

Chapter 16

Temporal and Spatial Changes in the Hugli Estuarine Environment: A Review of Nayachara Island



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16.1 Introduction

The downstream section of the Bhagirathi-Hugli River, as the western-most distributary of the Ganga, was submerged slowly and steadily by the Holocene transgression (6000–7000 YBP) and gradually reshaped by the Late Holocene to recent sub-recent fluvio-marine depositional processes in the Bengal Basin (Allison et al., 2003). At the downstream end of Diamond Harbour, the Hugli flares up to the mouth and represents a perfect funnel-shaped estuary with sedimentary depositional sink modified by asymmetric tidal behaviour by faster movement of flood tides and slower movement of ebb tides along its course. The late Holocene advancement of the Ganga delta took place by a series of deltaic lobes towards south-southeast directions, with the role of active distributary channels as sedimentary environmental foci from time to time. In this connection, the Bhagirathi-Hugli delta lobe advanced towards the Bay of Bengal at the western boundary of the Ganga delta,

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with the role of active sedimentary environmental foci (5200–5700 YBP) at the beginning stage of the Late Holocene deltaic evolution (Goodbred & Kuehl, 2000a, b).

The present study reveals the current depositional characteristics of the Hugli estuary, in which the modern hydrodynamic regimes and tidal sediment supply played major roles in the shaping, reshaping, and development of estuarine islands (Paul & Bandyopadhyay, 1986, 1987; Mukhopadhyay, 2007). Frequent cyclone breaks with storm surges and tidal surges transported shifting sands into the estuary section in the form of spits, bars, and shoals (Paul, 1996, 1997, 2000). The climate change reworking of the estuarine landscapes has produced a new trend of instability in the configurations of the younger and older islands within the morphodynamic setup. The islands are grouped into four major classes of morphodynamic setup in the downstream section of the Hugli estuary. They are known as: (i) the Haldia-Rangafala channel fringe estuarine complex, (ii) the Rangafala-Baratola channel fringe estuary complex, (iii) the Baratola-Muriganga channel fringe estuary section, and (iv) the shallow offshore complex at the confluence of the Muriganga and Hugli estuaries. In all cases, the local islands are forming and reforming into different shapes and sizes over a time scale under the impacts of energy levels, physiographic settings, hydrological behaviours, and sediment supply rates. Such dynamics will be more rapid and critical in the estuary sections with the impacts of sea level rise, climate change threats, and human activities in the river system (Paul, 2011, 2014, 2022; Paul & Kamila, 2018; Paul & Paul, 2022; Mukhopadhyay, 2007). The study also reveals that changing configurations of the islands, bank erosion in the estuary channel reaches, storm drift shifting sands, and tidal siltation provided sediment supply sources for the morphodynamic systems of the estuary sections of the region (Fig. 16.1).

16.2 Materials and Method of the Study

The downstream section of the Hugli estuary is delineated from the Survey of India (SOI) toposheets from Diamond Harbour to Sagar south to be considered the study area on the western margin of the lower Ganga delta (Fig. 16.1). Landsat 8 OLI and Google Earth Images (1985 and 2022) data are considered for the identification of the island configurations in the study. The estuary morphology of the Hugli downstream section is studied with the naval hydrographic chart and other bathymetric charts. Other aspects, such as data from different sources (India Meteorological Department (IMD), Indian National Center for Ocean Information Services (INCOIS), Kolkata Port Trust (KPT), etc.) and a field survey in the island territory, helped to carry out the final study.

