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Assessment of Physicochemical Characteristics of Sediment from Nwaja Creek, Niger Delta, Nigeria

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Abstract

Sediments are complex environments, with varying physicochemical characteristics, such as composition and type of organic matter, particle size distribution, and pH. Contaminated sediment is a significant environmental problem affecting many marine, estuarine and freshwater environments throughout the world. Most assessments of water quality have historically focused on water-soluble compounds, with relatively little attention paid to sediment. The aim of this research is to assess the physical and chemical parameters of sediments from Nwaja Creek, Niger Delta, Nigeria. Monitoring of this sediment quality is an important part of preserving and restoring the biological integrity of water bodies as well as protecting aquatic life, wild life and human health. Sediment samples from Nwaja Creek were sampled from seven sampling stations along the creek for over three months May to July, 2015, rainfall peak period, for assessment of their physical and chemical characteristics, such as grain size, organic carbon, pH, conductivity, nitrate and phosphate. These parameters are known to influence the interactions and dynamics of pollutants within sediment matrix. Sediment particle size distribution indicates that they have higher proportion of clay (clay > silt > sand), the mean percentage composition of clay, silt and sand ranged between 64.28% ± 22.04% - 72.36% ± 14.00%, 18.71% ± 12.03% - 27.32% ± 22.17% and 8.40% ± 6.28% - 9.76% ± 4.59% respectively. TOC in the study area is generally above 1% across all stations during the study period with a range between 0.98% and 4.58%. Minimal monthly and spatial variations are observed in particle distribution, pH (3.9 - 8.5) and phosphate (5.5 - 15.5 kg/mg) while significant variations are observed in conductivity (23.0 - 567.0 uS/cm), total organic carbon (0.98% - 4.58%) and nitrate (0.45 - 11.9 mg/kg) concentration. It is concluded that physicochemical characteristics of the sediments from Nwaja Creek are influenced by anthropogenic sources

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rather than natural as shown by the elevated phosphate and nitrate levels because the Niger Delta geology is not essentially rich in nitrate and its excess in surface or groundwater is considered as pollutant.

Keywords

Sediments, physicochemical Assessment, Nwaja Creek, Nitrates, Conductivity

1. Introduction

In Nigeria's Niger Delta, the challenges of water (surface and ground) and sediment pollution have been of concern to all stakeholders because of the rate and extent of impairment of the environment and aquatic bodies by human activities, particularly from industrial and domestic sources. Oil production and its other associated activities in the Niger Delta have increased the population growth rate in the region and also the volumes of waste generated [1]. The Niger Delta is the richest part of Nigeria in terms of natural resources with large deposits of hydrocarbon [2] [3].

Sediment is the loose sand, silt and other soil particles that settle at the bottom of a body of water [4]. Sediment strata serve as an important habitat for the benthic macro invertebrates whose metabolic activities contribute to aquatic productivity [5]. Sediment is also the major site for organic matter decomposition which is largely carried out by bacteria. Important macro-nutrients such as nitrogen and phosphorous are continuously being interchanged between sediment and overlying water [5]. Sediment input may impact stream communities through a variety of direct and indirect processes [6], including reduced light penetration, smothering, habitat reduction and introduction of absorbed pollutants (pesticides, metals, nutrients). The structure of the sediments in the intertidal zone plays a major role in the distribution of the organisms that live in or on them [7]. Benthic organisms show habitat preference for specific types of sediment [8]. The physicochemical parameters of the sediments such as salinity, dissolved oxygen, pH, and organic carbon can also influence the occurrence and abundance of species distributed in them [9]. Sediment also serves as reservoir for pollutants and therefore a potential source of pollutants to the water column, organisms, and ultimately human consumers of those organisms. Contaminated sediment can cause lethal and sub-lethal effect in benthic and other sediment associated organisms [10].

Fine grained sediment (silt + clay) is responsible for a significant proportion of the annual transport of metals, phosphorus, chlorinated pesticides and many industrial compounds such as polynuclear aromatic hydrocarbons, polychlorinated biphenyls, dioxins and furans. Of the 128 priority pollutants listed by the United States Environmental Protection Agency [10], 65 percent are found mainly, or exclusively, in association with sediment and biota. Consequently, water quality programmes that focus only on the water phase miss most of the more toxic contaminants. In North America, it has been found that up to 95 percent of the annual phosphorus load in rivers is transported in association with suspended sediment. Organic micropollutants are mainly bound to the organic component of the suspended matter, which is commonly measured as total organic carbon [10].

Monitoring sediment quality is an important part of preserving and restoring the biological integrity of our Nation's water as well as protecting aquatic life, wild life and human health. Sediment is an integral component of aquatic ecosystem providing habitat, feeding, spawning and rearing areas for many aquatic organisms. Results from studying the sediment physical and chemical characteristics from Nwaja River in the Niger Delta area of Nigeria will facilitate the management of the water and similar water bodies. It will also provide base line data for further studies.

