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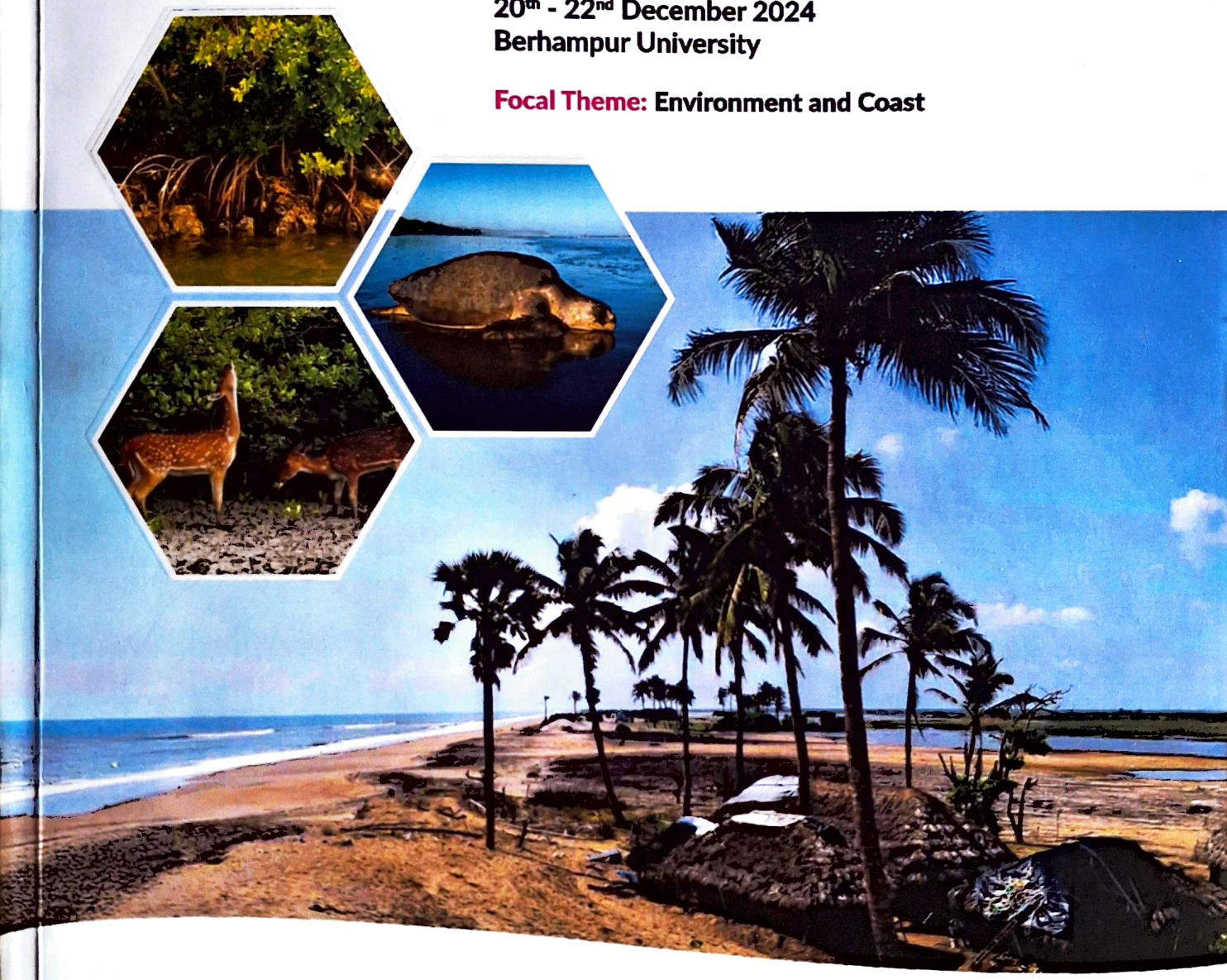

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Inundating Coast: An Insight into Gangasagar Island, West Bengal

