Characteristics of Sediment in the Inner Shelf Zone of Bangladesh

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Abstract

The continental shelf zone of Bangladesh is one of the highest sediment deposition centers of the world. Sediment carried by the vast drainage system surrounding the shelf is widely distributed in the northern part of the Bay of Bengal, where the Swatch of No Ground (SoNG) acts as a triggering factor. In this study, the off-shore bottom sediments from six different locations (around the Bangabandhu Island, SoNG, Nijhum Dwip, Feni river mouth, Meghna estuary and Cox's bazar) have been used for the analysis of particle size, particle shape, mineralogical properties and bio-markers. It has been found that the distribution of bottom sediments in the northern Bay is distinctive and lead by the land-ocean interface. The western part, part of central zone and eastern part of the shelf is dominated by coarse particles, whereas the greater part of the Meghna estuary is dominated by finer particles. The combined flow Ganges-Brhmaputra-Meghna rivers through the Meghna estuary is the main source of the coarse sediment influx. These sediments are drift westward to the SoNG. The particle shape shows that the sediments in western part are long-drifted and rich in heavy mineral concentration compare to the eastern part. The sediments in the eastern shelf are short-drifted, possibly derived from nearby hill ranges and/or localized erosion. The bio-marker (diatom) indicates that the greater portion of the Meghna estuary is a unique sediment regime and ecologically very sensitive. This estuarine belt is highly susceptible to marine pollution. However, for sustainable Integrated Coastal Zone Management (ICZM) in Bangladesh, interaction between land and ocean needs to be unraveled connectivity and recording the properties of sediments of the shelf zone could be a good proxy to unveil this links.

Keywords: Continental shelf, Bottom sediment, Swatch of No Ground, Sediment dynamics

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1. Introduction

Sedimentation is one of the striking oceanographic processes in the shelf zone of Bangladesh which has not yet been properly studied and understood. Denudation of the Himalaya has resulted in the formation of the Ganges Brahmaputra Meghna (GBM) mega delta and abundant supply of sediments in the Bay of Bengal thorough its complex river system. A total of six million m^3s^{-1} of water discharge through the GBM river system carry an estimated 31.5 $10^3m^3s^{-1}$ tons of sediment down to the sea each year (Curray and Moore, 1971). In the Bay of Bengal mainly terrigenous and calcareous types of sediments dominate the continental shelf and deep sea respectively (Duxbury et. al., 2005). The size of sediment, their deposition and distribution in the shelf zone, and period of suspension are controlled by several fluvial and oceanographic factors such as water discharge, ocean wave and tide, ocean current, sea surface temperature and water salinity (Roy and Islam, 2016). The spatial and temporal patterns in sediment transport and distribution is helpful in understanding the shelf morphology and sub-aquatic ecology. The present research is an attempt to study the spatial distribution of the bottom sediment concentration and their properties in the continental shelf zone of Bangladesh

2. Study Area

Bangladesh has an extensive continental shelf in the south. Based on the map provided by Khan et al (2009) it is found that the area of the continental shelf of Bangladesh is about 66045 km^2. The width of the shelf varies considerably from less 100 km off the coast of Cox's Bazar to more than 185 km off the south-west coast. The shelf area has a very gentle slope towards south. Khan et al (2009) have shown that in the western part of the shelf the width is 172km at a water depth of 234m. The average gradient of this shelf is 0.029^o upto 54 km, 0.215^o between 54 and 68km, 0.048^o between 44 and 155 km and 0.351^o upto the shelf break. Swatch of No Ground (SoNG) is the most prominent features in the western shelf zone that influences the ocean dynamics and sediment dispersion in the northern Bay of Bengal. The width of the central shelf zone is 216km at a water depth of 170m. The average gradient of this shelf is 0.013^o upto 100km, 0.150^o between 100 and 120km, 0.022^o between 120 and 185 km and 0.190^o upto the shelf break. The eastern shelf is relatively narrow and its width is 95km at a water depth of 155m. The average gradient of this shelf is 0.044^o upto 31km, 0.111^o between 31 and 59km, 0.063^o between 59 and 79 km and 0.610^o upto the shelf break. The present study covers a wide area in northern part of the shelf zone of Bangladesh (See Figure-1).

