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Morphodynamics of Barrier Spits and Tidal Inlets of Subarnarekha Delta: a study at Talsari-Subarnapur spit, Odisha, India

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A B S T R A C T

The barrier-inlet system along the shoreline of Subarnarekha deltaic coast of Odisha state has most diverse morphologies of any barrier system in Indian coast. The delicate adjustment between wave and tide generated processes on the moderate energy coast allows only slight to moderate changes in either of these processes to result in significant and dynamically developing morphologic responses. Some of the natural phenomena such as cyclones induced opening of tidal inlets across the barrier spits, closure of inlets due to longshore transport of sediment, and changes in sediment input into the coastal zones are the result of responses produced by the interaction of energy levels and availability of materials in the coast.

Tidal basin behind the barrier spits of Subarnarekha delta plays a significant role in controlling inlet morphology as well as tidal prisms. The various modifications by development have resulted in important morphodynamic changes in the barrier inlet system. These include the fishery ponds, fishing harbours in the basin, hardening of the coast along the banks of inlets by engineering structures, and construction of earthen embankments along the basin fringe areas. Such activities have inhibited normal coastal processes in the region. Severe erosion of barrier spits at the southwest corner adjacent to the inlet mouth, and cliffing of the barrier based beach ridge-dune complex on the seafront areas are examples of instability in the system.

Impacts of above activities and basin filling by sediments with associated change in energy levels inhibit the environment of barrier spits and tidal inlets of Subarnarekha delta from responding to open coast processes of the Bay of Bengal at present.

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1. Introduction

Moderate wave energy and moderate tidal range with wide range in tidal prism, supply of sediments into the coastal zone by Subarnarekha river floods and gently sloping shallow shelf has produced one of the most significant diverse barrier spits in the present day shoreline of Subarnarekha delta. Interaction between mixed energy of waves, tides, stream floods, and winds or storms with available supply of sediment materials have produced wave dominated and tide dominated elements in the barrier system of Subarnarekha delta. Morphodynamic changes of the present day barrier spits are rapid in the coast (Fig. 1).

Morphodynamic behaviour of barrier-inlet systems of the Gulf coast of Florida is well documented by Davis, R. A. (2006, 2003, 1999, 1989, 1994, 1985) and others to identify the morphologic responses of inlets and adjacent barriers after the development of the coast by humans. Subarnarekha deltaic coast dominated by present day barrier spits and chenier sand ridges of past with wide spaced swales are studied by Niyogi, D. (1975), Paul, Ashis Kr. (1996, 2002), Chakrobarty, P. S. (1991), and Maiti, Sabyasachi (2009, 2013) for exploration of geomorphological diversity. However, the present study highlights the morphodynamic responses of barrier spit and tidal inlet system of the tropical coast in episodic events of mixed wave-tide energy, cyclonic storms and river floods in the coastal zones.

2. Objectives

The present study is conducted in part of Subarnarekha delta (eastern part of estuary) in consideration with barrier spits, tidal inlets, tidal basin and Subarnarekha estuary fringe areas of modern shoreline dynamics under physiographic settings and associated energy variables. Following objectives of such study are of interest:

i. To identify the morphodynamic behaviour of barrier spits in Subarnarekha delta;
ii. To record the pattern of changes of spits and tidal basin experiencing at various time scales; and
iii. To enquire about the energy variables in physiographic settings of the deltaic coast.

3. Methods of the study

The temporal change of Talsari-Subarnapur tidal basin shapes and shoreline configurations of the barrier spit and tidal inlets are studied with multi dates images (1973, 1990, 2005, 2010 and 2013) for identification of erosion and deposition within a recurrence period (about 40 years) along the mixed wave-tide environment of Subarnarekha deltaic shoreline. Various geomorphic surfaces are recognized with digitizing the tidal, marine and wind depositional features from google images and aerial photographs of the region. Seasonal field survey was conducted to monitor the basin morphology, hydrodynamic behaviours of tidal channels, and spit front shoreline retreat and advancement.

4. Results and discussions

4.1 Morphological changes

The barrier spits protect the tidal basin of Subarnarekha delta from open marine environment, and tidal inlets act as the interactive drainage link between the lagoonal tidal basin and open marine shelf region in the entire system. The fate of elongated tidal lagoon is depended upon rate of sedimentation and zone of sediment deposition. Subarnarekha estuary section is also connected with the tidal lagoon by tidal channels.

