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COASTAL ENVIRONMENT OF WEST BENGAL – A REVIEW

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Abstract: Coastal zone of West Bengal, characterized as a typical lowland coast under a meso-macrotidal regime, register evidence of accretion and erosion that control configuration of the coastline. At present, West Bengal coast is a hostile coastal tract in nature evidenced by severe erosion that leads to lowering of coastal plains and landward advancement of coastline as it is a cyclone prone area. The coastal zone of the state is the outcome of the combined depositional effects of Ganga-Brahmaputra River and the Bay of Bengal. Tidal fluctuations, wave parameters, longshore currents, sand flats, and beach ridges are the characteristic features of the coastal areas of the state. Major catastrophic events like cyclonic storms, tidal bores, storm surges, breaking types, high tidal range, strong littoral drift that control the coastal configuration of West Bengal are examined accordingly. Nature of beach materials and different sedimentary structures on the intertidal zones are identified.

Keywords: Coastal divisions, Coastal sectors, Coastal processes, Wave parameters, Coastal waters, Beach characters, Bedforms, Sediment texture, Breaker types

1. INTRODUCTION

The West Bengal coast is a relatively hostile environment because it is constantly changing. The nature and character of the coast is influenced by several factors such as the local geology, state of the sea, configuration of the coast, terrestrial and submarine slopes, magnitude of inshore and offshore currents, and sediments brought into the sea by the rivers of both major and minor categories. Interaction of these factors imparts distinctive characters and behavioural pattern to the shores. The shore, broader aspect of a coast, may remain essentially stable for decades which may impart a vague sense of security to the inhabitants but when a severe devastating cyclonic storm surges or wave action or catastrophic waves of high magnitude ravage the coast, it causes heavy loss of life and property in the surrounding areas adjacent to the coastal West Bengal [1].

Natural disaster on the shores may be multiplied by human interferences in the form of tampering with the parts of the coast leading to damages of short- and long-term basis and damaging of an intertidal or dune areas may lead to serving coastal erosion by depriving the coastal zone of its quota of protective sediments. In general, coastal

areas is divided into beach zone, perched zone on cliff slopes above the sea, estuaries, and deltas, though the cliffed coastal zone is uncommon in the coastal region of West Bengal. Identification and interpretation of different environmental parameters in the coastal zone of West Bengal is the objective of the present study.

2. WEST BENGAL COAST

Coastal zone of West Bengal, influenced by the changing river courses and sites of sedimentation, and shifted erratically in response to intermittent structural changes due to quaternary faulting and subsidence of the Bengal basin through sediment compaction, is characterized with the beaches, tidal islands, coastal sand dunes, sand flats, mud flats, casuarina tree lines, world famous mangrove swamps and marshes, networks of rivers and tidal inlets, along 157.5 km long coastlines in the lap of the Bay of Bengal. The length of the West Bengal coast is approximately 210 km inclusive of the rivers, creeks, tidal inlets, and tidal islands along the coastal stretch. The coastline of West Bengal is not a continuous one because of the presence of a number of estuaries along the coastal tract of the state [2]. The Hugli River estuary acts as a border in between the districts breaking the continuity of the coastlines and meets the Bay of Bengal in the extreme south of the state (Fig. 1).

3. COASTAL DIVISIONS

Coastal areas of West Bengal may be divided into two major coastal divisions: i) South 24 Parganas Coastal Division and ii) Purba Medinipur Coastal Division. Coastal division consists of several coastal sectors like Bakkhali-Fraserganj, Ganga Sagar, Sunderbans of South 24 Parganas coastal division and Digha-Shankarpur coastal sector under Purba Medinipur coastal division.

Coastal division–South 24 Parganas Coastal Division
Coastal sectors: i) Bakkhali Fraserganj
ii) Ganga Sagar – Chuksar Island
iii) Sunderbans

Coastal division–Purba Medinipur Coastal Division
Coastal sector: i) Digha - Shankarpur

3.1 South 24 Parganas Coastal Division

Coastal areas of the South 24 Parganas district are almost covered with the mangrove vegetation of the Sunderbans leaving only Bakkhali-Fraserganj, and Ganga Sagar as sandy seashores covered with casuarina trees along the coastlines. Sunderbans is an estuarine deltaic deposit with the characteristic features of 64 mangroves and its associated species. Depositional environment of the Sunderbans indicates its formation in the Quaternary age evidenced by the gravelly quartz, siltstone, and sandstone at the bottom of the clayey sediment deposits borne by the Ganga-Brahmaputra-Meghna system and accreted from a part of 8 million tons sediments transported by these rivers every year. Upliftment of the river Ganga at its western part towards river Padma due to morphogenic tilt and neotectonics movement between the twelfth and sixteenth century

accelerated the deltaic formation of the Sunderbans. As a result, West Bengal coast is lacking fertile alluvial soils as the accreted sediment has not been desalinated by the fresh water carried by the rivers in the deltas of the Sunderbans of the South 24 Parganas district. Therefore, the accretionary zone with numbers of delta isolated with the tidal rivers and inlets, and an intricate coastal zone are the characteristic features of the coastal region of the South 24 Parganas district. Seashores of the major parts of the Sunderbans other than Bakkhali-Fraserganj, and Ganga Sagar, are not accessible as those areas are confined to the reserved forests and restricted from human interference [3]. Among sea beaches, Bakkhali-Fraserganj, and Ganga Sagar coastal sectors of South 24 Parganas district are enlisted as sea resorts in the map of tourism along the coastal stretch of West Bengal (Fig 1).

3.2 Purba Medinipur Coastal Division

Purba Medinipur coast is characterized with the natural beach features along the classified lowland coast of West Bengal and is controlled by the neotectonics at its western part and cuspate delta of the Subarnarekha River. High salinity with less turbid seawater from the Bay of Bengal due to less river discharges, rip currents, littoral drifts, longshore currents, coastal sand dunes, and casuarina tree lines are the characteristic features of the Purba Medinipur coastal division. Among sea beaches, Digha, Shankarpur, Mandarmani, Tajpur, Junput, and Udaipur of Purba Medinipur district are considered for the survey that are also enlisted as sea resorts in the map of tourism along the coastal stretch of West Bengal (Fig 1).

