ISSN (Online): 3078-4476; ISSN (Print): 3078-4468

Life Science Studies

Journal Homepage: www.journal.inrrd.com/lss

Original Article

Monitoring Channel Dynamics of the Padma River Using Remotely Sensed Data

Ahsan Imam[1], Prodip Kumar[2*], Md. Rakib Uddin[1] and Md. Al-Amin[1]

[1]*Environmental Science Discipline, Khulna University, Khulna-9208, Bangladesh*
[2]*Department of Geography and Environmental Studies, University of Rajshahi, Rajshahi-6205, Bangladesh*

ARTICLE INFO

Article history
Received 01 March 2025
Revised 30 April 2025
Accepted 14 May 2025
Available online 25 May 2025

Keywords
Sinuosity Index
River Morphology
Sedimentation
Land Cover Change
Padma River

ABSTRACT

Floodplains are complex landforms that result from the interaction of fluvial processes such sediment transport, water flow, and channel characteristics. This study investigates the dynamic fluvial channel processes and morphological changes of the Padma River in northwestern Bangladesh, focusing on a 45 km stretch near Charghat, Bagha, and Pakshi Upazilas of Rajshahi and Pabna districts. Utilizing multi-temporal Landsat satellite imagery from 1988, 2000, and 2016, combined with Geographic Information System (GIS) techniques, the research monitors channel migration, bank erosion, and sedimentation patterns over a 28-year period. The analysis reveals a significant increase in land cover from 67.93% in 1988 to 89.23% in 2016, attributed to rapid sedimentation, particularly along the right (west) bank, leading to a narrowing of the river channel. The sinuosity index, a key indicator of meandering behavior, increased from 1.536 in 1988 to 1.686 in 2000, with a secondary channel recording 1.241 in 2016, reflecting the river's evolving sinuous nature. The study highlights westward channel migration and a marked rise in lateral erosion due to high sedimentation rates. Remote sensing and GIS prove effective in retrospectively analyzing large-scale river dynamics, offering valuable insights for flood management, bank protection, and watershed planning. The findings underscore the necessity of continuous monitoring and adaptive strategies to mitigate the impacts of morphological changes on local ecosystems and communities.

Introduction

Floodplains are generated by the intricate interaction of fluvial processes. Their character and evolution rely on stream strength, sediment behavior, and channel features (Thayer & Ashmore 2016). Floodplains have been frequently utilized for human activities such as agriculture, settlement, and industry for millennia, and they are susceptible to morphologic changes in adjacent channels. The research of floodplain development, stability, and the frequency of flooding is extremely important in the river sciences (Kiedrzyńska et al. 2015). Changes in river courses and channel morphology modify floodplain features, perhaps leading to floodplains being abandoned as terraces. These modifications frequently occur on a spatial scale that is perfect for remote sensing study. Floodplain modifications can be slow and progressive or quick in geologic time, either naturally or as a result of human activity. Padma (Ganges) exhibits a meandering pattern with a high sinuosity single channel (Halder & Chowdhury 2023). The Padma River modifies morphological characteristics more than any other river (Islam et al. 2021). This study looks at a huge river system that underwent fast alteration as a result of enormous sedimentation. Alluvial plains exhibit three primary channel patterns: braided, meandering, and straight. River morphology is clarified in terms of channel patterns and channel shapes, and it is determined by associated aspects like as discharge, water surface slope, water velocity, depth, and width of channel and riverbed materials, among others (Manjusree et al. 2013). The oscillatory behavior of flow mainly acts as a major reason of meander formation (Seminara 2006; Monegaglia et al. 2019). Meandering rivers dissolve sediment from the outer curve of each meander and deposit it in the inner curve of the downstream curves. The deepest area of a meandering river is on the outside of the bends, and the

*Corresponding author
Email: prodipkumar2136@gmail.com (Prodip Kumar)

water runs faster from the riverbank (Crosato 2008; Blanckaert 2011). The water flows slowly in the shallow portions inside the bend, resulting in more sediment deposition. Many factors influence meandering channel morphology, including discharge variability, sediment load, slope, channel resistance, vegetation, bank stability, bedrock (Latrubesse et al. 2005), neotectonic activity, and construction of hydroelectric dams. Meandering channels are a common phenomenon, and numerous ideas have attempted to explain the rationale for their genesis (Kleinhans et al. 2024; Dey 2024). River shifting is a reach-scale reaction by the waterway to local and regional actions (Downs et al. 2013). Assessing and monitoring stream movement is crucial for river maintenance, flood mitigation initiatives, and city development. Due to anthropogenic and climate change, most rivers are on the verge of degradation (Siddha & Sahu 2022). The declining condition of the world's principal rivers is one of the most severe indications of the global environmental threat, along with flood disasters and a drop-in drinking water supply. Water consumption is increasing over time due to expansion of the population, industry, and urbanization (Wang et al. 2022). To create an efficient management of waterways plan, one must first evaluate the river basin's morphology, erosion status, and drainage pattern (Pande & Pande 2020). Sinuosity studies help to understand the topographical and hydrological aspects of the drainage basin (Krishnan 2024). The objective of this research is to investigate the morphological shifts of the Padma River throughout time and evaluate the sinuosity index of the region in order to determine the River Padma's meandering habit.

