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Carbon Storage of Mangrove Sediments in Kibani, Eastern Niger Delta, Nigeria: Implications on the Environment

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Abstract: The amount of carbon stored in the mangrove sediments in Kibani area of Eastern Niger Delta was quantified. The objectives were to determine the sediment bulk density (SBD) and organic carbon concentration (% C) and estimate the amount of organic carbon stock in the top 100-cm depth of mangrove sediments and its carbon dioxide equivalent (CO_2e). A total of 312 sediment samples were collected from 24 different sampling points at seven locations. An open-cylindrical gouge auger of 100-cm length and 5-cm diameter was designed and fabricated for the purpose of sediment sampling. Field measurement, laboratory analysis, data presentation and result presentation followed the Guidelines for Forest Carbon Measurement, Monitoring and Reporting. The sediment type has a major control on the distribution of organic carbon. The lithology is a typical of mangrove forest and included peat and clay with pockets of sands. Sediment bulk density (SBD) and %C ranged from 0.95 g/cm^3 to 1.97 g/cm^3 (mean = 1.30 g/cm^3) and 0.9 % to 33.6 % (mean = 12.48 %) respectively. Carbon stocks ranged from 24.12± 15.18 Mg C ha^{-1}to 3245.76 ± 15.18 Mg C ha^{-1}(mean value = 39.80 Mg ha^{-1}) while CO_2e ranged 88.52 ± 15.18 Mg CO_2 ha^{-1} to 11, 911.94 ± 15.18 Mg CO_2 ha^{-1} (mean = 2, 348.07 ± 15.18 Mg CO_2 ha^{-1}). The total carbon stock of the study area was estimated at 947.78 ± 55.64 Gg C, equivalent to 3, 478.36 ± 55.64 Gg CO_2. The study revealed that 732, 595.71 ± 55.64 Mg of carbon dioxide is stored in the sediments. This amount could either be removed or released to the atmosphere through forest management practices and/or degradation to exacerbate climate change and /or mitigate it. It is recommended that Niger Delta region of Nigeria should be protected against all anthropogenic-related degradation which influences the amount of carbon storage.

Key words: Carbon storage · Climate Change · Mangrove Sediments · Niger Delta · Environment

INTRODUCTION

Our climate is changing. This has become one of the global environmental issues. Carbon dioxide (CO_2) is known to play a key role in climate change [1, 2]. Anthropogenic-related increase of greenhouse gases, CO_2 in particular is the major cause of global warming, accounting for as much as three-quarters of greenhouse effect [3, 4]. Global warming drives the climate change and it has been predicted that global warming will continue for decades with its multiple negative effects being experienced by all and sundry [3]. Climate change has tremendous impacts on both humans and the environment. Some of these impacts include severe water shortages, accentuated rise in sea level (with consequent destruction of the ecosystem, biodiversity and human economic activities), depletion of natural resources, increased occurrence of storm surges, decimation of wetlands and extreme weather events such as aggravated droughts and catastrophic floods (which cause crop damages and failure, low agricultural yields, increased desertification), higher temperature on land and sea and heat waves, variability of rainfall, shift in the geographical range of plant species, changes in the length of growing season, melting of ice sheets, snow and glacier, salt water intrusion, decreased water quality, increased sediment

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load, accentuated erosion, etc. [3-7]. Adaptation is required in order to cope with climate change. Although mitigation measures are to be pursued, attention should be given to adaptation techniques only if there is no progress in mitigation actions [8].

The mangroves are becoming relevant at the global level because of the role they play as natural carbon sinks with eventual climate change mitigation potentials [9, 10]. Researches have revealed that the mangrove sediments can play a key role in climate change mitigation [11-18]. The amount of carbon that is stored in soils and/or sediments has been found to be twice the amount of carbon in the atmosphere [19]. This suggests that if carbon sequestration capacity of soils and/or sediments is enhanced, it can help to can ameliorate the effects of climate change.

