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Original Article

Assessment of organic carbon and carbon stock in the sediments of the estuarine area of Naf River and Maheshkhali Channel, Bangladesh: Investigating the influence of sediment texture and depositional conditions

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Abstract

This study deals with the relations of sediment texture and depositional conditions to the organic carbon (OC) and carbon (C) stock distribution, and estimates C sequestration in the coastal estuaries of the Naf River and Maheshkhali Channel of Bangladesh. In this study, the average OC percentages were 0.65% and 0.55%, the C stocks were calculated as 9.02 t/ha and 9.87 t/ha, and the conversion of C stock to total C sequestration became 33.35 t CO_2/ha and 36.54 t CO_2/ha, with the monetary values $1000.42 and $1096.26 per hectar of the Naf River and Maheshkhali Channel estuaries, respectively. The distribution of OC and C stock mostly depends on the sedimentary depositional conditions and sediment texture, as well as on the existence of mangrove and salt marsh along the banks of the estuaries. Low energy and velocity conditions and unidirectional fluvial settings tend to increase the concentration of OC and C stock, and also moderate grain-size with poorly sorted sediment contains high OC and C stock. Transportation mode with two populations (traction and saltation) increases the concentration of OC and C stock by more than three populations. There is some effect from the mixing environment and heavy mineral concentration on the OC and C stock distributions.

Keywords: organic carbon, carbon sequestration, Maheshkhali Channel, Naf River, sediment texture

1. Introduction

Large volumes of organic carbon (OC) are taken up and stored by continental margin systems collectively (Bianchi, Blair, Burdige, Eglinton, & Galy, 2018) where the estuarine areas are connected to the C cycle of the continental margin (Canuel, Cammer, McIntosh, & Pondell, 2012). Estuaries can contribute effectively to the coastal zone's OC budget (Khohinoor, 2008). The Bay of Bengal coast (490×10^9 gC/yr) receives larger amounts of organic matter (OM) from Indian estuaries than the Arabian Sea (50×10^9 gC/yr) does (Kumar & Sarma, 2018). Also the sediment fluxes are very high at 500 Million tons/yr through the estuary system of Bangladesh (Rahman *et al*., 2018). Rakib *et al*. (2022) mentioned that in order to determine the concentrations and effects of OC and OM in the Bay of Bengal region, study on organic matter is required because the Bangladeshi estuaries are linked to the northern Bay of Bengal. Cammen (1982) found no relationship of OC with sediment particle size. But Falco, Teräsvuori, and Matteucci (2004) found an association of sediment grain size with OC distribution of the surface sediment in the Cabras lagoon (Sardinia). Li and Pang (2014) found higher OC in clay than in sand particles. Also, the grain-size effect is driven by the association of degraded OC

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with particle surfaces (Mayer, 1994b). There is a direct relation between OC mass and particle surface area of the sediment, with the higher ratios (>1.9 mg OC/m^2) occurring in the estuarine system (Bianchi *et al*., 2018). In this study the effects of grain size as well as sediment depositional conditions on OC distribution in the estuarine system were examined. There are only four significant estuary systems in Bangladesh's eastern coastal zone, two of which the Naf River estuary in the south and the Maheshkhali Channel estuary in the north of the study area are crucial for managing the region's dynamic system. Also, these studied estuaries have good contributions in the economic activities, particularly fish culture, salt production, and transportation, in this zone. As this study area still has natural characteristics, organic carbon stock should be measured to find out contributions in the climate change mitigation from this region. In order to examine the impacts of sediment texture and depositional environment on the carbon stock, the study reported in this paper was carried out.

2. Materials and Methods

2.1 Study area

The study area is situated along the estuaries of the Naf River and the Maheshkhali Channel in Cox's Bazar district of Bangladesh. The Maheshkhali Channel is connected to Bay of Bengal in the south-western side and bounded by N 21.44 to N 21.51 degrees latitude and E 91.91 to E 91.99 degrees longitude. There are discrete locations with mangrove and salt pan along the channel bank. This channel is influenced by semidiurnal tides with marine currents increasing from south to north mainly in the coastal area (Misra, Chandramohan, Satyanarayana, Panigrahi, & Mahadevan, 2013). The hydrological characteristics are heavily influenced by the monsoon season (June-September) (Shahadat, Kwei, & Lin, 2001). The water temperature of the channel varies from 22°C to 33°C and salinity from 2.2% to 3.5% (Jewel, Haque, Haq, & Khan, 2002). The water depth at the sampling stations is from 2 to 7.2 m. The station near to the mouth of the estuary is labeled M6, while stations M5, M4, M3, M2, and M1 are located towards the upper estuary of the study channel (Figure 1).

