

# Comprehensive analysis of shoreline fluctuation pattern in and around Gangasagar Coast, Sundarbans Delta, India

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## ABSTRACT

The Gangasagar coast, forming the southern fringe of the Sundarbans delta, represents one of the most dynamic and hazard-prone coastal environments of eastern India. Over the past five decades (1975 to 2025), the shoreline has undergone significant spatial and temporal shifts, documented through satellite imagery, topographic analysis, and systematic field observations. Historical shoreline positions were extracted from Landsat datasets using MNDWI analysis at 8-15 year intervals, allowing spatio-temporal comparisons that reflect post-cyclone shoreline adjustments. Variations in the low water line across Beguakhali, Gangasagar and Dhublhat sectors reveal alternating episodes of erosion and accretion controlled mainly by recurrent cyclonic disturbances. Intense storms such as Aila, Amphan, and Yaas triggered large-scale coastal retreat, embankment collapse, and mangrove degradation. Phases of limited recovery were observed only during relatively calm intervals, yet subsequent events repeatedly reversed these trends. Between 1975 and 2025, the shoreline retreated landward by approximately 697 m at Beguakhali, 69 m at Gangasagar, and 1064 m at Dhublhat, indicating the highest erosion intensity in the Dhublhat sector. The cumulative geomorphic imprint of recurring cyclones indicates a long-term transformation of the Gangasagar shoreline toward increasing instability, reduced sediment resilience, and progressive loss of coastal land and ecosystem integrity.

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## 1. Introduction

Gangasagar Island, also known as Sagar Island, is one of the largest deltaic islands in the South 24 Parganas district of West Bengal, India, located at the confluence of the Ganga River and the Bay of Bengal on the northeastern coast of the Indian Ocean. Positioned between 21°37' 21" to 21°52' 28" N latitudes and 88°02' 17" to 88°10' 25" E longitudes, the island forms the seaward margin of the Sundarbans delta and covers an area of approximately 300 km<sup>2</sup> (Fig. 1). The Hooghly River bifurcates near its northern tip, with the Muriganga channel to the east and the main Hooghly channel to the west, creating a dynamic fluvio-marine setting. The study area, which is actually the southern coastal tract of Gangasagar,

extends for nearly 11 km. This stretch can be divided into three sectors with their distinct geomorphic features: the central Gangasagar beach, the eastern Dhublhat beach and the western Beguakhali beach. Several studies have addressed the problem of coastal erosion and management in Sagar Island, highlighting the increasing vulnerability of its shoreline to natural and anthropogenic pressures (Bandyopadhyay, 1997; Chakraborty and Saha, 2020). The combined effects of relative sea-level rise, sediment supply variations and cyclonic events have contributed to the island's instability (Hazra et al., 2002; Nandi et al., 2016). Repeated occurrences of severe cyclones such as Aila of 2009, Bulbul of 2019 and Amphan of 2020 have triggered large-scale shoreline retreat, embankment

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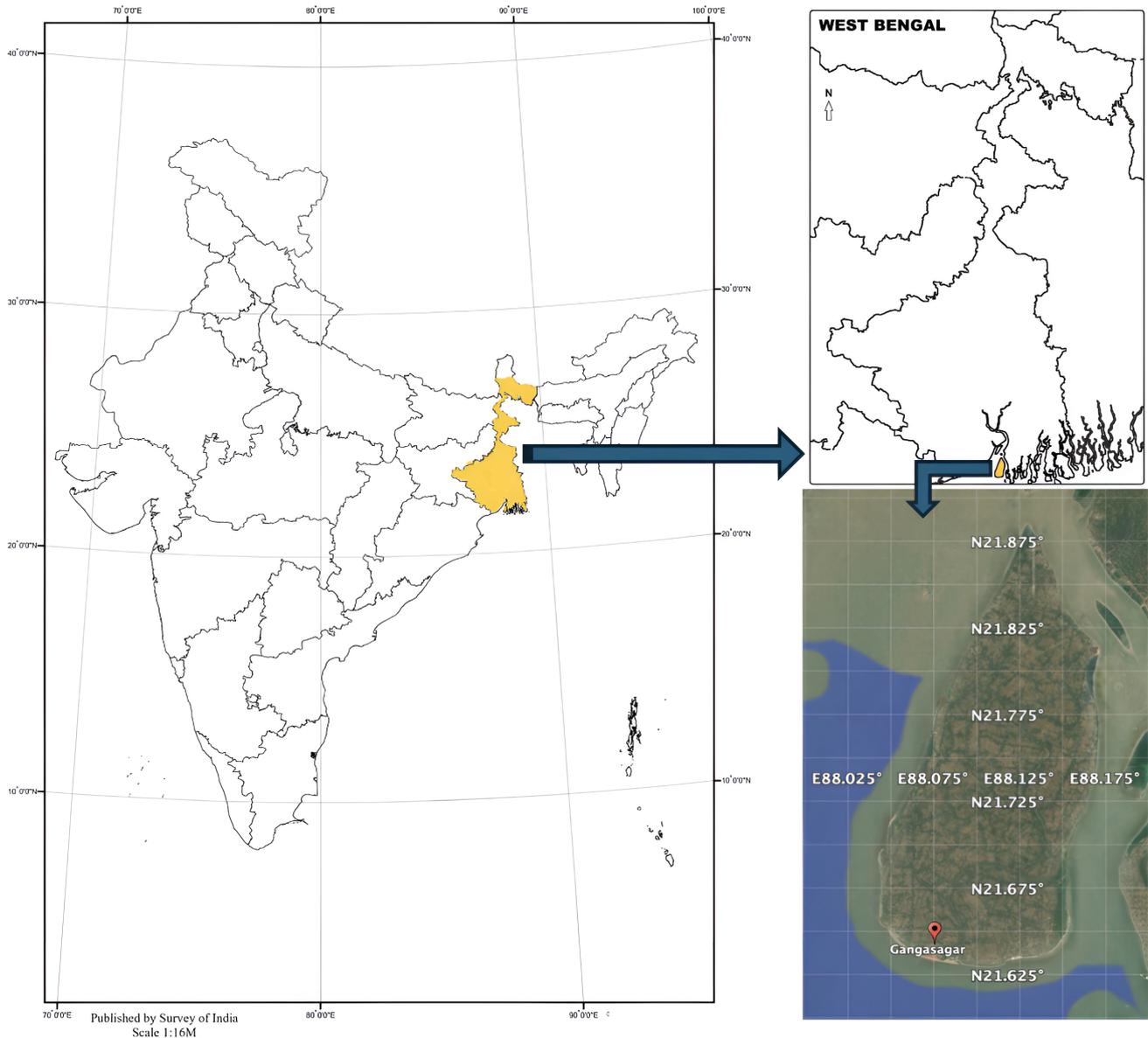