Materials and methods

Study area

The research region is in northern Bangladesh, in the channel-bar complex along the bank of the Padma River in Charghat and Bagha Upazilas of Rajshahi district, and Pakshi Upazila of Pabna district (Fig. 1).

Data acquired and source

For this study, multispectral, multi-temporal LANDSAT satellite data of the Padma River were acquired for three years: 1988, 2000 and 2016. All the LANDSAT images have been taken from USGS Earth Explorer. The 1988 image is a TM image, and the 2015 image is an OLI-TIRS image, both having a resolution of 30 meters. All satellite imagery has been transformed to the Universal Transverse Mercator (UTM) Zone 45N projection and the World Geodetic System 1988 (WGS-84) datum (Appendix 1).

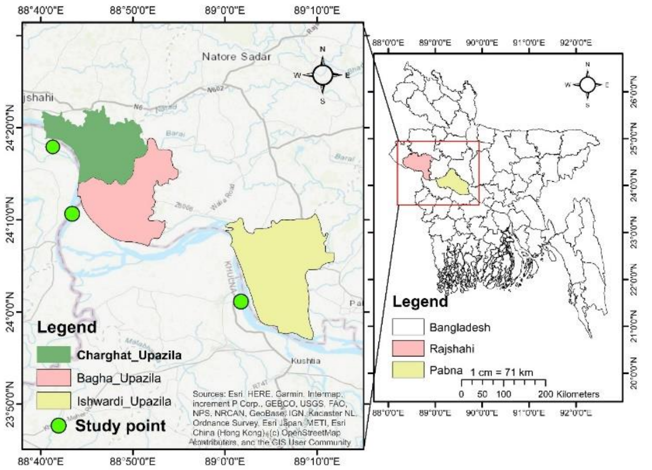

Fig. 1. Study area map indicating Charghat, Bagha and Pakshi upazilas

ENVI Classic 5.3, Arc GIS 10.3 and Microsoft Excel 2013 are used for this study. The Landsat images were collected as “level 1 data” from the website of Earth Explorer hosted by the United States Geological Survey (USGS). To make the Landsat data easily usable, the bands are combined to standard BSQ format images. A total of three ground control points (GCP) were chosen for each image. The geometric error was checked for each image using the following equation,

$$\mathbf{RMS_{error}} = \sqrt{(\mathbf{x'} - \mathbf{x_{orig}})^2 + (\mathbf{y'} - \mathbf{y_{orig}})^2} \ldots\ldots (1)$$

Where, x' = latitude of the image
y' = longitude of the image
x_{orig}= original latitude of the ground
y_{orig}= original longitude of the ground

Mask building and sub setting the study area

To avoid complexity the image is resized using the map coordinates of the study are base map. Following that, and prior to the categorization procedure, an accurate research area map is digitized utilizing the ROI tool of ENVI Classic 5.3 to generate a mask band (Appendix 2).

Classification using ROI (regions of interest) and maximum likelihood algorithm

Based on the Landsat band metrics and my personal observation the study area is classified with ROI of corresponding classification scheme mentioned in Appendix 2. At first four classes are divided according to our interest and regions of interest is selected according to our necessity within the four possible regions. These four are our main regions of interest though later we merged sand and soil and land coverage area. Then we included the merged the entire vegetation within the land cover to find out the land percentage of the area.

Land use mapping and land change detection

The categorized imagery is subsequently transformed to ENVI vector image format and then to shape file format, both of which are compatible with Arc GIS 10.3. The land use map is projected in WGS-84 format and includes all map requirements. The juxtaposition of land use and land cover statistics helped to establish the percentage change, trend, and rate of change between 1988 and 2016. To do this, the first step was to create a table that showed the area in square kilometers and the percentage change for each year (1988, 2000, and 2016) assessed across all land use land cover categories. The percentage change used to establish the trend of change is obtained from dividing the observed change by the total of changes multiplied by 100.

$$\text{(Trend) Percentage Change} = \frac{\text{Observed Change}}{\text{Sum of Change}} \times 100$$

In obtaining annual rate of change, the percentage change is divided by 100 and multiplied by the number of study year 1988 – 2000 (12years) 2000 – 2016 (16years). In studies of rivers, the sinuosity index (SI) is similar but not identical to the general form given above, being given by-

$$\text{SI} = \frac{\text{Channel Lenght}}{\text{Down Valley Lenght}}$$

The detailed methodology to achieve the above objectives is described in this section. A flowchart depicting the extensive procedures taken in this investigation to derive statistics about the study area's land use arrangement (Fig. 2).

