SPATIAL DISTRIBUTION, DYNAMICS AND MAPPING OF THE SOIL ORGANIC CARBON AND TOTAL NITROGEN DENSITY ESTIMATES IN LAGOS LAGOON WETLANDS

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Abstract

Accurate estimation of wetland carbon densities is a prerequisite for wetland conservation and implementation of carbon sink enhancement plans. This study was designed to investigate spatial distribution in Soil Organic Carbon (SOC) and Total Nitrogen (TN), and Soil Organic Carbon density (SOCD) and Total Nitrogen density (TND) stocks in Lagos lagoon wetlands and the influence of other soil physicochemical. The SOC content generally exhibited high seasonal variations for all the sampling points in the wetlands. During wet season it ranges from 12.71±0.15 - 164.995±1.65 g/kg with a coefficient of variation of 40.99%, and dry season ranged from 132.02±3.520 - 383.570±8.43 g/kg with a coefficient of variation of 34.45%. The soil carbon content in the wet season was much lower than the dry season. The total nitrogen content in the wet season ranged from 4.53 – 16.58 g/kg with a COV of 27.96%, while the dry season ranged between 10.16 and 40.31 g/kg with a coefficient of variation of 29.39%.The SOC density of Lagos lagoon wetlands for tops soils ranged from 10.53 to 37.89 kgm−2 with an arithmetic mean of 26.70±1.41 kgm−2 and TND ranged from 0.61 to 2.37 kgm−2 with an arithmetic mean of 1.96±0.09 kgm−2. Pearson correlation reveal a positive correlation between SOC and TN (r=0.643), bulk density and SOC (r=0.344), TN and bulk density (r=0.478) and soil moisture and pH (r=0.085). In the present study, a negative correlation was observed in SOC and pH, and TN and pH. The results suggest that nitrogen content, moisture content and bulk density, which are significantly influenced by vegetation, seasons and topography, are some of the factors affecting their accumulation and seasonal variation. Thus, density of nitrogen and carbon in wetlands are important for soil quality. They also influence the carbon and nitrogen sequestration potential as well as reducing atmospheric CO_2 and mitigating the threat of global warming.

Background: Soil organic carbon and total nitrogen are important components of wetland soils; they can greatly influence the wetland ecosystem fertility, quality and productivity. Accurate estimation of wetland carbon densities and pools is a

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prerequisite for wetland resource conservation and implementation of carbon sink enhancement plans. This study was designed to investigate the dynamics and spatial distribution in Soil Organic Carbon (SOC) and total nitrogen (TN), and SOC and TN density stocks in Lagos lagoon wetlands and the influence of other soil physicochemical parameters on them.
Results: The SOC content generally exhibited high seasonal variations for all the sampling points in the wetlands. For wet season it ranges from 12.71±0.15 - 164.995±1.65 g/kg with a coefficient of variation of 40.99%, and dry season ranged from 132.02±3.520 - 383.570±8.43 g/kg with a coefficient of variation of 34.45%. The soil carbon content in the wet season was much lower than the dry season. The total nitrogen content in the wet season ranged from 4.53 – 16.58 g/kg with a coefficient of variation of 27.96%, while the dry season ranged between 10.16 and 40.31 g/kg with a coefficient of variation of 29.39%.The SOC density of Lagos lagoon wetlands for tops soils ranged from 10.53 to 37.89 kgm^{-2} with an arithmetic mean of 26.70±1.41 kgm^{-2} and TND ranged from 0.61 to 2.37 kgm^{-2} with an arithmetic mean of 1.96±0.09 kgm^{-2}. Pearson correlation reveal a positive correlation between SOC and TN concentrations (r=0.643), bulk density was positively correlated also with SOC (r=0.344), TN and bulk density (r=0.478) and soil moisture content and pH (r=0.085) were also positively correlated. In the present study, a negative correlation was observed in SOC and pH, and TN and pH. The results suggest that nitrogen content, moisture content and bulk density, which are significantly influenced by vegetation cover and types, seasons and topography, are some of the factors affecting soil organic carbon and nitrogen accumulation and seasonal variation.
Conclusion: This study provided an insight in the understanding of the seasonal and spatial distribution of SOC and TN density in the Lagos lagoon wetland. In conclusion, the estimation of the density and storage of nitrogen and organic carbon in the wetlands are important for knowing and maintaining the quality of the soils, and they also influence the carbon and nitrogen sequestration potential of the wetlands as well as reducing atmospheric CO_2 and mitigating the threat of global warming.

