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Sediment and carbon accumulation in sub-tropical salt marsh and mangrove habitats of north-eastern coast of Bay of Bengal, Indian Ocean

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Abstract
Researches on salt marsh mangrove habitats as global carbon sink are increasing worldwide. However, uncertainties in measuring carbon sequestration capacity of the vulnerable subtropical South Asian coastal habitat thus obstructing the mapping sediment and carbon accumulation rate of their importance. The present investigation was carried out to assess the sedimentation and carbon accumulation rate in salt marsh and mangrove habitats in the vicinity of Sitakunda coast, Chittagong, Bangladesh. The data indicate that sedimentation rate was 22.76±2.56 mg/cm^2/day in mangrove area, 63.52±7.42 mg/cm^2/day in lower mangrove area, 97.02±6.64 mg/cm^2/day in higher marsh area, 5.91±1.16 mg/cm^2/day in lower marsh area and 9.81±0.03 mg/cm^2/day in muddy area. The average sedimentation rate was found 39.82±6.72 mg/cm^2/day during the study period. Soil organic matter in the newly deposited sediment was 3.89±1.28%, while 3.57±0.77% in accumulated peat sediment. Organic carbon of the newly deposited sediment was 2.05±0.93% and 1.89±0.55% in accumulated peat sediment. Usually, the organic materials were found higher in the peat soil in the wetland habitat, while lower amount of organic materials are found in the present peat soil. Lower amount of organic materials in peat soil in the study area could probably due to higher utilization of organic materials by aquatic plants. Further, uncertainties remain about sediment and carbon accumulation changes with tidal range, latitude and elevation in study area require long-term spatio-temporal investigation.

Keywords: Salt marsh; mangroves; sedimentation; soil organic carbon; wetland

1. Introduction
Salt marsh and mangrove habitats are taxonomically diverse group of salt-tolerant, mainly arboreal, flowering plants that grow primarily in tropical and subtropical regions [1]. They are the most productive ecosystems, lying between the land and sea [2, 3]. These habitat systems provide goods and services like transportation of nutrients, biogeochemical cycling, sinking of suspended sediment, carbon burial and protecting from extreme events like cyclone and storm surge [4]. Salt marsh and mangrove habitats act as sediment trap by their roots to control erosion and purify as well as enrich sediment with nutrients after decomposition of their leaves and detritus. Along the shores where the sea level rise, sediments in marshes often accumulate rapidly enough to maintain the surface marsh at an equilibrium level [5, 6]. The organic compound of this sediment is composed principally of carbon compounds, which may constitute a considerable fraction of marsh productivity that is locked up in long-term storage [7]. Highly productive Sundarbans mangrove ecosystems (4.71–6.54 mg C/ha/ year) with 4.85 mg C/ha/year of litter production [8] could be a source of organic matter, which could accelerate the microbial conversion from oxic to suboxic condition in the deeper layer of sediment column. Under a moderate sedimentation rate, a mangrove forest will accelerate the process of land formation. Too much sedimentation, on the other hand, can lead to mangrove mortality as the sediments asphyxiate the respiratory structures (e.g., lenticels and aerenchyma), which mangroves have developed to allow for gas exchange within the roots [9]. The mangrove trees catch sediment by their complex aerial root structure, thus functioning as land builders. In numerous cases, there has been proof of annual sedimentation rate in mangrove areas, ranging between 1.0 and 8.0 mm [10]. Sediment is transported to mangrove and salt marsh habitat by tide, wave action and storms, which carry inorganic and organic

substances like dead plants or detritus. This process helps to grow vegetation and make site for microscopic organisms. In addition, deferent types of mangrove plants and salt marsh are established in the newly deposited sediments. Sediment can be deposited when the salt marsh is flooded, however, all flood events do not contribute the same amount of sediment [11]. Sometimes such sedimentations play a vital role in creating new cultivable land areas. Moreover, these coastal ecosystems are squeezing due to dredging, filling, draining, construction and threatened from sea level rise [12-15].

