in ArcGIS. First, the required spectral bands were selected and combined to prepare false-color composite images for better separation between water and land surfaces. For Landsat-5 TM and Landsat-

7 ETM+ images, bands 4, 3, and 2 were used, while for Sentinel-2 MSI images, bands 8, 4, and 3 were used. These near-infrared false-color combinations enhanced contrast between the river water, exposed bars, vegetation, and surrounding land, improving visual interpretation of the riverbank position.

Second, all satellite images were checked for geometric consistency and projected into a common coordinate system, the Bangladesh Transverse Mercator (BTM) system. This step ensured that images from different years and sensors could be spatially overlaid without major positional mismatch. Using a common projection also helped maintain consistency when calculating erosion, accretion, and net land surface change.

Third, image layers were visually inspected after projection to confirm proper alignment of the river reach and surrounding features. Cloud-affected portions, shadowed areas, and unclear sections were carefully avoided during bankline interpretation. The prepared composite images were then used as the base layers for manual on-screen digitization of the Padma River banklines. Banklines were delineated at a fixed scale of 1:10,000 to maintain consistency among all years. After bankline extraction, the digitized polygons were compared between consecutive time periods using GIS overlay tools to calculate eroded and accreted areas.

Table 1. Specifications of satellite images used in the study (Source: USGS)

Image Type	Bands used	Scale	Spatial resolution (m)	Image Sensor	Date of collection
Landsat-5	4, 3, 2	1:10000	30 x 30	TM	January 1990
Landsat-7	4, 3, 2	1:10000	30 x 30	ETM+	January 2000
Landsat-7	4, 3, 2	1:10000	30 x 30	ETM+	March 2010
Sentinel-2	8, 4, 3	1:10000	10 x 10	MSI	November 2016
Sentinel-2	8, 4, 3	1:10000	10 x 10	MSI	December 2017
Sentinel-2	8, 4, 3	1:10000	10 x 10	MSI	November 2018
Sentinel-2	8, 4, 3	1:10000	10 x 10	MSI	November 2019
Sentinel-2	8, 4, 3	1:10000	10 x 10	MSI	November 2020
Sentinel-2	8, 4, 3	1:10000	10 x 10	MSI	December 2021
Sentinel-2	8, 4, 3	1:10000	10 x 10	MSI	November 2022

After downloading the necessary images from the USGS, they were processed in ArcGIS. Multiple Bands of the Landsat images were then merged to create composite bands. These composite bands offer multiple combinations, producing colors best suited to the work at hand. Finally, the images were ensured to be cloud-free, allowing the topography to be easily perceived.

2.3. Transformation of the Coordinate System

The coordinate system of the images obtained from the USGS was WGS 1984. For convenience, the images were projected to the BTM coordinate system (Bangladesh Transverse Mercator) using ArcGIS 10. The BTM coordinate system is a method used to represent the 3-dimensional Earth's surface on a 2-dimensional plane. The more popular coordinate system, UTM (Universal Transverse Mercator), was avoided because Bangladesh falls between two (2) zones, namely UTM 45N & 46N, which can increase complexity [28].

2.4. Bankline Delineation Accuracy and Uncertainty Assessment

To ensure consistency in bankline delineation, we manually digitized riverbank lines for all selected years using the same on-screen scale of 1:10,000 in ArcGIS. We interpreted the water-land boundary carefully by comparing the spectral contrast between the river channel, exposed bars, and adjacent floodplain areas. During digitization, ambiguous sections such as

https://doi.org/10.31436/iiumej.v27i3.4347

mixed pixels, temporary sandbars, and unclear water-land margins were examined cautiously to avoid overestimation or underestimation of bankline movement. The same interpretation approach was followed for all image years to keep the extracted banklines comparable across the study period.

Uncertainty in bankline extraction may arise from sensor resolution differences, georeferencing mismatches, seasonal water-level variation, mixed pixels along the river margin, and manual digitization error. Because Landsat images from earlier years had 30 m spatial resolution and Sentinel-2 images from later years had 10 m spatial resolution, very small bankline shifts near the image-resolution limit were not treated as major changes. Instead, the analysis focused on larger, spatially consistent erosion-accretion patterns that were clearly identifiable across consecutive image years. This helped reduce the influence of image-related and digitization-related uncertainty on the final estimation of erosion, accretion, and hotspot identification.

Using the Polygon feature of ArcGIS 10 software, the banklines of the river were delineated for ten (10) years, as shown in Fig. 2.

