Chapter – II

Chronological Development of Coastal Landscapes

2.1 Relevance

The physiography of alluvium coast plays a very significant role in coastal morphodynamics in response to outer environmental impacts with significant change in boundary conditions of the local area. The present chapter on 'Chronological Development of Coastal Landscapes' deals with the landform units in different orders of formations, their surface morphometry, drainage features, hydro-geomorphology and changing tidal prisms to explain the nature of shoreline dynamics of the coastal plain topography. The chronology of the coastal evolution is explained in this part of the thesis with the application of available dating records of different landform units in the existing literatures, estimation of present day wave hydro-dynamics and energy level along with the sediment budget estimation of the near shores to predict and establish the evolution of chenier coastal plain.

The landform units are classified and a detail contour plan prepared on the basis of Remote Sensing technology and high resolution interpolated DEM of the study area. The drainage features, coastal morphometric attributes (1 km by 1 km grid cells are used for identification of relief elements on the basis of DEM) and estimations of tidal prisms for the tidal inlet channels and tidal basins are delineated, image analysis and estimated from temporal Sentinel images as well as from shore profile transects under high tide and low tide exposures (Pattanayak et al., 2014) for hydro-geomorphic analysis of the coastal plain topography.

There are several calibrated dates of different landforms estimated by radiocarbon dating method and Optically Stimulated Luminescence (OSL) dating method by the GSI and by several individuals (Maiti, 2013; Pattanayak et al., 2014; Niyogi, 1970). The dating records are fully utilized for assessing the expected dates of other sub units of the landforms by comparative methods for the coastal plain topography.

The estimation of wave energy from the modern shoreline and the estimation of volume of sand size sediments from the existing beach ridges and the sand dunes helped to assess the past energy dynamics of the waves and transportation capacities of sediments for the evolution of landforms in the inner parts of the coastal plain topography.

2.2 Recent Plan Shape of Coastal Chenier Plain Topography (Ramnagar-I & II Blocks)

The coastal parts of Ramnagar-I and Ramnagar-II Administrative Blocks (Kanthi coastal plain) reveal diverse morphological features of three major categories of Paleo beach ridge with three different alignments parallel to the existence of past shorelines (Fig. 2.1).

From the contour map of 50 cm interval generated of the coastal belt such features can be clearly delineated though the alluvial coastal plain is highly modified by land use conversion during previous decades (1930s to 1990s, 2000k and 2010) through different human activities.

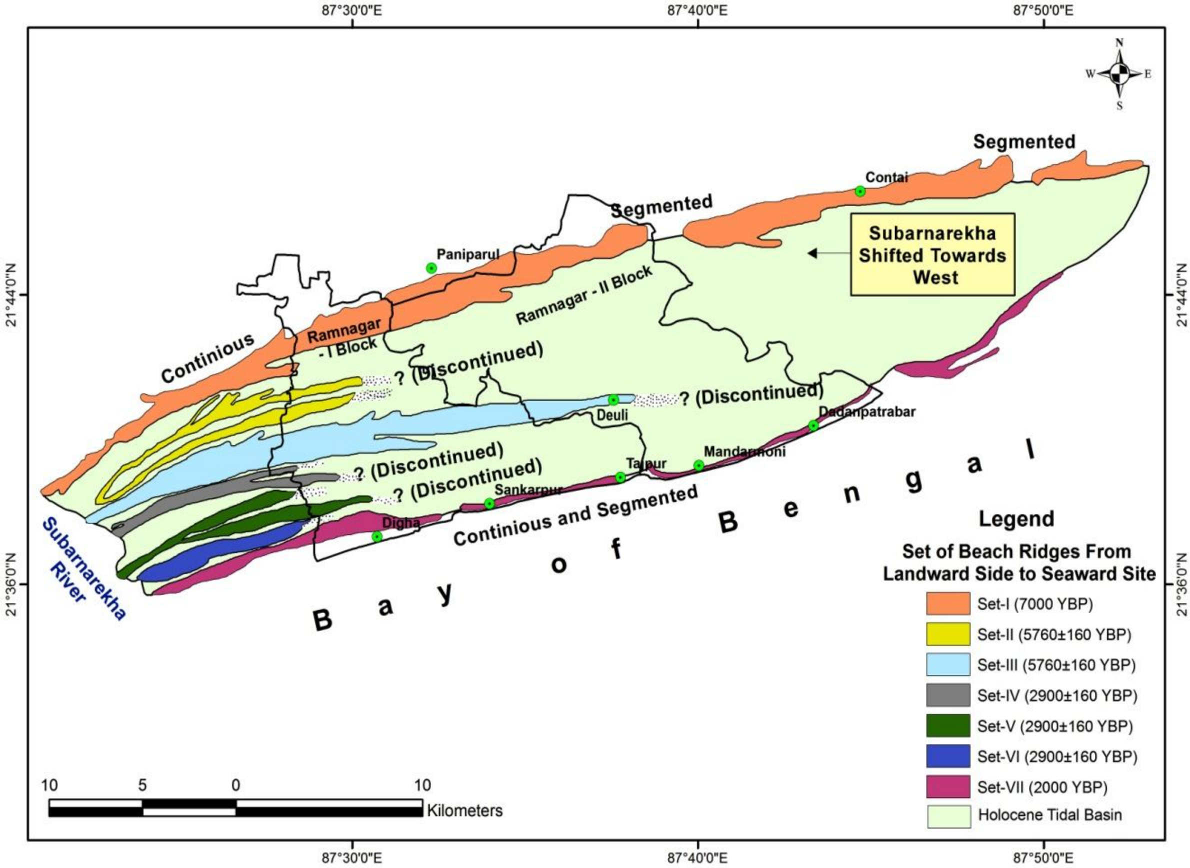

Fig. 2.1: Plan shape of beach ridge cheniers of Kanthi and Digha coast (eastern bank of Subarnarekha estuary).

The set of older beach ridges is separated by wide spaced valley flats and aligned from West-West South (W-WS) to East-East North (E-EN) with well preserved morphological features in the alluvial coastal plain. These Paleo beach ridges are relatively higher (7.1 m to 18 m), significantly wider separated into ridges and narrow swales, and geologically acted as the barrier against the open marine environment during the location of Paleo shorelines, and partially segmented by tidal rivers (e.g., Champa River, Pichaboni River, Jatra Nullah, Digha Estuary and Jaldha Estuary) in the part of Kanthi coastal plain. The present set older beach ridges are extensively used by location of settlements and also by coverage of coastal vegetations. The beach ridge sands are oxidized and over which the modern sand dunes are located by windblown sands from the sea sides in the near past.

A bifurcated set of three smaller beach ridges from the second major shore parallel beach ridge is aligned in East-South East (E-SE) direction towards Tajpur shoreline, Sankarpur shoreline and Digha shoreline. From Jaldha Estuary to Soula or Pichaboni River mouth towards further east of Tajpur no other beach ridges are present except some local surface depressions and fragmented natural levees (towards North West (NW) and W-WS) extended on the landward side (Fig. 2.2). Another set of two smaller beach ridges is also visible on the shore parallel location from Dadanpatrabar to Soula River mouth.

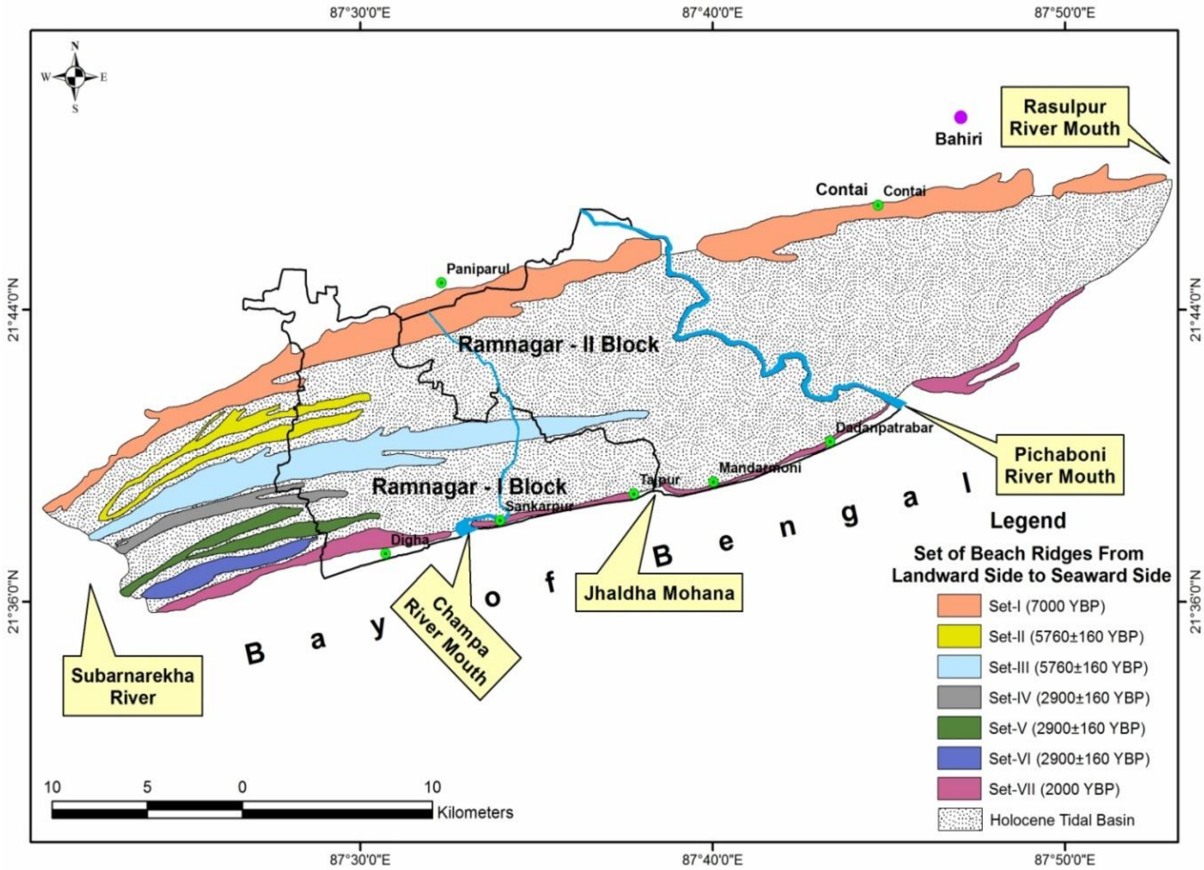

Fig. 2.2: Beach ridge cheniers of Kanthi and Digha coastal plain.

The major shore parallel beach ridges and sand dunes of the current shoreline following Digha, Sankarpur, Tajpur, Mandarmani and Dadanpatrabar are segmented and eroded with rare presence of smaller residues of sand ridges at present. Erosion on the shore face has damaged the primary surface features of modern Bay of Bengal fringed beach ridge backed sand dunes.

2.3 The Contour Plan of Study Area and Topographic Characters

2.3.1 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 categorizes of surface formations under different processes (Fig. 2.3). Some isolated ridges with above 10 m elevation are extended in a linear pattern with parallel to the modern shoreline behind Ramnagar-Deuli beach ridge sections belong to **first category** of landform.

These isolated ridges are the result of erosion and human modifications but bear the older residues of 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 depositional residues windblown sands over the ridge top surface. However, the under lying beach ridges are developed by wave deposition and storm wash deposition.

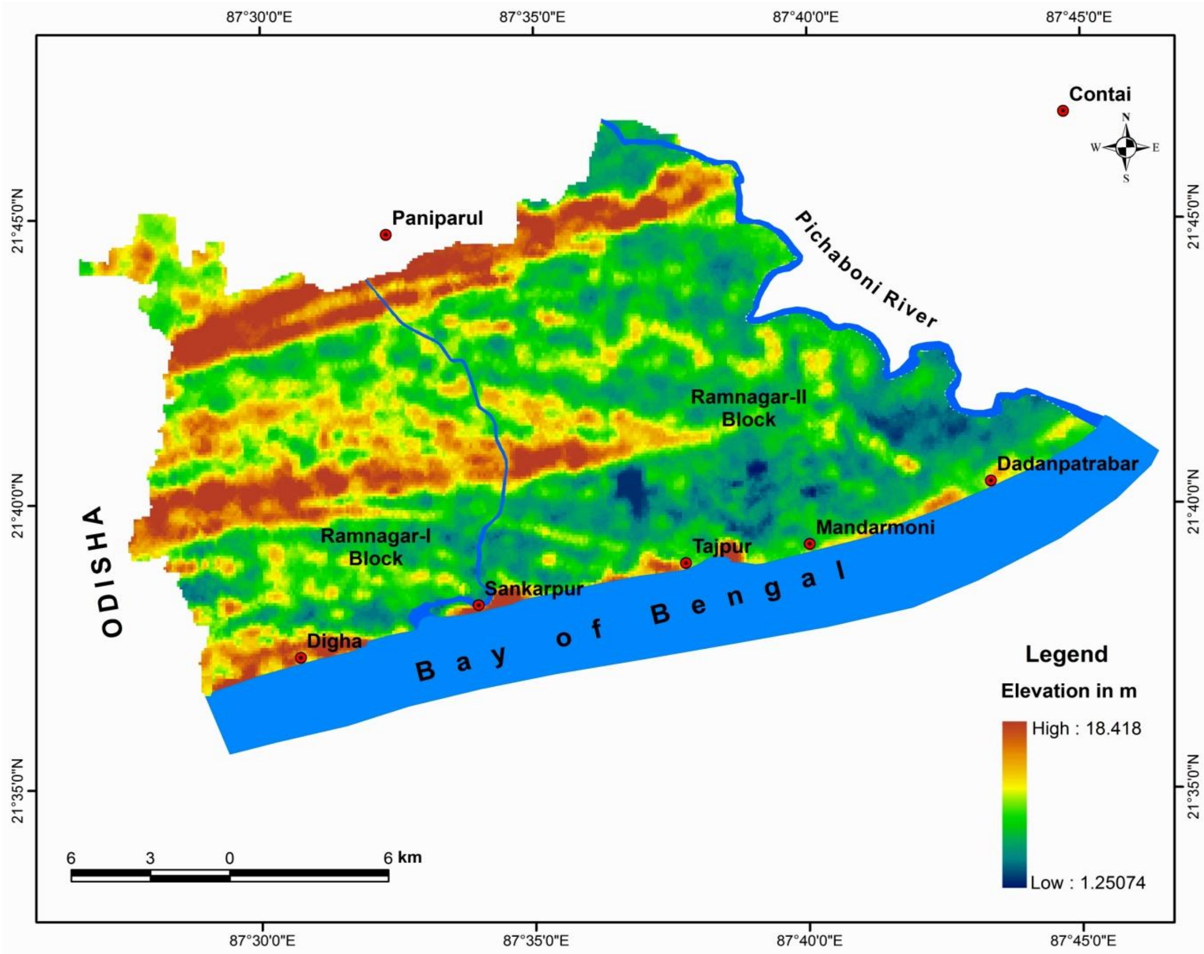

Fig. 2.3: High resolution Digital Elevation Model (DEM).