Sediments are the sources of organic and inorganic matter in the river, estuaries, oceans and other aquatic systems [16]. Sedimentation is a natural phenomenon in the coastal and marine habitat. It is a key component for sediment accumulation in the entire marine coast of sub tropical coasts. Sediment accumulation is not equal everywhere in the marine environment. Generally, the rate of sedimentation is higher in the coastal area where costal macrophytes i.e., mangrove, seagrass and salt marsh are well grown. Sedimentation in the coastal area also acts as counterpart against sea level rise [17]. Salt marshes and mangroves are highly productive source of organic matter, from which there is a net out welling of energy to support the complex estuarine and near shore web [18]. In coastal salt marshes, the substrate surface must remain adjusted relative to mean sea level in order for plants to survive. This stable equilibrium level is maintained as a balance between the rate of sedimentation and changes in relative sea level [19]. Sediment transport processes are complex. The main factors that affect sedimentation are marsh surface elevation, via depth, duration and frequency of inundation. The recorded sediment availability for deposition on the marsh surface is controlled not only by flooding frequency but also by proximity to the sediment source. There is a general trend for higher sedimentation rates at lower marsh elevations but there is a considerable variation between sedimentation rates at the same elevation [20].

The sedimentation process in the mangroves and salt marsh areas is very common in the coastal area of subtropical coasts liken Bangladesh, which plays a vital role in making a deltaic environment. However, this sedimentation and carbon accumulation process is poorly understood ecologically in subtropical region compared to other marine and estuarine ecosystems worldwide. It is well known that several environmental and physical factors i.e. soil organic matter, water quality, activities of domestic animals and coastal communities probably are important in controlling the sedimentation of coastal and estuarine macrophytes [21, 22]. Unlike other parts of world, in Bangladesh very little scientific information exists on sedimentation and carbon accumulation in the mangroves and salt marsh ecosystems and their related parameters. Keeping this view in mind, this study has been undertaken to investigate the sedimentation rate and organic carbon content of the peat soil in an ideal coast line enriched with mangrove vegetation and salt marsh situated at south-east coastal region of Bangladesh.

2. Materials and Methods

2.1 Study Area

The study area is located at Muradur, Sitakunda Upazila (Sub-District) in Chittagong district, locally known as Swandip Lunch Ghat, in South Eastern part of Bangladesh, 40 km far from Chittagong town. The approximate geographical location of the study area is 22° 35´ 20´´ N latitude and 91° 37´ 58´´ E longitude (Fig 1). The coast is influenced by semi-diurnal tide. This coast is planted by mangrove forest under the ADB green belt project on 1997-1998 and characterized by a long inter-tidal salt marsh mudflat (250 feet wide) and mangroves (1400 feet wide). The characteristic of the coast is muddy sandy.