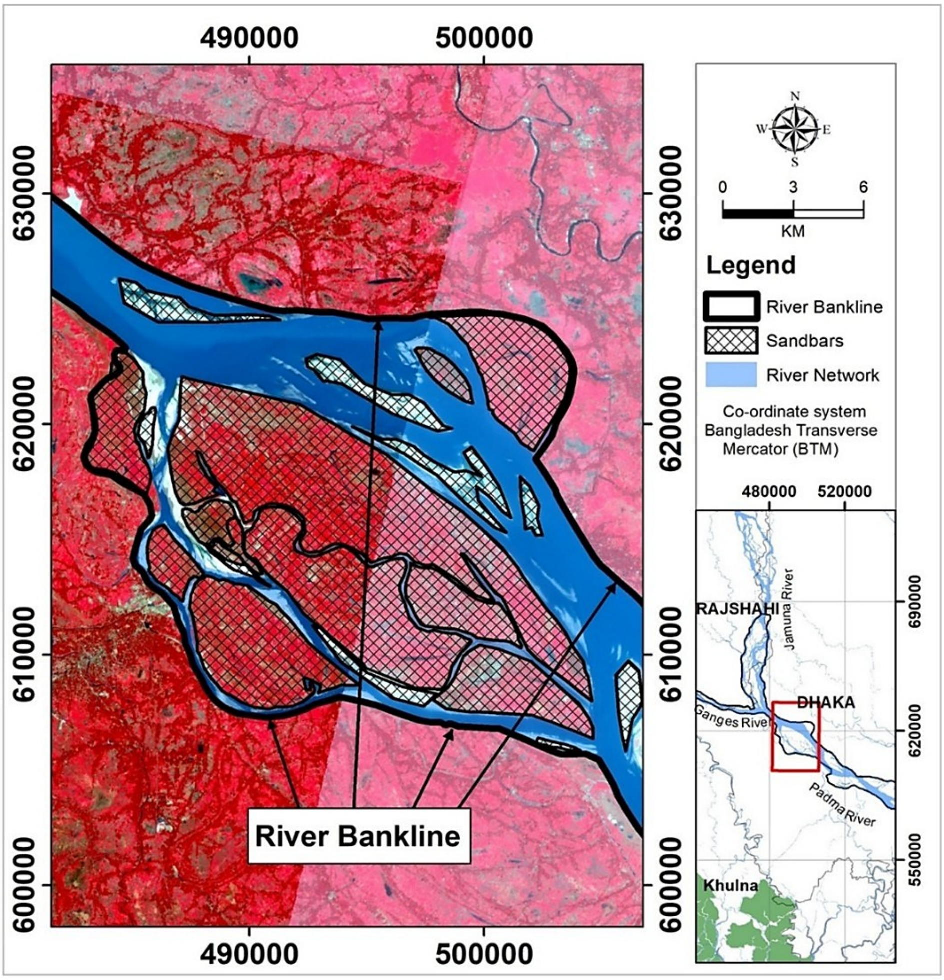

Figure 2. Bankline Delineation.

We performed both long-term decadal analyses for the periods 1990-2000, 2000-2010, and 2010-2020 and short-term year-by-year analyses for the period 2016-2022. Using the vector quantities (Bankline polygon features) as input, erosion and accretion were calculated using the "Erase Tool" in ArcGIS software. Additionally, the net change in land surface area was

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calculated from the difference between erosion and accretion (Erosion ~ Accretion) values. Fig. 3 shows the digitized banklines of the Padma River.

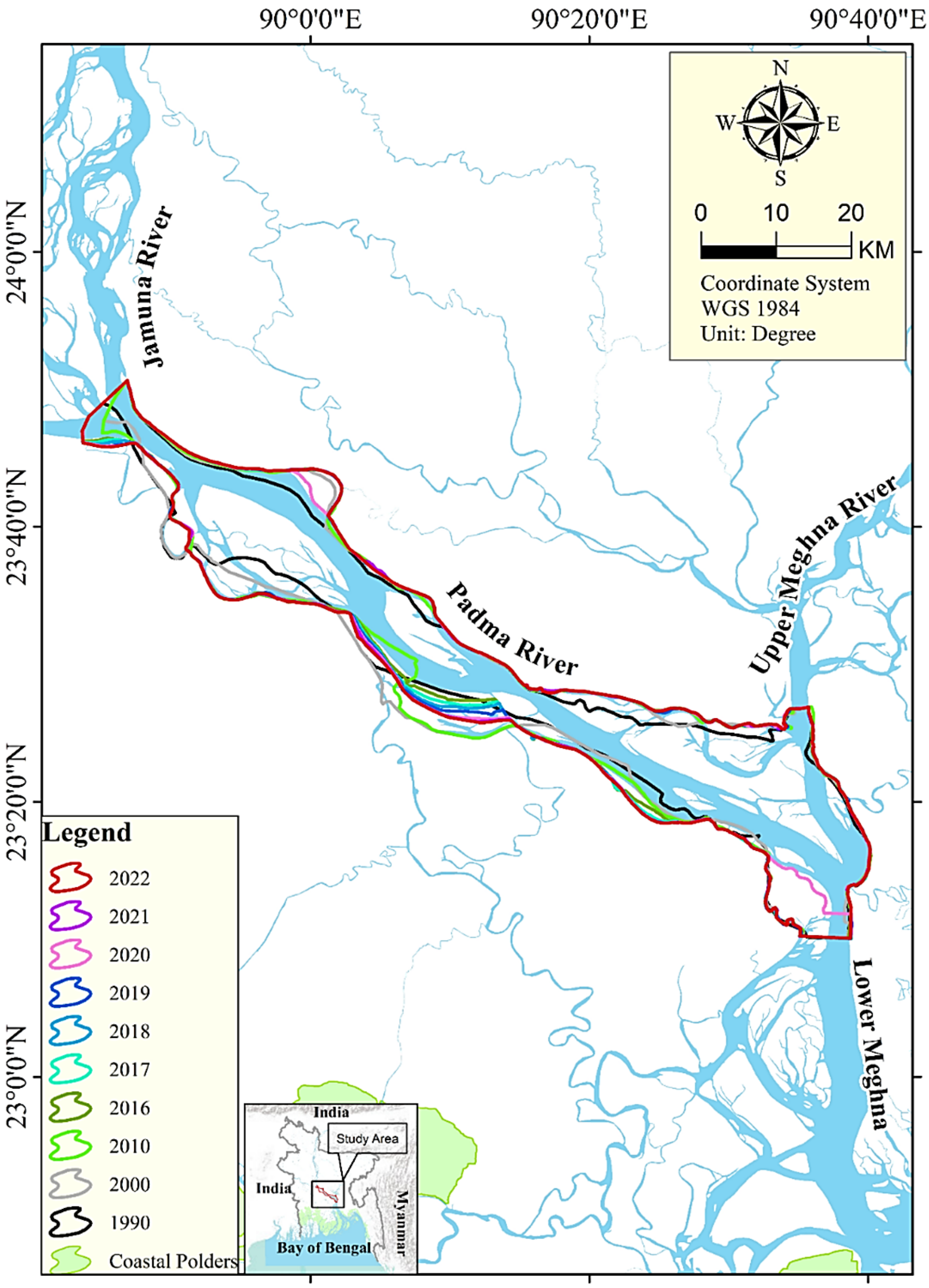

Figure 3. Digitized banklines of the Padma River.