Keywords: *Soil organic carbon density, Total nitrogen density, Phosphate, Moisture content, Bulk density, Wetlands*

Introduction

Wetland function as the biological supermarket and kidneys of the earth, wetlands provide comprehensive ecosystem and productive services in terms of large food chain, climate control, pollution prevention, biodiversity maintenance, bio-productivity protection, and rich genetic material (Yu et al., 2012). These ecosystems constitute a critical component of the global carbon (C) pool and contribute 20 - 25% of the total C stock of soils even though wetland area only accounts for 4% to 6% the earth land, they play an important role in the global carbon and nitrogen cycles (Parish and Looi, 1999; Wang et al., 2011).

Soil organic carbon (SOC) and total nitrogen (TN) are important components of wetland soils; they can greatly influence the wetland ecosystem fertility, quality and productivity (Zhang et al., 2013; Gebrehiwot et al., 2018). They also affect the concentration of greenhouse gases in the atmosphere and global climate change (Stockmann et al., 2013; Lehmann and Kleber, 2015). Soil organic carbon and total nitrogen are one of the foci of global climate change research in recent years (Wang et al., 2016). Soil organic carbon is one part in the much larger global carbon cycle that involves the cycling of carbon through the soil, vegetation, ocean and the atmosphere (FAO, 2017). The soil organic carbon pool stores an estimated 1500 PgC in the first meter of soil, which is more carbon than is contained in the atmosphere (roughly 800 PgC) and terrestrial vegetation (500 PgC) combined (FAO and ITPS, 2015). This remarkable soil organic carbon reservoir is not static, but is constantly cycling between the different global carbon pools in various molecular forms (Kane, 2015). SOC is the main component of soil organic matter (SOM). As an indicator for soil health, SOC contributes importantly to food production, mitigation and adaptation to climate change, and the achievement of the Sustainable Development Goals (SDGs) (Van der Wal and de Boer, 2017). Although the overall impact of climate change on SOC stocks is very variable according to the region and soil type, rising temperatures and increased frequency of extreme events are likely to lead to increased SOC losses (FAO, 2017).

Accurate quantification of SOC and TN stocks are important for assessing the C and N sink capacity of soils and the change rate of SOC and TN (Yang et al., 2016). In riparian wetlands, soil-forming processes are significantly affected by river dynamics (Bayley and Guimond, 2011; Myster, 2015). Soil organic carbon and nitrogen content can vary considerably based on river flows and the flood regime (Paradis and Saint-Laurent, 2017). It is also known that organic carbon and nitrogen concentrations can vary based on soil use (Wiesmeier et al., 2013). Also, certain physical soil properties such as pH, bulk density, texture, and moisture content can also affect the organic carbon and nitrogen contents in soils (Don et al., 2007; Bedison et al., 2013; Wiesmeier et al., 2015). Changes in the hydrological regime of wetlands can also have substantial effects on soil properties, particularly carbon and nitrogen accumulation and release due to alterations in their chemical forms and spatial movement (Craft, 2007). However, anthropogenic activities, such as industrialisation, deforestation, biomass burning and land use changes might also alter soil C and N levels (Wang et al., 2016; Adesuyi et al., 2016; Bai et al., 2013). Mitsch and Gosselink (2015) also reported that any variations in the distributions and abundances of soil C and N exert important effects on the carbon and nitrogen cycles at regional or global scales.

Given the importance of components such as organic carbon and nitrogen in soil biogeochemical processes, it seems critical to fully understand their distribution and variability in dynamic environments such as the wetlands ecosystems. This study was an attempt to investigate the spatial and seasonal distribution in soil organic carbon and total nitrogen, and TN and SOC and TN density stocks in

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Lagos lagoon wetlands and the influence of other soil physicochemical parameters on them. The specific objectives of this current study were: to determine the spatial patterns of SOC and TN in the wetlands associated with different seasons and flooding regimes; to explore the relationships between SOC, TN and other soil characteristic such as pH, bulk density and moisture contents; and to illustrate and map the spatial distribution of SOC density and TN density. Thus, an improved understanding of the quantitative short term spatial dynamic changes in soil carbon and nitrogen will contribute to the evaluation and identification of sources and sinks of soil carbon and nitrogen.

Materials and methods

Study area

The Lagos lagoon wetlands forms part of an intricate system of water ways made up of lagoons and creeks that are found along the coast line of Nigeria, Benin Republic. It is located between longitudes 3º 23' and 3° 40' E, and latitudes 6º 22' and 6º 38' N (Figure 1). Lagos lagoon is the largest of the four lagoon systems, mainly of the Gulf of Guinea, 2 covering an area of 257.49 km^2 (Philips et al., 2012). The area surrounding the Lagos lagoon is probably the most urbanized and industrialized in Nigeria (Okoye et al., 1991). This uncontrolled urban expansion in an unsystematic manner has had serious repercussions on the environmental quality of many parts of the wetlands (Obiefuna et al., 2013).

