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Physicochemical characteristics of sediment from odeama creek of the Niger Delta area of Nigeria

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Abstract
The coastal environment of the Niger Delta sub-region of Nigeria has been degraded over the years as a result of anthropogenic activity, particularly oil exploration and exploitation. This study is carried out to investigate if there are human influences on the quality of sediment in Odeama creek. Water samples were obtained from 20 sampling points and four control points during wet and dry season. The samples were analyzed using standard methods and procedures. The physical and chemical parameters analyzed showed no statistical difference (p> 0.05) at 95% confidence limit between sampling points except copper, which was statistically significant (p < 0.05) at 95% confidence interval during the wet season. The particle size analyses are in the order: sand > clay > silt. The percentage composition observed ranged from 52. 90 – 73. 20%, 15.60 – 33.20%, 5.50 - 19.0% for (sand, clay and silt respectively) and 70.6 –83.40%, 5.40 – 13.80%, 9.30 – 19.90% for (sand, clay and silt respectively); pH range of 2.80 – 5.10 and 4.30 – 6.70; TOC, 0.34 – 1.35mg/kg and 0.78 – 3.03 mg/kg; THC, 0.69 – 4.68mg/kg and 0.88 – 106.14 mg/kg; PAH, 0.00 – 3.54 mg/kg and 0.57 – 72.55mg/kg; chloride, 444.86 – 804.50 mg/kg and 924.71 – 1624mg/kg; Iron, 39.31 – 1171 mg/kg and 24.16 – 166.27 mg/kg; Zn, 1.04 – 30.98 mg/kg and 3.44 – 23.14 mg/kg, Cr, 0.01 –0.22 mg/kg and 0.002 – 0.04mg/kg; Pb, 0.00 – 0.06 mg/kg and 0.28-2.16 mg/kg during the wet and dry season respectively. The high values of PAH, THC, Iron, zinc, sulphate, chloride and sodium could be attributable to anthropogenic influence from illegal bunkering, oil spillage and runoff from surrounding farmlands. Low TOC and heavy metals with the exception of Iron; is an indication that most of the heavy metals and organic compounds produced from the observed anthropogenic influence in the study area may be dissolved more in the water column due to high percentage of sand particles in the study area. The level of PAH and THC observed could be detrimental to aquatic life and humans. Environmental monitoring of anthropogenic activities should therefore be conducted to curtail the adverse effect of the exceedances observed in this study.

Keywords: Niger Delta, odeama creek, sediment, sink

Introduction

The coastal environment of the Niger Delta sub-region of Nigeria, over the years, have been reported to be degraded due to oil exploration and exploitation and other anthropogenic activities carried out in the region; and that the extent of impairment of the environment is of great concern to all stakeholders in the region (Adesuyi *et al.*, 2016; Zabby *et a*l., 2021) [2]. Toxic pollutants released into aquatic systems as a result of natural processes and anthropogenic activities may dissolve in the water column, attach to suspended particles in the water body, settle as sediments at the bottom, or may seep into underground water. Sediments are a complex mixture of organic substances and particulate compounds; classified into suspended sediments, bottom sediments, and porewater (Reuther, 2009) [29]. Characterization of Sediments is an integral part of water quality assessment because sediments are sinks or stored in the water body that accumulates pollutants (Reuther, 2009) [29]. Contaminants accumulated in sediments include heavy metals, pathogens, organic chemicals, and nutrients (Michalec and Cupak, 2021) [25]. According to Adesuyi *et al.* (2016) [2], organic carbon content, pH, particle size, nitrate, and phosphorous influence the interaction and dynamics of contaminants within the sediment matrix Bottom sediment is classified into fine sediments or coarse sediments. The fine sediments are subdivided into clay and silt, while the coarse sediments are subdivided into sand and gravel (Salomons and Forstner, 1984) [33]. Particle size determines the amount of pollutants sediment accumulates; this is because silt and clay have larger surface area than sand and gravel, and as such can retain more pollutants (Adesuyi *et al.*, 2016) [2]. Heavy metals and organic contaminants stay in the water column for a long time if the percentage of coarse particles is higher in the sediment (Etesin *et al.*, 2013) [14]. The organic and inorganic compounds accumulated in sediment may be released back into the water column due to a shift in the equilibrium of the water-sediment interface, caused by a change in environmental conditions (Reuther, 2009; Zhang *et al.*, 2018) [29, 43]. The absorption of heavy metals in sediment is affected by several environmental factors such as pH, particle size, and conductivity. Absorption of Organic compounds in high concentration, low pH, and change in redox condition of the sediments are physicochemical changes that affect the release of heavy metals from the sediments into the water column (Salomons and Forstner, 1984; Sha'Ato *et al.*, 2020) [33, 35].