2. Materials and Methods

2.1. Study Area

Port Harcourt is located within the Niger Delta Basin of Southern Nigeria. It's located within the eastern lower Niger Delta in the south eastern part of Rivers State of Nigeria (**Figure 1**). It is situated at the right bank of the Bonny River approximately 65 km inland from the Bight of Bonny. Geographically, the area lies between latitudes 4030' and 5000'N and longitudes 6045' and 7030'E. It is bounded on the East and West by meandering Creeks, on the South by first the block-yard creeks, then the Bonny River and finally mangrove swamps and on the north by Abia State. The southern part of the town stands largely on raised levees with silts and clay foundation. These afford permanently dry and firm points within the zone of its fresh water swamps of the Niger Delta. It covers an area of 290 km^2 and the mean annual temperature is about 28˚C. Nwaja Creek is in the upper Bonny Estuary of the Niger Delta. Seven sampling stations (S1-S7) were located along the Nwaja Creek, to cover all land-based sources of contaminant inputs into the creek as well as presumably uncontaminated locations (**Figure 2**). The sampling stations and their geographical coordinates were all recorded and documented (**Table 1**).

Figure 1. Showing river state, Niger Delta, Nigeria (Source: Google earth image).

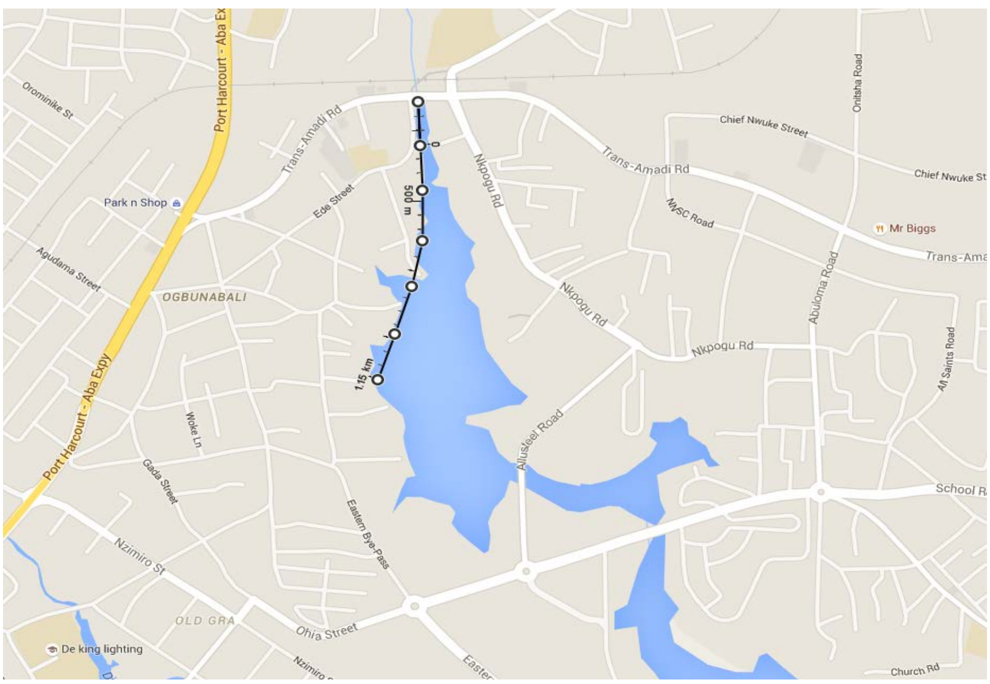


Figure 2. Map showing sampling stations (Source: Google earth map).

Table 1. Nwaja creek sampling stations GPS coordinates.

S/n	Sampling station code	Longitude	Latitude
1	S1	7.015592	4.809313
2	S2	7.015585	4.809011
3	S3	7.015562	4.808353
4	S4	7.015752	4.807685
5	S5	7.015805	4.807083
6	S6	7.015737	4.806236
7	S7	7.015919	4.805435

2.2. Sampling and Analyses

The study adopted both field and laboratory based procedures to generate the data required. Surface water samples were obtained at seven sampling stations (S1 to S7) located at equal distances of 100 km along the stretch of Nwaja creek. Sediment samples were collected monthly with an Ekman grab (15 cm by 15 cm) at each of the stations for a period of 3 months from May to July 2015 (rainfall peak period). Replicate grabs samples were collected for particle size analysis and physicochemical analysis of the sediment. These were transported to the laboratory in ice-cooled boxes.

The sediment samples were air-dried, sieved and used to perform the following physicochemical analysis except pH and conductivity for which wet samples were analyzed. The Bouyoucos hydrometer method was used for the particle size analysis. The pH and conductivity of the sediment were determined using a meter (model H1 8314, membrane HANNA instrument). The sediment samples were mixed in a ratio of 1:1 with distilled water in a beaker before inserting the probes. Readings were taken after allowing the instrument to stabilize. Total Organic Carbon (TOC) in percentage was determined by the wet combustion method of Walkley and Black method of ASTM and APHA [11] [12]. Nitrate (NO_3) levels in sediment were determined following the Brucine Method [13], while available phosphorus in sediment was determined by Bray and Kurt method [14].

2.3. Data Analysis

One-way ANOVA and correlation analyses were used for statistical analysis of each sediment variable.