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ABSTRACT

The Indian Sundarbans face significant vulnerabilities across physical, economic, and social dimensions. Coastal flooding and frequent inundation stem not only from extreme climatic events like tropical cyclones but also from the geomorphic nature of the region. The growth and decline of deltas are influenced by the occupation and abandonment of deltaic distributaries, while their stability depends on the interplay of wave, tide, and fluvial forces. Rivers promote delta growth, while waves and tides modify them through sediment redistribution. Premature land reclamation in the Sundarbans has reduced river spill areas, causing geomorphic instability. In response, the macro tidal Hugli estuary (tidal range > 4 m) breaches embankments to reclaim space, leading to channel sedimentation and reduced mean depth. Additionally, the funnel-shaped Hugli estuary exhibits time-velocity asymmetry, causing uneven high and low tides that further increase sedimentation and disrupt drainage systems. These combined factors destabilize the polarized landscape, with the shifting islands and shoals in the estuary highlighting that sea level rise alone isn't responsible for these changes. This study examines embankment breaches and coastal flooding on Gangasagar Island. Quantitative analysis includes measurements of breached Aila embankments at Beguakhali (summit width:

6 m) and Tapovan (summit width: 3.15 m), alongside qualitative insights from local perceptions. Sea level rise (4.101 mm/year) is assessed using satellite altimetry and tide gauge data. Erosion (12.982 km²) and accretion (10.244 km²) trends between 1968–2021 are identified using Survey of India toposheets and Landsat 8 imagery. The findings indicate that the Hugli estuary's configuration, the interplay of wave, tide, and fluvial dynamics, and human interventions are key factors reshaping Gangasagar Island.

Keywords: Sundarban, Ganagsagar Island, Hoogly Estuary, Tropical Cyclone, Coastal Flooding

1. INTRODUCTION:

The westernmost boundary of the mangrove forest of Sundarban was once delineated by Gangasagar island (21°37´-21°57´N ;88°02´- 88°11´E), the place well known and revered for the famous Gangasagar mela held each year. Although archaeological evidences speak about previous human habitation in Gangasagar Island, reclamation of Gangasagar Island was initiated in the year 1811. It is located at a distance from 100 km from Kolkata at the confluence of rivers Bhagirathi and Hugli. At present it is under the administration of Kakdwip subdivision, forming a community development block by itself. This island was formed by the quaternary sedimentation by river Ganga and it's distributaries. Laden with about 25 types of mangroves previously, the mangroves have now been destroyed due to expansion of agriculture and settlements. At present Gnewa *(Excoecaria agallocha)* and Baen *(Avicennia alba)* occupy the western and eastern fringes of the island sporadically. This island is around 30 km in north south extent and 12 km in east west extent. The elevation of the island is around 6 m. Covering an areal extent of about 300 km², this island is subjected to fluvial and coastal erosion as it is filled with soft silty mud.

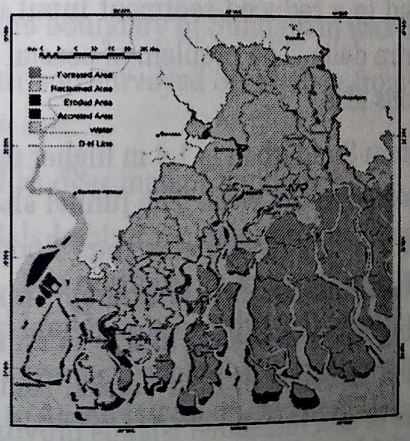

Figure 1
Location of Gangasagar Island
(Source: Bandyopadhyay et al, 2023)