Total organic carbon is a measure of organic matter present in sediment and can be used as an indicator of enrichment in the water body (Ronov, 1958; Marguerite *et al.*, 2011) [31, 23]. Organic carbon is a source of food for benthic organisms in the sediment, but at high concentrations, this could make abundant opportunist species dominate the benthos in the sediment. At an extremely high concentration of organic carbon in the sediment, bacterial mats may completely dominate the sediment. The concentration of organic carbon in the sediment is affected by particle size and the organic source, which includes municipal waste and industrial waste (Hyland, 2005; Marguerite *et al.*, 2011) [18, 23]. Benthic organism found in sediments easily ingests hydrocarbon from the sediment; which is then passed on along the food chain to man (Ezekiel *et al*., 2011; Wokoma, 2014) [15, 40].

Nitrate and phosphorus level in the sediment is a measure of the nutrient in the sediment and can be used as an indicator of anthropogenic influence (Daka and Moslen, 2013) [7]. Polycyclic aromatic hydrocarbons (PAH) are released into the environment from natural seeps, industrial use of petroleum, combustion of fossil fuel and coal, municipal waste, and oil spills (USEPA, 2006; Mcgrath *et al.*, 2019) [24]. PAH shows moderate to low solubility in the water column of aquatic systems and promote sorption to particulates in the water. PAH are harmful to benthic organisms found in sediments and some are known to be carcinogenic and mutagenic (USEPA, 2006; Mcgrath *et al*., 2019) [24]. Zinc, iron, chromium, lead, copper, cobalt, mercury, nickel, and vanadium are some examples of heavy metals. Copper, iron, zinc, and manganese are essential metals required for metabolic functions; but when ingested in high concentration can cause cellular and tissue damage and various diseases in humans. Metals such as lead, mercury, nickel, and vanadium are non-essential metals and have no established metabolic function (Tchounwou *et al.*, 2012) [38]. Mercury, copper, and lead are closely monitored because of their adverse effect on human health (USEPA, 2006).

Odeama creek is an estuary situated in Brass Local Government Area of Bayelsa State, in Niger Delta, Nigeria. There are four satellites oil-producing communities collectively called Odeama community situated along the creek. Inhabitance of the community sometimes uses the water from the creek for their domestic use. Fishing, farming, and boat making are sources of livelihood in the community. There is a growing concern in the community, about the water quality of the creek. The concern of the people is centered on pollution from oil exploration and illegal bunkering activities carried out in the community. One major issue associated with the production of crude oil is oil spillage, which is the discharge of crude oil into the environment. Heavy metals and hydrocarbons are constituents of crude oil (Speight, 2020) [36] that pollute the environment. Estuaries are more susceptible to accumulating pollutants because sediments in estuary serve as a filter for many pollutants between the land and the sea; only strong metal complexes and less hydrophobic organic chemicals escape into the sea (Zhou *et al.*, 1998; Chapman and Wang, 2001; Schubel and Kennedy, 1984) [44, 6, 32]. The natural mechanism in estuaries also prevents sediments from leaving the estuary (Salomons and Forstner, 1984) [33]; this may lead to the accumulation of toxic pollutants, which can adversely affect biodiversity in the water body. It is paramount to investigate the sediment quality of Odeama creek because of its proximity to oil and gas activities. This study, therefore, examines the quality of sediments in Odeama creek by assessing the physicochemical parameters of the sediment.

Material and methods

1. Study Area

Sediment samples were collected from 20 sampling points and 4 control points along Odeama creek. Odeama is a Nembe- speaking clan in Brass Local Government Area of Bayelsa State. Odeama creek is an estuary that flows directly into the Atlantic Ocean. The creek is situated in Brass Local Government Area of Bayelsa state. The populated census conducted in 2006 showed that Brass Local Government Area has a population figure of 317, 413, while Odeama community was 2,314. The vegetation around the creek is freshwater swamp forest and mangrove forest. The Sampling point and control points are shown in the study map in figure 1, while the coordinates of the sampling points are presented in Table 1.

2. Sample collection

Samples were collected following standard procedures. The sampling points were chosen near an operational oil and gas field, while the control points were selected in an area where there is minimum anthropogenic activity. Samples were collected using a steel Ekman Grab (0.0225m^2) sampler. Prior to the first deployment and between sample stations, the grab sampler was thoroughly rinsed to remove visible sediment. At each station, the grab sampler was deployed and then heaved out with sediments. One successful grab bite was collected per area. On retrieval, the grab bite sediment sample was scooped from the grab cup into a plastic container, it was transferred into various containers based on the parameters to be analyzed and preserved. Samples from the grab cup were transferred into labelled plastic containers that have been rinsed with distilled water prior to sampling. Samples for hydrocarbon analysis were collected in glass bottles, while those for heavy metal determination were preserved with nitric acid. All samples obtained were preserved at (< 4°C) and transported in that state to Dukoria laboratory Ltd, Effurun, Delta State, where all ex-situ analysis was carried out in line with adapted standard procedures that were validated in Dukoria Laboratories (APHA, 1998) [5].