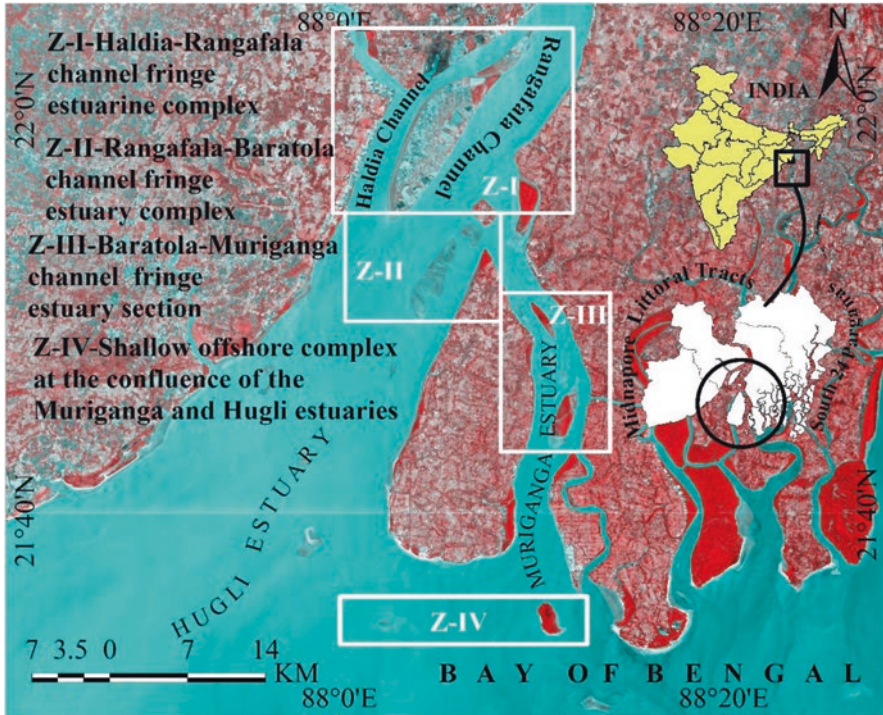


Fig. 16.1 Location of the study area and diversity in depositional landforms in Hugli estuary with four morphodynamic subsystems

16.3 Results and Discussion

The temporal and spatial changes in the estuarine landscapes depicted the system-subsystem sections in which the energy and materials interact with each other over a time to develop the depositional landforms. However, the interactions are guided by tidal energy variations, seasonal variation in downstream discharges, storm surge impacts into the arm of the sea, climate change reworking of the estuarine landscapes, coastal marine processes, and the rate of sea level rise in the funnel-shaped estuary complex of the Hugli River. The following sections will demonstrate the estuary subsystems as per the Hugli estuary channel, which reaches from Diamond Harbour point to the sea face of the Bay of Bengal.

16.3.1 Haldia Point Estuary Reach

Between the Rangafala channel and Haldia channel complex of the Hugli estuary, a number of islands and shoals are distributed in the form of Nayachar Island, Balari Island, Diamond sands, Haldia sands, and Nayachar south sand along a linear

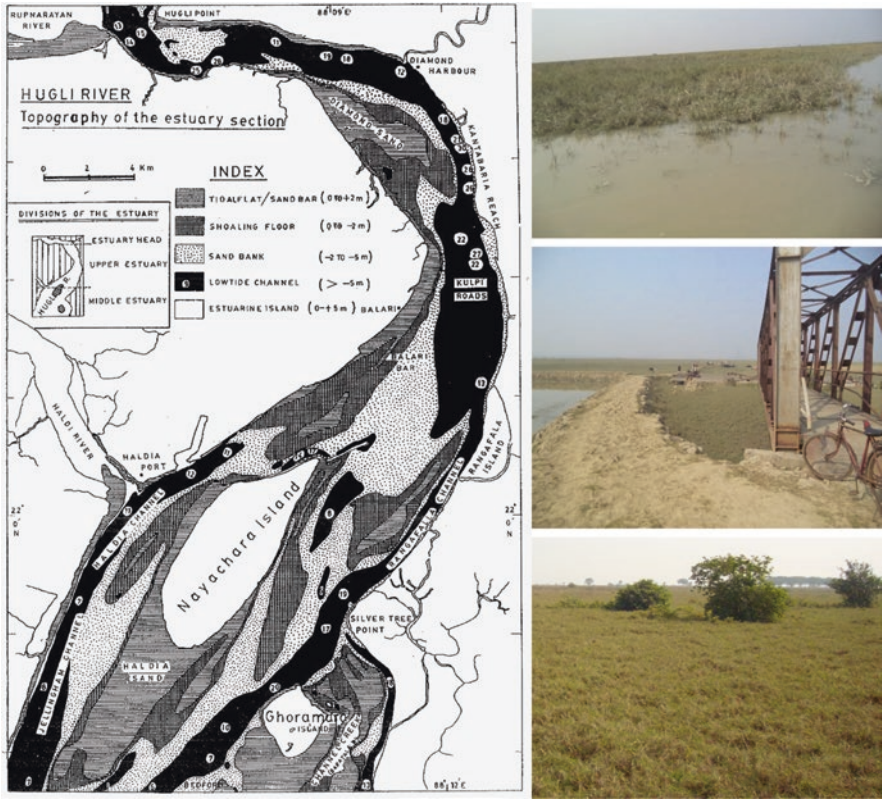


Fig. 16.2 The Haldia point and Silver Tree Point estuary reaches of the Hugli system with younger island surfaces of Nayachara Island colonised by halophytic grasses and mangroves

