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Morphodynamical Behavior of the Ghaghara River (Bahraich–Tanda Reach), Central Ganga Plain, Northern India

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Abstract

The Ghaghara River, a major Himalayan tributary of the Ganga River, exhibits pronounced morphodynamical variability within its alluvial reaches of the Central Ganga Plain, Northern India. This study examines the morphodynamic behavior of the middle reaches of the Ghaghara River, specifically between Bahraich and Tanda, using remote sensing and field observations. Multi-temporal Landsat satellite imagery spanning 1975–2022, integrated with GIS-based analyses and detailed field observations were employed to quantify planform evolution, bankline shifting, and reach-wise morphodynamic responses. Quantitative bankline analysis indicates that left-bank migration ranges from 3.12 km to 4.22 km. In contrast, right-bank migration ranges from 3.37 km to 7.91 km, reflecting contrasting erosion and accretion patterns under changing hydrological conditions. The highest degree of channel instability is observed around the Rudauli–Goshainganj reach, where active meander expansion, cut-bank erosion, and point-bar accretion are dominant geomorphic processes. Sinuosity index range from 1.07 to 1.27 in Reach-A (Bahraich-Colonelganj), 1.10 to 1.24 in Reach-B (Colonelganj–Rudauli), 1.21 to 1.37 in Reach-C (Rudauli–Goshainganj), and 1.14 to 1.31 in Reach-D (Goshainganj-Tanda), with peak sinuosity generally recorded during the 1990–2020 period. Variations in channel length further indicate progressive meander development and localized cut-off events, particularly in Reach B (Colonelganj–Rudauli) and Reach C (Rudauli–Goshainganj).

Keywords: Ghaghara River, Channel migration, Channel sinuosity, Central Ganga Plain, India

Introduction

River migration across floodplains is a natural geomorphic process influenced by both natural anthropogenic factors, and this phenomenon is particularly characteristic of meandering and braided river systems, where channels undergo spatial and temporal shifts (Leopold *et al*., 1964; Yang, 1971; Randle, 2006; Pati *et al*., 2008; Chakraborty and Mukhopadhyay, 2015; Manjare, 2017; Manjunatha *et al.,* 2017; Kamble *et al.,* 2019; Kale and Deshmukh, 2020; Gupta *et al.,* 2020; Tiwari *et al.,* 2025). Such variations may involve two-dimensional changes, such as adjustments in channel planform, as well as one-dimensional changes in parameters like channel depth, width, and thalweg length (Wallick *et al*., 2006). In cases where river channels are incised, as in many rivers of the Central Ganga Plain, their migration is confined to their valleys (Shukla et al., 2012; Singh et al., 2019; Singh *et al.,* 2022; Yadav *et al.,* 2025). Channel migration is of particular significance to communities residing in or near floodplains, as well as to government agencies responsible for infrastructure development and management in these areas (Philip *et al*., 1989; Philip *et al*., 1991; Petropoulos *et al*., 2015). The fluvial architecture and channel patterns serve as sensitive indicators of migration dynamics, responding to variations in sediment load, hydrological regimes, and active tectonic processes (Goswami *et al*., 1999; Schumm *et al*., 2000; Pati *et al*., 2008; Singh and Awasthi, 2011; Shukla *et al*., 2012; Kanhaiya *et al*., 2019). Lateral migration of river banks often leads to asymmetrical channel positioning within the valley, driven by changes in sediment-water discharge (Yang *et al*., 1999; Schumm *et al*., 2000; Thakur *et al*., 2012). Such migration involves variations in channel width, sinuosity, and braiding intensity (Parua, 2002). These processes can cause extensive bank erosion, floodplain inundation, and displacement of populations residing near riverbanks (Singh, 1996; Shukla *et al*., 2001; Srivastava and Shukla, 2009; Prakash *et al*., 2019).

Particularly in India, numerous studies have documented the spatiotemporal dynamics of riverbank migration across various river systems (Srivastava and Singh, 1999; Mani *et al*., 2003; Swamee *et al*., 2003; Kotoky *et al*., 2005; Pati *et al*., 2008; Singh and Awasthi, 2011; Thakur *et al*., 2012; Chakraborty and Mukhopadhyay, 2015; Prakash *et al*., 2016; Debnath *et al*., 2017; Kanhaiya *et al.,* 2019; Arya and Singh, 2021; Gautam *et al*., 2024). In light of previous studies, this work focuses on analyzing channel