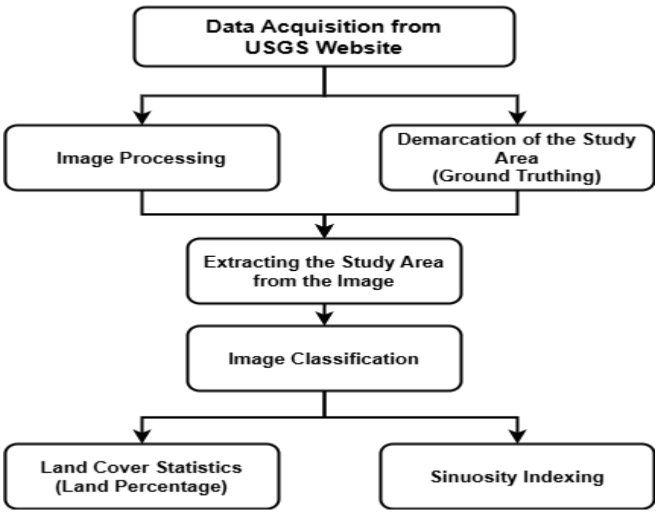

Fig. 2. Flow chart of the methodology

Results and Discussion

All of the analysis and discussion in this chapter is based on the study's objective. The findings are given in the form of maps, charts, and diagrams. They consist of the change and predicted land cover for each class, as well as the sinuosity index.

Land cover distribution

The land cover distribution for 1988, 2000, and 2016 demonstrate a significant change (Fig. 3). Water bodies significantly reduced from 90.43 sq km in 1988 to 37.05 sq km in 2016. At the same time sand area also decrease 65.07 sq km (1988) to 40.21 sq km (2016).

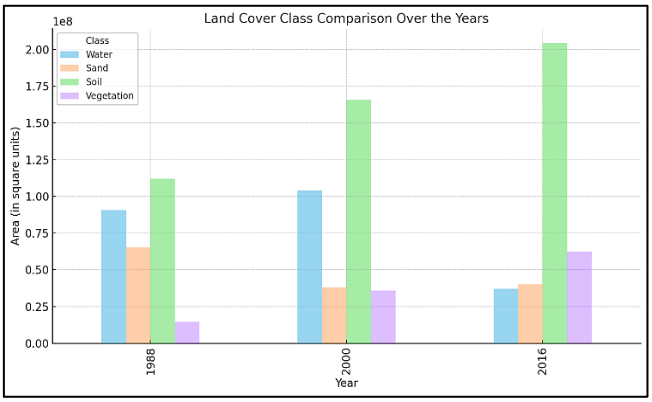

Fig. 3. Land Cover Distribution for 1988, 2000 and 2016

Though water bodies and sand area decrease soil coverage and vegetation increases dramatically which was a significant indicator of land area, land use expanse and also restoration of ecological imbalance or increase of agricultural activities. In 1988 soil coverage was 112 sq km rising to 204 sq km in 2016, and in case of vegetation, also demonstrate considerable increase from 15 sq km in 1988 to 62 sq km by 2016 (Fig. 3). In 1988 the land area both soil and sand cover only 67.93 %. This indicates the fact that the sedimentation level of that time was still very low. But with the respect of the scenario of 2000, it clearly identifies that the land percentage is increasing and it increased 67.93% to 69.70% which is in exact of 1.77 % increase of the total land cover of the river Padma from Charghat to Pakshi area of Rajshahi division. But in the last scenario the total increase of the land is remarkable. To be exact in the increase of the land at year 2016 is 89.23 % of the land and which actually indicates the increase of land of 19.53% of land (Fig. 4). It indicates large amount of deposition rate and decreases of the quantity of water of river Padma (Islam 2009). This indicates that the amount of land cover increases in the land cover indeed.

This distribution is showing the status of land and water proportion of the year 1988 (Fig. 4). Which shows that the water proportion we can get then was 32 % of the area. We have shown the entire land included vegetation, soil and sand. To compare the trend of change the following years. This is a clear indication of increase of land cover and decrease in water. To be exact the land percentage increased 1.77 % which is not really alarming at all. But it is a clear indication of its increasing trend of land cover. At year 2016 it shows an alarming increase in the entire land cover. It increased 19.53% land which indicates decrease of water (Fig. 3).