2.5. Partitioning the River Stretch into Small 5 km Intervals

To obtain a more detailed analysis of the erosion-accretion pattern, a 100 km reach of the Padma River was divided into 5 km intervals along its longitudinal section to generate 20 identical parallel sections, as shown in Fig. 4. The starting point (0 chainage) was chosen about 5 km upstream of the Daulatdia Ferry Ghat Terminal, from where 5 km linear intervals were taken, which represented locations along both banks of the river. Considering that chainage along the riverbank would not be feasible in this case, since the right bank chainage would vary

https://doi.org/10.31436/iiumej.v27i3.4347

from the left bank chainage. Moreover, the length of the bankline would vary each year, resulting in variation in chainage. This difference in chainage across the banks would not allow for comparison between the two. Thus, using a hypothetical box of equal intervals (5 km in this work) allowed comparison of erosion-accretion patterns over a similar extent along both banks of the Padma River, as well as identifying spots along the river prone to erosion.

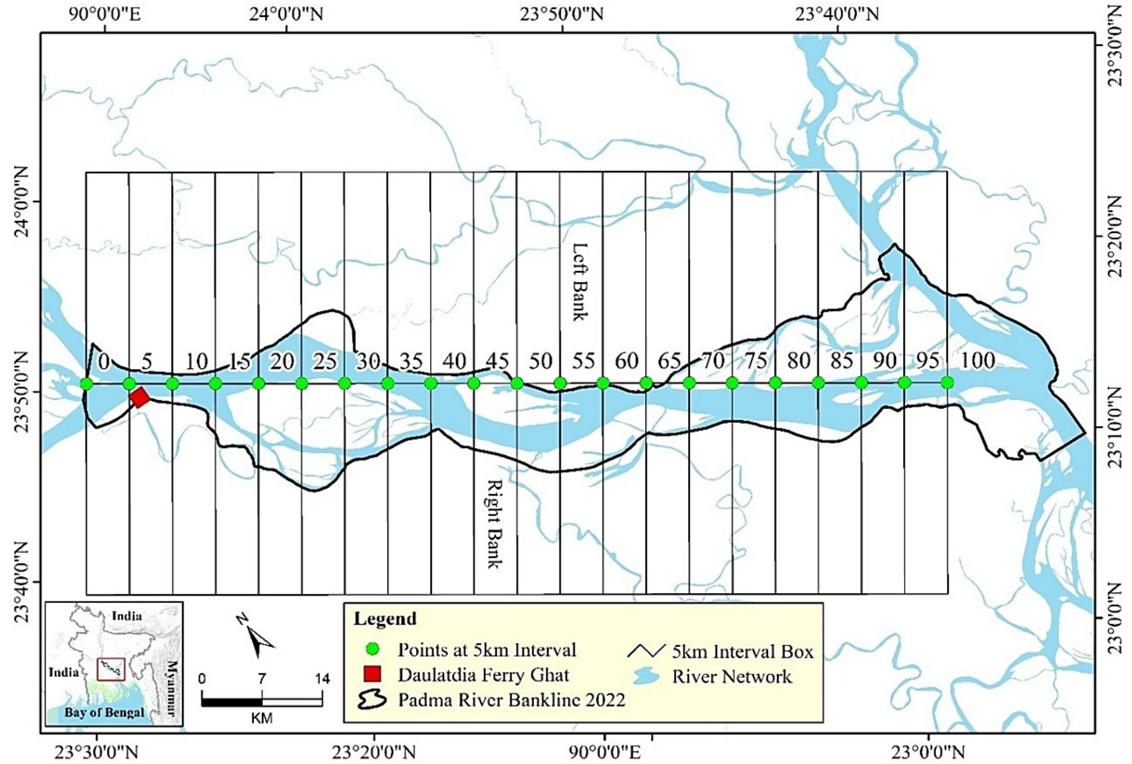

Figure 4. Map showing the division of the Padma River reach into 5 km intervals.

3. Results and Discussion

Estimates were made of the amount of erosion and accretion along both banks of the Padma River. Dividing the 100 km stretch of the river into smaller 5 km segments allowed visualization and comparison of erosion and accretion patterns within the same extent on either bank. The results were then used to analyze the land surface area loss in the eight affected districts. Finally, the net change in land surface area (Erosion ~ Accretion) was estimated for each bank over the last three decades (1990-2020).

3.1. Erosion and Accretion Rates for the Left and Right Banks of the Padma River

The erosion and accretion of the Padma River were estimated for both the left and right banks to determine total area change and average annual rates. The analysis covered the periods 1990-2000 (10 years), 2000-2010 (10 years), 2010-2020 (10 years), 2016-2022 (6 years), and 1990-2020 (30 years). Tables 2 and 3 present the estimated erosion and accretion rates for these periods. This study included both decadal and annual analyses to describe long-term and recent period-specific patterns; however, these comparisons are not presented as statistically tested temporal trends.

Between 1990 and 2000, erosion of the left and right banks was similar, with estimated erosion of 11130 ha (1113 ha/yr) and 11900 ha (1190 ha/yr), respectively. However, between 2000 and 2010, erosion was significantly higher along the right bank than the left bank, with

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estimated erosion of 6230 ha (623 ha/yr) and 1940 ha (194 ha/yr), respectively. Over the 30-year period (1990 to 2020), the average erosion rate on the left bank was 464 ha/yr, and the accretion rate was 18 ha/yr.

