Journal of Coastal Research	15	4	902–908	Royal Palm Beach, Florida	Fall 1999

Morphology and Sediments of the Cox's Bazar Coastal Plain, South-East Bangladesh

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ABSTRACT

ALAM, M.D.; HUQ, N.E. and RASHID, M.S., 1999. Morphology and Sediments of the Cox's Bazar Coastal Plain South-East Bangladesh. *Journal of Coastal Research,* 15(4), 902–908. Royal Palm Beach (Florida), ISSN 0749-0208.

The paper highlights the broad hydrogeomorphological characteristics of the Cox's Bazar coast of Bangladesh. High resolution air photographs of 1:20000 were interpreted for delineating the geomorphological boundaries of the coastal plain. Sediment samples collected from the each geomorphic units were analysed to understand the sedimentary environments. Based on the location and characteristics of the geomorphic units and types and spatial distribution of sediments, evolutionary history of the coast was developed. Finally, a weighted matrix was prepared for assessing the exposure of the geomorphic units to geohazards e.g., storm surges, flash flood. The study reveals that the coast of Cox's Bazar has landforms of two distinct origin: fluvial and marine. Beach and dunes are the two most prominent features of the coast. The sedimentation and its evolutionary sequence of the coastal plain indicates an infiling of a sheltered basin within a relatively high wave and micro- to meso tidal conditions. Cyclonic storms/storm surges appears to be the most common geohazard for most of the landform types of the area. Floodplain with most of the infrastructural investments would need protection from storm surge and flash flood.

ADDITIONAL INDEX WORDS: *Cox's Bazar, coastal plains, cyclonic storm surge, anthropogenic interference, relative risk, ganga lala, natural hazards, flash flood.*

BACKGROUND

Coastal plains are one of the key focal points of human interests. In Bangladesh, coastal areas are being used for a wide variety of purposes such as settlement, agriculture, fishing and communication. Over the last two–three decades rapid population expansion on the coastal plains have exerted tremendous pressure on the fragile coastal resource base. For instance, vast littoral Chakoria mangrove forest has been cleared for aquaculture. A large number of polders and embankments have been constructed along the sea fronts for reclaiming land, and securing settlement and agriculture against sea surges and saline water intrusion. Some of the estuarine tidal rivers have been regulated for augmenting dry season irrigation. These activities have significantly altered the hydrogeomorphological regime along the coast. Initial research interest on coastal zone started about more than three decades back with an aim at understanding the morohological characteristics of the coast. In the subsequent years, research priority has been shifted towards more on coastal zone management. However, systematic research efforts have not been accomplished so far. Understanding the present day coastal environments, particularly the land forms, processes and their products were considered as vital for an efficient management of the coastal zone.

Given this context, the present study focused attention on the Cox's Bazar coastal area (Figure 1). It is the most important tourist attraction of the country and as such, a good understanding of the geomorphology and sediment distribution of the area are essential for proper coastal zone management and future development of the area.

96136 Received 24 October 1996; accepted in revision 1 January 1998.

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PURPOSE OF THE STUDY

The research aims at understanding the broad hydro-geomorphological characteristics of the Cox's Bazar coast. Specifically, the objectives are:

(1) to delineate detailed geomorphological boundaries of the coastal plain;
(2) to identify the processes involved in the formation and examine the types and spatial distribution of different sediment grades;
(3) to determine the evolutionary history of the plain; and
(4) to classify the area into relative risk zones and recommend suitable areas for future development.

METHODOLOGY

Mapping Landform

High resolution vertical black and white air photograph of 1:20 000 scale were interpreted using zoom transferscope to draw the preliminary geomorphic map of the coastal plain. This map was then verified in the field and the final boundaries of the geomorphic units were drawn (Figure 2a). Geomorphic subdivisions of the dunes were made basically through field observations. All line drawings were done in mylar sheets. Final landform map was prepared using GIS ARC/INFO technique. Similar technique was followed to compute the areal extent of the landform types.