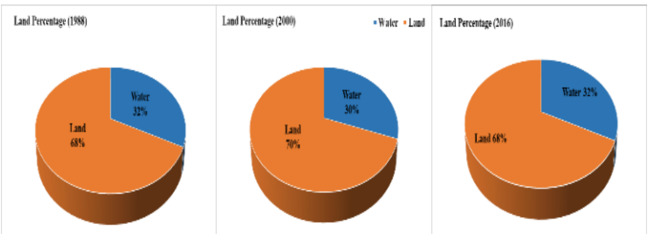

Fig. 4. Land Cover Distribution from 1988 to 2016

But while determining the nature of sinuosity of that area in 2016 we got a narrow channel of water flow due to the excess sedimentation and increase in land cover indeed. The marked increase in land coverage, particularly soil and vegetation, suggests significant environmental changes driven by sedimentation. Although the 19.53% rise in land by 2016 is not immediately alarming, it signals altered hydrological conditions, with reduced water bodies and increased sediment accumulation may affect local ecosystems, fisheries, and water management practices (McGlue et al. 2021). While vegetation growth is a positive sign, continued sedimentation could lead to long-term ecological issues (Wharton et al. 2017).

Land cover maps

The land cover distribution of the year 1988 is shown in Fig. 5. Here the water, sand, soil and vegetation are being shown separately. The continuous increase of the land is clearly seen in the maps and also the change of stream flow pattern is also visualized. Channel length and down valley length is also noticeable.

Map of 2000 showing the entire area nature and its meandering trend (Fig. 5). It is classified according to our desired ROI classification. Years channel area has been significantly changed for the rapid sedimentation

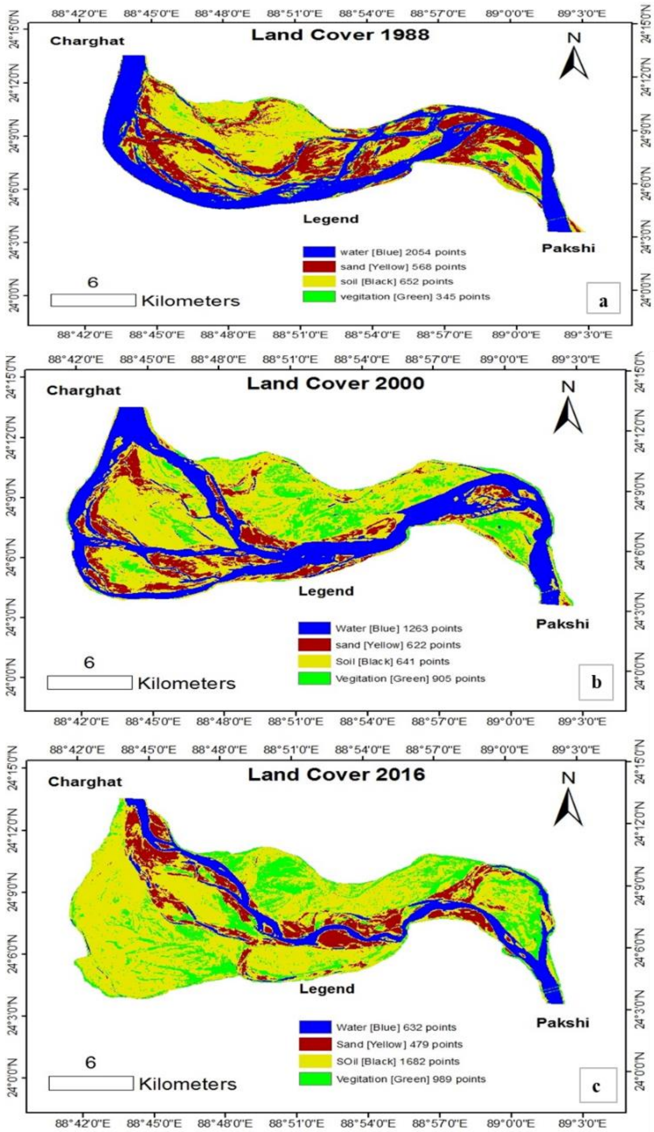

Fig. 5. Land cover (LC) map of the Padma river

in the right (west) bank rather than the left (east) bank due to sinuosity ration increased in right channel. It reveals that the lateral erosion has been increase because high rate of sedimentation over the 12-year time period. Most recent data show significant decrease of water and increase of land cover. Increase of the rate of the soil clearly shows that high rate of deposition is being done in the last 16 years. Decrease of water in the river indicates that the high rate of sedimentation (Hou et al. 2021). The land cover maps from 1988 and 2000 show a clear increase in land area and significant changes in the stream flow pattern of the River Padma. The map from 2000 reveals notable sedimentation on the right (west) bank, with increased sinuosity and lateral erosion. Over 12 years, sedimentation rates grew, causing a decrease in water coverage and an increase in soil deposition, indicating high sedimentation activity affecting the river's flow and land cover (Gusarov 2020).

