Geomorphic Characteristics of Coastal Beach using Geospatial Techniques: a Case Study of Kuakata Beaches, Bangladesh

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Abstract

Coastal land formations along the beaches of Kuakata have experienced a dramatic shift of form and structure, both natural and anthropogenic interference. This is an application to map coastal landforms around the coast utilizing remote sensing and GIS techniques. Spatial data sources such as topographic charts, Landsat images, GCPs data and SRTM DEM databases have been comprehensively studied to analyze coastal landforms. Twenty-three geomorphic features covering 23.61 km^2 were identified and further regionalized into three geographic processes. There is a need for time to consider unsustainable coastal structures in these geographical processes by fine-tuning the construction parameters and, at the same time, enable coastal systems to respond naturally to any form of variability. That flood plains comparatively have a low slope with fatter surface and cover grater area and complex fluvio-marine environment formed coastal upland which has a steeper slope. This paper intends to contribute several suggestions to the sustainable management of coastal resources and transforming quality ecosystem services for the future generation.

Keywords: Geomorphology, Coast, Kuakata Beach, Geospatial Techniques.

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1. Introduction

Coastal geomorphology studied the coast's outward conditions and developed a mutual understanding between hydrodynamics condition and physical properties (Wright and Thom 1977) . It has also involved in the sediment transport system. The geomorphic landforms are an example of the long-term characteristics of the coastal processes that prevail. The Coastal transition zone land-forms are susceptible to erosion and depositional processes because of coastal current, Wind, transport of sediments, and other anthropogenic activities (Carter and Woodroffe, 1955) and also regulated by wave energy, sediment size, and even by shelf geomorphology (Bastos and Silva 2003).

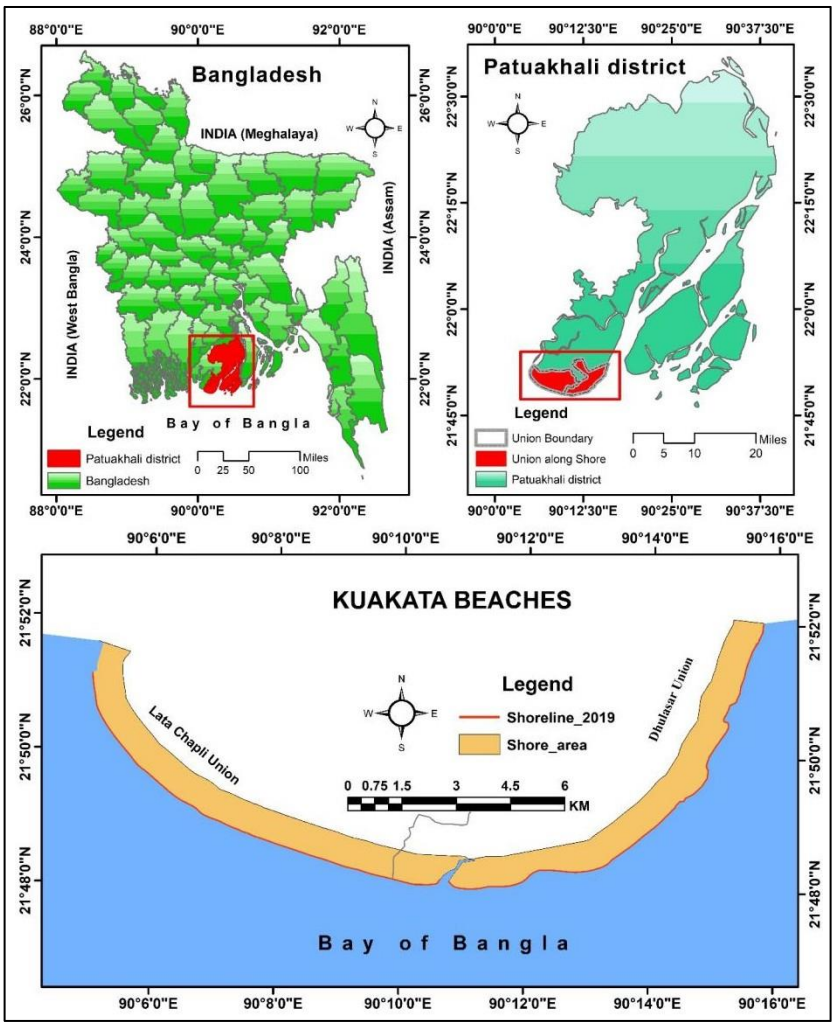
The coastal area is considered one of the preferable habitat zones because of its scenic beauty, recreational environment, and lots of economic opportunities, so half of the total world population is spotted near the narrow-stripped area (Komar 1998) . Bangladesh's coastal zone is mainly used for the purpose of settlement, agriculture, fishing, and communication. The length of the coastline area is 711 square kilometres (M. B. Hossain 2011) and almost 41.8 million people live in the coastal plain land (BBS 2015) . But this region has a dynamic river network, sandy beaches, and an estuarine system (D. M. Rahman 2010). The Bay of Bengal is designated as the margin of deltaic plain land where large amounts of sediments deposited that carried out by the Ganges-Brahmaputra-Meghna (GBM) river network system, which considered as one of the most productive ecosystems of the world (Barua and Kana 1995) and dominated by high tide and wave energy (Herbich 1990) . The coastal topography of the Bay of Bengal plays an important role in developing the contrary's economic condition. Experts observed that tidal behaviour on the coast of Bangladesh is different in magnitude, not in the pattern (M. S. Hossain 2001) . The highest range is found at the head of the Bay of Bengal. Along with that, drainage congestion, unsteady morphological processes, freshwater abundance, etc., are also making the coastal region diversify. Erosion and accretion are common phenomena in the coastal area; the shape of the coast always changed. Since waves and currents combination is different, experts assumed that sediment transport patterns complex, which is not always reflected by bedform configuration (Oertel 1972).

