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CONCENTRATIONS AND ASSOCIATED RISK OF SELECTED ALIPHATIC HYDROCARBONS IN SEDIMENTS FROM RIVER ETHIOPE, SOUTHERN NIGERIA.

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ABSTRACT

The contamination of aquatic ecosystems by hydrocarbon compounds poses severe environmental and human health concerns. Hence this study aimed to investigate the concentrations and associated risk of selected aliphatic hydrocarbons in sediments from the River Ethiope, an important water resource in Nigeria. A comprehensive sampling was conducted, collecting sediment samples at various locations (Umuaja, Obinoba, Abraka, Eku, Okpara, Aghalokpe, and Sapele) along the river. The samples were analyzed using gas chromatography (GC) to quantify the concentrations of hydrocarbons, with a specific focus on aliphatic hydrocarbons. These compounds are known for their potential adverse effects on human health and the environment. From the results obtained in this study, the total concentrations of Aliphatic compounds at various site from sites ranged from 10897 - 316783 µg/kg in (C8-C39), with Okpara containing the highest concentration and Eku with the lowest concentration. Hydrocarbon C_{36} was not detected in Umuaja while hydrocarbon C_{37} was not discovered in Aghalokpe, Okpara-Waterside and Sapele. Also, hydrocarbon C_{10}, C_{11} and C_{12} was not detected in Okpara-Waterside and Sapele. There were significant differences ($p<0.05$) in all hydrocarbons detected among the different sampling locations except in hydrocarbon C_{34} which showed no significant different ($p>0.05$). The outcome of this study from carbon preference index (CPI) reveals that the major source of hydrocarbon contamination is associated with petroleum activities and have contributed valuable information for environmental monitoring programs, policymaking, and decision-making processes aimed at safeguarding water quality and mitigating the potential detrimental effects of hydrocarbon contamination in similar aquatic environments.

Keywords: Aliphatic hydrocarbons, PAHs, Sediments, contamination, River, Human risk

INTRODUCTION

Aliphatic hydrocarbons are widespread environmental contaminants which have been studied extensively due to their toxicity, mutagenicity and carcinogenicity (Wang *et al*., 2007). These compounds are mostly produced and released during five incomplete combustion processes of organic matter, which are frequently connected to biomass burning, combustion engines, and industrial operations (Wang *et al*., 2007; Emoyan *et al*., 2015).

Numerous studies have demonstrated that these hydrocarbons are known to find their way into aquatic habitats through the burning of fossil fuels, atmospheric sedimentation, urban and industrial discharges, and petroleum spills. Due to their low solubility and high lipophilicity, aliphatic hydrocarbon (AHCs) in water tend to accumulate in bottom sediments and bioaccumulate through the food chain leading to elevated levels of DNA mutation, reproductive defects, and increased risk of cancer and other adverse health effects upon exposure (Liu *et al*., 2012).

Rivers in Nigeria are usually waste (industrial or domestic waste) discharge site thereby introducing AHCs and other organic and inorganic contaminants into the river. Because of anthropogenic wastes dumped into water systems, sediments are parts of our environment that act as storage facilities for harmful chemical species. Sediments are recognized as reservoirs and carriers of hazardous chemical in aquatic system (Osakwe and Clarke, 2013). Due to insolubility of hydrocarbons in water, most of this organic contaminants such as AHCs, heavy metals, are deposited in the sediment of river bed.

Aliphatic hydrocarbons (AHCs), are compounds that consist mainly of hydrogen and

carbon atoms coupled together through single bond, double bond, triple bonds which can either be a straight chain or branched chain. AHCs are persistent organic environmental polutantants due to their lengthy decomposition time in the environment, and the components of AHCs ranged from gasoline to bitumen which is used as a source of energy in residential, industrial, commercial and transport operations. They are also used as monomers for the synthesis of various chemicals and products used in commercial, industrial and domestic applications (Iwegbue *et al*., 2016). Processes which includes burning of woods, gas flaring, petroleum spill, activities of crude oil bunker, direct discharge of industrial waste into river bodies as well as leakage of vessels and ships carrying petroleum or its product and hydrocarbon containing run-off, introduces AHCs into river bodies. The presence of AHCs in sediment poses a great threat to aquatic life, it can also lead to non-fertilization of eggs of aquatic organisms. AHCs causes irritation of the lungs thereby posing a threat to aquatic organisms which may alter the quality of oxygen in water bodies and due to their persistent, ubiquitous and bioaccumulation properties they are considered to be significant for human health and environmental concern (Emoyan *et al*., 2020b).