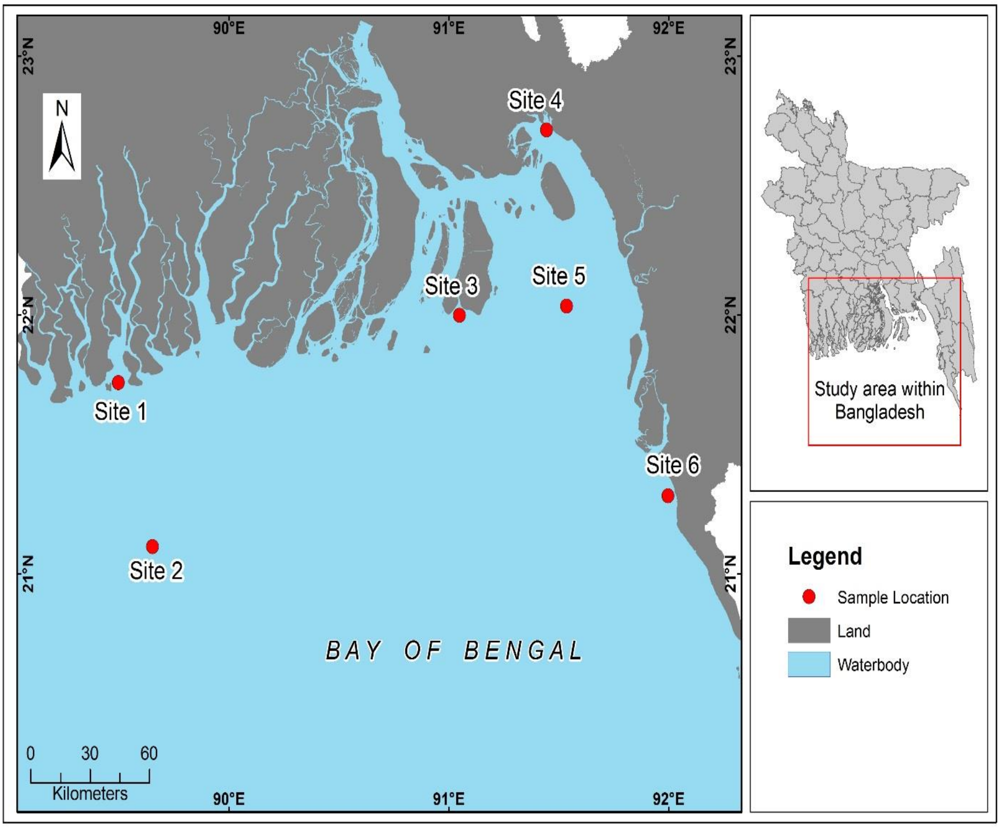

Figure 1: Map of Study Area showing Sample Location

3. Methodology

The present paper is the outcome of the ongoing research project on sediment dynamics of the Bay of Bengal, jointly funded and supported by the Ministry of Science and Technology, Govt. of Bangladesh and Bangladesh Centre for Coastal and Ocean Studies (BACCOS). Previously two papers have been published under this project on heavy metal contaminations of the ocean water and ocean sediment in the self-zone of Bangladesh (Islam and Meem, 2017; Islam and Das, 2019). The aim of this paper is to study the physical and ecological properties of the bottom sediment in the shelf zone of Bangladesh. Bottom sediment samples were collected, using *VAN BEEN* grab sampler, from six different off-shore locations, under a series of fieldworks between 2015 and 2019) extending from Bangabandhu Island in the west to Cox's Bazar in the east (see Table -1). The grabber was operated from the fishing trawler/country boat at stable position. During each try, about 1-2 kg bottom sediments were collected and samples were preserved in polybags to carry to the laboratory.

Table 1: Coordinates and Depths of Sediment Sample Sites

Site Name	Latitude (^{0} N)	Longitude (^{0} E)	Geographical Location	Sample Type	Water Depth
Site-1	21.7811	89.5354	Off-Bangabandhu Island	Grab Sediment	8.00
Site-2	21.21	89.6833	Near SoNG	Grab Sediment	70.00
Site-3	21.971	91.0137	Off-Nijhum Dwip	Grab Sediment	2.00
Site-4	22.747673	91.363894	Off-Feni River Mouth	Grab Sediment	12.00
Site-5	22.0379	91.5424	Meghna Estuary	Grab Sediment	17.00
Site-6	21.3654	91.9756	Off-Cox's Bazar	Grab Sediment	10.00

Samples were considered for particle size analysis using the standard hydrometer methods. Particle size distribution is the quantitative determination of three sizes of primary soil particles as determined by their settling rates in an aqueous solution using a hydrometer. Proportions are represented by stated class sizes: sand (ranging from 2000 – 63 µm), silt (ranging from 63 – 2.0 µm) and clay (< 2.0 µm) and those stated by the USDA Soil Survey and Canadian Soil Survey Committee. Settling rates of primary particles are based on the principle of sedimentation as described by Stokes' Law and measured using a hydrometer (Folk, 1981).

The same samples were used for particle shape analysis. The visual identification of roundness and sphericity of detrital grains is a widely method suggested by Krumbein and Sloss (1963) for particle shape analysis. Samples used were sieved through 500 um, 250 um and 63 um sieves, and the gran sizes between 63-250 um and 250-500 um have separately been considered for particle shape analysis. More than 150 grains were identified under stereo-microscope, using the roundness and sphericity chart suggested by Krumbein and Sloss (1963).

All six samples were used for heavy mineral separation using both physical identification under polarized microscope and XRD analysis. Heavy minerals were separated using standard method of bromoform solution and of separatory funnel. Slides were prepared and heavy minerals were identified using the laboratory facilities in the Geology Department of Dhaka University.