3. Results

The results of the particle size distribution of the sediments (mean percentage in months and stations) are shown in **Table 2** and **Figure 3** and they are observed to be clay > silt > sand. The mean monthly percentage composition of clay, silt and sand ranged between 64.28% ± 22.04% - 72.36% ±14.00%, 18.71% ± 12.03% - 27.32% ± 22.17% and 8.40% ± 6.28% - 9.76% ± 4.59% respectively (**Table 2**). The highest percentage of clay (90.55%) was recorded at station 3 in the month of May while the least (35.89%) was recorded at station 7 also in the month of May. The lowest value (6.6%) of silt particle was observed at station 3 in the month of May while the highest mean value (60.95%) in the same month was at station 7. The highest value of sand (22.40%) was observed at station 1 in July and the least (2.85%) at station 3 in May. There were no significant differences ($p < 0.05$) in sediment stations and months for clay, silt and sand for this study in Nwaja Creek.

The metal concentration level of heavy metals in plant samples is shown in **Table 3**.

The mean monthly pH values for sediment are 5.39 ± 1.16 in May, 6.54 ± 0.95 in June and 4.65 ± 0.65 in July. The highest pH (8.50) was recorded at station 2 in the month of May and the least (3.90) at station 2 in the month of July (**Table 3**). There were spatial and monthly significant differences ($p < 0.05$) in pH level of the study area (**Figure 4**). Minimal variations in stations and months were observed in the pH of sediments in the study area.

High variations were observed in stations and months for the mean conductivity values of the sediments. Mean values (**Figure 5**) obtained for months ranged between 44.98 ± 20.79 uS/cm (July) and 266.21 ± 151.62 uS/cm (May) while for stations ranged between 79.50 ± 64.97 (Station 6) and 280.83 ± 253.19 uS/cm. The highest conductivity (567.0 uS/cm) was recorded at station 1 in the month of May while the least (23.0 uS/cm)

Table 2. Sediments composition and particle sizes (%).

	May			June			July		
	Clay (%)	Silt (%)	Sand (%)	Clay (%)	Silt (%)	Sand (%)	Clay (%)	Silt (%)	Sand (%)
Station 1	79.3	11.2	9.5	82.5	9.65	7.85	65.2	12.4	22.4
Station 2	85.56	10.8	3.64	79.51	15.85	4.64	72.8	19.45	7.75
Station 3	90.55	6.6	2.85	65.42	18.35	16.23	78.56	14.62	6.82
Station 4	55.65	26	18.35	72.91	16.81	10.28	88.5	7.88	3.62
Station 5	64.52	20.08	15.4	75.6	12.5	11.9	89.05	7.7	3.25
Station 6	38.5	55.61	5.89	40.5	45.9	13.6	52.65	40.64	6.71
Station 7	35.89	60.95	3.16	54.8	41.35	3.85	59.74	28.3	11.96

Table 3. Physicochemical parameters of sediments.

	Month	Statn 1	Statn 2	Statn 3	Statn 4	Statn 5	Statn 6	Statn 7	Mean	SD
pH	May	5.6	7.56	5.52	5.9	4.54	4.45	4.19	5.394286	1.16017
	June	6.1	5.78	6.89	8.5	6.45	5.78	6.25	6.535714	0.94912
	July	4.58	3.9	4.5	5.8	4.99	3.95	4.86	4.654286	0.653449
	Mean	5.42666667	5.74666667	5.63666667	6.73333333	5.32666667	4.72666667	5.1		
	SD	0.77468273	1.83022767	1.19926366	1.530795	0.99851556	0.94585059	1.05076163		
Conductivity (uS/cm)	May	567	340	290.5	148.8	167	150.5	199.7	266.2143	151.6299
	June	189.6	158.9	89	70	90	65	88	107.2143	47.64985
	July	85.9	45	32	56	38	23	35	44.98571	20.79987
	Mean	280.833333	181.3	137.166667	91.6	98.3333333	79.5	107.566667		
	SD	253.19349	73.0897394	135.814518	50.0287917	64.902491	64.9749952	84.0753432		
Organic carbon (%)	May	4.58	3.89	2.5	2.96	3.55	5.45	3.56	3.784286	0.987672
	June	1.7	2.54	1.98	3.09	2.65	1.87	0.98	2.115714	0.701923
	July	2.23	4.4	1.5	1.98	2.9	3.65	1.67	2.618571	1.08215
	Mean	2.83666667	3.61	1.99333333	2.67666667	3.03333333	3.65666667	2.07		
	SD	1.53285137	0.96109313	0.50013332	0.60682232	0.46457866	1.79000931	1.33570206		
Phosphate (mg/kg)	May	10.5	15.5	12.68	11.4	7.89	14.89	16.89	12.82143	3.155828
	June	5.68	12.56	9.5	12.58	6.9	8.55	11.33	9.585714	2.720367
	July	6.54	6.98	9.2	8.56	5.5	9	8.65	7.775714	1.428634
	Mean	7.57333333	11.68	10.46	10.8466667	6.76333333	10.8133333	12.29		
	SD	2.57078458	4.32763215	1.92841904	2.06633331	1.20084692	3.5376593	4.20304651		
Nitrate (mg/kg)	May	3.9	5.05	3.44	6.5	7	11.9	9.95	6.82	3.131075
	June	3.65	3.89	0.45	1.65	1.55	2.56	2.56	2.33	1.217032
	July	1.76	4.06	3.58	3.5	3.25	5.55	6.7	4.057143	1.616567
	Mean	3.1033333	4.3333333	2.49	3.8833333	3.9333333	6.67	6.4033333		
	SD	1.170057	0.626445	1.7680781	2.4476179	2.7885181	4.7696646	3.7039213		