Changes detection over time

Landsat imagery was utilized to depict the variations in the Padma River stream characteristics throughout three decades. The sinuosity index was 1.536, 1.686 and 1.628 (secondary channel of SI is 1.241 of 2016) (Fig. 6). It suggests that the Padma River developed a serpentine nature throughout time. The island area accounted for approximately 67.93%, 69.70%, and 89.23% of the river's total area. The island area has seen significant changes, which are expected to continue. It demonstrated that bank line erosion had increased dramatically, as well as alterations in river channel dynamics (Fig. 7). The channel area has altered substantially for rapid sedimentation in the right (west) bank rather than the left (east) bank as the sinuosity index has grown in the right channel. It demonstrates that the lateral erosion has risen due to the high sedimentation rate over the 28-years.

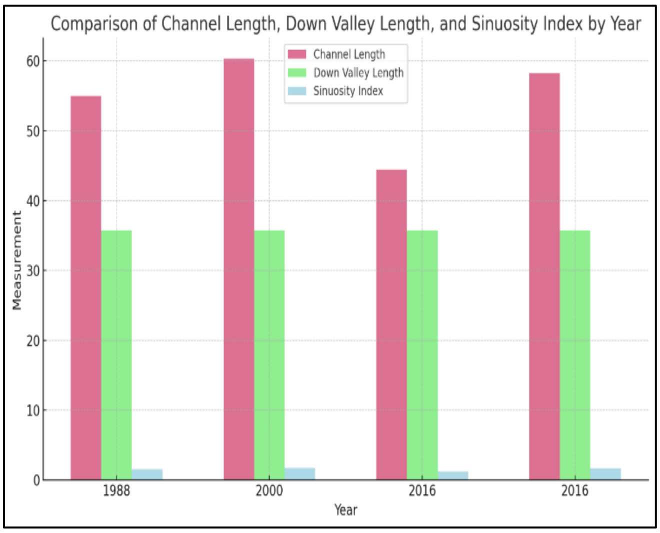

Fig. 6. Comparison of sinuosity indexing

This shift in channel dynamics imply that the river should be monitored for temporal shifts throughout the year (Naim & Hredoy 2021). The findings are compatible with the analysis of changing morphometry and shifting bank lines.

Channel shifting

Quantitative analyses of the positions of channel shifting demonstrate that westward migration has occurred in the Padma River. Geomorphological map and its superimposed bank lines of Landsat TM 1988, EMT plus 2000 and TIRS 2016 (Fig. 8).

