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An assessment of geomorphic evolution and some erosion affected areas of Digha-Sankarpur coastal tract, West Bengal, India

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Abstract

The coastal sites of Ramnagar-I and Ramnagar-II Administrative Blocks (Kanthi Coastal Plain), Purba Medinipur District, West Bengal, India, reveal various morphological features, which are represented by four categories of surface formation under different processes in the present study through a contour plan with 50 cm contour interval. The first category of landform being some isolated ridges with above 10 m elevation, which are stretched out in a linear pattern parallel to the modern shoreline behind Ramnagar-Deuli beach ridge section. The second set of landforms of the area which ranges from 7 m to 10 m elevation from the MSL is extended in the form of sandy terrace and continuous sand ridge surface along the sides of the first category landform. The third category of landform is visible along the edges of the second category of continuous sand ridge topography in the form of an extensive sandy tract with the reactivated sand surface.Last category of the ancient surface with an elevation of 2.5 m to 5.0 m above MSL is also clearly visible from the wide valley flat surface depressions in between the Contai-Paniparul beach ridge section and Ramnagar-Deuli beach ridge section at present. Some crenulated ridges of sandy sediments observed in the the present contour plan, particularly along the bank of abandoned channels. These are most probably evolved in the ancient period by natural levee depositions from various fluvio-tidal channels of the coastal plain. They are also categorized into older natural levees and younger natural levees delineated from the tonal contrasts of images and field verification of lose sediments. The older natural levees represent oxidized soils and the younger one represents the grey white color of sediments. Tidal prisms are the result of spring time tidal waves, keeping pressure on the seaward sides and spill over the backshore area by entering into the tidal channels at the time of high tide in the coastal belt. The study reveal the effects of significant increase of tidal prism estimated from 1990 to 2017.

Keywords Digital elevation model (DEM) · Landform order · Chronology of coastal formation · Micro contour plan and tidal prism

Introduction

The coast has a dynamic environment where land, sea and atmosphere interact and interplay continuously influencing a strip of spatial zone defined as the coastal zone. Coastal zones are the most fragile, dynamic and productive ecosystem and are quite often under pressure from both anthropogenic activities and natural processes (Paul 2002; Woodroffe 2002; Sander et al. 2016). The coast is an active, dynamic zone because there are so many geomorphic agents playing their active role to change the pattern and nature of the coast. So, the coastal geomorphic features like the beach, cusp, dune, beach berm are formed in the shorefront region of the coast (Hellemaa 1998; Long 2003; Szkornik et al. 2008). On the other hand, beach formation and paleobiology are studied through some empirical models in the Bengal Basin during the Holocene period (Bagnold 1940; Banerjee and Sen 1987). However, the coast is a hazard-prone area, where so many hazards like flooding, inundation, cyclone, storms, and tsunami occurred. When a natural calamity or hazard occurs, the coastal geomorphology of both the coastal belt and the shoreface are changed (Clemmensen et al. 2001; Berglund et al. 2005). Prasad and Kumar (2014) were investigated the characteristics of shoreface storms deposits by some modern and ancient examples.

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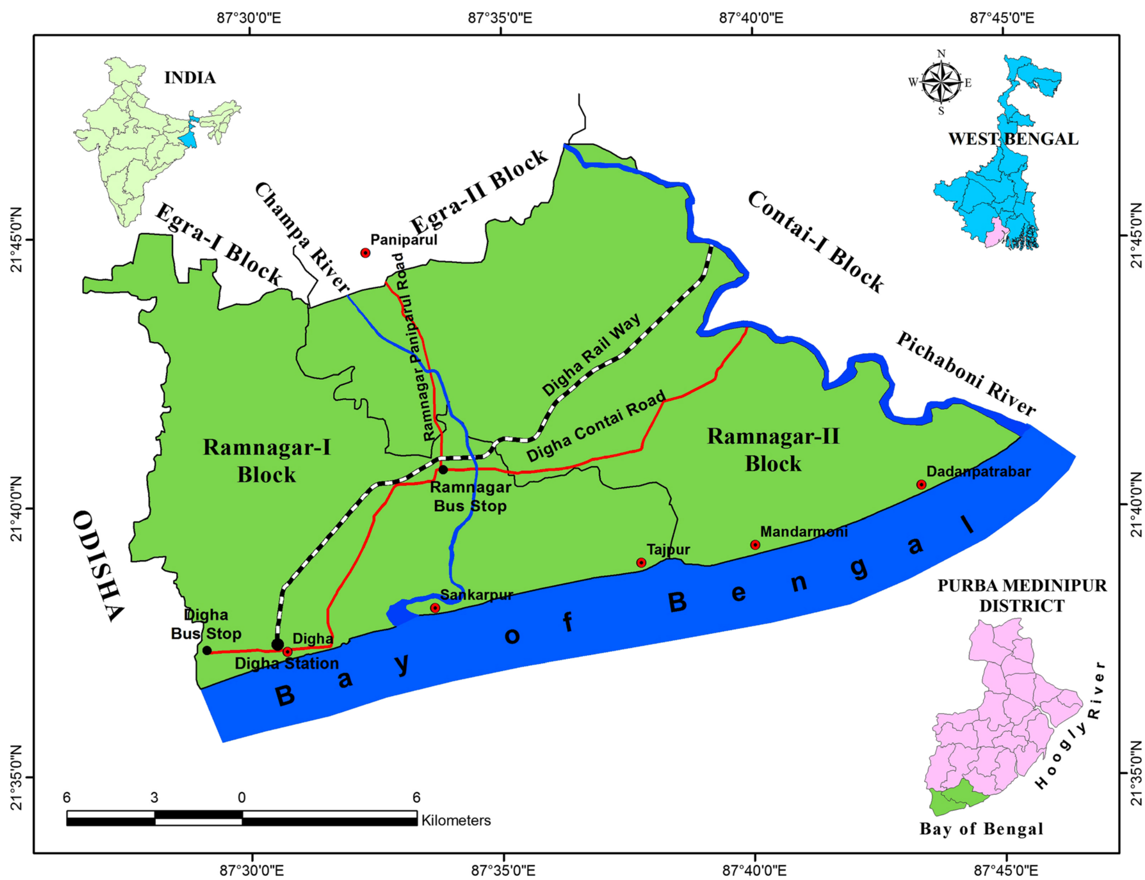