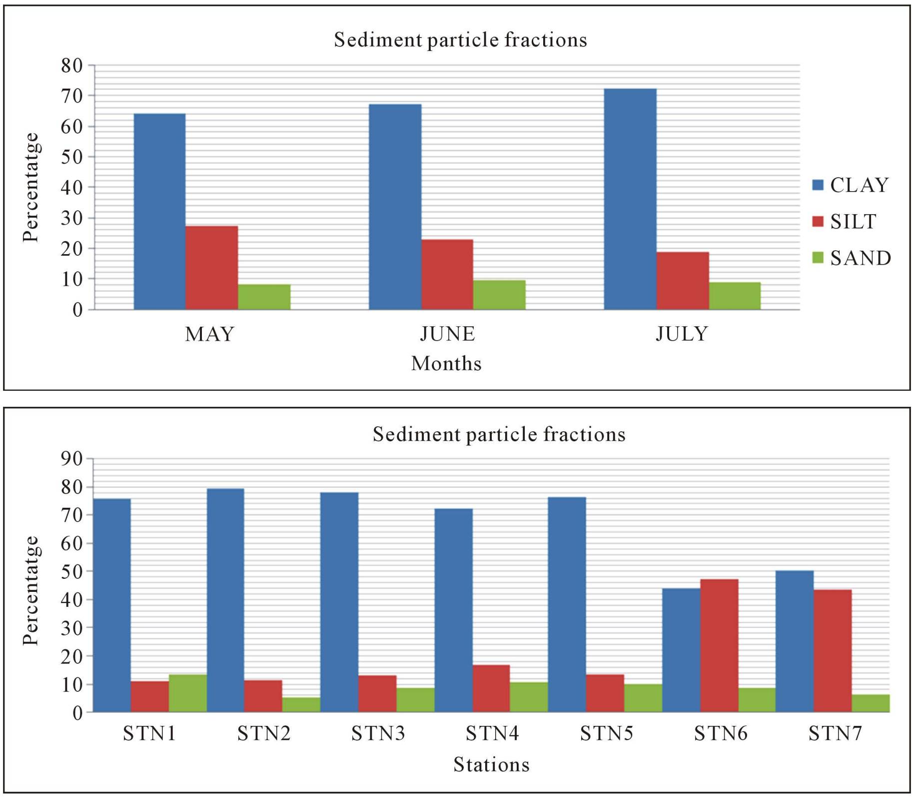


Figure 3. Mean particle size distribution of sediments.

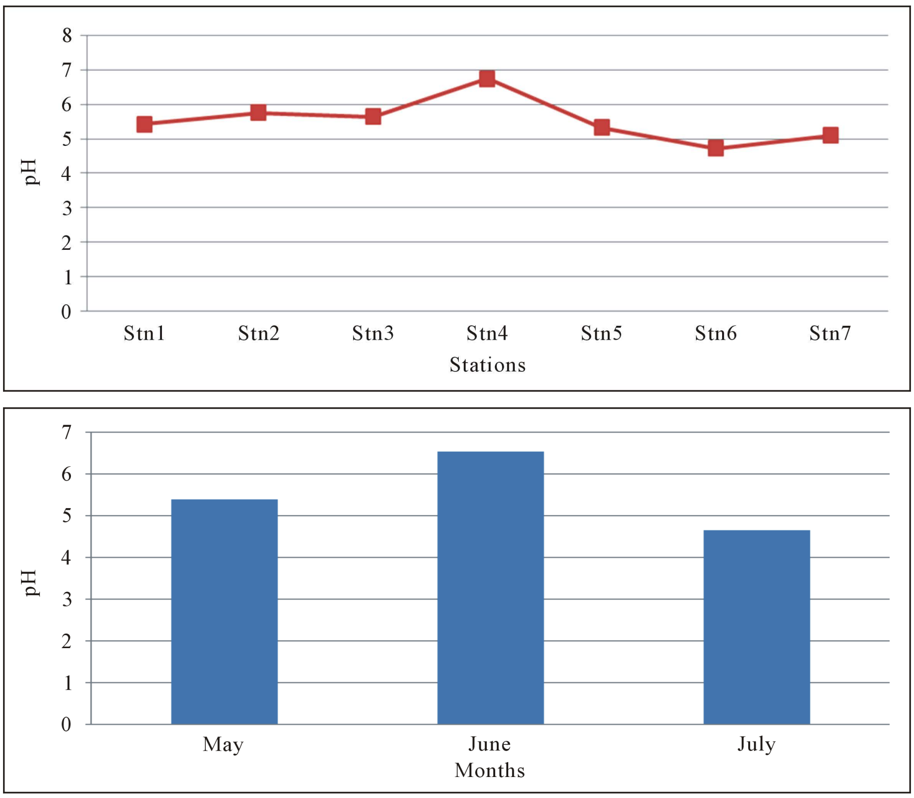
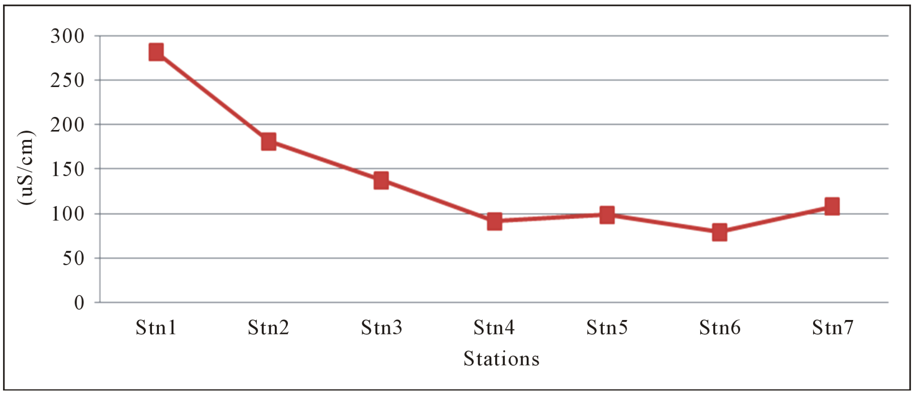