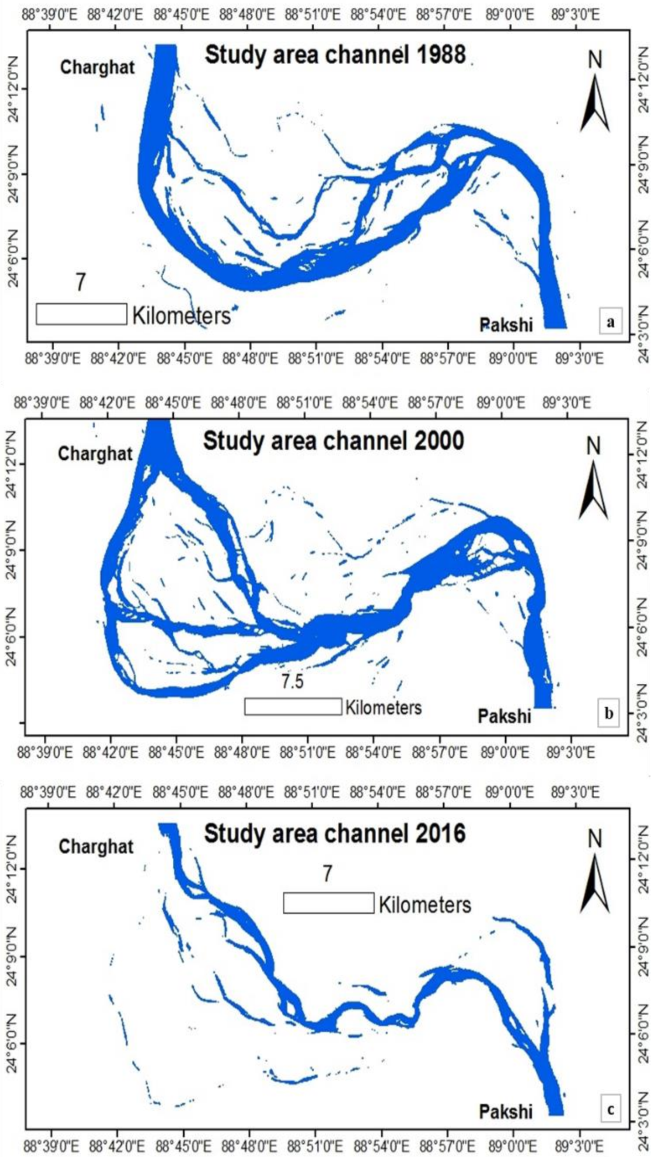

Fig. 7. Channel dynamics detection of the Padma river

River bank analysis also been done by separating the color shown in the map which describes the in-detail criteria of the map and region. The GIS image illustrates the channel dynamics of a river near Charghat and Pakshi from 1988 to 2016. Panel (a) provides a zoomed-out view, while panel (b) offers a detailed perspective. The river's course is mapped in blue (1988), red (2000), and green (2016), revealing significant shifts over the 28-year period (Fig. 8). The river exhibits notable meandering, with substantial eastward migration by 2016. A scale bar indicates 7 kilometers for spatial reference, and coordinates range from 88°39'0" E to 89°3'0" E and 24°0'0" N to 24°12'0" N. This analysis highlights the river's dynamic geomorphological evolution, critical for understanding regional hydrological changes.

Sinuosity indexing

In the comparison of the sinuosity index for the years 1988, 2000, and 2016, here observe significant variations (Fig. 6 & Fig. 9). In 1988, the channel length was 55 km, and the down valley length was 35.775 km, resulting in a sinuosity index of 1.53652 (Fig. 9). This

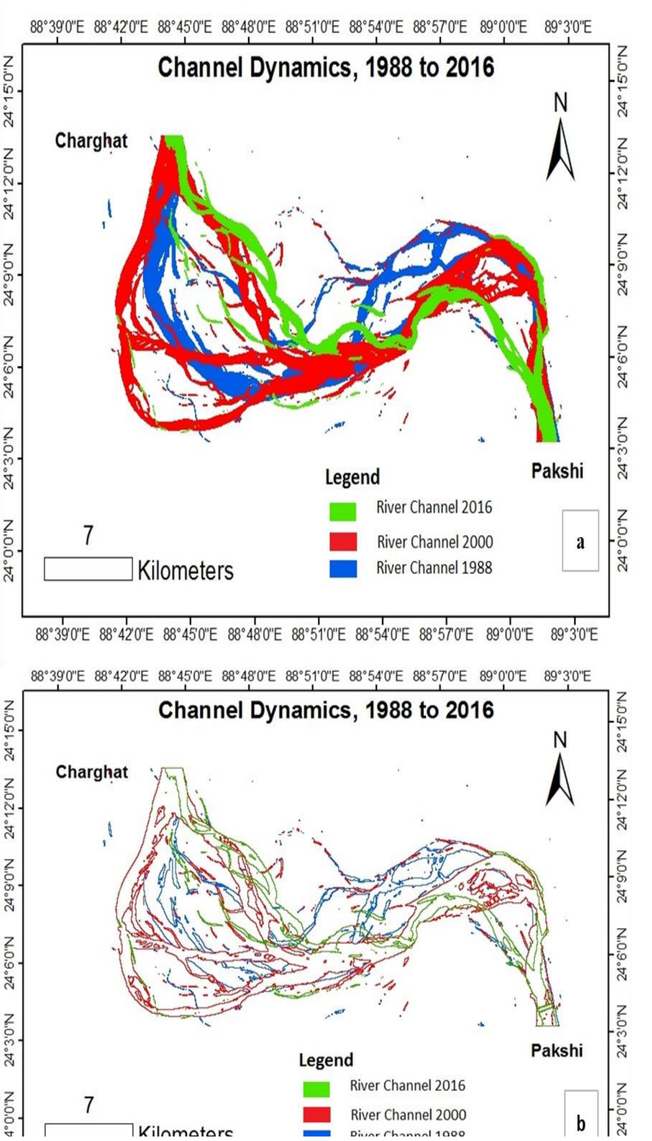

Fig. 8. Channel dynamics (a) and superimposed channel dynamics (b) analysis

value indicates a moderately winding stream. By 2000, the channel length had increased to 60 km, while the down valley length remained constant at 36 km. This led to a higher sinuosity index of 1.686094, reflecting a more meandering stream channel. However, by 2016, the sinuosity index showed a noticeable decrease in one of the measurements, dropping to 1.241901, with a direct and less meandering stream in this instance.

Channel length of 44 km. This reduction suggests a more Interestingly, another measurement for 2016 presented a sinuosity index of 1.628903, based on a longer channel length of 58 km, which is closer to the value recorded in 2000. The presence of two different results for 2016, 1.242 and 1.623, could indicate the analysis of two distinct sections of the stream or the impact of varying environmental or anthropogenic influences during that period (Fig. 6 & Fig. 9).