Mangrove forests are among the largest organic carbon reserves which contain organic soils up to several metres deep [20]. They are a community of plant species which occupy fringy, shallow sandy or muddy areas and occur in the intertidal and shallow subtidal zones of tropical and subtropical tidal marshes [21]. Mangrove forests cover about 137, 600 km^2 of coastlines and span over 118 countries, contributing about 30 to 35 % to the global area of tropical wetland forest [22-25]. About 20 % of the world's mangrove forest is found in Africa which makes it the 3rd largest continent in terms of mangrove cover [14, 24, 26]. Nigeria's mangrove forest lies within the coastal region of Niger Delta. It is the largest mangrove in Africa and the 4th largest in the world stretching along the coast and covering about nine states [23, 25, 27].

The mangrove sediments are highly vulnerable to change in land use and/or climate as significant amount of carbon stored in them could be released back to the atmosphere if the sediments are disturbed [18]. Such change in land use and/or land cover such as deforestation, conversion, degradation and afforestation are caused by land clearing, aquaculture expansion, overharvesting and development and could lead to loss of the entire belowground carbon pool of tidal wetland sediments [18, 28-30]. Deforestation is the second largest anthropogenic sources of atmospheric CO_2 emissions, accounting for about 20 % of global anthropogenic CO_2 [3, 4, 24, 31]. It has dual consequences in that it reduces the amount of carbon stored in mangrove sediments and releases significant amount of CO_2 back to the atmosphere [26]. Owing to deforestation and other forms of forest degradation caused by oil and gas exploration/ exploitation, developmental projects in coastal communities, unregulated lumbering for construction and wood carving, the mangrove forests of Niger Delta are being threatened [32, 33]. This threat can influence the amount of carbon storage and as well undermine its role in climate change mitigation [15]. The assessment of carbon storage of mangrove sediments is a key to determining the amount of CO_2 released to the atmosphere via forest disturbances. It is pertinent to carry out this assessment in Niger Delta since exploration/ exploitation of crude oil and the activities of artisanal crude oil refinery have continued to release $CO_2$to the atmosphere while deforestation and other forms of forest degradation which have remained unabated in the region not only reduce CO_2 intake but increase its release. Determining the amount of carbon stored in mangrove sediments remains the key to knowing the importance of mangrove sediments in climate change mitigation. This is important particularly in the mangrove sediments of Niger Delta where no such research has been carried out. This study assessed the carbon storage of the mangrove sediments in Kibani, Eastern Niger Delta, Nigeria. The objectives were to determine the sediment bulk density (SBD) and organic carbon concentration (%C) and estimate the amount of organic carbon stock in the top 100-cm depth of mangrove sediments and its carbon dioxide equivalent (CO_2e).

MATERIALS AND METHODS

Study Area: The study was carried out in Kibani tidal flats of Gokana Local Government Area of Rivers State. This area falls within the Mangrove Swamp Forest of Niger Delta, Nigeria which shares boundary with Bonny L.G.A to the west, Khana L.G.A to the north, Opobo/Nkoro L.G.A to the east and the Atlantic Ocean to the south. It lies between Latitude 4° 33' to 4° 35'N and Longitude 7° 16' to 7°17'E and stretches along the coastline. The tidal flat covers an area of 47.53 ha (Figure 1). The study area is characterized by a humid tropical climate with mean annual rainfall reaching 4000 mm during the peak of rainy season (July-September) while the salinity of water fluctuates seasonally reaching as high as 3.8 ‰ in the dry season and dropping to 0.5 ‰ in the rainy season [33]. The monthly temperature of air varies from 26°C to 30°C [32]. The soils are commonly referred to as "Chikoko mud" and are sandy, clayey and muddy with dark grey colour. The vegetation types include *Rhizophora racemosa*, *Rhizophora harisona, Rhizophora mangle, Avicenia africana* and *Nypa fruticans* with *Rhizophora* genus being dominant [27, 34]. The mudflat is inundated with water during high tides.