Table 2. Erosion and accretion rates for the left bank of the Padma River

Duration	Erosion (ha)	Rate of Erosion (ha/yr)	Accretion (ha)	Rate of Accretion (ha/yr)
1990-2000 (10 years)	11129	1113	140	14
2000-2010 (10 years)	1937	194	235	23
2010-2020 (10 years)	866	87	167	17
2016-2017 (1 Year)	139	139	174	174
2017-2018 (1 Year)	87	87	84	84
2018-2019 (1 Year)	85	85	102	102
2019-2020 (1 Year)	304	304	325	325
2020-2021 (1 Year)	527	527	203	203
2021-2022 (1 Year)	183	183	176	176
2016-2022 (6 years)	1324	221	1065	177
1990-2020 (30 years)	13932	464	541	18

During 2010-2020, the right bank continued to show a higher erosion rate than the left bank, with estimated erosion of 4604 ha (460 ha/year) and 866 ha (87 ha/year), respectively. These corrected values were checked against Tables 2 and 3 to ensure numerical consistency between the text and tabulated results. For the decadal analysis, the erosion and accretion rates during 1990-2020 were estimated by averaging the total eroded and accreted areas over each corresponding 10-year period. Over the 30-year period (1990 to 2020), the average erosion rate on the right bank was 758 ha/yr, and the accretion rate was 285 ha/yr.

Table 3. Erosion and accretion rates for the right bank of the Padma River

Duration	Erosion (ha)	Rate of Erosion (ha/yr)	Accretion (ha)	Rate of Accretion (ha/yr)
1990-2000 (10 years)	11897	1190	1061	106
2000-2010 (10 years)	6227	623	6937	694
2010-2020 (10 years)	4604	460	563	56
2016-2017 (1 Year)	1589	1589	149	149
2017-2018 (1 Year)	992	992	145	145
2018-2019 (1 Year)	1022	1022	113	113
2019-2020 (1 Year)	248	248	486	486
2020-2021 (1 Year)	1880	1880	108	108
2021-2022 (1 Year)	481	481	22	22
2016-2022 (6 years)	6212	1035	1023	171
1990-2020 (30 years)	22728	758	8561	285

Fig. 5 shows the annual erosion and accretion rates of the Padma River averaged over the respective decadal periods. The right bank showed larger erosion and accretion magnitudes than the left bank, indicating greater morphological activity on the right side of the river within the study reach.

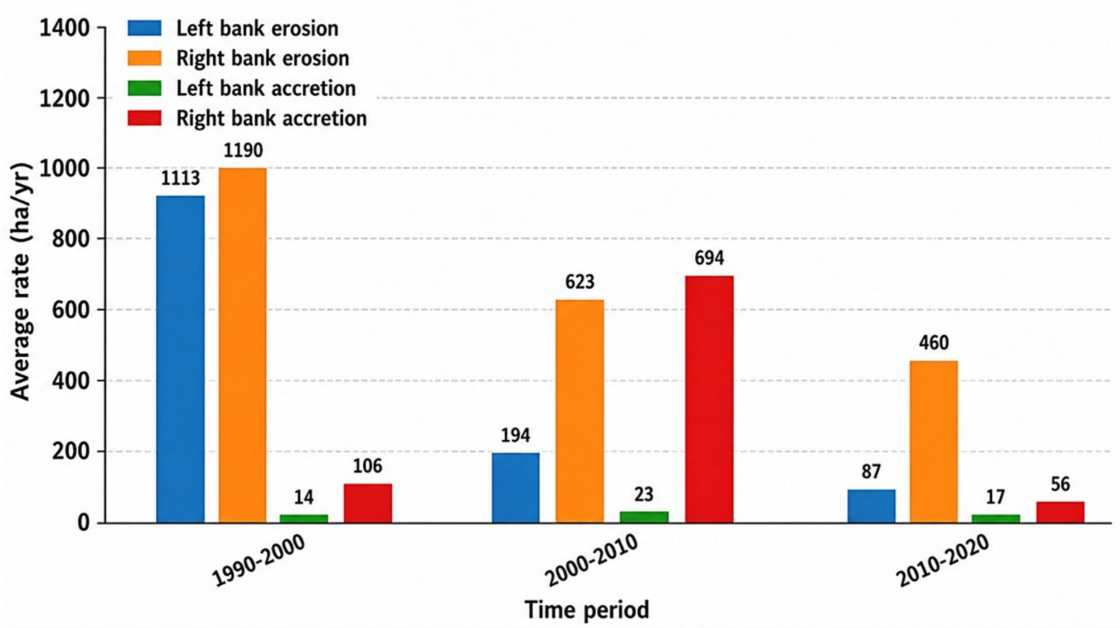

Figure 5. Annual erosion-accretion rates along the Padma River averaged over the respective decades.

Additionally, while analyzing the yearly data between 2016 and 2022, the maximum annual erosion rate was observed during 2020-2021, with approximately 1880 ha/year on the right bank and 527 ha/year on the left bank, as shown in Fig. 6. In each one-year interval except 2019-2020, the annual erosion rate on the right bank was greater than that on the left bank. Considering the 6-year time period, which is 2016 to 2022, the average erosion rate on the left bank was 221 ha/yr, and on the right bank was 1035 ha/yr, and the accretion rate on the left bank was 177 ha/yr and on the right bank was 171 ha/yr, respectively.