stretch (Paul, 2002). The subsystem is developed at the flared-up section of the estuary reach below Diamond Harbour Point and extended southward up to Nayachar South Sands. The linear depositional features are aligned by the downdrift currents of Rangafala Channel (eastern margin thalweg) and the updrift currents of Haldia Channel (western margin thalweg). Accretionary bars initiated at the inner bank of the Hugli estuary in the form of Diamond sands and gradually evolved into Nayachar, Balari, Haldia Sands, and Nayachar South Sands into the linear depositional subsystems guided by the hydrodynamic regimes of tidal currents, residual currents, storm surge waves, and sediment transport paths between the source and sink (Figs. 16.2 and 16.3a).

The ebb tide currents are stronger in the Rangafala channel compared to the Haldia channel, which represents a flood tide-dominated channel in the estuary reach. Thus, under the blocking effects of Balari and Nayachar islands, the Haldia channel arrests flood tide sediments with a rapid rate of siltation process to extend the Haldia sands on the eastern fringe of Nayachar island. The Nayachar South sands, on the other hand, were deposited by an uprushing tidal surge through the

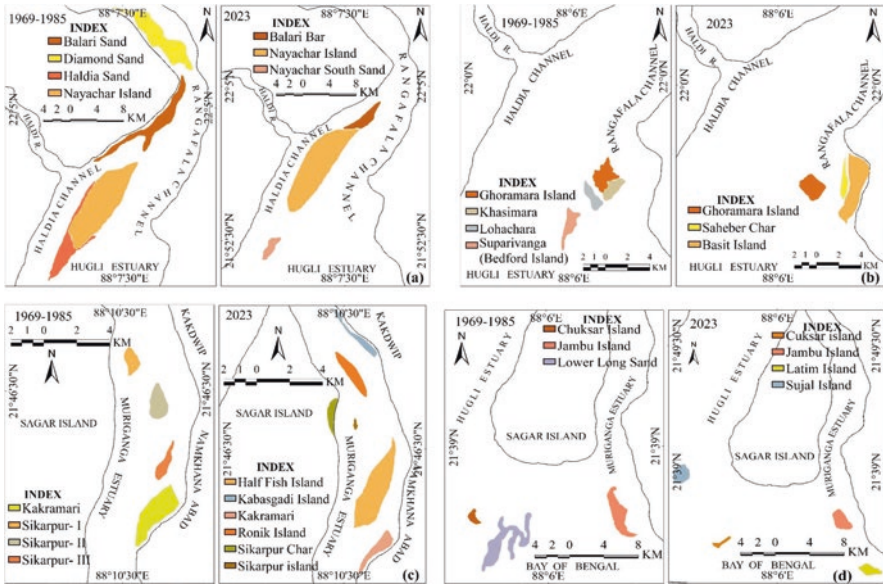


Fig. 16.3 Morphodynamic Subsystems (a) Haldia Point estuary reach with Nayachar island; (b) Silver tree point estuary reach with Ghoramara Island; (c) Muriganga-Baratola reach with Rohnik Island and Sagar Island; and (d) the sea facing distal islands subsystem with Jambu Island of the Hugli estuary from Diamond Harbours to the sea face of the Bay of Bengal

Hugli mouth and also by the accumulation of shifting sands during the storm surges in the estuary reach. Further, it was realigned by the downdrift currents of Rangafala channel and reshaped by the impacts of repeated cyclone landfalls when the Hugli downstream section acted as the passage of northward-advancing storm surges in the near past. Nayachar and Balari islands are covered by halophytic grasslands and mangroves (Paul et al., 2005, 2017) and drained by a network of tidal creeks. Both aggradation and progradation occur rapidly during the submergence of astronomic tides and occasional higher tides, but erosion occurs along the north-eastern margins of Nayachar when strong down-drift currents hit the island banks in the Rangafala channel section of the estuary.