Several growing human communities, including Umutu, Obinomba, Abraka, Eku, Okpara-waterside, Aghalokpe, and Amukpe, are found along the course of the River Ethiope. These communities are well-known for a variety of commercial and industrial activities, such as the disposal of solid waste from consumer products and drainage into rivers. It is well recognised that the solid waste and effluents generated by these operations contain toxic chemicals like AHCs. Therefore, it is necessary to ascertain the level of AHCs in sediments from the River Ethiope in Delta State, Southern Nigeria, as well as their sources and related dangers.

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MATERIALS AND METHODS

Study Area

Delta State is located in the low-lying coastal area of Nigeria; rivers, creeks, streams, swamps and estuaries being dominant in this coastal landscape. Major rivers in Delta State are River Ethiope, Escravos River and the Warri River (Editors of Encyclopedia Britannica ,1998). The River Ethiope, which originates at the base of a massive silk cotton tree in Umuaja, Ukwuani Local Government Areas, Delta State, is thought to be the deepest inland waterway in Africa, spanning 176 kilometers. The River course stretches through various communities such as Obinomba, Abraka, Eku, Igun,. Okpara-waterside, Amukpe and Aghalokpe. It is located on the coast of West Africa in southern Nigeria, within the Niger Delta basin, and is bounded by the Atlantic Ocean (Adesalu and Nwankwo, 2005).

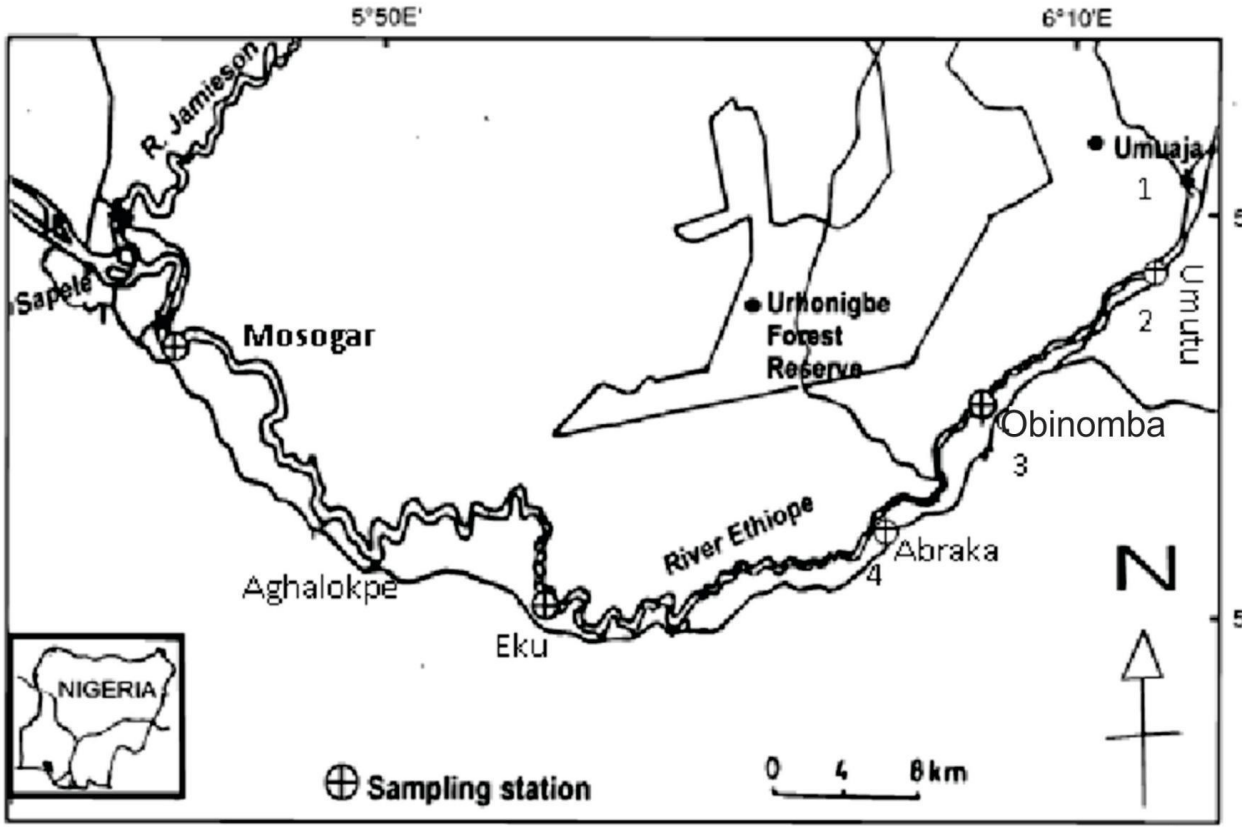

Figure 1: Map of Nigeria showing the study area and sample sites (Ikomi and Arimoro, 2014)