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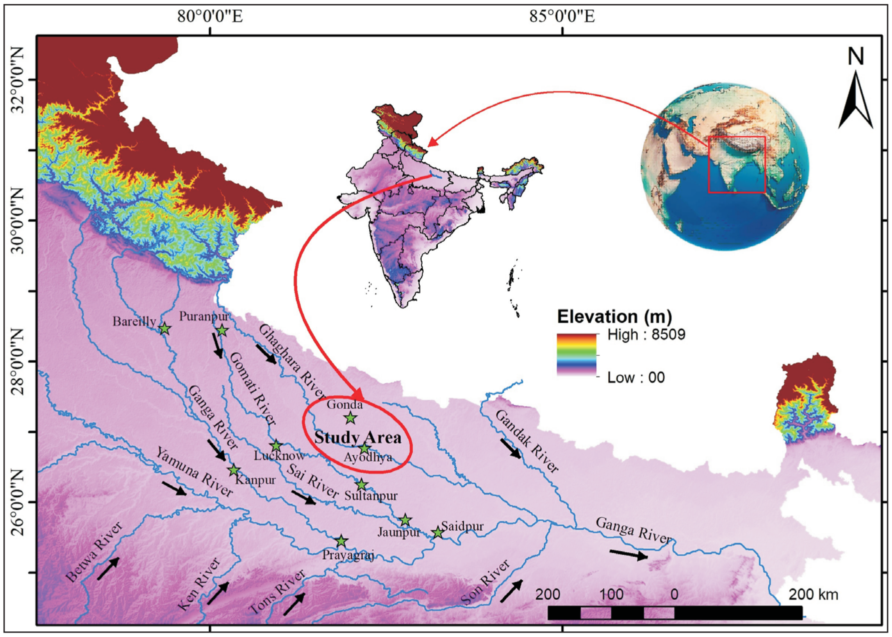

Fig. 1. The regional physiographic and topographic setting of the Central Ganga Plain, illustrating the location of the Ghaghara River and the selected study area. The digital elevation model highlights pronounced relief contrasts between the Himalayan orogenic belt in the North and the low-lying alluvial plains to the south.

morphology variations in the Ghaghara River using a morphological and cross-sectional approach. The focus is specifically on determining the migration behaviour of the Ghaghara River within the valley (Bahraich–Tanda reach) by scrutinizing 47 years of satellite imagery (Fig. 1). Lateral shifting of river banks reflects an asymmetric position of the channel in the river valley, influenced by alterations in sediment–water discharge. River migration, characterized by modifications in width, sinuosity, and braiding patterns, results in substantial riverbank erosion, flooding, and impacts on surrounding communities. As the river flows through densely populated, highly cultivated areas, even slight changes in its flow direction can significantly affect these regions. This paper examines the socio-economic implications of river migration, including community displacement, loss of agricultural land, and the need for adaptive strategies to mitigate the risks associated with these changes.

Ghaghara River

The Ghaghara River, the second-longest tributary of the Ganga River in terms of length and the largest in terms of discharge volume, is a perennial transboundary river system (Dwivedi *et al.*, 2017). It originates from the Matsatung Glacier at an elevation of approximately 4,800 m near Tibet, flowing between 25°47′–30°55′ N latitudes and 79°29′–84°49′ E longitudes (Ravi *et al.*, 2021). The basin has a total water potential of ~ 40,855.33 MCM and an average annual discharge of approximately ~ 94,400 m^3 per year (Mohan, 2018). According to the 2011 census, it supports a population of ~25.86 million, of whom ~92% live in rural areas. The area experiences a subtropical monsoonal climate, characterized by an average annual rainfall of ~ 1,000 mm and temperatures ranging from 10.9 °C to 31.7 °C (Arya and Singh, 2021; Shukla *et al.*, 2012). Morphologically, the basin comprises piedmont zones at the base of the Siwalik Hills, riverine plains formed by active fluvial deposition, and upland interfluves (Mohan, 2018). The region is underlain by older Pleistocene alluvium (yellow-brown in color) and newer Holocene alluvium (grey to black, organic-rich sediments) (Shah, 2016). The lower interfluve areas are dominated by newer alluvium. In contrast, the higher interfluves consist of older deposits characterized by unconsolidated materials such as kankar, sand, gravel, silt, and clay, typical of Indo-Gangetic alluvium (Singh *et al.*, 2020).

Methodology

Landsat satellite data of multispectral scanning system (MSS) with a spatial resolution of 79 m, Thematic Mapper (TM) with 30 m resolution, and Enhanced Thematic Mapper Plus (ETM+) with 30 m spatial resolution were obtained from Earth Explorer for a comprehensive analysis of morphodynamic and riverbank erosion along the Ghaghara River (Fig. 2). Satellite data were enhanced using ERDAS IMAGINE 2014 software by applying techniques such as layer stacking, histogram equalization, and haze reduction. For the morphodynamic assessment, Landsat images from different years were digitally processed and analyzed in ArcGIS 10.8 to map the riverbanks accurately. The delineation process was carried out to identify and emphasize key characteristics essential for understanding riverbank dynamics. Field verification was conducted within the study area to validate and supplement the remote sensing results, thereby providing crucial ground-based support (Fig. 2).