X-ray diffraction (XRD) is the most common technique used to study the characteristics of crystalline structure and to determine the mineralogy of sediments. In this study samples in crystal powdered form were submitted to the '*Centre for Advanced Research in Sciences (CARS*) of Dhaka University for heavy mineral separation using XRD analysis. Same samples were also used for heavy metal identification using Flame-AAS method. CARS is one of the finest laboratory in Bangladesh having the facilities to analysis heavy mineral concentration in ocean sediment. The sample is provided in crystal powder form by grinding and angle is considered 2 theta (0-70) degree. The wavelength used for the analysis is Cu-Ka (1.541874 A0). XRD analysis provides result as a document with the value of angles, diffraction and intensities. Using Match 3 software the relative intensity is calculated and the crystal structure is matched with any specific mineral composition. Crystallography Open Database is used for mineral phase matching in this software.

To infer the ecological characteristic of the bottom sediment of the shelf, diatom species have been identified. Diatom is a microscopic algae and it is highly sensitive to environment, temperature, oxygen, water depth and water quality (Battarbee *et al*, 1984). de Wolf (1982) classified diatom into five salinity groups- polyhalobous, mesohalobous, oligohalobous-halophile, oligohalobous-indifferent and halophobous, which Islam (2001) recognized as synonymous to marine, brackish and freshwater ecology. The use of relative abundances of marine, brackish and fresh diatom is an indicator to determine the nature and charecteristics of bio-ecological characteristics of the sub-aquatic environment of the shelf zone.

4. Results and Discussion

4.1. Particle size Analysis

Site-1 is situated around 1 kilometer away from the Bangabandhu Island and is dominated by medium and coarse silt particles (48%). The occurrence of medium to fine grans is also very high (31%). Site-2 is located around 58 kilometers away from the land and this location is in proximity to the head of the Swatch of No Ground. Clay is the dominating particle size with high percentage to fine sand (26%). Site-1 and 2 represents the western part of the shelf zone of Bangladesh. Site-3 is located about 1 km south of the the Nijhum island. The bottom sediment is dominated by coarse and medium sand particle (92%), with some presence of silt and clay (8%). This site represents the north-central part of the shelf. Site-4 is located about 14 km down of Feni river mouth and is dominated by silt (56%) and clay (32%) particles. Fine to medium sands are also present (12%) in the bottom sediment. This location is dominated by the sediment coming from the Feni river. Site-5 about 25 km off-shore of Chittagong city, is dominated by silt particles (62%). Sand (16%) and clay (22%) are also present in the bottom sediment. Site-4 and 5 represent the eastern part of the Meghna estuary. Site-6, which represents the eastern shelf zone, is located about 2 km off-Cox’s Bazar main land. The site is dominated by coarse to medium sand particles (66%), followed by silt (24%) and clay (20%).

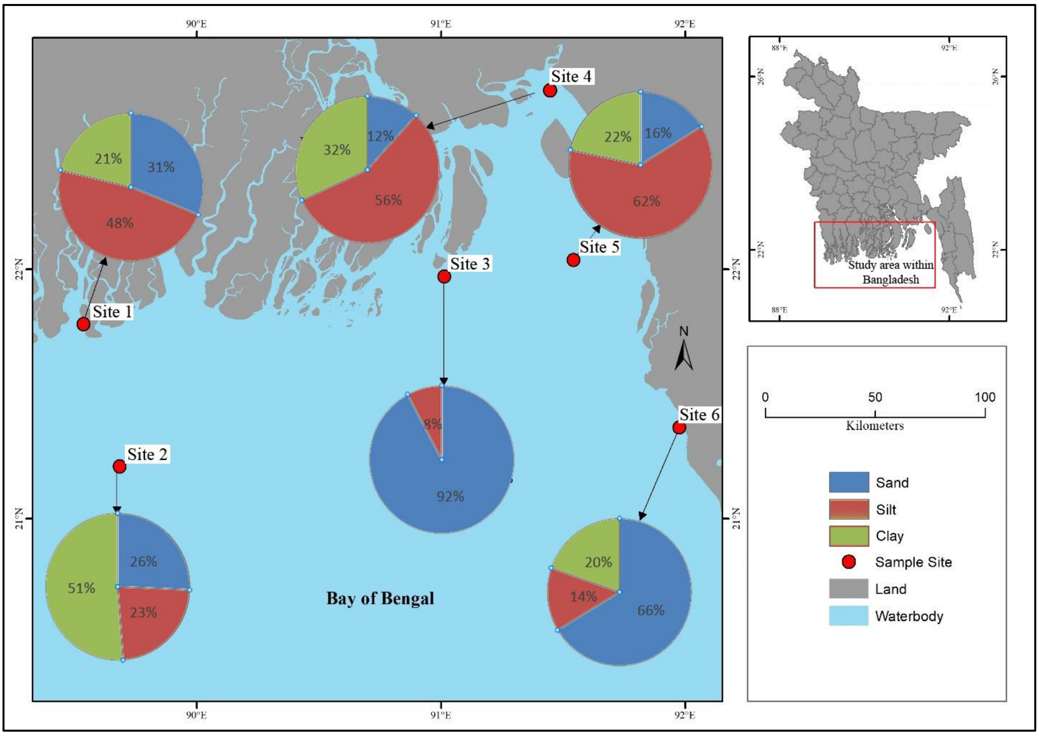

Figure 2: Particle Size Distribution of Sample Sites

The GBM river system, flowing through Bangladesh, collectively deliver about $400 \pm 50 \times 10^6$ tons of sediment to the Bengal basin annually (Milliman and Syvitski, 1992). These sediments flows up to 8°S latitude, travelling more 3000 km away from the Meghna mouth (Curray, *et al* 1982; Curray and Moore, 1971). A significant variation of sediment dispersal by grain size and their concertation reflects the spatial-temporal changes of marine dynamics of the shelf zone. Khan *et al* (2009) have shown that silt and fine sand are predominant in area of less than 20 m water depth, but inner shelf mud deposits are present in some places. The presence of these mud deposits indicates seasonal variations in the shelf dynamics.