Sample Collection

A total of twenty four sediments samples were collected starting from the river source (Umuaja) and others at various points along the river route. The sampling points was geo-located with Global Positioning System (GPS) to ensure consistency. Sediment samples were collected with clean samplers from sediment of about 0-200 mm depth below the water body and wrapped with

aluminium foil to prevent contamination. The samples were kept in a room temperature and transported to the laboratory for chemical analysis.

Reagents

The chemicals and reagents employed in this investigation were of analytical grade. BDH (Poole, UK) provided the dichloromethane (LC grade) and alumina, while Aldrich (USA) provided the n-hexane.

Determination of Sediments Physicochemical Characteristics

pH

The pH was determined in sediment suspension (1:2 sediment to water ratio) using a glass electrode pH meter (Abollino *et al.*, 2002). 10 g of sediment was weighed into a beaker; after which 20-ml of deionized water was added. The mixture was stirred and allow to stand for 15 minutes. Then, pH meter sensor was placed into sample suspensions (sample needed at room temperature) and read directly off display.

Conductivity

Sediment samples of 5 g was weighed into a beaker, after which 10-ml of deionized water was added. The mixture was stirred and allow to stand for 15 minutes. Then, conductivity probe was placed into sample mixtures and read straight from the screen by making sure it's reading starts from zero.

Total Organic Carbon

The wet oxidation digestion method of Walkley and Black (1934) as described by Radojevic and Bashkin (1999) was used. This method involves the quantification of the amount of oxidizable carbon as determined by reaction with excess dichromate and sulphuric acid. The remaining unreacted dichromate was titrated with ferrous sulphate using 1, 10-phenanthroline as indicator.

Determination of ACHs

Extraction and Clean up of ACHs from Sample

About 10 g of sediment was weighed into a Teflon bottle of 250 ml. Sodium sulphate of about 1-3 spatula full was mixed with the samples in the Teflon bottles to ensure removal of any liquid that may be present. Extraction was done using 20 ml of hexane in the ratio 1:1 three times, totalling 60 ml of the extraction solvent. Teflon bottles that had been covered was vigorously shaken for 30 min at 70 °C in an ultrasonic sonicator bath. Sodium sulphate was used to dry the decanted organic layer (Bamidele *et al* ., 2020).

The EPA Method 3630C (Silica Gel Clean-up) was employed for the purification of samples column, 11g ± 0.01g of activated silica gel was weighed into a beaker, Hexane/Methylene chloride was then added to form a slurry that was poured into the chromatographic column with a based glass wool, rinsing all the silica gel into the column with the solvent used. 10 ml of hexane was used to condition the column, while 20 ml of methylene chloride was also used for elution at a rate of 1 drop/sec. The elution was stopped when the solvent reaches the top of the column after which the eluate will be concentrated to 2 ml using rotary evaporator, and about 1 g Sodium sulphate

was then added to remove any remaining water in the extract which was stored in a 2 ml GC vial below 4 °C prior to GC analysis (Bamidele *et al* ., 2020). The quantification of the ACHs in the extracts was carried out by using an Agilent 7890B gas chromatography (GC) coupled to flame ionization detector (FID).

RESULTS AND DISCUSSIONS

Table 1: Aliphatic profiles of hydrocarbons in the sediment of River Ethiope at different stations