Sediment Sampling and Analysis

Sediment samples from each geomorphic units were collected and these were taken after scraping the disturbed sed-

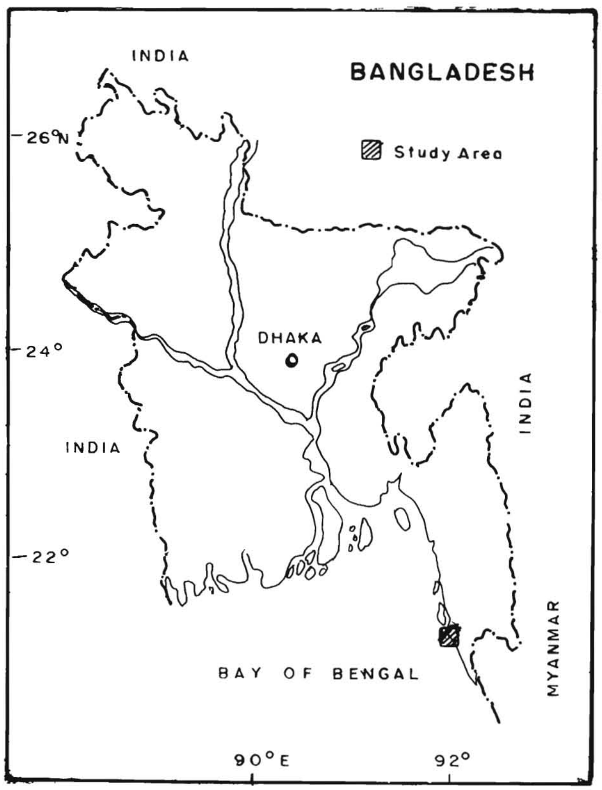

Figure 1. Location of study area: Cox's Bazar.

iments from the surface. Generally the samples were taken from a depth of about 10–30 cm to reach the sediments of the desired geomorphic units. Because of the practical limitations, mechanised drilling could not be undertaken. The evolutionary history of the area was developed on the basis of the

(1) types and spatial distribution of geomorphic units,
(2) type and spatial distribution of sediments,
(3) relative elevations of geomorphic units and
(4) location of the marginal hills.

Relative Risk Zonation

The coastal processes active on the various geomorphic units include flooding due to cyclonic storm surge, rain induced flash flood, wave action, wind action, compaction/subsidence, and anthropogenic interference. All of these processes may cause damage to resources, threatens lives and properties and thereby they may be treated as hazards. The impact of hazards are measured by vulnerability (risk potential) which describes the degree to which an area, people, physical structures or economic assets are exposed to loss, injury or damage. Vulnerability of the different geomorphic units thus depends on the nature and extent of damage potentials of the hazards they are exposed to and also on their relative location from the hazard source (*e.g.* sea for storm surge) and to their elevational position. For instance, beach being located at the shore front, the unit is exposed to cyclonic storm surge, wave action and intense wind action because all of these hazards originate from sea. On the other hand, dune being just behind the beach, it experiences mostly cyclonic storms, wind action and wave action of considerably reduced strength as the events has to pass over the beach. Flood plain, however, lying in between the dune and piedmont plain, is primarily exposed to anthropogenic disturbances, flash flood, and cyclonic storm of much lower strength. Similarly, piedmont plain is exposed to mainly anthropogenic disturbances and intense flash flooding. Mud flats, sand bar, spit and tidal creeks are commonly exposed to cyclonic storms.

In terms of population concentration, and infrastructural development, most of the Cox's Bazar town have been developed on the flood plain because of its topographic advantages, easy and cheaper to develop. Only a small part of the town developed on the piedmont plain as the unit covers limited space. The beach and the dune do not have any settlement, therefore damage potential in case of any hazard events are minimum in compare to floodplain as the beach goers moves to safe shelter. Mud flat is mainly used for shrimp culture and for salt bed and therefore, its damage potential is high in case of storm surge event.