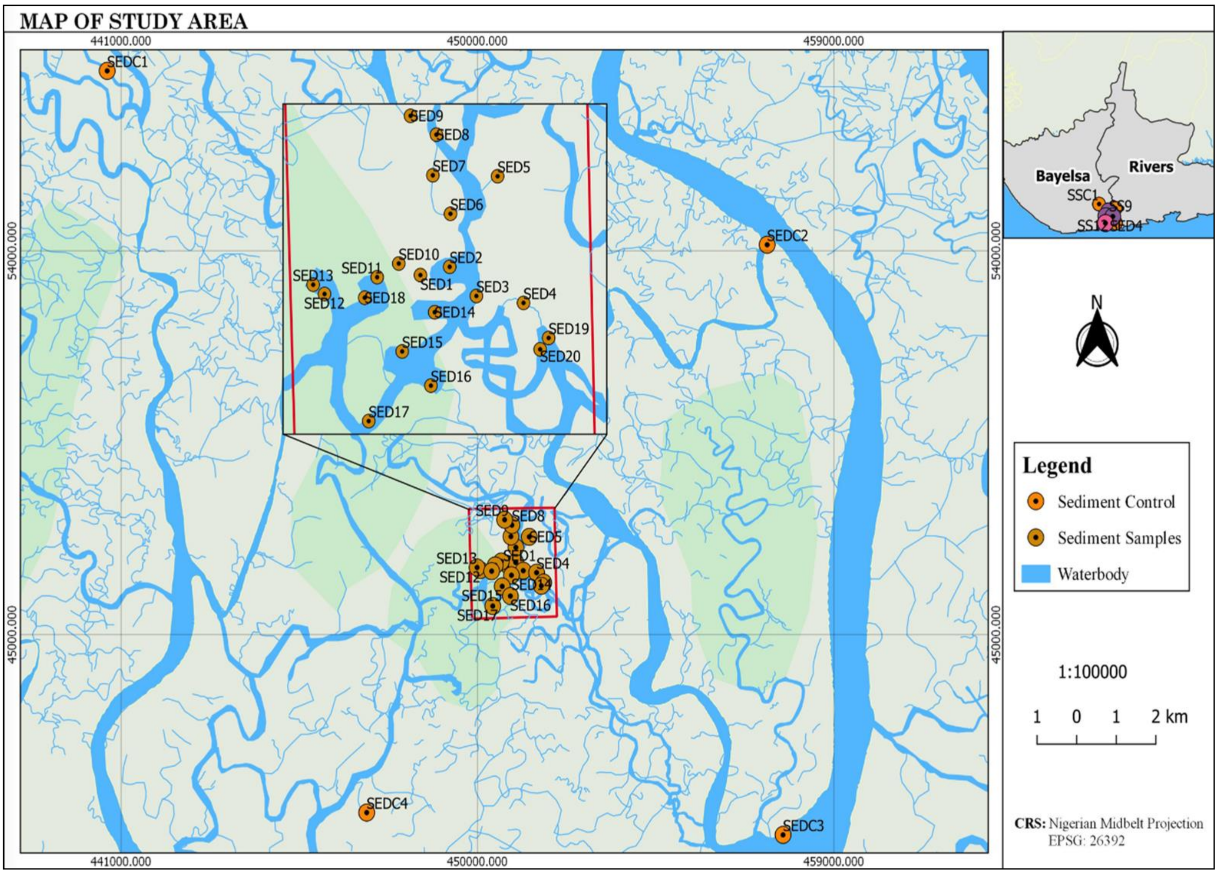

Fig 1: Map of study area showing the sampling points and control points.

3. Statistical Analysis

The results of the physicochemical parameters were subjected to descriptive statistics and test of significance between sampling points ($p < 0.05$) at 95% confidence interval, using Microsoft Excel, office 365.