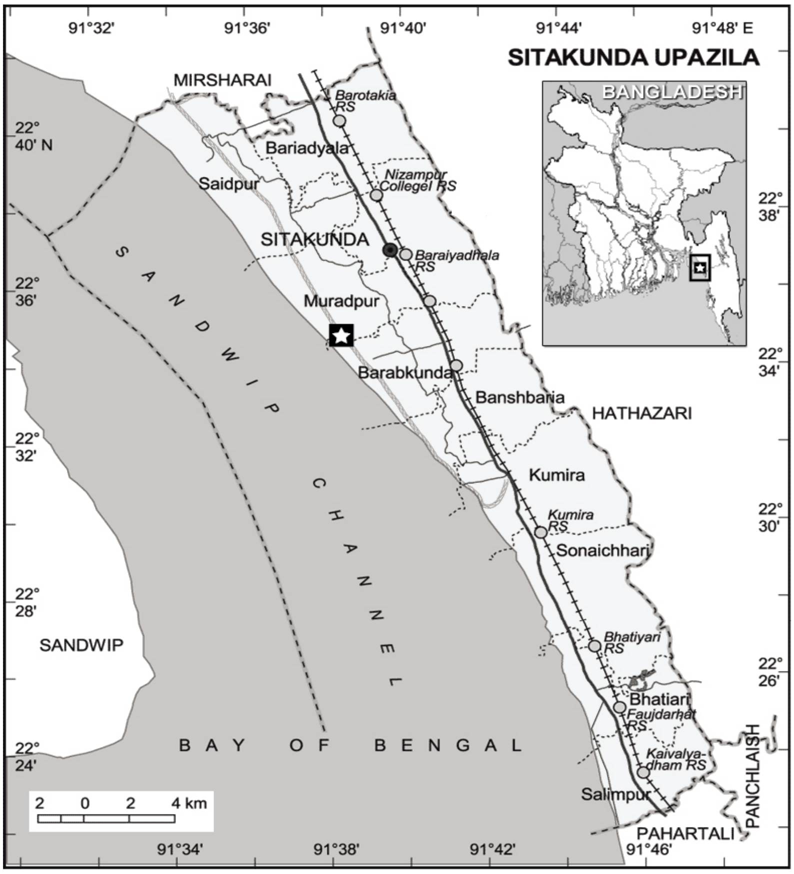

Fig 1: Location of study area showing the location of experimental station at Chittagong, Bangladesh.

2.2 Collection and Analysis of Sediment Sample

The study required monitoring of surface deposition of sediment in mangrove and salt marsh habitat. Samples were collected using sediment traps during different tide cycles in March 2009 from five stations. The data gathered from this study could be used for the calculative annual sediment budget in this coast. Samples were collected by sediment traps, which were made from aluminum sheet (Fig 2).

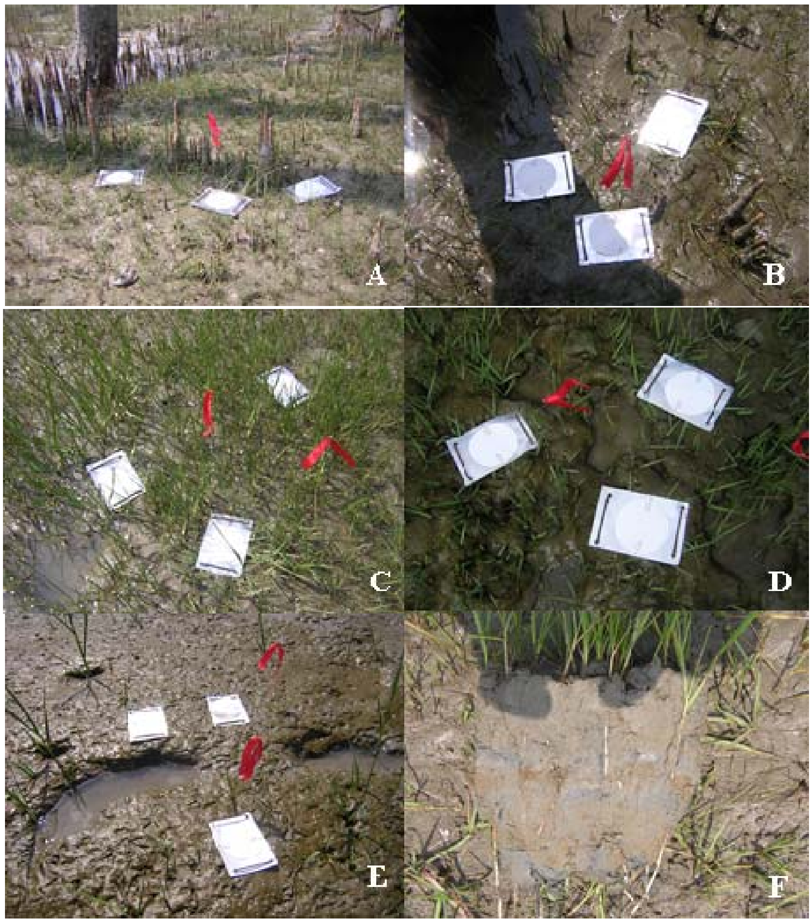

Fig 2: Sediment traps in mangrove area (A), in lower mangrove (B), in higher marsh (C), in lower marsh (D), in muddy area (E) and accumulated layer of fresh sediment and organic matter (F) in the peat of salt marsh and mangrove habitats of Sitakunda coast, Bay of Bengal.

