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Review Paper

Beach Environments along the Coastal Stretches of West Bengal, India

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Abstract

West Bengal coast has been classified as a typical lowland coast by its origin and is a very significant product of extensive fluvio-marine deposits carried by the Ganga River and the Bay of Bengal. Tidal fluctuations, wave parameters, long shore currents, sand flats, and beach ridges are the characteristic features of the coastal areas of West Bengal. Beach is one of the dominant features in the coastal region that explains the characteristics and nature of the coast. Steep wave crests break in the surf zone of the beach and the formation of breakers depends on the beach width and beach slope, and the breaking types, in general, are spilling to collapsing as recorded in the West Bengal coasts. In the beach environment, higher the beach width, less the beach slope, and both these factors control the wave parameters as wave is one of the important factors in controlling the nature and shape of the depositional environment as well as the grain size distribution of the coastal areas. Observations revealed that the coastal region of West Bengal is an erosive one as it is a cyclone prone area. The cyclonic storms that ravaged the coast off and on devastate the coastlines on a regular basis indicating the West Bengal coastal zone as a vulnerable one. Sea level rise due to climatic change is another factor that might be considered as a probable reason for the coastal erosion in most of the beaches in South 24 Parganas and Purba Medinipur districts comprising coastal regions in the state of West Bengal. Such erosional features and the bedding structures exposed along the plain of erosional sites help in the interpretation of the coastal morphodynamics along the vulnerable coastal tract of the state.

Keywords: Coastal processes, Wave parameters, Beach morphology, Bedforms, Sediment texture, Breakers, Coastal waters, Beach characters.

Introduction

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, 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 river islands along the coastal stretch. The coastline of West Bengal is not a continuous one as the Hugli River flows in between South 24 Parganas and Purba Medinipur districts that comprises the coastal areas of the state[1]. The Hugli River estuary acts as a vertical border in between the districts breaking the continuity of the coastlines and meets the Bay of Bengal in the extreme south of the state.

Coastal zone of South 24 Parganas

Mangroves cover almost entire areas of the extreme southern portion of the district particularly in the Sunderbans except two famous sea resorts like 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. Among sea beaches, salient coastal features of Bakkhali-Fraserganj, and Ganga Sagar of South 24 Parganas district and their significance are the objectives of the present study. Bakkhali-Fraserganj, and

Ganga Sagar are enlisted as sea resorts in the map of tourism along the coastal stretch of West Bengal[2].

Coastal Areas of Purba Medinipur

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 zone. Among sea beaches, Digha, Shankarpur, Mandarmani, Tajpur, Junput, and Udaipur of Purba Medinipur district are considered for the present study that are also enlisted in the map of tourism along the coastal stretch of West Bengal.

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 28-37^{0}C, winter temperature varies from 10-24^{0}C. 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 2-4m, 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 – 50kmph and minimum wind velocity is recorded during the winter (December-February) and varies from 10.7 to 11.8kmph. 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 80–160kmph with gusty winds of 180-190kmph. 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 3.5-4.5m, whereas the wave heights from 0.0 to 0.6m are recorded in a calm and quiet sea with the wave period of 5-7secs. Wave height of the rough sea during the summer ranges between 1.8m and 2.4m along the coastal stretch of West Bengal[3].

Coastal processes

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 3.5m depth from the surface might have been accreted at the rate of 4 cm/100 years[4]. Along the coastal tract of West Bengal, sea beaches like Digha, Bakkhali-Fraserganj 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 210km length of coastal stretch[5]. Devastation by the consecutive strike of cyclonic storms have modified the coastal nature, characters, and morphology of the West Bengal coast recently. Beaches are widened with the 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[6]. 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.

Coastal Sediment composition

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[7]. 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, horn-blende, olivine, apatite, magnetite, and ilmenite are of crystalline rock origin, and the rest of the minerals like epidote, zoisite, garnet, kyanite, sillimanite and biotite like minerals are of metamorphic rocks origin.

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-Frazerganj 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-

Frazerganj and Ganga Sagar areas of West Bengal are beyond the permissible limit and hence the coastal water in these particular areas becomes polluted. COD ranges from 420 to 671 mg/L, and TDS varies from 664 to 994mg/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 shows the spatial variations of DO ranging from 6.8 to 8.8mg/L, BOD from 3.9 to 5.7mg/L, turbidity from 488 to 929 NTU, and count of Bacteria/ml shows the numbers varies from 77 to 150. 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 31.6ppt, water temperature from 27.5 to 31.5^{0}C, and conductivity 1.72 to 1.97 Ms/C in the coastal waters of Bakkhali-Fraserganj and Ganga Sagar coastal belt of West Bengal[8].