Figure 4. Mean pH values (monthly and station).



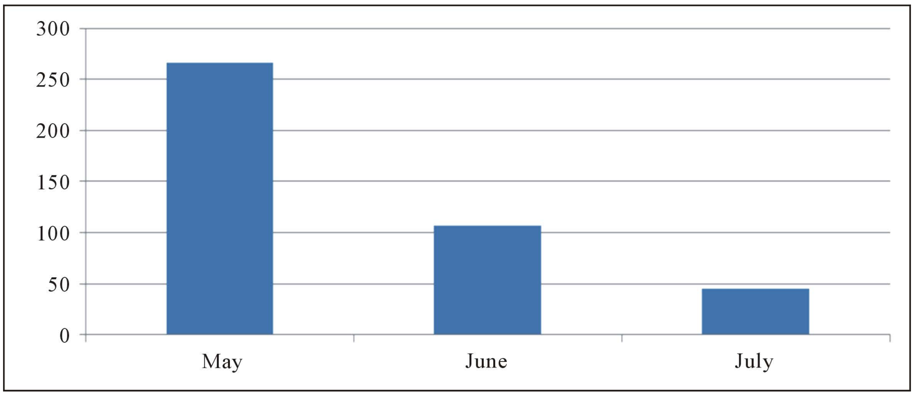


Figure 5. Mean conductivity (monthly and station).

was recorded at station 6. There were significant differences ($p < 0.05$) in conductivity across stations and months in this study of Nwaja Creek sediments.

The values of total organic carbon in the study area varied greatly in months and across stations with higher values observed during the month of May (**Figure 6**). The TOC values in the study area were generally above 1% across all stations during the study period. The lowest mean value recorded was at station 3 (1.99% ± 0.5%) while the highest mean value was at station 6 (3.65% ± 1.79%). In mean monthly variation, the month of May had the highest mean (3.78% ± 0.98%) while the month of June had the lowest mean (2.11% ± 0.70%). Significant differences were observed in the ANOVA results between stations and months ($p < 0.05$).

The mean monthly Phosphate level in Nwaja sediment (**Figure 7**) ranged between 7.77 ± 1.42 mg/kg (July) and 12.82 ± 3.15 mg/kg (May) while the mean phosphate level across stations ranged between 6.76 ± 1.20 mg/kg (station 5) and 12.29 ± 4.20 mg/kg (station 7). The highest value of phosphate was recorded at station 7 (16.89 mg/kg) in the month of May while the least at station 5 (5.50 mg/kg) in the month of July. Phosphate levels in this study were recorded to be higher than nitrate concentration. ANOVA showed significant difference ($p < 0.05$) in mean phosphate concentrations between stations and months, and significant interaction between months and locations.

The nitrate level in Nwaja Creek was quite high and varied across the study stations and sampling months (**Figure 8**). The mean monthly concentration of nitrate in sediment varied between 2.33 ± 1.21 mg/kg in June and 6.82 ± 3.13 mg/kg in May. Mean concentration across the stations varied between 2.49 ± 1.76 mg/kg in station 3 and 6.67 ± 4.76 mg/kg in station 6. Significant differences ($p < 0.05$) were observed in Nitrates between stations and across all the sampling points.