The assessment of river migration spanning 1975, 1980, 1990, 2000, 2010, 2020, and 2022 involved the differentiation of transects perpendicular to the channel. The migration distance was computed as the distance between the intersection points and the channel bank, following the methods proposed by Leopold (1964), Gurnell *et al.* (1994) and Giardino and Lee (2011). Transects were strategically drawn at 30 km intervals for each location, minimizing bias in selecting migration points. The mathematical formula ($Dm = T1 - T2$, where Dm is migration distance, T1 and T2 represent the successive years of investigation for river migration) was utilized for calculating migration distance (Dm) as per Giardino and Lee

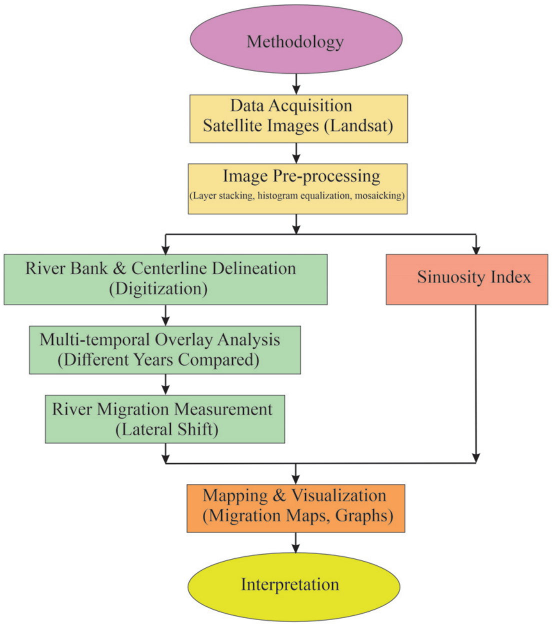

Fig. 2. A schematic workflow illustrating the methodological framework adopted for analyzing channel migration and planform dynamics of the Ghaghara River.

(2011). Overlay maps illustrating riverbank migration from 1975 to 2022 were generated to comprehensively depict erosion and deposition patterns along the Ghaghara River (Bahraich–Tanda reach). The investigation used Landsat imagery in ArcGIS (ArcInfo 10) to estimate riverbank migration. Manual digitization (visual interpretation) of Ghaghara River banks in the study area was performed in 1975, 1980, 1990, 2000, 2010, 2020, and 2022 at a scale of 1:50,000. Topological corrections in ArcGIS 10.8 were applied to eliminate digitization errors, such as overshooting and undershooting. The sinuosity index (SI = CL / VL, where SI is the sinuosity index, CL is channel length, and VL is valley length) was calculated following Leopold *et al*. (1964) and Mueller (1968).

Results

An analysis of satellite imagery from the years 1975, 1980, 1990, 2000, 2010, 2020, and 2022 shows that the Ghaghara River has undergone noticeable migration within its valley, with significant changes in channel geometry observed over each decade (Fig. 3). Between Bahraich and Tanda, the Ghaghara River is classified into four distinct reaches based on variations in valley width, floodplain and channel-bar characteristics. These four reaches are: (A) Bahraich-Colonelganj reach, (B) Colonelganj-Rudauli reach, (C) Rudauli-Goshainganj reach, and (D) Goshainganj-Tanda reach accordingly. Fig. 3 and 4 highlight that channel migration along the Ghaghara River is spatially variable and strongly reach-dependent.

Bahraich-Colonelganj reach

In Reach-A near Bahraich, the river exhibits relatively constrained migration with localized meander development and moderate lateral shifts (Fig. 3-4). Between Bahraich and Colonelganj, the Ghaghara flows southeast, and this tributary input strongly influences its morphology. Upstream of the confluence with the Sarda, the river exhibits a braided pattern, while a river island has formed downstream, reflecting the dynamic redistribution of sediment. This reach (Bahraich-Colonelganj) displays various geomorphic features associated with channel migration, including meander scars, paleochannels, abandoned meandering channels, and meander cut-offs, particularly along the northern bank. These features indicate that the river has historically undergone significant lateral shifts and adjustments. As far as lateral channel migration is concerned, the right bank of the river had the maximum displacement (5.69 km) in 2000, while the minimum