16.3.2 Silver Tree Point Estuary Reach

During 1969 (SOI Toposheet), Ghoramara, Khasimara, Lohachara, Bedford, and Suparibhanga islands were aligned in NE-SW directions parallel to the projected bank of Silver Tree Point in the estuary reach. This is another subsystem of the Hugli estuary system, which represents the barrier between Rangafala downdrift currents and Baratola updrift currents in the region during the events of ebb tides and flood tides. Suddenly, the nucleus of the group Ghoramara island was severely

affected by undermining the northwestern banks with direct hitting of Rangafala downdrift currents in the estuary reach. Active erosion has reduced the area from 19 km² to less than 6 km² and broken it into reduced Ghoramara, Bedford Shoal, and Shiber Char in the estuary reaches. Sliver Tree Point of the eastern bank of the Hugli estuary is affected by severe erosion caused by undermining the basement of the bank wall during the 1990s and the formation of an extensive char land at the bank margins. Baratola-Muriganga flood currents transported sediments through the tidal surges into the Shiber Char shoaling flat of the estuary reach. In the 1920s, a large part of the Khasimara-Lohachara group was covered by mangroves, tidal flats, and muddy tracts with tidal channel creeks (SOI Toposheet, 1925) in the estuary reach. Gradually, with a rapid rate of erosion, the islands were eroded due to the thalweg-shifting in Rangafala and the Baratola channel complex triggered by cyclone land-falls (1970, 1991, 1997, 1988–89) in the region of the Sundarban coastal tract. Lohachara-Khasimara-Ghoramara islands were reclaimed and inhabited by settlements (Paul, 2002) in the estuary reach. Eroded sediments of the subsystems are transported and accumulated in “Shiber Char” and “Bedford” in the form of shoaling flats in the region. Ghoramara was the nucleus of this island group in the subsystem, but the volume of sediments transferred and drifted from the centre to the secondary islands of smaller size in the form of accumulated bodies of shoals under the impacts of high energy events. Gradually, other islands grew by aggradation and progradation with an emerging colony of halophytic grasslands, mangroves, and other littoral vegetation on the basis of available soil nutrients, tidal drainage conditions, and the rate of fresh silt accumulation over time (Paul et al., 2017). Ghoramara will be further reduced in size by interplaying with increasing event frequencies of high energy phases and sediment transfers from island to island in the morphodynamic settings (Figs. 16.2 and 16.3b).

16.3.3 Baratola-Muriganga Estuary Channel Reach

The eastern branch of the Hugli estuary is separated by the location of Sagar Island and known as the Baratola-Muriganga channel section from north to south at the downstream course of 30 km length. The system includes three charlands fringed with the right bank and left bank of Muriganga (e.g., Kabasgadir char, Kakramari char, and Shikarpur char) and three mid-Channel Islands of elongated size along the lower most course of the estuary reach (i.e., Rohnik Island, Shikarpur Island, and Half Fish Island). Muriganga is a strong ebb-dominated channel in which islands and charlands are aligned with the downdrift currents (2.67 m/s, below 10 m depths over 5 m/s). The bank attached charlands and mid-Channel Islands are covered by mangroves and salt marshes with tidal creeks and mud flats. Bank erosion, island fragmentation, and island drifting occur in the high-energy events and supply sediments into the accumulated shoals in the estuary section. Temporary stability is achieved with long relaxation times (>20 years) between the high energy events frequency in the depositional environment. However, climate change-induced

reworking of the estuarine landscapes will make them more dynamic with repeated landfalls of cyclones and an increasing rate of sea level rise processes. Increased tidal prisms in the Muriganga Estuary during the vents of surge elevation produced a major threat to the stability of the depositional environment. Thus, the Half Fish Island is broken into fragmented shoals, with bank margins at Mousuni Island and Sagar Island showing instability, and mangrove wetlands of the estuary fringe tidal flats getting trapped by overwashed sands and shifting sands in the estuary reach (Fig. 16.3c).

16.3.4 Sea Facing Distal Islands

The morphodynamic subsystem of the estuarine landscapes provides a critical condition in the sea face in which the distal islands are breaking into shoals, reducing into respective sizes, changing island configurations, and surprisingly drifting from their original sites in the Bay of Bengal due to the effects of storm surges, tidal surges, and cyclone landfalls in the previous decades. There are a number of islands and shoals in the region, and they are known as Jambu Island, Latim Island, Sagar Island, Lower Long Sand, Chuksar Island, and South Sand. They are rapidly interacting with each other by transferring the volume of sediments onto the shallow offshores, guided by the energy events and longshore sediment supply. Mangroves and tidal flat habitats are seriously affected in the distal islands due to their reduced sizes and fragmentations at present.