Fig. 1. Location of Sagar Island, Sundarbans Delta, India.

failures, and saline water intrusion, affecting both the land and people living there (Gopinath and Seralathan, 2005; Chakraborty and Saha, 2020). Paul et al. (2024) found that overwash vulnerability and shoreline changes are connected, and both are worsened by climate change and extreme weather. Although previous studies have highlighted the high vulnerability of this coast to erosion, storm surges, and cyclone impacts, yet long-term shoreline dynamics remain inadequately explored. The present study conducts a multi-decadal analysis of the low water line (LWL) from 1975 to 2025, using topographic maps, satellite datasets, and published sources. By assessing spatial and temporal shoreline migration

across different Gangasagar Island.

## 2. Methodology

Fieldwork was conducted along the Beguakhali-Gangasagar-Dhublat coastal tract between December 2024 and January 2025. The low water line (LWL) and high water line (HWL) were traced using handheld GPS, with geomorphic features such as palaeomud exposures, ripple marks, dunes, mangroves, and anthropogenic embankments systematically recorded (Fig. 2). Sediment samples were collected from intertidal, dune, and palaeomud zones. GPS data were processed in QGIS, where shorelines were digitized

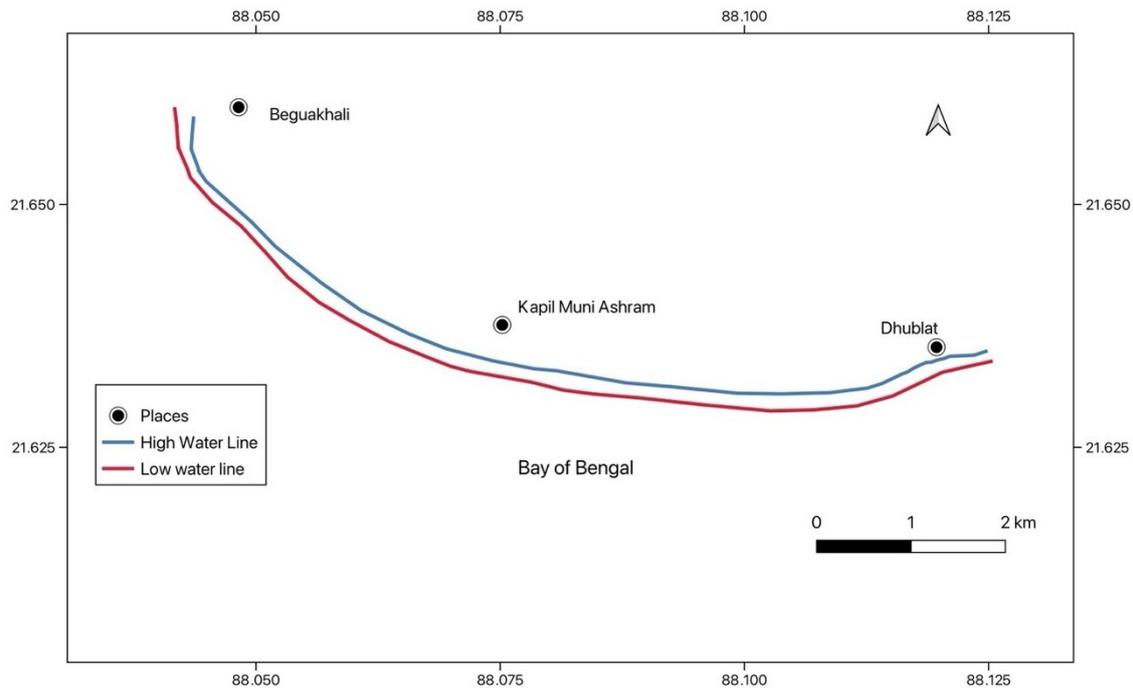


Fig. 2. Low water line and high water line of Gangasagar region 2025.

as vector lines and compared with Google Earth imagery for positional accuracy. Historical shoreline vectors (1975, 1990, 2001, and 2017) were derived from Landsat datasets through NDWI (Normalized Difference Water Index) and MNDWI (Modified Normalized Difference Water Index) analysis. Data intervals ranging from 8 to 15 years were deliberately selected to align with significant cyclonic occurrences (Table 1 & 2). This approach allowed a clearer interpretation of the shoreline's progressive shifts and recovery phases in relation to major storm impacts. In the laboratory, samples were dried, treated with hydrogen peroxide and ammonia, and subjected to wet and dry sieving, with silt and clay fractions determined by pipette analysis using Stoke's law. Grain-size data were classified following Shepard's scheme to interpret sedimentary environments.