Researchers stated that coastal formation mainly depends on the geology, morphology, sediment supply, sea-level fluctuations, extreme events, human activity, etc. Latest geospatial advances, numerical and geo-computational

modelling algorithms revolutionized the scope of geomorphology, and geoscientists were allowed to leave beyond traditional cartography (Bishop, et al. 2012) . GIS technique is a useful tool with corresponding attributes for thematic mapping features. Geo-computational algorithms enable the automatic removal of geomorphic landforms from the combination of data sets such as satellite image, DEM and topographical map using numerical modelling, pixel-based classification and automated cellular techniques in the GIS environment (Dawson and Smithers 2010). GIS-based Geomorphic change detection is provided topographic elevation and slope angle, land cover and shoreline dynamics. The main aims of this study are to identify the processes involved in the formation and examine the types and spatial distribution of different terrain grade that will be further helpful to the policymakers and other researchers to understand the coastal processes as well as assist for developing various management strategies to adapt with the extreme conditions.

2. Study Area

Kuakata sea beach is located in the southernmost tip of Bangladesh, located in Kalapara Upazila of Patuakhali district and along the western side of the Meghna estuary which is locally known as the 'daughter of the sea.' This beautiful sandy beach of Bangladesh is situated within 21°47" N to 21°52" N latitude and 90°05"E to 90°16" E longitude (Figure 1) which mainly lies between two unions (Lata Chapli and Dhulasar Union). This beach's length is 23.56 kilometers, which consisted of dark, marbled sand and has gentle slopes. This is the sanctuary for migratory birds. Gongamati reserved forest is found on the eastern side of this beach which is similar to the Sundarban Mangrove Forest. Experts stated that this area is continuously faced with threats from the erosion activity of the Bay of Bengal. It is estimated that erosion occurred in 13.59 km and deposition situation found in 9.97 kilometres from the period of 1973 to 2010 (Rahman, Mitra and Akter 2011) . Kuakata sea beach shows the characteristics of sandy beach along with mangrove forest and acts as one of the contrary's major tourist spots. Bangladesh's middle, most diverse coastline, the sedimentary outlet of Padma, Meghna and Brahmaputra, dominated by the river. Relatively, the Kuakata coast has a convex form toward the coastal side, and coastal processes have a significant effect on its convex boundary, indicating seasonal variations. Hence, these beaches are selected for this study.



[Source: Open Street Map, 2020]

Figure 1: Study Area Map

3. Materials and Methods

Coastal land-form mapping is primary for understanding the process of any coastal region. Bangladesh's southern coast consists of numerous landforms undergoing morphodynamic shape, scale, and distribution changes due to various coastal hydrodynamic factors like human interferences (Hentry, Chandrasekar and Saravanan 2012) . Advance geospatial platforms are devices that are designed to map coastal landforms and also to investigate processes of spatial and temporal variability. The following databases were used to classify geomorphic landforms and also to describe coastal geomorphic landforms naturally (Table 1).

Name of Data	Year of publication	Scale/ Resolution	Source
Landsat 8 (ETM+)	2019	30 m (path - 137, Row – 45)	http://earthexplorer.usgs.gov
SRTM	2015	30 m	http://earthexplorer.usgs.gov
Topographic sheet	2011	1:50000	Geological Survey of Bangladesh
Field survey data using GPS	2020	>1 m	Field Survey