2. PROCESS AND PROBLEM OF RECLAMATION

Sagar island was reclaimed like the rest of Sundarban, by embanking the coastline and major tidal channels completely blocking the smaller tidal creeks and subsequent deforestation. This in turn has turned the islands into polders by cutting down the spill areas of the rivers. Reclamation deprives the islands of the sediment laden water and the reclaimed areas remain forever lower than the highest high tide. This increases their susceptibility to coastal inundation consequent upon embankment breaching and storm surge. Reclamation by preventing the tidal spill area also results in loss of morphologic equilibrium. As Hugli estuary is a macrotidal resonant estuary, loss of tidal spill area results in disequilibrium by reducing the intertidal area and increasing the mean depth of the estuary. The estuary then tries to restore the equilibrium by active erosion of embanked channel margins and by in channel sedimentation which reduces the depth (Pethick, 1994). The progradation and retrogradation of any delta is dominated by the occupation and abandonment of the distributary channels. The relative dominance of erosive wave and tidal action and accreting fluvial forces decides the stability of any delta. The Ganga Brahmaputra delta being a tide dominated delta, the western part of Ganga Brahmaputra delta is retrograding in nature facing decay of distributaries. A progressive younging towards the east can be observed by the presence of three overlapping deltaic lobes (Allison et al., 2003; Sarkar et al., 2009). The southwestern section between Hugli and Baleswar Haringhata estuaries is macro to meso tidal in nature growing about 7-1.8 kyr ago (Bandyopadhyay et al., 2023). Abandonment of the Western Ganga Brahmaputra delta was also brought about by a Late Holocene eastward tilt (Morgan and McIntire, 1959). This along with sediment sinks at Swatch of No Ground submarine canyon and multipurpose river valley projects in the post independent era led to a reduced sediment input in the Western section of the Ganga Brahmaputra delta. The problem of coastal erosion can be further attributed to these reasons also.

Also, tidal range of western Sundarban is 1.4 m higher than the eastern portion and this accentuates erosion to the west. The funnel shaped macrotidal Hugli estuary results in time velocity asymmetry thus flood tide takes less time (3 hours) to complete than the ebb tide (9 hours). This results in increasing sedimentation, increasing towards the north due to an increase in tidal range northwards. This has led to decay of tidal creeks, leading to island merging events even more in case of non reclaimed islands proving that there is no such relation between reclamation status and island merging events. Interestingly, the shift in median location of tropical cyclones to the east suggests no such relation between cyclones and coastal retreat.

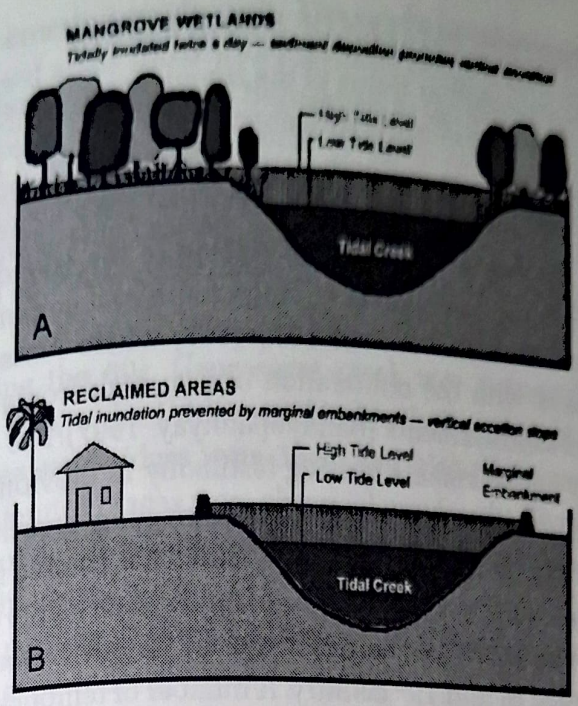

Figure 2.
Disequilibrium due to premature reclamation: a: Intertidal areas are not reclaimed; estuary is in morphological equilibrium; b: Intertidal areas are reclaimed; mean depth is increased; estuary is removed from morphological equilibrium. Feedback would include in channel siltation and erosion of embankments (Mallik and Bandyopadhyay, 2024)

- 1757: East India Company gets property rights of two 24 Parganas and Sundarbans from the Nawab of Bengal.
- 1770: Claude Russell starts reclaiming Sundarban by deforestation.
- 1784: According to the orders issued by Tilman Henckell, the then district collector of Jessore, 64,928 bighas of land were ordered to be reclaimed.
- 1784: On 3rd April, the boundary of Sundarban was delineated.
- 1811-1814: W.E. Morrison surveyed Sundarban from Hugli river to the west to Passur river to the east.
- 1831: Preparation of Hodges map of Sundarban.