### 3. Analysis

Cyclonic activity in the Bay of Bengal has historically effected shoreline dynamics in the Gangasagar region. The frequency of severe cyclones increased notably after the late 1980s, with events such as the 1988 cyclone, the 1999 Odisha super cyclone, and subsequent 21<sup>st</sup>-century landfalls (Aila of 2009, Phailin of 2013, Bulbul of 2019, Amphan of 2020, Yaas of 2021 and Remal of 2024) leaving measurable geomorphic imprints. Earlier research using re-

mote sensing and GIS has established that Sagar Island's coastline has undergone rapid land-loss since the late 20th century, with significant transformations detected between 1973 and 2014 (Dinesh Kumar et al., 2007; Kundu et al., 2014; Nandi et al., 2016). The integration of multi-temporal satellite data and field validation has proved essential in understanding the spatial variability of shoreline dynamics (Jayappa et al., 2006). The low water line datasets, when juxtaposed with cyclone timings, consistently indicate phases of abrupt retreat immediately following severe storms, interspersed with partial recovery during intervening moderately calmer years. Positive value indicates shifting of LWL towards land.

#### 3.1. Beguakhali Sector

The Beguakhali coastal stretch, monitored through P1 and P2 profile line, exhibits high sensitivity to cyclonic impacts due to its proximity to active tidal creeks and a discontinuous mangrove fringe (Fig. 3). The LWL positions from 2001 onward reveal alternating erosion–accretion patterns, with major landward displacements coinciding with the passage of Aila (2009) and Amphan (2020). During Aila, storm surge penetration dismantled sections of the earthen embankment. P1 showed the greatest displacement after 2009, consistent with this local geomorphic setting. A partial recovery phase was noted

Table 1. Low water line data sources.

Year	Source	Measurement Process
1975	LANDSAT- 2 MSS	NDWI= (Green-NIR) / (Green+ NIR)
1990	LANDSAT- 5 TM	MNDWI= (Green-SWIR1) / (Green+SWIR1)
2001	LANDSAT- 5 TM	MNDWI= (Green-SWIR1) / (Green+SWIR1)
2009	LWL Map from Chakraborty and Saha (2020)	Georeferencing the digital map followed by vector plotting
2017	LANDSAT- 8 OLI	MNDWI= (Green-SWIR1) / (Green+SWIR1)
2025	Field study	GPS data processing followed by vector plotting

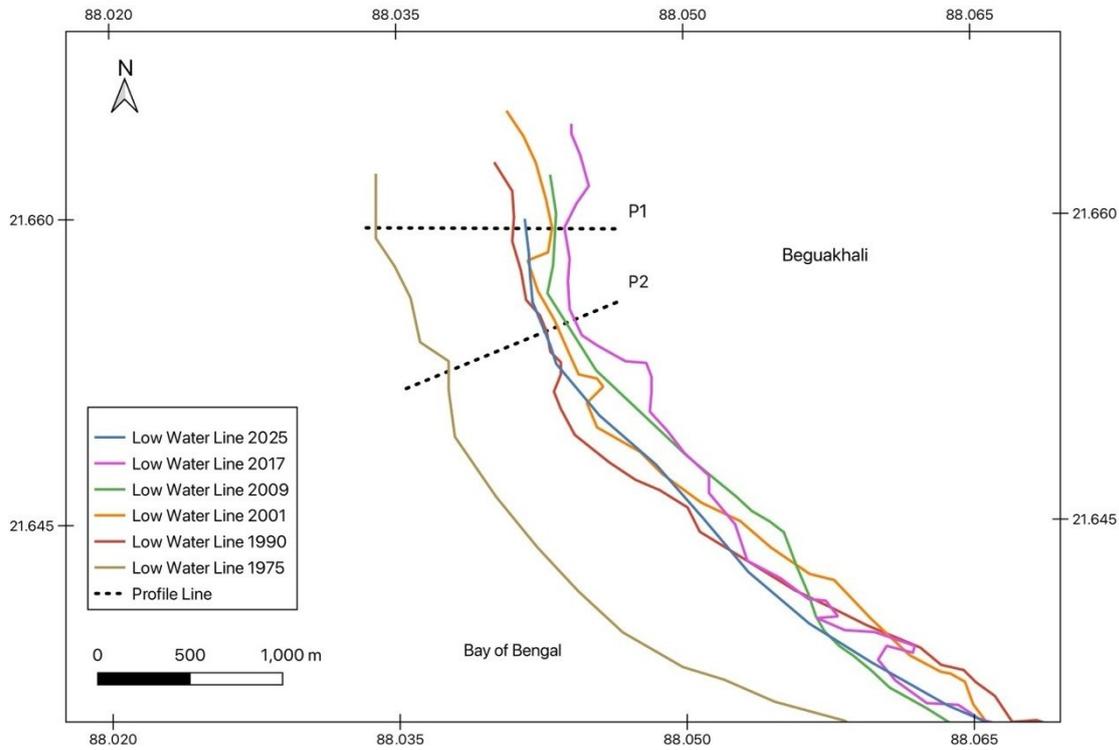


Fig. 3. Low water line analysis from 1975 to 2025 at Beguakhali region.