Table 1: Source of databases used for analysis for the study

Geological survey Bangladesh, topographic sheets with a scale of 1:50,000, were scanned at 600 dpi using HP Scan Jet 3300 C scanner and saved before georeferencing in Tagg Image File Format (TIFF). It is necessary to be pre-prepared satellite images before analysis. Top of Atmosphere (TOA) planetary reflectance values converted by using reflectance coefficient values that are available in the metadata file of the image from the reflectance value of selected images (USGS 2016) . The ETM+ images and scanned topographic sheets were rectified using 200 – 300 ground control points taken from field surveys using GPS. Ground control point (GCP) was used for the pixel coordinates of ETM+ images and topographic sheets using affine transformation representing the real world with an overall RMSE of less than 1 meter. All the georeferenced images were projected to the UTM system, WGS-84 and Zone 45 North and clipped, stacked to match the entire area's boundary. On-screen image interpretation techniques were used for mapping coastal landforms in the study area. Additionally, Normalized difference water index (NWDI) and Normalized difference vegetation index (NDVI) were applied to highlight the coastal geomorphic feature. Non-directional filter was used to enhance the edge regardless of edge direction. After that 'ISO Cluster' tool will be used to digitize the study area's geomorphological features. Three dimensional or terrain data are one of the best data for geo-analysis of landforms. Shuttle Radar Topography Mission (SRTM) data with 30m and Bathymetry data. Coefficient of water attenuation for each respective Landsat Band and the maximum depth of penetration (DOP) in a band was estimated to calculate bathymetry data and a resample of 1km was used to create a digital elevation model. GPS ground truth data and SRTM fill free software was used to patch the null data hole and progressive infilling of the surrounding data. The relief and dissection pattern of landforms were analyzed using DEM, bathymetry data and topographic sheets. Hill shading with different azimuths and sun elevation angles were used for mapping structural changes in the study area. Besides, the created geomorphic landforms were overlaid with DEM. Also, elevation and slope angles were calculated by the 3D analyst tool of ArcGIS. Ancillary data such as the GIS database, current geomorphological database, Google Earth is used for geo- information analysis and update.

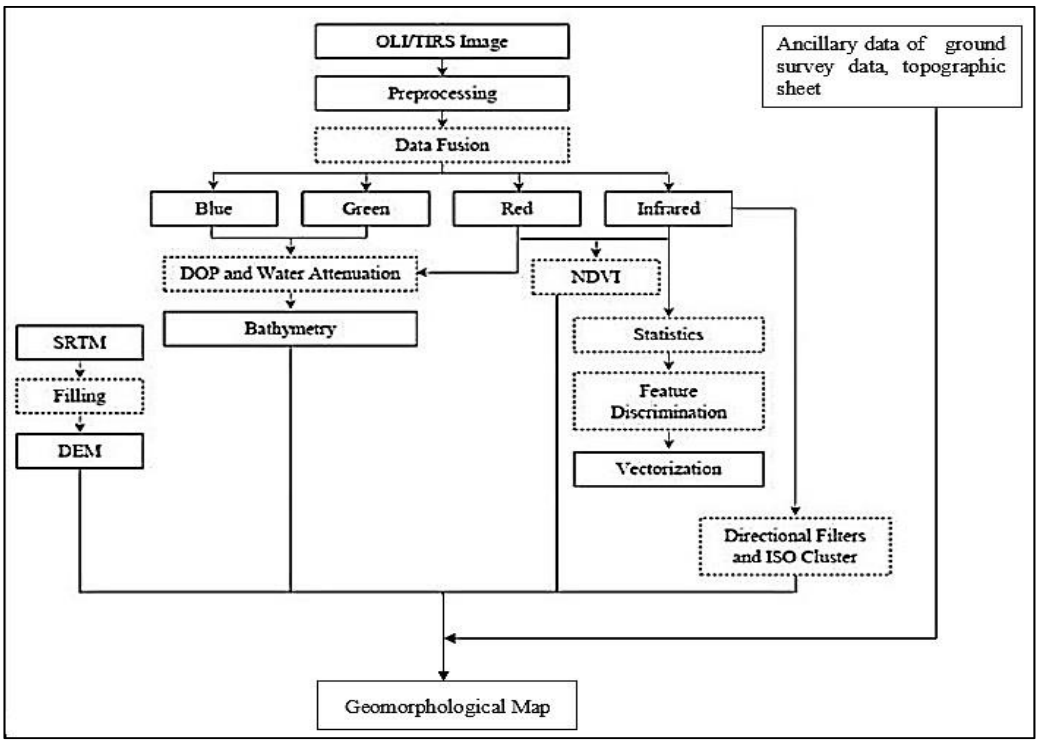


Figure 2: Methodology framework used coastal geomorphic mapping in the study area

4. Results and Discussion

Geomorphology is the study of landforms on the Earth's surface, its structures, forms, and sediments. The study involves looking at ecosystems to figure out how processes of the Earth's surface, such as air, water, and ice, can form the countryside. Landforms are formed by erosion or deposition as these earth-surface processes take away rock and sediment and are transported and deposited to different locations. The different climatic environments create different suites of landforms.

Mapping of Geomorphic Feature of Kuakata Beaches

The different types of geomorphic landforms are extracted from the nearshore of Kuakata

Sl. No	Origin process of landforms	Geomorphic landforms		Factors influencing landforms formation
		Erosional	Depositional	
1	**Marine**	Beach cusps,	Barrier Bar, Beach berms, Beach ridges, Flood Tidal	**Erosion** – is due to the backwashing of sediments by the tide, currents and

			plains, Lagoon, Marsh, Mud flats, Old Coastal Plain, Point bar, Sandy Beach, Sandspit, Tidal Flats, Tidal Intel Younger coastal plains,	man-made structures. **Accretion** – is due to swashing of sediments by low wave energy and sediment deposition by longshore drift
2	**Fluvio-Marine**		Abandoned Coastal Upland, Deltaic plain, channels, River terraces, Estuaries,	**Modification of landforms** – due to tidal regime, divergent wave action. **Formation of landforms** – due to the accumulation of river discharged sediments by tidal and wave divergent action.
3	**Fluvial**	River	Flood plains, Natural levees,	**Erosion of landform** – due to runoff and overland flow

Table 2: Classification of geomorphic landforms of the study area.