In this study, it is noticeable that silt and fine sand are predominant in area of less than 20 m water depth but also inner shelf mud deposits are present in some places. In the shelf zone around the SoNG shows high percentage of sand particles, although silt and clay is the major component. Islam and Meem (2017) have also found higher concentration of sand particle (27-38%) in the south-western shelf zone. Sediments of the Swatch of No Ground are mainly consisted of entirely greenish-gray terrigenous clayey silt and silty sand (Michels et al., 2003). According to Michels et al. (2003) sediments of the Swatch of No Ground is mainly composed of sand-silt and silt-clay layers and most of the sand-silt layers have a clearly sharped basal sandy contact that silty is weakly eroded. The sands are drifted towards west due to strong fluvial influence, ocean current and tidal actions. Kuehl *et al* (1989) also identified similar particle size distribution in the shelf zone and have suggested that these sediments may be mobilized during the summer monsoon season. In the eastern shelf zone, sand is also higher, due to its proximity to the eastern shore and high influx of coarse material from the hill slope erosion of Chittagong hill region. The eastern part of the Meghna estuary, particularly along the Swandip channel, silt and clay is the dominating grain size. Because of strong tidal influence, sediment reworking and accumulation of mud deposits is very high, particularly in the south.

Based on existing data (Islam and Meem, 2017; Islam and Das, 2019: Khan, 2009) and new data available in this study, a map showing a tentative sediment regimes in the inner shelf zone of Bangladesh is suggested below, although it is very challenging to draw such sediment regimes in the inner shelf zone, based on such limited number of field records. However, the broken lines in the map indicate that the boundary of each sediment regime is tentative and can further be improved in future with more records available from the field. Despite such limitation, this proposed map is a bench mark for the ocean scientists to further improvement