The similar category of older beach ridge capped sand dunes is extended from Bhograi-Paniparul to Contai-Dariapur section parallel to the present day shoreline but slightly curved towards north east 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 human activities and modification of the surface. The sands and beach section is also like Ramnagar-Deuli beach ridge section. This type of extensive beach ridge section is relatively older than Ramnagar-Deuli beach ridge section. The beach ridges of Contai-Paniparul and Ramnagar-Deuli sections are oxidized by the sub aerial exposure over due to prolonged still stand conditions.

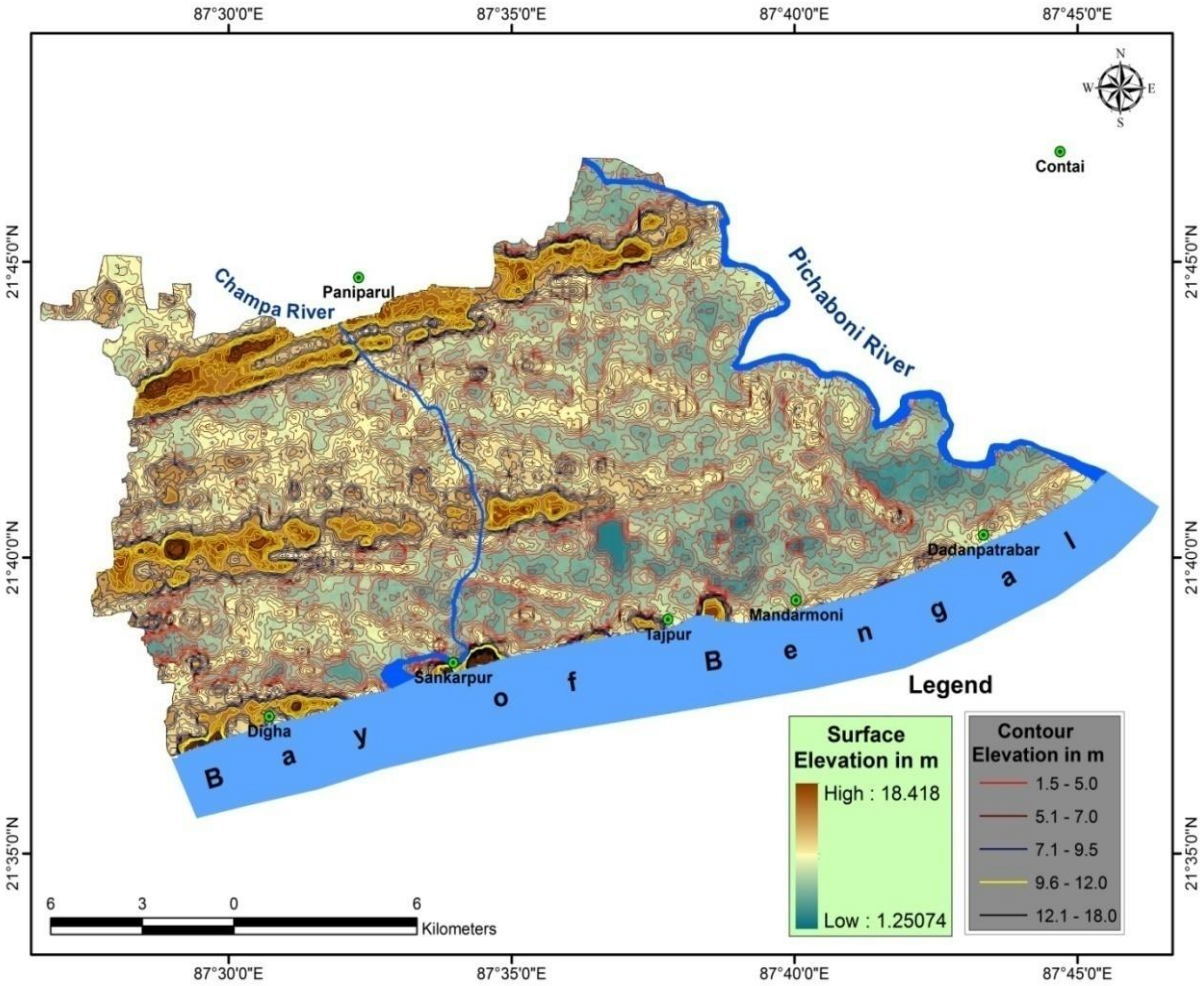

Fig. 2.4: The contour plan of coastal plain topography from high resolution interpolated DEM (50 cm interval).

The **second category** of landform of the region is extended in the form of 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 systems and sub aerial processes.

The **third category** of landform is visible along the margins of second category of continuous sand ridge topography in the form of extensive sandy tract with 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 **another category** of ancient surface with elevation of 2.5 m to 5.0 m above MSL is also clearly visible from the wide valley flat surface depressions in between Contai-Paniparul beach ridge section and Ramnagar-Deuli beach ridge section at present. 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 monsoon flood plain deposition with Subarnarekha distributary channels of the area in the past.

There are number of crenulated ridges of sandy sediments from the present contour plan particularly along the banks of abandoned channels. These are probably developed in the ancient period by natural levee depositions with various fluvio-tidal channels of the coastal plain. They are also categorizing into older levees and younger levees from the tonal contrasts and field verifications of soil materials. The older natural levees represent oxidized soils and the younger one represents grey whites color of soil materials at present. As the rivers are abandoned and reflected their ancient dynamic shifting behaviors in that area, they existed in multiple sets of levee topography (5 m to 7 m in elevation) at present over the valley flat surface (Fig. 2.4).

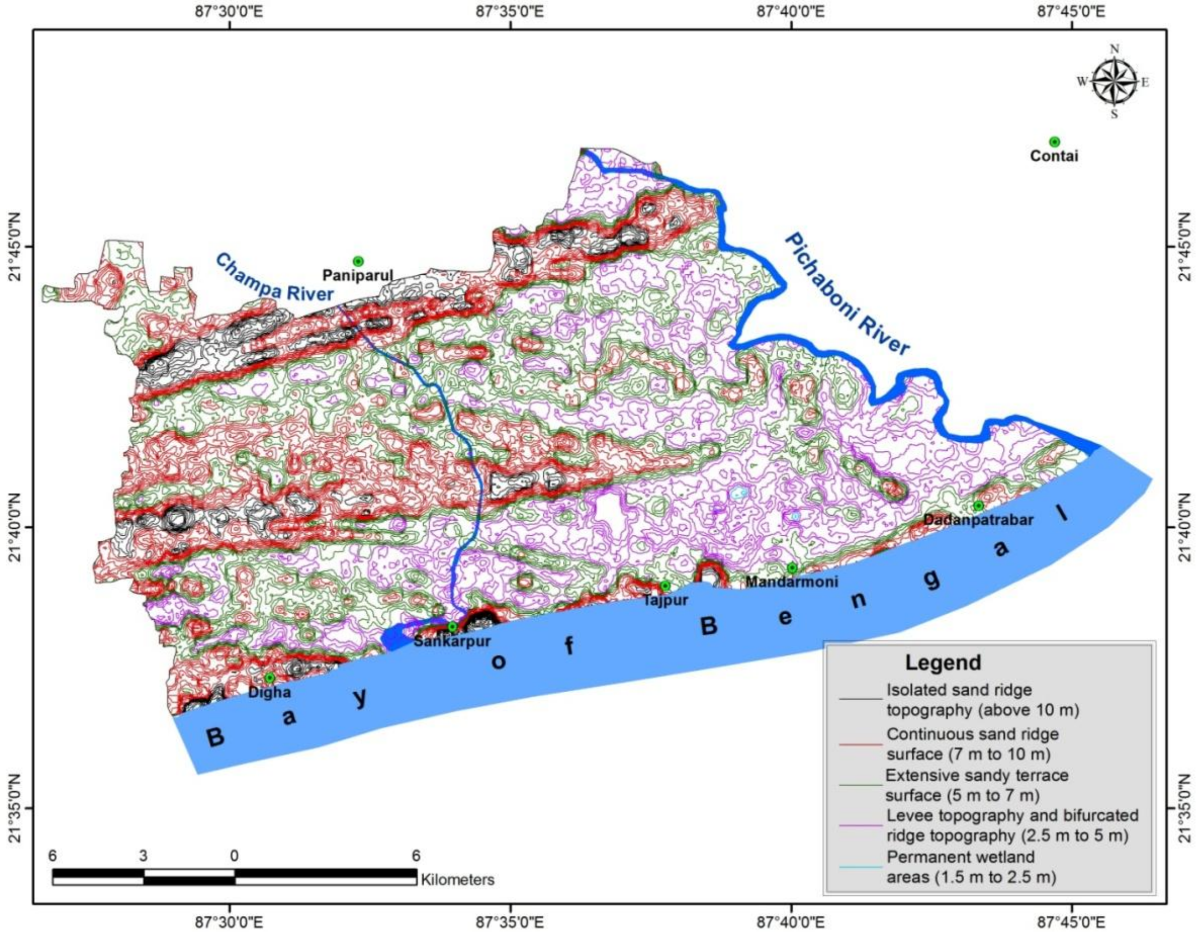

Fig. 2.5: Various relief units of the coastal plain on the basis of elevations from the MSL.

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 Hugli River mouth embayment. Now, their elevation is ranging from 1.5 m to 2.5 m from the MSL and holds surface water pockets by rain water sources. Physiographically, they belong to the narrow swale topography in between Mandarmani beach ridge and 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 Ramnagar-Deuli beach ridge section and Digha-Junput beach ridge section. These bifurcated ridges are aligned towards South-South East (S-SE) direction and played active roles in the form of small size barriers in the past (Fig. 2.5).

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 ridge lines and represent as linear tidal basins of that time. To the east, the wider flats of tidal basins are characterized by location of younger natural levees and older natural levees and some depressed wetlands. During the period of such development the minor fluctuations of sea level took place and west ward shifting of Subarnarekha estuary also took place. The ancient tidal basins between two beach ridge sections were extended in the past. 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 excessive load of sand size sediments and over wash sand fan lobes. Such features are the impact of modern sea level rise in the present scenario.

2.4 Understanding of Coastal Dynamics

2.4.1 Coastal Setup

The coastal plain region is characterized by typical barrier bar morphology with habitats of beaches, sand dunes, salt marshes and tidal inlet channel under meso-tidal settings (Tidal Range (TR) 2 to 4 m; Wave height 90 cm to 120 cm).

2.4.2 Coastal Wetland Morphology

Coastal wetlands are made up of tidal flats, tidal creeks, tidal river mouths and abandoned channels of the coast. Older river mouths and major tidal channels have been affected by shaping and reshaping of geomorphology of the region under the influences of (1) sea level variation in the past, (2) seasonal inundations with extensive tidal spill grounds (usually from June to November), (3) Subarnarekha flood plain deposition and (4) Hugli-Rasulpur estuarine flood plain deposition.

2.4.3 Beach Characters

Beaches are characterized by flat and gentle beach plain with dissipative energy of waves and high tidal range dominated by finer sands. No existence of beach berm surface at the upper part of beach plain.

2.4.4 General Character of Sand Dunes

Coastal shore fringed topography is characterized by wider dune fields (over 1,200 m) with altitude ranging from 10 m to 17 m in the year of 1972. Presently dunes are narrowed (less than 60 m) at the shoreline and reduced into the elevation ranging from 6 m to 12 m (Paul, 2002). Indigenous vegetations of the dune field are removed from many places of the coast. Sea front of the dune is scarped.

2.4.5 Near Shore Dynamics

Presence of rip currents, under toe, long shore currents and tidal currents, wide surf zone with incidental waves and wave run-up zone are major characters of the near shore region of the shallow sea.

The modern shoreline of the coastal plain is fringed by high elevated sand dunes up to 17 m in height, but presently, they are isolated and segmented into twelve (12) dune ridge topography along the shore face by extensive erosion for the landward advancing sea and human activities. These sand dunes of wide extensive sandy tract were acting as a major physical barrier against the sea water encroachment at the time of tidal floods and storm surges. 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. 2.6). 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 erosive shoreline section is delluviated by marine erosion and advancement of the sea to the inland portions.

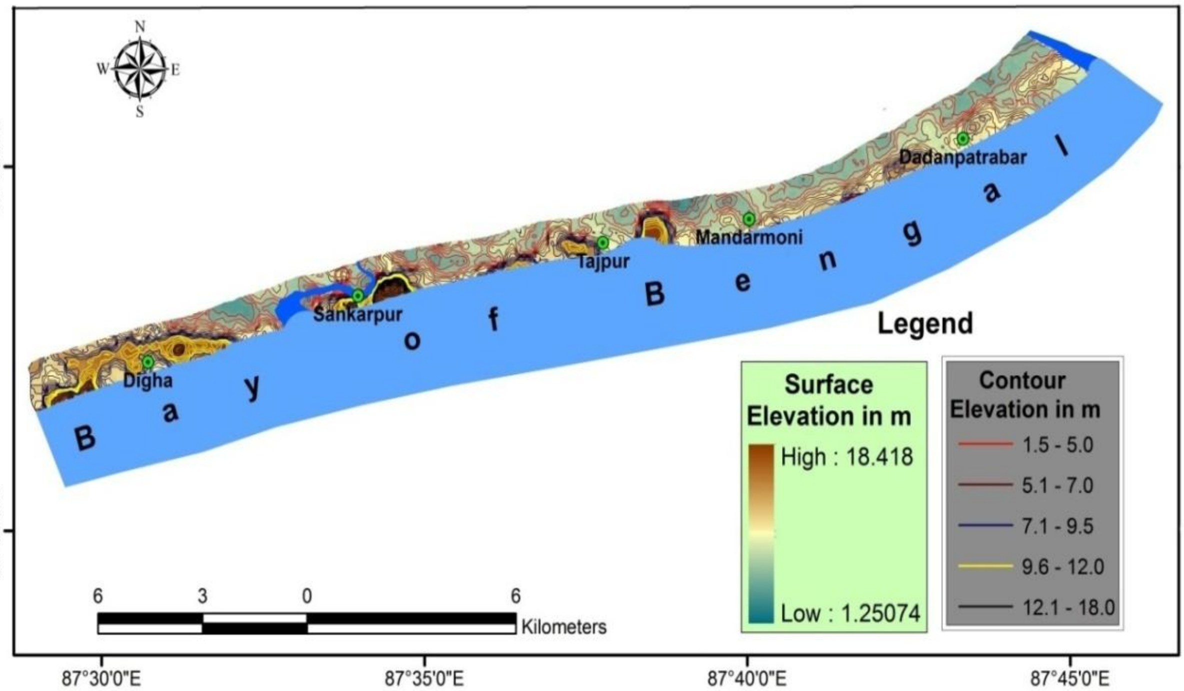

Fig. 2.6: Erosive dune face of the beach fringed shoreline of the study area.