The morphology of spits, inlets and tidal channels is always getting modified with tidal, riverine, longshore, storm related over wash deposition and windblown sand deposition in different seasons with process activities. Present study shows the morphological changes of spits and tidal inlets to adjust with the process response systems over time and space. Southwestern parts of the spits ware protected towards the sea since 1942 to 1973 and thereafter retreated landward side by erosion up to 2005. The northeastern parts of the spits are also slightly advanced seaward in compare to 1973, but eroded and retreated landward side significantly after 2005. Subtidal shoaling flats and intertidal depositional areas are now increased (2010 to 2013) in the southeastern parts of spits with some subaerial erosional signatures. However, the northeastern section of spits is significantly retreated landward side by rollover process in the deltaic shore. Various geomorphological signatures proved the activities of longshore currents, inlet migrations, and storm effects in the region in modification of current morphology of spits and tidal inlets (Table 1, Fig. 2 and 3).

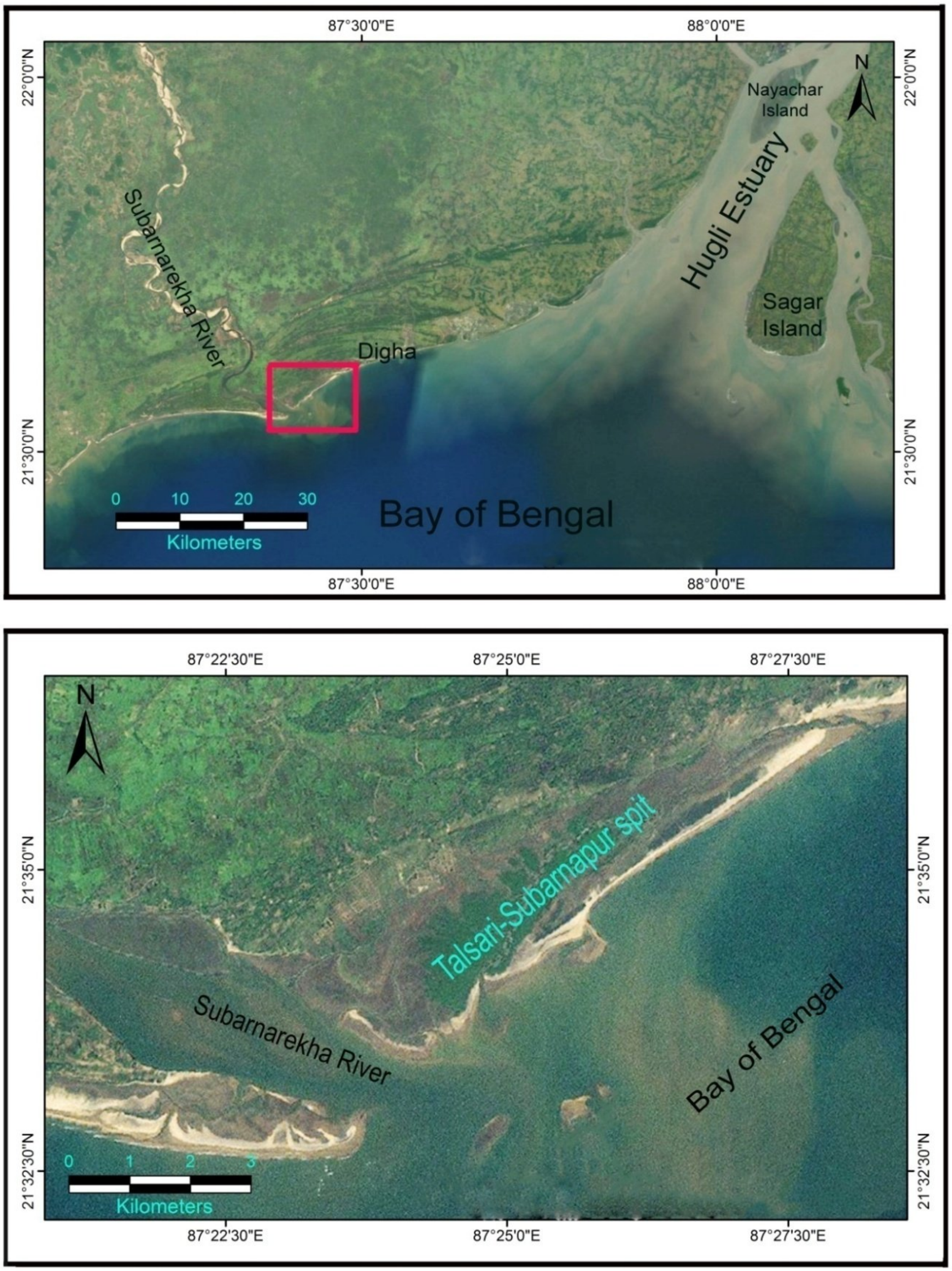

Fig. 1 : Location Map of Study Area

4.2 Morphodynamic states

The delicate balance between tidal and wave generated longshore current processes on this mixed energy coast permits changes in morphologic responses of spits and tidal inlets. Some of these responses are the result of natural phenomena such as cyclones (1988-1989, 1999, 2007, 2009, 2013) opened tidal inlets partially and totally, closed inlets due to long shore transport of sediments along the shorelines, and changes in the availability of sediments (supply from erosion from shore cliffs, flood input of river Subarnarekha etc.) in the region.

Tidal prism also fluctuated through the inlets and they have controlled the inlet morphology with areas of erosion, shifting and deposition. The fluctuations of tidal prisms are greatly influenced by human activities in the back barrier basins (landuse conversion, jetty structures, cliff erosion protection, embanking etc.). The various modifications by such development have resulted in important morphodynamic changes in the barrier inlet system of the region. The plan shape of barrier spit is changed due to emerged sand ridges in the shallow shelf adjacent to existing shoreline (Table 3, Fig. 4 and 5).

4.3 Cyclic changes in shoreline dynamics