Fig. 1 Location map of the studied area

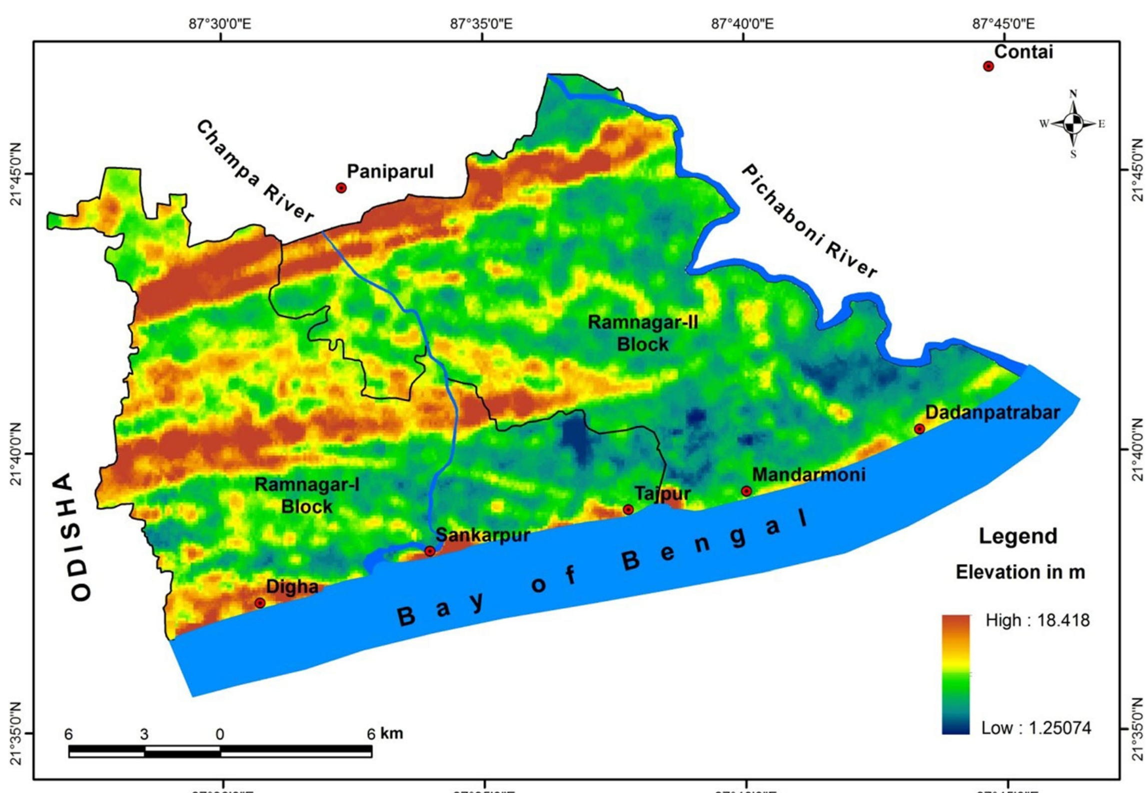

Fig. 2 High-resolution Digital Elevation Model (DEM)

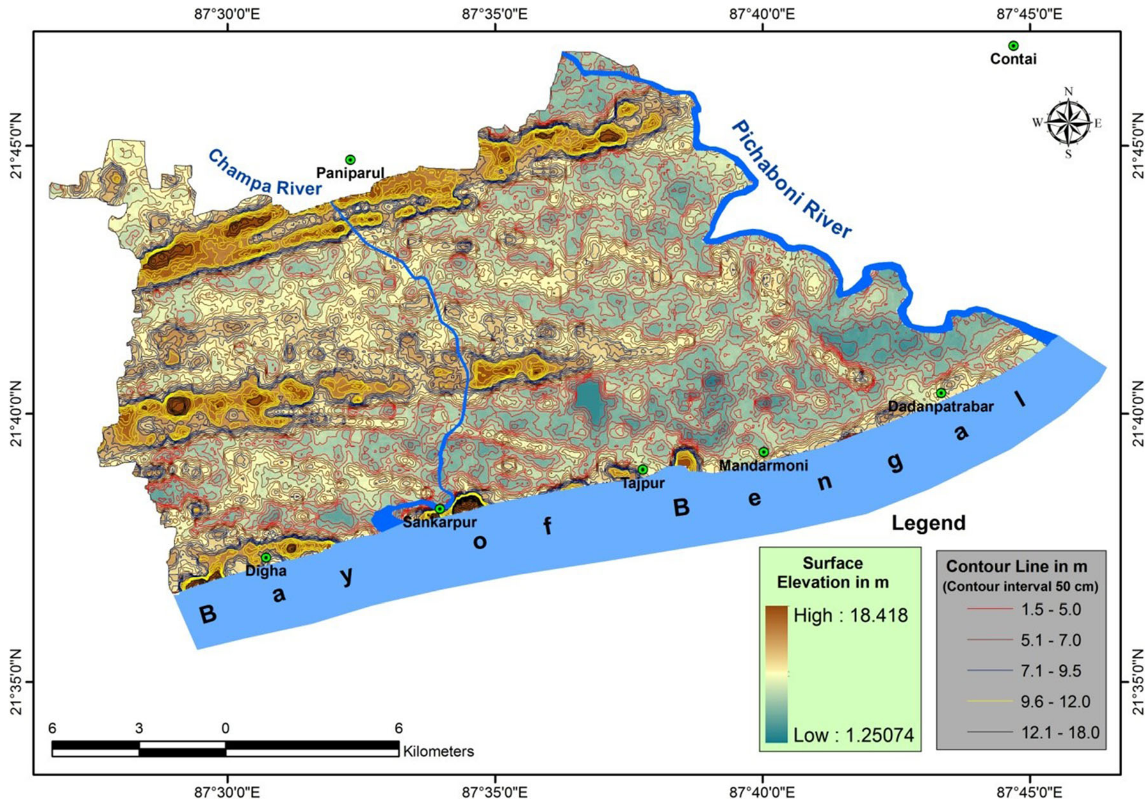

Fig. 3 The contour plan of coastal plain topography from high resolution interpolated DEM (50 cm interval)

In the coastal belt, marine terrace is an imprint of coastal morphodynamic processes which helps to understand the sea level changing scenario (Niyogi 1970; Pethick 1990; Masselink et al. 2008). Coastal wash over is also a part of morpho-dynamics and it is a process by which sediments shift from the seaward side to the landward side and it is usually occurred at the time of monsoon or cyclone etc. (; Niyogi 1970; Pethick 1984; Ganesan and Gaonkar 2006; Hede et al. 2013). Coastal morphodynamics are directly related to the coastal geomorphology. Morphodynamics of the coastal tract of West Bengal and northeast India is thoroughly studied by several researchers (Bird et al. 1984; Maiti and Bhattacharya 2009). There are so many geomorphological processes involved in the formation of coasts such as a river, wind, tide, and currents which are either erode or deposit on the coast. So, sedimentation is a vital process to develop a coast that is beach formation, beach erosion (Komar 1983, 2018). Geologically, the area is characterized by ordinary alluvium deposits of Holocene to the recent origin and was brought down by the Subarnarekha and Ganges river system (Bhandari and Das 1998; Maiti 2013). The existence of colonies of sand dunes and marshy areas is parallel to the shoreline which is most frequent in the area. The dune of this vicinity lies adjacent and parallel to the Bay of Bengal (Anthony et al. 2006;

Plate 1 Coastal wetlands of landward part and seaward part of Ramnagar-I and II Blocks with the change in elevation and inundation levels