Beaches (850m buffer from the shoreline). Based on the original process, there are three types of landforms found in the Kuakata beaches presented in Table 2 and Figure 3. The marine process is found where depositional landforms are beach berms, Beach ridges, lagoon, marsh, tidal flats, coastal plains, Bars, etc. (Mishra and Sharma 2009) (Kumar, et al. 2010) (Kaliraj and Chandrasekar 2012). Fluvio-marine landforms are dominated by both erosion and deposition. In comparison, floodplains are the most northern feature; after that comes coastal plains, beach ridges, beach, beach berms, beach cups and tidal features. Costal upland is found in the western, middle and eastern sides because of the interaction of the river. It is also known as the estuarine environment.

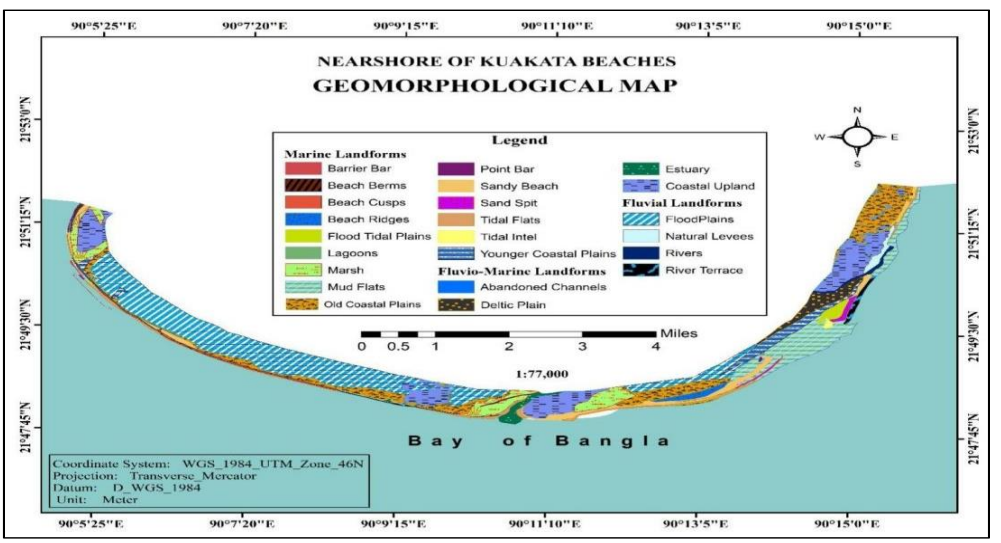


Figure 3: Geomorphological Map of Kuakata Beaches
[Source: Landsat 8 image, SRTM DEM, Topological Map and field survey]

4.1 Spatial Distribution of Feature of the Study Area

A Floodplain is part of the process, being the smaller area over which the rivers flood at a particular time and A deltaic plain consist of active or abandoned deltas, which are either overlapping or contiguous to one another. Table 3 showed that the total area of floodplain and deltaic plain concentrate 7.67 km2 of the study area, covering the highest portion of this study area. Coastal Upland covers 15.86% area of the study area. A flat or gently sloping surface distributed along the backshore region is the Coastal Plain that composite of sand, silt and clay particles established as geomorphological units subsequent from the deposition of sediments over long periods. The total area of the new and old coastal plain covers 4.16 km2. The Beach landforms such as Sandy Beaches, Cusps, Ridges, Berms, Terraces, Barrier Bars and Sand Spits are distributed along the nearshore region. Beach Ridges are formed due to sediments swash as narrow and curve-shaped features parallel to the shoreline. Similarly, due to the action of breaking waves at the surface region, the narrow and swelling Berms and Terraces are formed in beach areas and cusps are broadly scattered landforms in several portions of the analysis. Depositional geomorphological features like Mud Flats, Tidal Flats and Tidal Intel comprise 12.95% of the study area. Fluvial processes are included in the motion of sediment and erosion or deposition on the river bed. These processes play an essential and conspicuous role in the denudation of land surfaces and rock detritus transport from higher to lower levels. River and river terraces total cover 0.46% km2 area of the study area.