	Umuaja	Obinomba	Abraka	Eku	Aghalokpe	Okpara-waterside	Sapele	p-value
C8	3013.33±2723.53	779.67±1068.79	156.78±102.68	548.67±553.29	285.00±80.61	244.50±190.21	253.60±54.09	0.02
C9	446.33±220.98	176.00±179.07	297.78±242.03	533.33±465.89	384.50±81.31	199.00±39.59	204.90±6.76	0.00
C10	103.33±61.25	341.00±419.89	183.67±78.86	232.33±109.92	247.00±181.01	0.00±0.00	0.00±0.00	0.00
C11	136.00±68.47	272.33±138.67	780.22±1576.08	718.33±1078.09	269.00±42.42	0.00±0.00	0.00±0.00	0.01
C12	428.67±265.45	298.00±210.81	220.67±193.29	107.67±93.46	163.50±30.40	0.00±0.00	0.00±0.00	0.02
C13	244.33±9.33	277.67±96.93	226.00±206.30	220.00±223.06	197.50±4.94	310.50±439.11	310.50±32.87	0.00
C14	240.33±26.18	173.67±0.57	302.67±206.66	161.67±140.65	181.50±4.94	649.00±917.82	649.35±23.98	0.00
C15	514.00±108.01	2409.33±3380.32	507.22±257.16	720.67±204.33	698.00±318.19	323.00±24.04	302.50±21.72	0.00
C16	476.33±20.41	490.33±48.99	435.33±188.20	1250.33±1367.28	441.50±6.36	934.50±654.07	988.50±361.65	0.00
C17	989.67±285.67	669.00±50.31	1016.33±1035.23	937.33±160.79	675.00±38.18	732.50±21.92	699.50±51.11	0.01
Pr	1171.67±452.32	612.00±96.01	606.33±145.54	916.67±673.87	650.00±243.24	508.00±19.79	523.34±258.78	0.00
C18	692.33±24.96	720.33±104.88	1404.22±2893.01	1368.67±1219.79	708.50±36.06	677.00±21.21	701.25±45.89	0.01

Ph	767.67±72.54	632.00±25.53	701.33±492.22	789.67±226.24	605.00±11.31	659.50±44.54	634.80±71.23	0.00
C11	1118.00±129.76	813.00±266.85	751.22±246.83	1668.33±1383.89	841.50±342.94	680.00±55.15	580.00±23.45	0.00
C20	719.00±60.96	668.33±46.05	1058.44±1041.30	1458.33±1007.07	571.50±4.94	651.00±74.95	887.32±68.36	0.00
C21	946.67±117.48	820.33±120.50	868.11±193.21	1421.00±879.59	887.50±236.88	859.50±68.58	812.50±56.41	0.00
C22	806.33±102.41	601.00±553.22	662.22±252.77	1161.33±820.01	7950.00±1.41	794.50±180.31	803.27±2210.63	0.00
C23	894.33±107.65	579.33±514.28	840.56±435.40	760.00±35.08	758.50±17.67	836.50±60.10	786±.54±74.33	0.02
C24	2085.00±40.85	858.67±749.05	1106.22±480.91	2090.33±747.17	1391.50±795.49	1094.50±283.54	1106.50±246.38	0.00
C25	782.67±7.96	510.67±442.32	798.78±347.35	781.33±15.53	801.00±38.18	806.50±68.58	806.50±39.99	0.04
C26	835.67±10.26	561.67±489.13	800.33±315.60	857.33±76.05	820.50±30.40	849.00±42.42	867.30±63.52	0.04
C27	958.33±15.59	639.33±553.71	882.33±342.93	1019.00±44.30	1057.00±87.68	933.00±15.55	896.90±22.93	0.00
C28	1009.00±55.36	647.00±561.37	914.33±359.67	932.00±15.58	930.00±18.38	981.50±44.54	906.89±1030.32	0.04
C29	1065.67±13.92	709.00±614.04	951.11±357.27	1192.33±257.79	1055.00±221.62	1060.50±24.74	1045.50±370.26	0.03
C30	1093.67±19.22	690.33±598.10	931.00±350.16	1033.33±13.05	1081.00±66.46	1065.50±6.36	996.50±67.94	0.03
C31	1034.33±5.17	1552.00±837.19	903.89±345.35	1027.00±6.92	1028.50±281.99	1121.00±134..35	1115.00±245.74	0.00
C32	863.67±2.02	961.67±88.63	793.33±299.51	905.67±60.96	974.00±117.37	941.50±119.50	941.50±84.56	0.03
C38	808.33±17.43	1906.33±1687.11	883.00±145.70	850.67±97.43	898.50±144.95	793.00±33.94	734.00±46.13	0.02
C37	777.33±52.66	814.67±70.55	736.11±170.	637.67±292.	735.00±79.	707.00±83.	729.00±64.	0.0

4	1	7	99	52	19	43	779	6
C35	368.00±28.04	439.33±35.83	395.89±59.00	225.67±201.36	371.00±111.72	312.50±33.23	294.50±27.31	0.04
C36	0.00±0.00	161.33±188.81	20.44±34.96	120.67±209.00	15.50±21.92	36.50±51.61	56.50±9.94	0.00
C37	12.00±12.00	92.33±29.26	52.89±83.86	158.33±133.78	0.00±0.00	0.00±0.00	0.00±0.00	0.00
C38	99.00±8.32	136.67±56.21	232.67±186.09	532.67±365.01	53.50±10.60	54.50±3.53	54.50±5.23	0.01
C39	692.67±19.09	806.67±66.33	710.33±139.60	549.33±488.06	646.50±27.57	707.00±50.91	707.00±69.52	0.02
C40	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	1.00