The Naf River estuary is situated in the southernmost part of Bangladesh by the international border with Myanmar and defined by N 20.73 to N 20.92 degrees latitude and E 91.28 to E 91.36 degrees longitude (Figure 1). Also, there are some discrete mangrove patches along the Bangladesh side bank. The river flow through the apex of the Bay of Bengal is affected by southerly winds and swells, and convergence with northbound currents is influenced by oceanographic conditions in the downstream of the river (Sarker *et al*., 2021). The station near to the mouth of the Naf River labeled N6, while stations N5, N4, N3, N2, and N1 are located towards the upper channel. The depths at the sampling stations are from 2 to 9 m.

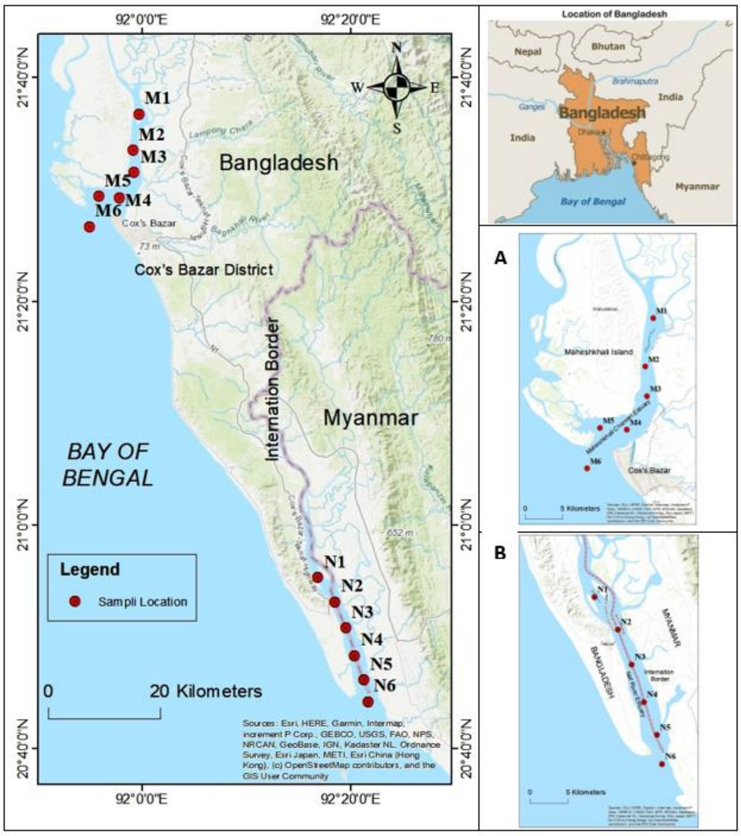


Figure 1. Study area map showing sampling locations in two estuaries; (A) Maheshkhali Channel, and (B) Naf River (Source: Basemap of Esri, 2023)

2.2 Field investigation

Sample collection was carried out over a distance of 5 km along the mid-point of the estuary channel by using a local fishing boat. A 15 liter capacity Van Veen grab sampler was used to collect six samples (N1 to N6) from the Naf River and six samples (M1 to M6) from the Maheshkhali Channel. Sample area covered about 1,000 cm^2 at each station with sample thickness of 0-18 cm. Collected samples were stored in a black polybag and carried to the laboratory. Samples were sub-divided to 100 g for sieve analysis and 5 g for loss on ignition (LOI) analysis.