The traps were 15 cm long and 8.2 cm wide. The sampling site was divided into five zones such as mangrove, lower mangrove, higher marsh, lower marsh and muddy area. The traps were placed on the marsh and mangrove surface during low tide by 10-inch long metal sod staples. During the high tide all the traps were inundated by tidal water. After high tide all traps were collected and placed in the polythene bags and labeled. After collection all the samples were brought back to the IMSF laboratory for analysis. The sediment those were trapped on the sediment traps were collected and dried at 80° C for 4 hours. Then the samples were cooled in desiccators and weighted values reported in terms of mg/cm^2/day and mean values were presented [11].

Calculation

$$\text{Sedimentation rate (mg/cm}^2\text{/day)} = \frac{\text{mg of sediment}}{\text{Area of traps}}$$

2.3 Analysis of Organic Matter (OM) and Organic Carbon (OC)

About 2 cm^3 of accumulated peat sediment were collected from four different regions such as mangrove, grass bed, marsh area and mud for determining organic matter. In laboratory the samples were dried at 80°C for 4 hours. Then the organic matter was determined by the following Boyd [23] method. The oven dried peat sediment samples and fresh sediment samples (those were collected by sediment traps) were weighted and placed in porcelain crucibles and labeled. The crucibles were placed into a muffle furnace (OSK 6347, OGAWA SEIKI CO, LTD) at 450°C for 4 hours. Then the samples were cooled inside the desiccators before weighing.

$$\text{Percentage of organic matter} = \frac{X - Y}{X} \times 100$$

Where, X = oven dried weight of sample,
Y = burning weight of sample in muffle furnace
Soil organic carbon was calculated dividing the organic matter by a factor of 1.9 [24].

$$\text{Percentage of organic carbon} = \frac{\text{\% of Organic Matter}}{1.9}$$

3. Results and Discussion

3.1 Sedimentation Rate

The results of the present study showed highest sedimentation rate in higher marsh (97.02 mg/cm^2/day) and the lowest in lower marsh (5.91 mg/cm^2/day) and the average sedimentation rate was 39.82 mg/cm^2/day (ranges from 4.88 to 135.45 mg/cm^2/day) in Sitakunda coast (Table 1). This sedimentation rate was very high, and it could probably be due to the presence of different types of mangroves and salt marsh species specially *Porteresia coarctata* (Fig 3). Their roots and stems act as sediment traps, which help to deposit sediment. Studies by Lynch *et al.* [25] found that sedimentation rate for the Rookery Bay of USA is from 1.4 to 1.7 mm/year, with an average of 2.4 mm/year. They observed that vertical sedimentation rates are influenced by subsidence of the land and/or sea level rise. Inundation is associated with the transport and deposition of water borne inorganic sediments and fringe cores are subject to greater loading from the water. The values of sea level rise are generally estimated about to be 1.4 to 1.6 mm/year [26, 27]. Usually, sedimentation is the key component for the accretion of coastal land in the subtropical coastal marine water where mangroves and salt marsh grow as pioneer species. Sedimentation is not same in every place and determination of sedimentation rate accurately is not possible by short time study since the rate of sedimentation is influenced by tide, wave, current, cyclones and other physical hazards.

Fig 3: Accumulation of sediment in the salt marsh *Porteresia coarctata* bed in Sitakunda coast, Bay of Bengal.