The basement structures of the island are exposed as base clay, sand sheet, compact sit flat, beach ridge, and sand dunes with vegetation (Paul, 1988, 1994). At the embayed shores surrounded by spits and beach ridges, mangroves often occupy the tidal flats of backwater settings in many occasions. Sandy shoals, on the other hand, were modified rapidly with rippled flats, sand waves, tidal pools, and beach plains by the littoral drifts and surging waves. During storms, the islands and shoals are submerged by seawater and wave reworked thus breaking into fragmented shoals or islands before compaction of the sediments. When the event frequency increases, the broken islands spread over a large area into a number of shoals and islands of low height surfaces on the sea face of the Hugli estuary. The western branch of the Hugli estuary to the west of Sagar Island is over 30 km wide and usually characterised by a flood-dominated channel that acts as the passage of landward-moving tropical cyclones from the northern Bay of Bengal (Fig. 16.3).

16.3.5 Energy Levels and Sediment Supply

The morphodynamics settings of the estuary reaches are affected by various energy levels at present. They are identified as anthropogenic controlled fluvial discharges and sediment loads, tidal asymmetry in the estuary, occurrences of

tidal bores with high resonant waves, velocity variations in flood tide and ebb tide currents into the estuary, increased tidal prisms with surge water levels, climate change reworking with rising sea level, increased event frequency of cyclone landfalls and inundations, tidal surges during eastern winds, longshore current transport of sediment, and swell waves with steeper gradients into the system. Aggradation and progradation do not occur at similar rates under the impacts of various energy levels and diversity in morphodynamic settings at different estuary reach distances in the depositional environment. Multiple sediment supply sources feed the systems to operate through longshore transport, sea bed scouring in the storm surges, bank erosion materials, tidal sediments, and reworking of island sediments in the estuary system. The island groups in the morphodynamic settings interact and interplay with each other to adjust the various energy levels and reduced sediment supply to develop the signatures of landforms in the estuary reaches at present (Table 16.1).

Table 16.1 The configuration dynamics of the depositional landforms with island drift and island accumulation

Nayachara Group	Area-1969–1985 (sq.km)	Nayachara Group	Area-2023 (sq.km)	Ghoramara Group	Area-1969–1985 (sq.km)	Ghoramara Group	Area-2023 (sq.km)
Nayachar Island	35.4	Nayachar Island	48.2	Ghoramara Island	3.6	Ghoramara Island	3.54
Haldia Sand	10	Nayachar south sand	4	Khasimara	2.16	Basit Island	8.21
Diamond Sand	17.7	Balari Bar	6.44	Lohachara	2	Saheber Char	1.45
Balari Bar	13.7			Suparivanga	2.55		
Total area	76.8		58.64	Total area	10.31		13.2
Muriganga Group	Area-1969–1985 (sq.km)	Muriganga Group	Area-2023 (sq.km)	Jambu Group	Area-1969–1985 (sq.km)	Jambu Group	Area-2023 (sq.km)
Sirkarpur-I	1.1	Ronik Island	2.34	Jambu Island	7.92	Jambu Island	5.41
Sirkarpur-II	1.77	Kabasgadi Island	1.42	Chuksar Island	1.45	Chuksar Island	1.35
Sirkarpur-III	1	Sikarpur Char	1.13	Lower long Sand	3.4	Latim Island	3.37
Kakramari	4.1	Sikarpur Island	0.17			Sujal Island	5
		Half fish Island	8.7	Total area	12.77		15.13
		Kakramari	2.1				
Total area	7.97		15.86				

16.3.6 Estuary Process Variables

The wide, funnel-shaped estuary also acts as an arm of the sea in the downstream section of the Hugli River. Present-day processes involve multiple components of tidal, shallow marine, and fluvial environments, and they interplay and interact with each other within the physiographic settings of the estuary (Table 16.2).

16.3.7 Tidal Processes in the Estuary

Tidal influences with variable amplitudes (>6.0 m in Haldia and >5.0 m in Sagar) and ranges, flood tide-ebb tide velocities, asymmetry in tidal movements into the estuary reaches, events of tidal bores, tidal flood inundation levels into the islands and creeks, emerging tidal surge waves during the cyclonic winds (i.e., the Yass cyclone, 2021), and events of astronomic tides (HAT phase) interact to produce a significant energy level in sediment transport within the morphodynamic settings of the estuary reaches (Figs. 16.4 and 16.5).