2.3 Sediment texture analysis

Sieving has become the most popular method for processing sand since the pioneering work of Udden (1898, 1924). In this method, samples are air dried for two weeks and lightly rolled to disaggregate the particles. Standard mesh sizes of 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.063 mm, and pan (<0.063mm) have been used in a sieving machine for 20 minutes, and the size distribution has been weighted and recorded. Folk and Ward (1957) statistical method was used to calculate mean size, standard deviation, skewness and kurtosis. Size grade (in the phi scale) vs. cumulative weight % is plotted for cumulative curves (in g). In order to determine the depositional process and environment, the sieving results have undergone statistical analysis and are shown in a scatter plot. Formulas for calculating grain size statistical parameters by graphical methods after Folk and Ward (1957) are:

1. Graphic mean
   $(M_Z) = (\varphi_{16} + \varphi_{50} + \varphi_{84})/3$
2. Graphic standard deviation
   $Q_i = \{(\varphi_{84} - \varphi_{16})/4\}+\{(\varphi_{95} - \varphi_5)/6.6\}$
3. Inclusive graphic skewness
   $SK_i = \{(\varphi_{84}+\varphi_{16}-2\varphi_{50})/ \{2(\varphi_{84}-\varphi_{16})\}\} + \{(\varphi_{95}+\varphi_5- 2\varphi_{50}) / \{2(\varphi_{95} - \varphi_5)\}\}$
4. Graphic kurtosis = $(\varphi_{95} - \varphi_5) / \{2.44 (\varphi_{75} - \varphi_{25})\}$

2.4 Organic matter (OM) and organic carbon (OC) measurement

Heaton, Fullen, and Bhattacharyya (2016) found strong relation between OM and OC data. LOI is a very common method to measure organic matter whereas usually organic carbon can be calculated using the OM value (Pribyl, 2010). First, the sediment samples have been dried in the air and taken for OM measurement using the LOI method. Sieve analysis record tells that all the collected samples are below 2 mm in particle size. The sampling depth was 18 cm (sediment thickness 0-18 cm) for all samples. A 5 g sample was taken, and the moisture was removed by drying it at 105°C to estimate the OM. Weight was measured after the moisture was removed. The samples were next heated to 375°C for 17 hours in a muffle furnace (Nebertherm GmbH, 1400°C) to measure the OM (Ball, 1964; Blume, Schumacher, Shaffer, Cappo, & Papp, 1990; Nelson & Sommers, 1996; Wang *et al*., 1996). Many authors (Dean, 1974; Heiri, Lotter, & Lemcke, 2001; Santisteban *et al*., 2004) have used 550°C temperature for 4 hours of ignition, but according to Ball (1964), ignition temperature 375°C is ideal considering minimizing the weight loss of the structural water of clay minerals in the samples. Also, Pribyl (2010) suggests that use of too low or too high temperature for LOI can be impact the results of organic carbon estimation. The weight of OM (%) has been determined from the weight difference between 105°C and 375°C as follows (Kumar, Ghoteka, & Dadhwal, 2019):

$$\text{LOI or OM } (\%) = \frac{\text{Dry weight of soil - Weight of soil after ignition}}{\text{Dry weight of soil}} \times 100$$

Van Bemmelen (1890b) conversion factor of 1.724 is usually used for converting OM data to OC data (Heaton *et al*., 2016; Minasny *et al*., 2020). However, this conversion factor usually underestimates the OC (Heaton *et al*., 2016). Pribyl (2010) suggests the conversion factor for Organic Matter to Organic Carbon as 2 instead of 1.724. Although, Pribyl (2010) mentioned that the conversion factor may vary because of the other factors for soil or sediment. So, the OC has been calculated from the OM using the conversion factor 2, as shown below.

Organic Matter (%) = *Organic Carbon* (%) × *2*
So, *Organic Carbon* (%) = *Organic Matter* (%) / *2*

2.5 Calculation of carbon stock

Avelar, Voort, and Eglinton, (2017) show an equation for the measurement of the C stock of soils and marine sediments. For estimating carbon stocks, OC concentrations (%) and bulk density (BD) (g/cm^3) of samples have been measured. To calculate BD, the sample volume was determined and then the samples were dried in an oven at 105°C for 24 h and weight was measured. Two pycnometers (density bottles) of 50 ml and 25 ml were used in this experiment; following calibration at 27°C, their volumes were 50.269 ml and 27.2155 ml, respectively. The BD has been calculated by dividing the oven-dry mass of the sample by total volume of the sample, including pore volume and solid volume (Han *et al*., 2017) using the following equation:

$$\text{Bulk Density } (g/cm^3) = \frac{\text{Weight of the dry sample } (g)}{\text{Total volume of the sample } (cm^3)}$$