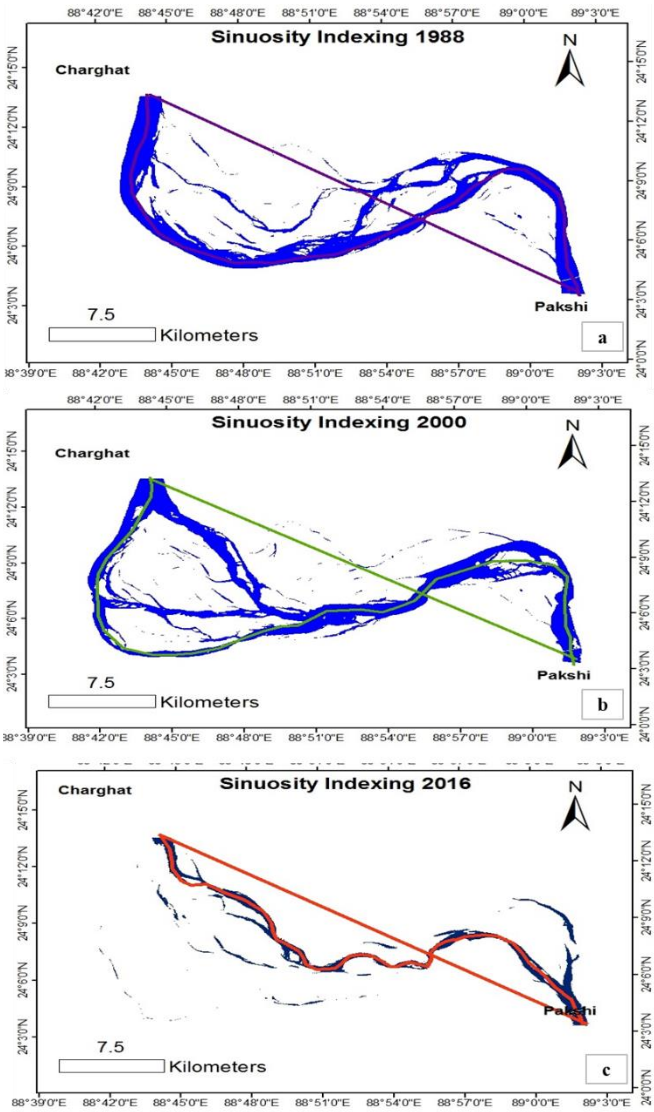

Fig. 9. Sinuosity indexing

The comparison of sinuosity indices over these years reveals a fluctuating pattern of stream channel morphology, with some sections showing more natural meandering, while others have become more constrained (Dente et al. 2021; Billi & Bartholdy 2024). These changes can be attributed to both natural processes and human intervention, such as land use and land cover alterations. The presence of multiple results for 2016 further indicates complexity in the channel dynamics during that year.

Conclusion

Meandering nature of the Padma River has shown significant morphological changes due to natural and human induced causes. Between the year 1988 and 2016 this study reveals fluctuation in sinuosity index which indicates alterations in the river channel dynamics. The sinuosity index fluctuation indicates increased amount of sedimentation and shifting of hydrological condition of the stream pattern. Land cover (LC) study indicates a declining pattern of water and sand while increasing pattern in soil coverage and vegetation. This is the clear indication of decreasing water volume and increasing more deposition in the study area and increased amount of land cover between the year 2000 and 2016. The findings of this study will be helpful for river management, future flood mitigation and developing substantial development of that region. Understanding the sinuosity shift and land cover change will support future regional planning and keeping the ecological balance.

Competing Interest

The authors declare that they have no known competing financial interests.

Authors' contribution

Ahsan Imam and Md. Rakib Uddin conceived the concept. Md. Al-Amin collected data, arranged the tables and figures. Ahsan Imam wrote the manuscript. Prodip Kumar revised the manuscript.

References

Billi P & Bartholdy J (2024). Human impact and channel dynamics of a low sinuosity pseudomeandering river. Catena, 239, 107895.

Blanckaert K (2011). Hydrodynamic processes in sharp meander bends and their morphological implications. Journal of Geophysical Research. Earth Surface, 116(F1). https://doi.org/10.1029/2010JF001806

Crosato A (2008). Analysis and modelling of river meandering. IOS press.

Dente E, Lensky NG, Morin E & Enzel Y (2021). From straight to deeply incised meandering channels: Slope impact on sinuosity of confined streams. Earth Surface Processes and Landforms, 46(5), 1041-1054.