The linear tidal basin of Talsari-Subarnapur and Kirtania-Bichitrapur sections is more or less protected by a shore parallel barrier spit and estuary margin sand ridges. General shoreline changes of the barrier spit and estuary margin sand ridges are affected by energy levels of tides, long shore currents, sea waves, storms and storm surges, floods and southwest monsoon brace in the region. Comparison between shorelines of different years from 1942 to 2013 exhibits progressive change in a short term period and cyclic change in long term period. The northwestern section of barrier spit shoreline is little affected by erosion and deposition. The migration, opening and closing of tidal inlets have produced such changes along the shoreline of the barrier spit. However, the southwestern section of the barrier spit is showing progressive changes in terms of erosion up to certain time. The high water levels of storms, tides, southwestern monsoon phases usually converge with the low height barriers of this area. Overlying sand sheets of the region are removed by various impact levels of energy factors. The mud banks with degraded mangrove wetlands are now directly exposed to the open sea marine forcing factors (sea waves, magnitude of tidal currents and long shore currents). The current images (2010, 2013) of this part of the shoreline are showing some depositional signatures in the form of tidal shoaling flats and long shore bars in the shallow sea. The erosion will be minimized after the growth of such features in the region in near future (Table 4 and Fig. 6).

4.4 Hydrodynamic behaviour

Tidal heights fluctuates on several scales like other areas of northern Bay of Bengal coasts as high tide and low tide twice a day, springs and neaps at fortnightly, equinox tides at seasonally, and as nodal cycle in every 18.6 years (the last nodal cycle maximum was in 2007-2008) in the mixed wave-tide deltaic setup. The entire tidal lagoon basin becomes inundated in the equinoxial tides, and the vertical accretion rates are influenced by the effect of frequency of tidal inundation. Active tidal flats with criss-crossed tidal channels and accumulated fresh silts provide ideal substrate for colony development of mangroves and salt marsh vegetations in the lagoon.

Tidal elevation ranges from 2.5m to 3.2m in the basin and as a result of such moderate heights of tides the older depositional surface at the lagoon fringe becomes affected by drainage loss. Tidal prisms also fluctuate on the basis of fluctuated heights and stages of tides into the basin. The western part of the tidal inlet is ebb dominated and produced significant ebb delta lobes in its shore face position.

Linear approach of the spit as well as of shore parallel sand ridges of shallow shelf indicates the presence of strong long shore drift from west to east along the shores. Significant wave heights with approaching angles from southwest transport sediments along the shores to modify the beach ridges and spits of the region. Storm depositions occurs with surging waves and wash over fan lobes by wash over process (Table 5).