Table 2.1: 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	7,000 years BP	Early Holocene	Windblown deposits and erosion by tidal waves	Sea level steel stand
Second Category of Landscapes	7 m to 10 m	Shore parallel sand ridge topography	Oxidized sands	Brownish to yellowish	5,760±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	2,900±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	2,000 ±100 years BP	Recent to Sub Recent	Wave induced currents and fluvial currents	Regressive seas

The sea level was stranded for a long time in between Contai-Paniparul beach ridge section and Ramnagar-Deuli beach ridge section (Plate 2.1). The isostatic up-liftment may took place on the valley flat surface during the west ward shifting of Subarnarekha estuary in the coastal plain, and for which the deposition of sand lobes over the valley flats have been increased in the past (Table 2.1).

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 part of the beach ridges are heavily truncated by wave erosion and concentrated currents in the past. The modern coastal plain of valley flats between ancient beach ridges are also covered by sand sheets in the past.

2.5 Drainage Features

The drainage features recorded from the study area represent three different categories of channel systems named as (1) active channels (2) degraded channels and (3) abandoned channels in the coastal plain. The active channels of today are influenced by encroaching high tides and out fall of tide water in the low tides. The river systems of such types are affected by depositions of tidal souls and bars during the period of tidal ingression. Among them, Champa river, Jaldha estuary, Digha estuary and Pichaboni river system are draining across the coastal plain with salt water flow. These river systems were probably the present form of abandoned distributary channels of river Subarnarekha delta (Fig. 2.7).

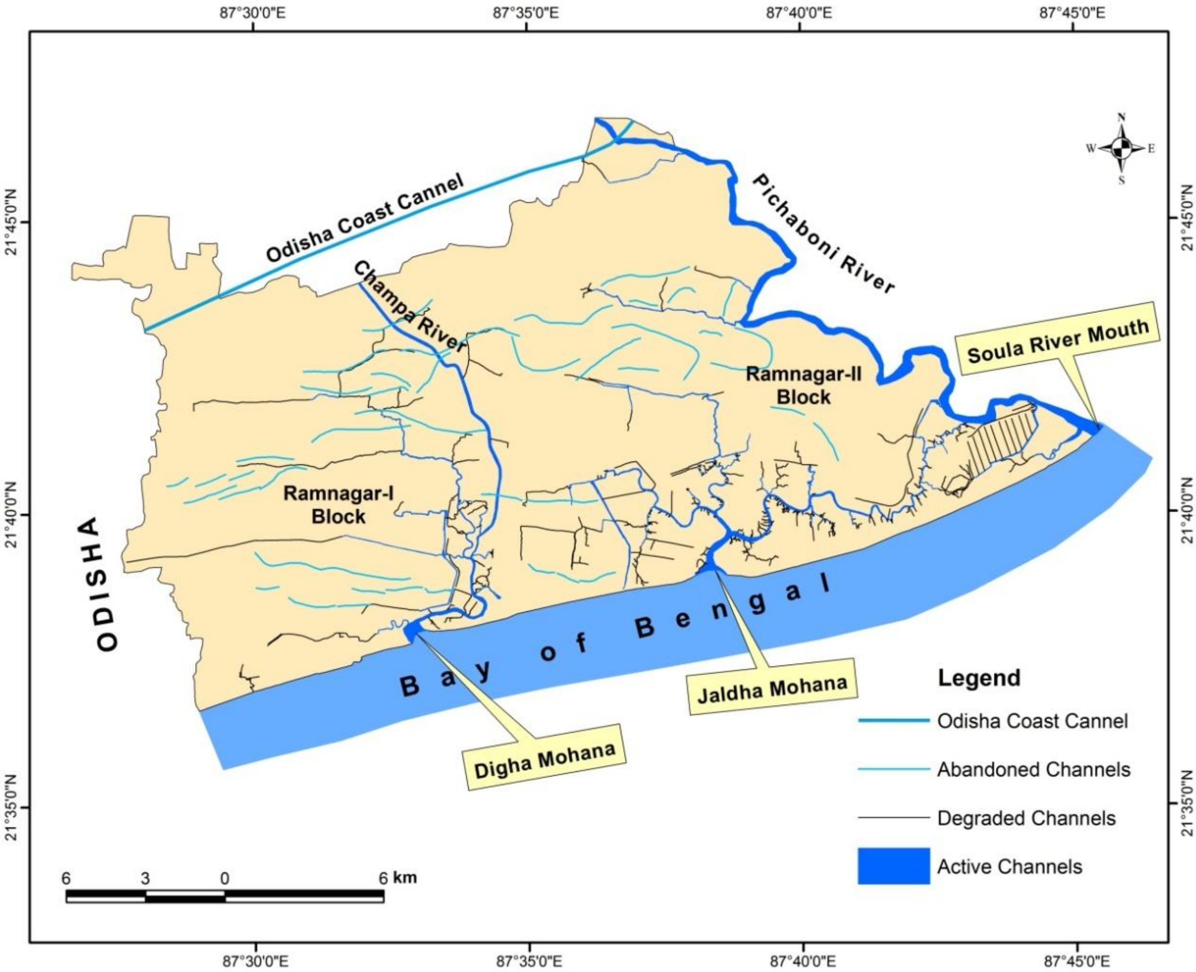

Fig. 2.7: Drainage network of the study area.

Plate 2.1: Sectional exposure of older sand dunes at Depal and exposure of mud banks on the shoreline of Sankarpur due to removal of sand sheets from the area.

Extensive tidal wetlands have been developed around the margins of such river systems. The degraded river systems are connected with the active channels and they are mostly affected by tidal sediment filled channels with moistured soil surface and salt marsh patches. These rivers are not used by the local people but they provide wide areas of low land topography with frequent location of tide pools that supported the colony of mangrove forest development in the region. The another category of drainage channels are known as abandoned tidal channels in the form of discontinuous channel beds with existing natural levees on their banks. They were active in the past by Subarnarekha flood flows and incoming tidal flows. These channels are also the old channels of active distributary systems of Subarnarekha River in the past.

2.6 Validation of Evolution in Studied Coast through Existing Records / Existing Dated Record

The earlier researchers (Bhandari and Das, 1998; Paul, 2002; Maiti, 2013; Pattanayak et al., 2014) were involved in the study of coastal processes and sediment movement patterns along the shoreline by estimation the long shore currents and sediment loss estimation (Table 2.2; Fig. 2.8). Following their results of estimation, the long shore current energy for ancient beach ridge cheniers are estimated and predicted. Seasonal variations of long shore sediment drift and offshore sediment drift are estimated by Bhandari and Das (1998) with the mathematical model study of beach dynamics around Digha coast. The study shows that the net long shore sediment drift is from west to east in the monsoon season and it follows reverse direction, from east to west in the winter season along the same coast. However, the amount of monsoon sediment drifts (19,000 m^3-23,400 m^3 / month) is comparatively high at every section of the shore line than the amount of winter sediment drift (10,200 m^3-12,700 m^3 / month). The net annual sediment drift is recorded from west to east and the amount varies from 65,160 m^3 / year to 1,28,000 m^3 / year along the shoreline.

There are also variations of offshore and onshore sediment drift (12.0-30.4 m^3/month in the monsoon season and it is 10.7 m^3 to 15.7 m^3/month in the winter season) in the coast, but the net sediment drift is from onshore to offshore (122.8 m^3 to 195.2 m^3/year) direction.

Table 2.2: The coastal chenier stage formations proposed by Maiti, (2013) for the reconstruction of the past.

Stages	Age (Years BP)	Sea Level	Location	Sediment Supply
1st Stage	7,000 years BP	High	Contai-Paniparul beach ridge	Sand supply mainly by long shore drift
2nd Stage	5,760±160 years BP	High	Ranisai-Dedanri beach ridge	Very high mud supply in initial stage
3rd Stage	5,760±160 years BP	High	Ramnagar-Deuli beach ridge	Very high mud supply in initial stage
4th Stage	2,900±160 years BP	Low	Kaubani-Taladi beach ridge	Low but equal sand and mud supply
5th Stage	2,900±160 years BP	Low	Chandipur-Kantabania beach ridge	Low but equal sand and mud supply
6th Stage	2,900±160 years BP	Low	Sarabani-Bichitrapur beach ridge	Low but equal sand and mud supply

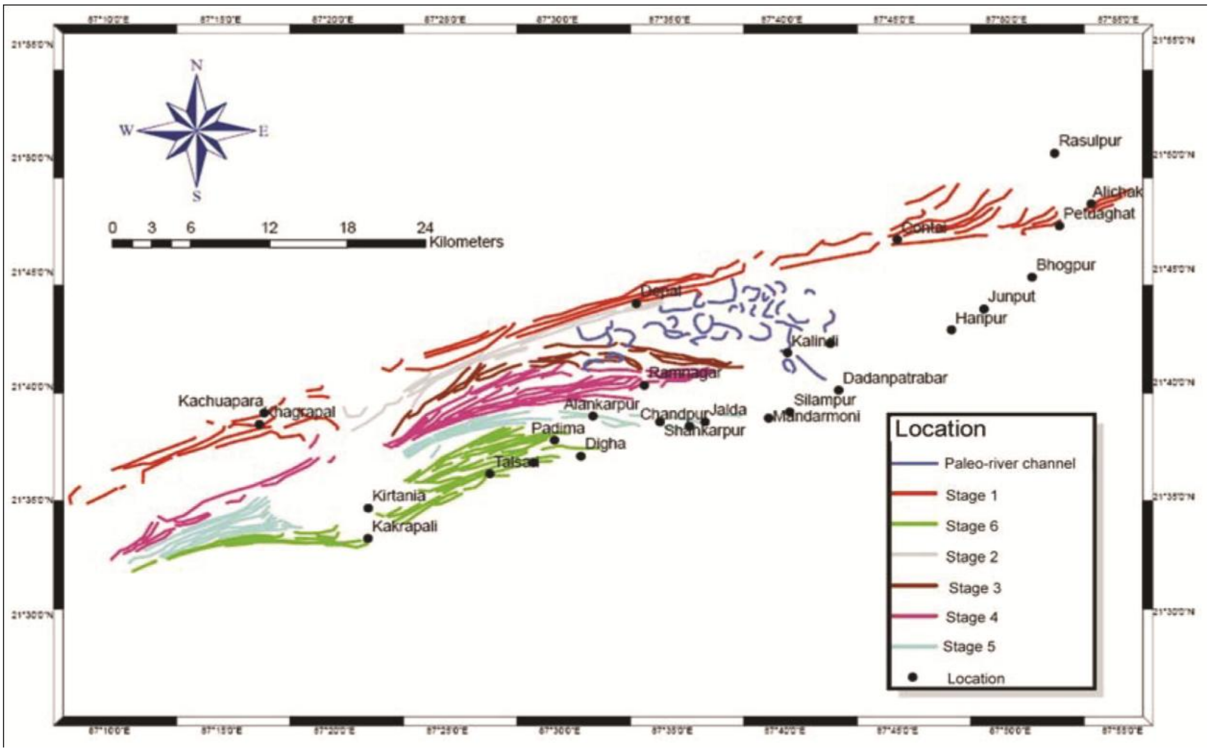

Fig. 2.8: The stages of evolution of the chenier costal plain (Maiti, 2013).

As reflected in International Geological Correlation Programme (IGCP) project-218 report (1986-88), by A. B. Goswami and Partha Sarathi Chakrabarti, the 14C dating of the sediments from earliest fluvio-tidal plain (5,760 ± 140 years BP) adjoining the early dune series in the north corroborates that the elevated thread line of the post-glacial stage is at current correspond to an earliest dune complex which is approximately 6,000 years BP (Pattanayak et al., 2014). The 14C dating of sediments commencing earliest intertidal flat (just south of the ancient dune belt) provides an age 2,920± 160 years BP which designates the first punctuation in the deterioration of the Holocene Sea in the region under concern (Table 2.3).

Table 2.3: OSL dating of coastal sediments from the surface of beach ridge cheniers by Pattanayak et al, 2014.

Location of Stages	Depth in cm	Age (Years)
1st Stage, Kanthi (Upper)	4.4	477±26 years
1st Stage, Kanthi (Lower)	0.5	532±26 years
2nd Stage, Digha (Upper)	0.5	<200 years
2nd Stage, Digha (Lower)	14	<200 years
Jaleswswarpur	0.5	378±19 years

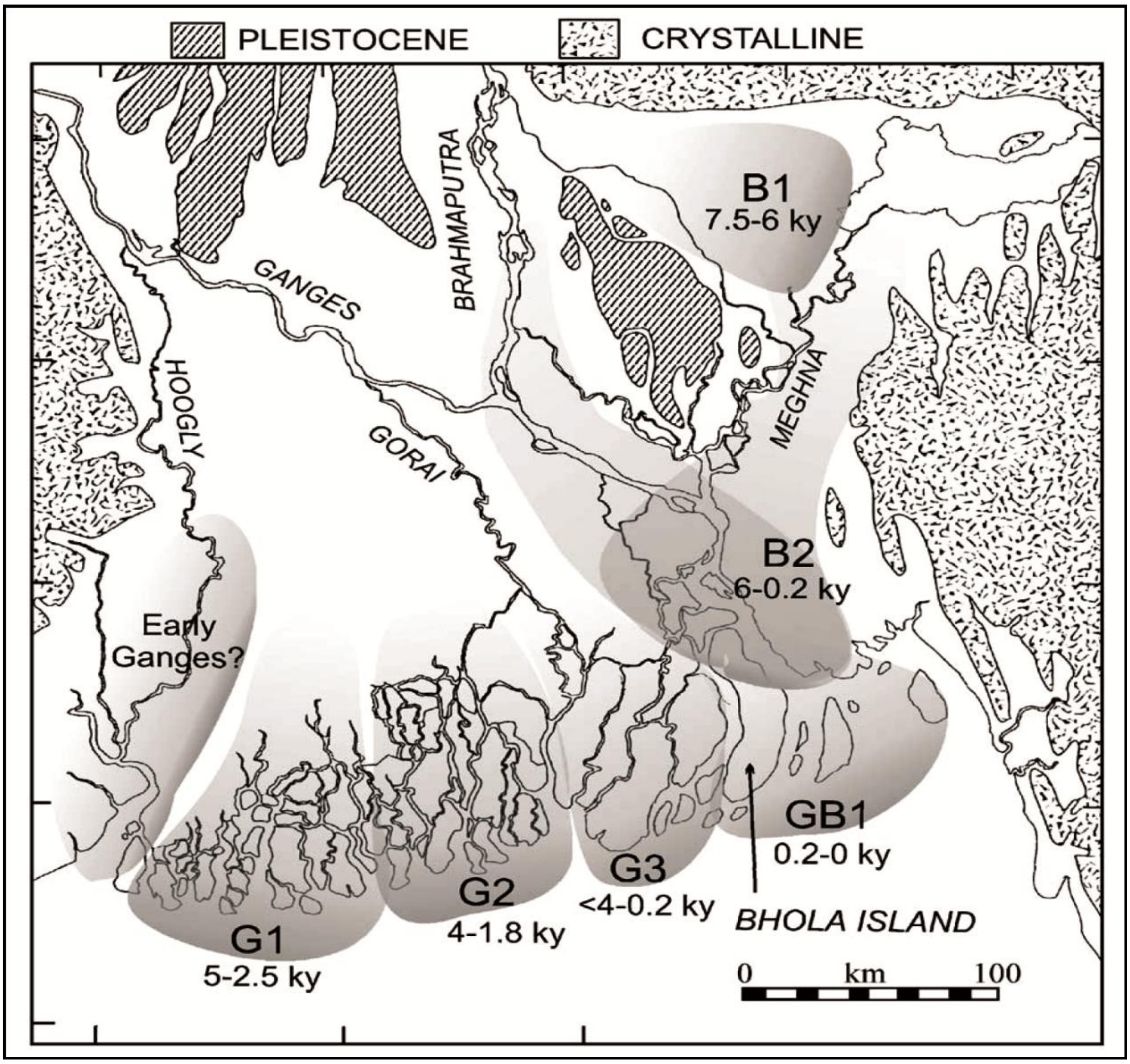

Fig. 2.9: The evolution of Bhagarathi-Hugli Delta fan lobes estimated by Allison et al, (2003) by lithological dating methods on the eastern fringe of the present chenier coast.