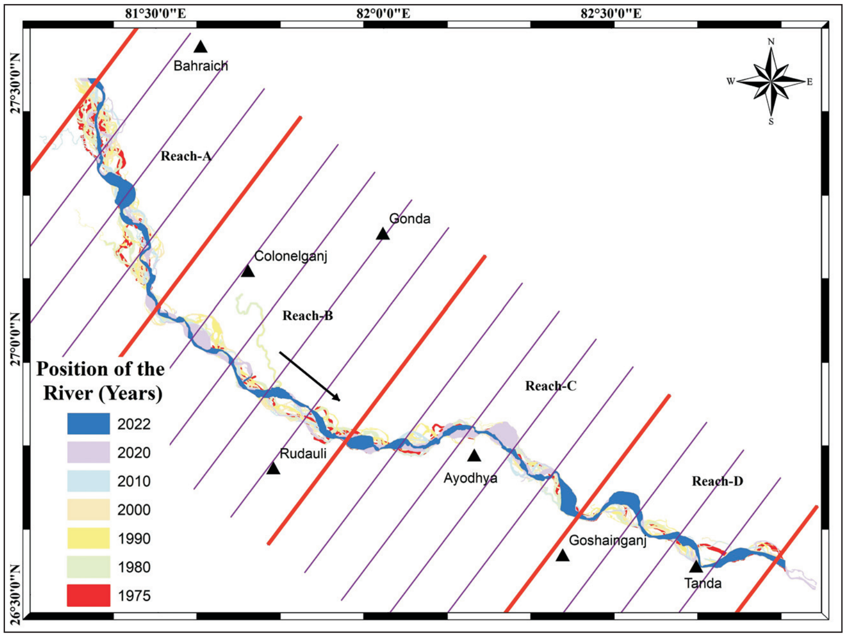

Fig. 3. The spatio-temporal variation in the channel position of the Ghaghara River between Bahraich and Tanda based on multi-temporal satellite imagery spanning 1975 to 2022. Superimposed river outlines for different years clearly illustrate pronounced lateral migration, channel shifting, and planform adjustments over the last five decades. The study's reach is divided into four segments (Reach A–D) to highlight differences in channel behavior and migration intensity.

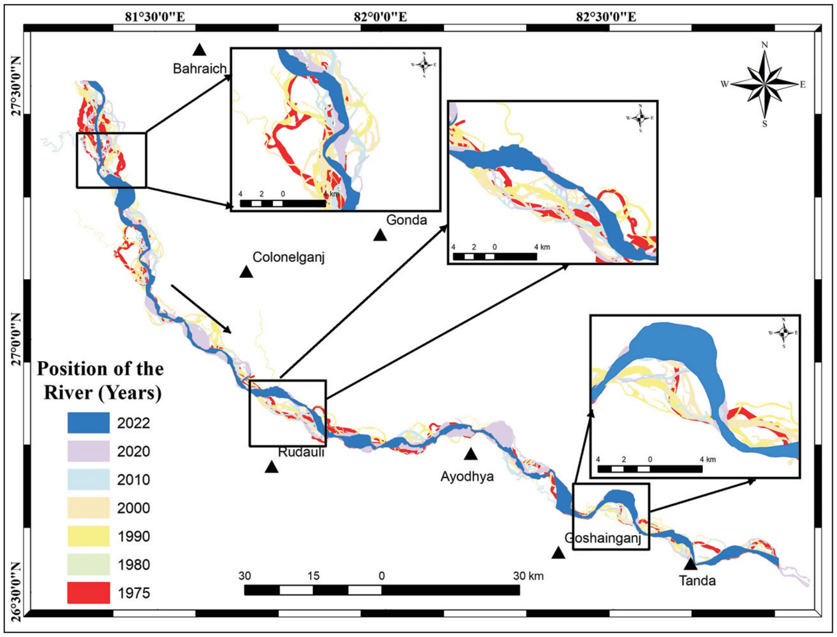

Fig. 4. Detailed spatio-temporal changes in the channel position of the Ghaghara River between Bahraich and Tanda based on multi-temporal satellite data from 1975 to 2022. The superimposed river outlines clearly demonstrate significant lateral migration, channel shifting, and planform reorganization over the past five decades. Enlarged inset maps highlight representative locations along the river course to emphasize localized migration patterns and bankline adjustments at finer spatial scales.

shift was 0.041 km in 2010 (Table 1; Fig. 5). Such changes promote the formation of mid-channel bars, diverting secondary channels, and driving further lateral migration (Madej *et al*., 1994; Parua, 2002; Kotoky *et al*., 2005). The sinuosity index in the Bahraich–Colonelganj reach ranges from 1.07 to 1.27, suggesting a moderately sinuous channel (Table 2; Fig. 5).