Table 1: Coordinates of sampling point

Sample Code	Sample Type	Eastings	Northing
SED1	Sediment	4°50711.031″	4°6654.446″
SED2	Sediment	4°50933.298″	4°6731.280″
SED3	Sediment	4°51165.816″	4°6487.321″
SED4	Sediment	4°51520.909″	4°6408.951″
SED5	Sediment	4°51367.494″	4°7172.562″
SED6	Sediment	4°50867.387″	4°6996.919″
SED7	Sediment	4°50668.093″	4°7207.609″
SED8	Sediment	4°50790.964″	4°7483.805″
SED9	Sediment	4°50724.819″	4°7660.957″
SED10	Sediment	4°50544.336″	4°6599.585″
SED11	Sediment	4°50300.186″	4°6644.481″
SED12	Sediment	4°50011.268″	4°6556.764″
SED13	Sediment	4°49911.695″	4°6689.763″
SED14	Sediment	4°50455.069″	4°6433.909″
SED15	Sediment	4°50676.572″	4°6223.160″
SED16	Sediment	4°50709.204″	4°5968.671″
SED17	Sediment	4°50364.032″	4°5604.577″
SED18	Sediment	4°50299.773″	4°6489.628″
SED19	Sediment	4°51531.924″	4°6375.739″
SED20	Sediment	4°51586.852″	4°6154.375″
SEDC1	Sediment	4°40561.631″	5°8175.134″
SEDC2	Sediment	4°57325.977″	5°4246.763″

SEDC3	Sediment	4°57745.600″	4°0486.339″
SEDC4	Sediment	4°47074.376″	4°0346.056″

Table 2: Analytical methods for parameters analyzed in this study

Parameters	**Analytical Methods**
Physico-chemical	
pH	APHA 4500-H^+B
Particle size %	APHA 2560
Organics	
Total organic compounds (TOC), mg/kg	APHA 5310
Total Hydrocarbon Content (THC), mg/kg	APHA 5520B
Anions	
Sulphate, mg/kg	Turbidimetric method APHA (4500)
Nitrate, mg/kg	APHA 4500-$NO3^-$
Inorganics	
Magnesium, mg/kg	APHA 3111B
Metals	Varian 200 Atomic Absorption Spectrophotometer, (AAS), (APHA 3111B)
PAH	Polynuclear Aromatic Hydrocarbons (APHA 6440)

Source: APHA, (2012)

Table 3: Descriptive statistics of physicochemical parameters of sediment in wet season

Physicochemical parameters	**Mean**	**Standard deviation**	**Range**	**P- value, 95%**	**Ctl mean**	**Ctl range**
pH	4.16	0.57	2.80– 5.10	P > 0.05	5.03	4.80 – 5.30
Particle Size, %						
Sand	64.01	6.06	52.90 – 73.2	P > 0.05	62.18	57.40 – 70.40
Clay	23.54	5.48	15.60 – 33.2	P > 0.05	27.28	18.70 – 31.40
Silt	12.46	3.83	5.50 – 19.9	P > 0.05	10.55	9.30 – 11.20
Organics, mg/kg						
Total Organic Content (TOC)	0.91	0.36	0.34 – 1.35	P > 0.05	1.08	0.67 – 1.34
Total Hydrocarbon Content (THC)	2.35	1.27	0.69 – 4.68	P > 0.05	2.73	1.19 – 4.68
Polynuclear Aromatic Hydrocarbon (PAH)	0.70	1.06	0.00 – 3.54	P > 0.05	0.29	0 – 1.10
BTEX	<0.005	<0.005	<0.005	-	<0.005	-
Anions (mg/kg)						
Chloride	590.76	112.02	444.86 – 804. 50	P > 0.05	624.81	469.85 – 984.69
Sulphate	811.02	221.19	524.28 – 1196.26	P > 0.05	323.88	317.11 – 333.04
Nitrate	62.11	277.72	0.005 – 1242	P > 0.05	0.02	0.011 – 0.022
Cations (mg/kg)						
Calcium, (Ca^{2+})	341.333	189.01	24.48 – 726.55	P > 0.05	330	295 – 376
Magnesium,(Mg^{2+})	223.167	123.57	16.01 – 475.02	P > 0.05	215	193 – 246
Potassium, (K^+)	96.2515	53.29	6.9 – 204.88	P > 0.05	93.16	83.14 – 106.15
Sodium, (Na^{2+})	809.268	448.12	58.04 – 1722.58	P > 0.05	783	699.02 – 892.5
Heavy Metals (mg/kg)						
Iron, (Fe)	549.80	304.53	39.31 – 1171	P > 0.05	532	475.35 – 606.42
Zinc, (Zn)	14.55	8.06	1.04 - 30.98	P > 0.05	14.08	12.57 – 16.05
Chromium, (Cr)	0.10	0.06	0.01 – 0.22	P > 0.05	0.09	0.09 – 0.11
Lead, (Pb)	0.03	0.02	0 - 0.06	P > 0.05	0.03	0.02 – 0.03
Copper, (Cu)	0.005	0.005	0 – 0.01	P < 0.05	0.002	0 – 0.01
Cadmium, (Cd)	<0.002	<0.002	<0.002	-	<0.002	-
Mercury, (Hg)	<0.006	<0.006	<0.006	-	<0.006	-