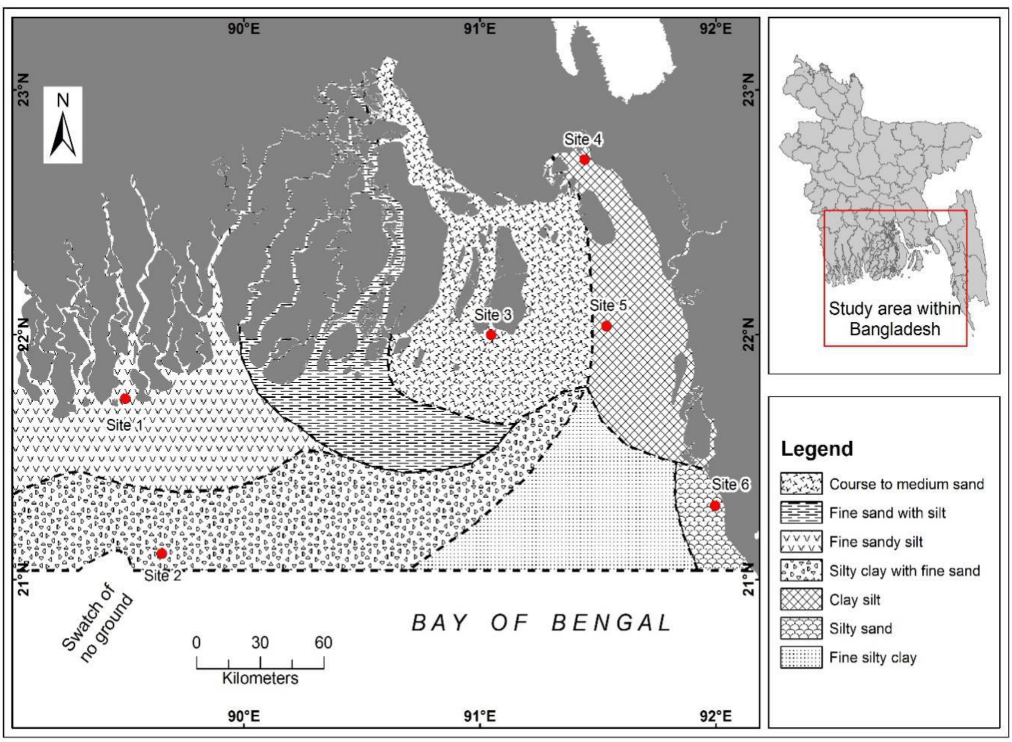

Figure 3: Sediment Distribution in the Shelf Zone of Bangladesh

The map shows high concentration of medium to course sands in the mouth of the Meghna river occupying greater part of the Meghna estuary. Based on sediment characteristics it can be suggested that major source of these course sediments are long-drifted materials from the upstream as well as highly eroded local sediment. A greater portion of such materials are drifted towards the west and has developed two distinct sediment regime of fine silty sand in the middle and fine sandy-silt in the west across the inner shelf zone. In the inner shelf zone, deposits are reworked during the southwest monsoon season (May-October), when high discharge strong winds and moderate waves dominate shelf sediment transport (Khan et al, 2009). The area around the SoNG, particularly in the north and east is characterised by silty-clay with high concentration of fine sand. The presence of the SoNG is a driving force to sediment distribution and accumulation in the shelf zone, particularly in the west. The eastern part of the Meghna estuary, particularly along the Swandwip channel is dominated by clay-silt. Along the eastern part of the zone, particularly off-Cox's Bazar coastal belt is dominated by silly fine to medium sand. The main source of these sands is from the eroded surface of the adjacent hilly areas of the eastern part of Bangladesh. West of this zone, there is a wide sediment regime of fine silty-clay, which occupies a greater part of the shelf zone. In the extreme south of the shelf, clay and mud deposits are accumulated far upto the sharp break of slope of the shelf.

4.2. Particle Shape Distribution

Particle shape analysis is mainly done to know the transportation process and energy of the agents. The property is mainly controlled by the shape of the mineral grains in the parent rock, hardness, mineralogical composition, size, mode, the fluidity, distance of transport, energy condition of transporting agents, environment of accumulation and the digenetic changes experienced by the sediments (Krumbein and Sloss, 1963; Griffiths, 1967; Folk, 1976). Pettijohn (1957) concluded that roundness of a particle is the sum of its abrasional history and the measure of sharpness or smoothness of the perimeter. Sphericity more largely reflects the condition of deposition at the moment of accumulation; to a more limited extent, the abrasion process modifies spherecity. The low sphericity reflects chemical action accompanying unusual episodes in early or late diagenesis (Griffiths, 1967). According to Kumbrein and Sloss (1941), the roundness is measured from 0.1 to 0.9 to different scale. Sphericity is the overall particle shape and similitude with a sphere. Again according to Kumbrein and Sloss (1941), the spherecity is measured from 0.3 to 0.9 to different scale.

Fine sand (>63um) and medium sand (>250um) have been isolated for roundness and sphericity analysis and are shown in Figure 1 and 2.

The roundness of sand particles does not show any noticeable change for fine and medium sand grains among all the sample sites, except in Meghna estuary (site-5). This difference is possibly due to strong tidal force and redistribution of sediment budget. High frequency of rounded and sub-rounded particle shape of the bottom sediment along the shelf zone, particularly in the western belt reflects their long-drifted transformation under fuvio-marine conditions.

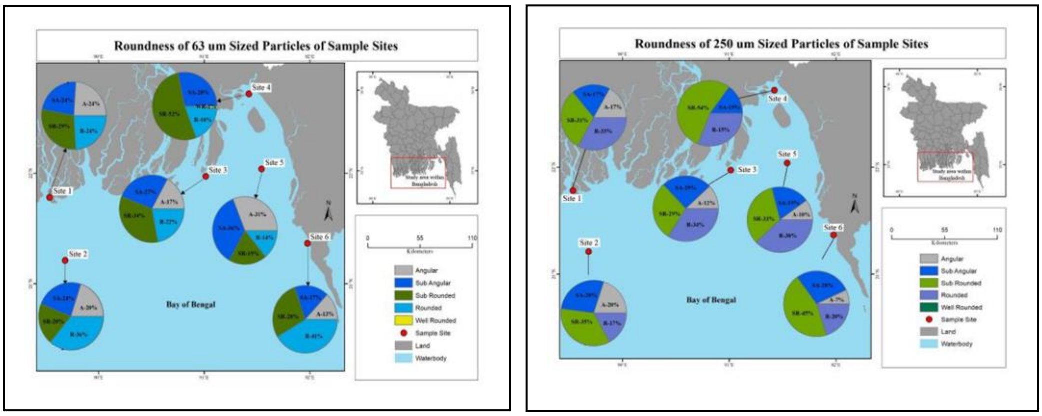

Figure 4: Roundness of Sand Particles: >63 um(left) and >250um (right)

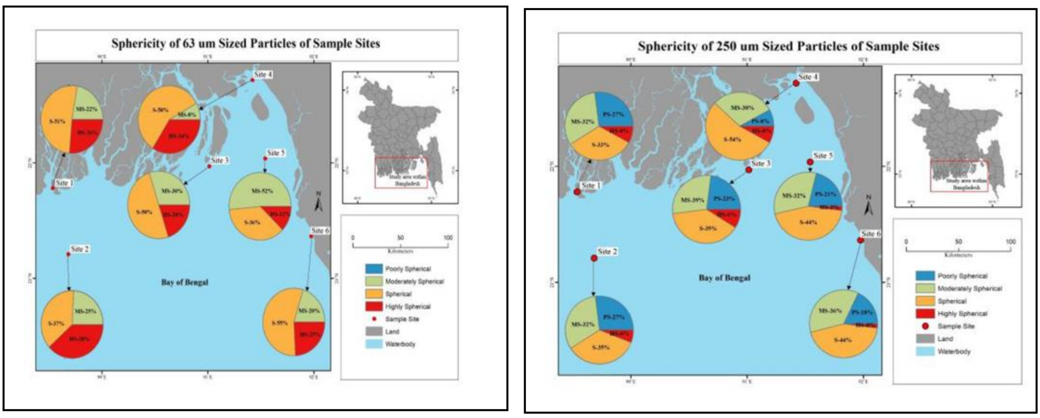

Figure 5: Sphericity of Sand Particles: >63 um(left) and >250um (right)