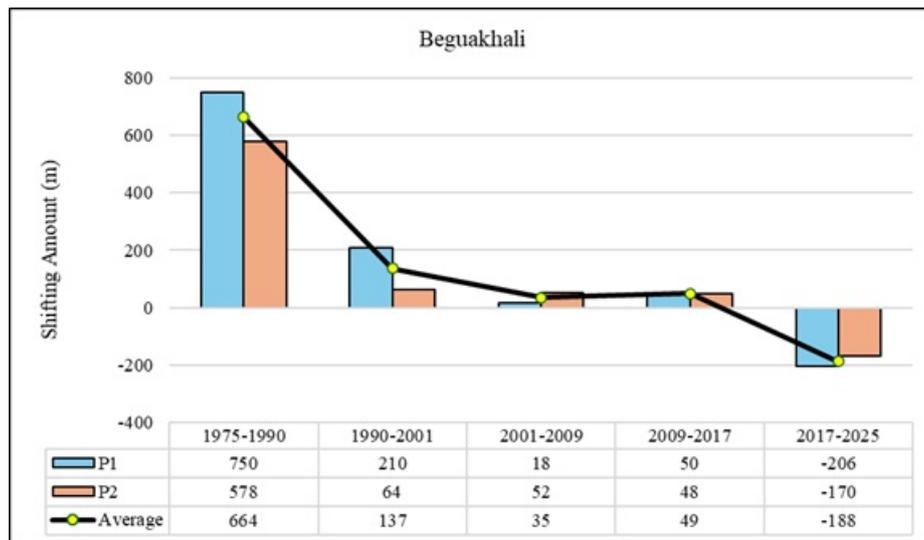


Fig. 4. Analysis of amount of shifting from 1975 to 2025 at Beguakhali region.

between 2011 and 2017, when relative calm allowed sediment reaccumulation along the tidal flats. However, the onset of Bulbul in 2019 reversed this accre-

tionary tendency, pushing the LWL landward once again (Table 3 and Fig. 4). Amphan (2020) represented the most catastrophic disturbance of the study

Table 2. List of Cyclones effecting Sagar Island and Sundarbans (1970–2025) (according to Centre for Science and Environment Data and IMD report).

Name of Event	Year	Time of Impact	Effects on Gangasagar / Sundarbans
Bhola	1970	Nov, 1970	Sundarbans region experienced inundation and heavy loss in adjacent areas. Sagar Island likely experienced abnormal surge, flooding and salt intrusion (reports focus on Bangladesh but West Bengal coasts also recorded heavy rain/flooding)
Cyclonic storms (Sundarbans)	1971, 1973	Nov, 1971 and Dec, 1973	Localized inundation, embankment overtopping on low islands including Sagar or nearby chars.
Bangladesh cyclone	1991	29 Apr 1991	Sundarbans and adjacent Indian coasts saw heavy flooding and coastal stress; Sagar Island likely experienced strong surge and coastal flooding.
Super Cyclone (Odisha)	1999	Oct, 1999	Primarily hitting Odisha; effects on Sagar Island were limited/indirect
Multiple Depressions / Deep Depressions	2001–2006	Various dates	Produced heavy rainfall and localized flooding; occasional embankment breaches and loss of life in West Bengal and Sundarbans.
<b>Indian Ocean Tsunami</b>	2004	26 Dec 2004	Tsunami waves reached Sundarbans and Sagar Island; caused tidal surges, saltwater intrusion into croplands, minor flooding of low-lying areas; limited damage compared to Andaman & Tamil Nadu.
Extremely Severe Cyclonic Storm <b>Sidr</b>	2007	15 Nov 2007	Massive storm surge and winds; widespread destruction of Sundarbans mangroves, houses, and infrastructure; many fatalities.
Severe Cyclonic Storm <b>Aila</b>	2009	25 May 2009	Breached embankments, inundated Sagar Island, salinisation of croplands; hundreds of deaths and >1 million affected.
Very Severe Cyclonic Storm <b>Phailin</b>	2013	12 Oct 2013	Made landfall in Odisha; indirect impacts included heavy rain and wind in coastal West Bengal including Gangasagar.
Cyclone <b>Hudhud</b>	2014	12 Oct 2014	Primarily affected Andhra Pradesh; Gangasagar region experienced heavy rainfall and moderate storm surge.
Cyclone <b>Komen</b>	2015	30 Jul 2015	Heavy rainfall and flooding in coastal West Bengal; moderate local impacts in Sundarbans/Gangasagar.
Cyclone <b>Roanu</b>	2016	21 May 2016	Caused heavy rainfall and flooding in coastal West Bengal including Sundarbans and Gangasagar.
Very Severe Cyclonic Storm <b>Mora</b>	2017	30 May 2017	Heavy rains and moderate storm surges impacted Sundarbans and Gangasagar.
Extremely Severe Cyclonic Storm <b>Fani</b>	2019	3 May 2019	Major landfall in Odisha; indirect strong winds and rain in Gangasagar region.
Extremely Severe Cyclonic Storm <b>Bulbul</b>	2019	9–10 Nov 2019	Made landfall near Sagar Island; severe damage to crops, mangroves, houses, and infrastructure.
Super Cyclonic Storm <b>Amphan</b>	2020	20 May 2020	Directly impacted Sundarbans and Gangasagar; catastrophic destruction of houses, embankments, trees, and power.
Very Severe Cyclonic Storm <b>Yaas</b>	2021	26 May 2021	Made landfall in Odisha; caused storm surge, heavy flooding, and embankment breaches in Gangasagar.
Cyclonic Storm <b>Jawad</b>	2021	Dec 2021	Weakened before landfall; heavy rainfall in West Bengal including Gangasagar.
Severe Cyclonic Storm <b>Sitrang</b>	2022	24 Oct 2022	Heavy rains and moderate flooding in Gangasagar and Sundarbans region.
Cyclonic Storm <b>Midhili</b>	2023	Nov 2023	Moderate rainfall and winds in Gangasagar region.
Cyclonic Storm <b>Remal</b>	2024	26–27 May 2024	Severe impact in Sundarbans and Gangasagar; heavy flooding, crop loss, and damage to houses.