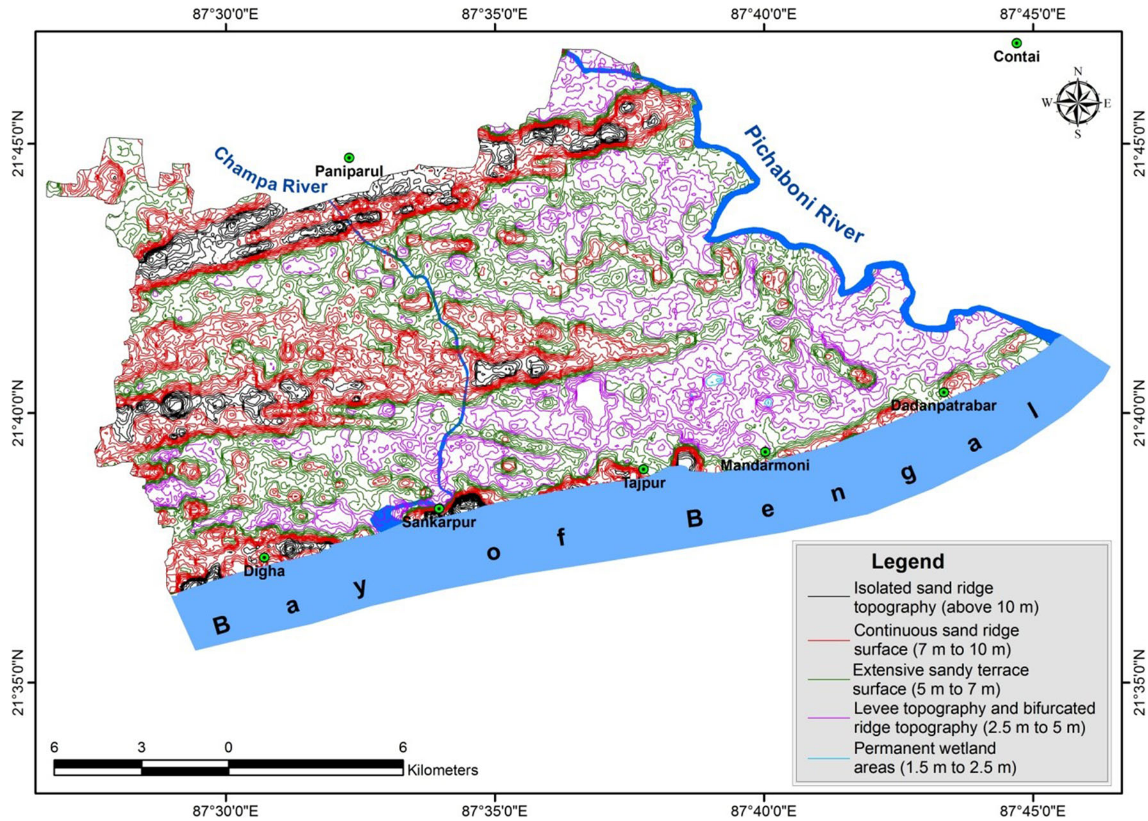

Fig. 4 Various relief units of the coastal plain based on elevations from the MSL

Maiti and Bhattacharya 2009; Bendixen et al. 2013). In certain places dunes emerges at the distance of 5 to 6 km from the coast and 11 to 12 m height. Purba Medinipur coastal tract is characterized by sand dunes, longshore currents, major river emancipations, less turbid but high saline seawater influence. The cuspate delta of the Jaldha river and neo-tectonic depressions in the north which covered mostly by sandy clay and silty loam soils that developed under a brackish environment. Thus, the studied coast did not receive matured alluvium as in the past and the topography is not desalinated by fresh water river floodings. The wide beaches and an intensive network of inlets and creeks, mangrove swamps, mudflats, frequent coastal dunes and sand flats are the major characteristics of this coastal region.

Materials and methods

In this study, the geomorphic features and a detailed contour plan have been categorized based on Remote Sensing and GIS technology. High resolutions interpolated Digital Elevation Model (DEM) have been prepared through the replication of image calculation procedure for the recognition of micro geomorphological components of the studied area. Two thousand Ground Control Points (GCP) were marked in the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), Global Digital Elevation Model (GDEM), (Version-215 m, 2014), Shuttle Radar Topography Mission (SRTM: 1 arc-second, 30 m, 2014) DEM and Google Earth Image to identify the altitudinal disparity of the study area. Then the Root Mean Square Error (RMSE), Mean Error (ME) and Absolute Mean Error (AME) have been calculated to simulate the significance as well as the accuracy of GCP sets. These data were projected through the bootstrapped iterations to beat the inaccuracy of the model. Because the bootstrap iterations offer an advantage to determine the precision of statistics stochastically for the opposing implementation of the deterministic derivation of these statistics (Sharma et al. 2010) and several principle positions had been selected for the Total Station (TS) survey to integrate and validate the elevation points for the analysis of landscape characteristics as well as evolution processes of coastal tract since 1990. The drainage features, coastal morphometric attributes (1 km by 1 km grid cells are used for the identification of relief elements based on DEM), and estimations of tidal prisms for the tidal inlet channels and tidal basins are delineated through the Sentinel images of different temporal scale. Hydro-geomorphological analysis of the coastal plain topography has been assessed through the shore profile transects under high tide and low tide exposures of the study area. The tidal range is