Sl. No	Geomorphic Landforms	Areal extent of landforms (km^2)	Percentage of distribution (%)
	Marine Origin		
1	**Barrier Bar**	0.02	0.07
2	**Beach berms**	0.08	0.32
3	**Beach cusps**	0.28	1.17
4	**Beach ridges**	0.31	1.32
5	**Flood Tidal plains**	0.20	0.83
6	**Lagoon**	0.01	0.05
7	**Marsh**	1.56	6.61
8	**Mud flats**	2.36	10.00
9	**Old Coastal plains**	3.41	14.47
10	**Point bar**	0.03	0.13
11	**Sandy Beach**	1.20	5.09
12	**Sandspit**	0.18	0.75

13	**Tidal Flats**	0.66	2.78
14	**Tidal Intel**	0.04	0.17
15	**Younger coastal plains**	0.75	3.20
	Fluvio Marine origin		
16	**Abandoned channels**	0.01	0.03
17	**Coastal Upland**	3.74	15.86
18	**Deltaic plain**	0.66	2.79
19	**Estuaries**	0.30	1.28
	Fluvial origin		
20	**Flood plains**	7.01	29.70
21	**Natural levees**	0.34	1.43
22	**River**	0.26	1.09
23	**River terraces**	0.20	0.86

Table 3: Spatial distribution and area of the geomorphic landforms of Kuakata Beaches
[Source: Landsat 8 image, SRTM DEM, Topological Map and Ground survey, 2020]

4.2 Topographic Profile of the Study Area with Slope Angles

The topographic profile is a graphic representation of a vertical land section on a specific terrestrial surface using a contour line or intersection of a vertical plane with the terrestrial surface. Topographic profiles are useful to study landforms, in territorial planning, build communication routes, etc. For this study, using a 2000 m interval for interpolating line segments, which were around 2000m horizontally distance from the initial point that calculated 1000m buffer from the 2019s shoreline. All of the interpolate line initial points are from land to seaward. It was observed that the elevation of the study area is varied -5 m to 38 m and had slope is varied 0 to 17.96 degree above sea level. Also, the study's average elevation is low about 3.87 meters and has a gentle slope of an average of 1.12 degrees. For the analysis, 12 interpolate line was used for extract profile graph. For the topographic profile, the elevation of each interpolates horizontal line distance from initial ridge point landward buffer zone to seaward are calculated. The highest elevation found in profile-1 (38 m elevation where coastal upland situated) seems to generate a steep slope of about 1000m where the shoreline is situated with a risen slope (9 degrees). Also, elevation extended 16 m at 788 m horizontal distance. However, the slope tends to decrease and then at a distance of 182m horizontal. It is dramatically has a steep slope that tends to the highest area and the lowest elevation of the study in profile-1 (-1.49 m). Besides that, the highest slope

was found in profile-1 (13.08 degree) and the lowest slope from mean sea level found in profile -11 (0.09 degree). It is observed from the profile graph that western profiles (1), mid profiles (7) and eastern profiles (11,12) were relatively high from others. Furthermore, the lowest horizontal distance was found in profile-10 where elevation started.