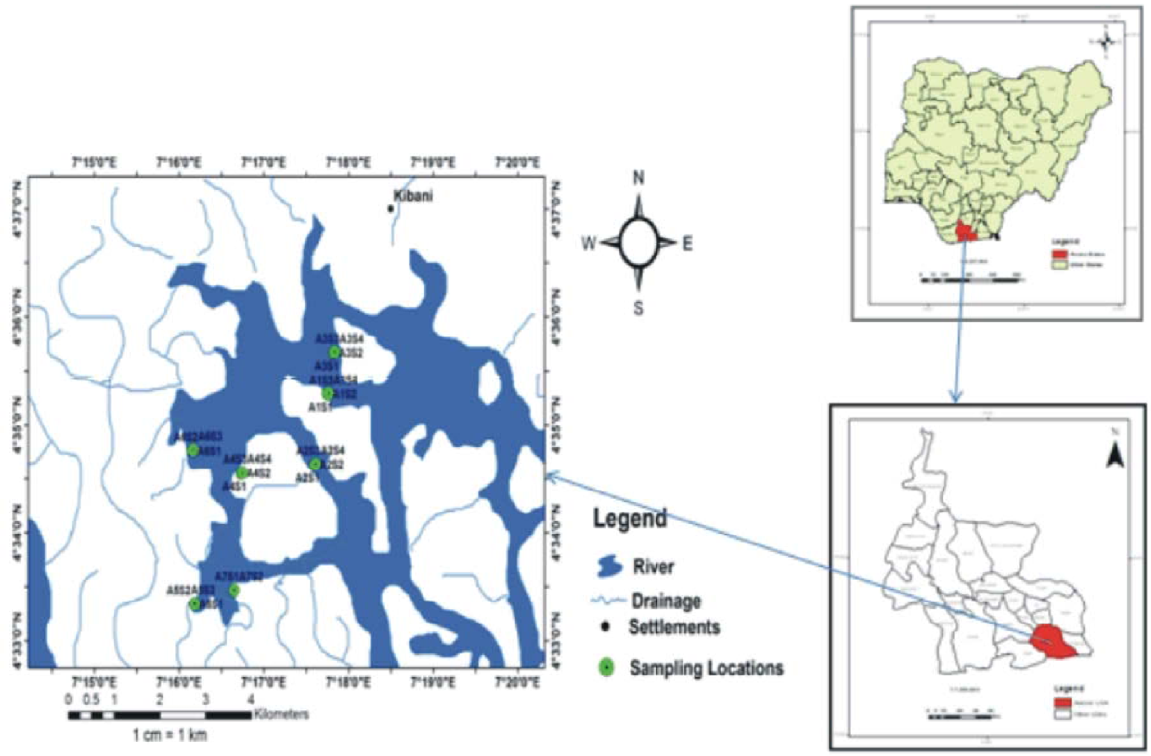

Fig. 1: Location Map of the Study Area

In terms of lithology, the Niger Delta Basin contains sediments that reach about 12, 000 metres [35]. The sediments are grouped into three stratigraphic units on the basis of the ratio of sand to shale contained in the sediments and include continental (at the top), paralic and marine sediments [36, 37]. These stratigraphic units are known as Benin Formation, Agbada Formation and Akata Formation respectively [38]. Akata Formation is a basal marine shale unit deposited in prodelta environments and consists of clays and shales with minor intercalation of sands which is usually less than 30 % in composition [38]. Agbada Formation is a coastal marine sediment consisting of alternating sands and shales and represents sediments deposited in the transitional environment such as mangrove swamps, floodplain, marsh (that is, lower delta plain), coastal barrier and fluvio-marine zones. The percentage of sand in Agbada Formation ranges from 30 % to 70 %. It is about 3000 metres thick and ranges from Paleocenee to Recent in age [38]. Benin Formation is the top layer of the depositional sequence of Niger Delta. It has a very high percentage of sand which varies from 70 % to 100 %. The coastal plain sands dominate. The sediments were deposited in the continental environment of the upper delta plain such as braided and meandering of fluvial systems.