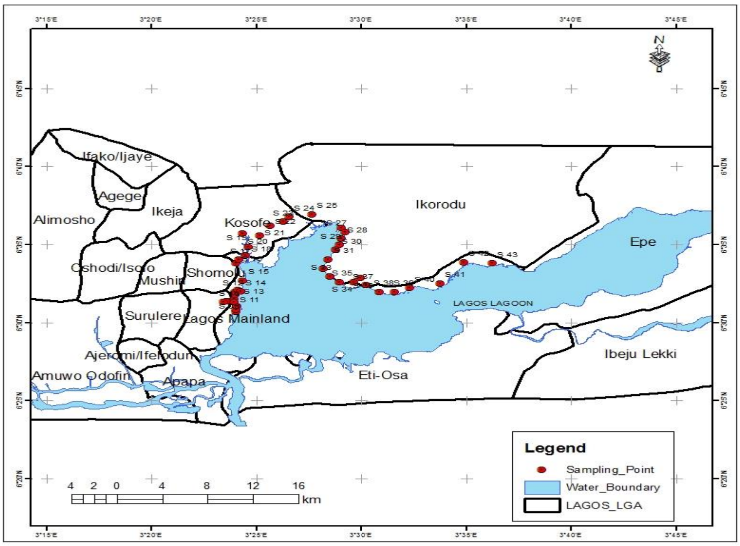

Figure 1
Study area

Sampling points

The sampling period was between May and June 2015 (wet season) and January and February 2016 (dry), and the position of the sampling points in the transects

was determined using a GPS (Garmin 60CSx). The GPS data were exported into mapping software (ArcGis® 13.4.1).
The soil sampling sites were located along random transects perpendicular to the bank of the lagoon within the floodplain that cuts across vegetated areas. A total of 86 soil samples were collected for this study at a depth of 10 cm using an Eijkelkamp hand auger at the predetermined dept. The soil samples were placed in polyethylene bags, kept on ice in the field, and stored at 4 ^{0}C (field moist) in the laboratory until subsequent processing. One half of the samples were air-dried for soil organic carbon (SOC), total nitrogen (TN), pH and bulk density and the other half used to test for the moisture content.

Soil analyses

All soil analyses were done using three analytical replicates per sample type. In the laboratory, the samples were air dried and passed through a 2-mm sieve. Samples were used to analyse the bulk density, organic carbon, total nitrogen, and pH of the wetland soils. Soil pH was determined from soil extracted with distilled water at a 1:5 soil-water ratio using a pH meter (IQ 120, Hach, Loveland, CO, USA). Soil water content was determined by comparing the field moist weight with oven dried samples (Wang et al., 2011) The TN levels were measured in duplicate using dry combustion with an Elementar Vario C/N Analyzer. The soil organic carbon was analyzed using Automated Carbon analyser. The bulk density of soil samples was measured using a cutting ring method.
The SOC density at each sampling site was calculated by using the following equation:

$$\text{SOCD} = \text{SOC x BD x H x } 0.01 \qquad [1]$$

where SOCD is the SOC density, expressed as the SOC per unit area (kg m^{-2}), and BD is the soil bulk density, and H is the thickness of the soil layer (cm) (Wang et al., 2016).
The following equation was used to calculate soil total N density (TND):

$$\text{TND} = \text{BD x TN x H x } 0.01 \qquad [2]$$

where TND is expressed as soil nitrogen per unit area (kg m^{-2}), BD is the soil bulk density, and H is the thickness of the soil layer (cm).

GIS and soil properties mapping

Geo-statistics were calculated by using the software of ArcGIS 13.4.1. The map was generated by the application of the Ordinary Krigging interpolation of the spatial grid method of ArcGIS 13.4.1 according to the measuring data of organic carbon concentration and bulk density in soils sampled in the wetlands.

Statistical analysis

Analysis of variation (ANOVA) to test for differences in seasonal SOC and TN between the different sampling points ($p < 0.05$). The Pearson correlation analysis

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was used to indicate the relationships among different soil properties. The ANOVA and Pearson correlation analysis were performed using the GraphPad statistical package 7.0.