One of the major officials behind reclamation Mr. Troyd had organized Sagar Island Society in 1822. The northern and central sectors of Gangasagar Island are still known as Troyd land because of this initiative. In 1842, 1864 and 1867, many freshwater ponds were excavated which were embanked, coupled with grain stores. According to Ascoli (1921), 11,783 bigha land of Ghoramara, 15,258 bighas of Ferintosh, 7486 bighas of Sikarpur, 7349 bighas of Troyd land, 3826 bighas of Bamankhali and 17,726 bighas of land in Dhablat were reclaimed to initiate settlements.

3. EROSION ACCRETION PATTERN OF SAGAR ISLAND

Irrespective of the reclamation status of the island, erosion and accretion both can be found to occur sporadically, with erosion being the major characteristic. Between 1903 and 1904, the northern part of Gangasagar Island got detached from the islet of Ghoramara episodically. During 1851 – 1997, the average recession rate in the sea-facing southern section of the island was 28.6 m/yr (Goudie, 1995). Shibpur Boatkhali area in the south east corner of Sagar Island recorded maximum erosion between 1922-1997, where recession rates were as high as 23.8 m/yr with the obliteration of 6 m high frontal dune and two successive rows of embankments (Bandyopadhyay, 1997).The coast is marked by the abandoned embankments bearing testimony to previous erosion. Also, the existing marginal embankments are characterised by breaches which result in coastal inundation. Erosion at Gangasagar Island has been so frequent that the Kapil Muni temple a shrine of great cultural significance had to be shifted about six times since it was built. The earliest recorded temple (Anon, 1841; Wilson, 1846) was submerged in mid 19th century. A number of temporary temples were constructed subsequently (O Malley, 1914; Mitra, 1954; Ray, 1971). Though a permanent building was constructed in the year 1961 but it too got eroded. The present temple was constructed in 1973, some 1.5 km inside the spring tide line (Bandyopadhyay, 1997).

Interestingly, an erosion accretion cycle got superposed over the dominant erosive pattern at the southern sector between Gangasagar and Basantapur since 1922-23. This region retrograded during 1922- 1942, prograded during 1942-1969, retrograded again during 1968-69 – 1975 and was almost stable during 1975-1997. Small islands in the Baratala branch to the east of Sagar island grew and disappeared bearing testimony to the ephemeral nature of Hugli estuary. A fusion of Kabasgadi Island to the left bank of the estuary between 1967-68 and 2001 was observed. The widening of the Baratala river throughout previous 200 years remarked that Sagar was attached to the area to it's east sometimes in the past (Bandyopadhyay, 2000). Long term oscillations in the thalweg of Hugli is observed and changes in the islands of Hugli estuary are linked to the changes in it's tidal channels and sand ridges. Reworking of sediments by wave action plays an important role in regulating the ephemeral nature of islands in Hugli estuary. Moreover the islands are characterized by cyclical patterns of erosion and accretion and this strongly discards the model of sea level rise.

Even in the 80s, Muriganga river was accessible, better than the present times. Vessels used to ply regularly from Lot no 8 of Kakdwip to Kochuberia of Gangasagar Island. The journey was hassle free unlike today when vessel service needs to be kept closed for at least 5 hours daily as there is a risk of getting obstructed by bars. Even the coastline was different; one had to walk

for about 2 km crossing sandy path. The sandy beach was interspersed with runnels (depressed areas filled with clay) and beach berms (sand dunes). One had to cross a tidal creek to reach Beguakhali to the east from Gangasagar. This path was laden with mangrove patch. A lighthouse was present even then about 500 m from sea. High sand dunes were present in Tapovan area. Concrete embankment which was created in 2022 March breached within September 2022. Even high concrete embankments broke down during cyclone Sitrang of 2023.

Previously, during the 80s, Gangasagar creek was surrounded by mangrove patch and to its east, a sand ridge used to block the creek perpendicularly. At some places these sand ridges were 30-40 feet high. Even sand encroachment at Raspur, Basantapur villages were observed previously. Even past remnants of zamindari embankments used to get exposed in these areas along with exposure of tree trunks. This bears testimony to the fact that there was a forested stretch to the southern portion of these settlements. For the previous 30 years, these areas have been experiencing beach lowering.