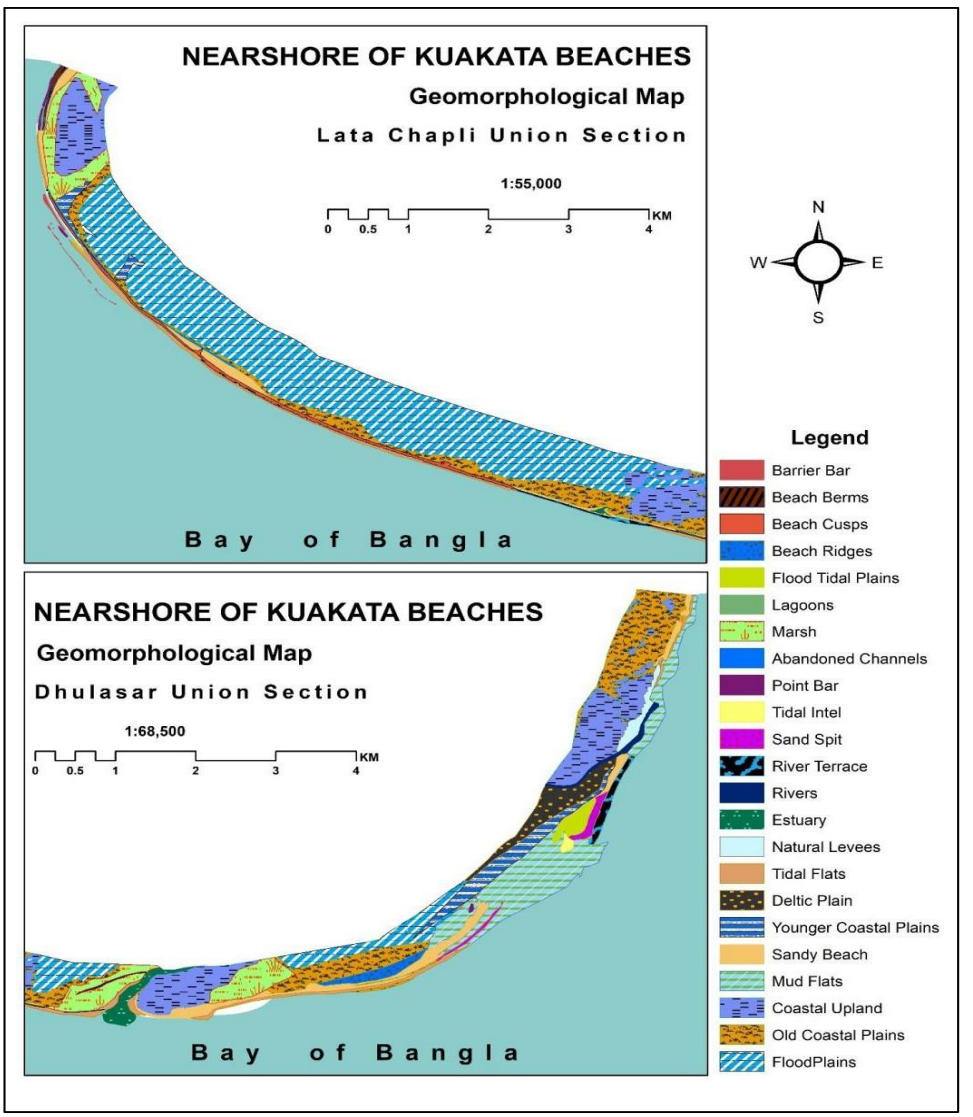


Figure 4. Union Wise Geomorphic Features
[Source: Landsat 8 image, SRTM DEM, Topological Map and field survey]

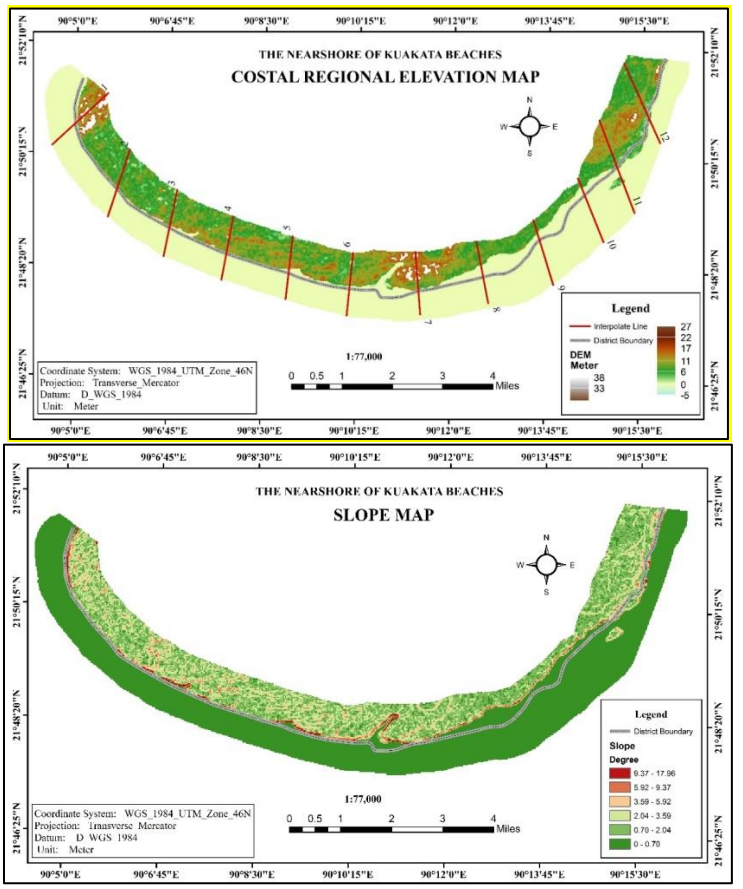
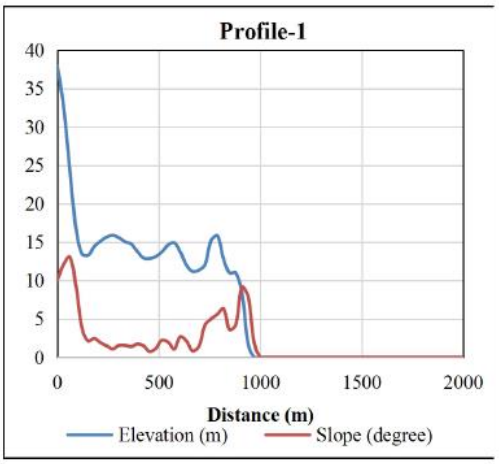


Figure 1: Elevation map and Slope Map of the study area *[Data source: NASA JPL, 2015]*

Costal upland is higher land from which has the highest elevation that is the influence of river sediment as alongside river discharge area. Floodplains are the southern feature that elevation is 6m to 10m, mostly flat with slope 1 to 4 degrees with someplace. After that, the study area's coastal plains vary 4m to 7m elevations with a gentle slope before sandy beaches area shape like mostly as concave shape. Natural levees are emphasized 2-5 m elevation with 4° to 8° slope with a small wide-range mainly coincide into floodplains area. Sandy beach in the study area is founded to more irregularly shape that elevation range is small but the slope range is high due to lengthy drift deposition. Beach cusps are a tiny feature in this study area and also width is minimal that sometimes can be distinguished from another feature. Beach ridges are relatively high land towards shore with a gentle slope, but the width is very small in this area. Flood-tidal plains have a more complex marine-fluvial environment with a shallow slope with lower elevation such as a flat. The sand spit is likely to convex but as longshore drift, it is more like to flat. Besides, Mudflats is highly unstable that spread a wide range of near flats with sea level. Average tidal flats have a steeper slope that varies more than another feature shaped like concave to straight (Figure 4 and Figure 5)