The sphericity analysis of fine and medium sand particles are in harmony with the findings derived from roundness date. The bottom sediments of the shelf zone is dominant in spherical and highly spherical shape, which is the indication of the grains that are derived from crystalline rocks and older sedimentary rocks exposed in regions far from deposit basin. Particularly in the western shelf zone, the combined sphericity (moderately spherical, spherical and highly spherical) reflects that the sediments are well acted upon by strong wave, tide and fluvial actions. The particles are moderately spherical in north-central part of the shelf and mostly contributed by localized eroded sands.

4.3. Concentration of Heavy and Light Minerals

Bengal Basin has known deposits of heavy mineral sand occurrences. As the river and drainage systems within Bangladesh are extensive, they carry large quantities of sand sediments with high concentration of heavy minerals to the coastal regions. Beach

Mineral Exploration Centre (BMEC) has identified 17 potential reservoirs of heavy mineral deposits along the coastal belt of Bangladesh (Rajib et al 2007). However, the concentration of heavy minerals in the off-shore sediment has not yet been properly explored. The study shows the presences of heavy minerals in the bottom sediment in the shelf zone. However, the proportionate of heavy minerals is low (1.60- 11.14%) compare to the concentration of light minerals, except the site near Bangabandhu Island. The area surrounding the island shows extremely high concentration (77.78%) of heavy minerals, followed by Meghna estuary (17.39%). Heavy mineral concentration is very poor (1.60%) in the off-shore sediment of Cox's Bazar area. The unusual high and low concentration of heavy minerals near Bangabandhu Island and off-Cox's Bazar, respectively needs further studies.

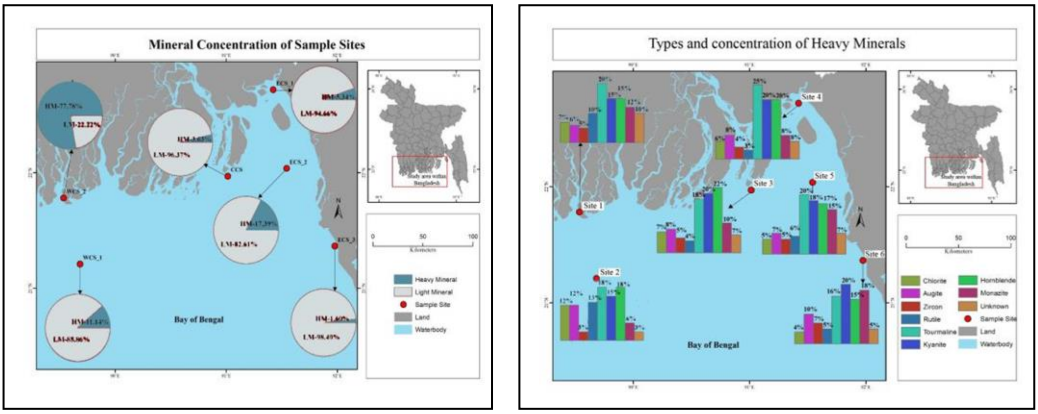

Figure 6: Heavy and Light Minerals Concentration (left) and Types (right) of Sample Sites

The XRD data derived from the samples shows that the common minerals found in the samples are chlorite, augite, hornblende, monazite, kyanite, tourmaline, zircon and rutile, and the percentage of tourmaline, kyanite, rulite and hornblende is considerably high. Tourmaline is high off- Feni river mouth, around Bangabandhu Island and in Meghna estuary; monazite concentration is high in the eastern shelf zone; and hornblende concentration is high in the shallow water nearshore belt of the shelf. Six common light minerals found in the samples are quartz, muscovite, biotite, plagioclase feldspar, potash feldspar and microcline feldspar. Quartz is a common (40-73%) light mineral found in all locations

The mineralogical maturity of the heavy mineral assemblages of sandstones is quantitatively defined by a proposed zircon-tourmaline-rutile (ZTR) index. The ZTR index is the percentage of the combined zircon, tourmaline, and rutile grains among the transparent, nonmicaceous, detrital heavy minerals. The ZTR index is over 90% in most orthoquartzite sandstones. The ZTR index is commonly high in beach or littoral zone depositional environments due to the long transport distances from the source and the high energy of the environment. These minerals are found in abundance due to their high specific gravity and resistance to weathering. As the ZTR index increases, a concentration occurs of the varieties based on color, inclusions, and form of tourmaline, zircon, and rutile, together with a decrease in the number of species of transparent heavy minerals. The ZTR value shows that bottom sediments in the western shelf zone are more matured, and have transported from long distance source. The bottom sediments are weathered chemically and mechanically, and are the resultant of high energetic environment.