BD is used to convert organic carbon concentrations to mass per sediment area at a chosen depth. C stock is calculated as tons of carbon per hectare (t/ha), where OC data is described as a percentage (%) (Avelar, Voort, & Eglinton, 2017) using the following equation:

C stock (*t*/*ha*) = *TOC* (%) × *BD* (*g*/*cm^3*) × *depth* (*cm*)

2.6 Heavy Mineral (HM) Separation

Following the procedure mentioned in Faupl, Pavlopoulos, and Migiros (1998), heavy minerals were separated using bromoform (BrH_3) as a heavy liquid (density of 2.89 g/cm^3) from naturally dried loose sediment samples. A total of 12 samples from the study area were investigated for the heavy minerals.

3. Results

3.1 Organic matter (OM) and organic carbon (OC) concentrations

The Naf River sediments had OM and OC values ranging from 0.39% to 2.21%, and from 0.19% to 1.10%, respectively. Sample N6, which is close to the ocean, had the lowest OM & OC, whereas upper estuary sample N3 had the largest ones. The OM and OC range in the Maheshkhali Channel is from 0.33% to 1.95%, and from 0.16% to 0.97%, respectively. Samples M5 and M6 showed the least OM and OC, from locations near the marine area. The maximum values were found in the M1 sample, which was taken far from the marine area. The Naf River shows larger fluctuations in OM and OC than the Maheshkhali Channel (Table 1).

3.2 Bulk density (BD)

The carbon stock of sediment depends on the total organic carbon present in the sample, the bulk density of the sample, and the depth (thickness of the sample). The Naf River estuary's sediment had bulk density range from 0.87 to 0.73 g/cm^3. The mean bulk density of the sediments in the river was 0.77 g/cm^3. The sample N2 showed higher value, located far from the sea, but the other samples showed lower values and a low standard deviation. The Maheshkhali Channel sediment displays a value range between 0.77 and 1.37 g/cm^3 with the highest values recorded in the upper channel (M1) and close to the marine area (M5) also. The bulk density distribution of the sediments in the Naf River is therefore comparable, but the Maheshkhali Channel sediments have greater values and more variability (Table 1).

3.3 Carbon stock (C stock)

C stock calculated into tons per hectare by taking the OC value in percentage form, the bulk density (BD) in terms of grams per cubic centimeter, and the depth in centimeters. The Naf River estuary's highest and lowest carbon stock levels were 14.57 t/ha in the upper estuary area and 2.77 t/ha in the estuary's mouth area, indicating that the carbon supply is dwindling as one approaches the sea entrance. The Maheshkhali Channel shows a diminishing C stock in seaward direction with a maximum of 23.75 t/ha in the upper estuary area and the lowest value of 2.82 t/ha in the mouth of the estuary (Table 1). The N5 and N6 samples, which are from close to the estuary's mouth, also had lower C stock values. According to average C stock values of 9.87 t/ha and 9.02 t/ha for the Maheshkhali Channel and Naf River estuaries, respectively, the Maheshkhali Channel has a higher concentration of C stock than the Naf River estuary (Table 1). The total C stock for carbon sequestration can be estimated by conversion from t C/ha to t CO_2/ha as per the ratio 1:3.7, according to Lydia (2014). So, the total carbon sequestration value became 33.34 t CO_2/ha for the Naf River and 36.54 t CO_2/ha for the Maheshkhali Channel estuary (Table 1). Also, carbon sequestration can be shown as a monetary value by use of $30 per tonne of CO_2 as suggested by Garnaut (2008). So the monetary value found was $1000.41 per hectare of the Naf River and $1096.26 per hectare of the Maheshkhali Channel estuary (Table 1).