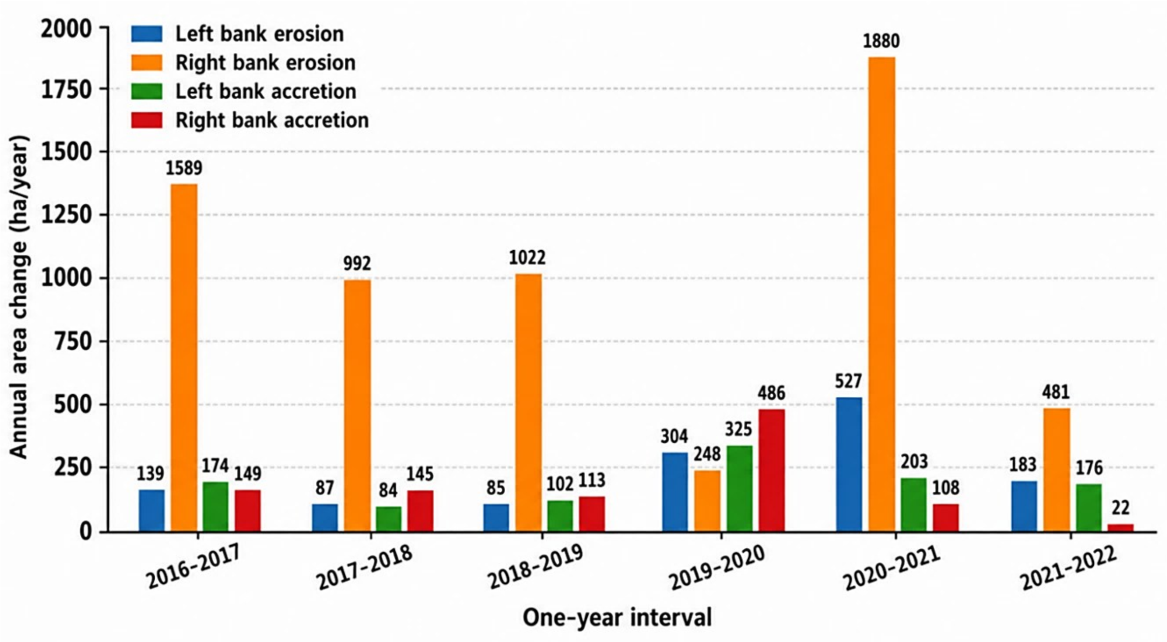

Figure 6. Annual erosion and accretion rates along both banks of the Padma River from 2016 to 2022.

Therefore, the annual observations of recent years (2016-2022) also indicate that the right bank experienced comparatively higher erosion rates than the left bank during most one-year intervals. The higher right-bank values in the recent annual analysis should be interpreted as period-specific observations rather than evidence of a statistically significant increasing trend.

The observed erosion-accretion pattern can be explained by the combined influence of bank material composition, channel curvature, discharge variation, and subaqueous bank failure processes. The right bank's higher erosion susceptibility is consistent with previous studies. The left bank of the Padma River consists of relatively more cohesive, weathered, and consolidated Pleistocene-aged sediments, which act as a natural barrier against erosion [29]. Such resistant materials are comparatively rarer along the right bank; therefore, the right bank is naturally more vulnerable to erosion [29]. This explains why the present study found greater erosion and accretion magnitudes along the right bank than along the left bank. Reports also support the right bank's higher vulnerability, noting that bank failure in the Naria region is aggravated by approximately 200 ft of alternating cross-bedded silt and micaceous fine sand, characterized by high dilatancy and a low angle of friction [30]. They further noted that deep vertical trenches along the Naria curvature increase the possibility of subaqueous slope failure [30].

Hydrological variation also plays an important role in explaining the erosion-accretion dynamics of the Padma River. The river experiences high flow during the monsoon season and low flow during the dry season, which causes repeated erosion and deposition of the riverbed as well as annual flooding [31]. Both the maximum annual discharge and average annual discharge are correlated with total annual erosion in the Padma River [13]. Similarly, a thorough analysis at the Mawa reach of the Padma River reported a strong correlation between annual riverbank erosion and average annual discharge [32]. It was observed that, during and after the 2020 monsoon floods, the largest flood extent occurred in the first week of August, whereas the highest riverbank erosion occurred in July, when both maximum and average river discharge were at their peak [32]. This suggests that bank erosion is more strongly associated with peak river discharge than with maximum flood inundation.

3.2. District-Wise Erosion and Accretion Analysis

The districts directly affected by the Padma River's erosion-accretion process include Dhaka, Manikganj, Rajbari, Faridpur, Munshiganj, Madaripur, Chandpur, and Shariatpur. Among these eight districts, four (Dhaka, Manikganj, Munshiganj, and Chandpur) are on the left bank of the Padma River, while the other four (Rajbari, Faridpur, Madaripur, and Shariatpur) are on the right bank. Tables 4 and 5 provide detailed estimates of erosion, accretion, and net change in land surface area for these districts, along with their respective erosion rates over the past 30 years (1990-2020).

On the left bank, the total amount of eroded land across the districts along the Padma River was approximately 12499 ha over the last 30 years (1990-2020), while the total amount of accreted land was approximately 815 ha. Net land loss during that period was approximately 11684 ha (erosion), highlighting the vulnerability of these districts to erosion compared with accretion (Table 4). Considering the annual average erosion rate calculated over the 30-year period from 1990 to 2020, Munshiganj experienced the highest level of riverbank erosion (174 ha/yr), followed by Manikganj (157 ha/yr), Dhaka (55 ha/yr), and Chandpur (31 ha/yr) (Fig. 7). In terms of the total eroded area in a single decade, it has been observed that the highest erosion occurred during 1990-2000 for all the districts, followed by lower erosion magnitudes during the subsequent decades (Fig. 8).

https://doi.org/10.31436/iiumej.v27i3.4347

Table 4. Erosion and accretion analysis for affected districts located along the left bankline

District	Year Interval	Total Eroded Area (ha)	Total Accreted Area (ha)	Net Land Surface Change (ha)	Total Net Land Surface Change over 30 years (ha)	Rate of Net Land Surface Change (ha/yr)	Average Erosion Rate (ha/yr)
Dhaka	1990-2000	1247	0	-1247	-1484	-50	55
	2000-2010	50	46	-4			
	2010-2020	346	112	-234			
Manikganj	1990-2000	3671	10	-3661	-4700	-156	157
	2000-2010	793	15	-778			
	2010-2020	261	0	-261			
Munshiganj	1990-2000	3953	88	-3865	-4943	-165	174
	2000-2010	1058	142	-916			
	2010-2020	202	40	-162			
Chandpur	1990-2000	471	239	-232	-558	-19	31
	2000-2010	287	95	-192			
	2010-2020	161	27	-134			
Total for 30 years (1990-2020)		12499	815	-11684			