Correlation between variables in sediment samples is shown in the **Table 4** and **Figure 9**. The relationship between pH and conductivity, organic carbon and conductivity, phosphate and pH, Nitrate and organic carbon; and Nitrate and phosphate were all positively correlated. However the correlation between organic carbon and pH, phosphate and conductivity, phosphate and organic carbon, nitrate and pH; and nitrate and conductivity were all negatively correlated. These relations were statistically not significant and it shows weak relationship among the variables. Thecorrelation between soil and plant for all the metals are all positive. These relations

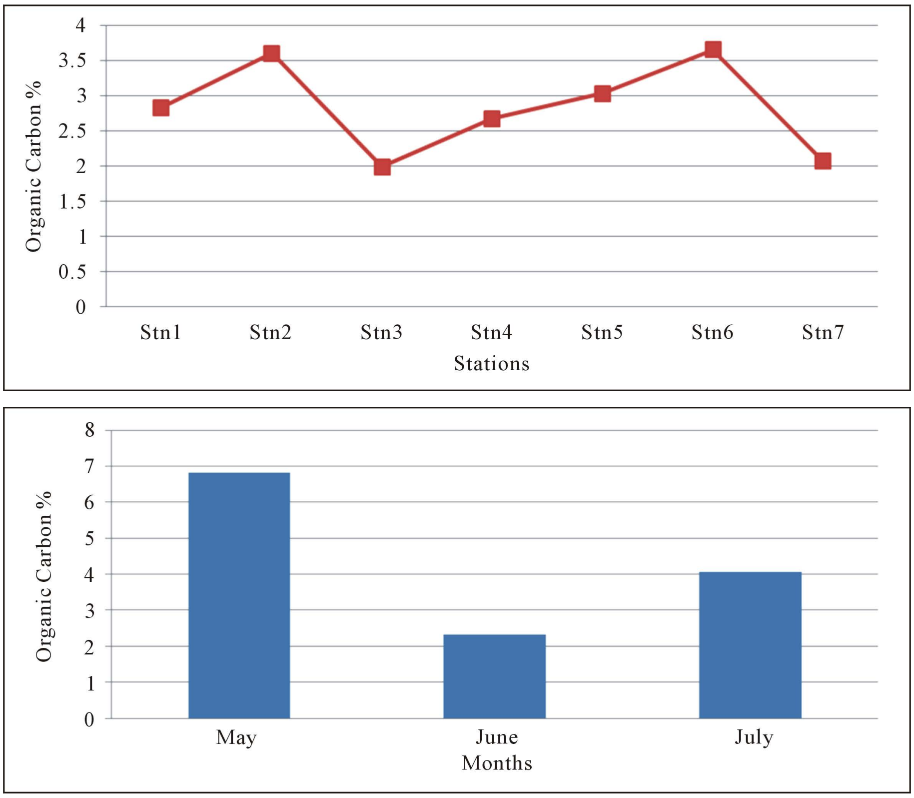


Figure 6. Mean organic carbon (monthly and station).

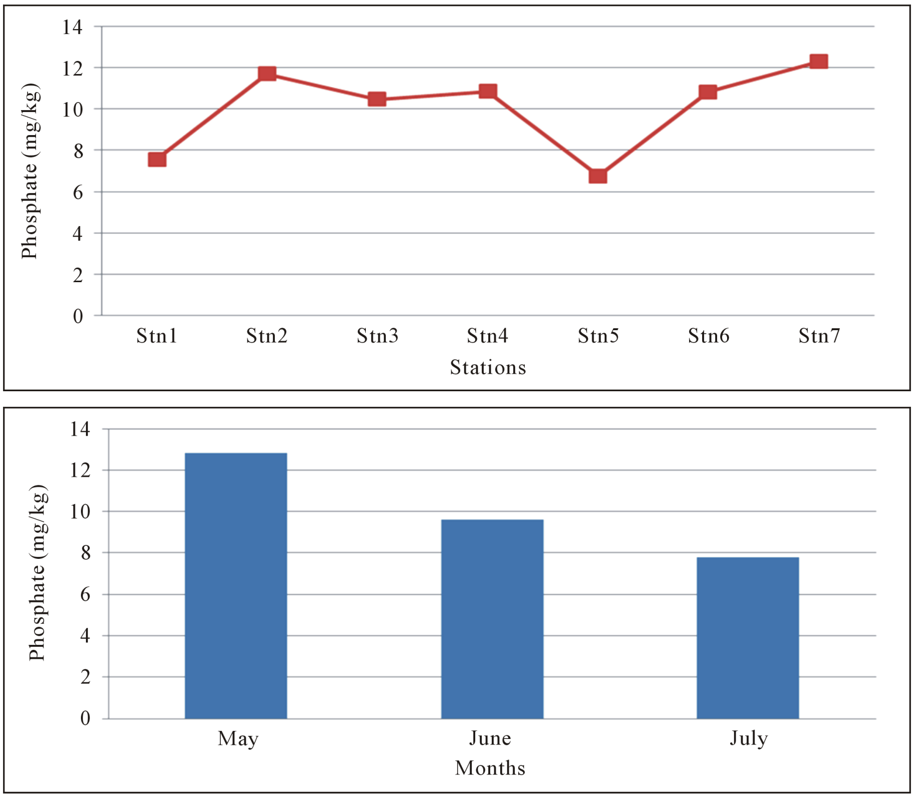
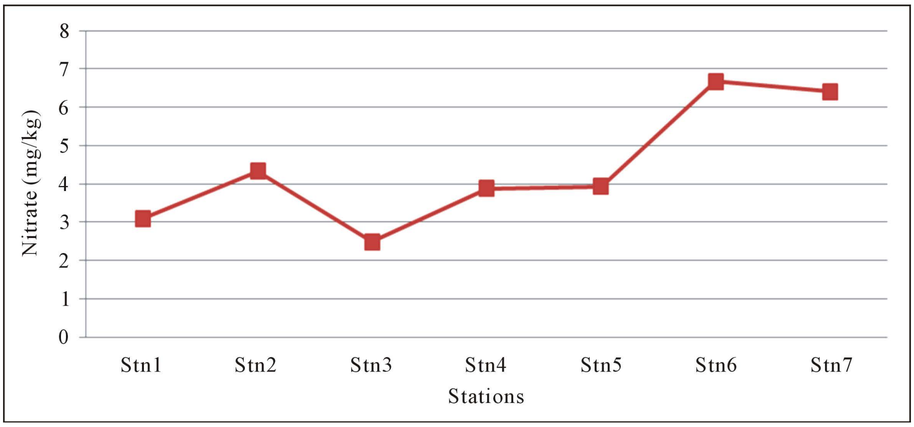