Colonelganj-Rudauli reach

Downstream, Reach-B (Colonelganj–Rudauli) shows enhanced lateral migration marked by frequent changes in channel alignment, indicating active bank erosion and point-bar accretion. The overlapping river positions demonstrate repeated oscillatory movement, suggesting dynamic meander growth influenced by floodplain width and sediment availability (Fig. 3-4). Between Colonelganj and Rudauli, the Ghaghara River flows southeastward, yet this stretch is characterized by pronounced sinuosity and dynamic channel behavior. The river frequently migrates laterally, oscillating between the valley margins, and exhibits characteristic fluvial landforms such as meanders, mid-channel bars, and point bars. These features indicate active sediment redistribution and highlight the floodplain's persistent reworking by erosional and depositional forces (Randle, 2006; Pati *et al*., 2008; Singh, 2017). On the left bank, maximum lateral displacement reached 4.22 km in 1990, while the minimum shift narrowed to 0.03 km in 2022 (Table 1; Fig. 5). Conversely, the right bank showed a maximum change of 2.27 km in 2022, with the lowest displacement measured, i.e., 0.02 km in the same year (Table 1). These dynamics, as

Table 1: Cross-sectional variation (1975-2022) in riverbank migration for the left and right banks of the Ghaghara River (Bahraich – Tanda Reach)

Distance along	1975-1990		1975-2000		1975-2010		1975-2020		1975-2022	
the river (km)	Left bank	Right bank	Left bank	Right bank	Left bank	Right bank	Left bank	Right bank	Left bank	Right bank
0	0.60	1.29	0.27	1.36	2.37	3.96	2.92	4.00	2.96	3.73
17.5	2.40	4.16	1.36	4.89	3.80	7.91	1.02	5.01	-2.71	0.89
33.77	-1.50	1.15	-1.81	0.77	-3.26	-0.04	1.53	4.14	1.81	4.40
47.59	3.70	5.18	1.93	5.69	1.00	5.26	2.10	5.43	2.16	6.28
61.61	-0.71	-0.26	1.38	-1.88	-0.35	0.70	0.00	-0.64	0.11	0.59
71.89	4.22	0.63	-0.73	0.30	1.22	3.13	0.55	-0.20	-1.65	-0.10
82.05	-0.23	0.75	1.40	1.83	1.16	1.03	0.49	-0.01	0.03	-0.04
97.46	-0.14	-1.20	-1.03	-1.36	0.42	0.71	0.66	0.52	1.15	-0.16
109.28	-0.98	-0.02	-0.88	0.11	1.11	-0.01	1.55	-0.07	1.57	2.78
120.24	-1.53	0.77	-2.24	0.09	-1.73	-0.01	-0.79	-0.06	-0.77	-0.02
132.34	1.69	0.56	-0.07	0.30	3.99	1.14	0.32	0.72	2.00	0.56
149.49	0.48	0.88	1.19	0.43	-0.62	0.34	0.44	-0.32	1.14	1.74
165.12	0.16	-0.37	-1.85	-2.02	-1.16	-1.59	0.34	0.07	-0.18	-0.71
178.04	0.68	1.58	0.52	1.21	0.57	1.03	0.63	0.71	0.65	-0.95
190.92	-0.55	0.10	-0.83	0.04	-0.003	0.03	-0.10	0.02	0.01	0.02
209.58	0.08	0.61	0.94	0.11	3.13	0.44	3.65	2.70	3.73	2.60
221.74	1.56	0.43	0.09	-0.40	0.84	0.40	1.56	-0.32	1.59	0.59
234.24	-3.12	-3.37	-2.91	-3.31	-2.56	-3.35	-2.55	-3.31	-2.49	-3.25
248.15	-1.38	-1.19	-0.53	0.11	-1.32	-1.18	-1.25	-1.19	-0.83	-1.19

Note: The negative values denote south-westward (SW) migration, and positive values denote northeastward (NE) migration of the river bank illustrated in Figs. 3-4, highlight the ongoing reshaping of the river corridor over time. The sinuosity index of the Ghaghara River within this section ranges between 1.10 and 1.24, classifying it as moderately sinuous.