Table 5. Erosion and accretion analysis for affected districts located along the right bankline

District	Year Interval	Total Eroded Area (ha)	Total Accreted Area (ha)	Net Land Surface Change (ha)	Total Net Land Surface Change over 30 years (ha)	Rate of Net Land Surface Change (ha/yr)	Average Erosion Rate (ha/yr)
Rajbari	1990-2000	0	404	404	369	12	41
	2000-2010	643	898	255			
	2010-2020	597	307	-290			
Faridpur	1990-2000	4388	136	-4252	-3130	-104	318
	2000-2010	3022	5853	2831			
	2010-2020	2120	411	-1709			
Madaripur	1990-2000	5987	0	-5987	-5873	-196	300
	2000-2010	0	96	96			
	2010-2020	7	25	18			
Shariatpur	1990-2000	1575	650	-925	-5368	-179	208
	2000-2010	2727	124	-2603			
	2010-2020	1918	79	-1840			
Total for 30 years (1990-2020)		22986	8985	-14002			

On the right bank, the total amount of eroded land was approximately 22986 ha over the last 30 years (1990-2020), while the total amount of accreted land was approximately 8985 ha. Net land loss during that time period was approximately 14002 ha (erosion). Hence, districts on the right bank of the river were also more susceptible to erosion, similar to districts on the other bank. Based on the annual average erosion rate calculated over the 30-year period from 1990 to 2020, Faridpur experienced the highest level of riverbank erosion (318 ha/yr), followed by Madaripur (300 ha/yr), Shariatpur (208 ha/yr), and Rajbari (41 ha/yr) (Fig. 7). In terms of total eroded area in a single decade, it has been observed that, among the right-bank districts, Madaripur and Faridpur experienced their highest erosion during 1990-2000, followed by a comparatively lower erosion magnitudes in the subsequent decades. Conversely, Shariatpur and Rajbari showed a different decadal pattern, with the highest erosion recorded during 2000-2010, followed by lower erosion values during 2010-2020 (Fig. 8). Overall, the right-bank

https://doi.org/10.31436/iiumej.v27i3.4347

districts showed higher erosion magnitudes than the left-bank districts, indicating greater erosion susceptibility along the right bank of the Padma River.