Figure 7. Mean phosphate (mg/kg) in stations and months.



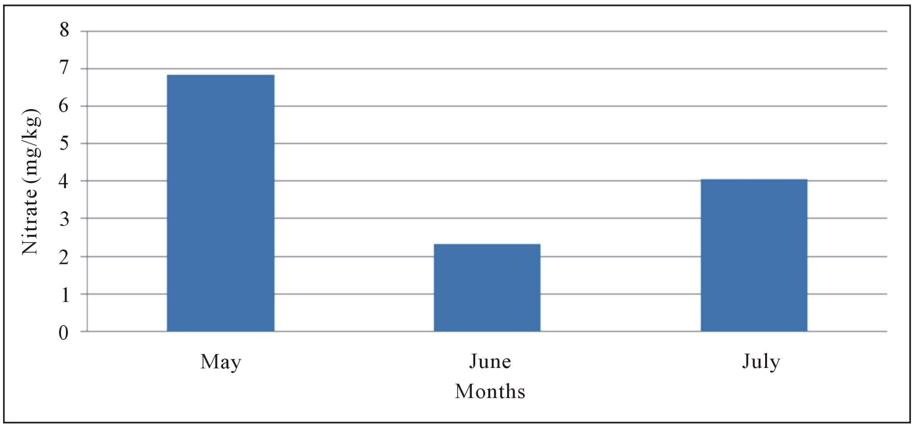


Figure 8. Mean nitrate (mg/kg) in months and station.

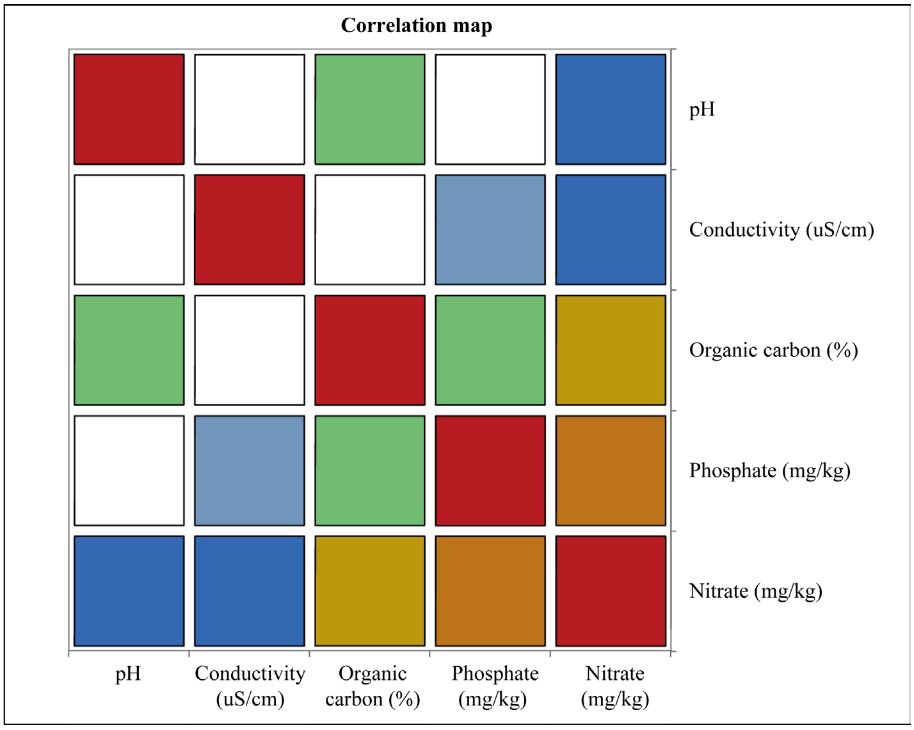


Figure 9. Physicochemical parameters correlation map.