Results

The distributions of SOC content and SOC density stock in wetlands surface soil

The result of the seasonal soil organic carbon content (g/kg) and soil total nitrogen content (g/kg) is presented in table 1. The SOC content generally exhibited high seasonal variations for all the sampling points in the wetlands. For wet season it ranges from 12.71±0.15 - 164.995±1.65 g/kg with a coefficient of variation of 40.99%, and dry season ranged from 132.02±3.520 - 383.570±8.43 g/kg with a coefficient of variation of 34.45%. The soil carbon content in the dry season was much higher than the wet season. The peaks of the SOC distribution during the wet season were concentrated between sampling points 11 to sampling 43, showing a wider distribution. The peak of the SOC distribution during the dry season was concentrated at sampling points 16 to sampling points 25 which ranged from 318.465±15.06 to 385.00±0.50 g/kg. Comparing the SOC across the sampling points in the wet and dry seasons, the differences of SOC contents were highly significant ($p<0.05$). The soil organic carbon density in 10 cm soil layer was calculated from the SOC and soil bulk density (Eq. 1). The spatial distribution of soil organic carbon density in Lagos lagoon wetlands landscape is shown in Figure 2. The SOC density of Lagos lagoon wetlands for tops soils ranged from 10.53 to 37.89 kgm^{-2} with an arithmetic mean of 26.70±1.41 kgm^{-2} and geometric mean of 24.84 kgm^{-2}.

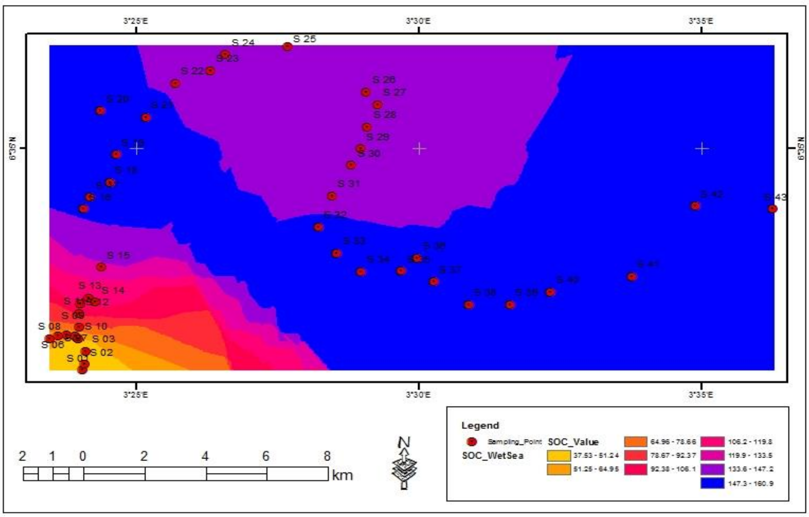

Figure 2
The spatial distribution of SOC density in Lagos lagoon wetlands

Table 1. *Seasonal soil organic carbon content and soil total nitrogen content (g/kg)*

Sampling points	Soil organic carbon (g/kg)		Soil total nitrogen (g/kg)	
	Wet season	Dry season	Wet season	Dry season
S 01	12.94±0.20	145.5±10.1	10.47±0.525	36.50±2.050
S 02	12.92±0.20	133.7±1.30	10.41±0.495	35.75±0.785
S 03	13.45±0.96	139.0±3.55	9.975±0.075	35.20±1.800
S 04	12.71±0.15	141.4±1.92	10.38±0.280	35.47±2.600
S 05	13.01±0.14	132.0±3.52	9.465±0.475	31.37±1.280
S 06	29.42±0.03	196.7±0.97	4.530±0.110	23.74±0.315
S 07	64.36±4.98	185.8±12.0	4.530±0.100	23.42±1.020
S 08	69.73±0.41	171.7±5.99	4.670±0.020	22.72±0.780
S 09	69.67±9.98	192.8±2.07	4.565±0.045	23.70±1.260
S 10	69.50±0.62	187.6±2.99	4.575±0.145	23.75±1.350
S 11	151.8±0.50	153.6±1.90	15.40±0.050	10.20±0.005
S 12	150.2±1.98	154.2±0.43	15.35±0.050	10.16±0.000
S 13	149.2±1.08	152.6±2.06	15.80±0.345	10.17±0.050
S 14	150.0±0.20	154.2±1.23	15.38±0.165	10.19±0.040
S 15	153,0±0.68	155.9±3.66	15.40±0.075	10.20±0.015
S 16	154.7±0.10	385.0±0.50	16.39±0.090	39.57±0.065
S 17	157.1±2.68	372.3±3.10	16.40±0.045	39.57±0.045
S 18	152.1±1.58	379.8±15.3	16.20±0.045	39.58±0.095
S 19	152.7±7.78	373.8±21.7	16.37±0.110	39.58±0.040
S 20	153.8±0.07	383.6±8.43	16.38±0.030	39.55±0.050
S 21	142.2±2.01	320.2±0.60	15.21±0.030	38.54±0.960
S 22	143.7±2.58	323.6±9.89	15.25±0.010	38.55±0.990
S 23	145.1±4.99	321.9±12.3	15.20±0.050	38.55±0.960
S 24	146.2±3.23	318.8±1.56	15.22±0.020	38.52±1.015
S 25	145.0±5.21	318.5±15.1	15.23±0.036	38.57±0.955
S 26	131.0±1.41	182.9±2.15	13.88±0.000	37.32±1.970
S 27	130.5±0.04	183.8±0.08	13.87±0.065	37.31±1.995
S 28	131.2±6.36	184.8±4.01	13.91±0.095	37.32±2.015
S 29	131.6±2.93	183.2±0.67	13.83±0.070	37.30±2.005
S 30	131.3±0.29	183.6±2.99	13.89±0.030	37.31±2.000
S 31	153.2±1.22	324.2±4.34	16.55±0.035	40.31±0.020
S 32	152.3±2.23	334.4±6.01	16.56±0.045	40.28±0.030
S 33	154.4±4.19	325.9±16.5	16.58±0.015	40.29±0.005
S 34	153.7±0.19	325.6±14.1	16.55±0.020	40.27±0.070
S 35	154.5±4.79	335.2±5.26	16.57±0.085	40.95±0.025
S 36	150.8±1.80	346.5±1.09	15.50±0.050	36.88±0.930
S 37	150.7±0.65	312.6±2.57	15.46±0.055	36.87±0.935
S 38	150.2±2.46	244.6±8.70	15.53±0.055	36.90±0.935
S 39	150.9±9.12	226.0±4.33	15.51±0.015	36.91±0.915
S 40	161.9±8.55	242.1±0.46	15.50±0.040	36.90±0.965
S 41	161.9±1.58	266.2±9.43	14.92±0.015	35.38±2.425
S 42	165.0±1.65	273.9±2.55	14.98±0.010	35.40±2.460
S 43	161.3±1.46	266.5±4.02	14.95±0.020	35.42±2.485