Field Sampling: Field sampling was carried out between August 4 and 24, 2021. A total of 312 sediment samples were collected from 24 sampling points at seven locations (K1-K7; Table 1). Procedures for Forest Carbon Measurement and Monitoring specified by [18] were followed. An open-cylindrical gouge auger of dimensions 100 cm long and 5 cm wide, specially designed for environmental research purposes was designed, fabricated and used in sampling (Plate 1). A systematic sampling approach was adopted. At each location, a rectangular plot was established. The number of sampling points depended on the size of the tidal flat. Sediments were sampled at depth of 100 cm. The organic litters were removed from the ground surface while the auger was inserted vertically into the ground by pushing until the top of the auger got to the level of the ground surface. The auger was turned in a clockwise direction a few times to cut through the sediment. The auger with sediment in it was gently pulled out of the ground while turning it to retrieve the sample. When pulled out, a measuring tape was used to measure the required depth intervals while a spatula knife was used to split the sample. At each sampling point, the samples were split into 13 subsamples with varying depth intervals (six 5-cm depth intervals and seven 10-cm depth intervals).

Table 1: The Coordinates of Sampled Locations

S/N	Location	Points Sampled	Sampling point ID	Latitude	Longitude	Number of Samples
1	K1	4	K1S1 K1S2 K1S3 K1S4	4° 35' 17''	7° 17' 45''	52
2	K2	4	K2S1 K2S2 K2S3 K2S4	4° 34' 38''	7° 17' 36''	52
3	K3	4	K3S1 K3S2 K3S3 K3S4	4° 35' 40''	7° 17' 49''	52
4	A4	4	K4S1 K4S2 K4S3 K4S4	4° 34' 33''	7° 16' 44''	52
5	K5	3	K5S1 K5S2 K5S3	4° 33' 20''	7° 16' 08''	39
6	K6	3	K6S1 K6S2 K6S3	4° 34' 45''	7° 16' 09''	39
7	A7	2	K7S1 K7S2	4° 33' 28''	7° 16' 39''	26

Plate 1: Field Sampling

The auger was disassembled and washed with water after each deployment. The sampling dates, coordinates, depth intervals, plot and sample numbers/foil identification numbers were all recorded in the field notebook and later transferred to the field datasheet. All samples were put into pre-labelled aluminium foils, sealed and kept in core boxes in the field and were later transported to the Engineering Geology Laboratory of the Department of Geology at University of Port Harcourt, Nigeria for analysis.

Data Analysis: The parameters needed to estimate the amount of carbon storage include the sediment bulk density and organic carbon concentrations at different depth intervals. The sediment samples were analysed based on standard laboratory procedures. Bulk density for each depth interval was determined standard density formula (equation 1).

Sediment bulk density = mass of sample/volume of sample (1)

The organic matter content in the samples was determined using the loss-on-ignition (LOI), which is a semi-quantitative method [39]. The sample was placed in a Lenton Furnace and heated to a temperature of 750°C to destroy all the organic matter in the sediment as described by Iticha [40]. A conventional conversion factor of 0.58 was used to convert organic matter content to organic carbon concentration (%C) using equation 2 [18]. This is described by Paulsen [19].

%C = LOI * 0.58 (2)

The carbon storage of each depth interval per hectare was estimated using equation 3 [14, 18].

Carbon stock = SBD * %C * D (3)

where: SBD = sediment bulk density, %C = organic carbon concentration and D = sediment depth interval)

The amount of carbon dioxide equivalent (CO_2e) in different locations of the study area was estimated by multiplying the carbon stored in each location by a factor of 3.67 as described by Iticha [41]. The factor was generated from the ratio of molecular weight of carbon dioxide (42) to carbon (12) as 1 Mg of sediment is equivalent to carbon 3.67 Mg of CO_2 sequestered [42, 43]. Therefore, the equivalent CO_2 (Mg) in Kibani area of Niger Delta was estimated based on the total carbon storage as shown in equation 4 [42, 43].

CO_2e = 3.67 * carbon storage (4)

RESULTS AND DISCUSSIONS

Two major parameters are important in the estimation of organic carbon stored in the sediment and they include sediment bulk density (SBD) and organic carbon concentration (%C). Sediment bulk density, %C and carbon storage significantly vary with depth and lithology; Tables 2a and 2b.