Gangasagar Island has lost about 12.982 km² and gained about 10.244 km² within 1968 and 2021. Erosion persists more in the north east and south east portions adjacent to Kochuberia, Haradhanpur, Dhablat and Beguakhali to the west.

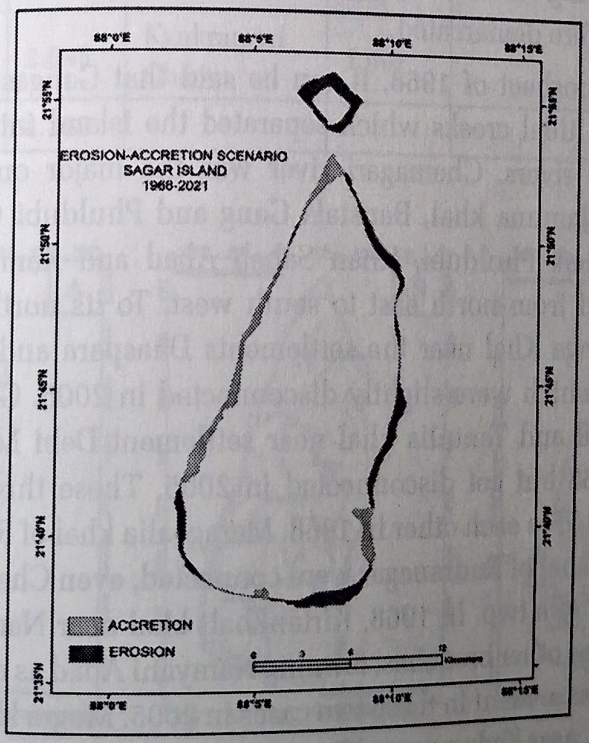

Figure 3
Erosion accretion behaviour of Gangasagar Island

4. GANGASAGAR ISLAND: A SAGA OF RAPID CHANGE

The biggest emblem of cultural significance in Gangasagar Island is the Kapil Muni Temple and the famous Ganga Sagar mela during Makar Sankranti. This temple was discovered by British surveyor Robertson in the year 1810. As a part of Sundarban, Gangasagar Island has suffered the brunt of many natural hazards.

A change detection study was carried out using Survey of India toposheet and Satellite images. The details of these are given below:

Table 1
Inventory of maps and satellite images used

Map/Image used	Scale/Spatial Resolution	Survey Year	Source
79C/1, 79C/2	1:50,000	1968	Survey of India
79C/1, 79C/2	1:50,000	2005	Survey of India
Landsat 8	30 m	13.01.2020	USGS Earth Explorer

To analyse the changes, the toposheets and image were georeferenced. The boundary of Gangasagar Island was digitized to make vectors from rasters. Both the maps and images were converted to same scale and projection and were superimposed. Using vector difference tool of QGIS 2.8.9. software, erosion and accretion zones were demarcated.

Observing the toposheet of 1968, it can be said that Gangasagar Island was interspersed with tidal creeks which separated the island into many smaller islands. Of these rivers, Chemagari river was the major one which had a connection with Jamuna khal, Banstala Gang and Phuldubi Gang (along the settlements of Chak Phuldubi, Khan Saheb Abad and Kamalpur), dividing Gangasagar Island from north east to south west. To its north east, Sikarpur khal and Muriganga Khal near the settlements Dhaspara and Company Char were connected which were slightly disconnected in 2005. Gobindapur khal, Mahishamari khal and Tentulia khal near settlement Debi Mathurapur were connected in 1968 but got disconnected in 2005. These three river systems were also connected to each other in 1968. Maragoalia khal of Radhakrishnapur and Marichkhali khal of Rudranagar were connected, even Chemagari khal was connected with these two. In 1968, Kirtankhali khal near Narayani Abad was connected with the other branches, forming Narayani Abad as a separate island. Disconnection was evident in these two cases in 2005. Mogra khal and Satbanki khal to the south, near Kedarpur and Raspur were interconnected forming these settlements into islands. Beguakhali and Gangasagar also resembled islands as Gangasagar Khal, Beguakhali khal, Pagoda Creek, Mogra Khal, Sankar Khal and

Hatipota Khal were connected. The interconnected stretches to the west could be traced in 2005 but those of the eastern section have lost their connections. The only major river system still present in 2020 is Chemaguri Gang and Phuldubi Gang system.