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The distributions of TN content and TN Density in wetlands soils

The total nitrogen content in the wet season ranged from 4.53 – 16.58 g/kg with a coefficient of variation of 27.96%, while the dry season ranged between 10.16 and 40.31 g/kg with a coefficient of variation of 29.39%. Significant differences ($p<0.05$) in TN in seasons and sampling points was obvious across the different sections of this wetlands. Higher levels of SOC and TN are observed in these wetlands during the dry season, which may be due to the presence of litter which allows a sufficient contribution of organic matter for the soil. Total nitrogen density spatial distribution in the soil of Lagos lagoon wetlands landscape is shown in Figure 3. The TND for 0-10cm soil for these wetlands ranged from 0.61 to 2.37 kgm^{-2} with an arithmetic and geometric mean of 1.96±0.09 kgm^{-2} and 1.84 kgm^{-2} respectively.

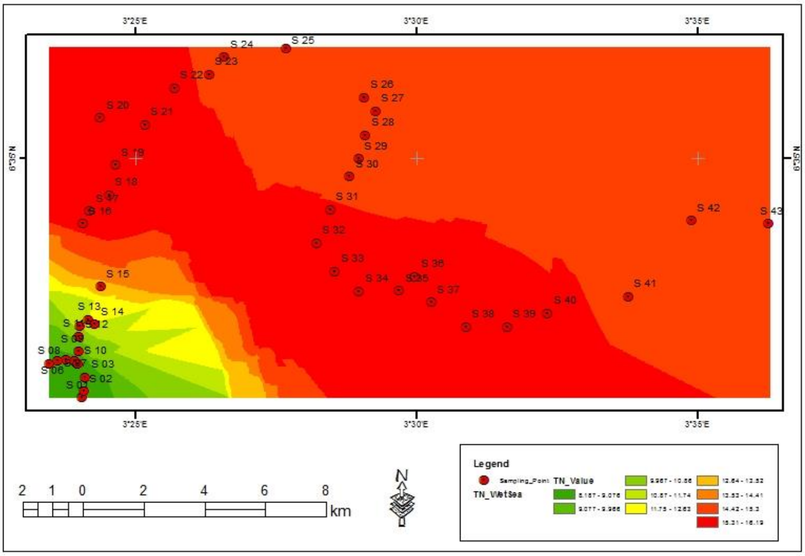

Figure 3 *The spatial distribution of soil TN density in Lagos lagoon wetlands*

Variation and relationship between soil physicochemical properties, soil organic carbon and total nitrogen contents.