Manganese, (Mn)	<0.003	<0.003	<0.003	-	<0.003	-
Nickel, (Ni)	3.55	1.97	0.25 – 7.57	P > 0.05	3.44	3.07 – 3.92
Barium, (Ba)	<0.005	<0.005	<0.005	-	<0.005	-
Vanadium, (V)	<0.005	<0.005	<0.005	-	<0.005	-

BTEX - benzene toluene ethylbenzene Ctl – control

Table 4: Descriptive statistics of physicochemical parameters of sediment in dry season

Physicochemical parameters	Mean	Standard deviation	Range	P- value, 95%	Ctl mean	Ctl range
pH	5.34	0.73	4.30 – 6.70	P > 0.05	5.78	4.75 – 6.2
Particle Size, %						
Sand	77.19	4.26	70.6 – 83.40	P > 0.05	75.88	69.7 - 80.60
Clay	9.02	2.18	5.40 – 13.80	P > 0.05	7.8	5.9 – 11.30
Silt	13.85	3.13	9.30 – 19.90	P > 0.05	16.33	13.5 – 19.0
Organics, mg/kg						
Total Organic Content (TOC)	2.53	0.48	0.78 – 3.03	P > 0.05	2.98	2.83 – 3.26
Total Hydrocarbon Content (THC)	16.69	23.88	0.88 – 106.14	P > 0.05	5.59	4.38 – 7.41
Polynuclear Aromatic Hydrocarbon (PAH)	8.88	19.48	0.57 – 72.55	P > 0.05	1.48	0.79 – 2.11
BTEX	<0.005	<0.005	<0.005	-	<0.005	-
Anions (mg/kg)						
Chloride	1168.39	238.05	924.71 – 1624.5	P > 0.05	849.74	725 – 975
Sulphate	463.58	75.38	258.43- 547.39	P > 0.05	272.09	198.39 – 366
Nitrate	0.05	0.04	0.02 – 0.17	P > 0.05	0.04	0.01 – 0.10
Cations (mg/kg)						
Calcium, (Ca 2+)	292.95	121.74	118.75 – 471.58	P > 0.05	157.15	118.49 – 245.36
Magnesium,(Mg2+)	215.77	98.19	97.31 – 381.45	P > 0.05	123.43	89.75 – 167.48
Potassium, (K+)	165.76	80.44	67.49 – 311.78	P > 0.05	97.77	76.35 – 123.41
Sodium, (Na2+)	2500.35	509.42	1978.88 – 3476	P > 0.05	1818.44	1551 – 2086
Heavy Metals (mg/kg)						
Iron, (Fe)	74.13	44.29	24.16 – 166.27	P > 0.05	62.65	50 – 78.51
Zinc, (Zn)	9.24	4.89	3.44 – 23.14	P > 0.05	6.95	4.32 – 9.42
Chromium, (Cr)	0.02	0.01	0.002 – 0.04	P > 0.05	0.007	0.003 – 0.01
Lead, (Pb)	0.94	0.62	0.289 – 2.16	P > 0.05	0.49	0.325 – 0.67
Copper, (Cu)	<0.003	<0.003	<0.003	-	<0.003	-
Cadmium, (Cd)	<0.002	<0.002	<0.002	-	<0.003	-
Mercury, (Hg)	<0.006	<0.006	<0.006	-	<0.006	-
Manganese, (Mn)	<0.003	<0.003	<0.003	-	<0.003	-
Nickel, (Ni)	0.7014	0.39	1.33	P > 0.05	0.65	0.52 – 0.77
Barium, (Ba)	<0.005	<0.005	<0.005	-	<0.005	-
Vanadium (V)	<0.005	<0.005	<0.005	-	<0.005	-

BTEX - benzene toluene ethylbenzene Ctl – control

Result and Discussion

The descriptive statistics of physicochemical parameters of sediment from Odeama creek in the wet and dry seasons are presented in Table 3 and Table 4, respectively. Significance of difference was determined for the data where $P > 0.05$ in the table of results (Table 3 and Table 4) indicates that the difference between values at the sampling stations is statistically insignificant at 95% confidence interval; while $P < 0.05$ connotes that the differences are statistically significant at 95% confidence interval.

The particle size analysis observed in this study revealed the order of magnitude as Sand > Clay> silt. The percentage composition of particle size ranged from 52.9 – 73.2% (sand), 15.6 – 33.2 % (clay) and 5.5 – 19.9% (silt) observed during the wet seasonis comparable to 57.40 – 70.40%(sand), 18.70 – 31.40% (clay), 9.30 – 11.20 %(silt) were observed in the control points during the wet season; while values 70.60 – 83.40% (sand), 5.40 – 13.80%(clay), 9.30 – 19.90 %(silt) observed in the study area during the dry season is consistent with values 69.70 – 80.60%(sand), 5.90 – 11.30% (clay), 13.50 – 19%(silt) recorded in the control point during the dry season. There was no statistical difference ($p > 0.05$) at 95% confidence interval of particle size distribution between sampling stations. The sediment texture in this study is consistent with sediment fractions reported by Nsikak*et al*, (2008) [26]; Etesin *et al*, (2013) [14] from Iko river sediments, in Nigeria. The distribution pattern of the sediment texture observed in this study may be due to high tide and offshore drift current (Etesin *et al.*, 2013) [14].