Dey S (2024). Fluvial processes: Meandering and braiding. In Fluvial Hydrodynamics: Hydrodynamic and Sediment Transport Phenomena. Cham: Springer International Publishing, 693-752 pp.

Downs PW, Dusterhoff SR & Sears WA (2013). Reach-scale channel sensitivity to multiple human activities and natural events: Lower Santa Clara River, California, USA. Geomorphology, 189, 121-134.

Gusarov AV (2020). The response of water flow, suspended sediment yield and erosion intensity to contemporary long-term changes in climate and land use/cover in river basins of the Middle Volga Region, European Russia. Science of The Total Environment, 719, 134770.

Halder A & Chowdhury MR (2023). Evaluation of the river Padma morphological transition in the central Bangladesh using GIS and remote sensing techniques. International Journal of River Basin Management, 21(1), 21-35.

Hou C, Yi Y, Song J & Zhou Y (2021). Effect of water-sediment regulation operation on sediment grain size and nutrient content in the lower Yellow River. Journal of Cleaner Production, 279, 123533.

Islam MA, Munir MS, Bashar MA, Sumon KA, 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(2), 167-184.

Islam MT (2009). Bank erosion and movement of river channel: A study of Padma and Jamuna Rivers in Bangladesh using remote sensing and GIS. Division of Geoinformatics, Royal Institute of Technology, Stockholm, Sweden.

Kiedrzyńska E, Kiedrzyński M & Zalewski M (2015). Sustainable floodplain management for flood prevention and water quality improvement. Natural Hazards, 76, 955-977.

Kleinhans MG, McMahon WJ & Davies NS (2024). What even is a meandering river? A philosophy-enhanced synthesis of multilevel causes and systemic interactions contributing to river meandering. Geological Society, London, Special Publications, 540 (1), 43-74. https://doi.org/10.1144/SP540-2022-138

Krishnan A (2024). Morphometric analysis in the sub basins of the Kali River using Geographic Information System, Karnataka, India. Geomatica, 76(2), 100013.

Latrubesse EM, Stevaux JC & Sinha R (2005). Tropical Rivers. Geomorphology, 70, 187-206.

Manjusree P, Satyanarayana P, Bhatt CM, Sharma SVSP & Srinivasa RG (2013). Remote sensing and GIS for river morphology studies. National natural resources management system, 51.

McGlue MM, Yeager KM, Soreghan MJ, Behm M, Kimirei IA, Cohen AS & McInytre PB (2021). Spatial variability in nearshore sediment pollution in Lake Tanganyika (East Africa) and implications for fisheries conservation. Anthropocene, 33, 100281.

Monegaglia F, Tubino M & Zolezzi G (2019). Interaction between curvature-driven width oscillations and channel curvature in evolving meander bends. Journal of Fluid Mechanics, 876, 985-1017.

Naim MNH & Hredoy MSN (2021). Simulation of channel dynamics of the Padma River considering seasonal variations: a GIS and statistical approach. Environmental Challenges, 4, 100169.

Pande CB & Pande CB (2020). Watershed management and development. In: Pande CB (Ed) Sustainable Watershed Development: A Case Study of Semi-arid Region in Maharashtra State of India. Springer Cham, 13-26 pp.

Seminara G (2006). Meanders. Journal of fluid mechanics, 554, 271-297.

Siddha S & Sahu P (2022). Impact of climate change on the river ecosystem. In Ecological significance of river ecosystems. Elsevier, 79-104 pp.

Thayer JB & Ashmore P (2016). Floodplain morphology, sedimentology, and development processes of a partially alluvial channel. Geomorphology, 269, 160-174.

Wang Y, Zhang Y, Sun W & Zhu L (2022). The impact of new urbanization and industrial structural changes on regional water stress based on water footprints. Sustainable Cities and Society, 79, 103686.

Wharton G, Mohajeri SH & Righetti M (2017). The pernicious problem of streambed colmation: A multi-disciplinary reflection on the mechanisms, causes, impacts, and management challenges. Wiley Interdisciplinary Reviews: Water, 4(5), e1231

How to cite this article: Imam A, Kumar P, Uddin MR & Al-Amin M (2025). Monitoring Channel Dynamics of the Padma River Using Remotely Sensed Data. Life Science Studies, 02, 33-42.

Appendix 1. Acquired data and source

Data type & ID	Production date	Scale (m)	Source
Landsat 5 (TM)	05-12-1988	79	Earth Explorer, USGS
Landsat 5 (TM)	02-04-2000	30	
Landsat 8 (OLI-TIRS)	04-02-2016	30	

Appendix 2. Classification scheme

Class	Description
Water Body	River stream
Soil	Soil around the study area
Vegetation	Woody vegetation, sparsely vegetated area
Sand	Sandy area around the rive