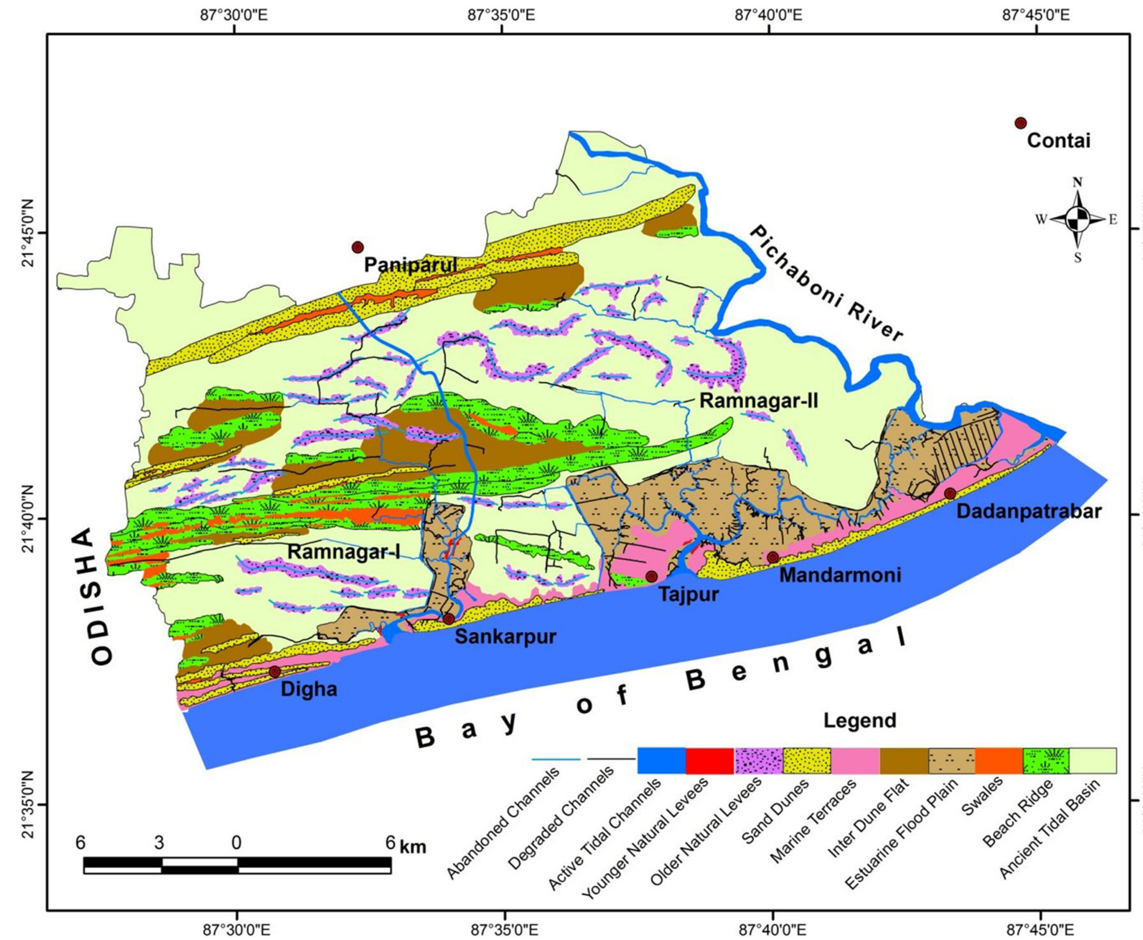

Fig. 5 Micro geomorphological units of the studied coast

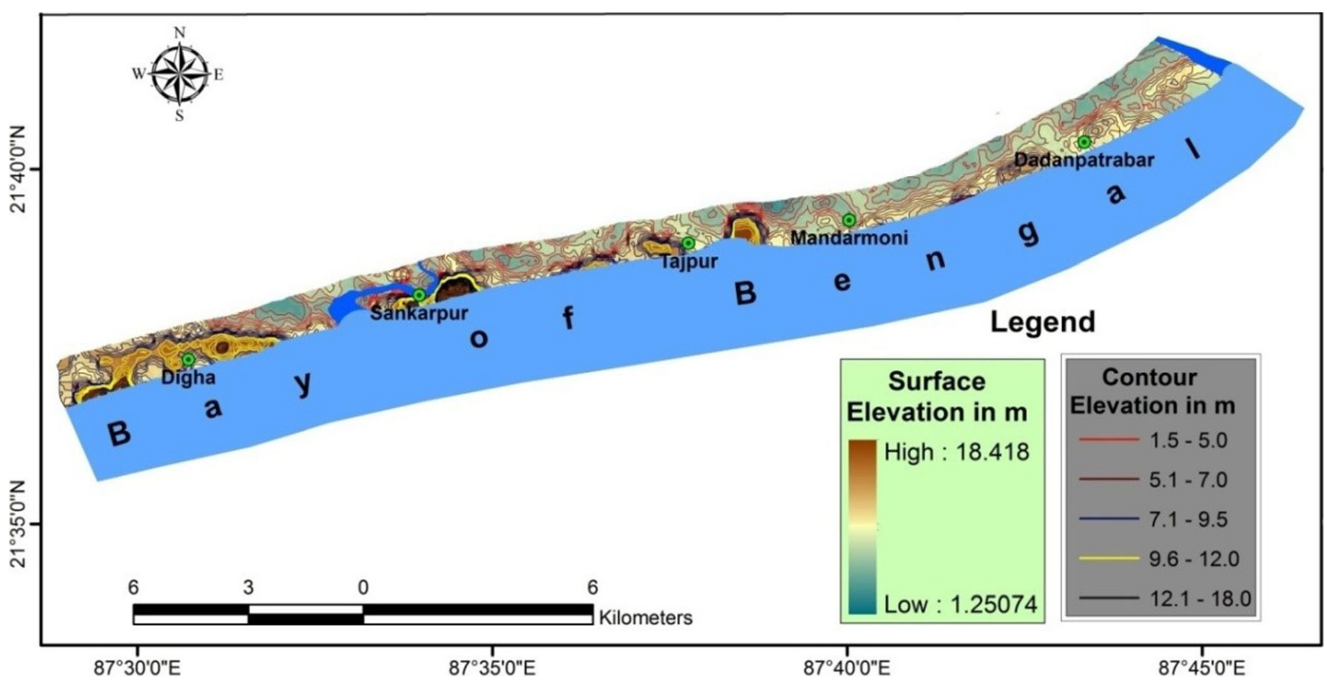

Fig. 6 Erosive dune face of the beach fringed shoreline of the study area

Table 1 Chronology of coastal formations in the study areas of Ramnagar-I and II Administrative Blocks

Landscapes	Elevation	Pattern	Soil material	Tonal contrast	Existing dated age	Probable age	Ancient processes involved	Sea level indicators
First category of landscapes	Above 10 m	Shore parallel isolated sand ridge	Oxidized sands	Brownish	7000 years BP	Early Holocene	Windblown deposits and erosion by t idal waves	Sea level steel stand
Second category of landscapes	7 m to 10 m	Shore parallel sand ridge topography	Oxidized sands	Brownish to yellowish	5760 ± 160 years BP	Middle Holocene	Windblown and wind-tidal	Sea level steel stand
Third category of landscapes	5 m to 7 m	Extensive sandy tract on the both side of ridges	Sandy	Grayish	2900 ± 160 years BP	Late Holocene	Over wash reactivated deposits	Transgressive seas
Fourth category of landscapes	2.5 m to 5.0 m	Bifurcated ridges and crenulated levees	Sandy and loamy	Dark grey	2000 ± 100 years BP	Recent to Sub Recent	Wave induced currents and fluvial currents	Regressive seas

estimated from the beach profiles with their differences between high tide levels and low tide levels for each shoreline sections. As a whole, the five profiles or transects under different tidal phases are estimated and measured by the GSI People (Pattanayak et al. 2014).

Study area

The studied coast is (Ramnagar-I and II Blocks of Purba Medinipur District, West Bengal) a widespread coastal region in the southwestern part of the state. This coastal plain is made up of sand and mud deposited by fluvial and aeolian process which is also a mid-eastern division of Kanthi Coastal Plain and covers an area of about 294.39 km^2 stretching between 21°37′54.88“N to 21°46’39.78”N latitude and 87°26′40.90“E to 87°37’36.64”E longitude (Fig. 1). The study area has a complex coastline, bunches of early growing deltas with interlinked tidal creeks and estuary. Deltaic expanses are generally clayey composition due to higher deposit of sediments through the Subarnarekha system in the right and also through the Ganges river system in the left.

A clayey bedspread covering gravels of sandstone, siltstone and quartz which are labelled quaternary era of the area. Consequently, the present coast does not receive the fertile alluvium as before and the topography is not desalinated by river floods. The wide beaches and an intensive network of inlets and creeks, mangrove swamps, mudflats, frequent coastal dunes and sand flats are the major characteristics of this coastal region.

Topographic characters and order of landforms

Topographically, it is also visible from the present contour plan (50 cm interval) that the morphological features behind the Ramnagar-Deuli beach ridge sections represent three categories of surface formations under different processes

Plate 2 Sectional exposure of older sand dunes at Depal and exposure of mud banks on the shoreline of Sankarpur due to the removal of sand sheets from the area

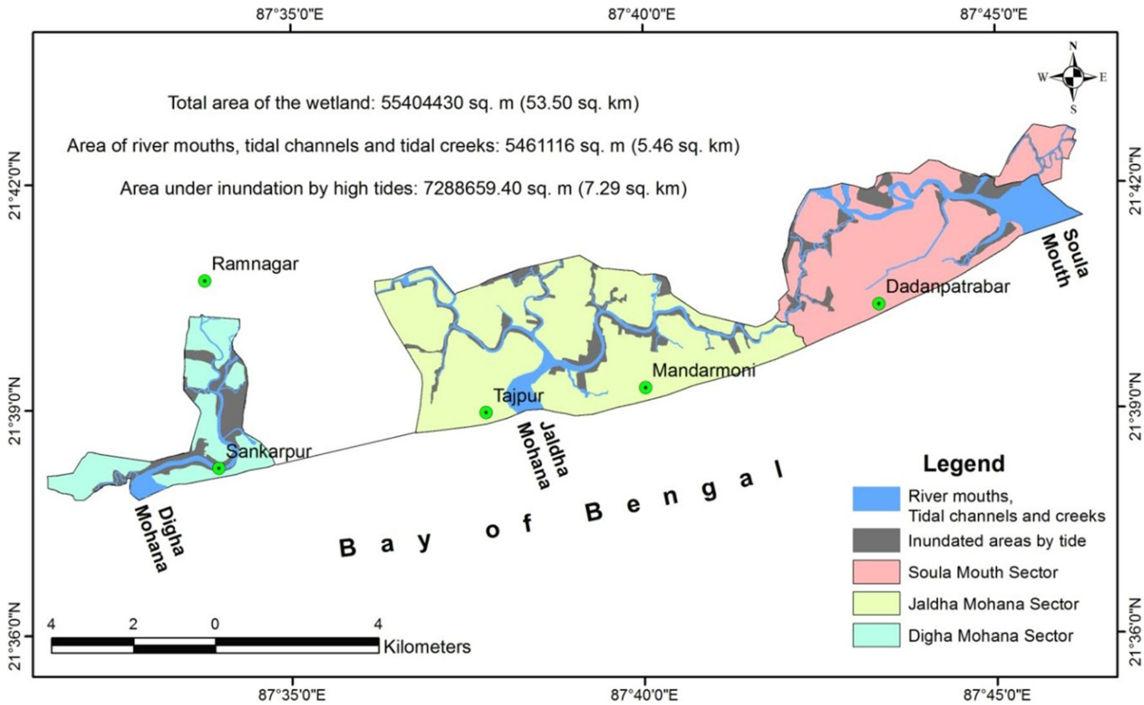

Fig. 7 Sector-wise categorization of tidal wetlands with their inundation areas during 2017