In addition to this, there has been a lot of changes in the areal extent of the bars on river Muriganga, to the east of Gangasagar Island.

Table 2
Areal change of bars on Hugli estuary

1968		2005		2020	
Bar	Area (km2)	Bar	Area (km2)	Bar	Area (km2)
Kabasgadi Island	3.311	Kabasgadi Island	3.414	Kabasgadi Island	2.245
Kabasgadi Island (Reserve Forest)	0.546	Kabasgadi Island (Reserve Forest)	1.779	Shikarpur, Dhanir Char and Kankramari Char cumulatively	7.556
Shikarpur Island	2.255	Shikarpur Island	0.915		
Kankramari Char	1.247	Dhanir Char	1.075		
Lohachara	2.045	Kankramari Char	1.997		
Suparibhanga	4.169				

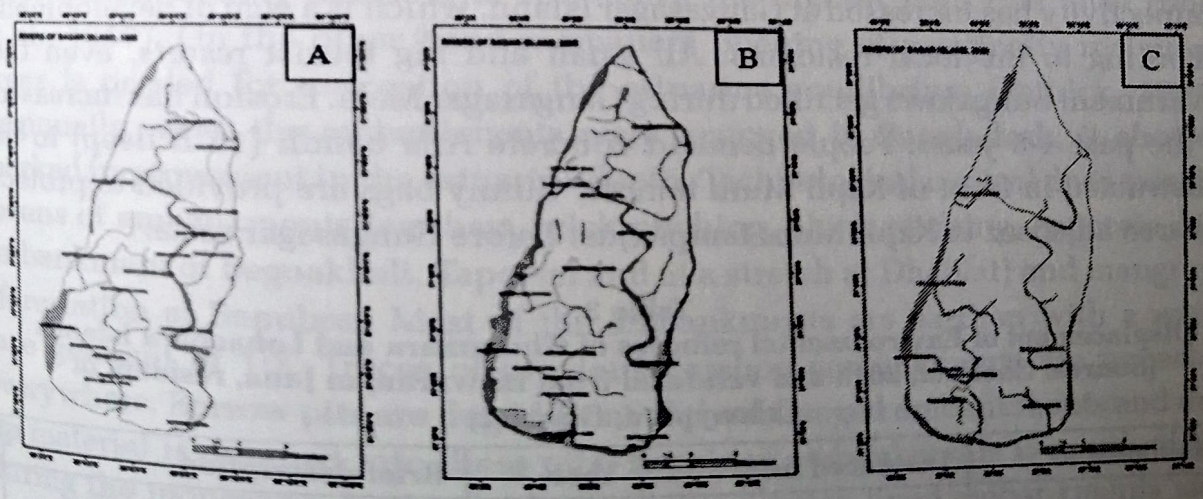

Figure 4
Changing scenario of rivers of Gangasagar Island (A-1980, B-2005, C-2020)