The regression stage which has been nearby experiential in the West Bengal coast and not internationally may be due to neotetonic commotion. This has previously been recognized by earlier researchers that a sequence of en-echelon faults traverses the western boundary of the Bengal Basin, between the Shield area and the Hugli River, in a North-North East (N-NE) to South-South West (S-SW) direction (Pattanayak et al., 2014).

The Bhagirathi-Hugli delta lobe was advanced seaward during the period between 2.5 ky to 5.0 ky as per the estimation of Allison et al., (2003) in their work. During this period of morphologic evolution the eastern most extension of beach ridges was terminated particularly blocked by advanced lobe of Bhagirathi-Hugli River system of the Ganga delta (Fig. 2.9). The Subarnarekha River of that period also probably drifted towards west leaving the older distributary mouth of Rasulpur River towards east. As the beach ridges of second sets are not advanced towards east a wide basin or swale flat was formed in between Ramnagar beach ridges and Digha-Junput beach ridges.

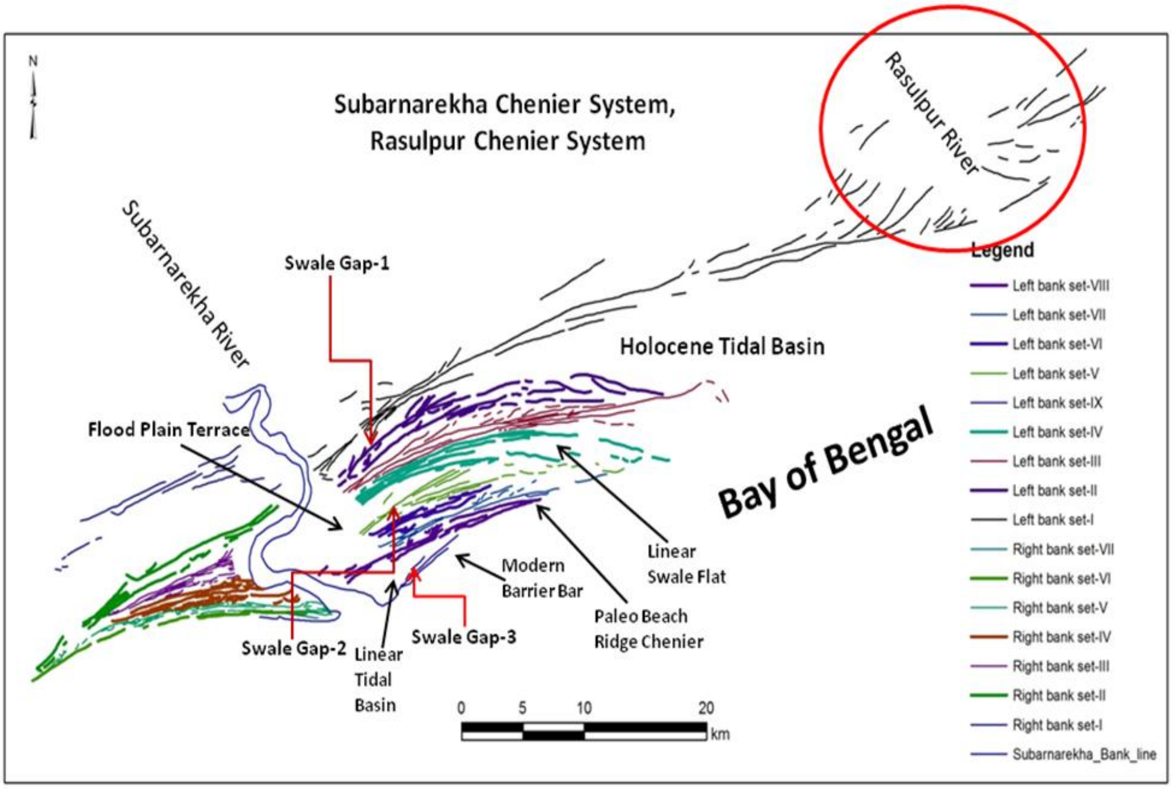

Fig. 2.10: Nine sets of chenier sand ridges on Subarnarekha deltaic surface.

However, the wide and extensive swale surface was probably flooded by tides and acted as a backwater behind Digha-Junput barrier spits shoreline. Later, the basinal depression was filled up by regular floods of Kaliaghai River and Subarnarekha River systems in the present forms (Fig. 2.10).

2.7 Reconstruction of Geological and Geomorphological History of Subarnarekha Chenier Delta

About 7,000 years ago (years BP) during early Holocene phase, Subarnarekha River jointly with Rasulpur River mouth was debouching into the Bay of Bengal in the form of two distributary channels in deltaic plan form. Later in course of time, Contai-Paniparul and Bahiri beach ridge section was formed significantly with the Subarnarekha flood discharges of silica sands and repeatedly aligned with shoreline deposition with strong influences of long shore current velocity directed towards E-EN of Subarnarekha ancient delta. During this period the shoreline was located and remained stable along the beach ridge chenier for almost 1,240 years in a same position.

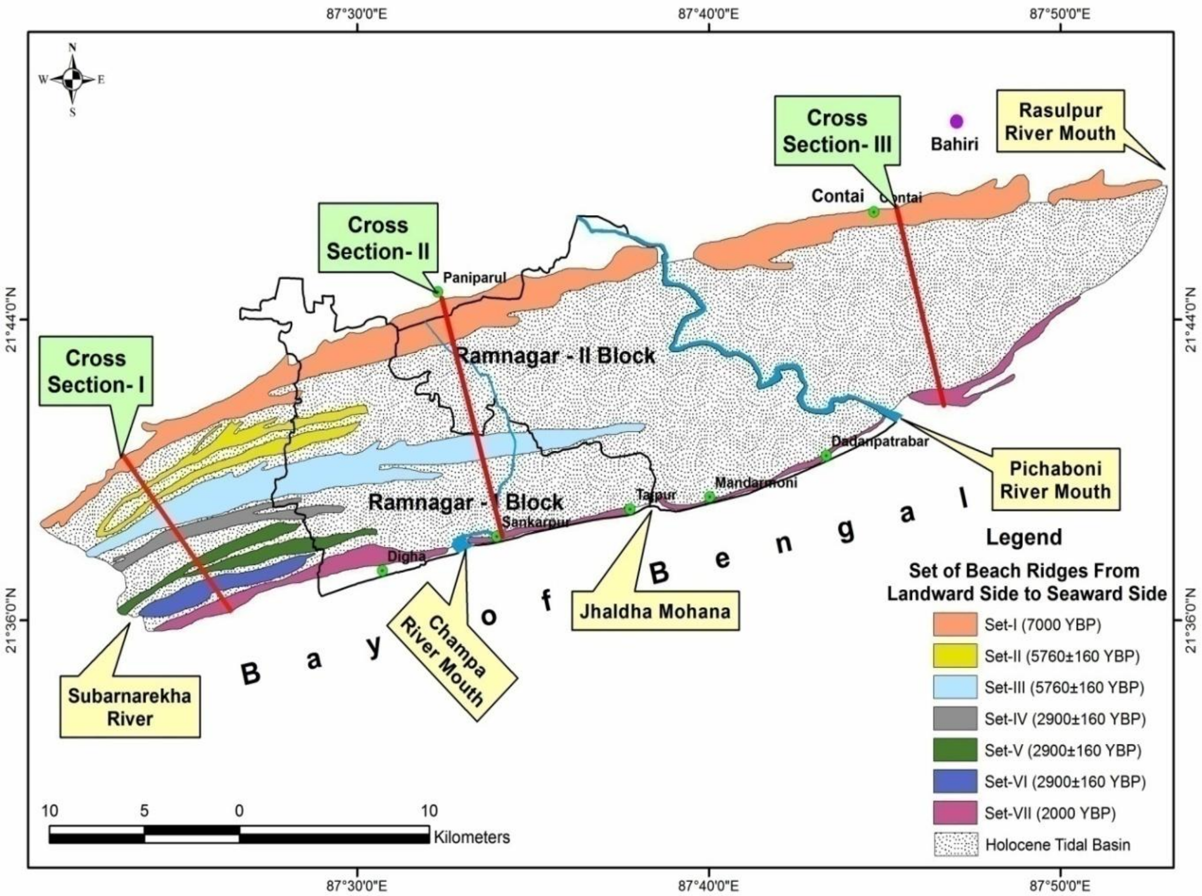

Fig. 2.11: Chronological cross sections of the coastal plain topography.

Gradually, at the time of 5,000 years BP, the Hugli Delta lobe of Ganga Delta system was a stronger sedimentary environmental focie (Allison et al., 2003) nearby Rasulpur River mouth of Subarnarekha distributary channel system. The finer sediments of mud dominated materials were thrown into the wide shallow back shores of barrier bar environment at the sea face of Subarnarekha delta (behind Digha-Junput beach ridge chenier) by the Hugli River mouth at that time. The river Subarnarekha was also drifted towards west and Rasulpur distrubutary system became disconnected from Subarnarekha system by local tectonic impacts (Figs. 2.11, 2.12).

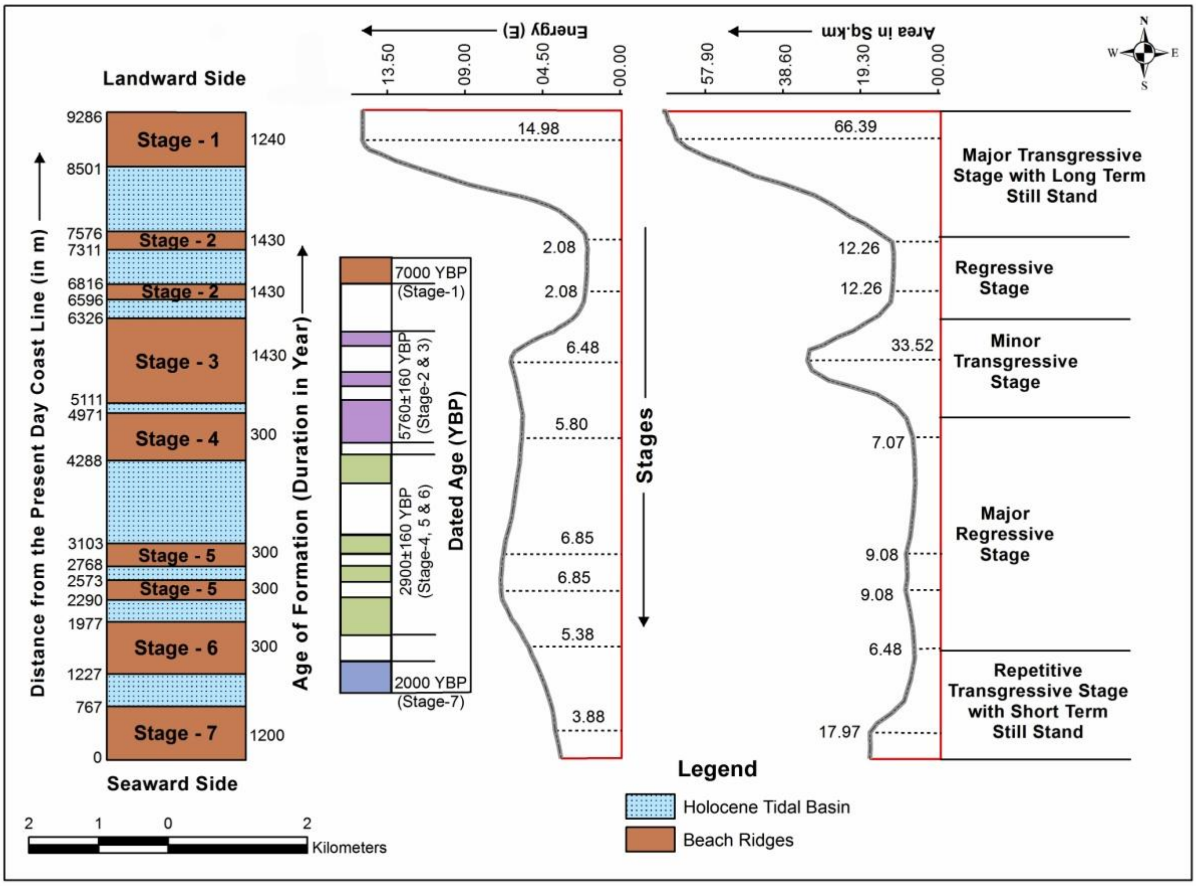

Fig. 2.12: The predicted wave energy, estimated dune areas, cross sectional topographic forms and chronological formations of cross section-1 in the coastal plain of the study area.