(Fig. 2). Some isolated ridges with above 10 m elevation are extended in a linear patternparallel to the modern shoreline behind Ramnagar-Deuli beach ridge sections belong to the **first category** of landform. These isolated ridges are the result of erosion and human modifications, but bear the older residues of an ancient shoreline. They were probably eroded by storm surge effects of the Northern Bay of Bengal. The vertical ridge section of this category represents the location of

Table 2 Estimation of tidal ranges from beach profile transects of the Pre-Monsoon phase (2013–2014)

Beach profile of Pre-Monsoon phase					
Sl. No.	Tidal phase	Horizontal distance (m)	Distance difference (m)	Tidal height (m)	Tidal range (m)
Profile - A					
1	Profile on full moon day (spring tide)	240–26.67	213.33	1.403–4.417	3.014
2	Profile on full moon day (neap tide)	179.98–40.78	139.20	0.293–2.413	2.12
3	Profile on new moon day (spring tide)	210.1–34.03	176.07	0.993–2.609	1.616
Profile - B					
1	Profile on full moon day (spring tide)	245.06–59	186.06	−1.469–1.78	3.249
2	Profile on full moon day (neap tide)	168.063–60.819	107.24	−0.169–1.57	1.739
3	Profile on new moon day (spring tide)	210.063–55	155.06	0.916–2.05	1.134
Profile - C					
1	Profile on full moon day (spring tide)	162.04–30	132.04	−1.765– −0.179	1.586
2	Profile on full moon day (neap tide)	56.607–30	26.61	0.399–0.200	0.599
3	Profile on new moon day (spring tide)	120.00–30	90	1.080–0.050	1.03
Profile - D					
1	Profile on full moon day (spring tide)	86.48–37	49.48	−2.194–0.052	2.246
Profile - E					
1	Profile on full moon day (spring tide)	260–74.270	185.73	−1.360–4.556	5.916
2	Profile on full moon day (neap tide)	85.700–55.500	32.20	0.544–2.462	1.918
3	Profile on new moon day (spring tide)	130.700–71.075	59.63	1.236–2.721	1.485

Table 3 Estimation of tidal ranges from beach profile transects of the Post-Monsoon phase (2013–2014)

Beach profile of Post-Monsoon phase					
Sl. No.	Tidal phase	Horizontal distance (m)	Distance difference (m)	Tidal height (m)	Tidal range (m)
Profile - A					
1	Profile line on neap tide	205–50	155	−0.778–1.660	2.438
2	Profile line on spring tide	250–46.67	203.33	−0.639–1.844	2.483
Profile - B					
1	Profile line on neap tide	245.06–70	175.06	−0.609–1.338	1.947
2	Profile line on spring tide	245–55	190	−1.453–2.055	3.508
Profile - C					
1	Profile line on neap tide	112–25	87	−0.705−0.545	1.250
2	Profile line on spring tide	140–25	115	−0.142–0.850	0.992
Profile - D					
1	Profile line on neap tide	70–30	40	−0.863−0.108	0.971
2	Profile line on spring tide	156.50–35	121.50	−2.278−0.035	2.313
Profile - E					
1	Profile Line on Neap Tide	230–45	185	−0.011–2.250	2.261
2	Profile Line on Spring Tide	295–50	245	−1.865–2.170	4.035

depositional residues, windblown sands over the ridge top surface. However, the underlying beach ridges are developed by wave deposition and storm wash deposition.

The similar category of the older beach ridge capped sand dunes is extended from Bhograi-Paniparul to the Contai-Dariapur section parallel to the present-day shoreline but slightly curved towards the northeast direction. The major portion of the older beach ridge section is located on the northern boundary of Ramnagar-I and Ramnagar-II Administrative Blocks. The elevation of the older beach ridge section is ranging from 10 m to 12 m and in many places, it is reduced because of anthropogenic activities and modification of the surface. The sands and beach sections are also like the Ramnagar-Deuli beach ridge section. This type of extensive beach ridge section is relatively older than the Ramnagar-Deuli beach ridge section. The beach ridges of Contai-Paniparul and Ramnagar-Deuli sections are oxidized by the sub-aerial exposure overdue to prolonged still stand conditions.

The **second category** of landform of the region is extended in the form of the sandy terrace and continuous sand ridge surface along the sides of first category landform which is ranging from 7 m to 10 m in elevation from the Mean Sea Level (MSL), and the surface was probably the remnant of ancient wash over sand fan lobes developed with landward encroachment of storm surge induced over wash deposits. Now, they are highly modified by human interventions and sub-aerial processes.

The **third category** of landform is visible along the margins of the second category of continuous sand ridge topography in the form of an extensive sandy tract with the reactivated sand surface. The reactivation of the surface was probably possible by storm surge induced wash over deposition and extension of lobes. They are ranging from 5 m to 7 m elevation at present.

The **fourth category** of the ancient surface with the elevation of 2.5 m to 5.0 m above MSL is also clearly visible from the wide valley flat surface depressions in between the Contai-Paniparul beach ridge section and Ramnagar-Deuli beach ridge section at present (Fig. 3). They are probably developed in the form of tidal basins or tidal lagoons in the ancient period, and modified gradually by tidal deposition as well as by the monsoon flood plain deposition with Subarnarekha distributary channels of the area in the past.

There are some low lying permanent wetland surface depressions behind the Mandarmani beach ridge section from the contour plan at present. They are probably the remnant of barrier back lagoonal depressions of the past. Later, they were partially filled up with sediments derived from estuarine flood plain deposition of Subarnarekha River and tidal deposition from the side of the Hugli River mouth embayment.