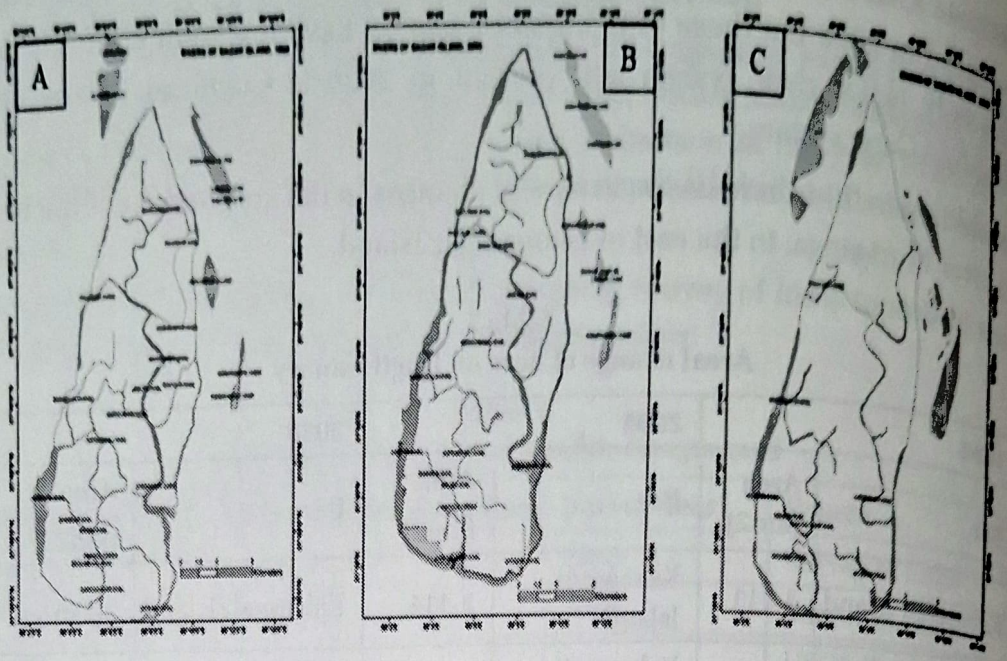

Figure 4
Changing scenario of bars on River Muriganga (A-1980, B-2005, C-2020)

5. PRESENT SCENARIO OF GANGASAGAR ISLAND – DISPLACEMENT AND CONFLICT:

People of Lohachara and Khashimara (Ghoramara) have been rehabilitated at Dhablat, where at present 267 families reside. Presently, agriculture relies on paddy and khesari (pulses). Freshwater supply has resulted in cultivation of Aman paddy and potatoes in the winter. Watermelon is no longer profitable. Also, people of Lohachara have bought land at Kakdwip. Literacy is high in Gangasagar Island but outmigration is common among the young generation.

Connectivity has increased at Gangasagar Island, which is a sign of development according to the local residents. All small and big tourist resorts, even the government bungalows get filled during Gangasagar Mela. Erosion has increased in the past 4-5 years. People demand concrete Aila bandh (15 ft deep) to be constructed in front of Kapil Muni temple. Gunny bags are provided to protect the area adjacent to Kapil Muni temple just before Gangasagar mela.

Table 3:
Displacement of Environmental refugees of Ghoramara and Lohachara Islands (Source: Chakma, 2013 and validated from Biswaranjan Jana, resident of Colonypara, Dhablat)

Displaced to	Displaced from	Year	Brief description
Phuldubi (80-85 families)	Khashimara, Ghoramara	1964	Each family was given 0.533 ha of land from the Government

Dakshin Haradhanpur (50 families approximately)	Khasimara	1964	Each family was given 0.533 ha of land from the Government
Bankimnagar	Lohachara	1972	Each family was given 0.883 ha of land from the Government. Bankimnagar Colony Fisherman Co-operative Society was established.
Gangasagar Colony	Ghoramara	1981	Each family was given 0.267 ha of land from the Government and one room earthen house was given.
Jibantala Kamalpur	Lohachara, Ghoramara	1983	Each family was provided with asbestos roof pucca house and 0.2 ha land.

6. PRESENT MANAGEMENT AND CONCLUDING REMARKS:

The coastal fringe in front of Kapil Muni temple is protected by geojute which is at times filled with mud, which gets washed away in each spring tide. The Kadambini Primary School had to be shifted thrice due to coastal erosion. Almost 2-3 bighas of land of the local resident Laksmirani Das of Dhablat were washed away. Even the Aila embankment had to be repaired twice.

Enhancement of elevation of prematurely reclaimed Sundarbans can be achieved by allowing sediment laden tidal spill in a controlled manner unless they are sufficiently accreted to rise above the highest high tide level (Bose et al., 1957). On the other hand permanent opening of marginally reclaimed areas is needed for restoration of the estuarine equilibrium (Pethick, 1994). Regionally when the embankments were removed in Bangladesh, it showed marked improvement in the estuarine depth. Technological control does exist by means of embankments (earthen, brick pitching, block pitching, concrete Aila embankment of Beguakhali, Tapovan and at a stretch at Dhablat) and mangrove aforestation at Benubon. Most of the embankments are earthen with a water face gradient of 1:2. Traces of previous bamboo embankments are traceable everywhere. Borrow pits are dug in front of the damaged embankments and dug up material is dumped into these pits. Repair of embankments is mostly done during the monsoons. In the eroding coastline, brick lined embankments also get breached by breaking sea waves washing away the earth fill supporting the cemented structure, leading to structural collapse of the embankment.