Table 3. Shifting of shoreline in Beguakhali region.

Time	Profile line	Total Shifting Amount (m)	Average Shifting (m)	Average Shifting Direction
1975 to 1990	P1	750 – Landward	664	Landward
	P2	578 – Landward		
1990 to 2001	P1	210 – Landward	137	Landward
	P2	64 – Landward		
2001 to 2009	P1	18 – Landward	35	Landward
	P2	52 – Landward		
2009 to 2017	P1	50 – Landward	49	Landward
	P2	48 – Landward		
2017 to 2025	P1	206 – Seaward	188	Seaward
	P2	170 – Seaward		
1975 to 2025 (Net Shifting)	P1	822 – Landward	697	Landward
	P2	572 – Landward		

Table 4. Shifting of shoreline in Gangasagar region.

Time	Profile line	Total Shifting Amount (m)	Average Shifting (m)	Average Shifting Direction
1975 to 1990	P3	300 – Landward	212.5	Landward
	P4	125 – Landward		
1990 to 2001	P3	25 – Seaward	72	Seaward
	P4	119 – Seaward		
2001 to 2009	P3	147 – Seaward	252.5	Seaward
	P4	358 – Seaward		
2009 to 2017	P3	164 – Landward	347	Landward
	P4	530 – Landward		
2017 to 2025	P3	17 – Seaward	166	Seaward
	P4	315 – Seaward		
1975 to 2025 (Net Shifting)	P3	275 – Landward	69	Landward
	P4	137 – Seaward		

period. The combination of extreme wind velocity and storm surge inundation led to widespread embankment overtopping. The LWL along P2 shifted significantly landward. Subsequent to Amphan, Yaas (2021) further compounded erosion, though with less severity compared to the preceding event. By 2025, Beguakhali continued to display a retreat-prone tendency, with no significant sedimentary recovery despite episodic low-intensity events such as Remal (2024).

### 3.2. Gangasagar Main Beach

In the Gangasagar beach, profile lines P3 and P4 traverse a relatively open sandy foreshore that is frequently reworked by tidal and wave action. Unlike Beguakhali, this sector benefits from a wider beach profile but remains equally exposed to cyclonic storm surges. The 2001 to 2009 interval recorded relatively modest shoreline variability, with the LWL maintaining a moderately stable alignment. However, the landfall of Aila induced immediate foreshore erosion and flattening of the beach gradient. Following partial stabilization during the mid 2010s, the beach sector experienced renewed retreat under the influence of Bulbul. The compounded effects of Amphan

were particularly visible here: the LWL displaced markedly landward, tidal channels incised across the foreshore, and dry beach width was drastically reduced (Table 4 and Fig. 5). Post-Amphan recovery has remained incomplete. Yaas of 2021 introduced further erosion, while subsequent lower-intensity systems failed to deposit sufficient sediments for meaningful progradation. By 2025, P3 and P4 continue to reflect a net erosional state, rendering the Gangasagar beach increasingly vulnerable to both natural hazards and socio-economic disruptions linked to pilgrimage activities (Fig. 6).

### 3.3. Dhublhat Sector

In Dhublhat region, profile lines P5 and P6 document significant variability, indicating the dual influence of tidal dynamics and cyclonic perturbations (Fig. 7). The period from 2001 to 2008 displayed limited LWL fluctuations, suggesting a temporary phase of stability. However, Aila (2009) initiated dramatic landward movement of the shoreline. Field reports identified embankment collapses and saline water ingress into agricultural fields, reshaping local livelihoods. Dhublhat's exposure to open marine fetch amplified wave energy during cyclones, explaining the

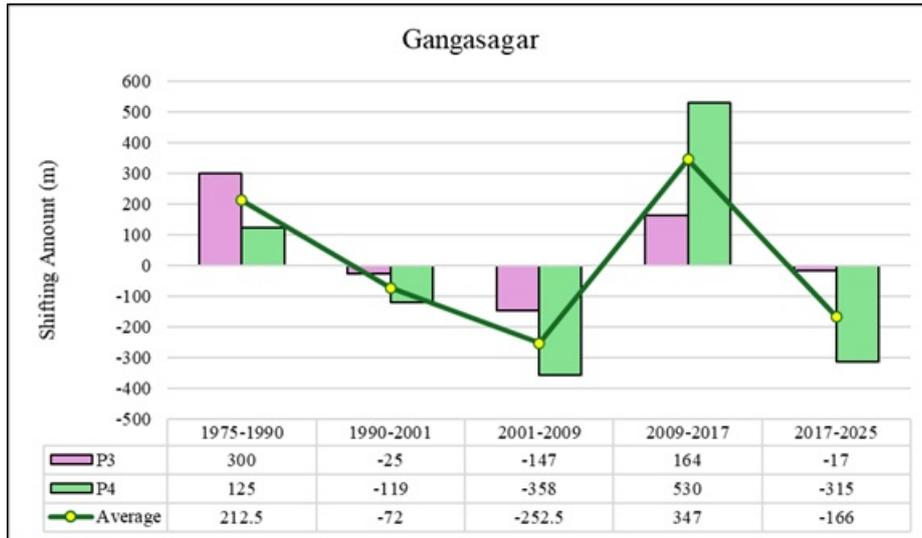


Fig. 5. Analysis of amount of shifting from 1975 to 2025 at Gangasagar region.