Now, their elevation ranges from 1.5 m to 2.5 m from the MSL and holds surface water pockets by rainwater sources (Plate 1). Physiographically, they belong to the narrow swale topography in between the Mandarmani beach ridge and the Ramnagar-Deuli beach ridge section. There are three bifurcated ridges in the form of narrow and low height ridges in the wide valley flat surface in between the Ramnagar-Deuli beach ridge section and Digha-Junput beach ridge section. These bifurcated ridges are aligned towards South-South East (S-

Table 4 Comparative study of the Pre and Post-Monsoon profiles (2013–2014)

Comparative study of pre and post-monsoon profiles					
Sl. No.	Tidal phase	Horizontal distance (m)	Distance difference (m)	Tidal height (m)	Tidal range (m)
Profile - A					
1	Profile line of pre-monsoon (spring tide)	240–26.67	213.33	−1.403–4.417	5.82
2	Profile line of post-monsoon (spring tide)	250–46.67	203.33	−0.707–1.844	2.55
Profile - B					
1	Profile line of pre-monsoon (spring tide)	245.06–40	205.06	−1.468–4.069	5.54
2	Profile line of post-monsoon (spring tide)	245–55	190	−1.453–2.055	3.51
Profile - C					
1	Profile line of pre-monsoon (spring tide)	162.04–30	132.04	−1.765– −0.179	1.59
2	Profile line of post-monsoon (spring tide)	138–24	114	−1.452–0.850	2.30
Profile - D					
1	Profile line of pre-monsoon (spring tide)	86.48–35	51.48	−2.194–0.052	2.25
2	Profile line of post-monsoon (spring tide)	156.50–35	121.50	−2.278–0.035	2.31
Profile - E					
1	Profile line of pre-monsoon (spring tide)	260–74.270	185.73	−1.360–4.556	5.91
2	Profile line of post-monsoon (spring tide)	295–50	245	−1.865–2.170	4.01

The tidal prisms are estimated in 1990 and 2017 to compare the voluminous tidewater inflow into the tidal wetlands. The tidal prisms are estimated as the total areas of river mouths, tidal channels and tidal creeks in m^2 and area under inundation by high tides in m^2, and the total area are again multiplied by the tidal range (m) of different phases (Table 5; Fig. 9)

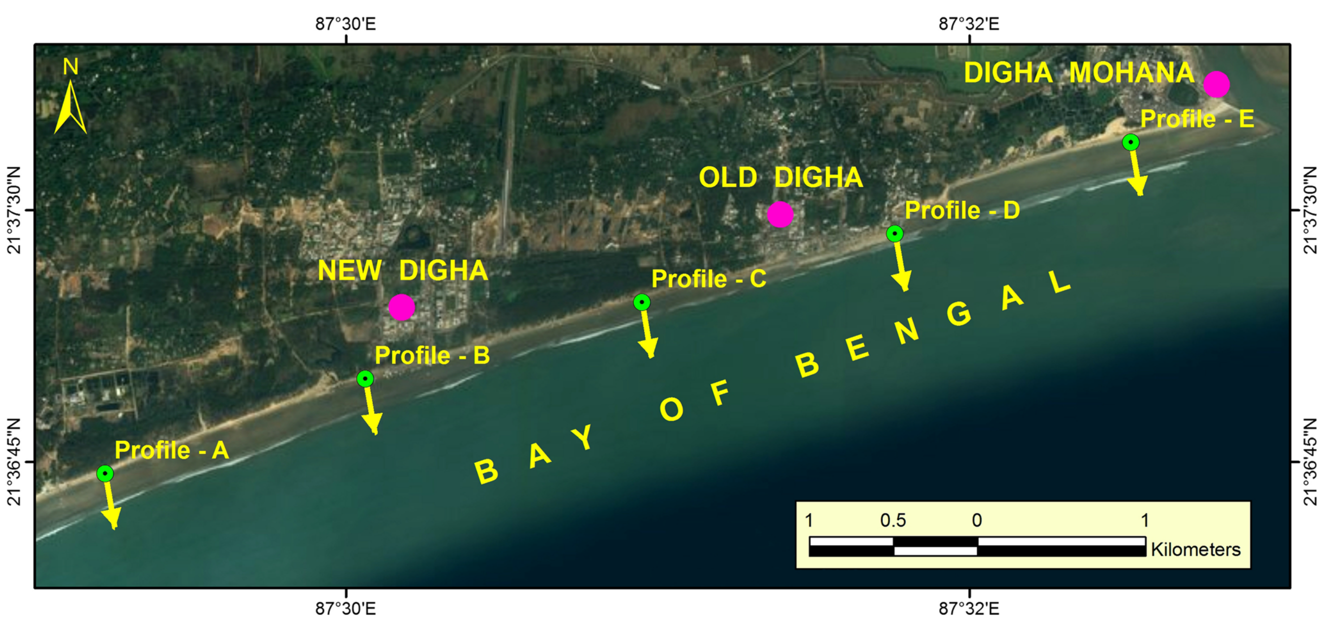

Fig. 8 Location of profile sections surveyed by GSI (2013–14)

Table 5 Sector-wise tidal prism estimation in 2017

Sectors	Area of river mouths, tidal channels and tidal creeks in m^2	Area under inundation by high tides in m^2	Tidal range and tidal phase	Tidal Prism in m^3
Soula Mouth (area = 1,98,99,000 m^2)	28,32,480 m^2	25,77,753.30 m^2	TR at 5.916 m (high spring)	32,006,940.18 m^3
			TR at 1.918 m (average spring)	10,376,827.46 m^3
			TR at 1.485 m (neap tide)	8,034,196.45 m^3
Jaldha Mohana (area = 2,73,84,200 m^2)	18,80,740 m^2	27,88,058.50 m^2	TR at 5.916 m (high spring)	27,620,611.93 m^3
			TR at 1.918 m (average spring)	8,954,755.52 m^3
			TR at 1.485 m (neap tide)	6,933,165.77 m^3
Digha Mohana (area = 8,12,1230 m^2)	7,86,896 m^2	20,42,539.60 m^2	TR at 5.916 m (high spring)	16,738,941.01 m^3
			TR at 1.918 m (average spring)	5,426,857.48 m^3
			TR at 1.485 m (neap tide)	4,201,711.86 m^3

SE) direction and played active roles in the form of small size barriers in the past (Fig. 4). They are ranging from 5 m to 7 m in altitude from the MSL. The three barriers are separated by linear depressions running parallel to the present ridgelines and represent linear tidal basins of that time. To the east, the wider flats of tidal basins are characterized by the location of younger natural levees and older natural levees and some depressed wetlands.

The present study attempt and also incorporated twelve (12) consecutive classes like abandoned channels, degraded channels, active tidal channels, younger natural levees, older natural levees, sand dunes, marine terraces, interdune flat, estuarine flood plain, swales, beach ridge and ancient tidal basin according to their topographic characteristics (Fig. 5).

The southernmost beach ridges of Digha-Junput sections parallel to the present-day shoreline represent higher beach ridges of 12 m to 18 m altitude at present. They are currently segmented and highly eroded on their sea faces by transgressive seas. The present-day beach ridges are affected by windblown activities and modifications by wind processes in the form of degraded sand dunes. At present, the Jaldha River mouth, Pichaboni River mouth, Digha Mohana and Jatra Nullah are filled up with an excessive load of sand-size sediments and overwash sand fan lobes. The study reveals the above mentioned features which show the sea-level rise in the present scenario.