Rudauli-Goshainganj reach

Reach-C (Rudauli-Goshainganj) represents a zone of maximum geomorphic activity, where repeated lateral adjustments have significantly reworked the floodplain (Fig. 3-4). Between Rudauli and Goshainganj, the Ghaghara River flows northeastward as it approaches Ayodhya. After passing through Ayodhya, the river course shifts southeast, marking a significant deviation that reflects its long history of channel migration and floodplain evolution. This directional change is not a modern occurrence, but rather part of a broader pattern of fluvial dynamics that have shaped the region over centuries. Hydrological data further underscore the extent of channel migration. On the right bank, the river has undergone lateral shifts, reaching a maximum displacement of 2.02 km in 2000, which highlights the intensity of bank erosion and channel adjustment (Table 1; Fig. 5). Such movement illustrates the dynamic interaction between erosional and depositional forces that continuously reshape the alluvial landscape (Joshi and Bhartiya, 1991; Ta *et al*., 2013). The sinuosity index of the Ghaghara River within this stretch ranges from 1.21 to 1.37, placing it in the category of moderate meandering (Table 2; Fig. 5).

Goshainganj-Tanda Reach

Further downstream, Reach-D (Goshainganj–Tanda) shows comparatively reduced lateral displacement but continued channel adjustment through localized bank erosion and minor shifts in channel position. (Fig. 3-4). From Goshainganj to Tanda, the Ghaghara River flows generally southeastward, shaping the surrounding landscape with diverse geomorphic features. Within this stretch of the valley, clear evidence of channel migration can be observed in the form of meander scars, paleochannels, abandoned meandering channels, and cut-offs. These features reflect the river's dynamic nature and its history of lateral movement (Holbrook and Schumm, 1991; Tooth *et al*., 2002; Mani *et al*., 2003). Analysis of channel shifts indicates significant temporal variation. On the right bank, the maximum lateral shift was recorded at 3.37 km in 1990, while the minimum change was 0.32 km in 2020 (Fig. 5). In contrast, the left bank exhibited a maximum shift of 3.73 km in 2022 and a minimum displacement of 0.08 km in 1990 (Table 1; Fig. 5). Such fluctuations highlight the asymmetry of bank erosion and deposition processes, with the river exerting a greater influence on different banks at different times (Thornbury, 1954; Randle, 2006; Prakash *et al., 2016*). Moreover, the channel sinuosity index in this sector ranges from 1.14 to 1.34, indicating moderate meandering (Table 2; Fig. 5).

Table 2: Sinuosity index variation (1975-2022) of the Ghaghara River channel (Bahraich – Tanda Reach)

Reach	Sinuosity index						
	1975	1980	1990	2000	2010	2020	2022
A	1.08	1.07	1.17	1.19	1.26	1.27	1.19
B	1.11	1.17	1.24	1.24	1.18	1.18	1.10
C	1.21	1.27	1.37	1.24	1.32	1.31	1.21
D	1.24	1.25	1.14	1.24	1.24	1.31	1.24

Discussion

The morphodynamical behavior of the Ghaghara River between Bahraich and Tanda reflects the inherent instability typical of large Himalayan-fed alluvial rivers flowing across the Central Ganga Plain. Integration of multi-temporal satellite imagery, GIS-based planform analysis, and detailed field observations provides clear evidence of sustained lateral channel migration, asymmetric bank erosion–accretion processes, and pronounced spatial variability along the river course. These characteristics are consistent with rivers influenced by high sediment supply, strong monsoonal discharge variability, gentle floodplain gradients, and unconsolidated alluvial deposits (Goodberd, 2003). The widespread presence of paleochannels, meander scars, abandoned channels, and cut-off loops further indicates continuous floodplain reworking during the late Quaternary period (Arya and Singh, 2021; Gautam *et al*., 2024). The present analysis quantifies substantial bank-line migration over the past five decades, with left-bank displacement ranging from –3.12 km to +4.22 km and right-bank