Table 2.4: The assessment of hydro-morphodynamics of the past landforms on the basis of modern available data.

Stages	Area of beach ridges in m^2	Average height of beach ridges in m	Volume of depositional sediment in m^3	Duration of deposition in year	Volume of deposition per year in m^3	Energy concentration (e) per year	Area of beach ridges in km^2
1st stage	6,63,96,200	10.38	689,192,556	1240	5,55,800.45	14.98	66.39
2nd stage	1,22,61,700	9.01	110,477,917	1430	77,257.28	2.08	12.26
3rd stage	3,35,20,800	10.25	343,588,200	1430	2,40,271.45	6.48	33.52
4th stage	7,00,6,760	9.21	645,322,59	300	2,15,107.53	5.80	7.07
5th stage	90,82,150	8.40	762,900,60	300	23,54,300.20	6.85	9.08
6th stage	64,82,380	9.24	59,897,191	300	1,99,657.30	5.38	6.48
7th stage	1,79,75,600	9.61	172,745,516	1200	1,43,954.60	3.88	17.97

Table 2.5: Relative wave characters of the modern and ancient shoreline environment (estimated from the modern records).

Stages	Wave height (H) in m	Wave length (L) in m	Wave period (T) in second	Wave steepness (H/L)	Wave Form velocity (L/T)	Wave energy (E)
Digha (Paul, 2002)	1.50	40	5.00	0.04	8.00	3.45
1st Stage	6.51304348	171.2	21.4	0.17368116	34.24	14.98
2nd Stage	0.90434783	23.77143	2.971429	0.02411594	4.754286	2.08
3rd Stage	2.8173913	74.05714	9.257143	0.07513043	14.81143	6.48
4th Stage	2.52173913	66.28571	8.285714	0.06724638	13.25714	5.80
5th Stage	2.97826087	78.28571	9.785714	0.07942029	15.65714	6.85
6th Stage	2.33913043	61.48571	7.685714	0.06237681	12.29714	5.38
7th Stage	1.68695652	44.34286	5.542857	0.04498551	8.868571	3.88

Source: *Wave recorded at the normal monsoon and post monsoon seasons at the shallow water depth (1-1.5 m) in the years 1990, 1993 & 1999.*

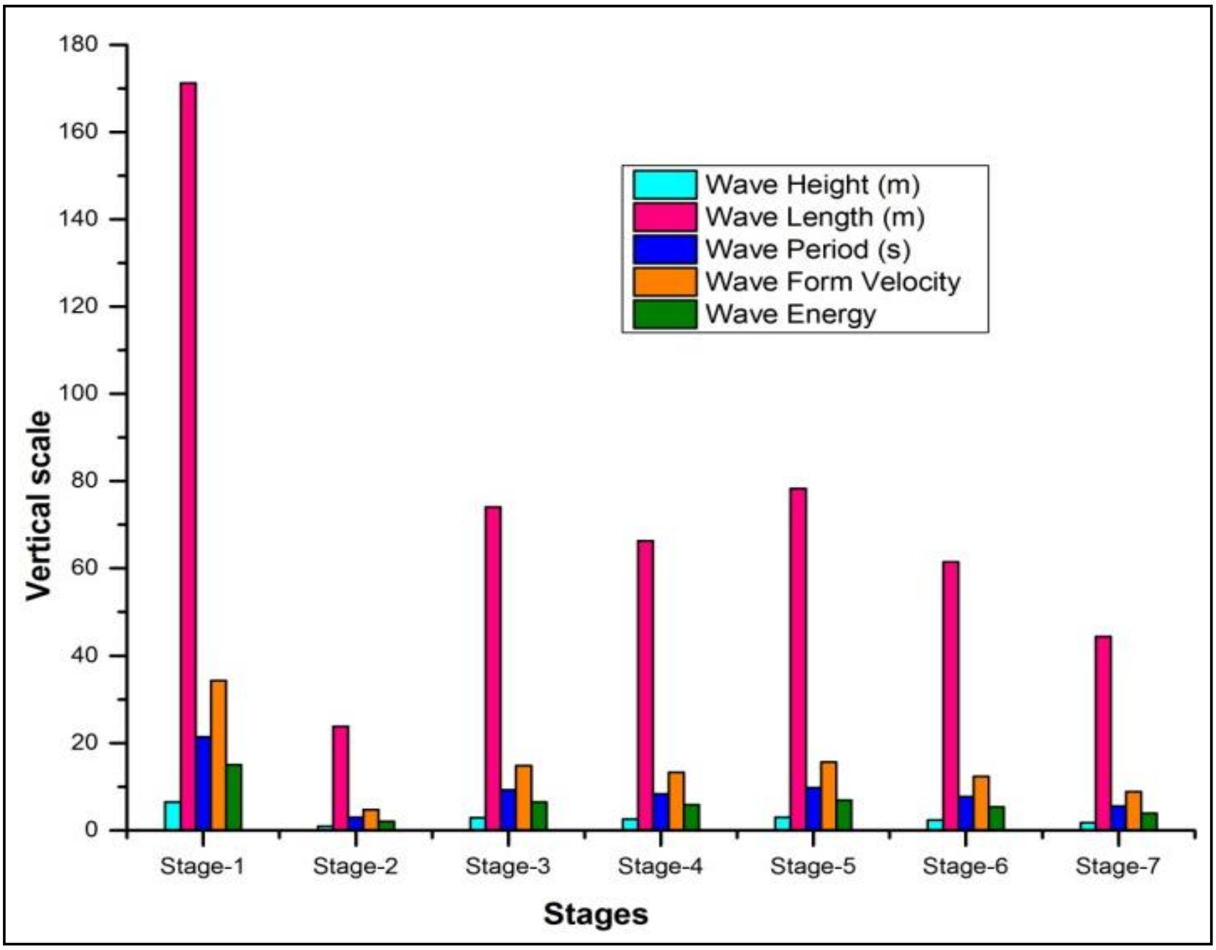

Fig. 2.13: Estimation of relative wave parameters.

Subarnarekha estuary system at this stage produced a series of shorter length beach ridge cheniers in between Contai and Digha systems of beach ridge cheniers by repeated flood events and input of silica size sands in the south western part of the delta. During this period (5,000 years BP to 5,760 years BP), the beach ridge sediments were not advanced towards E-EN of the coastal plain due to the presence of weaker long shore currents in eastward direction. For which above reasons a wide and shallow tidal basin was active in the form of lagoonal setup behind the barrier bar environment. The length of the three set of beach ridges indicate the low volume of sand size sediment supply at the event of Subarnarekha flood discharges during that period of formation (Tables 2.4, 2.5; Fig. 2.13).

However, the repeated development of shore parallel beach ridge cheniers of this period (2,900 years BP) with narrow spaced swale topography highlights the concomitant sea level changes and east ward drift of chenier sediments by relatively weaker long shore currents with estuarine flood plain deposition adjacent to Subarnarekha estuary location. At this period, the flood plain terraces have been built up along the eastern bank of Subarnarekha River by repeated floods and impacts of neo-tectonics. The Subarnarekha River mouth was lying at the furthest position from the eastern bank margin towards west at this time, during which the west bank beach ridge cheniers were formed in a fullest development by strong west ward long shore drift currents till the period of 2,000 years BP.

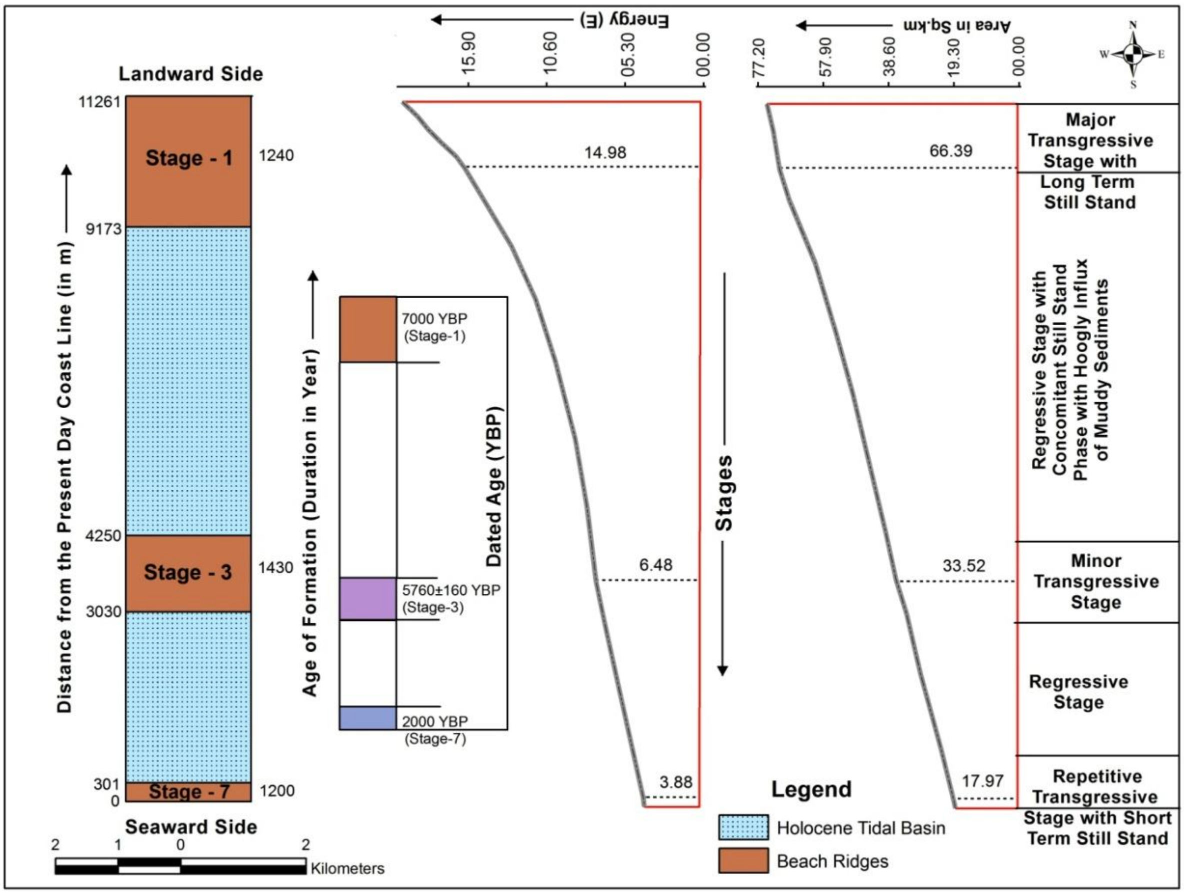

Fig. 2.14: The predicted wave energy, estimated dune areas, cross sectional topographic forms and chronological formations of cross section-2 in the coastal plain of the study area.

Suddenly, after the formation of west ward beach ridge cheniers, the river mouth of Subarnarekha again shifted towards East-East South (E-ES) direction across the shoreline position of the region. The flood induced sediment supply of silica rich sands had thrown towards south eastern parts of the coastal zone, from which the strong long shore drift currents from south west to north east direction pushed the sediments along the shore line of Bay of Bengal up to the Hugli River mouth. During this period, the distributaries River of Ganga system have shifted towards east from Hugli sedimentary focie, defeated by the long shore current transported sediments coming from Subarnarekha River mouth areas. Finally, by the span of over 1,500 years, the modern shore line fringed beach ridge chenier has been built up along the Bay of Bengal from Subarnarekha River mouth to Hugli River mouth (Fig. 2.14).

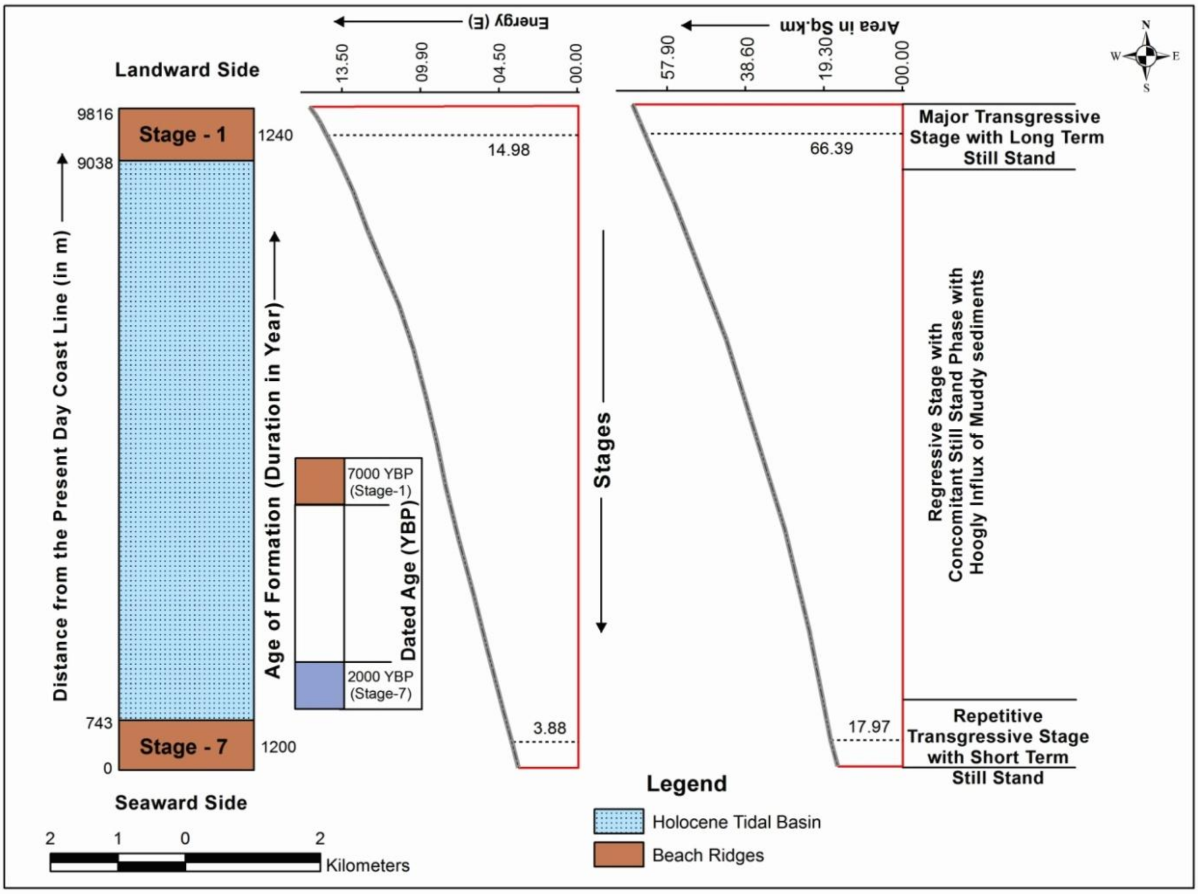

Fig. 2.15: The predicted wave energy, estimated dune areas, cross sectional topographic forms and chronological formations of cross section-3 in the coastal plain of the study area.