Thus it appears that in the study area three different factors are critical for evaluating the risk potential of the geomorphic units. These are distance from the sea, the relative elevation, and present utilization of the land. Based on these factors, a relative risk assessment matrix of the coastal processes have been developed (Table 4) which is only indicative of the level of exposure of the geomorphic units to the various natural hazards identified in the study area.

THE COX'S BAZAR: THE GEOGRAPHICAL SETTING

The Cox's Bazar coastal plain is located at the south eastern corner of Bangladesh (Figure 1). It is bound on the east by low hill ranges (elevations of about 100 meters), on the west by the Bay of Bengal, on the north by the Bakkhali estuary and Maheshkhali channel and on the south by the headlands. The land appears as a bulge towards the Bay; with a wide base of approximately 20 km in a north-south direction and gradually narrows down to about 3 km at the seaward end. The area is directly exposed to the long shore current and periodic tidal oscillations with occasional wash over by cyclonic storm surges.

Landform Types

On the basis of surfacial forms the coastal plain can be broadly divided initially in to two: (1) the flood plain and (2) the beach plain (Figure 2a). The beach plain unit can be further subdivided into: dunes, tidal creeks and beach. Figure 2b is a schematic cross-section of the coastal plain which is a synthesis of geomorphic features, their dimensions and spatial distribution. The spatial extent of the various landform units identified are given in Table 1 and their important characteristics are referred in Table 2.

The floodplain unit of the coastal plain is located closest to the Tertiary hills and in between the hills and the beach