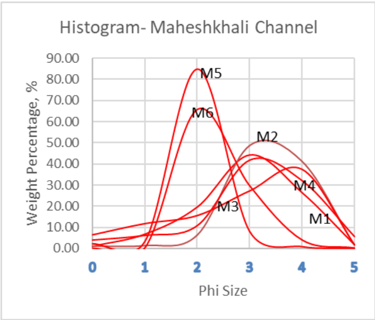
3.4 Sediment distribution and texture

3.4.1 Frequency curve

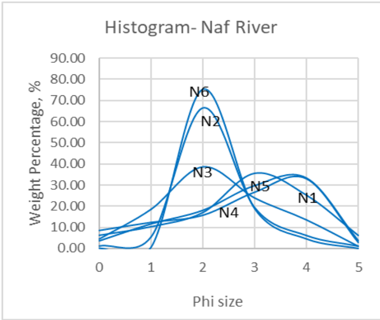
A frequency curve is essentially a histogram constructed to determine the modal size (Boggs, 1995). The sediment distributions of the Naf River and Maheshkhali Channel estuaries are more or less similar in mean size and modality (Figure 2a and 2b). From the graph, it is found that the sediment is unimodal in nature. The frequency curves of samples M5 and M6 in the Maheshkhali Channel, as well as samples N2 and N6 of the Naf River, show a sharp peak with normal distribution. However, the other samples from both estuaries show flat and wide size distributions of sediment.

Table 1. Estimates of carbon stock from OC, bulk density and depth values

Study area (Estuary name)	Sample ID	% of OM	% of OC	Standard deviation (SD) of OC value	Bulk density (BD), g/cm^3	SD of BD value	Depth of sediment, cm	Carbon stock (t/ha)	Carbon sequestration value, t CO_2/ha	C stock monetary value, USD/ha	Heavy mineral, %
Naf River	N1	1.3527	0.6763	-0.0229	0.7416	0.0349	18	9.0284	33.41	1002.15	1.46
	N2	1.0423	0.5211	0.1323	0.8733	-0.0968	18	8.1924	30.31	909.36	1.41
	N3	2.2181	1.1091	-0.4557	0.7303	0.0462	18	14.5790	53.94	1618.27	0.50
	N4	1.1865	0.5932	0.0602	0.7799	-0.0034	18	8.3276	30.81	924.36	0.35
	N5	1.6461	0.8231	-0.1697	0.7543	0.0222	18	11.1749	41.35	1240.42	0.36
	N6	0.3953	0.1976	0.4558	0.7797	-0.0032	18	2.7739	10.26	307.91	1.89
	Average	1.3064	0.6534		0.7765			9.0284	33.35	1000.41	1.00
Maheshkhali Channel	M1	1.9539	0.9770	-0.4262	1.3509	-0.3656	18	23.7555	87.90	2636.86	1.20
	M2	0.8586	0.4293	0.1215	0.7806	0.2047	18	6.0322	22.32	669.58	1.23
	M3	1.6388	0.8194	-0.2686	0.8734	0.1119	18	12.8826	47.67	1429.97	1.50
	M4	1.4251	0.7125	-0.1617	0.7549	0.2304	18	9.6822	35.82	1074.72	4.41
	M5	0.3303	0.1651	0.3857	1.3719	-0.3866	18	4.0781	15.09	452.67	0.16
	M6	0.4027	0.2014	0.3494	0.7799	0.2054	18	2.8268	10.46	313.78	6.89
	Average	1.1016	0.5508		0.9852			9.8762	36.54	1096.26	2.56



(a)



(b)

Figure 2. Frequency curves based on sediment size and individual weight percentages for (a) Maheshkhali Channel, and (b) Naf River

3.4.2 Cumulative curve

Boggs (1995) mentioned that the cumulative curve is the most useful of the grain-size plots. In the arithmetic scale, the curve often exhibits an S-shape. With some very fine grain sand, the samples are predominantly fine-grained in the study area. Samples M5 and M6 in the Maheshkhali Channel and samples N6 and N2 in the Naf River show a steep slope in the curve. Other samples of the area show a gentle and broad slope of the curve (Figure 3a & 3b).

3.5 Grain-size parameters

Table 2 shows calculated values of the grain size parameters mean, standard deviation, skewness, and kurtosis for the Naf River and Maheshkhali Channel sediment deposits. The calculations have been carried out using the Folk and Ward (1957) method.

Mean grain size: The mean size of the sediment in both study areas shows medium sand to fine sand (Figure 4a). For both areas, samples N2, N3, N6, M5, and M6 show medium sizes of sand, and samples N5, N4, M1, M2, M3, and M4 show fine sand size characteristics (Table 2).

Standard deviation: Sorting varies between poorly sorted and moderately well sorted for both study areas (Figure 4b). Samples M3, M4, N5, N4, N3, and N1 are poorly sorted, whereas samples M5, M6, N2, and N6 are moderately well sorted.