3.3 Coastal Sectors

About 157.5 km long coast of West Bengal is an extremely complex coastal belt because of the geomorphological situation and continuous interaction of the coastal processes particularly by the action of waves, storm surges, tides, winds, and discharge of the large quantity of sediments by the Ganga – Brahmaputra rivers, though a major part of the sediments is transported to the deep sea by the submarine canyon – Swatch of No Ground. Several relevant factors such as tides, waves, sea level rise, tectonic and geological factors affect the entire coastal areas of the state significantly. Along this coastline, continuous sediment loss by the wave swash and tidal action, storm surges, and water level fluctuation in the Bay of Bengal plays a significant role for erosion leading the West Bengal coastal region as a vulnerable and fragile coast. Continuous transport of sands from the beach of the coastal areas results in erosion of almost all the coastal sectors of the state because the beach is the buffer zone between land and sea. Like erosion, major issues like coastal zone management and coastal regulations are considered in the coastal sectors. The following coastal sectors in the state of West Bengal are considered for the search and survey.

i) Bakkhali – Fraserganj Coastal Sector
ii) Ganga Sagar and Chuksar Island Coastal Sector
iii) Digha – Shankarpur Coastal Sector
iv) Sunderbans Coastal Sector

3.4 Digha – Shankarpur Coastal Sector

The breakers proceed towards the shore and lash until they turn into the surf at the seashore of Digha of coastal West Bengal - the state's most beautiful natural sandy sea beach. The breakers are not rough, and the tourists move easily for their bath. Swatting casuarina trees separate the sea from the land. A lush green coastal vegetation, on an average 100-150 feet high, exists parallel to the sea beach. The coastal town Digha (Latitude 21037'N and Longitude 87031'E) is famous for its natural white sandy beach, and it stretches far beyond the area from the town. About 3 km-long metal road runs from east to west parallel to the beach and extends up to Udaipur beach, a spot along the stretch of Digha beach. Udaipur is situated adjacent to the border line between West Bengal and Odisha states. Tourists can travel in auto-rickshaws or private cars along the metal road from Old Digha to Udaipur beach areas. Digha beach is enchanting when anybody looks through the casuarina groves, stands on the coast, and sees the fishing boats take a nap on the beach after sailing from the sea. The harmonious blending of casuarina and sea beach in the same place is spell-bounding. The downward journey of the crimson sun on the western horizon behind the distant silhouetted ships on sea makes tourists spellbound at twilight time.

The main spot for tourists is the seashore at Old Digha as well as New Digha adjacent to Digha town. Most tourists enjoy bathing in the sea, gliding and spending leisure time at the seashore of Old Digha, New Digha, Digha Mohana, and Udaipur. Despite its heavenly natural beauty besides being the natural sandy sea beach, with greenery, Digha is yet to acquire the stature of an international tourist spot in a big way.

Tourism is the only source of income in Digha, the most famous and beautiful tourist spots in West Bengal. Digha sea beach is visited by millions of locals and natives as well as international tourists every year. Present days fishing of lobsters including usual capture of hilsa fishes from the deep seas are collected at Digha Mohana and their exports far away from this sea resort are the other sources of income in Digha coastal areas. Although Digha sea beach is a famous sea resort, it stands in the highly risky area of cyclones and 2-5 cyclones on an average hit the coast almost every year. This coastal zone faced devastating waves as usual, almost about three to five meters high during the cyclonic events. Despite several hazards of natural calamity and economy, the natural sea beach, Digha is now receiving the attention of international tourists due to proper monitoring and management of the present State Government.

3.5 Bakkhali-Fraserganj Coastal Sector

Fraserganj and Bakkhali are the sea resorts of beautiful landscape and bountiful enchant-ments amidst tall casuarinas at the coast of the Bay of Bengal. Both these sea-resorts with the distances of about 2 km in between situated near the confluence of the Hugli River with the Bay of Bengal. Fraserganj and Bakkhali stand at the distances of 134 and 136 kms from Kolkata respectively and both the places can be reached by crossing the recently built Hatania Doaniabridge at Namkhana and then traveling another 25 km

by road towards the extreme south on the lap of Bay of Bengal. Fraserganj, a natural solitary sea resort, only 2 km west from the well-known Bakkhali sea beach stands at the southernmost ends of West Bengal where coastal landmass meets the Bay of Bengal. Fraserganj was so named after the name of Sir Andrew Fraser, the Bengal Governor during 1903-08 who was more famous as the advisor of Lord Curzon for the division of the then undivided Bengal. Andrew Fraser took the project to set up a tourist spot for spending leisure time of the employees specially for the British nationals during the last year of his Governorship in Bengal in the year 1908.

3.6 Ganga Sagar-Chuksar Island Coastal Sector

Ganga Sagar beach of the South 24 Parganas district, comparatively wider in length, is better known for the Ganga Sagar Mela rather than its acquaintances as a beach. The Makar Sankranti mela at Ganga Sagar attracts thousands of Hindu pilgrims from all over the country. The temple of holy man, Kapil Muni at Ganga Sagar south is a sacred spot where holy Ganga mingled its water with the sea. The festival of Ganga Sagar mela commences on the day of Makar Sankranti i.e., the last day of the month of Poush (a month in Bengali calendar) when the sun enters Capricorn. The spot of Ganga Sagar can be reached by motor launch, barge, vessels from lot No. 8 of Kakdwip. Apart from such mythological interest, Ganga Sagar beach is important for its unique bedforms features where numbers of large-scale and small-scale sedimentary structures are identified.