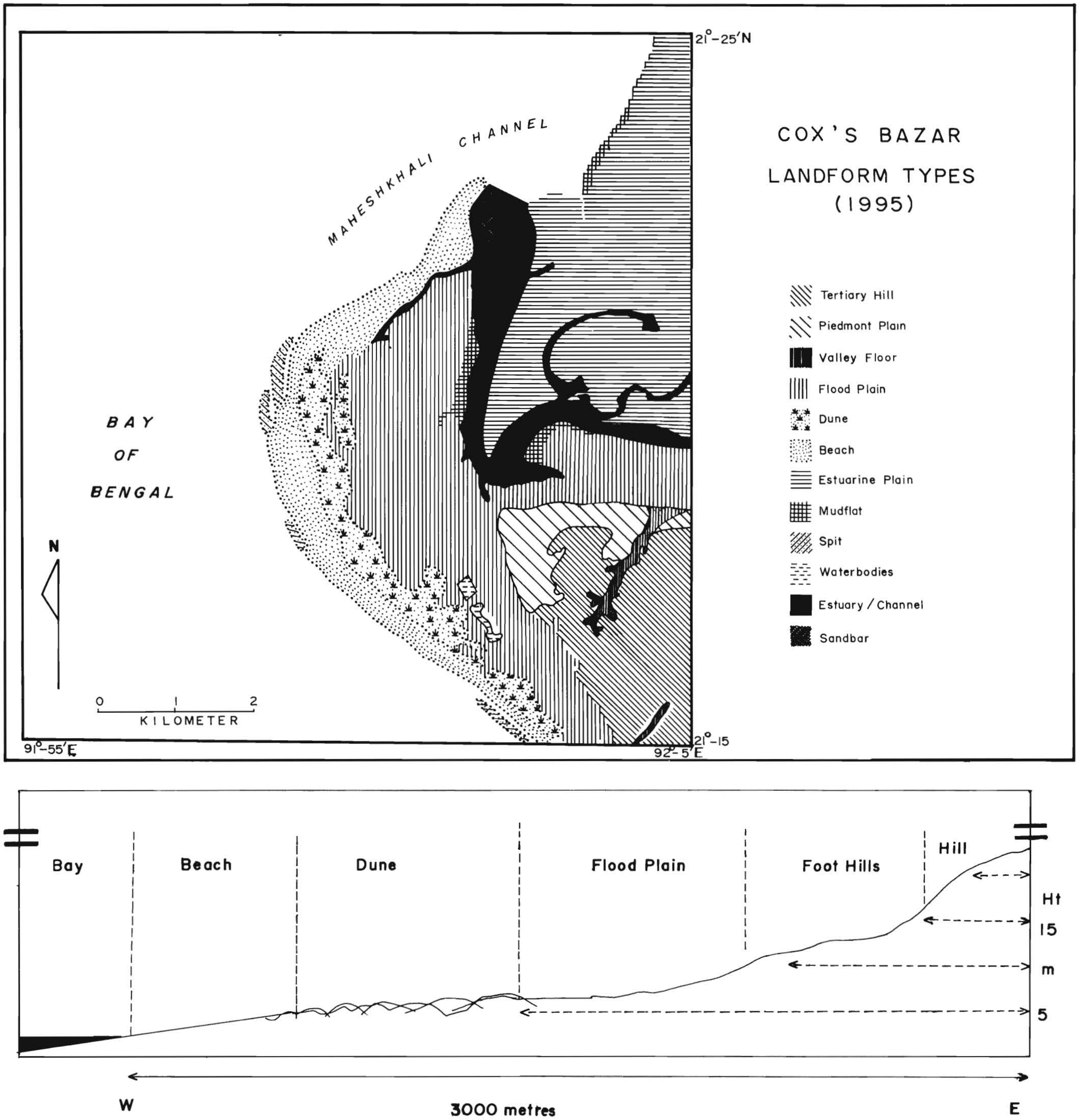

Figure 2a. (Top): landforms. Figure 2b. (Bottom): Schematic cross-section of the Cox's Bazar coastal plain.

plain (Figure 2b). It is elongated in shape and covers an area of 9.30 km^2. The area lies at lower elevation than the dunes of the beach plain (this in the order of 1 to 2 meters) and gently slopes towards the sea. The floodplain is connected to the sea by narrow outlets of the coastal channels and tidal creeks.

The beach plain covers an area of 2.60 km^2, is also an elongated piece of land. It is elevated at their landward parts and gradually slope towards the sea. The elevation of the marginal parts of this plain is of the order of 2 to 3 m above mean sea level and these areas are covered by dunes (Figure 2b). The beach is a flat piece of land tilted in the direction of the

Table 1. *Areal extent of landform types based on 1995 aerial photographs.*

Features	Area (km^2)
Tertiary hills	3.90
Piedmont plain	1.40
Valley floor	0.24
Flood plain	9.30
Dune	1.60
Beach	2.60
Estuarine plain	8.10
Mud flat	0.53
Spit	0.77
Sand bar	0.14
Water bodies	0.09
Estuary/Channel/Tidal creeks	3.00

sea, located at the land-water interface, is an accumulation of varied types of sediment, usually of sand size or above. At the mean sea level the width of the beach is 200–300 m. In most parts of the beach plain, dunes and beach are located side by side but occasionally these two units are separated by tidal creeks. Tidal creeks are shallow and wide channels with variable depths and widths ranging from 1–1.5 and 50–100 m respectively. Degree of tidal intrusion into the tidal creeks are dependent upon the incoming tidal level, and the elevation of the creek bottom. In most low water levels, these creeks are dry and are submerged under high tides only. Another characteristic features of the beach plain is that it ends with a spit. The total area of spits are about 0.77 km^2 and in most cases the spits are wide at the base end and narrow at distal end.