Very recently, from 1,500 years BP to 2,000 years BP, the segmentation of beach ridge cheniers by smaller distributary channels of the past (Talsari Channel, Jatra Nullah, Champa River, Jaldha River and Pichaboni River), natural levee formations, and development of sand dunes over the beach ridge platforms continued in the course of time by windblown sands and advancement of drainage channels (Fig. 2.15). The events of estuarine floods from river Hugli Mouth and Subarnarekha River mouth pushed the estuarine flood plain sediments (finer size) into the wide spaced swale topography in between beach ridge cheniers, and influenced the degradations of natural levees and abandonment of drainage channels over the tidal basin by sediment deposition. Consequently, the rising sea level trend of the northern Bay of Bengal has eroded and engulfed the shore front sand dunes and sea beaches into the present form of modified beach ridge cheniers along the present day shoreline.

2.8 Tidal Prism in the Coastal Wetlands

Tidal prism is the volume of tide water entire into the tidal spill grounds through the tidal inlet channels from the sea face and return the same volume tide water at the ebbing stage of tides through the same tidal inlets. Tidal prisms are the result of high standing tidal waves keeping pressure on the seaward sides to spill over the back shore area by entering into the tidal channels at the time of high tide levels in the coastal belt. A large volume of salt water flux with sediments are always transferred into the low lying wetlands 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 back shore 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 back shore tidal wetlands behind the coastal sand dunes and barrier bars are always getting modified by the transfer of sediments, salt water flow and nutrient loads during the period of tidal prisms (Plate 2.2).

Plate 2.2: The low tide and high tide conditions of the sandy shore platform at Dadanpatrabar sector.

2.8.1 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. 2.16). Tidal prisms are therefore estimated in three different wetlands to compare the volume of tidal prism among three different sectors.

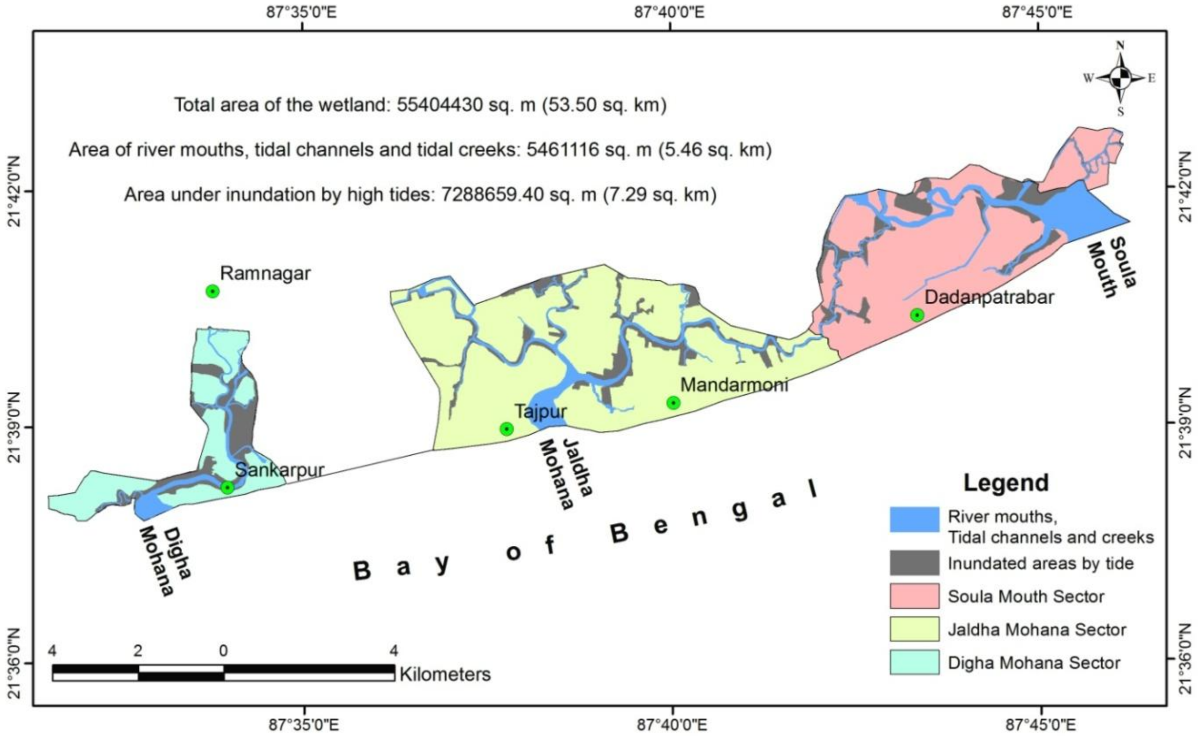

Fig. 2.16: Sector wise categorization of tidal wetlands with their inundation areas during 2017.

However, the each sector of tidal prism is again classified into three stages of 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 2.6, 2.7, 2.8). The levels of tides under high spring phase, average spring phase and neap tide phase are estimated from temporal beach profile sections of such loner 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 other phase and also from one section to other section on the basis of loner 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.

Table 2.6: Estimation of tidal ranges from beach profile transects of Pre-Monsoon phase (2013-2014).

Beach profile of Pre-Monsoon phase					
Profile - A					
Sl. No.	Tidal phase	Horizontal distance (m)	Distance difference (m)	Tidal height (m)	Tidal range (m)
1	Profile on full moon day (spring tide)	240-26.67	213.33	1.403-4.417	3.014

Sl. No.	Tidal phase	Horizontal distance (m)	Distance difference (m)	Tidal height (m)	Tidal range (m)
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			
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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			
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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			
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
1	Profile on full moon day (spring tide)	86.48-37	49.48	-2.194-0.052	2.246
		Profile - E			
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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 2.7: Estimation of tidal ranges from beach profile transects of Post-Monsoon phase (2013-2014).

		Beach profile of Post-Monsoon phase			
		Profile - A			
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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			
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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			
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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			
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**

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					
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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

Table 2.8: Comparative study of Pre and Post-Monsoon profiles (2013-2014).

Comparative study of pre and post-monsoon profiles					
Profile - A					
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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					
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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					
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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					
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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					
Sl. No.	**Tidal phase**	**Horizontal distance (m)**	**Distance difference (m)**	**Tidal height (m)**	**Tidal range (m)**
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 range is estimated from the beach profiles with their differences between high tide level and low tide level 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) in the coastal part of Ramnagar-I and Ramnagar-II Administrative Blocks (Fig. 2.17).

The tidal prisms are estimated in 1990 and 2017 to compare the voluminous tide water 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 2.9; Fig. 2.18).

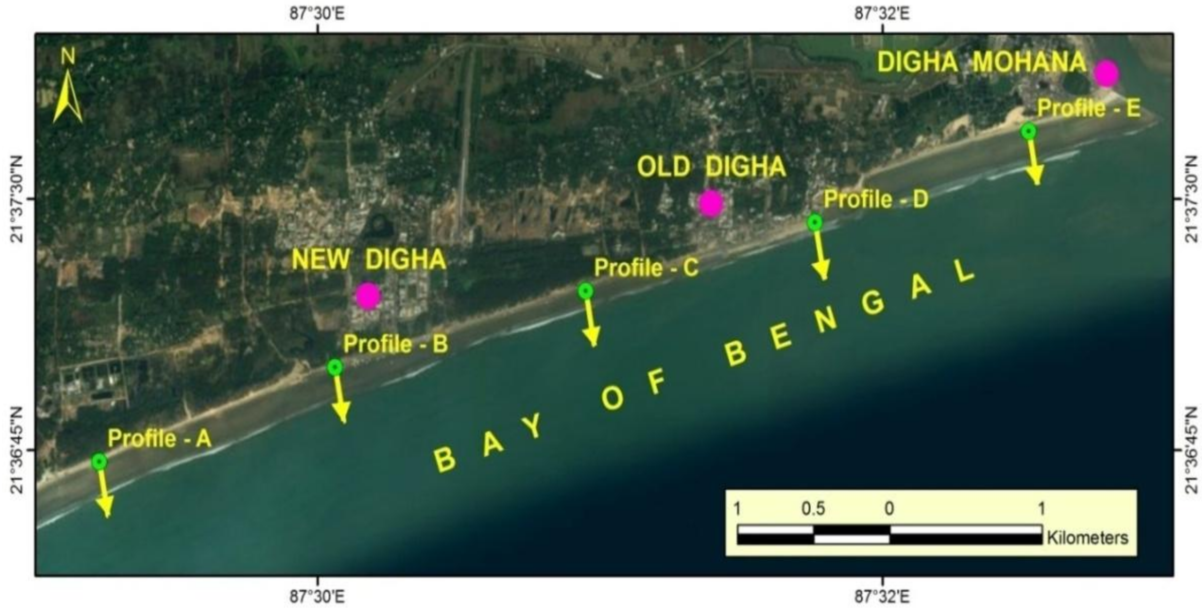

Fig. 2.17: Location of profile sections surveyed by GSI (2013-14).

Table 2.9: 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

2.8.2 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 work. Tidal prisms are significantly increased in 2017 in compare to the year 1990 in coastal belt of study (Plate 2.3; Fig. 2.19).

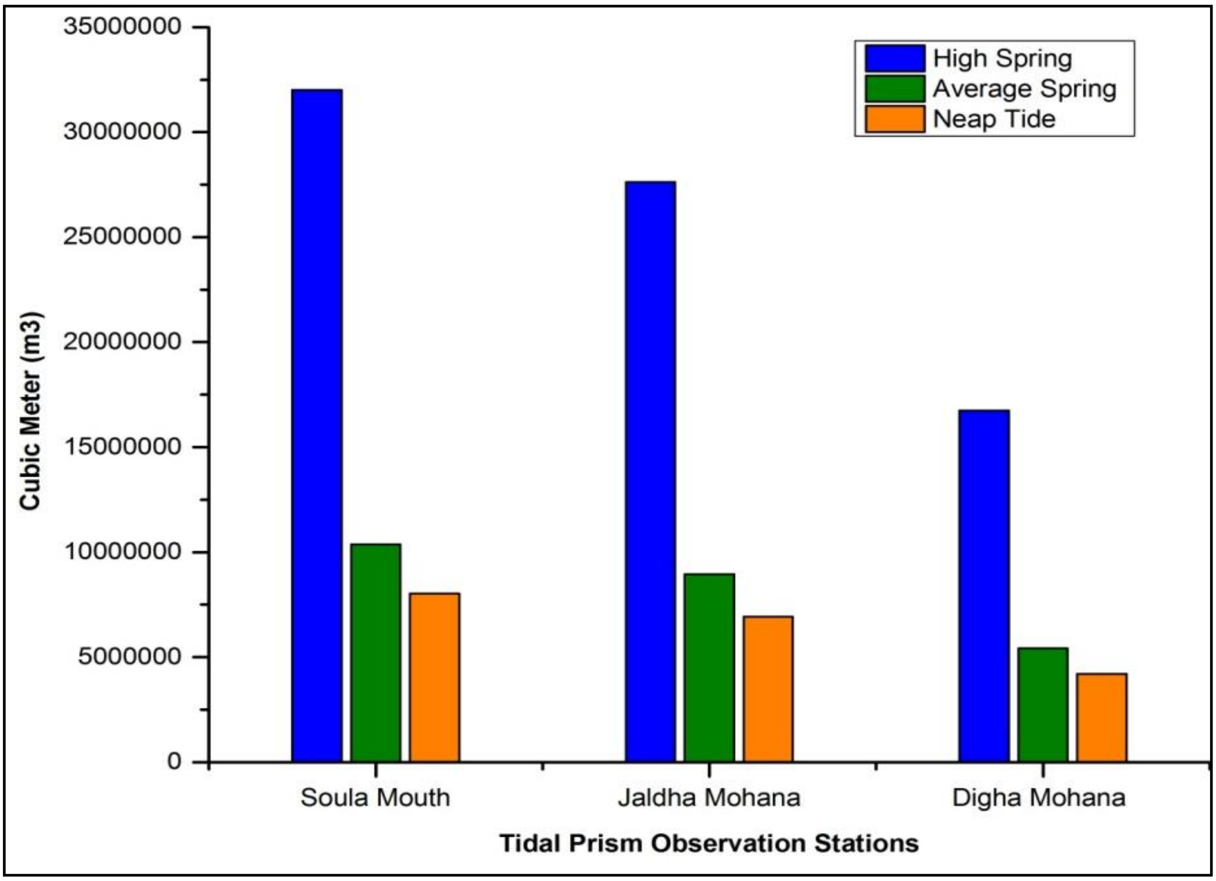

Fig. 2.18: Volume of tidal prism estimation (m^3) in different sectors.

Plate 2.3: The low tide and high tide conditions of the sandy shore platform at Soula river mouth.

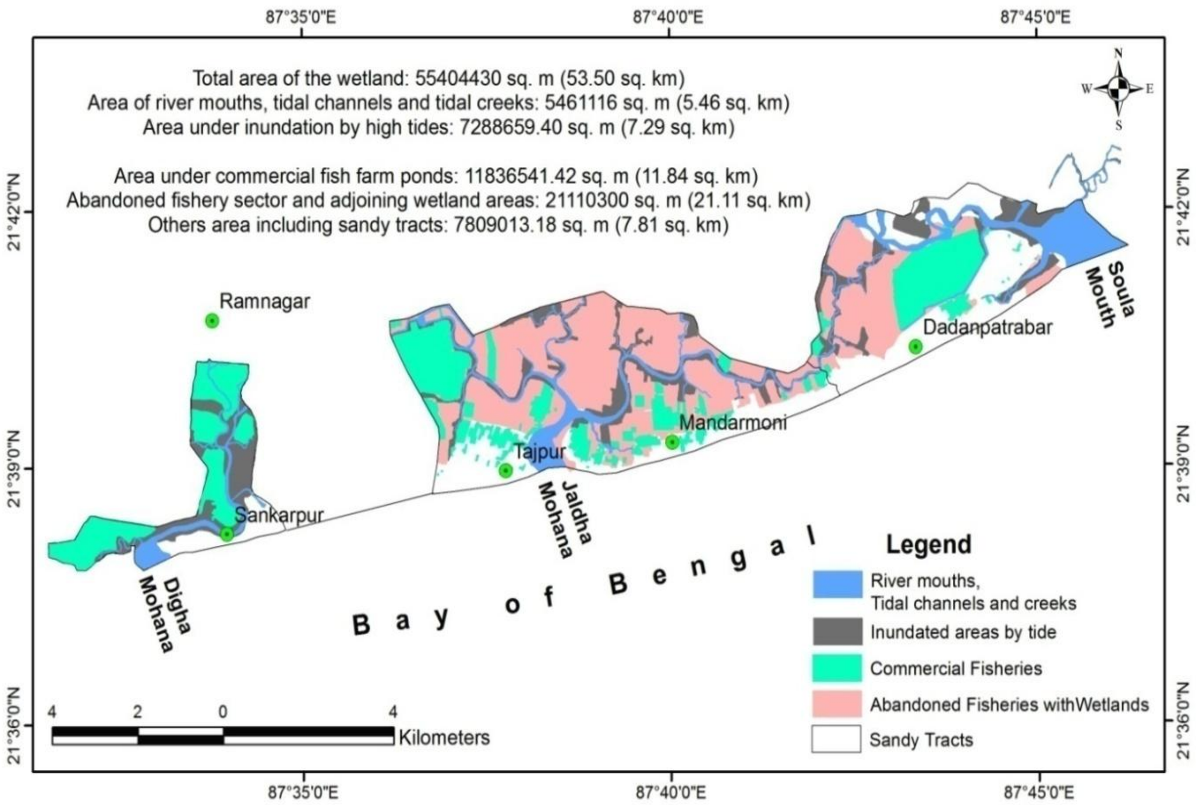

Fig. 2.19: The tidal wetlands occupied by commercial fish firms, abandoned tidal flat, tidal drainage channels and beach ridges or sand dunes.