4.4. Concentration of Clay Mineral

Bejugam and Nayak (2016) have shown that near the SoNG the common clay minerals are illite, kaolinite, smecite and chlorite; illite has the high concentration (65.19 to 73.49%) followed by kaolinite (12.05 to 15.55%). In this study, the XRD analysis shows that berlinite is the dominant mineral in the entire near shelf zone, followed by birrensite. Other common clay mineral are bearsite, bavenite, phengite, laurelite and danalite (Table -1).

Table 2: Clay Minerals Identified in the Sample Sites

Site Name	List of Clay Minerals
Site-1	Berlinite, Laurelite, Bearsite, Lipscombite,Caminite, Despujolsite, Lautarite, Alarsite, Dukeite, Retgersite, Choloalite, Effenbergerite, Wesselsite, Helvine, Canfiedite, Marshite, Danalite, Bavenite
Site-2	Berlinite, Bearsite, Laurelite, Birnessite, Retgersite, Lipsocombite, Lautarite, Wroewolfeite, Despujolsite, Cohenite, Tridymite, Dukeite, Bavenite, Kelite, Alabandite, Carrolite, Volborthite, Violarite, Burtite, Halite
Site-3	Berlinite, Lipscombite, Helvine, Dukeite, Laurelite, Genthelvite, Bearsite, Caminite, Despujolsite, Danalite, Retgersite, Effenbergerite, Wesselsite
Site-4	Berlinite, Laurelite, Birnessite, Retgersite, Lipsocombite, Despujolsite, Tridymite, Dukeite, Bavenite, Brinessite, , Volvborthite, Violarite, Caminite, Danalite, Alarsite, Helvine, Thorianite, Browneite
Site-5	Berlinite, Bearsite, Laurelite, Lipsocombite, Caminite, Despujolsite, Birnessite, Hapkeite, Indium, Dukeite, Wollastonite
Site-6	Berlinite, Laurelite, Bearsite, Lipsocombite, Indium, Choloalite, Despujolsite, Effenbergerite, Wesselsite, Caminite, Regersite, Dukeite, Alarsite, Helvine, Canfieldite, Tetradymite, Danalite

4.5. Diatom Analysis

In this study, diatom has been used as a marker to infer the ecological characteristics and productivity in the shelf zone of Bangladesh. Commonly identified species are *Navicula recenes*, *Actinocuclus ellipticus*, *Surirella gemma*, *Coscinodiscus asteromphalus*, *Synedra ulna*, *Tabularia fasciculate*, *Nitzschia filiformis* and *Asteronella glacialis*. The diatom assemblage shows that there exists a distinctive depositional environment and ecological characteristics in the shelf zone.