There was little spatial and spatial variation in soil pH and they were significant ($p<0.05$). pH ranged from 6.17 – 7.12 with a coefficient of variation of 4.64% for all the wetland soils in wet seasons and ranged from 4.39 – 5.03 with a coefficient variation 4.06% in dry season. There was significance difference between the dry and wet season ($p<0.05$). Despite the variations in pH across the sampling points, they were not significant ($p>0.05$) for both seasons (Table 2).

Soil moisture content in wet season was ranged between 29.50 and 84.50 %, while for the dry season it was ranged between 20.6 and 87.18 %. There are more reduced moisture contents during dry season than wet season and it was significant ($p<0.05$). Spatial differences in moisture content were also observed in this study.

Table 2. *Seasonal bulk density (g/cm^2), pH and moisture content (%) of the wetland soils*

Sample point	Bulk density g/cm^2		pH		Soil moisture content	
	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
S 01	1.40±0.06	1.50±0.02	7.10±0.10	5.03±0.14	75.25±0.15	84.1±4.0
S 02	1.40±0.08	1.50±0.03	7.12±0.10	5.02±0.14	75.25±0.15	84.6±2.5
S 03	1.40±0.07	1.50±0.01	7.12±0.60	5.02±0.56	75.25±0.15	85.2±4.1
S 04	1.40±0.06	1.51±0.01	7.11±0.30	4.97±2.28	75.25±0.15	84.1±2.0
S 05	1.41±0.06	1.50±0.04	7.10±0.20	5.02±0.42	75.25±0.15	85.6±1.5
S 06	1.30±0.03	1.40±0.05	6.82±0.10	4.87±0.15	54.5±0.8	20.6±0.2
S 07	1.30±0.02	1.40±0.06	6.80±0.21	4.87±0.29	54.5±0.8	22.1±0.7
S 08	1.31±0.02	1.40±0.07	6.80±0.00	4.90±0.15	54.5±0.8	22.1±0.3
S 09	1.30±0.02	1.38±0.06	6.81±0.42	4.91±0.29	54.5±0.8	21.6±0.2
S 10	1.31±0.04	1.41±0.06	6.82±0.10	4.90±0.29	54.5±0.8	22.1±1.3
S 11	1.60±0.06	1.20±0.03	6.30±0.22	4.92±0.29	59.1±0.0	85.0±1.4
S 12	1.60±0.07	1.19±0.03	6.32±0.11	4.93±0.29	59.1±0.0	84.1±1.2
S 13	1.60±0.08	1.21±0.03	6.30±0.00	4.94±0.29	59.1±0.0	84.1±1.4
S 14	1.60±0.06	1.22±0.03	6.32±0.00	4.94±0.00	59.1±0.0	84.6±0.2
S 15	1.61±0.05	1.21±0.04	6.31±0.00	4.94±0.29	59.1±0.0	85.1±1.5
S 16	1.49±0.06	1.3±0.040	6.25±0.00	4.56±0.16	80.1±5.0	85.8±1.9
S 17	1.49±0.04	1.31±0.06	6.27±0.23	4.56±0.00	80.1±5.0	86.3±0.6
S 18	1.50±0.04	1.30±0.06	6.25±0.23	4.56±0.47	80.1±5.0	84.3±2.3
S 19	1.51±0.02	1.31±0.04	6.25±0.00	4.55±0.93	80.1±5.0	83.7±0.7
S 20	1.51±0.07	1.32±0.04	6.23±0.11	4.54±0.16	80.1±5.0	85.4±3.4
S 21	1.61±0.03	1.45±0.06	6.50±0.11	4.39±0.16	84.5±0.6	87.0±0.4
S 22	1.59±0.02	1.46±0.06	6.52±0.11	4.41±0.48	84.5±0.6	84.7±0.5
S 23	1.59±0.03	1.46±0.05	6.53±0.11	4.40±0.32	84.5±0.6	87.1±0.9
S 24	1.60±0.05	1.47±0.05	6.50±0.00	4.40±0.08	84.5±0.6	86.2±0.0
S 25	1.58±0.04	1.46±0.03	6.53±0.11	4.40±1.29	84.5±0.6	83.7±0.5
S 26	1.45±0.04	1.31±0.01	6.41±0.11	4.88±0.15	75.6±2.7	86.8±2.9
S 27	1.45±0.03	1.32±0.00	6.41±0.22	4.87±0.29	75.6±2.7	85.9±2.9
S 28	1.45±0.05	1.30±0.01	6.41±0.33	4.90±0.14	75.6±2.7	86.7±3.1
S 29	1.44±0.03	1.29±0.00	6.42±0.11	4.88±0.29	75.6±2.7	85.8±3.2
S 30	1.44±0.02	1.30±0.02	6.40±0.22	4.90±0.43	75.6±2.7	86.0±4.0
S 31	1.46±0.05	1.40±0.04	6.20±0.23	4.72±0.30	32.0±0.4	28.6±1.0
S 32	1.46±0.06	1.40±0.05	6.21±0.11	4.72±0.15	32.0±0.4	27.7±1.2
S 33	1.45±0.06	1.40±0.04	6.21±0.34	4.73±0.00	32.0±0.4	27.7±1.4
S 34	1.48±0.05	1.39±0.05	6.21±0.11	4.74±0.90	32.0±0.4	28.2±0.0
S 35	1.45±0.04	1.39±0.03	6.20±0.46	4.72±0.45	32,0±0.4	28.4±0.7
S 36	1.05±0.01	1.50±0.05	6.18±0.12	4.70±0.30	29.5±0.6	35.1±1.0
S 37	1.51±0.01	1.49±0.05	6.19±0.00	4.71±0.90	29.5±0.6	34.1±0.1
S 38	1.51±0.02	1.50±0.04	6.17±0.23	4.73±0.15	29.5±0.6	34.4±0.4
S 39	1.51±0.00	1.49±0.06	6.18±0.57	4.72±0.30	29.5±0.6	35.0±0.1
S 40	1.50±0.00	1.51±0.07	6.20±0.34	4.71±0.45	29.5±0.6	35.4±0.7
S 41	1.61±0.08	1.46±0.03	6.50±0.22	4.92±0.43	32.0±0.5	42.3±1.3
S 42	1.60±0.08	1.45±0.03	6.53±0.11	4.92±0.58	32.0±0.5	41.9±1.0
S 43	1.61±0.07	1.44±0.03	6.49±1.09	4.89±0.72	32.0±0.5	42.9±0.1