4.5 Migration of tidal inlet and related shoreline change

Inlet changes are associated with migration of the inlet channels (Talsari and Subarnapur) and also with the nature of the ebb tidal deltas at their mouths. The morphological changes of the barrier spits are associated with wash over of low and narrow sections, and with the progradation of beach/dune ridges on the barriers. The northern tidal inlet of Talsari is pushed northward by growth of barrier spit by 1.95km within 20 years as the longshore drift is primarily directed towards northeast along the present day coastline. Migration of tidal inlet has taken place as the result of a loss of tidal prism within the linear tidal basin located behind the barrier spit of Subarnarekha delta. However, the advancement of southern spit is restricted by the location of deep

Table 1: Various geomorphic features with their linear forms and occupied areas of the barrier coast of Subarnarekha delta.

Geomorphic features	Area (m^2)	Length (m)
Indurated sand layer		68.18
Concrete sea walls		1571.07
Cliffing with erosional signature		5299.33
Talsari tidal channel		131539.50
Older beach plain deposit	159985.46	
Erosive surface with exposure of mud bank	283887.21	
Channel fill deposit on the bank line	846.24	
Bar depositional surface	4211294.44	
Artificial swamp surfaces	2530927.30	
Wind-tidal flat deposits	54959.56	
Wash over sand fan lobes surfaces	25284.89	
Tidal mud flat depositional surfaces with fresh silts	205366.10	
Swamp deposit surfaces	4108895.32	
Sub-tidal shoal bank deposits at the outer fringe	694179.15	
Sand spit with vegetation cover	849892.06	
Older beach ridge deposit	367926.33	
Younger beach ridge deposits	397028.18	
Younger beach plain deposits	2058792.85	

tidal inlet. This part of the spit is more or less eroded by cyclone waves of 1989 and 1999. Ebb tidal deltas at their mouths also displayed significant changes, typically as a result of changes in tidal prism. Increase in prism causes inlets to trend toward a tide dominated morphology whereas a decrease causes instability and wave-dominated conditions.

4.6 Energy variables in physiographic settings

Various physiographic settings have been identified in the study area on the basis of energy factors, landform assemblages, morphodynamic responses, episodic changes experienced over a time scale (Table 6).

Large river floods and high magnitude cyclones together with other energy variables at southwest monsoon braces and highest astronomical tidal phases can produce a significant change in morphologies in response to morphodynamic adjustments in the above coastal zones of Subarnarekha delta. As tidal basin under lagoonal set up is getting filled up gradually with sediments from different sources, the dynamism of modern barrier spits and tidal inlets will be more dynamic in the near future. The entire system is the result of interactions between the four physiographic settings with variables of energies and materials.

5. Conclusion

The Subarnarekha deltaic barrier coast of Odisha represents one of the most diverse, wave-tide mixed energy barrier coasts in India. It ranges from distinctly wave and longshore current dominated to distinctly tide dominated conditions under tidal ranges of 3m or less and mean annual wave heights of 30cm with southwest monsoon wave heights of 80cm. This coast includes all types of modern barriers, Holocene barriers, linear tidal basins, and estuarine islands.

The barrier spits, tidal basins, estuaries, and shallow shelf provinces always try to achieve the equilibrium stage between the relative influence of wave and tidal processes, storminess of the sea, high magnitude of