Skewness: The graph shows the fine skewed and coarse skewed sediment for the Naf River, and coarse skewed to near symmetrical skewed for the Maheshkhali Channel sediment (Figure 4c). In the Naf River, sample N6 shows fine skewed sediment, and N2 shows strongly fine skewed sediment. Samples N1, N4, and N5 are coarsely skewed, while N3 is nearly symmetrical. In the Maheshkhali Channel, samples M1, M4, and M5 are coarsely skewed, and M3 is strongly coarse skewed sediment. Sample M6 is fine skewed and M2 has near symmetrical nature in skewness of the sediment.

Kurtosis: The kurtosis expresses the packedness of the grain size distribution. The study area sediments are leptokurtic to platykurtic in nature (Figure 4d).

3.6 Visher diagram

The diagram developed by Visher (1969) can be applied to modern sediment analysis. The probability scale represents the data to the segment of two or three straight lines, which reflect the different modes of transportation of sediment. The Visher diagram (Figure 5a & 5b) shows the dominants of the double saltation (saltation I and saltation II) population with a single suspension and traction population for some of the samples of both zones. In the Naf River, samples N2 and N6 show three distinct sand populations, whereas other samples (N1, N3, N4, and N5) show two distinct sand populations (traction and saltation) (Figure 5a). Samples M5 and M6 have three distinct sand populations, whereas the other samples (M1, M2, M3, and M4) have two distinct sand populations (traction and saltation) (Figure 5b). The mode of sediment transportation is quite similar for both zones.

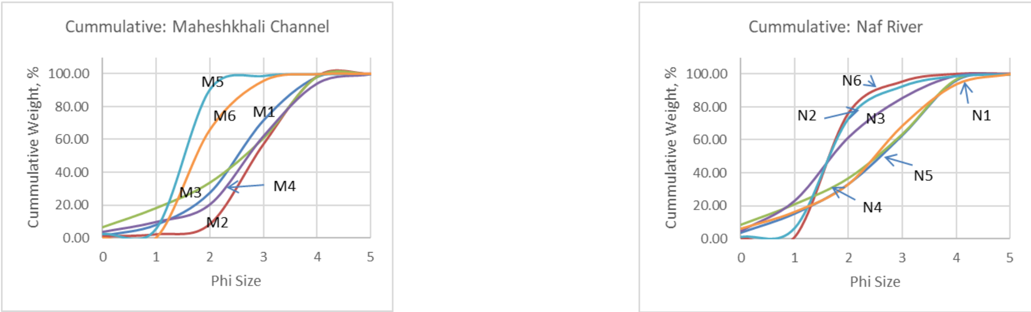
3.7 Heavy minerals

Table 1 shows a higher weight percentage of heavy minerals in the Maheshkhali Channel than in the Naf River. The status of the heavy minerals in the study area is 0.16 to 6.89% in the Maheshkhali Channel and 0.35 to 1.89% of the in the Naf River (Table 1). Samples M6 and N6 had the highest percentages of heavy minerals in the study area.

4. Discussion

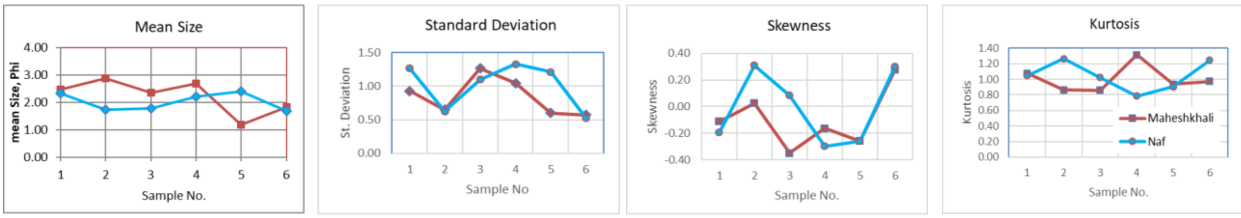
4.1 Carbon stock and organic carbon distribution