Comparatively, the lower rate of sedimentation in the present study could be due to the pre monsoon or dry season when terrestrial run off was less in this coastal area. This value could probably be higher during monsoon (rainy season) due to heavy rainfall causing terrestrial and river run offs which carry sediment organic detritus and debris, hence required more investigation. Based on the present findings, the estimated value of annual sediment budget in this area was found to be ~14534.30 mg/cm^2/day. This value could be higher and lower since different types of factors such as tidal height, rainfall pattern, wave action, wind direction and terrestrial activities could affects on the sedimentation process as well as the rate of sedimentation in the coastal and marine water. The rate of sedimentation in the present study (0.04 gm/cm^2/day) was lower than the value (0.117 gm/day) reported by Reed [11] for Terrebonne Bay, Louisiana, USA. Such trend in the present study could probably due to the lower rate of river run off while other energy forces like wave action and current activities was low during pre monsoon period. Richard [28] estimated the sedimentation rate of Flax Pond salt marsh on the north shore of Long Island, New York. He divided the site into different plots and determined the sedimentation rates for October, 1974 to February, 1976 were as follows: bare mud flats 20.5 to 45.5 mm/year; recently vegetated mud flats 9.5 to 37.0 mm/year; and high inter tidal peat surface 2.0 to 4.45 mm/year. His study also noted that sedimentation rates decrease with increasing elevation because of the reduced tidal submergence time and decreased height of the overlying water column. On the other hand, Stevenson *et al.* [29], shows sedimentation rates range from 4.3 to 5.5 mm/year and the rates to which sea level rises range from 0.9 to 2.0 mm/year from Delaware to Massachusetts, which rates are lower than sedimentation rate of Sitakunda coastal area of Bangladesh.

3.2 Organic Matter (OM)

Two types of sediment's organic matter were determined for the comparative study within two sediment types for Sitakunda coast. One type of sediment was newly deposited and another was accumulated peat sediment. Results of the study showed that the newly deposited sediment contains more organic matter than accumulated peat sediment. Newly deposited sediment contains an average 3.89% (range 1.74% to 6.67%) of organic matter and accumulated peat sediment contains an average of 3.57% (range 2.68% to 4.33%) organic matter. Soil organic matter in the area was higher than the recorded values (0.2-0.4%) as reported by Rajyalakshmi and Chandra [30] in Chilka lagoon, India and in mangrove areas (0.5-1.7%) of Bangladesh [31]. The higher soil organic matter content at the study area revealed that the accumulation of carbon in the superficial soil is the results of the continuous input of organic matters from aquatic macrophytes i.e., marsh and mangroves [31].

3.3 Organic Carbon (OC)

The mean value of organic carbon of newly deposited sediment contained 2.05% (range 0.91% to 3.51%) and in accumulated peat sediment contained 1.89% (range 1.41% to 2.28%). Usually, the organic materials were found higher in the peat soil in the wetland habitat while lower amount of organic materials was found in the present peat soil (Tables 4 and 5). The lower amount of organic materials in the peat soil in the present study area could probably due to the utilization of organic materials by aquatic plants or higher energy forces could wash away the surface soil nutrients into the adjacent coastal water. Studies by Jonathan *et al.* [32], estimated soil organic carbon (OC) values in the core samples from Indian Sundarbans are very low varying from 0.18% to 3.52% at a depth of 32–36 cm which is also observed by previous workers from this wetland [33, 34]. In the present study, organic carbon value from the peat soil of Sitakunda coastal area varied from 1.41% to 2.28%, which was lower than Indian Sundarbans. The prevalent low values of organic carbon are mainly attributed to the mixing processes and marine sedimentation at the sediment water interface, where the rate of delivery, as well as the rate of degradation by microbial-mediated processes, can be high [35]. These are also probably related to the poor absorbability of organics on negatively charged quartz grains, which predominate in the intertidal siliciclastic sediments of this estuarine environment [36]. Organic carbon concentration becomes higher as it runs through the agricultural and aquaculture ponds [37, 38].

Table 1: Sedimentation rate (mg/cm^2/day) in different habitats of Sitakunda coast, Chittagong, Bangladesh.