The area covered by dunes is about 1.60 km^2, with a maximum width of approximately 200 m. It lies in a north-south direction, and almost parallel to the beach plain Table 2 and Figure 2a. The boundary between the dunes and the upper beaches is dynamic due to regular interactions between these two geomorphic units induced primarily by the wind and also by the intensity of creeper vegetation 'ganga lata' (*Ipomea*) (ALAM *et al.* 1996). The dunes are intersected by shallow channels which can be termed as dune valleys. These micro-valleys are formed by the wave actions during extraordinary high seas. These dunes themselves are also products of high seas at times of storms, but unlike dune valleys, these are depositional features. These dune valleys are in fact, reworked features, formed by erosion of previously formed dunes.

Dunes are highly susceptible to coastal hazards, such as storm surge, spring tide, cyclonic wind etc; where dune yields to these hazards. However, they can recover in a matter of 3 to 6 months. The mechanism of rebuilding starts with formation of a nuclei around a 'ganga lata' which then acts as a trap for airborn sediments and undergoes exponential growth. Similar observations on dune resilience have been observed on the dune fields of Lake Ontario, Canada (WHITE and BONANNO 1994).

Sediment Characteristics

The sediments of the floodplain are generally finer grain than those of the beach plain (Table 3). The former are dominantly composed of very fine sands and silts while the latter are primarily composed of fine sands. Sediments of the beach plain are mostly coarsely skewed while those of the floodplain are finely skewed. Beach plain sediments are also better sort-

Table 2. *Landform characteristics of the Cox's Bazar coastal plain.*

Feature	Height (metre)	Slope	Shape	Processes	Width	Use
Flood plain	5	∠1°	Flat and occasionally dissected by rills	Mainly fluvial origin, flash flood and occasional marine wash over, minor rills are common	<5–>3 km	Built up area and agriculture
Dunes	3–4	>10°	Undulating, develops parallel to the flood plain	Mainly wave and wind controlled. While wind accumulates sand, waves rework on it. Wind generated sand ripples àre common	highly variable	Acts as barrier between sea and land against rising sea wave and aeolian action
Beach	2–3	4°–6°	Concave shape, controlled by wave action	Wave and wind actions are predominant with occasional storm surge induced flooding	<200 m to >500 m	Tourists main attraction, burrowing crabs concentrate at the lower end of the backshore
Mudflat	≤1	∠1°	Flat, gently merges with estuaries/open seas	Subject to erosion and accretion through regular tidal action and periodically submerged	50–200m	Used by intertidal benthos and as shrimp bed
Spit	1–2	most cases steep, varies from 2°–>4°	Convex seaward with a ridge	Exposed to wave and wind action and submerged to high spring tide	<50 m from the ridge	Red crabs and other burrowing fauna are common
Tidal creek	0.5–1.5	slopes gently down sea-ward	Concave valley floor, gently progress seaward	Limited wave action and exposed to regular tidal exchange	<10 m to 150 m	Acts as land and water interface through tidal exchange

Table 3. *Summary of sediment characteristics of different geomorphic units in the Cox's Bazar coastal plain.*

Geomorphic unit	Mean Grain Size	Sorting	Skewness
1. Floodplain	Very fine sand to silt	Poorly	Finely skewed
2. Beach plain			
2.1 Dune	Fine sand	Well to moderately well sorted	Near symmetrical
2.2 Beach	Medium to fine sand	Moderately well sorted	Near symmetrical
3. Mudflats	Clay to silty clay with very fine sand intercalations		
4. Spit	Fine sand to silty clay	Sand is poorly sorted	Sand is finely skewed
5. Tidal Creek	Medium sand with occasional clay intercalation	Sand is moderately sorted	Sand is finely skewed

ed than those of the floodplain deposits. The sediment characteristics of the floodplain show spatial variability. In areas close to the Tertiary hills and piedmont plains, the sediment grains are generally coarser than those areas of the floodplain away from the hills and closer to the estuary. In hill-proximal areas grain size may reach medium sand grade while in the distal areas, most of the floodplain sediments are very fine sand grade with substantial mud. However, the proximal-distal factor do not affect the sorting of the floodplain deposits.