According to Flynn, Kuel, Harris, & Fair, (2022), the %OC in the mouth of Ayeyarwady ranges from 0.03–1.10%, and they mentioned that the highest value occurred near the Indo-Burman Ranges; also, they mentioned that the northwestern shelf in the Bay of Bengal displayed 0.82-1.0% of OC with an increasing trend toward north. The averages of OC in the Naf River and the Maheshkhali Channel were 0.65% and 0.55%, respectively, which are moderately high percentages of OC. The average OC shows that the Naf River contains a higher amount of OC than the Maheshkhali Channel, but the amounts are near each other (Table 1). Ray *et al*. (2011) studied the Indian mangrove forest and mentioned the above-ground biomass (total carbon) as 49.54±17.42 t C/ha and the below-ground biomass as 9.61±3.37 t C/ha. In this study, the average C stock (in t/ha) of the Naf River was 9.02 and in the Maheshkhali Channel it was 9.87, which are comparable to the below-ground biomass levels of the mangrove forest in this region, being rich in OC.



(a) (b)

Figure 3. Cumulative weight percentage logarithmic curves based on grain size of the (a) Maheshkhali Channel, and (b) Naf River



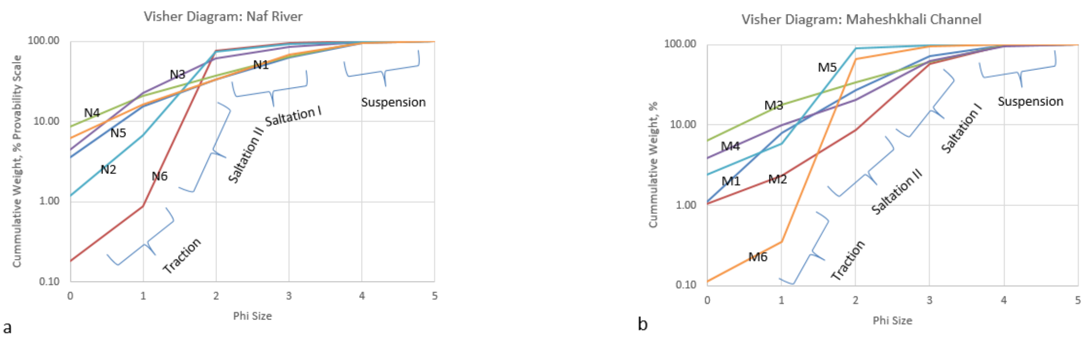
(a) (b) (c) (d)

Figure 4. Graphical plots of Naf River and Maheshkhali Channel sediments: (a) mean size, (b) standard deviation or sorting, (c) skewness, and (d) kurtosis of the sediment. Note: Study samples no. N1 to N6 and M1 to M6 shown in the graphs as samples no. 1 to 6

Table 2. Statistical parameters of sediment texture in the samples (after Folk, 1974)

Study area (Estuary name)	Sample no	Graphic mean	Verbal class	Standard deviation	Verbal class	Skewness	Verbal class	Kurtosis	Verbal class
Naf River	N1	2.33	F	1.27	PS	-0.19	CSk	1.05	Meso
	N2	1.73	M	0.63	MWS	0.31	SFSk	1.26	Lepto
	N3	1.78	M	1.10	PS	0.08	NSy	1.02	Meso
	N4	2.22	F	1.33	PS	-0.30	CSk	0.78	Platy
	N5	2.41	F	1.21	PS	-0.26	CSk	0.90	Platy
	N6	1.70	M	0.52	MWS	0.30	FSk	1.24	Lepto
Maheshkhali channel	M1	2.48	F	0.93	MS	-0.11	CSk	1.08	Meso
	M2	2.87	F	0.65	MWS	0.03	NSy	0.86	Platy
	M3	2.35	F	1.26	PS	-0.35	SCSk	0.86	Platy
	M4	2.68	F	1.05	PS	-0.16	CSk	1.31	Lepto
	M5	1.19	M	0.60	MWS	-0.26	CSk	0.93	Meso
	M6	1.84	M	0.57	MWS	0.28	FSk	0.97	Meso

Note: F= Fine Sand, M=Medium Sand, PS= Poorly Sorted, MWS= Moderately Well Sorted, CSk=Coarse Skewed, FSk=Fine Skewed, NSy=Near Symetrical, SCSk= Strongly Coarse Skewed, Platy= Platykurtic, Lepto= Leptokurtic, Meso= Mesokurtic



(a) (b)

Figure 5. Cumulative weight percentage probability curves (Visher diagram) of the (a) Maheshkhali Channel, and (b) Naf River