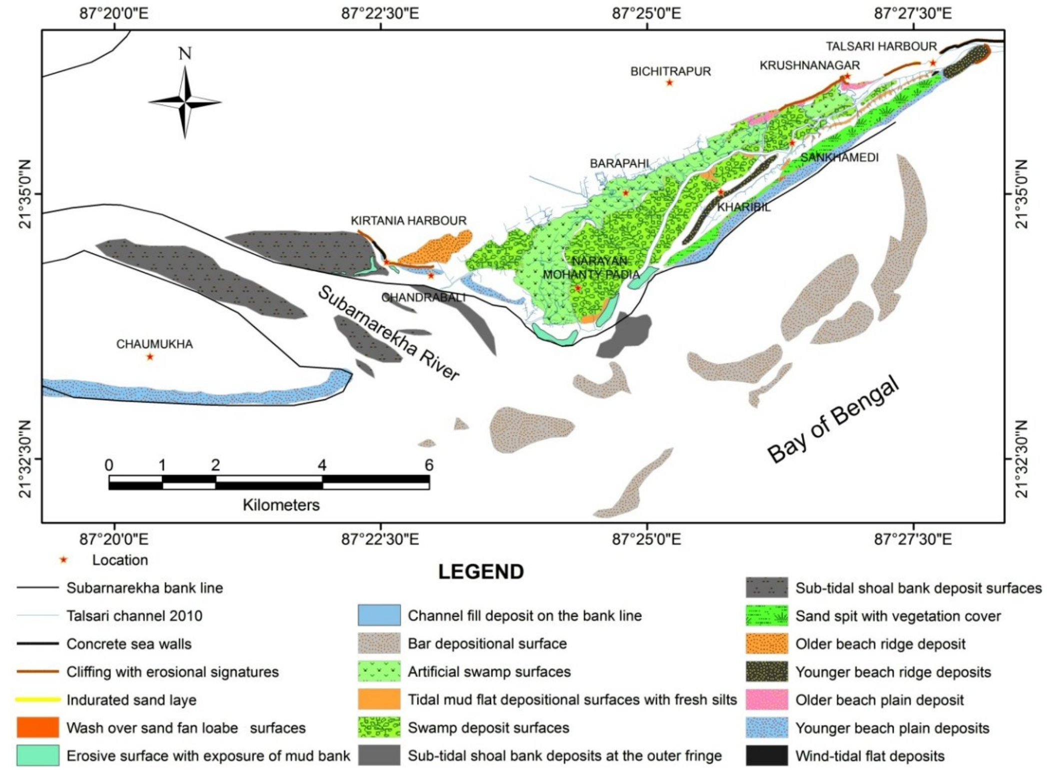

Fig. 2 Depositional features of the modern barrier coast of Subarnarekha delta.

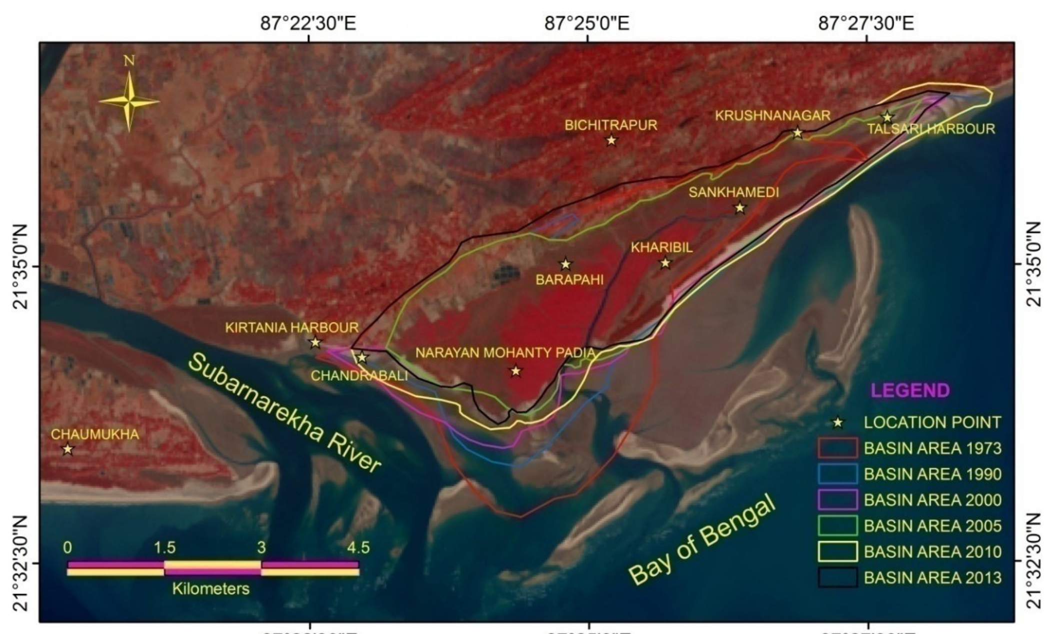

Fig. 3 Barrier coast areas ranging from 1973 to 2013 with superimposition of temporal satellite images (8th February, 2014).