The pH range of 2.80 – 5.10 (wet season) and 4.30 – 6.70 (dry season) in the study area is consistent with values 4.80 – 5.30 and 4.75 – 6.2 recorded in the control area for the wet and dry season, respectively. There was no statistical difference between sampling stations ($p > 0.05$) at 95% confidence interval in the oberved pH values. The result revealed that sediment in the study area and control area is acidic in both seasons. Higher pH values were observed during the dry season. A similar variation was observed by Iwegbue *et al.*, (2007) [20] in a similar study carried out in Ase River, in Niger Delta, and Davies (2009) [8] from Okpoka creek sediments, in Niger Delta. The low pH observed in this study may be due to the reaction of sulphate and water present in the sediment to form sulphuric acid. The sulphuric acid may also be responsible for the black colour of the sediment observed in the study area (Robert, 2001; Derk *et al.*, 2003) [30, 9].

Total Organic Carbon (TOC) range 0.34 – 1.35 mg/kg (wet season) and range 0.78 – 3.03 mg/kg (dry season) observed in the study area are within the values 0.67 – 1.34 mg/kg and 2.83 – 3.26 mg/kg observed in the control points during wet and dry season respectively. There was no statistical difference in (TOC) values between sampling points ($p > 0.05$) at 95% confidence interval. The low value of TOC observed in this study may be due to the coarse particle size observed in this study and the rate of decomposition of organic matter (Adesuyi *et al.*, 2016) [2].

Total Hydrocarbon Content (THC) range 0.69 – 4.68 mg/kg (wet season) recorded in the study area is consistent with 1.19 – 4.68 mg/kg (wet season) observed in the control points. 0.88 – 106.14 mg/kg (dry season) observed in the sampling stations is higher than 4.38 – 7.41 mg/kg (dry season) observed in the control point. The difference of THC values between sampling points is statistically insignificant ($p > 0.05$) at 95% confidence interval. The values observed in this study during the wet season are not a threat to an aquatic system (Wokoma, 2014) [40]. The high values of THC observed may be due to an increase in commercial transport activities in the waterway and oil spillage (Ezekiel *et al*., 2011) [15]. THC values in the range 21.6 – 52.7 mg/kg was reported by Ezekiel *et al,* (2011) [15] from Sombreiro River sediments, in Niger Delta; while 2.31- 6.81 mg/kg was reported by Seiyaboh *et al,* (2016) [34] in a study carried out on sediments from Ikoli creek, in Niger Delta. Higher mean values in the range 210-10,750 mg/kg were reported by (Daka and Moslen, 2013) [7] in a study on sediments from Azuabie creek of upper Bonny estuary, in Niger Delta.

Polynuclear Aromatic Hydrocarbon (PAH) range 0.00 – 3.54 mg/kg (wet season) observed in the study area is relatively comparable to the range 0 – 1.10 mg/kg (wet season) recorded in the control area. The (PAH) range 0.57 – 72.55 mg/kg (dry season) observed in the study area is higher than 0.79 – 2.11 mg/kg (dry season) observed in the control points. There was no statistical difference in (PAH) values between sampling points ($p > 0.05$) at 95% confidence interval. Similar PAH values were reported by Edjere *et al*. (2020) from River Ethiope sediments in Niger Delta. In this study, the high PAH values observed during the dry season may be due to higher temperature in the dry season, which leads to evaporation and concentration of PAH which then settles at the bottom; oil spillage and leaks from fuel tanks of boats in the creek (USEPA, 1996; Essumang *et al*., 2018) [39, 13].

The Chloride ion values range 444.86 – 804. 50 mg/kg (wet season) observed in the study area, corresponds with values 469.85 – 984.69 mg/kg (wet season) observed in the control area. 924.71 – 1624.5 mg/kg (dry season) observed in the study area is higher than 725 – 975 mg/kg (dry season) recorded in the control points. Chloride ion values were statistically insignificant ($p > 0.05$) at 95% confidence interval between sampling stations. The high concentration of chloride observed may be due to seawater incursion, pesticides from surrounding farms washed into the creek, and weathering of chloride-rich rock in the study area (Helen and Ramalingom, 2014; Sha'Ato *et al,* 2020) [16, 35]. A lower concentration of chloride ion was reported by Howard *et al,* (2017) [17] from a study on River bed sediments and Sha'Ato et *al,* (2020) [35] in a study carried out on Ihetutu Minefield sediments, in Ishiagu, Nigeria.