Profile-1
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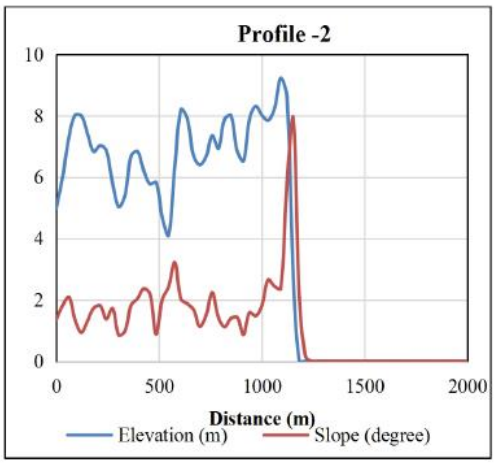
Distance (m)
Elevation (m)
Slope (degree)


Profile -2
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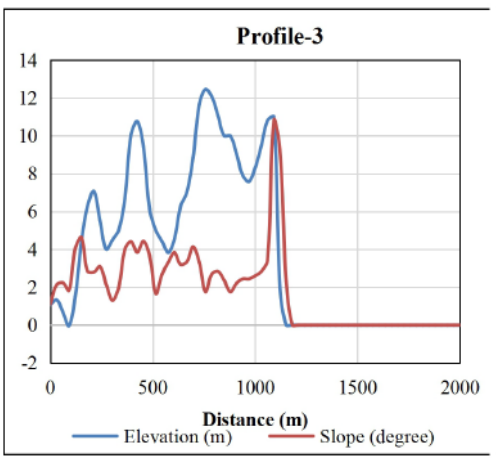
Profile-3
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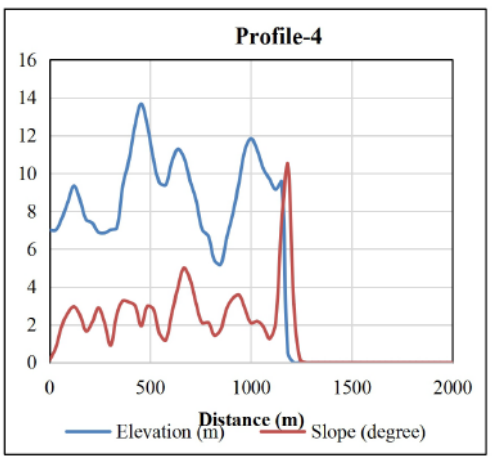
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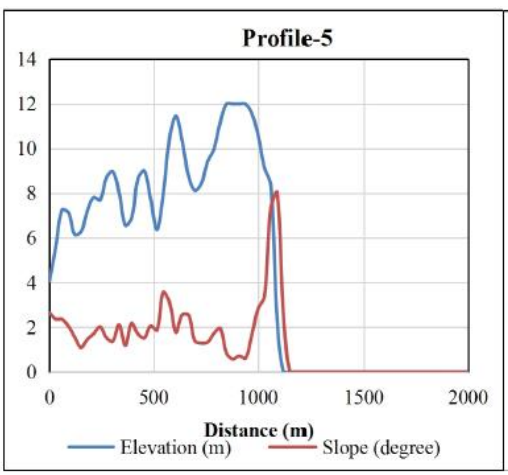
Profile-5
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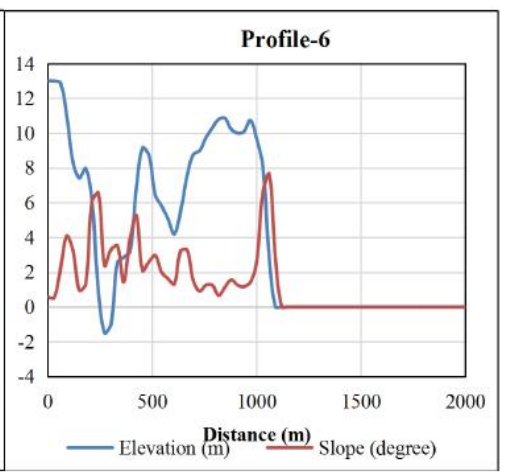
Distance (m)
Elevation (m)
Slope (degree)


Profile-6
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Slope (degree)