Table 3: Year wise variation of constructed and eroded areas of Talsari-Subarnapur tidal basin.

Years	1942-1973	1973-1990	1990-2000	2000-2005	2005-2010	2010-2013
Constructed area (km^2)	19.56	2.00	0.58	0.38	0.39	0.20
No. of constructed pockets	1	1	4	4	7	5
Eroded area (km^2)	-	3.25	1.09	1.60	0.19	0.22
No. of eroded pockets	-	1	3	4	8	6

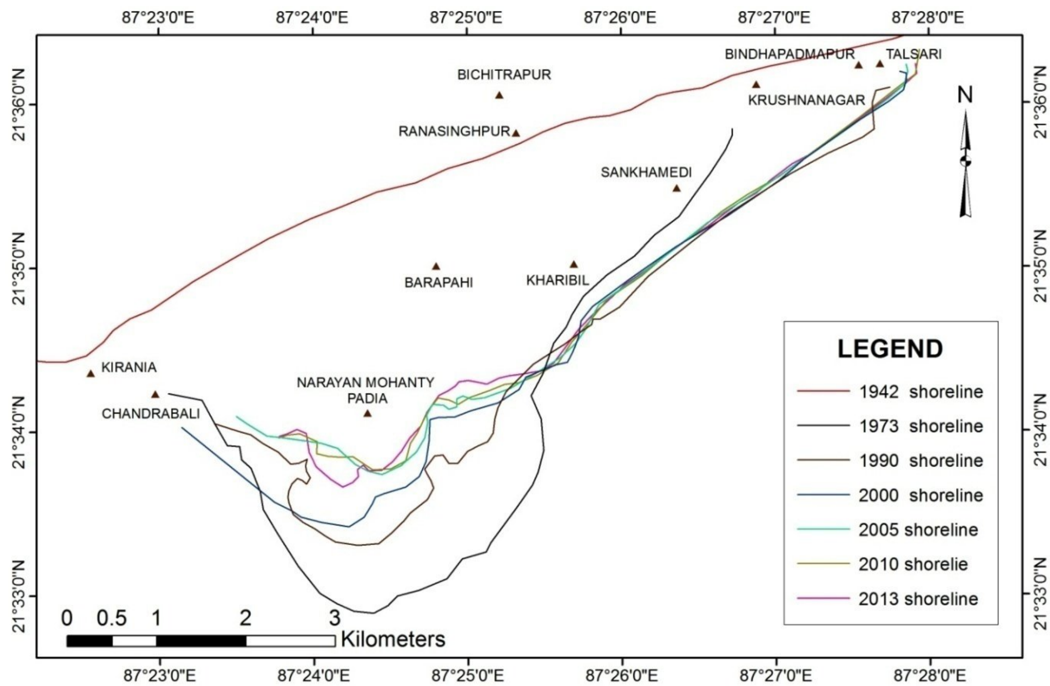

Fig. 4 Shoreline position of Talsari-Subarnapur spit from 1942 to 2013.

river floods, longshore currents and coastal morphology; but they never can achieve this balance. Thus, the coastal morphology of diverse physical settings can change rapidly as this balance changes with episodic events and sediment sources in the entire system. Numerous examples of this condition have taken place over the past several decades (1950-2010). Additionally, the development of the coast by humans has impacted the barrier systems not only directly due to conversion of tidal basins and damming the river Subarnarekha at different stations of upstream portion but also indirectly by modification of adjacent shorelines of the barrier coast. Changes in tidal prism caused by back barrier sediment filling and some constructions have been especially important in causing morphologic responses of both the affected tidal inlets and adjacent shorelines of the barrier spits in the deltaic coast.