Sulphate range524.28 – 1196.26 mg/kg (wet season) and 258.43- 547.39mg/kg (dry season) observed in the study area is higher than values 317.11 – 333.04 mg/kg and 198.39 – 366 mg/kg recorded in the control area during the wet and dry season respectively. No statistical difference ($p > 0.05$) at 95% confidence interval was observed for sulphate values between sampling stations. Lower values of sulphate in the range 21.0 – 30mg/kg was reported by (Ezekiel *et al,* 2011) [15]. A High level of sulphate in sediment may be due to surface runoff of sulphate-rich fertilizer from surrounding farmland (Helen and Ramalingom, 2014) [16]. A Mean concentration of 215 1± 100.2 was reported by (Howard *et al,* 2017) [17].

Nitrate range 0.005 – 0.097 mg/kg (wet season) and 0.02 – 0.17 mg/kg (dry season) observed in the study area corresponds with 0.011 – 0.022 mg/kg (wet season) and 0.01 – 0.10(dry season) mg/kg recorded in the control area. There was no Statistical difference ($p > 0.05$) at 95% confidence interval for nitrate values between sampling stations. Higher nitrate in the range 2.32 – 7.84 mg/kg was reported by (Daka and Moslen, 2013) [7].

Magnesium, (Mg^{2+}) range16.01 – 475.02 mg/kg (wet season) and 97.31 – 381.45 mg/kg (dry season) observed in the study area is higher than Mg^{2+}values 193 – 246 mg/kg and 89.75 – 167.48 mg/kg recorded in the control area for wet and dry season respectively. No statistical difference ($p > 0.05$) at 95% confidence interval was observed for Mg^{2+}values between sampling stations. The inconsistency observed may be due to anthropogenic influence. A Lower value of magnesium was reported by (Seiyaboh *et al.*, 2016) [34].

Calcium range 24.48 – 726.55 mg/kg (wet season) observed in the study area is lower than 469.85 – 984.69 mg/kg (wet season) observed in the control area. The range 118.75 – 471.58 mg/kg (dry season) observed in the study area is higher than 118.49 – 245.36 mg/kg (dry season) observed in the control area. There was no statistical difference ($p > 0.05$) at 95% confidence interval for calcium value between sampling stations. A Lower value of 2.53-6.76 mg/kg was reported by (Seiyaboh *et al*, 2016) [34]. The high calcium observed in this study may be from weathering of rocks in the study area and leaches from shells of dead organisms (Helen and Ramalingom, 2014) [16].

Potassium (K^+) range 6.9 – 204.88 (wet season) and 67.49 – 311.78 (dry season) recorded in the sampling stations is higher than 83.14 – 106.15 (wet season) and76.35 – 123.41 (dry season) recorded in the control area. There was no statistical difference ($p > 0.05$) at 95% confidence limit for K^+ values between sampling stations. Potassium is a natural constituent of sediment but an increase in concentration may be due to domestic waste washed in the water body and weathering of rocks in the study area (Sobha *et al,* 2008) [37]. A Lower value of K^+ was reported by (Seiyaboh *et al,* 2016) [34].

Sodium (Na^{2+}) range of 58.04 – 1722.58 (wet season) and 1978.88 – 3476 (dry season) in the study area are higher than 699.02 – 892.5 and1551 – 2086 recorded in the control area for wet and dry season respectively. There was no statistical difference ($p > 0.05$) at 95% confidence interval of Na^+ values between sampling points. Although sodium is a natural constituent of sediment, an increase in concentration may be due to anthropogenic influences such as runoff of fertilizer from surrounding farms into the water body and domestic waste. Seawater incursion may also be a reason for the high values observed in this study (Sobha *et al,* 2008; Helen and Ramalingom, 2014) [37, 16].