Table 4. Correlation table for studied variables.

	pH	Conductivity (uS/cm)	Organic carbon (%)	Phosphate (mg/kg)	Nitrate (mg/kg)
pH	1				
Conductivity (uS/cm)	0.0255	1			
Organic carbon (%)	−0.1929	0.0323	1		
Phosphate (mg/kg)	0.0892	−0.3412	−0.1149	1	
Nitrate (mg/kg)	−0.5509	−0.5010	0.2986	0.4895	1

were significant for copper, iron, lead and cadmium (r = 0.718, r = 0.644, r = 0.705 and r = 0.010 respectively) but not significant for zinc (0.030).

4. Discussion

Sediments with fine particles provide better surface areas for pollutants to adsorb than those with coarse particles. The nature of the sediment and the organic matter composition also determine the benthic community structure found in particular sediments. Grain size analyses show that sediments from the Nwaja Creek were generally clay > silt > sandy in nature with the texture characteristics being fairly constant over the study period. All sampling stations had more clay-silt compositions except in the month of May at station 7. The mean percentage values for clay, silt and sand in this study compared favourably with the observation of Daka and Moslen [15] who recorded mean spatial values ranging from 0.4% ± 0.42% - 45.85% ± 2.16%, 1.57% ± 0.49% - 54.50% ± 6.37% and 5.51% ± 2.68% - 96.70% ± 1.98% for sand, silt and clay respectively. The study revealed that the particle size of the sediments of Nwaja River were generally sandy mud in nature.

There were minimal monthly and spatial variations in the mean pH values of sediment in the study area. pH values were higher during the month of June and lower in the month of July. Station 2 had the highest pH value in the month of May, station 4 in the month of June and station 4 also in the month of July. The values obtained for sediment pH levels during this study were consistent with those of Daka *et al*. [16] who recorded range between of 2.5 - 3.5 in Azuabie creek of the upper Bonny Estuary. These values are acidic and would pose serious challenges to organisms in nature. But this study does not compare favourably well with the report of Braide *et al*. [3] who reported alkaline range of 6.9 - 7.8 from the freshwater stream of Minichida stream also in Niger Delta. Whereas Minichida stream sediment is alkaline that of Azuabie and Nwaja is acidic. This might be due to anthropogenic sources such as oil and gas exploration and production, discharge of industrial effluents, domestic and human wastes etc.

The conductivity of the study area ranged between 23 uS/cm and 567.0 uS/cm. These high variations may be as a result of dilution due to the heavy rainfalls during this period. This compares favorably with the range of 40.0 - 1940.0 uS/cm with a mean of 528.75 uS/cm reported by Ezekiel *et al*. [17] in Sombreiro River, Niger Delta.

The organic carbon content of the study area ranged between 0.98% - 4.58%. This value is similar to those observed in Azuabie Creek (0.82% - 2.16%) by Daka and Moslen [15] and Sombreiro River (2.02% - 4.1%) by Ezekiel *et al.* (2011) [17]. Sediment is a major site for organic matter decomposition which is largely carried out by bacteria. The level of organic matter decomposition may be attributed for the variation in organic carbon content. Fine sediment particles have larger relative surface areas than coarse particles and can absorb colloidal and dissolved organic matter forming sedimentary complexes [15]. The variation in organic carbon content may be attributed to difference in deposition of organic matter at the various stations.

Nitrate and phosphates give an indication of the nutrient level in the study area. High variations were observed monthly and also across stations for the concentrations of these nutrients. Domestic waste input from human settlements near these stations and surface run-offs into the creek could be responsible for the appreciably high nutrient level recorded at these stations. Nitrate concentration ranged between 0.45 - 11.9 mg/kg with a mean of 6.18 mg/kg this is in agreement with the range (2.60 - 4.10 mg/kg) recorded by Ezekiel *et al*. [17] in a study in the Sombreiro River, Niger Delta, Nigeria. This value is quite high especially when it is compared to the low regional nutrient level of the Niger Delta. The Niger Delta geology is not essentially rich in nitrate and its excess in surface or groundwater is considered as pollutant [18]. Similarly, the phosphate values (5.5 - 15.5 mg/kg) observed in this study is in a range similar to values obtained by Daka and Moslen [15] with a mean phosphate concentration of 13.43 mg/kg in a study of Azuabie River sediment. The conditions which affected nitrate concentration also affect phosphate distribution in the stations. Excess phosphate in water is considered a pollutant [19]. As reported by Adesuyi *et al*. [18] about Nwaja Creek surface water becoming highly polluted with nitrates and phosphates, it's obvious that this river need to be monitored and assessed regularly to avoid algal bloom and full scale pollution.

Conclusion

The monitoring of sediment quality is a very important process in the restoration and protection of the biological integrity of our nation's waters as well as our aquatic/wildlife resources. This study presents the results of the physicochemical quality of the bottom sediment of Nwaja Creek in Niger Delta, Nigeria. Minimal monthly and spatial variations are observed in particle distribution, pH and phosphate while significant variations are observed in conductivity, total organic carbon and nitrate concentration. This observation may be due to anthropogenic influences rather than natural as shown by the elevated nitrate level which is known to be minimal in the geology of the Niger Delta. It is concluded that Nwaja Creek should be constantly monitored for trends in surface water and sediments biological and physicochemical parameters.

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