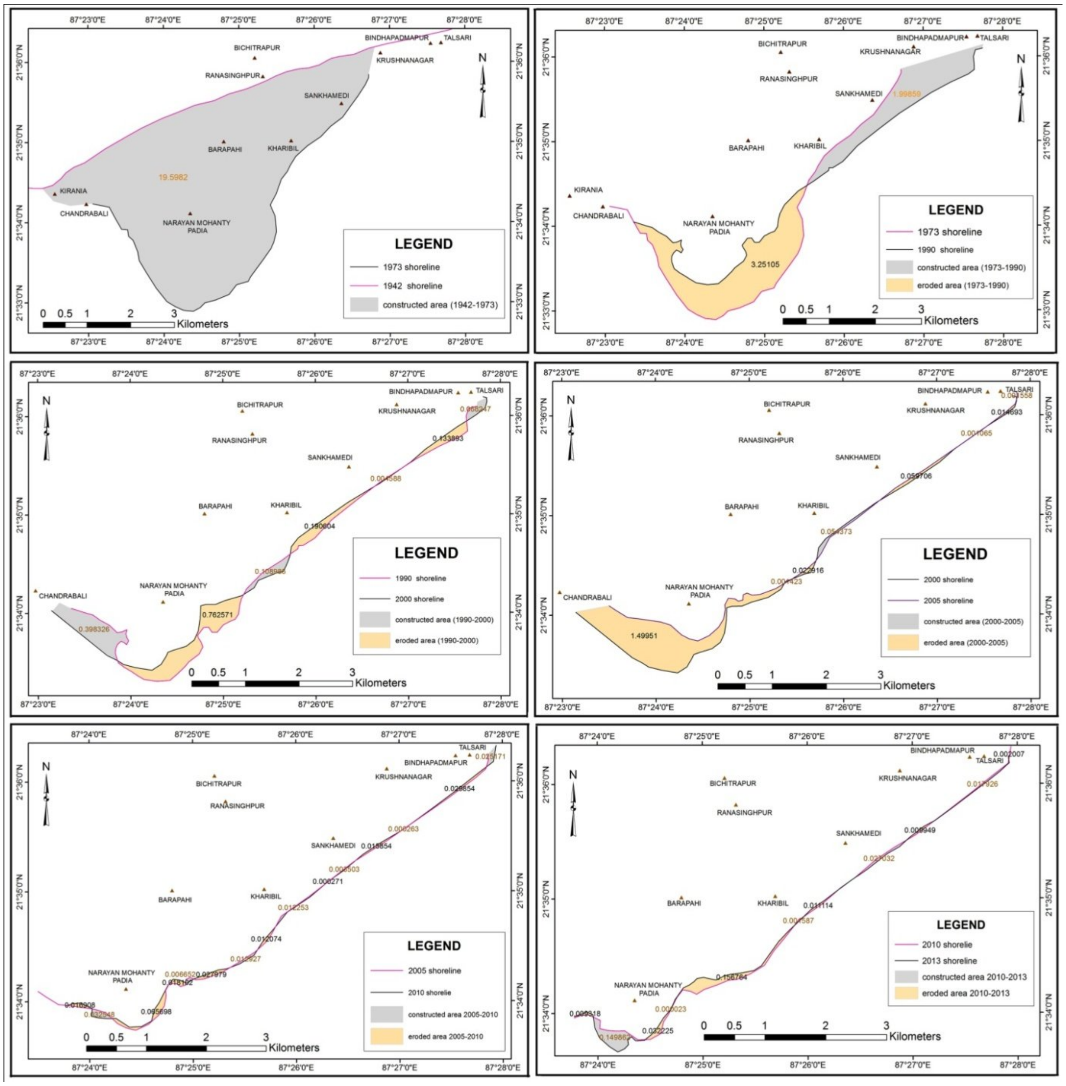

Fig. 5 Several eroded and constructed pocket areas in response to shoreline change from 1942 to 2013.

Table 4: Year wise variation of area and perimeter of Talsari-Subarnapur tidal basin.

Talsari-Subarnapur spit (1973-2013)						
Years	1973	1990	2000	2005	2010	2013
Area (km^2)	17.79	16.02	14.88	12.85	17.12	14.82
Perimeter (km)	22.51	26.08	23.50	20.42	23.53	22.30