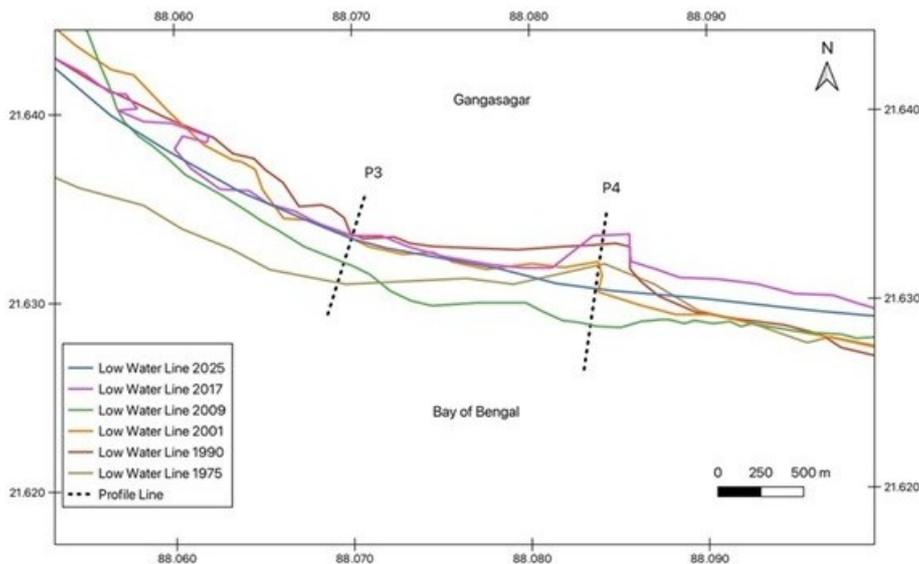


Fig. 6. Low water line analysis from 1975 to 2025 at Gangasagar region.

pronounced displacements observed. The 2010 to 2017 interval allowed partial sediment accretion, visible in the modest seaward adjustment of the LWL. Bulbul of 2019 once again destabilized the sector. Fishing infrastructure was damaged, and mangrove patches were uprooted, directly reflected in LWL retreat at P6. Amphan’s 2020 devastation was equally severe here, with Dhublat recording one of the largest single-event displacements of the LWL across all transects. The subsequent erosional surface was further modified by Yaas of 2021, which, although less catastrophic, prevented recovery. Even minor systems such as Remal of 2024 reinforced the erosional trajectory through cumulative wave action (Table 5 and Fig. 8). By 2025, Dhublat remains highly degraded,

with P5 and P6 exhibiting consistent landward positions relative to the early 2000s baseline.

Analysis of net amount of shifting in three different sectors shows that in Dhublat region the amount of shifting is maximum (Fig. 9).

#### 4. Conclusions

Synthesizing the P1 to P6 results, a clear pattern emerges: cyclone frequency and intensity dictate the rhythm of shoreline change more decisively than background tidal or sedimentary process. Beguakhali and Dhublat, with weaker embankments and discontinuous mangroves, show the highest magnitude of landward LWL displacements. Khan (2023) sug-

Table 5. Shifting of shoreline in Dhublat region.

Time	Profile line	Total Shifting Amount (m)	Average Shifting (m)	Average Shifting Direction
1975 to 1990	P5	367 – Landward	376	Landward
	P6	385 – Landward		
1990 to 2001	P5	282 – Landward	298.5	Landward
	P6	315 – Landward		
2001 to 2009	P5	77 – Seaward	117.5	Seaward
	P6	158 – Seaward		
2009 to 2017	P5	560 – Landward	567	Landward
	P6	574 – Landward		
2017 to 2025	P5	123 – Seaward	60	Seaward
	P6	03 – Landward		
1975 to 2025 (Net Shifting)	P5	1009 – Landward	1064	Landward
	P6	1119 – Landward		

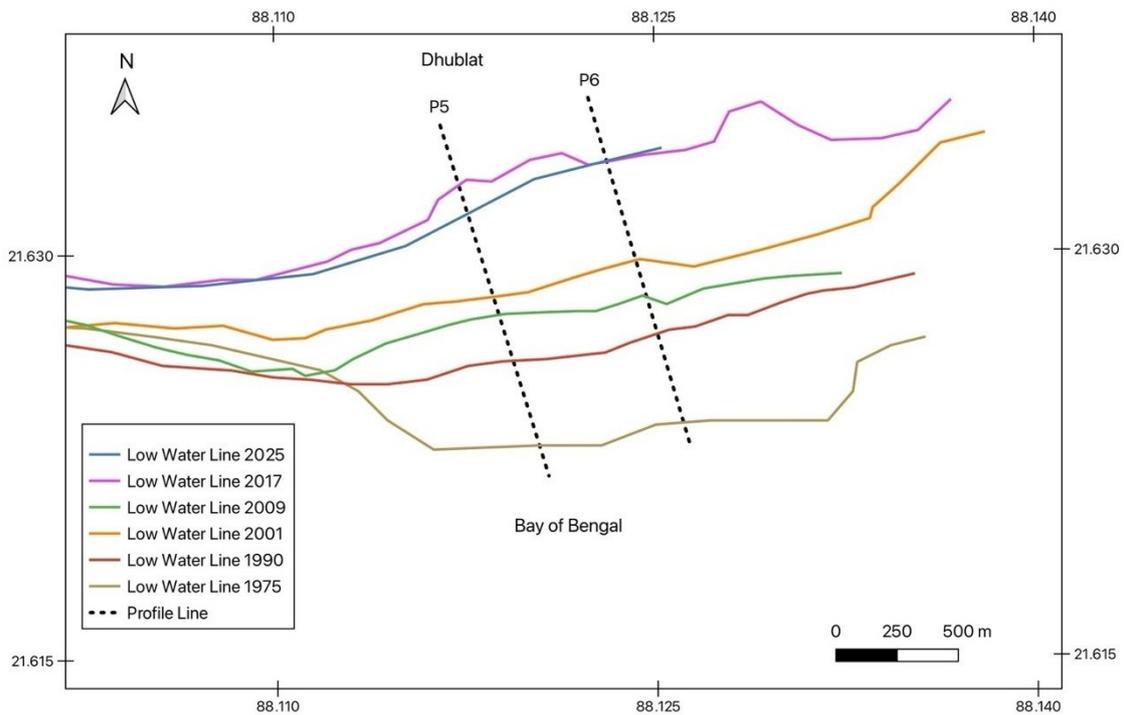


Fig. 7. Low water line analysis from 1975 to 2025 at Dhublat region.