Iron, (Fe) range 39.31 – 1171 mg/kg (wet season) and 24.16 – 166.27 mg/kg (dry season) observed in the study area is higher than 475.35 – 606.42 mg/kg and 50 – 78.51 mg/kg recorded in the control area for wet and dry season respectively. No statistical difference ($p > 0.05$) at 95% confidence interval was observed for Fe values between sampling stations. The variation observed in this study depicts anthropogenic influence. According to Aderinola *et al*., (2009) [1] and Vincent – Akpu and Yanadi, (2014) [41], the Fe values in the range observed in this study is expected because iron is one of the most abundant elements on earth; and this is in agreement with various studies that have reported high Fe concentration in Nigerian soils. Weathering of rocks caused by surface runoff and corrosion of abandoned vessels in the creek may also be the reason for the high Fe values observed in this study (Osakwe and Peretiemo-Clarke, 2013; Nwadinigwe *et al*, 2014) [28, 27]. Fe value 65.91 – 83.52 mg/kg was reported by (Ebong and John, 2021) [10] from the study carried out on sediments from major estuaries in Niger Delta, Nigeria. Vincent – Akpu and Yanadi, (2014) [41] reported Fe value in the range 128125 – 192284 mg/kg from Iwofe site sediments in New Calabar River, River State. Zinc, (Zn) range of 1.04 - 30.98mg/kg (wet season) and 3.44 – 23.14 mg/kg (dry season) in the study area is higher than 12.57 – 16.05 mg/kg (wet season) and4.32 – 9.42 mg/kg (dry season) observed in the control points. There was no significant difference between sampling points for Zn values ($p > 0.05$) at 95% confidence interval. The higher Zn values recorded in this study may be due to soil erosion and runoff from farms around the creek that may have washed pesticides and fertilizer in the water body (Makanjuola and Makanjuola, 2018) [22]. A Mean concentration of 92.1±170 mg/kg concentration was reported by (Akporido and Ipeaiyeda, 2014) [3] from Benin River sediments in Nigeria. Zn values in this range observed in this study may not pose threat to organisms in sediment (Ebong and John, 2021) [10]. Chromium, (Cr) range of 0.01 – 0.22 mg/kg (wet season) and 0.002 – 0.04 mg/kg (dry season) in the study area is comparable to 0.09 – 0.11 and 0.003 – 0.01 recorded in the control area for wet and dry season, respectively. There was no statistical difference ($p > 0.05$) at 95% confidence interval for Crvalues between sampling points. The values observed in this study correspond to values reported by (Nsikak *et al.,* 2008) [26] from Iko river sediment. Lead, (Pb) range of 0 - 0.06 mg/kg (wet season) and 0.28 – 2.16 mg/kg (dry season) in the study area is comparable to 0.02 – 0.03 mg/kg (wet season) and0.325 – 0.67 mg/kg (dry season) obtained in the control points. The difference between Pb values between sampling stations was statistically insignificant ($p > 0.05$) at 95% confidence interval. Pb values in this study are in agreement with Pb values reported by Nsikak *et al.* (2008) [26] in a similar study conducted on sediments from Iko River, Nigeria; and Inengite *et al.* (2010) [19] from Kolo creek sediment in Niger Delta. Inengite *et al* (2010) [19] noted that values in this range may not be harmful to the environment.Copper, (Cu) range of 0 – 0.01 mg/kg (wet season) in the study area is consistent with values 0 – 0.01 mg/kg (wet season) observed in the control area. Copper was below the detection limit at < 0.003 during the dry season. Statistical difference ($p < 0.05$) at 95% confidence limit was observed for Cu values between sampling stations. The Cu values observed in this study are lower than values reported by (Kpee and Ekpete, 2014) [21] from Kalabari creek sediments in River state. Cu values are consistent with values reported by (Nsikak *et al,* 2008) [26]. Nickel (Ni) range of 0.25 – 7.57 mg/kg (wet season) and 0.073 – 1.33 mg/kg (dry season) in the study area is slightly higher than values 3.07 – 3.92 mg/kg (wet season) and 0.52 – 0.77mg/kg (dry season) recorded in the control area. There was no statistical difference at 95% ($p > 0.05$) confidence interval for Ni values between sampling stations. Ni values observed in this study are consistent with values reported by (Nsikak*et al,* 2008 [26]; Inengite *et al,* 2010) [19]. Ni values in this range may not be lethal to the environment (Inengite *et al,* 2010) [19].

Conclusion

The physicochemical parameters revealed low concentration of heavy metals except for iron which showed higher values during the wet season. The high concentration of Fe observed in this study may be due to the abundance of Iron in the soil and corrosion of abandoned vessels in the waterway. Elevated pH, Polycyclic aromatic hydrocarbon, total hydrocarbon content, chloride, and sodium observed during the dry season indicate

human influence, which includes illegal bunkering activities, influences from surrounding farmlands and leaks from boat tanks in the creek. Zinc, Iron, sulphate, and sodium in the study area, higher than values observed in the control points, is an indication of human influences that may be due to surface runoff from surrounding farmlands.
The low values of total organic carbon and heavy metals may be due to the high percentage of sand particles in the study area. The anthropogenic influence observed in this study is, therefore an indication that most of the heavy metals and organic compounds in the study area may be dissolved in the water column due to the particle size and low pH of the sediments. In view of the proximity of the sampling points to oil and gas industrial activities, it is recommended that periodic monitoring of sediment in Odeama creek be conducted to examine its physicochemical characteristics.

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