3.7 Sunderbans Coastal Sector

Sunderbans, a coastal forest with luxuriant mangroves, inundated twice daily on regular basis in the semidiurnal tidal regime, and occurred on the flood plains of the inlets, creeks and rivers and tiger lurking inside the Phoenix (Hental) bushes, has just the perfect blend of natural beauty and mystery to make it a thrilling experience for any tourist visiting the place. Tourism is now flourishing in the deep forests particularly in the buffer zones of Sunderbans. Of late a few private and non-government organizations are coming up with many new tourist projects. The morphodynamics of the mangrove ecosystem in Sunderbans enriched with magnificent biodiversity has cast the possibility for developing ecotourism. Luxuriant mangroves are beautiful and unique. Its calm and quietness is really attractive. Animals are diverse and abundant. Sunderbans is the abode of the famous Royal Bengal Tiger. Apart from the tiger, the major animals found in this region for the tourism attraction include spotted deer, wild boar, rhesus monkeys, estuarine crocodiles, water monitors, dolphins, sea turtles etc. Rare glance of yellow-black striped Royal Bengal tiger is really heart throbbing with the rhythmic undulation of the Hental tree (Phoenix paludosa) which are the major floral components of the Badaban i.e., the Sunderbans. Here the rhesus monkeys cover their bodies with a mud layer protecting them before going to taste honey. Sometimes crocodiles are found lying in the river floodplains like a wood log or water monitors are climbing towards the top of the Garjan tree. Tourist spots with such natural beauties of the Sunderbans are always welcomed by thousands of tourists and nature lovers.

4. COASTAL GEOMORPHIC FEATURES

4.1 Beach zones

The beach including supratidal and intertidal zones is the zone of loose sediments extending from low water level to the coastal dunes or to the uppermost level reached by the storm winds, surf, or swash (up rushing water) as indicated by permanent vegetation or other evidence of wave limit. Beaches may form a continuous approach along straight cliffed coast, along irregular steep coast, the beaches may be restricted to sheltered coves between promontories as pocket beach (e.g., Fraserganj). Along other irregular coasts, beaches may appear as sand spits and bars (submerged or exposed sand ridges, e.g., Bakkhali). Along the low plain coast, beaches appear locally as fringes along the mainland shore but primarily along the seaward side of barrier islands. In the offshore, a submerged barrier island was formed at the Bakkhali coastal region in the east about a decade back, but that natural structure has been modified by the effects of the consecutive cyclonic storms ravaging the coastal region.

4.2 Nature of beach materials

Most beaches consist of sands because of turbulence occurring on the breakers in the inshore region as well as the turbulence shoreward caused by surf and swash, smaller sedimentary particles are kept in suspension and eventually come to rest as mud in the deeper quiet the water offshore. These particles are moved by coastal currents to long distances and finally settle out which are the characteristic features of the coastal areas of West Bengal.

Beaches in calm water or particularly in centered areas may consist of mud. Beach rapidly converted into marshes by accumulation of grasses. Heavy minerals concentration (specific gravity > 2.9) may become exposed by beach face cut back during storm conditions to form a temporary black sand beach. Heavy minerals composing black sand beaches may be biotite, phlogopite, chlorite, garnets, amphiboles, tourmalines, zircon monazite and similar other minerals. Shells and shell fragments are important in many beaches especially in the west coast of India. Shale materials may be abundant because of the supply of terrigenous sands. A concentration of shell by selective sorting process on certain portions of beaches is not uncommon in a portion of Juhu beach adjacent to the Mumbai metropolis. Some beaches in the arid regions are composed of oolites, nearly spherical sand size carbonate grains. These are formed by direct precipitation from the sea water and so are required to warm, shallow agitated super-saturated with calcium carbonate.

4.3 Estuary

An estuary is that portion of the lower coast of a river system (funnel shaped) that experiences tides (e.g., Hooghly-Matla estuary). Estuarine sediments consist of tiniest particles of sediments brought down into the estuary and shifted about by tidal currents until they settle to the bottom. Deposition of sediments may take place far from their point of entry [4].

Estuaries with their associated salt marshes are drowned basins. Tidal marshes, while common to estuaries, are not confined to

them. They may develop in any sheltered area where the process of siltation occurs. Once the vegetation takes fold, it encourages further siltation by acting as a sediment trap, other salt marshes accumulate behind sand spits or bars or at the heads of bays lacking large different rivers (e.g., Junput).

Salt marsh principally Porteresiacoarctata, characteristic features of the coastal areas including Sunderbans spread rapidly over the soft mud of estuaries, and coastal mud-flats. In tropical areas along the coastal fringe of West Bengal, mangroves take the place of these salt marshes, and it typically forms mangrove swamps– a sub-environment characteristic of estuarine and coastal environments. Mangroves is principally but not exclusively a saltwater plant, and its roots must be alternately submerged and exposed if it is to flourish. Estuaries and tidal marshes are unique ecological preserves that act as important stop over for the migrating birds. The life span of estuaries is limited because of filling by the sediments and growth of tidal vegetation.

Cliffed coastal zones are uncommon in the coastal areas of West Bengal apart from the coastal sand dunes bordering the land and sea, though a world-famous estuary (Hooghly-Matla estuary) is present in the coast [2]. Hooghly-Matla estuary occupying the major portion of the coastal areas under South 24 Parganas district of West Bengal is a part of deltaic plain of fluvio-marine deposits of the world's largest Ganga-Brahmaputra delta at the confluence of Bay of Bengal. Naturally the coastal area of West Bengal consists of two major divisions– beach environments of Purba Medinipur district and the deltaic Sunderbans in the Hooghly-Matla estuarine complex under South 24 Parganas district.

4.4 Climate and Hydrology

The climate of the coastal areas of West Bengal is typically tropical oceanic. In the coastal region, three seasons viz., pre-monsoon (March-June), monsoon (July-October) and post-monsoon (November-February) are recognized. Summer temperature is comparatively high and ranges from 28-370C, winter temperature varies from 10-240C. Rainfall is moderate and ranges between 1500 and 2400 mm, salinity of coastal waters ranges from 16 to 31.5 ppt, and pH ranges between 7.5 and 8.6. Salinity becomes higher during the summer and shows low values during the transition period between monsoon and post-monsoon. In general, the West Bengal coast is a mesotidal coast with the tidal amplitude 2-4 m, occasionally it is macrotidal in the monsoon time with > 4 m tidal amplitude. The coastal areas belong to the semidiurnal tidal regime with a slight diurnal inequality. During the monsoon period, heavy rainfall influences the fluctuations of the flood and ebb tidal currents. Wind velocity is moderate and maximum during April to June and ranges from 16.7 – 50 kmph and minimum wind velocity is recorded during the winter (December-February) and varies from 10.7 to 11.8 kmph. Wind velocity becomes higher during cyclonic storms as the coastal West Bengal is a cyclone prone zone. Generally, 2–5 cyclonic storms hit the West Bengal coast every year with strong winds intensifying to 80–160 kmph with gusty winds of 180-190 kmph. Cyclonic storms devastating the

coast modify the coastal configuration by the large-scale littoral drift. Wave heights in the rough sea during the cyclonic storms become higher and it goes up to 3.5-4.5 m, whereas the wave heights from 0.0 to 0.6 m are recorded in a calm and quiet sea with the wave period of 5-7 s. Wave height of the rough sea during the summer ranges between 1.8 m and 2.4 m along the coastal stretch of West Bengal [5].