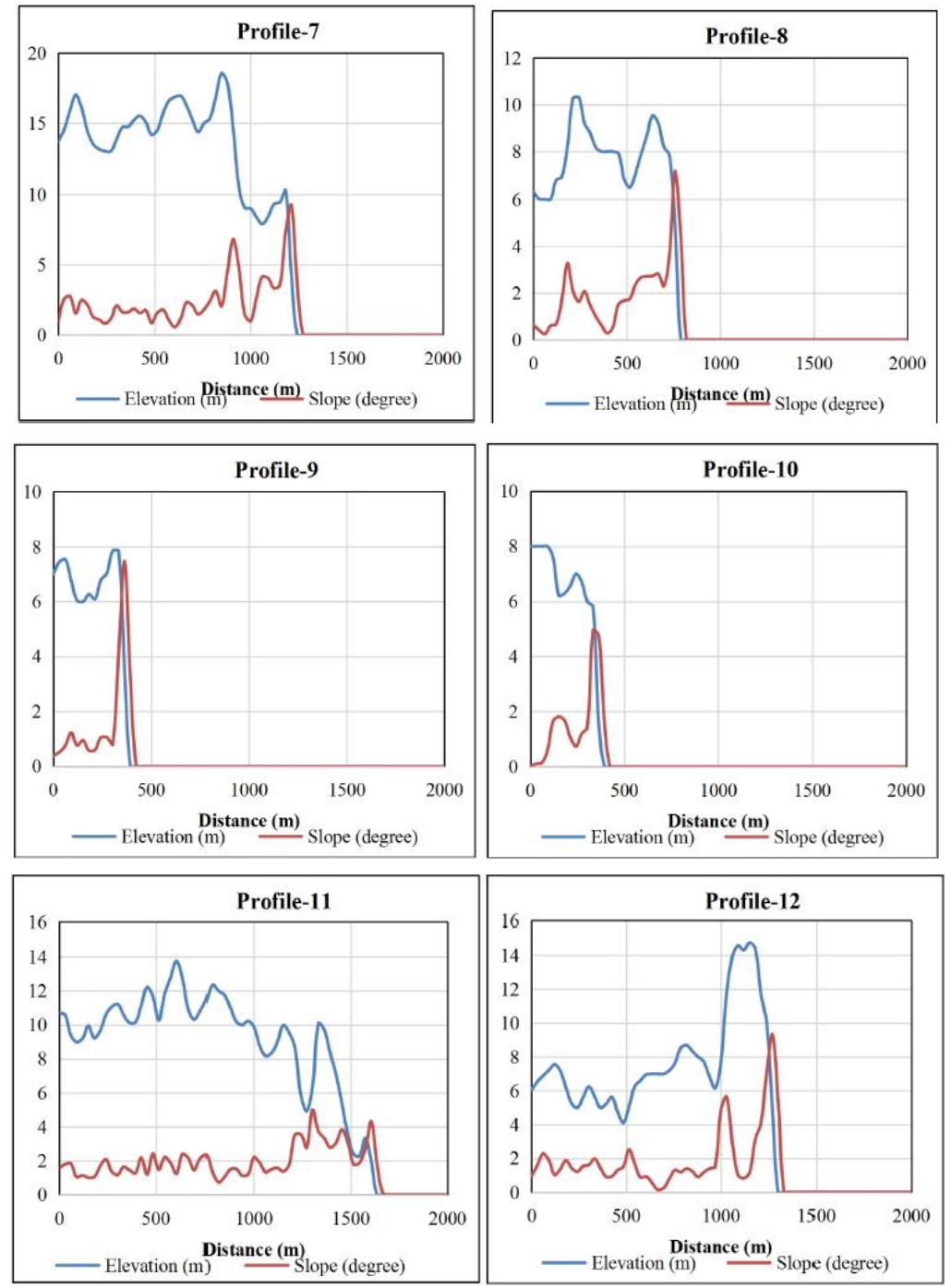

Figure 6: Profile Graph with slope angles*[Data source: NASA JPL, 2015]*

	Feature	Elevation (m)	Slope (deg)	Wide
N	Floodplains	6-10	1-4	> 2 km
▲	Coastal Upland	13.-38	4-9	300-1000m
▲	Coastal Plains	4-7	1-2	100-650
▲	Natural levees/ River Terrace	2-5	4-8	10-50 m
▲	Sandy Beach	1-2	4-8	150-350 m
▲	Beach ridges	2-3	2-4	≤ 10 m
▲	Beach cusps/Berms	≤1	≤ 1	≤ 9 m
▲	Flood Tidal plains	≤1	≤1	≤ 50 m
▲	Sand spit	≤1.5	1-3	30-130
▲	Deltic Plain	≤1	2-4	Highly variable
▼	Mud Flats	≤ 1	≤ 1	150-600
S	Tidal Flats	≤ 2	≤ 4	10-150 m

Table 4: Summary of Topographic Characteristics of the study area
[Data source: NASA JPL, 2015, NASA LP DAAC 2019]

5. Conclusion

The evidences from the study suggest that the coast of Kuakata has diverse landform of three distinct origins viz., fluvial (e.g., flood plain), Fluvio-marine (e.g., Coastal Upland) and marine (e.g., beach and dune). Processes like wave and wind action, flood interact and interchange are responsible for bringing about geomorphological changes of the coast. The most dynamic features include beach and dunes both develop parallel to the coast, mainly due to the deposition over a long period. That is why a wide range of floodplains can be found here and coastal upland is the highest edge landform those are stable rather than other landform.

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