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 3^0 and 5^0 and current speed varying from 17cm/sec to 25cm/sec. Average wave height varies in between 1.5 and 2.2m though the breakers generally form with an average wave height of 49cm [9]. 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).

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[10-12]. 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-Frasergunj and Gangasagar coastal region of South 24 Parganas district and Junput, Mandarmani, Tajpur, Shankarpur, Digha Mohana, New Digha, and Udaipur beaches 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. Average beach slope of Digha-Shankarpur is between 0.5^0 and 1.5^0. 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[13-14].

Table-1: Environment and wave parameters along the Digha – Shankarpur coastal stretch of West Bengal[9].

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
Average Wave Height (H)	49 cm
Average Wave Period (T)	17 cm
Average Wavelength (L) at a water depth of 1.5 m	65.21 m
Wave Steepness (H/L)	0.065
Surf Scaling Factor (Ý)	4.60
Wave Energy (E)	282.5

The breaker types are further classified by the determination of the surf scaling factor following the formula of Wright et al., (1985), $\in = a.2\pi/Gt \tan^2ß$, where a = wave height, and ß = beach slope[15-16]. 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, Bakkhali- Fraserganj and Ganga Sagar coastal region of West Bengal (Table-2)[9].

Beach width and beach slope

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 (0.42^0). In the present field observations, the minimum beach width (44 m) and maximum beach slope (1.64^0) are observed at Old Digha area along the coastal tract of Purba Medinipur district of West Bengal (Table-3).

Coastal vegetation: Vegetation pattern controls the morphology, evolution, and abundance of coastal sand dunes. Herbaceous vegetation like creepers and grasses control the stabilization of the sand dunes. Vegetation that initiates the formation of the coastal dunes are herbs like *Salicornia* sp., *Suaeda maritima*, *Suaeda nudiflora*, *Aeluropus lagopoides*, *Ipomoea pes-caprae*, *Launica* sp., *Sesuvium portulacastrum*, 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.

Rich coastal vegetation along the coastlines of West Bengal is considered as an ecologically sensitive area. Coastal areas of Bakkhali-Frazerganj, Ganga Sagar, Junput, Shankarpur, and Tajpur is covered with *Casuarina equisetifolia*, *Tamarix gallica*, and mangroves like *Avicennia marina* and *Excoecaria agallocha* 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 *Tamarix gallica* compose the floral assemblages in the Bakkhali- Frazerganj 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 (Figure-1).

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

Breaker types	Season		
	Pre-monsoon	Monsoon	Post-monsoon
Spilling			Bakkhali-Frasergunj, 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-Frasergunj, Ganga Sagar, New Digha, Shankarpur, Udaipur, Mandarmani, Tajpur, Junput	

Table-3: Average beach width and beach slope for selected spots of the West Bengal coast.

Beach parameters	Name of the beaches				
	Bakkhali-Frasergunj	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

Figure-1: Ravaged coastal vegetation because of consecutive strikes by the cyclonic storms at Bakkhali along the coastal stretches of West Bengal.

Digha – Shankarpur coastlines: 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. Lush green coastal vegetation, on an average 100-150 feet high, exists parallel to the sea beach. The coastal town Digha (Latitude $21^0$37'N and Longitude $87^0$31'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, 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 then faced devastating waves, almost about three to five meters high. 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.

Grain size analysis of Digha-Shankarpur

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 (Table-4). 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. The cumulative curves mostly show a high peakedness with K_G (kurtosis) values often close to 1.0 (Table 5)[17-18].

Table-4: Composition of beach materials sampled from the Digha-Shankarpur coastal stretch.

Sample* No	Granule (%)	Sand (%)	Silt (%)	Clay (%)
ND-1	-	98.5062	1.4938	0.0
ND-2	0.1473	94.9179	4.9348	0.0
ND-3	-	97.6059	2.3941	0.0
ND-4	-	95.3732	4.6268	0.0
SK-1	-	96.5745	3.4255	0.0
SK-2	-	98.9897	1.0103	0.0
SK-3	-	96.0297	3.9703	0.0
SK-4	-	99.1399	0.8601	0.0

*ND – New Digha, SK – Shankarpur.

Bakkhali-Fraserganj and Ganga Sagar

Fraserganj and Bakkhali are the sea resorts of beautiful landscape and beautiful enchantments amidst tall casuarinas at the coast of the Bay of Bengal. Both these sea-resorts with the distances of approximately 2km in between the spots. Fraserganj and Bakkhali stand at the distances of 130 and 132 kms from Kolkata respectively and both the places can be reached by crossing the recently built Hatania Doania bridge at Namkhana and then travelling another 25 kms by road towards the extreme south.

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.

Grain size analysis of Ganga Sagar and Bakkhali-Fraserganj

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 (SI) 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 (Table-6, 7).