16.3.8 Shallow Marine Environment at the Sea Face of the Estuary

Significant marine influences are felt on the sea face of the Hugli estuary with Muriganga-Baratola tidal river confluence. The wide estuary mouth with 47 km stretches of opening receives impacts from strong wind waves, swell waves, storm surge, longshore currents, tidal currents, and residual currents in different seasons. In the bathymetric chart of the Hugli mouth, it is observed that the sub-aqueous shelf deposits are jagged and aligned parallel to the estuary channel from north to south as alternate sand ridges and channels. They are actually modified by strong

Table 16.2 Events of Large Floods and High Magnitudes Cyclones in and around the Hooghly Estuary

Event of large flood	Year	Event of high magnitude cyclones	Year	Remarks
Large flood	1950	Severe cyclone	1942	Emerged sand bar
Largest flood	1978	Severe cyclone	1971	Mud deposition
Moderate flood	1984	Sundarban cyclone	1989	Vegetation cover
Moderate flood	1991	Sundarban cyclone	1991	Mangrove wetland extension
Moderate flood	2000	Cyclone Cedere	2007	Sand bar extension
Large flood	2008	Nargis cyclone	2008	Balari extension
		Aila cyclone	2009	Erosion and siltation

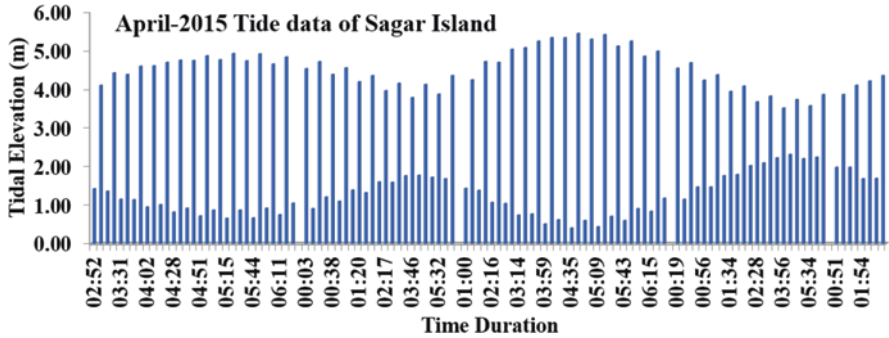


Fig. 16.4 The nature of monthly tidal cycles of Hugli estuary near Sagar Island. (on the basis of Tide Gauge data)

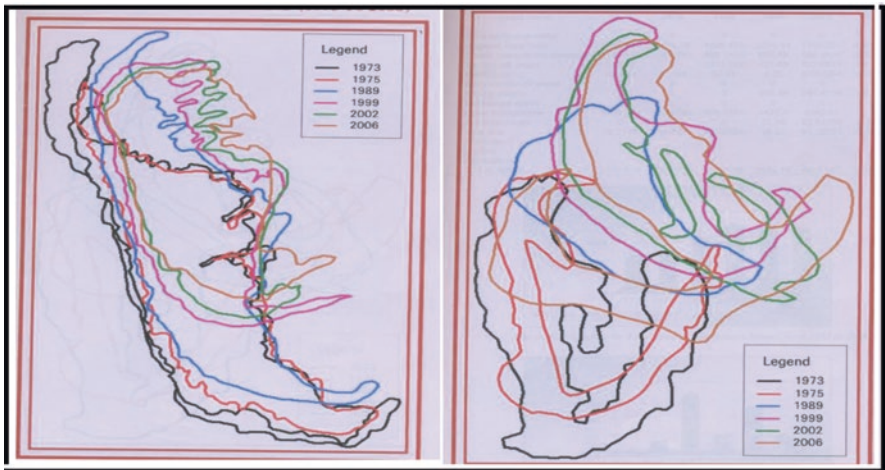


Fig. 16.5 Configuration dynamics of the distal islands (Jambu and Chuksar Island) in the Bay of Bengal with island drifting and reduction in sizes on the sea face of the Hugli estuary. (Using Landsat Images)

tidal currents and turbidity currents in the region, but possibly originated during the last glacial low stand (18,000 YBP) with the extension of fluvial valleys and natural levee deposits towards the sea. However, the early Holocene transgression (6000 YBP) submerged the extensive areas by the advanced sea and occupied the region of fluvial depositional features under the impacts of sub-marine processes and related modifications (Allison et al., 2003).