Bulk density ranged from 1.30 to 1.61 g/cm^2 in the wet season and from 1.19 to 1.51 g/cm^2 in the dry season. However, the results of the statistical tests do not reveal any significant spatial differences in the bulk density (BD) in the soils ($p>0.05$).

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The results of Pearson correlation tests obtained for organic carbon and nitrogen, as well as other soil properties measured on the soil surface is shown in Table 3. The results reveal a positive correlation between SOC and TN concentrations (r=0.643 and P<0.05), showing a close link between these two soil constituents. Furthermore, the bulk density was positively correlated also with SOC (r=0.344). TN and bulk density (r=0.478) and soil moisture content and pH (r=0.085) were also positively correlated. In the present study, a negative correlation was observed in SOC and pH, and TN and pH.

Table 3 *Correlation between different soil properties in Lagos lagoon wetlands*

	SOC	TN	Bulk density	pH	Moisture contents
SOC	1				
TN	0.643	1			
Bulk density	0.344	0.478	1		
pH	-0.919	-0.514	-0.249	1	
Moisture contents	-0.140	0.042	-0.067	0.085	1

Discussion

SOC seasonal variations and spatial distributions were consistent with those reported by Luo *et al* (2014) who investigated accumulation and seasonal dynamic of the soil organic carbon in wetland of the Yellow River Estuary, China. Each season across the sampling points has unique biogeochemical properties and hydrologic dynamics; therefore, SOC concentrations and C dynamics were expected to vary. In November and December, it's hot and still slightly raining in Lagos lagoon wetlands, providing the proper conditions for organic carbon mineralization and decomposition, and, thus, the content of soil organic carbon was higher. There were significant differences in seasonal SOC distribution across the wetlands (p<0.05), but the differences isn't significant across the sampling points (p>0.05). Higher SOC contents were associated with forested parts of the wetlands than human highly impacted areas in this study. Similar results were reported for Yellow River estuary wetlands and Liaohe estuarine wetlands (Luo *et al*., 2010; Luo *et al*., 2014). SOC densities in 0–30 cm soil layer in Yellow River Delta (one of three big deltas in China) ranged from 0.73±0.95 to 3.52±0.68 kgm^{-2} (Yu *et al*., 2012). Zhao *et al*. (2011) also estimated that the soil organic carbon density in Zhalong marsh in China was 3.79 g/cm^2 in 2006, which is the same as the result given by Zhang *et al*. (2011). According to the results of Zhao *et al*. (2011) and Liu (2004), the organic carbon density of marsh soils and peat soils in China were revised to 3.54 and 4.47 g/cm^2, respectively (Zheng *et al*., 2013).