Coastal tract of West Bengal on the extreme southern portions of Bengal deltaic plain in the Bengal Basin is a geological marvel for its pattern of sedimentation corresponding to the last stand of the transgressive sea during the Holocene period. The age determined from the carbonate samples collected in offshore areas along the coastal tract of West Bengal is about 8200 + 120 years BP which is significant for the coastal region indicating the sediment deposition all along the coast during the last stand at 8000 BP. The upper sediment layer up to 3 to 3.5 m depth from the surface might have been accreted at the rate of 4 cm/100 years [6]. Along the coastal tract of West Bengal, sea beaches like Digha, Bakkhali-Frasergani and Ganga Sagar are century old sea resorts known for the natural beauty and holy bath with the picturesque views of casuarinas admixture with the mangroves all along the coast lines.

Dynamic coastal processes of the West Bengal coast are induced by the tropical cyclones along its entire 210 km length of coastal stretch [7]. Devastation by the consecutive strike of cyclonic storms has modified the coastal nature, characters, and morphology of the West Bengal coast recently. Beaches are widened with the

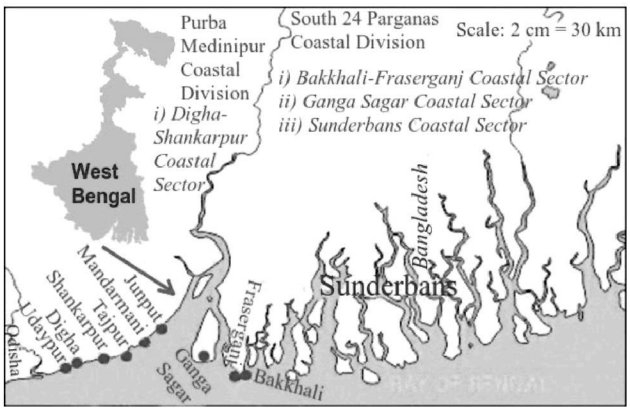

Fig. 1. Location map of the coastal sectors along the coastal tract of West Bengal Coastal processes

excessive supply of sand materials from the sea due to storm surges as observed in the field study. Supply of sands from the land side to the beach areas for abnormal cliff erosion of coastal sand dunes due to rough wave action during the cyclonic storms is unique as interpreted in the Bruun's Rule. According to the Bruun's Rule, submergence is the result of coastal recession and loss of beach materials to the offshore region [8]. Coastal sand dunes, sand flats, runnels and inlets, mudflats, casuarina tree lines, and the mangrove patches are considered as the important morphotypes of the beaches.

5. COASTAL WATERS

Coastal water is very much important for aquatic marine life and benthic dwellers in the intertidal zone along the coastal stretch. Not only for the marine animals, but coastal water is also a natural choice for a beach visitor for sea bathing and surfing that leads to increase the number of tourists and accelerate earning of revenue particularly in the tourism sectors of the sea resorts. The study of coastal waters shows the quality of water has gradually been deteriorating at Bakkhali-Fraserganj and Ganga Sagar coastal areas.

Chemical parameters of coastal water samples result the values of Chemical Oxygen Demand (COD) and Total Dissolved Solids (TDS) of Bakkhali-Fraserganj, and Ganga Sagar areas of West Bengal are beyond the permissible limit and hence the coastal water in these areas becomes polluted (Fig 2). COD ranges from 420 to 671 mg/L, and TDS varies from 664 to 994 mg/L for all three stations of sample collection. Chemical detergents, plastics, batteries, petrochemicals released from the Haldia industrial complex causes the toxic contamination, nutrient enrichment, hypoxia, harmful algal blooms, sedimentation, and many other forms for polluting environment by mixing of pollutant laden Hugli River waters to the coastal waters of the Bay of Bengal that pollutes the coastal water at Bakkhali-Fraserganj and Ganga Sagar coastal region. Other physico-chemical parameters are measured that show the spatial variations of DO ranging from 6.8 to 8.8 mg/L, BOD from 3.9 to 5.7 mg/L, turbidity from 488 to 929 NTU (Fig 2). Count of Bacteria/ml revealed the numbers varies from 77 to 150 in the water samples collected from the coastal region. Water pH, water salinity, and conductivity varies seasonally, where the seasonal variations of pH ranges from 8.11 to 8.68, salinity from 16.2 to 31.6 ppt, water temperature from 27.5 to 31.50C, and conductivity 1.72 to 1.97 Ms/C in the coastal waters of Bakkhali-Fraserganj and Ganga Sagar coastal belt in the extreme southern portionof South 24 Parganas district in West Bengal [9].

6. WAVE PARAMETERS

The environmental studies including the wave parameters of the coastal waters in the intertidal beach areas, in turn, define the environment to facilitate coastal zone management of Digha – Shankarpur coastal stretch of Purba Medinipur district, West Bengal. Visually the Junput part is an accretional area whereas well-known tourist spot Digha is a site of erosion. Old Digha in the east has comparatively a steeper topographically beach with high beach slope values than Shankarpur in the east and New Digha and Udaipur of the west part along the coast of Purba Medinipur. Spilling type breakers at Digha coastal belt are generally rare. Approaches of spilling to collapsing type of breakers with occasional minor plunging to surging nature in the surf zone of the beach are recorded with an average angle between 30 and 50 and current speed varying from 17 cm/s to 25 cm/s. Average wave height varies in between 1.5 and 2.2 m though the breakers generally form with an average wave height of 49 cm [10]. Entire coastal areas of Digha have gradually been eroded from the regular wave action. Sea levels rise due to global warming probably increases the wave height and intensifies the wave action along the coastal stretch of West Bengal (Table 1).