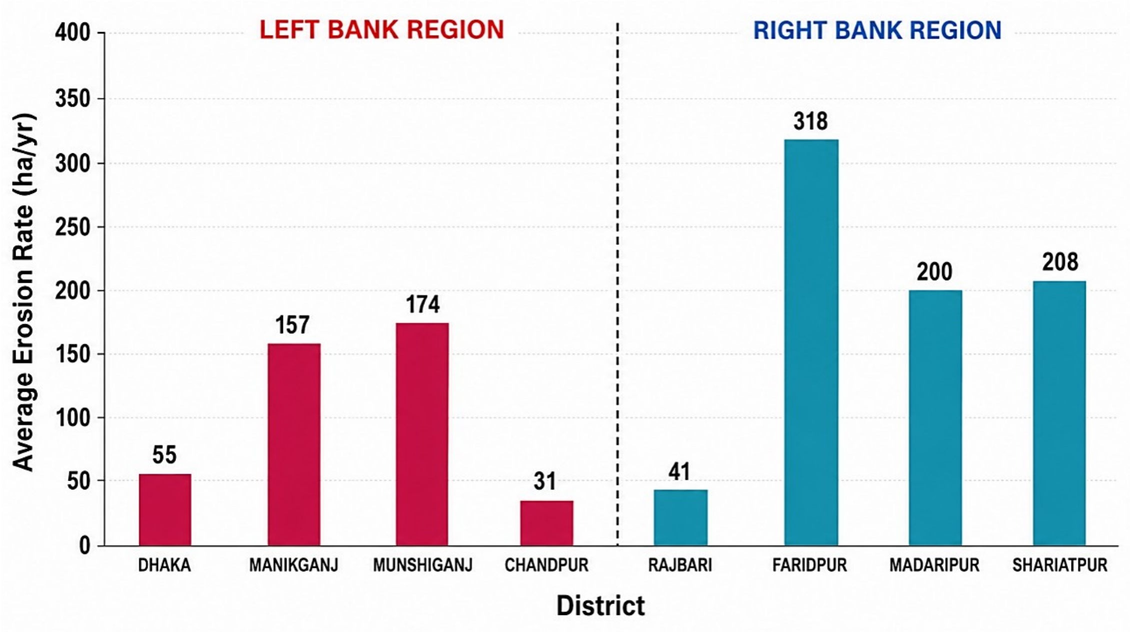

Figure 7. Average erosion rate (ha/yr) over 30 years during 1990-2020

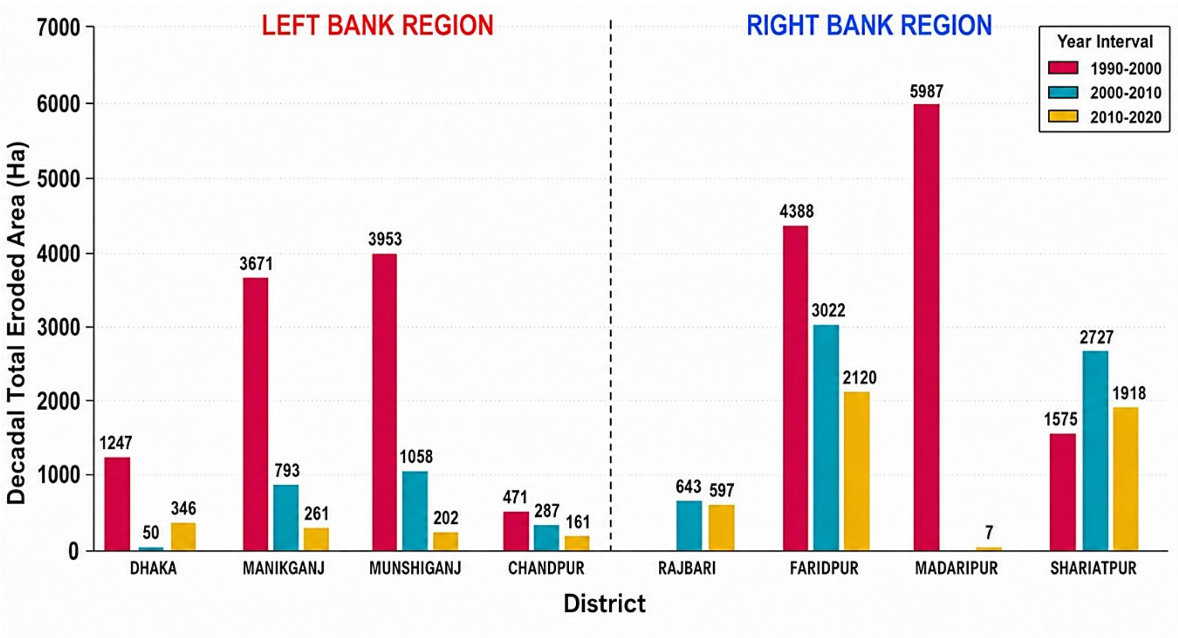

Figure 8. Total eroded area of the districts in a single decade over 1990-2020.

3.3. Net Land Change and Erosion Hotspots (5 km Interval)

Finally, a net change in land surface area from 1990 to 2020 was calculated to present a complete picture of net erosion and accretion along the river and was represented within every 5 km interval along both banks of the river, which would be helpful to visualize the area of the districts that are vulnerable to erosion. It was clear that erosion dominated accretion. Overall, the erosion-accretion process led to net land loss in most areas and net land gain in some areas. These net gains and losses were calculated within the 5 km interval along both banks of the river, deducting erosion from accretion using ArcGIS software. Fig. 9 depicts the net change in land surface area in the Padma River over the last 30 years (1990-2020). It was observed that both the left bank (solid line) and the right bank (broken line) experienced more net land loss, as the lines spent most of their time below the 0 (zero) line or the x-axis. Positive values indicated net land gain, whereas negative values indicated net land loss.

For the left bank, the chainage-wise net land surface change analysis showed that the maximum total net land loss over the 30-year period occurred at chainage 25-30 km, which lies within Manikganj, amounting to approximately 2933 ha (98 ha/yr). Another prominent erosion peak was observed at chainage 75-80 km within Munshiganj, followed by another loss-prone reach at chainage 45-50 km within Dhaka. In contrast, net land gain along the left bank was insignificant throughout most of the study reach, indicating that the left bank was mainly characterized by localized erosion-prone zones rather than substantial accretion.

This observation was further supported by the district-wise annualized net land surface change analysis, where Munshiganj experienced the highest average net land loss rate of approximately 165 ha/year, followed by Manikganj at 156 ha/year, Dhaka at 50 ha/year, and Chandpur at 19 ha/year during 1990-2020 (Table 4).

As for the right bank, the maximum total net land loss was observed at chainage 25-30 km within Faridpur, amounting to approximately 2877 ha (96 ha/yr) over the 30-year period. Another major net land loss zone was observed between chainage 55-65 km within Madaripur, where the loss reached approximately 2644 ha (88 ha/yr) around chainage 55-60 km, followed by another erosion-prone reach around chainage 80-85 km within Shariatpur. However, unlike the left bank, the right bank also showed noticeable accretion in some reaches. The highest net land gain was observed at chainage 15-20 km within Faridpur, amounting to approximately 1470 ha (49 ha/yr), followed by another accretion-prone reach between chainage 40-50 km, also located within Faridpur. Therefore, the chainage-wise analysis identifies Faridpur as the most dynamic right-bank zone, containing both severe erosion and substantial accretion.

However, when the district-wise annual average rate of net land surface change over the 30-year period was considered, Madaripur showed the highest average net land loss rate on the right bank at approximately 196 ha/year, followed by Shariatpur at 179 ha/year and Faridpur at 104 ha/year, whereas Rajbari showed a slight average net land gain of approximately 12 ha/year (Table 5). Thus, although Faridpur contained the most severe localized erosion and accretion hotspots, Madaripur and Shariatpur experienced greater long-term average net land loss at the district scale.

This comparison indicates that the 5 km chainage-wise analysis is useful for identifying specific erosion-accretion hotspots, while the district-wise annualized rate provides a broader understanding of long-term land loss severity across administrative regions.

The district-wise erosion-accretion findings are consistent with previous studies on the Padma River. Reports show that substantial erosion-accretion activity occurred along the Padma River during 1975-2015, with the right bank showing more pronounced morphological activity [13]. Remote sensing and GIS techniques were used to assess bank erosion and channel shifting of the Padma River in Munshiganj, Madaripur, and Shariatpur districts [10]. The findings confirm that these districts have historically experienced bankline instability, supporting the present study's identification of Munshiganj on the left bank and Madaripur-Shariatpur on the right bank as major erosion-affected districts [10]. Similarly, recent erosion-accretion assessments identified Faridpur, Madaripur, Munshiganj, and Shariatpur as important hotspot districts, which agrees with the chainage-wise hotspots detected in this study.