The SOC density in Lagos lagoon wetlands was also higher than that of Plum Island salt marshes, Louisiana coastal wetlands and Quanzhou Bay coastal wetlands in China (Dodla et al., 2008; Wang et al., 2007; Wang et al., 2003), indicating that Lagos lagoon wetlands are having and playing a huge carbon fixation role. According to Wang et al. (2012) SOC densities in a wetlands landscape is closely dependent on the land use land cover change and vegetation types. Higher levels of SOC and SOCD in the top soils (0-10 cm) have been suggested to be closely related to plant cycling (Jobbбgy and Jackson, 2001). Wang et al. (2016) also observed that carbon inputs from plant roots and plant residues were often found to be accumulated in the surface soil.

SOC and TN concentrations are directly related to the quantity and quality of litter (Paradis and Saint-Laurent, 2017). According to Wang et al. (2016), the top 10 cm soils contained significantly higher TN level and TNDs when compared to the deeper soils which can be attributed to the fact that nitrogen can return to surface soils through plant cycling. In other words, because of even higher inputs of organic material, SOC and TN levels are generally concentrated in topsoil. Similar results were reported by Wang et al. (2016) in total nitrogen contents in coastal wetlands affected by flow-sediment regulation in a Chinese delta. Higher nitrogen deposition in this region would contribute to elevated N levels in the surface soils (Yu et al., 2012). This different soil pH in the wetlands can be attributed to the type of parental material that make up the soil, but also as a result of the type and quantity of litter, which is more substantial in this zone. The presence of litter can contribute to the acidification of soils, particularly for surface horizons (D'Acqui et al., 2015; Paradis and Saint Laurent, 2017).

However, the absence of a larger number of tree species in the wetland zones can also cause a increase in the pH level, given that the breakdown of resinous debris (e.g. lignin, wax) plays a key role in soil acidification (Brady and Weil, 2007). Furthermore, the bulk density variations observed in the wetlands soils can be attributed to the mineral matrices with different origins (parental material), but also the soil structure (Gervais-Beaulac et al. 2013). Lower soil bulk density suggested that the soil became much looser, along with developing better permeability, stronger water-holding, and a higher storage capacity. This favoured the accumulation of nutrient elements, as well as the increase of accumulation of soil organic carbon and dissolved organic carbon (Sakin, 2012). Reeder et al. (2004) have also reported the positive correlation between bulk density and SOCS.

It is a generally known fact that soils with a certain concentration of organic carbon are also rich in nitrogen (Brady and Weil, 2007). The presence of nitrogen in the soil is therefore closely linked to the presence of carbon, the main source of which is the breakdown of organic matter (Paradis and Saint-Laurent, 2017). According to Liu et al (2012), higher soil moisture and improved SOC quality, will leads to higher plant productivity and substrate availability in ecosystems. Thus, this will indirectly leads to higher SOC and TN contents in related soils. Previous researches on relationships of SOC and pH are scanty. A negative correlation of pH and SOC was newly reported in northern Ethiopia (Gebrehiwot *et al*., 2018) as was in this study. The results suggest that nitrogen content, moisture content and bulk density, which are significantly influenced by vegetation types and microtopography, are dominant factors of soil organic carbon accumulation.

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Conclusion

We investigated the temporal changes in soil organic carbon and total nitrogen in the wetlands of the Lagos lagoon for wet season (2015) and dry season (2016). Marked seasonal differences ($p>0.05$) were found with respect to the concentrations of nutrients (organic carbon and nitrogen) in the soils that were analyzed in the different sampling sites of the study area. The stripping of the litter by floods in the wet seasons may be the reason for loss of organic matter, and has the effect of reducing the quantity of nutrients (that is, SOC and TN) in the soil. This study provides a better understanding of the dynamics of wetlands soils during wet and dry seasons with respect to flood frequency. In this study, the variation observed can be important to assess the quality of the soil, the processes, and the factors that influences SOC distribution in Lagos lagoon wetlands. Successful wetland restoration and management will create conditions for healthy, thriving wetland systems that are optimal for the sequestration and burial of carbon and prevent the release of carbon to the atmosphere. Thus, the most effective method to maintain wetland carbon pools and prevent emissions to the atmosphere is to avoid conversion and drainage through protection and sustainable management for these wetlands. Thus, more detailed study and research on the distribution of SOC, both horizontally and vertically, including accounts of its accuracy and its variability in this wetland, is necessary to improve estimates of the local carbon flow.

Authors' Contributions

This work formed part of AAA's PhD research. AAA designed the study, performed all of the experiments including necessary calculations and statistics analysis, and wrote the manuscript. NKL, ODN and AMO were the PhD project supervisory team, responsible for the joint experimental and project design and all made conceptual contributions. JOA provided substantial editor assistance, review and made conceptual contributions. All authors read and approved the final manuscript. The authors declare that they have no competing interest. Ethics approval and consent to participate: not Applicable and Availability of data and materials: Available.

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