Within different subunits of the beach plains, sediments of the tidal creeks have largest grain size (medium sand) and are best sorted. The sediments of the present beach are next in grain size (medium to fine sand) while in dunes are composed of finest grain sand (fine sand) compared to above. In common literature of tidal creeks (WALKER and JAMES 1992, MIALL 1990 and Reading 1995); muds (silt and clay collectively) are mentioned to be most common constituents. In contrast to these, the tidal creeks of the Cox's Bazar beach plains are composed of sands. This is explained in terms of the availability of the sediment types. The sands of the tidal creeks are actually reworked sands of the beaches. Mud flats are dominantly composed of grey coloured soft muds (clay and silt) with very fine sand in certain parts. The surface and near surface sediments are highly water saturated, bioturbated and laminated to ripple bedded at places. Most of the mudflats are produced by regular diurnal tidal action and within intertidal range. Supratidal flats are almost absent in the area. This may be because of the burial of such flats by the floodplain sediments and consequent rising of the surface beyond the reach of the spring-tide.

Spit area of the Cox's Bazar coastal plain have been modified since its original formation. The sandy (fine sand) spit is now surrounded by floodplain and tidal flat. Muds and silts on landward side (Figure 2a) and large parts of this spit is being reworked by estuary mouth processes. The initial formative factors of this spit (*i.e.* dominance of littoral sand drift due to wave and current) are now largely modified by the increasing dominance of estuarine discharge and processes.

Incidentally apart from tidal creeks seen on the beach plain, there are no tidal creeks of any significant size within the area. This may be due to (1) relatively weak tidal energy and (2) sufficient wave energy to produce long and well developed beach and dune systems which choke the mouth of the tidal creek, if any at all formed. There are a few streamlets adjacent to the estuary within the study area (Figure 2a) but these channels are tributaries to the estuarine fluvial channel rather than tidal creeks.

There are two distinct sections of the coastal plain evolution of the study area. One of these is the evolution of the floodplain and the other is the beach plain. These dunes are beyond the reach of normal tidal activity and are partially reworked by wind action. The tidal creeks are areas of the beach plain which are relatively lower areas of the beach and are exposed to normal tidal action.

The Cox's Bazar coastal plain is a product of shore proximal processes of the present day sea level which reached its present levels at around 6500 years BP, from about 100–120 m below the present level (ISLAM, 1996; UMITSU, 1993; MILLIMAN *et al.*, 1989). The configuration and elevations of the beach plain and floodplain suggests that most direct interface between sea and land was never any closer to the hills than present. The beach plain, specially the dune complexes have a much higher elevation than the present floodplain. This suggests that a sediment-sink existed between the beach plain and the Tertiary hills which has been gradually infilled by the small streams coming from the hills and also by relatively larger river (Bakkhali river) in the northern part of the plain (Figure 2a). The mud flats have been formed by joint action of river and tidal action.

The spit, located in the northern side of the plain and at the mouth of the river, have been formed by wave action and also due to littoral drift of sand into the Maheshkhali channel (Figure 2a). This spit was possibly formed about the same time as the beach plain. The presence of this spit compelled the oncoming (towards sea) river mouth to deviate northward and reach the Maheshkhali channel rather than reaching the Bay of Bengal through a straight route (Figure 2a).

The Cox's Bazar coastal plain sedimentation and its evolutionary sequence suggest an infilling of a sheltered basin within a relatively high wave and micro- to mesotidal conditions. Holocene infilling of similar sheltered basins with comparable processes and products have been described from other places of the world such as Australia (*e.g.* HUQ, 1995; ROY, 1984) and U.S.A. (NICHOL *et al.*, 1994).