The beach samples collected from the dunes, open-sea and mixed intertidal zone of Bakkhali- Fraserganj (BF) 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 (Table-6, 7). 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 linear in shape and very similar in pattern for both Ganga Sagar and Bakkhali-Frasergunj coastal areas[19-20].

Table-5: Textural parameters of beach sediments of Digha-Shankarpur coastal areas.

Sample* No	Median (Md)	Mean (M_Z)	Standard deviation (σ_1)	Skewness (SK_1)	Kurtosis (K_G)
ND-1	3.3317	3.3014	0.4733	-0.1089	0.8277
ND-2	3.2338	3.1870	0.7392	-0.2683	1.1165
ND-3	3.4042	3.3634	0.4594	-0.1635	0.8612
ND-4	3.2155	3.1620	0.7413	-0.2637	1.0948
SK-1	3.1894	3.2043	0.4754	0.0612	0.8489
SK-2	3.1362	3.1412	0.4487	0.0565	0.8770
SK-3	3.2044	3.2222	0.4702	0.0693	0.8510
SK-4	3.1413	3.1449	0.4465	0.0516	0.8792

*ND – New Digha, SK – Shankarpur.

Table-6: Textural analysis of beach materials of Ganga Sagar and Bakkhali-Frazerganj coastal areas.

Sample* Number	Median (Md)	Mean (M_Z)	Standard Deviation (σ_1)	Kurtosis (K_G)	Skewness (SK_1)
SI-1 (IT)	2.61	2.783	0.304	1.85	0.292
SI-2 (IT)	2.89	3.168	0.47	0.746	0.15
SI-3 (IT)	2.765	2.967	0.452	2.077	0.478
SI-4 (IT)	2.768	3.0	0.48	1.096	0.362
SI-5 (IT)	1.77	1.9	0.351	1.447	0.291
SI-6 (IT)	1.65	1.734	0.255	1.295	0.027
BF-1 (D)	3.2239	3.2241	0.4304	0.9176	0.0124
BF-2 (ST)	3.3994	3.3559	0.4423	0.8116	-0.1614
BF-3 (IT)	2.9637	3.0329	0.4173	0.8554	0.2726
BF- 4 (D)	3.2336	3.233	0.4371	0.8862	0.0037
BF-5 (ST)	3.4163	3.664	0.4413	0.8127	-0.1831
BF-6 (IT)	2.9428	3.021	0.4185	0.862	0.3146
BF-7 (D)	3.2188	3.2217	0.4369	0.8702	0.0207
BF-8 (ST)	3.3573	3.3236	0.4515	0.8059	-0.1221
BF-9 (IT)	2.9693	3.0545	0.4359	0.8306	0.3038

* SI – Gangasagar, BF – Bakkhali-Frazerganj; Sediment type – Sand in all beaches; U – Upper, L – Lower, IT – Intertidal, ST – Supratidal, D – Dune.

Table-7: Granulometric analysis of beach sands of Ganga Sagar and Bakkhali-Frazerganj coastal areas.

Sample* Number	Granule (%)	Sand (%)	Silt (%)	Clay (%)
SI-1 (IT)	0.0	99.97	0.68	0.0
SI-2 (IT)	0.0	99.32	0.09	0.0
SI-3 (IT)	0.0	99.91	0.09	0.0
SI-4 (IT)	0.0	99.27	0.0	0.0
SI-5 (IT)	0.0	100	0.0	0.0
SI-6 (IT)	0.0	100	0.0	0.0
BF-1 (D)	0.0	100	0.0	0.0
BF-2 (ST)	0.0	100	0.0	0.0
BF-3 (IT)	0.0	100	0.0	0.0
BF-4 (D)	0.0	100	0.0	0.0
BF-5 (ST)	0.0	100	0.0	0.0
BF-6 (IT)	0.0	100	0.0	0.0
BF-7 (D)	0.0	100	0.0	0.0
BF-8 (ST)	0.0	100	0.0	0.0
BF-9 (IT)	0.0	100	0.0	0.0

*SI – Gangasagar, BF – Bakkhali- Frazerganj; Sediment type – Sand in all beaches; U – Upper, L – Lower, IT – Intertidal, ST – Supratidal, D – Dune

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 megaripples and antidunes superimposed with the other forms of the small-scale bedforms. The large-scale bedforms like megaripples 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 (Figure-2). Large-scale and small-scale ripple marks are the common bedforms features of both Ganga Sagar and Bakkhali- Frazerganj 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 helps in the interpretation of morphodynamics of West Bengal coast[21].

Conclusion

Entire coastal region of West Bengal is considered as a vulnerable coast as it is 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[22]. 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 discharges 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, West Bengal coast is a biogenous coast as the coastal environment is controlled by several biological factors.

Figure-2: Wave ripples in the Udaipur beach of West Bengal.

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