People have demanded concrete embankment for umpteen times but the Aila embankment at Dhablat is still incomplete at stretches. An Aila embankment in front of Kapil Muni temple is of utmost importance. Also, it is hoped that attempts at constructing offshore breakwater can be useful in reducing coastal erosion.

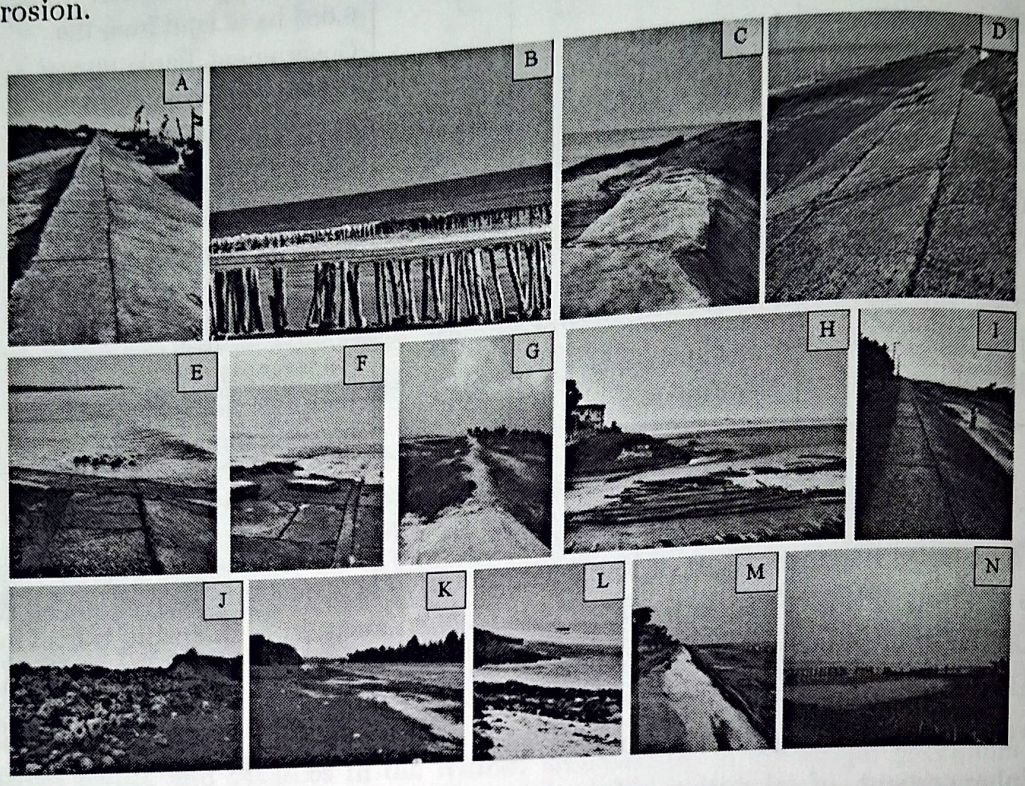

Plate 1:
A: Aila embankment at Tapovan; B: Remnants of bamboo embankments before Kapil Muni temple; C: Geojute embankment at Dhablat; D: Aila embankment at Dhablat; E: Concrete tetrapods in front of Aila embankment, Dhablat; F: Broken slabs in front of Aila embankment, Dhablat; G: Geojute and earthen embankment of Boatkhali; H: Scenario at Beguakhali; I: Aila embankment, Beguakhali; J: Laterite boulders at Beguakhali; K: Aila embankment at Beguakhali; L: Boulder and mesh protection at Beguakhali; M: Geojute at Gangasagar; N: Bamboo structure at Gangasagar

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