RELATIVE RISK ASSESSMENT AND FUTURE DEVELOPMENT

A qualitative matrix of relative risk associated with the individual geomorphic units are referred in Table 4 which indicates that the area is subjected to a wide range of coastal process related hazards that needs to be understood. In the matrix, each geomorhic unit is evaluated on the basis of its relative level of exposure to a specific hazard as mentioned

Table 4. *Relative risk assessment of the coastal processes.*

Feature	Cyclonic Storm	Flash Flood	Wave Action	Wind Action	Subsidence	Anthro-pogenic Interference	Rain Induced Erosion/ Landslide	Score
Flood plain (48.10)	3	4	0	1	1	3	1	13
Dune (8.27)	4	0	2	2	1	1	0	10
Beach (13.44)	3	0	3	3	1	0	0	10
Mudflat (2.74)	4	1	3	0	1	1	0	10
Spit (3.98)	3	0	3	3	1	0	0	10
Tidal creek (15.52)	3	1	2	1	0	0	0	7
Sand bar (0.72)	3	2	1	3	1	0	0	10
Piedmont plain (7.23)	1	3	0	0	0	4	3	11
Score	24	11	14	13	6	9	4	

Note: (a) Relative Risk associated with specific hazards are graded to Very High = 5, High = 4, Moderate = 3, Low = 2, Very low = 1 and Negligible = 0. (b) Figure shown within the parentheses under each feature indicates area in percent.

on the table. For a high damage potential of a unit due to a hazard was assigned a value of 5 and for no threat to a value of 0. Thus, the higher value indicates higher risk and the lower value indicates lower risk. Row wise score indicates the relative importance of different coastal process based hazards to each geomorphic unit. While the column score indicates the relative grading of the most common hazards on the basis of total score of each geomorphic unit exposed to a specific hazard. In scoring for the probable hazard potential from natural events, distance and elevation from the sea and the present utilization of a particular unit was taken into consideration. While scoring for the anthropogenic interference, factors considered were: removal of natural vegetation cover, cultivation on unstable soil, earth removal, obstruction to drainage, unplanned settlement on inappropriate locations and trampling.

According to the Table 4, it appears that subtropical cyclonic storm/storm surge (column score 24) is the major threat for most of the landform types of the area. The next important hazards of considerable importance include wave- and wind action, followed by flash flood and human interference. Among the landform types, the most susceptible feature is floodplain (row score 13), followed by piedmont plain (score 11). Dune, beach, spit, sand bar and mud flat scored the same 10. Among these, mud flat from economic point of view is more important than others because of shrimp and salt farming activities. From planning point, flood plain covering more than 48 percent of the area and with most of the infrastructural investments would need more protection from flash flood and storm surge. Piedmont plain also an important area and increasingly drawing investments would need protection from various anthropogenic interferences, flash flood and landslides.

CONCLUSIONS

The evidence suggests that the coast of Cox's Bazar has diverse landforms of two distinct origin: fluvial (*e.g.,* flood plain) and marine (*e.g.,* beach and dune). Processes like storm surges, wave and wind action, and flash flood interact and interchange for bringing about geomorphological changes on the coast. The most dynamic features include beach and dunes both develop parallel to the coast. The research implies that apart from anthropogenic interferences both cyclonic storms/storm surges, and wind action plays crucial role for maintaining the growth and stability of dune phases. The sediment of the floodplain varies from very fine sand to silt. Similarly, the beach plains exhibit variability in its mean grain size, from medium sand to silty clay with well to poor sorting tendency. The sedimentation and evolutionary sequence of the Cox's Bazar coastal plain possibly suggest an infilling of a sheltered basin within a relatively high wave and micro- and mesotidal conditions. Among others, cyclonic storms/ storm surges appears to the major threat for most of the coastal landforms of the area. In terms of exposure of the landform units to relative risk, flood plain seems most susceptible. Flood plains with most of its infrastructural investments would require protection from storm surge and flash flood.

ACKNOWLEDGEMENTS

The authors wish to thank Prof. S. Dara Shamsuddin for helping with constructive comments and valuable suggestions to improve the contents of the paper.

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