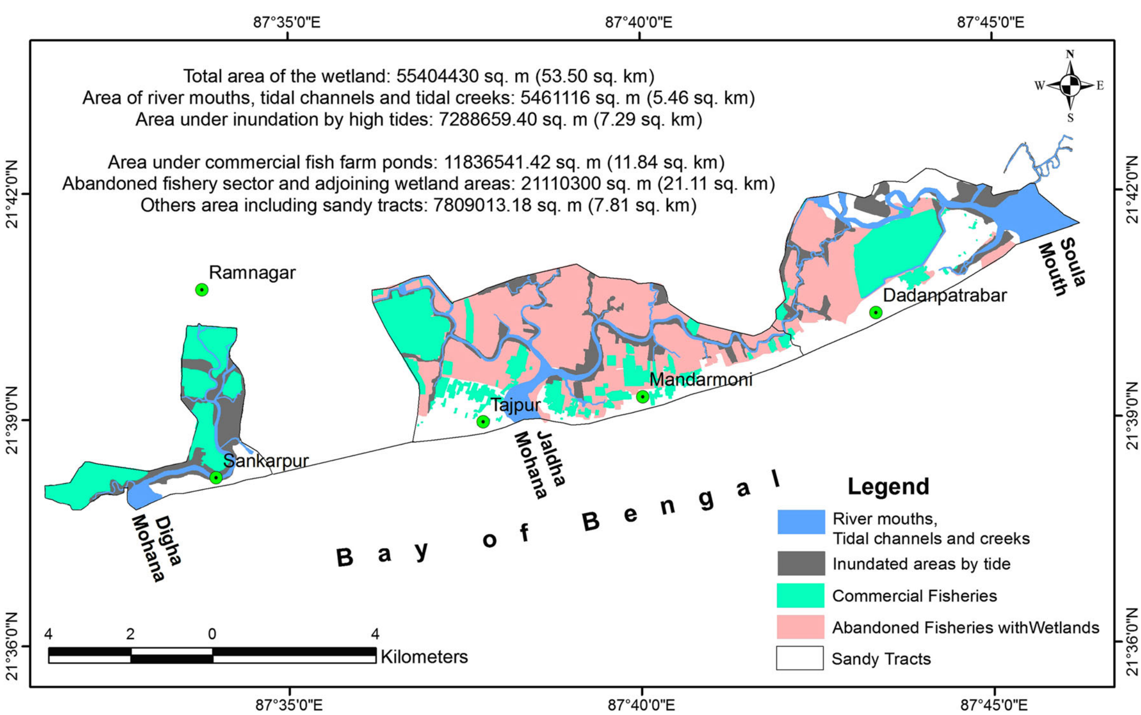

Fig. 9 The tidal wetlands occupied by commercial fish farms, abandoned tidal flat, tidal drainage channels and beach ridges, or sand dunes

Plate 3 The low tide and high tide conditions of the sandy shore platform at Soula river mouth

Today's sand dunes have retreated landward by cliffing and scarping process with changing hydrodynamic regimes and rising tide levels at or near the tidal river mouths (Fig. 6). The Digha township area is developed over the sand dune surface with marine terraces having the height ranging from 9.5 m to 12 m. The significant dune barrier in front of the erosive shoreline section is delluviated by marine erosion and the advance of the sea to the inland portions. The river systems of such types are affected by depositions of tidal souls and bars during the period of tidal ingression. Among them, the Champa river, Jaldha estuary, Digha estuary and the Pichaboni river system are draining across the coastal plain with the saltwater flow.

The sea level was stranded for a long time in between the Contai-Paniparul beach ridge section and the Ramnagar-Deuli beach ridge section (Plate 2). The isostatic upliftment may take place on the valley flat surface during the westward shifting of Subarnarekha estuary in the coastal plain, and for which the deposition of sand lobes over the valley flats has been increased in the past (Table 1).All the ancient beach ridges of the coastal plain are overlain by developed sand dune barriers with onshore wind movement over the geological period in the place. The inner parts of the beach ridges areheavily truncated by wave erosion and concentrated currents in the past. The modern coastal plain of valley flats between ancient beach ridges is also covered by sand sheets in the past.

Tidal prism in the coastal wetlands

Tidal prism is the volume of the tidewater enter into the tidal spill grounds through the tidal inlet channels from the sea face and returns the same volume tidewater at the ebbing stage of the tides through the same tidal inlets. Tidal prisms are the result of spring time tidal waves, keeping pressure on the seaward sides and spill over the backshore area by entering into the tidal channels at the time of high tide in the coastal belt. A large volume of saltwater flux with sediments are always transferred into the low lying wetlands

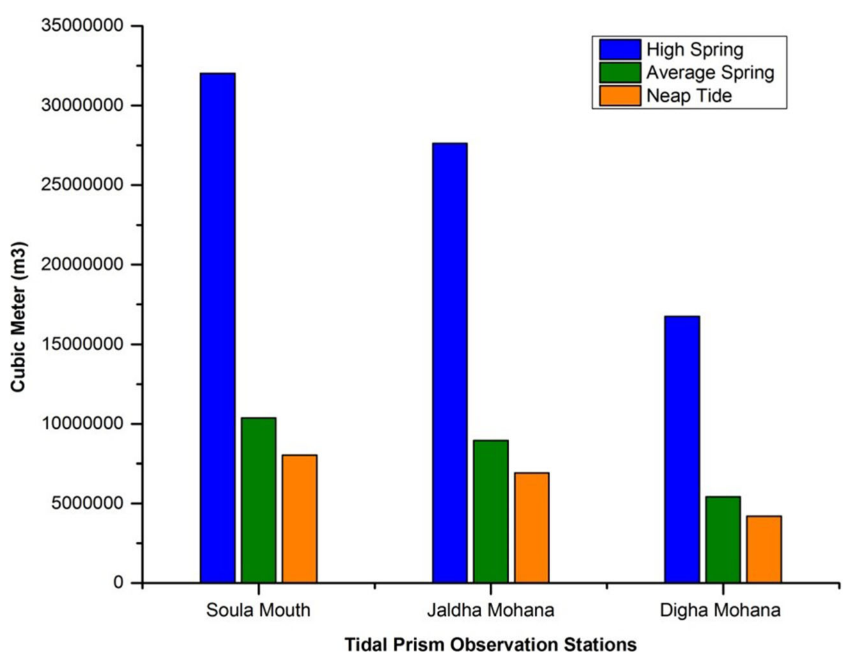

Fig. 10 Volume of tidal prism estimation (m^3) in different sectors

Table 6 Temporal changes of tidal prism in the coastal wetlands of Digha-Junput sectors

Tidal range and tidal phase	Tidal prism (2017)	Tidal prism (1990)
TR at 5.916 m (high spring)	75,4,27,671.21 m^3	61,8,41,747.055 m^3
TR at 1.918 m (average spring)	24,4,54,069.19 m^3	20,0,49,437.263 m^3
TR at 1.485 m (neap tide)	18,9,33,416.38 m^3	15,5,23,156.588 m^3

by the tidal prism for the maintaining of life support systems of the vegetated tidal flat behind the sand dunes or barrier bars along the coastal plain. A volume of fine sands and suspended silts are usually deposited in the backshore sheltered wetlands by this system of tidal prism movements, and some amount of sediment load also transported out from the wetland environment to the open marine environment through inlet channels. The result of such frequent tidal prism water movement controls the hydrodynamics and sedimentary geomorphological features in the coastal wetlands. The backshore tidal wetlands behind the coastal sand dunes and barrier bars are always getting modified by the transfer of sediments, saltwater flow and nutrient loads during the period of tidal prisms.

Method of the estimation of tidal prisms

The entire tidal wetland of the coastal belt under Ramnagar-I and Ramnagar-II Administrative Blocks are categorized into three different sectors fed by Digha Mohana, Jaldha Mohana and Pichaboni Mohana (Fig. 7).