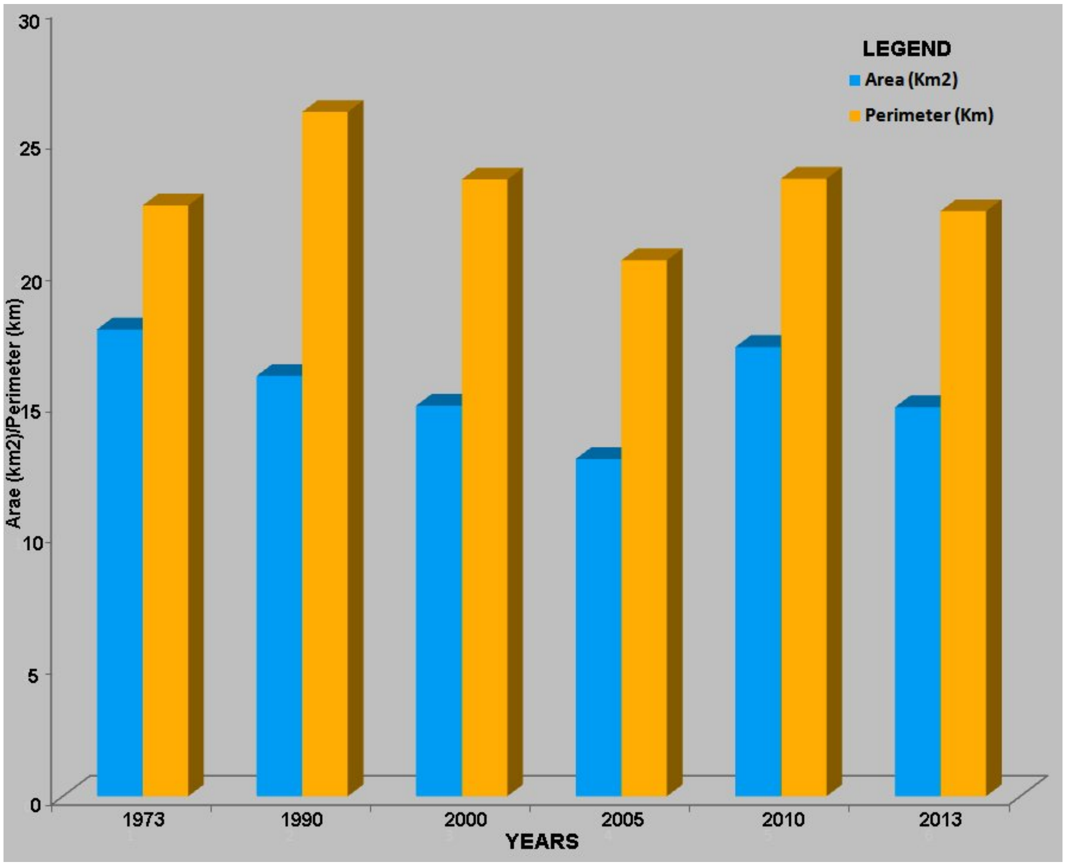

Fig. 6 Changing pattern of Talsari-Subarnapur tidal basin area and perimeter from 1973 to 2013.

Table 5: Longshore current velocity of three coastal stations of Odisha and West Bengal (Paul, 1985).

Place	Maximum orbital velocity of the wave (Um)	Wave approach angle		Longshore velocity (VL/m/sce.)
		sinsinα	cosα	
Subarnarekha river mouth	2.7 (constant)	sin 32=0.53	cos 32=0.85	1.2164
Baitarani river mouth	2.7 (constant)	sin 30=0.50	cos 30 0.87	1.1745
Digha coast	2.7 (constant)	sin 55=0.82	cos 55=0.57	1.2620

N.B. Calculation is based on the simplified formula of Komar and Inman (1970):

VI = 2.7 Um $\sin\alpha\cos\alpha$

Table 6: Physiographic settings with variables of morphology and hydrodynamics.

Physiographic settings	Landform assemblages	Morphodynamic responses	Episodic changes
Barrier spits	Extension of shore parallel sand spits, Beach ridges, Sand dunes	Longshore current transport of sediments with mixed wave-tide depositions	Cyclonic storms, Riverine impact of sediments in the floods
Tidal inlets	Inlet throats, Ebb delta, Flood delta	Inlet closing, Inlet opening, Inlet migration, Variation in inlet prisms	Tidal floods, Storm surges, Tidal jets
Tidal basin	Mangrove swamps, Tidal flats, Saltmarsh surface, Tidal creeks	Sediment accumulations, Sediment transportation, Shifting channels	Tidal floods, Estuarine floods, Storm surges, windblown sand deposition
Subarnarekha estuary	Emerged bars, Submerged bars, Islands, Tidal mudflats, Storm deposition of sands	Dynamic diversion of tidal currents, Sediment bypassing at the mouth, River flood with sediment input	River floods, Long shore transport, Wave impacts at the storms

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