Table 2.10: 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)	75,427,671.21m^3	61,841,747.055 m^3
TR at 1.918 m (average spring)	24,454,069.19 m^3	20,049,437.263 m^3
TR at 1.485 m (neap tide)	18,933,416.38 m^3	15,523,156.588 m^3

The result of such estimations shows that it is increased up to 13,585,924.15 m^3 in high spring phase, and 4,404,631.93 m^3 in average spring phase, and finally up to 3,410,259.79 m^3 in neap tide phase in this area (Table 2.10). Such enormous increase of tidal volumes and their advancing sea water movement have created many geomorphological problems in the coastal belt. The present day shore line 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 resulted at the mouth of tidal inlets as ebb deltaic deposition at present. The landward recession of coastal sand dune are increased significantly at the time of the high and average spring phases for developing pressure of tidal prisms on the shore face of the coastal stretch.

The down drift current during south west Monsoon months along the shoreline transport greater amount of sediment and partially deposit them into the narrow channel and majority of sediments are bypassing the channel mouth and entering into separate sector of the shoreline. As the sediments deposited by the down drift currents are modifying the inlets by high rate of deposition, the inlet mouth become narrower by advancing sand spit (Fig. 2.20; Plate 2.4).

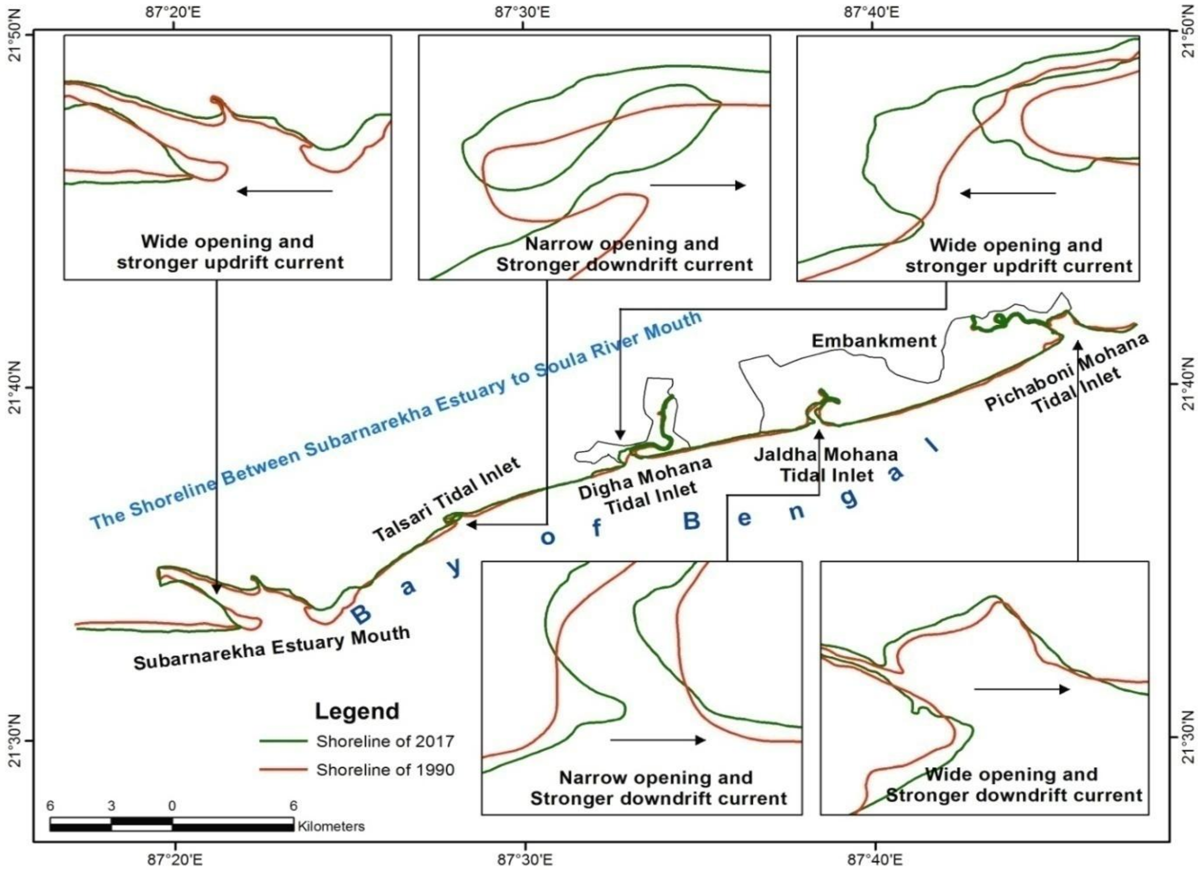

Fig. 2.20: Dynamic inlet mouths modified by down drift currents and up drift currents along the shore line.

Plate 2.4: Increased rate of beach cliffing and cliff recession along the shoreline of Jaldha mouth and Sankarpur due to the pressure of high tidal prisms.

However, the up drift current coming from N-NE wind systems along the shore parallel direction with moderate energy transport limited amount of sediments to fill the narrow inlet mouths. Therefore the inlet mouths become wider by limited amount of deposition. During high tides, the sub aqueous 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 back shore region and mouth become wider. During low tides, the ebb currents transport limited amount of sediments from the backshore area into the inlet mouth to rebuild the ebb delta at the mouth.

2.9 Coastal Morphometric Attributes

Morphometric analysis was accepted with facilitate of Geographical Information System (GIS) method which appraises a variety of important considerations for the West Bengal low lying coastal tract. Under this current endeavor, grid based morphometric analysis were implemented by using Arc GIS 10.1 software, to accomplish the morphometric results.

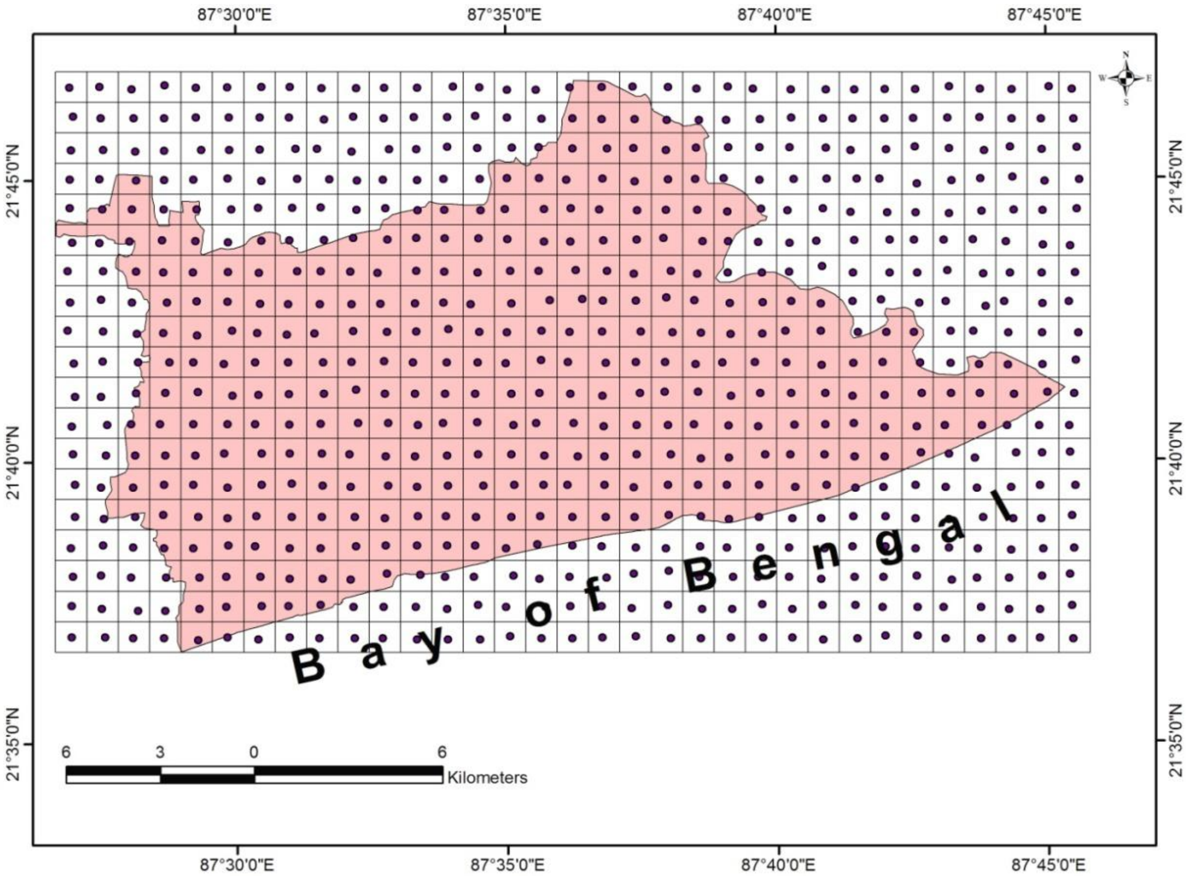

Fig. 2.21: Calculation of coastal morphometric attributes in 1 km ×1 km grid method.

The studied region was separated into 1 km × 1 km in grid pattern to establish with; then for every grid the linear, aerial and relief features have been considered for appraising the stream characteristics, morphometric surroundings of streams within the drainage system, to revise the hydrogeology, lithology, and geomorphology etc. of the area under study (Fig. 2.21).

Relief characteristic are considered with the assist of DEMs, which was also use designed for visual understanding, investigation of landscape, and modeling of surface processes. Accordingly from the DEM, the slope map was equipped by means of GIS method. Generally the present study illuminates significantly in light of morphometric analysis carried out efficiently comprises with remote sensing and GIS method than the conventional technique (Plate 2.5).

2.9.1 Relative Relief

Relative Relief also termed as amplitude of relief or local relief which represents actual variation of attitude in a unit area with respect to its local base level. Relative relief variation in studied cost is in between 0.92 to 14.65 i.e., less relative relief. Regarding the present variation of relative relief, especially in less undulating tract, no regular trend or distinct pattern are found to have developed.

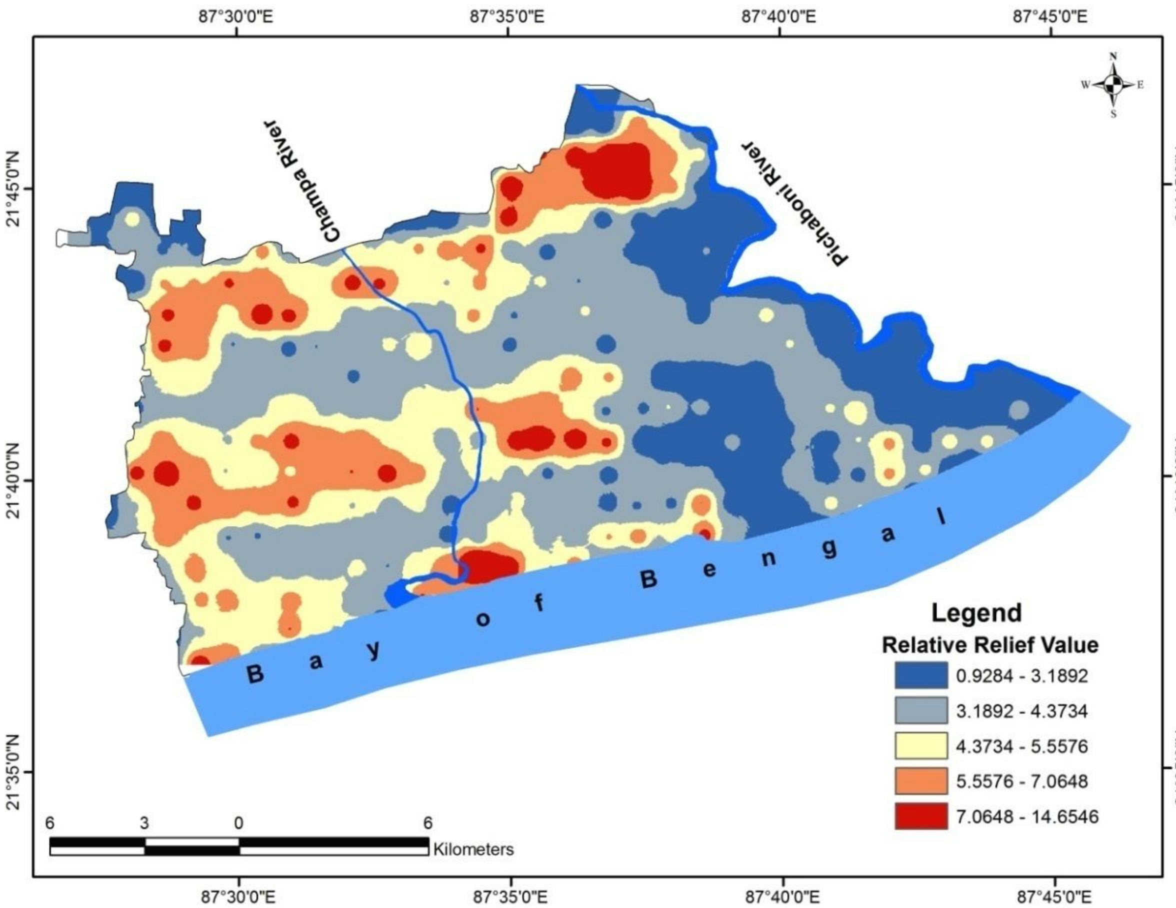

Fig. 2.22: Relative relief surface of the studied coast.