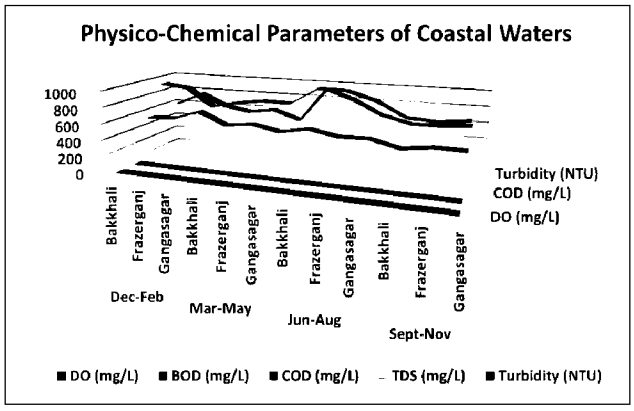

Fig. 2. Physico-chemical parameters of the coastal waters collected at Bakkhali, Fraserganj and Ganga Sagar coastal areas

Table 1 : Beach environment and wave parameters along the Digha– Shankarpur coastal stretch of West Bengal

Wave Parameters	Data Collected
Average Beach Width	80 m to 290 m
Average Beach Slope	0.45^0 to 1.43^0 ($< 5^0$)
Grain Size	Fine grained sand admixed with clayey silt
	49 cm
Average Wave Height (H)	17 cm
Average Wave Period (T)	65.21 m
Average Wavelength (L) at a water depth of 1.5 m	0.065
Wave Steepness (H/L)	4.60
Surf Scaling Factor (Ý)	282.5
Wave Energy (E)	

7. TYPES OF BREAKERS

Breaking types are identified categorically into spilling, plunging, collapsing, and surging breakers along the coastal tract of West Bengal. Breaker types are classified using the following formula of hydrodynamic phenomenon,

$$\xi_0 = \frac{m}{(H_0/L_0)^{1/2}}$$

Where, m = beach slope, H_0 = deep-sea wave height, and L_0 = deep-sea wavelength. A breaking type with the values of ξ_0<0.5 indicates spilling breakers, a plunging breaker is estimated with the values, ξ_0= 0.5 to 3.3, and when ξ_0>3.3, it is typically a surging breaker [11, 12, 13]. Spilling breakers are an undulation of water mass and these types of breakers never break as they move with low energy. Spilling breakers are characteristically common physical features of Bakkhali-Fraserganj and Ganga Sagar coastal region of South 24 Parganas district and Junput, Mandarmani, Tajpur, Shankarpur, Digha Mohana, New Digha, and Udaipur beaches of Purba Medinipur district in the calm and quiet situations of the sea during the post-monsoon period. Comparatively steeper upper wave crest that breaks in the surf zone of the intertidal region is a plunging breaker, and plunging breakers are characteristic features at Old Digha during the period from March to September. Over-steepened wave crest and plunging thereon forms the surging breakers, and they break into huge surf on the beach covering a large area. Plunging to surging breakers are the characteristic features of Old Digha coastal zone particularly in the sea situations during summer months for its comparatively steeper beach slopes. Breaker height of 14.9 cm with a wave period of 4 secs is the characteristic feature of the collapsing types of breakers (Table 2). Average beach slope of Digha-Shankarpur is between 0.50 and 1.50. The breaker types along the coastal tract of West Bengal are spilling to surging as per the hydrodynamic phenomenon considering the factors like beach slope, deep-sea wave height, and deep-sea wavelength [14, 15].

The breaker types are further classified by the determination of the surf scaling factor following the formula of Wright et al. (1985), $\in$ = a.2π/Gt $\tan^2$ß, where a = wave height, and ß = beach slope [16, 17]. According to

surf scaling factor values, breakers are spilling to collapsing types almost round the year in Junput, Mandarmani, Tajpur, Shankarpur, Digha Mohana, New Digha, and Udaipur beaches of Purba Medinipur district and Bakkhali-Fraserganj and Ganga Sagar coastal region of South 24 Parganas district along the coastal stretch of West Bengal (Table 2).

Table 2 : Types of breakers along the coastal stretch of West Bengal

Breaker types	Season		
	Pre-monsoon	Monsoon	Post-monsoon
Spilling			Bakkhali-Fraserganj, Ganga Sagar, New Digha, Shankarpur, Udaipur, Mandarmani, Tajpur, Junput
Plunging	Old Digha	Old Digha	
Surging	Old Digha	Old Digha	
Collapsing	Old Digha, New Digha, Shankarpur, Udaipur, Mandarmani, Tajpur, Junput	Bakkhali-Fraserganj, Ganga Sagar, New Digha, Shankarpur, Udaipur, Mandarmani, Tajpur, Junput	

8. BEACH WIDTH AND BEACH SLOPE

The fluctuation of tides in the form of rise and fall of water level causes migration of energy zones which result in characteristic features dependent on important factors like beach slope, local morphology, water depth, flow velocity, and sediment grain size. Sea beaches in the present study areas along the seashores of West Bengal are almost horizontal, flat, and wide. The beach width is directly correlated with the beach slope as the beach width increases with the low values of beach slopes where the vigour of wave action is also comparatively lower. The beach width of Shankarpur coastal areas is recorded maximum (407 m), where the beach slope of the same traverse is just the minimum (0.420). In the present field observations, the minimum beach width (44 m) and maximum beach slope (1.640) are observed at Old Digha area along the coastal tract of Purba Medinipur district of West Bengal (Table 3).