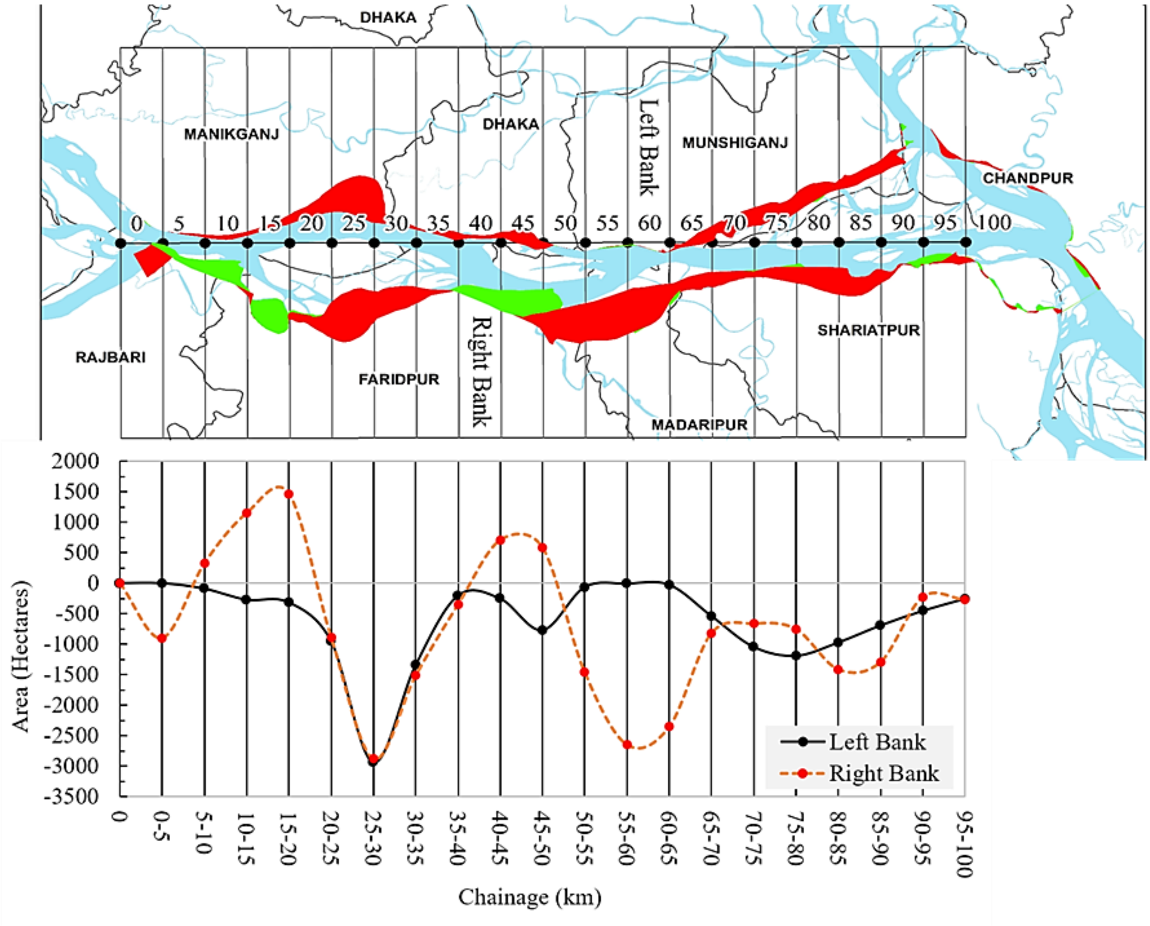

Figure 9. Net change in land surface area across left and right banks (1990-2020).

4. CONCLUSION

The study estimated erosion and accretion rates along both banks of the Padma River. The analysis included a long-term decadal assessment for 1990-2020 and a recent annual assessment for 2016-2022. These two periods were evaluated as separate period-specific estimates and were not interpreted as statistically tested increasing or decreasing trends. The results showed that the right bank experienced higher erosion activity than the left bank in both assessment periods. During 1990-2020, the average erosion rate was 758 ha/year on the right bank and 464 ha/year on the left bank. During 2016-2022, the corresponding average erosion rates were 1035 ha/year and 221 ha/year, respectively. These values indicate greater erosion susceptibility on the right bank, but they should not be interpreted as evidence of a statistically significant temporal increase or decrease because no formal trend test was conducted. The study also shows that, when erosion and accretion rates were considered separately, Faridpur had the highest average erosion rate on the right bank, followed by Madaripur, Shariatpur, and Rajbari. On the left bank, Munshiganj experienced the highest average erosion rate, followed by Manikganj, Dhaka, and Chandpur. However, this comparison does not reflect net land surface change or the specific hotspots within the districts. Accordingly, the analysis of net gain and net loss along the river showed that the most severe localized net land loss on the right bank occurred within Faridpur, followed by major erosion-prone reaches in Madaripur and Shariatpur. On the left bank, the most prominent localized erosion-prone reach was identified within Manikganj, followed by Munshiganj and Dhaka. At the district scale, the annualized net land surface change analysis showed that Madaripur and Shariatpur experienced greater long-term average net land loss on the right bank, whereas Munshiganj and Manikganj showed the highest average net land loss rates on the left bank.

Combined with the quantitative analysis of eroded land extent, this visual representation may help implement bank protection measures in a priority-based manner. Furthermore, these findings may be useful for predicting riverbank erosion and determining the locations for constructing hydraulic structures, bridges, and industries along the riverbanks. Therefore, such analysis could be useful not only in the context of a riverine country like Bangladesh but also in countries with torrential rivers prone to erosion. In light of the above study, the authors recommend integrating sandbar formation in this study, as sandbar or island formation, locally known as char lands, is an important issue that influences the channel and flow of the Padma River, which will provide more information and a better understanding of the erosion-accretion process of the Padma River.

ACKNOWLEDGMENT

The authors acknowledge and appreciate the generosity of the USGS (United States Geological Survey) for providing the necessary images used for the analysis.

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