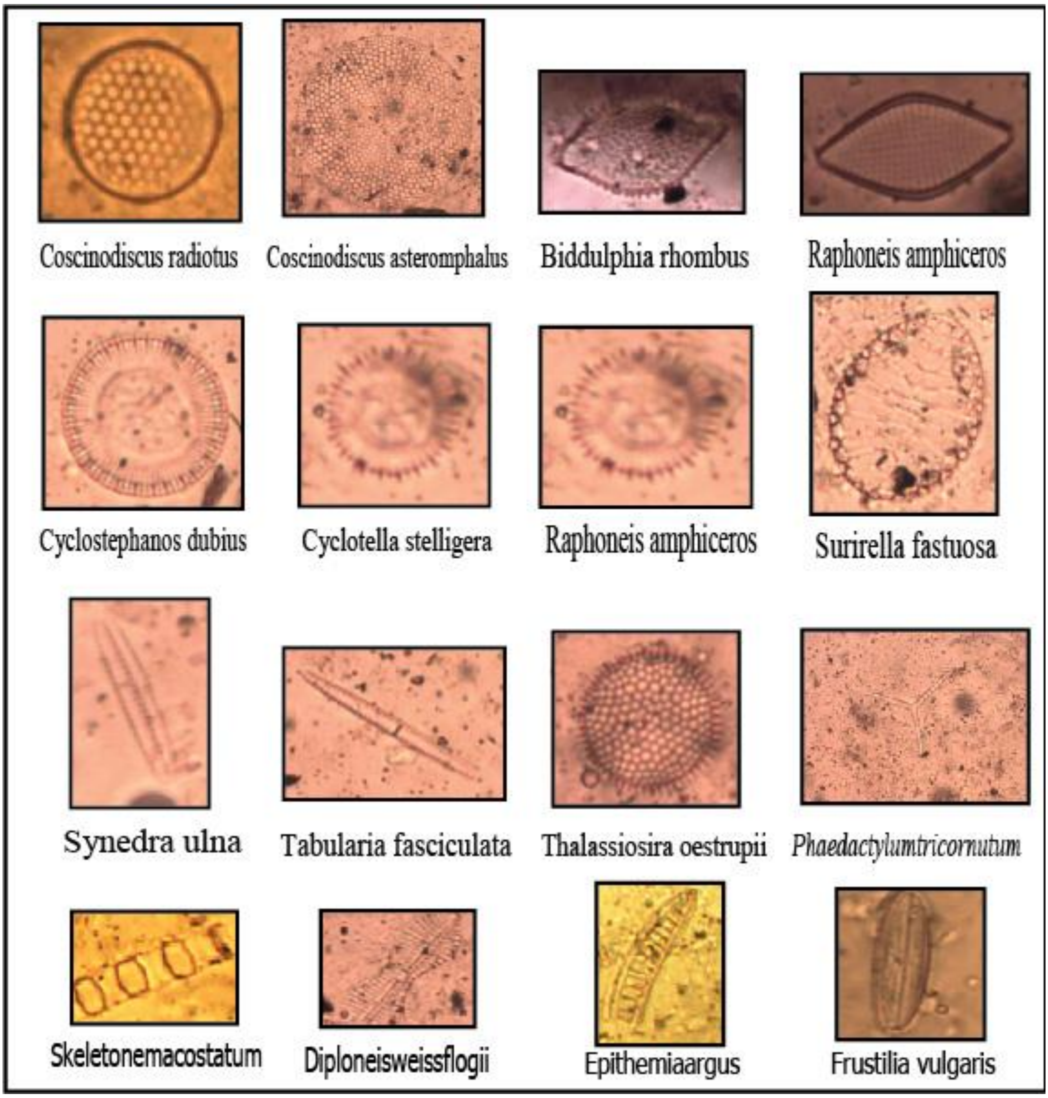

Plate-1: Diatom Species Identified in Samples.

In the western shelf the major assemblages are *Tabularia fasculata, Cyclostephanos dubius* and *Coscinodiscus radiotus*; in the central zone the assemblages are *Raphoneis amphiceros,* and *Nitzschia filiformus;* and in the eastern zone the assemblages are *Actynoptychus heliopelta*, *Tabularia fasculata* and *Surrirella fastuosa.* The eastern zone shows high concentration of diatom species and its depositional environment is significantly different from western zone

5. Conclusions

Bottom sediment is one of the significant parameters for monitoring underwater ecosystem, water quality and ocean dynamics. It also reflects the denudation processes in the long upstream sources and erosion/accretion characteristics at local scale. Bottom sediment also plays a critical role in the formation of new landmass on the sea-floor and emergence of off-shore islands. The bottom topography of the northern Bay of Bengal plays an important role in sediment transportation and redistribution, and frequent changes of shelf geomorphology. The huge amount of sediments carried deeper in to the Bay of Bengal, which later is drifted back to the near shore zone by underwater current. This dynamic process in the shallow shelf zone of northern Bay of Bengal demonstrates the dynamics characteristic of the coastal and shelf landscape. Krantz (1999) has shown that the long-shore current in the off-shore coastal belt of Bangladesh travels anticlockwise, which is being influenced by waves and tidal bores. Sediment transport to the near-shore zone of the shelf is a complex function of long-shore and cross-shore currents, and wave action. Sediments are transported to the near-shore zone by long-shore current. Moreover, the eroded materials from off-shore islands and river front are carried to add to the long-shore current to redistribute to the shelf.

The shelf topography of Bangladesh is rapidly changing with times as observed from analysis of the bathymetry data. Near to the estuary, this change is prominent due to the strong hydrological activities. The spatial-temporal variation of sediment dynamics, properties of sediments and land-ocean interface need adequate attention for integrated coastal zone management, management of ocean resources, navigation in the inner-shore zone, and introducing any major human interventions, such as construction of cross-dam and ports. In the current context, major maritime activities, such as fishing, navigation, tourism, extraction of hydrocarbons, and research works in Bangladesh are confined within the shelf zone. Bangladesh has formulated its integrated coastal zone management (ICZM) policy in 2005, which is primarily dictated by the doctrine of pro-development approach with little attention to protection and conservation of landscape ecology. However, until now, no well-defined and comprehensive marine policy, particularly in the doctrine of conservation of shelf morphology and ecology exits in

Bangladesh. A number of institutes, particularly related to fisheries, tourism, energy, navigation are engaged to promote and utilize the marine resources, and there is always a missing gap and lack of inter-institutional coordination. The shelf zone of Bangladesh is a dynamic hydro-ecological regime and its areal extension largely depends on topography, slope of landscape, fluvial dynamic, interaction between land-ocean interfaces, tidal range, and extent of tidal inundation, wave actions and seasonal variability of ocean current. To understand the science of ocean dynamics in the shelf zone, to extract shelf resources, to foster economic growth and to improve the livelihood of coastal people, the doctrine of pro-development initiative in any policy guidelines needs to be avoided. Rather the P^3C doctrine (Protection, Preservation, Prevention and Control) might have more durability and sustainability for ocean resource management of Bangladesh in general and shelf landscape in particular. This study with limited data source is a little effort that may provide a baseline scenario of spatial distribution of bottom sediment concentration and sediment characteristics over the shelf zone of Bangladesh. However, it requires repetition of similar research work with high frequency and high resolution data sets in future.

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