Table 3 : Average beach width and beach slope along the coastal stretch of West Bengal

Beach parameters	Name of the beaches				
	Bakkhali-Fraserganj	Ganga Sagar	Junput	Mandarmani	Tajpur
Beach width (m)	242	165	102	83	65
Beach slope (^{0})	0.88	0.91	1.04	1.19	1.52
	Shankarpur	Digha Mohana	Old Digha	New Digha	Udaipur
Beach width (m)	407	117	44	210	182
Beach slope (^{0})	0.42	1.46	1.64	0.84	0.98

9. COASTAL VEGETATION

Vegetation pattern controls the morphology, evolution, and abundance of coastal sand dunes. Herbaceous vegetation like creepers and grasses control the stabilization of these sand dunes in the coastal tract of West Bengal. Vegetation that initiates the forma-tion of the coastal dunes are herbs like *Salicornia* sp., *Suaeda maritima, Aeluropuslagopoides, Ipomoea pes-caprae, Launica* sp., *Sesuviumportulacastrum,* and grass like Paspalum vaginatum. These plant types help in the initiation of the embryonic phase of a coastal sand dune. With time, roots and rootlets of the herbaceous plants stabilize the dunes by acting as the sand binders. Dune vegetation helps in the growth of the coastal dune by trapping sand grains and ultimately stabilizing it by arresting the migration of the coastal sand dunes due to strong wind action coming out of the Bay of Bengal along the coastal stretch of West Bengal. Apart from the coastal dune vegetation, coastal vegetation consists of mangroves and casuarina tree lines. Mangrove vegetation is occasional in the coastal region of the state and is common in Bakkhali, Ganga Sagar, Junput, Tajpur, and Shankarpur coastal zone.

In the present study areas, the coastal morphodynamics, coastal processes and structures are greatly influenced by the coastal vegetation cover and its pattern. Natural vegetation as well as plantation species, enrich the coastal vegetation along the coastlines of West Bengal (Fig 3).Rich coastal vegetation along the coastlines of West Bengal is considered as an ecologically sensitive area. Coastal areas of Bakkhali-Fraserganj, Ganga Sagar, Junput, Shankarpur and Tajpur are covered with *Casuarina equisetifolia, Tamarix gallica,* and mangroves like *Avicennia marina* and *Excoecariaag-allocha* and *Phoenix* paludosa. Among them, *Casuarina equisetifolia* is the dominant species, whereas mangroves grow along the bank of Bakkhali creek, Mandar Mohan creek, Pichhaboni creek, and Diges Mohan creek, particularly in the muddy substratum inundated twice daily with the flood tide, and *Tamarix gallica* exists mainly in the sandy substrate soils. Coexistence of *Casuarina equisetifolia,* mangroves, and T*amarix gallica* compose the floral assemblages in the Bakkhali-Fraserganj coastal areas, whereas coastal vegetation consists of casuarina plantations in New Digha, and Udaipur coastal tract and vegetation is introduced by the forest department under the social forestry scheme. Cyclonic storms destroy coastal vegetation particularly the casuarina tree lines by consecutive strikes in the coastal areas of West Bengal (Fig4).

10. COASTAL SEDIMENT COMPOSITION

Beach sediments of the intertidal zone, mostly light grey in colour comprising 99% of light minerals, consists of quartz and chert (70-75%) and feldspar about 20-25%, and 1-5% heavy minerals like amphibole, pyroxene, epidote-zoisite, tourmaline, sphene, apatite, and oxides of iron. Availability of biotite is seen concentrating in certain laminations which are significant to mark delineations of laminations in some sections. Mineralogical analysis revealed the presence of calcite grains in the intertidal beach sediments. The coastal sediments collected from the beach areas of Bakkhali-Fraserganj, Ganga Sagar, Digha-

Shankarpur coastal areas show that the crystalline, metamorphic, and sedimentary rocks indicate source rocks of origin for coastal sediments in West Bengal [18]. Mineralogical studies revealed that the crystalline rocks and the metamorphic rocks are the source rocks of minerals identified from the collected sediment samples using a petrological microscope. Minerals like Zircon, tourmaline, rutile, topaz, barite, hornblende, olivine, apatite, magnetite,and ilmeniteareof crystalline rock origin, and the rest of the minerals like epidote, zoisite, garnet, kyanite, sillimanite like minerals is of metamorphic rocks origin.

Fig. 3. Casuarina plantations along the coastlines of New Digha

Fig. 4. Ravaged coastal vegetation because of consecutive strikes by the cyclonic storms at Shankarpur coastal areas of West Bengal

11. SEDIMENT GRAIN SIZE ANALYSIS

The beach sediments of the intertidal zone show fine sand in nature defining the area belonging to the medium hydrodynamic regime. Sedimentary structures in the foreshore of beach areas are almost absent. Beach sediment samples, eight in number, were collected from New Digha and Shankarpur and analyzed in detail by using mechanical sieve. The sediments are generally siliciclastic by nature. Only one lower intertidal sand sample from New Digha beach is with a small quantity of granules. Feldspar and quartz constitute the rest. Almost all sandy beach sediments are well sorted (σ_1 = 0.44 to 0.74 phi) with graphic mean size belonging mostly to the sand fraction (M_Z = 3.14 to 3.36 phi). About 50% of the total samples show a slight tendency of negative skewness (SK_1). All sediment samples collected from New Digha beach are slightly negatively skewed and beach sand samples from Shankarpur are all positively skewed [19, 20]. The cumulative curves mostly show a high peakedness with K_G (kurtosis) values often close to 1.0 (Fig 5).

The sand flats of Ganga Sagar and Bakkhali-Fraserganj coastal region exist parallel to the coastlines and marked lateral extension compared to the thickness. The beach samples collected from the open-sea and mixed intertidal zone of Ganga Sagar of southern part of West Bengal revealed about 99% fine to very fine well-sorted sands. The graphic mean size (M_Z) ranges between 1.734 and 3.168 phi and belongs to fine sandy beach materials. The inclusive graphic standard deviation (σ_1) ranges between 0.255 and 0.48 indicating an excellent sorting of the sand samples. For dune samples, the sorting value reflects a second cycle wind transportation of the previously reworked intertidal zone sediments. Collected sediment samples show a positive skewness (SK_1) and ranges from 0.15 to 0.478 phi. Kurtosis (K_G) ranges between 0.746 and 2.077 phi, a value characteristic for lognormal distribution (Fig.5).