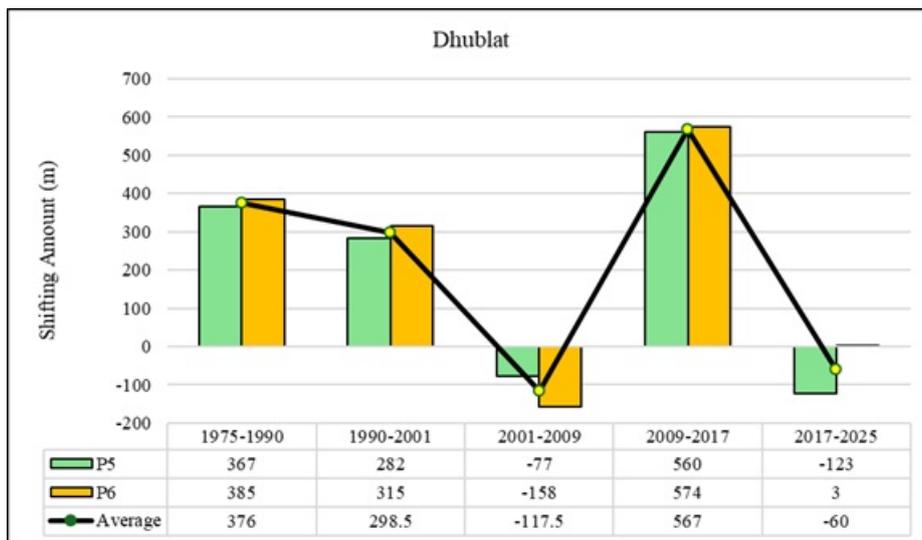


Fig. 8. Analysis of amount of shifting from 1975 to 2025 at Dhublat region.

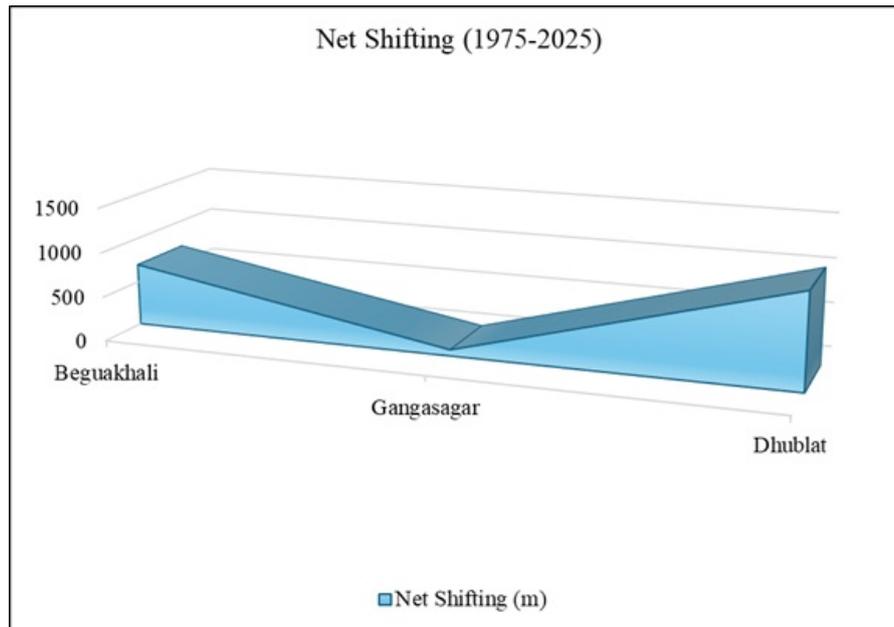


Fig. 9. Comparative analysis of net shifting from 1975 to 2025.

gested that this southern and eastern parts of Sagar Island are more affected by shoreline shift due to their lower elevation compared to the northern side. Gangasagar main beach, while initially buffered by its wider foreshore, ultimately experienced equivalent erosional consequences due to Amphan's scale. Importantly, recovery phases are temporally restricted. Only during relatively cyclone-free years (e.g., 2011–2017) did certain transects display modest seaward readjustments. However, these gains were systematically erased by subsequent cyclones, indicating that cumulative erosional effects outweigh accretionary adjustments in the long term.

From 2001 to 2025, three distinct temporal phases of shoreline behavior may be identified:

- 2001–2008: Relative stability with minor oscillations.
- 2009–2017: Episodic retreats associated with Aila, followed by partial recovery.
- 2018–2025: Persistent instability marked by Bulbul, Amphan, Yaas, and Remal, with no substantial recovery.