The distal islands and sandy shoals or bars on the sea face area, however, are influenced by the shallow marine environment with the activities of tides, currents, storms, littoral drifts, and the rate of present-day rising sea level (Fig. 16.5). Thus, the extensive tidal flats and mangrove wetland habitats of Jambu Island (6.36 km long and 1.70 km wide in 1985) are now reduced to a smaller island platform by erosion (3.2 km long and 2.06 km wide in 2023) and fragmentation in the sea face

due to the impacts of dynamic marine processes. The Chuksar island in the sea face of the Hugli estuary to the south of Sagar Island was represented as a tiny island with backwater mangroves surrounded by wide sandy platforms and back dunes (1.7 km long and 0.74 km wide in 1985; Paul, 1990). There is no island in the region at present; it has drifted and broken into sandy shoals over wide areas of the shallow marine environment. They were mostly affected by the cyclone landfalls on the passage of Hugli Mouth in 1989, 2009, 2019, 2020, and 2021 with active storm surge elevations (2.5 m to 5.9 m, INCOIS) and inundation events.

16.3.9 Fluvial Regimes in the Estuary

Anthropogenic controlled fluvial discharges and sediment loads contributed a significantly reduced amount of discharges and fluvial sediments into the estuary reaches of the study area in the modifications of the island groups. Before 1975, a set of estuarine sand banks (Diamond Sands, Balari Sands, and Haldia Sands) was pointed towards the south and aligned parallel to the strong residual currents in the flared-up section of the Hugli estuary when fluvial sediments contributed to the formation of sandy platforms in the region. The high-magnitude flood frequency events in Hugli (1950, 1978, 2000, and 2008) contributed sediments to the island platforms, river beds, and sand banks but discharged the suspension loads into the sea face in the form of plumes of total suspended material ($>80 \text{ mg/m}^3$, Paul, 2002). Aggradation and progradation were enhanced by fluvial sediment supply during the events of the annual floods before the anthropogenic controlled discharges and sediment transported into the island systems of the estuary sections. Presently, tidal influences pushed back the impacts of fluvial regimes back from the estuary sections in the form of fluvial backwater settings into the upstream sections of the Hugli River (Fig. 16.6). The estuary is acting as a significant mixing zone of freshwater discharges with the saltwater encroachments and pushing the saltwater into the sea during southwest monsoon months in the region. However, the similar estuary is dominated by tidal encroachments and also by marine influences during the dry months to control the morphodynamic systems in the modification of islands, shoals, bars, and bank margin depositional features.

16.4 Conclusion

The Hugli estuarine depositional features in specific physiographic settings of the four groups of islands and sandy shoals at the reach distances exchange sediment volumes with the interplay of energy and process variables under morphodynamic settings to modify their configurations over a time span in the region. The study reveals that the Nayachar group has changed to a relatively lesser extent in configuration in comparison to the Ghoramara group, Muriganga channel-reach island groups, and sea-facing island groups in the estuary system. The number of



Fig. 16.6 Mangroves and salt marsh creeks in Nayachar Island platform, Hugli Estuary

depositional units has changed from four islands to six islands (1985–2023) in the Muriganga estuary channel reach section between Sagar, Kakdwip, and Namkhana blocks. However, islands of the sea face at the confluences of Muriganga and Hugli demonstrated major changes due to climate change reworking with the storminess of the sea and an increasing rate of relative sea level change. On the other hand, the Ghoramara group of islands is lying at the junction between the impacts of a strong ebb-dominated channel (Rangafala) and the climate change reworking of estuarine landscapes to produce the dynamic depositional environment.

It is also believed that the rates of aggradation and progradation are relatively slower in the islands than the rates of storm frequency, climate change reworking, and saltwater inundations in the estuary system of the Hugli downstream section. All the major and older islands of the four morphodynamic settings are getting reduced in size (Sagar, Ghoramara, Jambu, and Nayachar islands) at present. Nayachar has expanded its linking with Balari Island, accumulation of sediments, vegetation cover surfaces, and extended tidal drainage systems with aggradation and rapid progradation processes in the estuary reaches. Human modifications of the island may invite a similar fate of size reduction like Ghoramara and Sagar Island by a rapid rate of erosion and an insignificant rate of aggradation.

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