Zone	Range	Mean ± SE
Mangrove	16.26 – 29.10	22.76±2.56
Lower mangrove	12.19 – 121.63	63.52±7.42
Higher marsh	48.78 – 135.45	97.02±6.64
Lower marsh	4.88 – 7.48	5.91±1.16
Mud	9.76 - 9.92	9.81±0.03
Mean	**4.88 – 135.45**	**39.82±6.72**
Estimated annual budget		**~14534.30**

Table 2: Organic matter (%) content of newly deposited sediment at Sitakunda coast, Sitakunda coast, Chittagong, Bangladesh.

Zone	Range	Mean± SE
Mangrove	2.79 – 4.00	3.21±0.82
Lower Mangrove	1.74 – 4.01	3.25±1.14
Higher Marsh	1.80 – 3. 09	2.63±0.85
Lower Marsh	3.03 – 6.67	5.41±1.43
Mud	3.33 – 6.67	4.97±1.29
Mean	**1.74 – 6.67**	**3.89±1.28**

Table 3: Organic matter (%) content of accumulated peat sediment (in 2 cm^3) at Sitakunda coast, Sitakunda coast, Chittagong, Bangladesh.

Zone	Range	Mean± SE
Mangrove	3.84 – 4.33	4.10±0.50
Grass	2.68 – 2.74	2.71±0.20
Marsh	2.99 – 3.82	3.39±0.64
Mud	3.80 – 3.98	3.89±0.36
Mean	**2.68 – 4.33**	**3.57±0.77**

Table 4: Organic carbon (%) of newly deposited sediment at Sitakunda coast.

Zone	Range	Mean± SE
Mangrove	1.47 – 2.10	1.69±0.60
Lower Mangrove	0.91 – 2.10	1.71±0.83
Higher Marsh	0.95 -1.62	1.38±0.61
Lower Marsh	1.59 – 3.51	2.84±1.04
Mud	1.75 – 3.51	2.62±0.94
Mean	**0.91- 3.51**	**2.05±0.93**

Table 5: Organic carbon (%) of accumulated peat sediment in salt marsh and mangrove habitat at Sitakunda coast.

Zone	Range	Mean± SE
Mangrove	2.02 – 2.28	2.16±0.36
Grass	1.41 – 1.44	1.42±0.15
Marsh	1.57 – 2.01	1.82±0.47
Mud	2.00 – 2.09	2.04±0.25
Mean	**1.41 – 2.28**	**1.89±0.55**

3.4 Conclusion
The sediment traps in the pioneer zone or salt marsh area measured the highest sedimentation rates caused by the strong current velocity reduction on the mudflat. The higher fractions of clay in the mangrove area compared to the mudflat showed that predominantly finer sediments were taken further towards the mangrove area. This study demonstrates that the bare mud bank of an estuary is highly dynamic until mangroves cover it. Sediment delivery to the vegetated zones is low but the protective effect of vegetation against erosion by waves and currents is strong. This result in small but steady actual sedimentation rates under mangroves and therefore sustained long term accretion. The study further identifies the need for similar measurements to be made in different seasons covering the effects of periodic storm events. Measurements showed that waves were able to stir up sediment from the mudflat, but hardly from the bed in the vegetated part. This shows that short-term sedimentation measurements must be treated with care and the effect of erosive events must be taken into account. Sedimentation rates inside the vegetated part of the estuary bank were higher than other coastal areas known from literature. This is possibly due to the high sediment discharge of the river. The sedimentation rates measured in the rear zone of the mangroves by the canvas sediment traps, the thin sections and the 210Pb dating showed good agreement. Therefore, for management purposes, knowledge of the behavior of the estuary banks is important, and in these cases direct measurements, taking the impact of events into account, are necessary to provide a better understanding of the key processes acting to redistribute sediment on the banks of the estuary. Conserving these ecological sensitive areas is necessary to manage large natural carbon pools. Further, developing a standard protocol measuring carbon accumulation, monetary values, and financial inceptive are valuable alternative for coastal ecosystem carbon marketing in this region.

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