The values of SBD ranged from 0.95 g cm^{-3} to 1.97 g cm^{-3} with mean value of 1.30 g cm^{-3}. The highest SBD value (1.97 g cm^{-3}) was obtained in depth interval of 90-100 cm in location K2S2, while the lowest value (0.95 g cm^{-3}) was obtained in depth interval of 5-10 cm in location K5S1. The mean SBD value is similar to 1.36 g cm^{-3} reported in Andoni flats by Ansa and Francis [44]. This is consistent with the value of 1.4 reported by Eid and Shaltout [25]. However, SBD was highly affected by soil type. Sandy clay had the highest value while peat had the lowest value. Although SBD seemed to increase with depth, lithology is the main control as reported by Donato *et al.* [24]. Variation of SBD across depth intervals of mangrove sediments can be attributed to the build-up of plant remains in the various layers of sediment [14]. SBD influences sediment's porosity and compaction, thereby controlling the distribution of organic matter content [14].

The values of organic carbon concentration (%C) ranged from 0.9 % to 33.6 % with mean value of 12.48 %. The highest %C value (33.6 %) was obtained in depth interval of 60-70 cm in location K3S2 (peaty clay), while the lowest (0.9 %) was obtained in depth interval of 90-100 cm in K6S3 (peaty sand). The total average %C value was low in sand (12 %) but high in peaty clay (1, 245 %) and clayey peat (1537 %) (Figure 2). Generally, %C decreases with depth (due to anthropogenic disturbances; Figure 3).

The highest %C in K3S2 could be attributed to depth, sediment type and SBD value. Variations of %C in mangrove ecosystem is dependent on forest composition and productivity, biomass, soil type, geographical and morphological settings, tidal range and anthropogenic effects [24, 45]. The variation of % C along depth intervals is consistent with the findings of [2, 14, 24-48]. It is clear that as depth increases, %C decreases due to variation in the ratio of organic matter obtained from the mangroves and allochthonous materials as well as from sources or organic carbon contained in sediments and organic material mineralization [26]. Also, decrease of %C with depth could result from decomposition, leaching, sediment regimes and biological cycling [17, 49]. The decrease of %C with depth in the study area could likely result from organic matter supply and its decomposition. Carbon storage increases with depth (due to increase in SBD value and depth) and is consistent with the findings of Shaltout *et al.* [50]. (As shown in Table 2a and 2b; Figures 4). Carbon storage was highest in peaty clay (81, 784 Mg C) and lowest in sand (970 Mg C) (Figure 5).

Table 2a: Variations of sediment bulk density (SBD), organic carbon concentration (%C) and Carbon Storage with Depth

Depth interval (cm)	Average SBD (g cm^{-3})	Average %C	Average Carbon Storage (Mg C)	Average CO_2e (Mg CO_2)
0-5	1.23	18.40	122.88	450.97
5-10	1.19	16.20	191.69	703.50
10-15	1.20	15.10	268.34	984.81
15-20	1.18	14.60	338.81	1243.43
20-25	1.23	14.20	440.15	1615.35
25-30	1.22	13.60	490.97	1801.86
30-40	1.28	11.40	562.27	2063.53
40-50	1.28	10.80	669.88	2458.46
50-60	1.33	11.20	885.92	3251.33
60-70	1.37	11.40	1062.67	3900.00
70-80	1.39	9.40	1069.18	3923.91
80-90	1.44	8.10	1049.60	3852.03
90-100	1.46	7.30	1064.35	3906.16

cm= centimetre, g cm^{-3}=Gram per cubic centimetre, %C =organic carbon concentration, Mg C =Megagram carbon, Mg CO_2=Megagram Carbon dioxide equivalent,

Table 2b: Variations of sediment bulk density (SBD), organic carbon concentration (%C) and Carbon Storage with Lithology

Lithology	Average SBD (g cm^{-3})	Average %C	Average Carbon Stock (Mg C)	Average CO_2e (Mg CO_2)
Clay	1.26	16.30	235.68	864.95
Peat	1.06	18.50	258.77	949.69
Sandy Clay	1.67	4.10	603.48	2214.77
Clayey Sand	1.49	2.80	326.0	1196.42
Peaty Clayey Sand	1.68	2.40	309.29	1135.09
Peaty Sand	1.47	3.70	164.85	605.00
Sandy Peat	1.30	8.60	226.56	831.48
Clayey Peat	1.23	14.90	614.48	2255.14
Peaty Clay	1.29	13.20	948.95	3482.65

g cm^{-3}=Gram per cubic centimetre, %C =organic carbon concentration, Mg C =Megagram carbon, Mg CO_2=Megagram Carbon dioxide equivalent