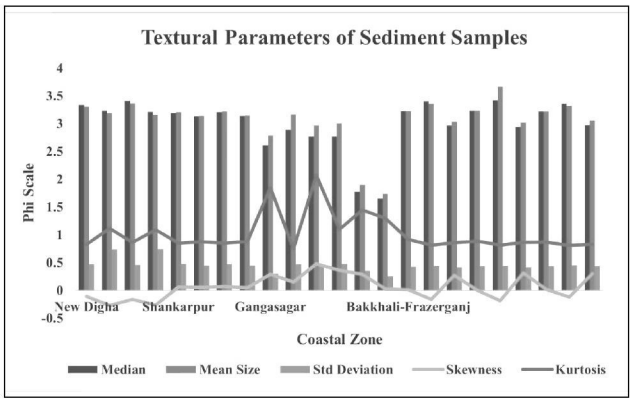

Fig.5 Textural parameters of the collected sediment samplesalong the coastal tract of West Bengal

The beach samples collected from the dunes, open-sea and mixed intertidal zone of Bakkhali-Fraserganj consist of 99% fine to very fine well-sorted sands. The graphic mean size (M_Z) ranges between 3.021 to 3.664 phi and belongs to very fine sandy beach materials. The inclusive graphic standard deviation (σ_1) ranges between 0.3510 and 0.4515 phi indicating an excellent sorting of the sand samples. For dune samples, the sorting value reflects a second cycle wind transportation of the previously reworked intertidal zone sediments. Collected sediment samples show a slightly negative to slightly positively skewed and the skewness (SK_1) value for Bakkhali-Fraserganj beach sands ranges from -0.1221 to 0.3146 phi. Kurtosis (K_G) revealed mostly platykurtic and ranges

between 0.8059 and 0.9176 phi indicating a value characteristic for lognormal distribution (Fig 5). Overall, the dune samples, in general, show a finer size and well sorting and revealed rather better sorting than those samples collected from the intertidal zone adjoining the coastal sand dunes. The cumulative curves for the beach sands of dune and intertidal zones are mostly non-linear with saltation mode of sediment transport as the chief population for the distributions and very similar in pattern for both Ganga Sagar and Bakkhali-Fraserganj coastal areas [21, 22]. Inflections at 2.5 to 3.5 phi is a statistical fact for all the samples and all the cumulative curves show close resemblances in pattern with each other.

12. SEDIMENTARY STRUCTURES

Bedforms in the intertidal zone of the beaches are regular in appearance during ebb tide after recession of waters. Among the beaches along the coastal stretches of West Bengal, Ganga Sagar beach shows diversity in occurrences of the sedimentary structures including mega ripples and antidunes superimposed with the other forms of the small-scale bedforms. The large-scale bedforms like mega ripples of both flood and ebb-oriented types are found generally in the mid intertidal zone superimposed with the small-scale ripple marks. Small-scale ripple marks are identified, and they are current ripple marks, wave ripple marks, current crescents, rhomboid ripple marks, tadpole nests, interference ripple marks and rill marks (Fig6). Large-scale and small-scale ripple marks are the common bedforms features of both Ganga Sagar and Bakkhali-Fraserganj beaches, whereas both the large-scale and small-scale bedforms are less visible in the beaches of Digha-Shankarpur sea beaches due to comparatively high wave vigour and strong tidal current. Swash marks comprising litters and debris, and backwash marks with high concentration of biotite and blackish in colour are identified in the intertidal zone in most of the beaches of coastal West Bengal. Beddings like flaser bedding, convolute bedding, and graded bedding with the traces of grass roots are visible in the places of erosion due to wave strike and tidal actions. Such erosional features in the form of bedding structures help in the interpretation of the coastal morphodynamics along the coastal tract of West Bengal [23].

Systematic variations of the bedforms are noticed in the beach profiles in the coastal West Bengal. Ripple marks and rill marks are common in almost all the beaches along the coastal region of West Bengal (Fig.6). Associated with these beach structures, bioturbation structures and accumulation of massive mud layers of variable thickness are also noticed. Ridges and runnels which migrate across the foreshore further impart some characteristic features of these beaches.

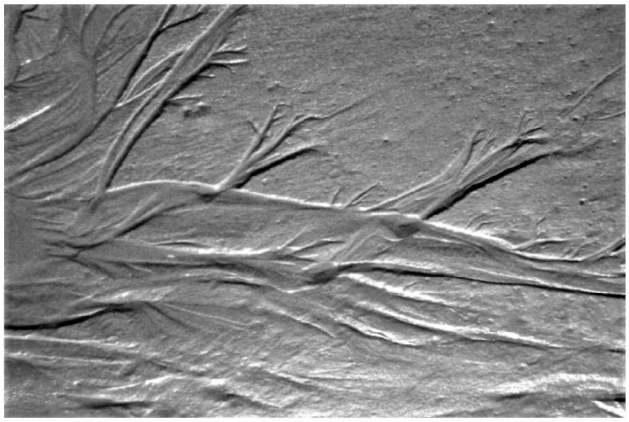

Fig. 6. Rill marks in the Bakkhali beach of West Bengal

13. CONCLUSION

Evidenced by erosional features, the entire coastal region of West Bengal is considered as a vulnerable coast as it stands in a cyclone prone area. Other than the huge devastation by the natural calamity, coastal areas of West Bengal are severely affected by the man-made pollution. Pollutants are introduced by the man directly or indirectly into the waters of coastal areas resulting in such deleterious effects as harm to aquatic living organisms, human health hazards, inhibition of fishing, navigation, tourism recreation and amenities [24]. There are several sources of pollutants in the coastal waters, such as sediments contained in the riverine inputs from the overland runoff from the river upstream will settle into the coastal waters. These materials can be damaging to aquatic life by burying them or clogging their gills or filtering organs and lead to detrimental effects to bathing or surfing by the sea visitors in the coastal waters. Intentional and negligent discharge of oil spills for the purpose of tank washing by the fishing trawlers transfer into the coastal waters cause the hazards to the aquatic lives and has made problems for the coastal amenities. Plastic and polythene packets are seen trapped in the beach sands which are further drifted to the coastlines with the water during flood tide. Plastic being a non-biodegradable waste poses a threat to the coastal ecosystem. It may lead to soil erosion and a hazardous agent towards the destruction of ecological balance for the coastal region. Even the microbial activities in the soil which help in decomposing the biodegradable materials will be destroyed if the soil is contaminated with the microscopic, tiny particles of the plastics. The coastal ecosystem can be pollution free if the locals, tourists, and the hotel owners show more responsibility by avoiding such litter thrown in the coastal areas, and none cannot avoid making a mistake in such matters for the maintenance of the coastal health of West Bengal. Along with the dynamic coastal processes, the biological factors play an important role in coastal evolution of West Bengal, and because of this reason, West Bengal coast is a biogenous coast. In such a vulnerable coast, artificial regeneration of coastal vegetation will be immensely helpful for the sustainable management of the coastal environment along the coastal stretch of West Bengal [25]. In the present study areas, the coastal morphodynamics, coastal processes and structures are greatly influenced by the coastal vegetation cover and its pattern. No change in the mineral deposits of coastal sediments in the coastal areas of West Bengal due to anthropogenic activities along the coastal line is reported. The sedimentary structures and erosional features along the coastal stretch of West Bengal are common parameters that interpret the coastal morphodynamics [26, 27].