Tidal prisms are therefore estimated in three different wetlands to compare the volume of tidal prism among three different sectors. However, each sector of the tidal prism is again classified into three stages of the tides (e.g., high spring tidal phase, average spring tidal phase and neap tidal phase) for estimation of prisms at different levels of tides per annum (Tables 2, 3, 4). The levels of tides under the high spring phase, average spring phase

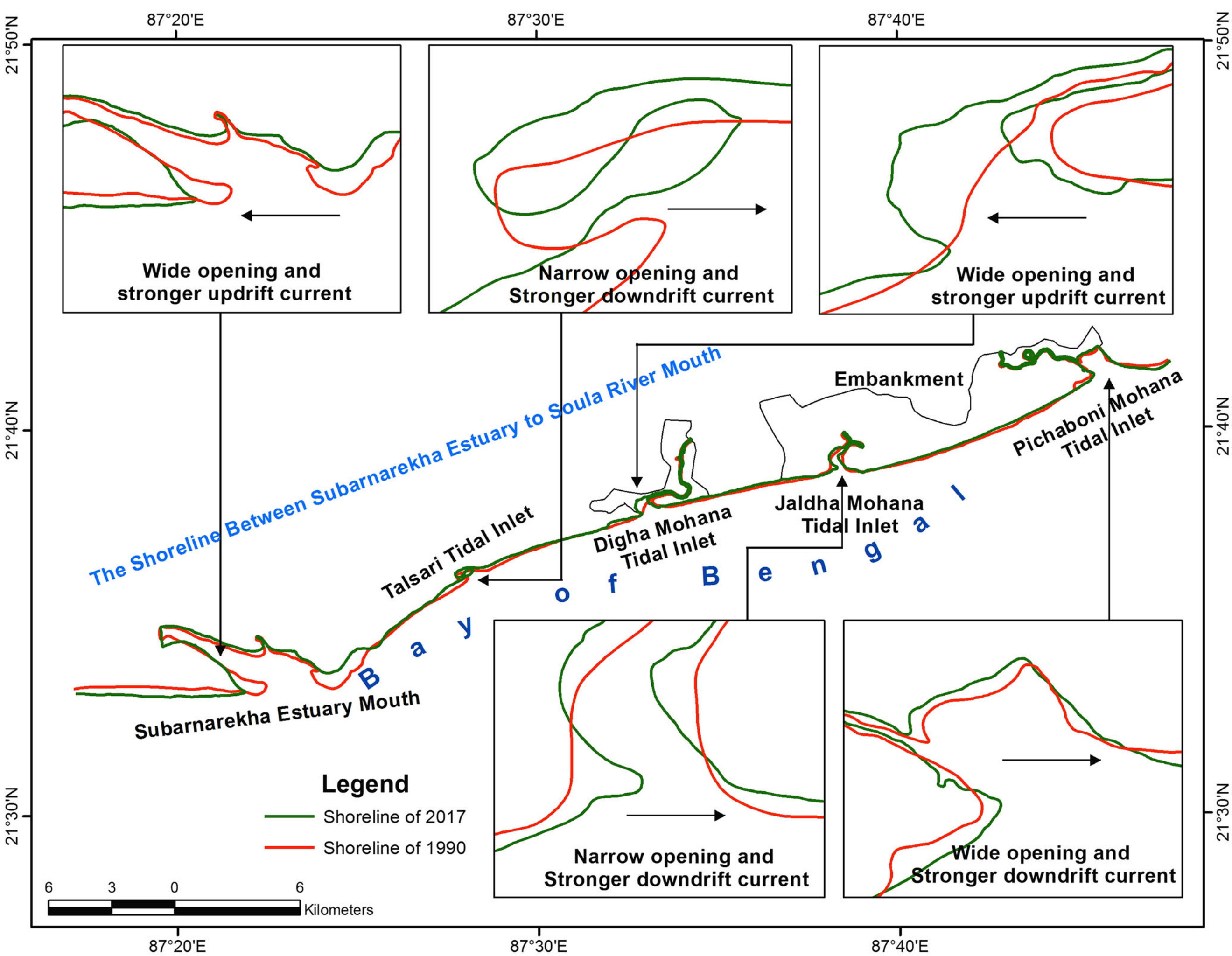

Fig. 11 Dynamic inlet mouths modified by down drift currents and up drift currents along the shoreline

Plate 4 Increased rate of beach cliffing and cliff recession along the shoreline of Jaldha mouth and Sankarpur due to the pressure of high tidal prisms

and neap tide phase are estimated from temporal beach profile sections of such lunar phases, surveyed by GSI in this part of the shoreline sections during 2013 and 2014 (Pattanayak et al. 2014). The levels of tides differ from one phase to another phase and also from one section to another section based on lunar phase differences and shoreline configuration changes. As the level of tide differs from place to place, and phase to phase, the estimated tidal prism also varied (Fig. 8).

The tidal prisms are estimated from 1990 to 2017 and compared with the voluminous tidewater inflow into the tidal wetlands. The tidal prisms are estimated as the total areas of river mouths, tidal channels and tidal creeks in m^2 and area under inundation by high tides in m^2, and the total area is again multiplied by the tidal range (m) of different phases (Table 5; Fig. 9).

Result of the estimated tidal prisms

The tidal prisms estimated from the images of 1990 and some available secondary data, as well as the prisms recorded in 2017, are compared to get the changes of tidal volumes and areas affected by tidal inundations by this study. Tidal prisms significantly increase in 2017 in comparison to the year 1990 in the coastal belt of the study area (Plate 3; Fig. 10). The result of such estimations shows that it is increased up to 13,5,85,924.15 m^3 in the high spring phase, and 4,40,4631.93 m^3 in the average spring phase, and finally up to 3,4,10,259.79 m^3 in the neap tide phase in this area (Table 6).

Such an enormous increase in tidal volumes and their advancing seawater movement have created many geomorphological diversity in the coastal belt. The present-day shoreline erosion and widening of tidal inlet mouths are directly caused by such increased tidal prisms in the coastal tract. A large volume of sand-size sediment and suspended silts are also distributed into the coastal wetlands as tidal flood deltaic landforms, and also the formation of ebb deltaic bars which result as ebb deltaic deposition at present in the mouth of tidal inlets.

The landward recession of coastal sand dune is increased significantly at the time of the high and average spring phases for developing pressure of tidal prisms on the shoreface of the coastal stretch.

The downdrift current during southwest Monsoon months along with the shoreline transport a greater amount of sediment and partially deposit them into the narrow channel and the majority of sediments is bypassing the channel mouth and entering into a separate sector of the shoreline. As the sediments deposited by the downdrift currents are modifying the inlets by a high rate of deposition, the inlet mouth becomes narrower by advancing sand spit (Fig. 11; Plate 4).

However, the up drift current coming from N-NE wind systems along the shore parallel direction with moderate energy transport and discharge the limited amount of sediments to fill the narrow inlet mouths. Therefore, the inlet mouths become wider by a limited amount of deposition. During high tides, the subaqueous sand bars of the inlet mouths are dragged into the backwaters by tidal flood currents through the inlet mouths which transport the sand size sediment into the wetland areas of the backshore region and mouth become wider. During low tides, the ebb currents transport a limited amount of sediments from the backshore area into the inlet mouth to rebuild the ebb delta at the mouth.

Conclusion

The present study area is an active, energetic zone because there are so many geomorphic agents that interplay their active role to change the pattern and nature of the coast. The study reveals that there are seven stages of coastal chenier formations, among them the longshore current energy is calculated and estimated as highest for the Contai-Paniparul beach ridge chenier, Ramnagar-Deuli beach ridge chenier and Digha-Junput beach ridge chenier after considering the volume of sediment estimation under modern sea face energy levels. However, the shorter beach ridge cheniers are produced under the weaker longshore current energy in East-East North (E-

EN) direction, parallel to the present-day shoreline. The wide, shallow flats in between landward and seaward beach ridge cheniers were formed by the finer sediments (swale topography) deposited under lagoonal setting behind the barrier bar systems, and supply of finer sediments by Hugli River discharges into the Late Holocene tidal basin. The modern shoreline beach ridge cheniers are segmented by older distributary channels and acted as tidal inlet mouths along the shoreface and modified by present-day coastal processes. Tidal prisms significantly increase from 1990 to 2017in the study area. As a result shoreline erosion, inlet shifting, distribution of sand-size sediment and suspended silts to the wetlands, and landward recession of coastal sand dune are directly caused by the increasing rate of tidal prisms in the coastal track at present.

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