The findings highlight the inseparability of geomorphic process and human dimensions along the Gangasagar coast. Pilgrimage infrastructure, fisheries, and agricultural fields are directly tied to the position of the shoreline. Cyclone-induced LWL dis-

placements not only represent physical reconfigurations but also dictate the extent of habitable and cultivable land. According to Bera et al. (2022), Dhublat, Shibpur and Beguakhali are among the most climate-sensitive areas of Gangasagar Island, where stronger cyclones and shrinking farmland have made local communities more vulnerable to livelihood losses. The disintegration of mangrove fringes has reduced the natural resilience of these coasts, amplifying sediment loss and tidal ingress (Ghosh et al., 2001). Banerjee et al. (2002) also observed significant morphological instability along the mid and southern parts of the Eastern Channel adjoining Sagar Island, where shifting tidal channels and sediment redistribution continuously modify the shoreline configuration. Moreover, the continued retreat trend, particularly after Amphan, signals an increasing risk of permanent land loss. Coastal infrastructures are heavily affected by overwash events associated with storm surges (Dieng et al., 2017). The mangrove status near Beguakhali and Gangasagar on the southwest coast is critical due to severe erosion, anthropogenic pressure, and wave action (Das, 2023). Without sustained mangrove restoration and embankment reinforcement, future cyclonic events are likely to exacerbate degradation. Besides this, temporary constructions during the Gangasagar Mela alter the high water line and inhibit the formation of neodunes, and construction-related impacts were also observed in the older dune region near Kapil Muni

Ashram. While this study focuses on a specific region, future research along the extended shoreline, combined with sediment analysis, could offer a more holistic view of coastal process along the Bay of Bengal.

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### CRedit statement

AS: Methodology, Data generation, Field work, Software handling, Writing– review & editing.  
DC: Conceptualization, Investigation, Field work, Writing– review & editing.

### Conflict of interest

The authors declare that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work.

### References

- Bandyopadhyay, S., 1997. Coastal erosion and its management in Sagar Island, South 24 Parganas, West Bengal. *Indian Journal of Earth Sciences* 24(3-4), 51–69. <https://doi.org/10.5281/zenodo.7264120>.
- Banerjee, A., Lahiri, S., Samaddar, A.K., Mitra, P.K., Kumar, J.P., Mitra, S.K., 2002. Morphological study of the Mid and Southern part of the Eastern Channel to the Sagar Island. *Marine Wing News Lett. Geol. Surv. India* 16(1).
- Bera, A., Maiti, R., Pal, S., Bandyopadhyay, S., Das, S., Mukhopadhyay, A., 2022. Vulnerability and risk assessment to climate change in Sagar Island, India. *Water* 14(5), 823. <https://doi.org/10.3390/w14050823>.
- Chakraborty, D., Saha, P., 2020. Vulnerability assessment for Sagar Island coast, West Bengal with respect to inundation hazards. *Indian journal of Geo Marine Sciences* 49(09), 1521–1527.
- Das, K.K., 2023. Flood hazard mapping of Sagar Island during cyclone ‘YAAS’ using remote sensing and GIS. *Journal of Geography & Natural Disasters* 13(2), 272. <https://doi.org/10.35841/2167-0587.23.13.272>.
- Dieng, H.B., Cazenave, A., Meyssignac, B., Ablain, M., 2017. New estimate of the current rate of sea level rise from a sea level budget approach. *Geophysical Research Letters* 44(8), 3744–3751. <https://doi.org/10.1002/2017GL073308>.
- Dinesh Kumar, P.K., Gopinath, G., Laluraj, C.M., Seralathan, P., Mitra, D., 2007. Change detection studies of Sagar Island, India, using Indian Remote Sensing Satellite 1C Linear Imaging Self-Scan Sensor III data. *Journal of Coastal Research* 23(6), 1498–1502. <https://doi.org/10.2112/05-0599.1>.
- Ghosh, T., Bhandari, G., Hazra, S., 2001. Assessment of land use/landcover dynamics and shoreline changes of Sagar Island through remote sensing, in: 22nd Asian Conference on Remote Sensing, p. 848–852.
- Gopinath, G., Seralathan, P., 2005. Rapid erosion of the coast of Sagar Island, West Bengal – India. *Environmental Earth Sciences* 48(8), 1058–1067. <https://doi.org/10.1007/s00254-005-0044-9>.
- Hazra, S., Ghosh, T., Das Gupta, R., Sen, G., 2002. Sea Level and associated changes in the Sundarbans. *Science and Culture* 68(9-12), 309–321.
- Jayappa, K.S., Mitra, D., Mishra, A.K., 2006. Coastal geomorphological and land-use and land-cover study of Sagar Island, Bay of Bengal (India) using remotely sensed data. *International Journal of Remote Sensing* 27(17), 3671–3682. <https://doi.org/10.1080/01431160500500375>.
- Khan, R., 2023. Evolution of shoreline in the fringe area of Sagar Island in Sundarban, West Bengal. *Journal of Oceanography & Marine Research* 11. Article 283.
- Kundu, S., Mondal, A., Khare, D., Mishra, P.K., Shukla, R., 2014. Shifting shoreline of Sagar Island Delta, India. *Journal of Maps* 10(4), 612–619. <https://doi.org/10.1080/17445647.2014.922131>.
- Nandi, S., Ghosh, M., Kundu, A., Dutta, D., Baksi, M., 2016. Shoreline shifting and its prediction using remote sensing and GIS techniques: a case study of Sagar Island, West Bengal, India. *Journal of Coastal Conservation* 20, 61–80. <https://doi.org/10.1007/s11852-015-0418-4>.
- Paul, S., Mishra, M., Pati, S., Acharyya, T., Santos, C.A.G., Silva, R.M., Guria, R., Laksono, F.X.A.T., 2024. Evaluation of overwash vulnerability and shoreline dynamics in cyclone-prone Sagar Island, Sundarbans (India). *Science of the Total Environment* 907, 167933. <https://doi.org/10.1016/j.scitotenv.2023.167933>.