REFERENCES

[1] Das, G. K., Cyclonic Hazards in the Recent Past in Peninsular India, Reason- A Technical Journal, Vol XIX, pp. 1-15, 2020. DOI:10.21843/reas/2020/1-15/209270

[2] Das, G. K., Forest Covers of West Bengal: A District-wise Review, Reason- A Technical Journal, Vol XIX, pp. 26-63, 2020. DOI:10.21843/reas/2020/26-63/209272

[3] Das, G. K., Sunderbans – Environment and Ecosystem, Sarat Book House, Kolkata, 254p., 2011.

[4] Das, G. K., Estuarine Morphodynamics of the Sunderbans, Springer, Switzerland, 211p., 2015.

[5] Das, G. K., and Bhattacharya, A., Dynamic Geomorphic Environment of Indian Sunderbans, pp. 284-298, in Changing Environmental Scenario of the Indian Subcontinent, ed. S. R. Basu, ACB publication, 471 p., 2002.

[6] Bhattacharyya, S., Rakshit, S., Roy Chaudhuri, S and Sengupta, R., Formation of Concretions and Compact Sediment – an Evidence of Holocene Sea Level still Stand, Geological Survey of India Report, Newsletter, Marine Wing, Vol. XVII, No. 1, pp. 18-19, 2003.

[7] Das, G. K., Tidal Sedimentation in the Sunderban's Thakuran Basin, Springer, Switzerland, 151p., 2017.

[8] Bhattacharya, A., Some Geomorphic Observations Indicating Shoreline Variation in the Coastal Tract of West Bengal (India) – A Case Study around Bakkhali in Sunderbans, Proc. Int. Quat. Seminar on INQUA Shoreline, Indian Ocean Sub-Commission, pp.32-37, 2000.

[9] Das, G. K., Environment Status of Bakkhali Beach, West Bengal, Geographical Review of India, Vol. 72, No.2, pp. 132–139, 2010.

[10] Mitra, P. K. and Samadder, A. K., Correlation of Wave Parameters with Beach Slope along Some Selected Coastal Tracts of West Bengal and Orissa, Geological Survey of India Report, Newsletter, Marine Wing, Vol. XVII, No.1, pp. 20-22, 2003.

[11] Samanta, S. and Paul, S. K., Geospatial Analysis of Shoreline and Land Use/ Land Cover Changes through Remote Sensing and GIS Techniques, Model Earth Syst. Environ. Vol. 2, p. 108, 2016. https://doi.org/10.1007/s40808-016-0180-0.

[12] Samanta, S. and Pal, D. K., Change Detection of Land Use and Land Cover over a Period of 20 Years in Papua New Guinea, Nat Sci, Vol. 8, pp. 138–151, 2016. DOI:10.4236/ns.2016.83017.

[13] Schwartz, M., Encyclopedia of Coastal Science, Springer, Netherlands, 1097 p., 2005.

[14] Shore Protection Manual. US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, US Government Printing Office, Washington, DC, Vol. 14, No. 2, pp.587–601, 1984.

[15] Zuzek, P. J., Nairn, R. B. and Thieme, S. J. Spatial and Temporal Consideration for Calculating Shoreline Change Rates in the Great Lakes Basin, J. Coast Res, Vol. 38, pp.125–146, 2003.

[16] Wright, L. D., Short, A. and Green, M., Short-term Changes in the Morphodynamic States of Beaches and Surf Zones: An Empirical Predictive Model, Marine Geology, Vol. 62, No.3-4, pp. 339-364, 1985. DOI: 10.1016/0025-3227(85)90123-9.

[17] Janssen, P., The Interaction of Ocean Waves and Wind, Cambridge Univ. Press, Cambridge, UK, 2004.

[18] Das, G. K., Sedimentation Processes in the Thakuran River Basin, Sunderbans, India. In Bengal Basin, Ed. S. R. Basu, ACB Publication, Kolkata, 2004.

[19] Das, G. K., Sediment Grain Size, pp. 555–558. In: Encyclopedia of Estuaries, M. J. Kennish (Ed.), Springer, 760p., 2016.

[20] Das, G. K., Sediment Characteristics of Beach Sands of Digha and Talseri, Indian Science Cruiser, Vol. 22, No. 5, pp.17-23, 2008.

[21] Das, G. K., Beach Processes of Tidal Islands of Hugli Estuary, West Bengal, Geographical Review of India, Vol. 71, No. 3, pp.240-248, 2009.

[22] Komar, P.D., Beach Processes and Sedimentation, Englewood Cliffs, Prentice-Hall, 1976.

[23] Das, G. K., Sedimentary Structures, pp. 568–572. In: Encyclopedia of Estuaries. M. J. Kennish (Ed.), Springer, 760 p., 2016.

[24] Das, G. K., Trash in the Sea Beach, Indian Science Cruiser, Vol. 23, No.2, pp.8-9, 2009.

[25] Das, G. K., Forests and Forestry of West Bengal– Survey and Analysis, Springer, pp. 1-231, 2021. DOI: 10.1007/978-3-030-80706-1

[26] Das, G. K., Multiple Correlation Analysis among Dominant Species of Coastal Vegetation at Bakkhali-Fraserganj, West Bengal, Indian Science Cruiser, Vol. 36, No.1, pp. 44-47.

[27] Das, G. K., Coastal Zone Management of West Bengal– A Review, Indian Science Cruiser, Vol. 36, No. 1, pp. 28-38.