4.2 Relation of sediment texture and OC distribution

From the histogram, the unimodal curve (Figure 2a & 2b) indicates the process of sediment deposition is consistent during the sediment settlement (Baiyegunhi, Liu, & Gwavava, 2017) and characteristic of a fluvial setting (Shettima, Buba, Kyari, & Bukar, 2012). The samples in the marine connected zone of both areas (samples M5, M6, and N6) show steep slopes in the cumulative curve (Figure 3a & 3b), indicating good sorting and wave winnowing action, and these samples are lower in OC and C stock. Other samples of both estuaries show broad and gentle slopes, which indicates deposition through low energy and velocity conditions (Boggs, 1995) and the samples in this upper estuary shows higher values of OC and C stock. The medium sand sizes in samples N2, N3, N6, M5, and M6 indicate moderately high energy conditions, whereas the fine sand sizes in the samples N5, N4, M1, M2, M3, and N4 indicate moderately low energy conditions (Baiyegunhi *et al*., 2017). The grain size may control the OC and C stock contents of sediment whereas medium-size sand may have higher values of OC and C stock.

Sorting can be used as a tool to measure the uniformity of current (Folk, 1964) and indicates fluctuations in the hydrodynamic conditions of the depositional environment (Sahu, 1964). In both estuaries, samples M3, M4, N5, N4, N3, and N1 show poorly sorted sediment, indicating variations in current energy conditions; samples M5, M6, and N6 are connected to the marine side and show moderately well-sorted sediment, possibly due to partial winnowing action (Angusamy & Rajamanickam, 2006; Rajesh, Anbarasu, & Rajamanickam, 2007; Ramanathan *et al*., 2009). Most of the studied samples in these estuaries show moderately well-sorted sediment, implying a moderate to far distance from the sediment source, while the poorly sorted sediment indicates the sediment source is near (Abdel-Wahab, Kholief, & Salem, 1992; Reineck & Singh, 1973; Shettima *et al*., 2012). Relatively poorly sorted sediment may contain higher amount OC and C stocks than well-sorted sediment in this area. Extreme values of skewness and kurtosis found for samples N2, N4, N5, and N6 in the Naf River and samples M3, and M4 in the Maheshkhali Channel indicated a zone of environmental mixing (Falk, 1964). Maybe there has been some impact of the mixing environment on OC distribution and carbon sequestration.

The upper channel in this study area exhibits dominance of two sand populations (traction and saltation) in Visher diagram as well as a higher percentage of OC indicating dominant depositional conditions (Martínez-Mena *et al*., 2019) and unidirectional current systems (Dike, 1972). The mouth of both estuaries exhibits low OC, which indicates erosional conditions (Martínez-Mena *et al*., 2019) and wave zones (three sand populations) (Visher, 1969). The higher percentage of heavy minerals in the study area shows a lower percentage of OC and C stock.

5. Conclusions

The distribution of OC percentage is comparable to the average value of the northwestern shelf area of the Bay of Bengal as well as to mangrove forests in India, which can maintain a valuable effect on carbon sequestration in Bangladesh. The monetary value of the carbon sequestration can be taken into consideration for policy making to mitigate climate change in this area. Considering the depositional conditions of the study area, wave winnowing conditions with good sorting of sediment reduce the OC and C stock. The low energy and velocity conditions with a unidirectional fluvial setting and medium grain-size with poor sorting tend to be associated with higher amount of OC and C stock in the estuarine sediment. Also, maybe there has been some impact on OC distribution in the zone of the mixing environment and heavy mineral distributions. The mode of sediment transportation has an effect on the OC distribution, which is related to depositional setting. So, the sediment texture and sediment depositional conditions may control the OC and C stock of an estuarine zone in the study area.

The depositional environment of the study area is favorable for carbon sequestration, which also may be expedited by the presence of mangrove and salt marsh areas on the banks of the both estuaries. Mangrove encroachment occurring along many shorelines increases the above-ground biomass and carbon stores in soils (Doughty *et al*. 2015; Kelleway, 2016). So, an increase in mangroves along the bank of the estuaries and shoreline will increase the capacity for carbon sequestration in the study area. Also, it is necessary to protect the environment of the study area to increase and retain the present favorable carbon sequestration conditions.

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