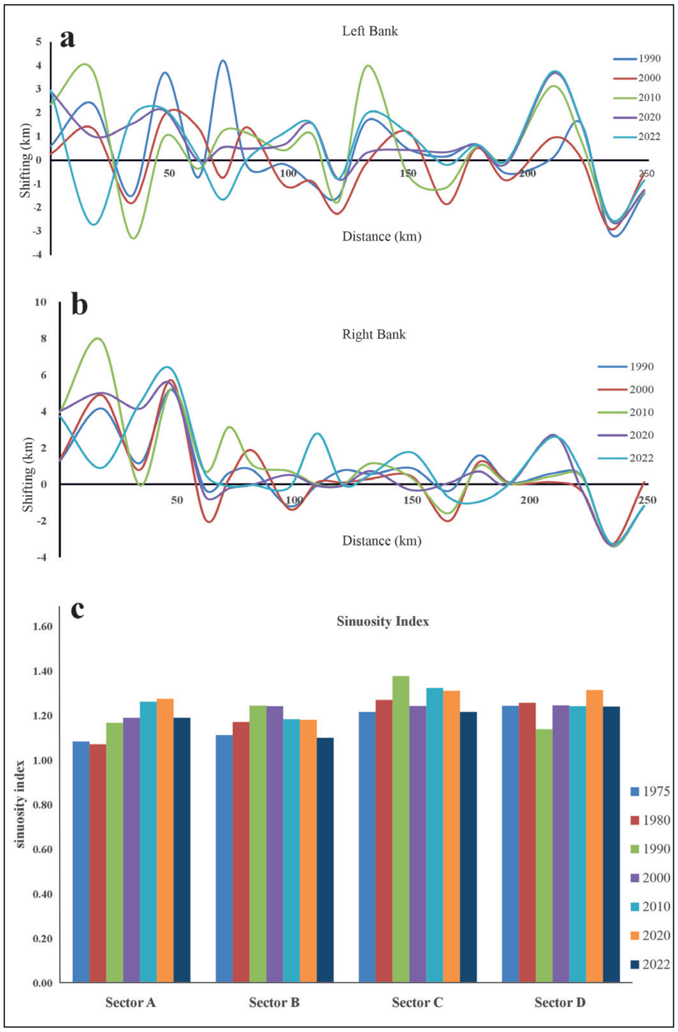

Fig. 5. Shows **(a)** and **(b)** show left- and right-bank lateral shifting along the Ghaghara River course (Bahraich – Tanda Reach) for different years, highlighting asymmetric and oscillatory migration patterns, while **(c)** presents reach-wise sinuosity indices indicating a predominantly meandering channel with higher sinuosity and instability in the middle sectors.

migration ranging from –3.37 km to +7.91 km. These values highlight the asymmetric nature of channel adjustment, in which lateral erosion remains the dominant mechanism driving channel migration and recurrent flooding (Gautam *et al.,* 2024). In the Bahraich-Colonelganj reach, higher magnitudes of right-bank migration indicate preferential erosion associated with local channel curvature, flow convergence, and variations in bank material resistance. Such behavior is characteristic of meandering rivers, where secondary circulation intensifies erosion along concave banks while promoting deposition on convex banks (Yang, 1971; Yang *et al*., 1999; Winterbottom and Gilvear, 2000).

Spatial analysis reveals that channel instability is not uniform, with the maximum lateral displacement concentrated particularly in the Rudauli–Goshainganj reach, where active meander expansion, cut-bank erosion, and bar development dominate. These reaches are characterized by wider floodplains and highly erodible alluvial sediments, which facilitate rapid lateral adjustment during high-discharge monsoonal events (Arya and Singh, 2021; Gautam *et al*., 2024). Sinuosity analysis provides further insight into the evolving planform dynamics of the Ghaghara River. Moderate to high sinuosity values across all reaches indicate a dominantly meandering channel pattern. Reach-wise variations, ranging from 1.07–1.27 in Reach-A to 1.21–1.37 in Reach-C, reflect differential morphodynamic responses controlled by local slope, channel confinement, and sediment availability. The highest sinuosity values in Reach-C correspond with intensified meander growth and lateral accretion, consistent with the high migration rates observed in this area. Temporal analysis indicates peak sinuosity during the 1990–2020 period, suggesting enhanced meander expansion and relatively fewer cut-off events, while minor reductions in sinuosity in later years likely reflect localized channel straightening following cut-offs.

Field observations corroborate satellite-based interpretations, documenting active bank collapse, exposure of stratified alluvial sediments, and extensive sandbar development along the river corridor (Fig. 6). Anthropogenic interventions such as embankments and bank protection structures locally restrict channel movement; however, they often intensify erosion downstream or along the opposite bank, thereby redistributing rather than reducing channel instability (Arya and Singh, 2021;

Fig. 6. Field photographs showing active morphodynamical processes along the Ghaghara River. (a) and (b) show sandy banks and steep cut banks with exposed stratified alluvium, indicating active lateral erosion, while (c) highlights floodplain modification and embankment-based protection measures, and (d) demonstrates continued bank retreat and damage to protective structures, reflecting persistent channel instability.

Gautam *et al*., 2024). The observed morphodynamic behavior highlights the combined influence of Himalayan sediment supply, monsoonal hydrology, erodible floodplain materials, and human interference in governing channel evolution. Persistent lateral migration and reach-specific instability pose serious challenges for floodplain settlements, agricultural land, and infrastructure in the Central Ganga Plain. Fig. 7 illustrates the regional geomorphological and tectonic framework of the study area, with faults/lineaments trending predominantly in NW–SE and NE–SW directions. These basement-controlled structures locally influence river alignment, meander orientation, and zones of enhanced lateral migration within the alluvial plain (Pati *et al*., 2015). The spatial association between the river course and mapped lineaments suggests that structural controls, together with high sediment supply and monsoonal discharge variability, play a significant role in governing channel instability in this region.