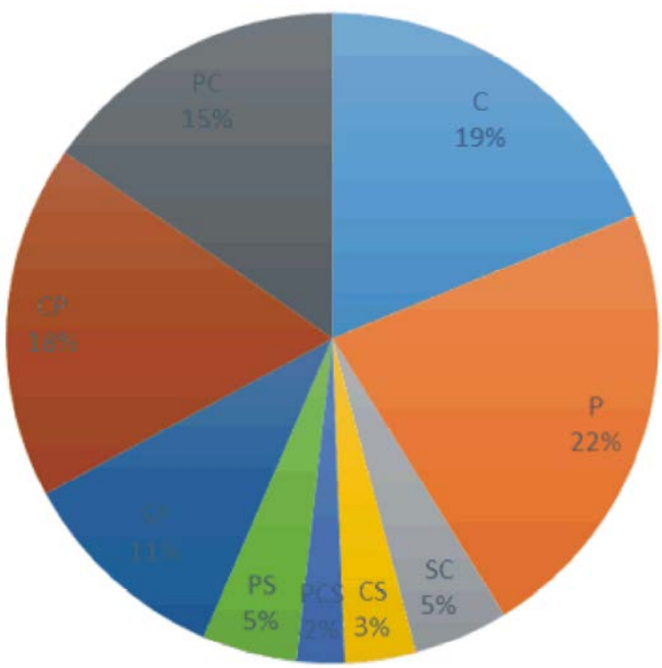

Fig. 2: Variation of Total Average Organic Carbon Concentration (%C) with Lithology
(C=clay, P=peat, SC=sandy clay, CS=clayey sand, PCS=peaty clayey sand, PS=peaty sand, SP=sandy peat, CP=clayey peat, PC=peaty clay)

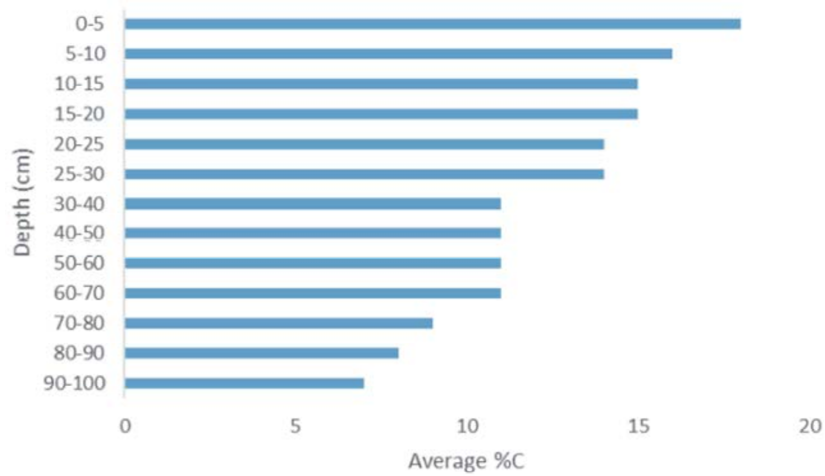

Fig. 3: Variation of Total Average Organic Carbon Concentration (%C) with Depth

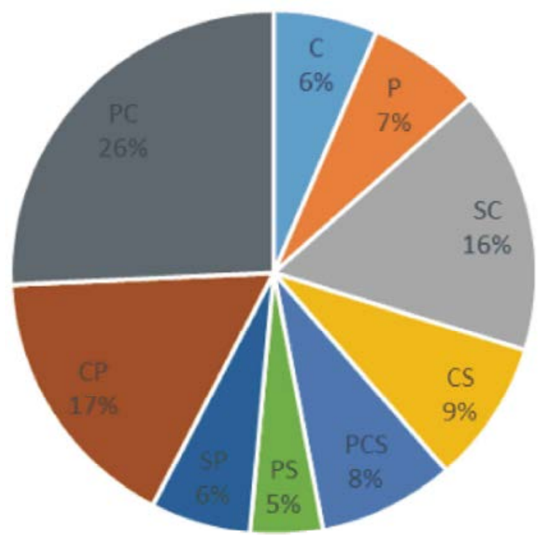

Fig. 4: Variation of Total Average Carbon Storage with Lithology
(C=clay, P=peat, SC=sandy clay, CS=clayey sand, PCS=peaty clayey sand, PS=peaty sand, SP=sandy peat, CP=clayey peat, PC=peaty clay).