Some isolated parts like fore dune and back barrier dune have attained relatively higher value (7.06 m – 14.65 m) to break the normal trend of gradually of such alignment. On the other hand the lower elevation in the wide river valley with gently undulating plains displays lower value to relative relief between 0.92 m – 3.12 m. The steep slopes near dune area are responsible for the development of this peculiar pattern of relatively higher elevation. Dune development processes have played a decisive role on attainment of such variations of amplitude of relief (Fig. 2.22).

2.9.2 Dissection Index

It is a ratio between relative relief and absolute amplitude. It ranges between 0.12 – 0.79 in studied area. Dissection index is an important parameter of drainage basin and useful in the study of terrain and drainage basin dynamics the stage attained by the stream in the course of the evolution of basin concerned. There is much variation in the attainment of such index in the different sections of the study area though they are located almost in same attitudinal zone. Dissection Index is useful in many respects and has got particular geomorphic interest.

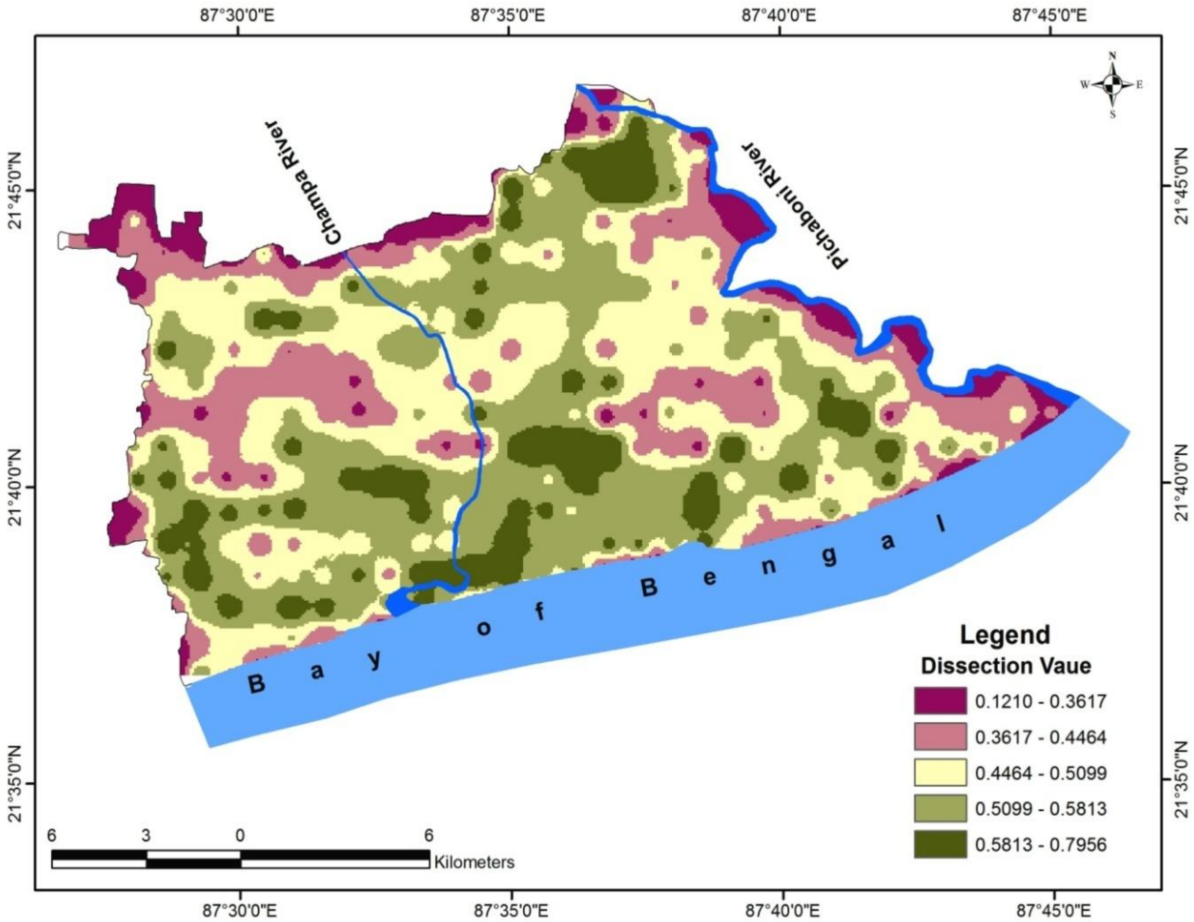

Fig. 2.23: Dissected surface of the studied coast.

The interest is connected with variations of relative relief, hill and slopes assisted by litho tectono structural and climatic controls. The elongated river basin, with varying degree of corrosion power or erosional potential due to variation in absolute relief, relative relief, slope vegetative cover and rainfall distribution show in a broad sense relatively mature stage of morphological evolution. Lower category of index (0.1 and below) is mainly confined in the undulating terrain lying swale topographic region (Fig. 2.23).

2.9.3 Average Slope

Slope is the vital determinant factor in the land use of any region. Higher altitude folded structure; local disturbance along with denudational effect of fluvial processes produces relatively higher values of slope in dune segment. The elevated region of dune region with average height above 5 m – 6 m from MSL shows the attainment of average slope about 5°- 22°. The gentle undulating surfaces and riverine flats constituting the study area, are characterized by lowest slope) < 1.13° with sudden patches of higher angle of slope. Variation in gradient litho-morphological condition, tectonic lineaments, stream corrosion power and differential weathering may be responsible for such variation (Fig. 2.24).

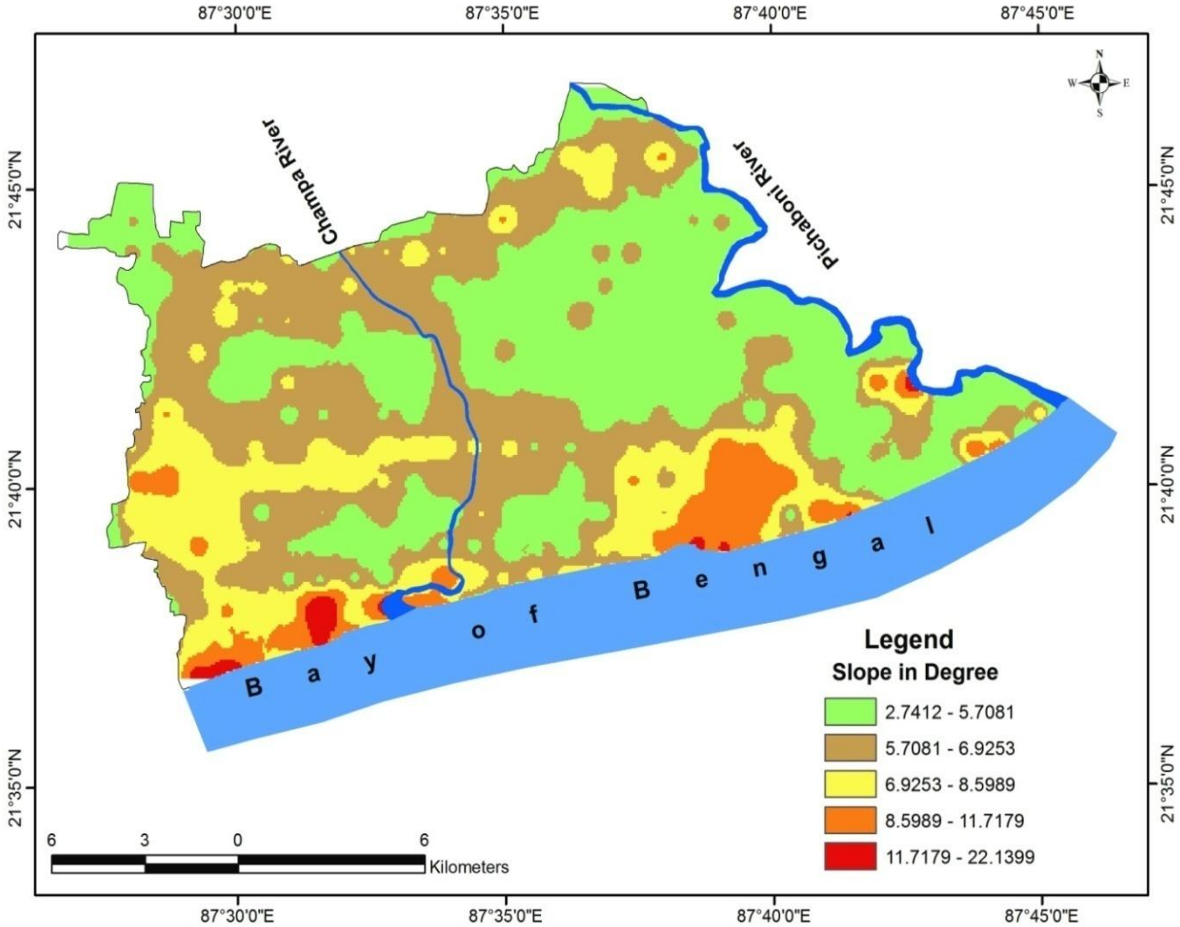

Fig. 2.24: Average slope of the studied coast.

2.9.4 Aspect of Slope Direction

The noted hydraulic engineer laid the foundation of quantitative and systematic approach in geomorphology based on morphometric techniques. The drainage basin is generally regarded as the most satisfactory basic unit for study because it is an areal unit and drainage systems can be placed in orderly hierarchies. Interest in drainage basin morphometry has grown since Horton drew serious attention in 1945 to certain basic laws. The work of Horton has been built upon and extended since then and knowledge of the mathematical properties of drainage basins had been greatly extended (Fig. 2.25).

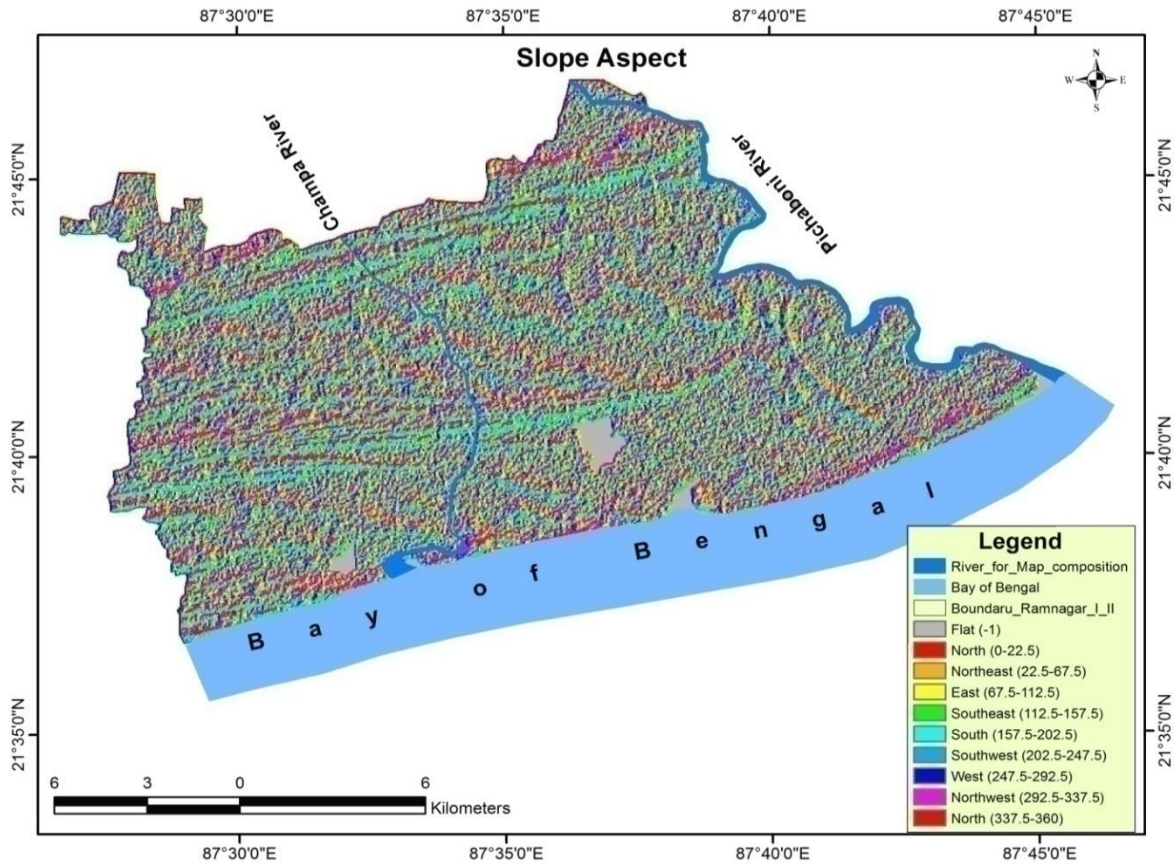

Fig. 2.25: Aspect of slope direction of the studied coast.

Plate 2.5: Morphometric characters of Contai-Paniparul and Ramnagar-Deuli beach ridge sections.

Thus, in any geomorphological study, drainage analysis has become an important part as described in the following pages. The aspect map shows that most of the portion of the studied coast having northern aspect where as the east aspect arenas are very least in the study area. But different directional aspects are also present in this part.

2.10 Major Findings

It is the specialized coastal plain topography of alluvium surface with beach ridge chenier and swales makeup the topographic diversity of the coastal belt.

- Geologically, the entire formation belongs to Early Holocene, Middle Holocene and Late Holocene period extending from 7,000 years BP to 500 years BP and sub recent stage.

- The chenier plain is the product of the combination of sediment discharge into the coastal zones by fluvio marine deposition with presence of strong long shore currents at the sea face, activities of repeated coastal storms, impacts of tectonics and past sea level fluctuations.

- There are seven stages of coastal chenier formations and among them the long shore 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 consideration with the volume of sediment estimation under modern sea face energy levels. However, the shorter beach ridge cheniers are produced under weaker long shore current energy in 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 mouth discharges into the Late Holocene tidal basin.

- Many channels were abandoned within the valley flats by lagoonal deposition and estuarine flood plain deposition of Subarnarekha and Hugli River systems. The younger natural levees and older natural levees are separately distributed around the abandoned channel sections.

- The modern shoreline beach ridge cheniers are segmented by older distributary channels and acted as tidal inlet mouths along the shore face and modified by present day coastal processes.

- Tidal prisms are significantly increased in 2017 in compare to the year 1990 in the coastal belt of today. Shore line 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 increasing rate of tidal prisms in the coastal tract at present.