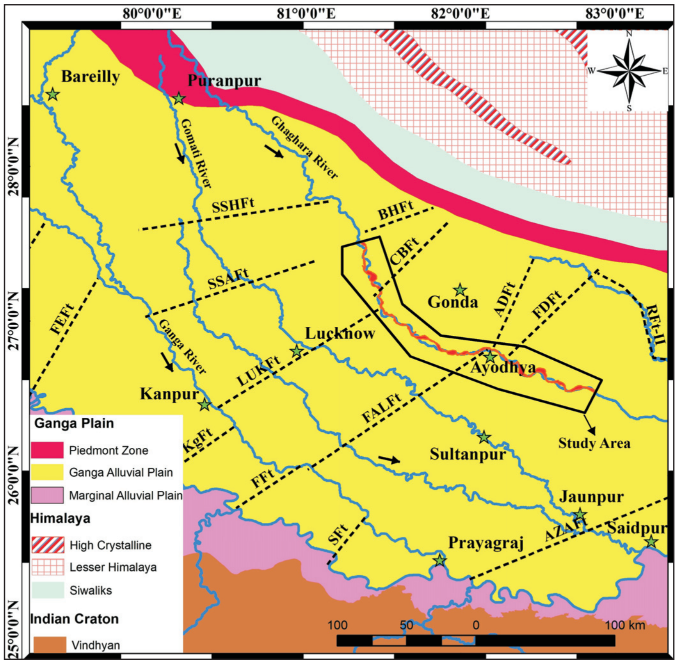

Fig. 7. Regional geomorphological and tectonic framework of the Central Ganga Plain showing major physiographic divisions, Himalayan tectonic units, and active basement lineaments (major fault-bounded blocks and sub-blocks). The highlighted polygon indicates the study area between Bahraich and Tanda. Physiographic zones include the Piedmont Zone, Ganga Alluvial Plain, and Marginal Alluvial Plain, while the Himalayan domains and the Vindhyan craton are shown for the regional tectonic context. Faults have been redrawn from Pati *et al*. (2015). (FEFt) Fatehgarh–Etawah Fault, (SSHFt) Sitapur–Shahjahanpur Fault, (SSAFt) Sidhaur–Sandila Fault, (LUKFt) Lucknow Fault, (FALFt) Faizabad–Lalganj Fault, (AZAFt) Azamgarh–Allahabad Fault, (CBFt) Colnelganj–Balrampur Fault, (BHFt) Bahraich Fault, (ADFt) Ayodhya–Dinkarpur Fault, (FDFt) Faizabad- Domariaganj Fault, (KGFt) Kanpur–Ghatampur Fault.

Conclusions

The present study provides a comprehensive evaluation of spatio-temporal channel migration and morphodynamic behavior of the Ghaghara River using multi-temporal satellite imagery (1975–2022). The results demonstrate that the river is highly dynamic and laterally unstable, characterized by pronounced reach-scale variability in channel position, bank erosion, and planform geometry. The river has shifted left-bank by 3.12 km to + 4.22 km and right-bank by – 3.37 km to + 7.91 km between Bahraich and Tanda over the last five decades. Field observations of steep cut banks, collapse of unconsolidated sandy alluvium, exposed stratified deposits, and abandoned channels clearly indicate that lateral erosion is the dominant geomorphic process. Quantitative migration analysis reveals strong asymmetry between the left and right banks, with alternating south-westward and northeastward shifts, reflecting oscillatory channel behavior rather than systematic unidirectional migration. Maximum lateral displacement is concentrated in the middle and downstream reaches, particularly around the Ayodhya-Goshainganj area, indicating this zone as a hotspot of geomorphic instability. Sinuosity values indicate a predominantly meandering channel pattern with moderate to high curvature, and temporal fluctuations suggest repeated cycles of meander growth, localized cut-offs, and partial channel straightening. Persistent lateral migration and bank erosion pose significant challenges for settlements, infrastructure, and agricultural land in the studied region, underscoring the limitations of static engineering solutions. Sustainable river management should therefore recognize channel migration as an inherent fluvial process and adopt a process-based, reach-specific approach that accommodates natural channel mobility.

Authors' Contributions

SKS: Investigation, Conceptualization. **SS:** Writing-Original Draft, Methodology. **VKC:** Supervision. **SK:** Reviewing and Editing. **SKY:** Data Curation, Formal Analysis.

Conflict of Interests

The authors declare no conflict of interest.

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