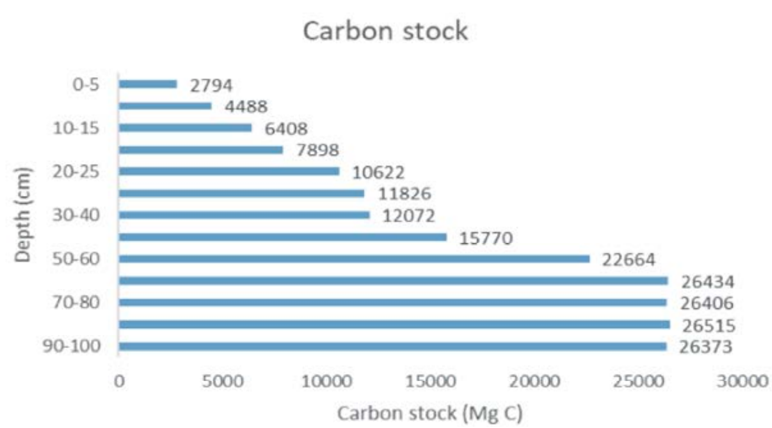

Fig. 5: Variation of Total Carbon Storage with Depth in the Study Area

The values ranged from 24.12Mg C ha^{-1} in depth interval of 15-20 cm in location K1S3 (sandy peat) to 3, 245.76 Mg C ha^{-1} in depth interval of 60-70 cm in location K3S2 (peaty clay) with mean value of 639.80 Mg C ha^{-1}. The value is 1.49 times less than the global mean mangrove carbon storage of 956 Mg C ha^{-1} [17]. The increase of carbon stock with depth could suggest the role of carbon cycling, decomposition and leaching enhanced by anthropogenic activities which are limited at higher depth [24, 50, 51]. Carbon dioxide equivalent (CO_2e) ranged from 88.52 ± 15.18 Mg CO_2 ha^{-1} to 11, 911.94 ± 15.18 Mg CO_2 ha^{-1} (mean = 2, 348.07 ± 15.18 Mg CO_2 ha^{-1})

The sediment types played a significant role in the spatial distribution of %C and together with SBD, control the amount of carbon stock in the study area. Lithology varies along the sediment profile. The sediment type included peat, peaty clay, clayey peat, clay and sand. The total carbon stock of the study area was estimated at 947.78 ± 55.64 Gg C with total carbon dioxide equivalent (CO_2e) of 3, 478.36 ± 55.64 Gg CO_2. The high value could be attributed to the mangrove cover of Niger Delta which is the largest in Africa [27, 28, 33].

CONCLUSIONS AND RECOMMENDATION

This research has revealed the carbon storage mangrove sediments in Eastern Niger Delta, Nigeria. The values of SBD, %C and carbon storage significantly vary with soil type. Total carbon stock of study area was estimated at 947.78 ± 55.64 Gg C (equivalent to 3, 478.36 ± 55.64 Gg CO_2).

This implies that 3, 478.36 ± 55.64Gg of carbon dioxide could either be removed from the atmosphere by the mangrove forest of Niger Delta if sustainable forest management is pursued. This can help mitigate climate change and reduce its negative impacts. On the other hands, this same amount of carbon stored in sediments could be released back to the atmosphere if the current rate of deforestation and other forms of forest degradation in the study area remains unabated. This would exacerbate climate change impacts on both humans and the environment.

Therefore, the study recommends that the mangrove forest of Niger Delta region of Nigeria should be restored and protected against all anthropogenic-related degradation in order to preserve its carbon storage and ameliorate climate change issues. In addition, there is need for future research to determine the trend in carbon storage resulting from anthropogenic activities in the study area.

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