The mean concentrations of n-alkanes in the sediment of Ethiope River are as presented in Table 1. The numbers of hydrocarbons detected were: 35 in Umuaja and Aghalokpe respectively, 36 in Obinomba, Abraka and Eku respectively, while 32 were detected in Okpara-Waterside and Sapele. Hydrocarbon C_8 had the highest concentration of hydrocarbon in Umuaja with mean value of 3013.33 µg/kg. Hydrocarbon C_{15} had the highest concentration (2409.33 µg/kg) of all AHCs detected in Obinomba, while hydrocarbon C_{24} had the highest concentration of hydrocarbon in Abraka and Eku with mean value of 1106.22 µg/kg and 2090.33 µg/kg respectively and C_{22} had the highest concentration of hydrocarbon in Aghalokpe with the mean concentration value of 7950.00 µg/kg. However, hydrocarbon C_{31} had the highest concentration of hydrocarbon in Okpara-Waterside and Sapele with mean value of 1106.22 µg/kg and 2090.33 µg/kg respectively. Hydrocarbon C_{40} was not detected in any of the sampling points in Ethiope River. Hydrocarbon C_{36} was not detected in Umuaja while hydrocarbon C_{37} was not discovered in Aghalokpe, Okpara-Waterside and Sapele. Also, hydrocarbon C_{10}, C_{11} and C_{12} was not detected in Okpara-Waterside and Sapele. There were significant differences ($p<0.05$) in all hydrocarbons detected among the different sampling locations except in hydrocarbon C_{34} which showed no significant different ($p>0.05$).

According to Chokor (2021), Gasoline Range Organic (GRO) generally includes C_8– C_{10} hydrocarbon, while (DRO) Diesel Range Organic include hydrocarbon from C_{10}– C_{28}, the Oil Range Organic (ORO) range from C_{28}– C_{40}. It was observed that the sediment of Ethiope River was mostly contaminated with hydrocarbons whose range fell between the categories of DRO and ORO with the highest concentration of mean value 7950.00 µg/kg falling in the categories of DRO. All the stations understudied were found to be contaminated with categories of GRO, DRO and ORO. However, most of the

hydrocarbons in Ethiope River fell in DRO and ORO categories. This observation is an indication that the largely contaminated sediment of Ethiope River had mixed sources of contamination.

The total aliphatic hydrocarbon concentrations in the analysed sediment samples of this study were higher than the range of 16.2 – 603.3 µg/kg reported by Iwegbue *et al*., 2016 for sediments in Niger Delta (Forcados River) Nigeria is 0.95 – 2.87 µg/g and 0.22 – 1.49 µg/g reported by Lukas *et al*., 2019 for sediments from typical estuarine system; but were within the ranges of 2.94 – 114.7mg/kg reported by Amini *et al*., 2021 for urban runoff sediments from mega city of Tehran, Iran; 13.76 – 99.53 µg/g reported by Yuan *et al*., 2021 for sediments of the Laizhou Penisula, South China; and the range of 33.97 – 553.98 reported by Dalia *et al*., 2014 for sediments in Egypt from the Red Sea.

The total concentrations of aliphatic hydrocarbons recorded in the analysed sediment samples of this study were above the limit of 10000 µg/kg set by the United Nations Environmental Program (UNEP) for aliphatic hydrocarbons in sediments. This suggests health and ecological risk to humans and organisms arising from exposure to aliphatic hydrocarbons in sediments from River Ethiope.

Table 2: Calculated aliphatic hydrocarbon source diagnostic ratios in the sampled station

Diagnostics indices	**Umuaja**	**Obinomba**	**Abraka**	**Eku**	**Aghalokpe**	**Okpara-Waterside**	**Sapele**
∑LMW/∑HMW	1.54	1.00	1.49	1.95	2.1	1.27	1.27
E/O	1.26	0.70	0.92	1.05	1.57	1.03	1.00
LHC/SHC	1.45	0.95	1.26	1.42	0.93	1.10	1.28
nC31/nC19	0.93	1.91	1.20	0.62	1.16	1.65	1.65
CPI	1.65	2.53	1.72	1.74	1.72	1.63	1.45
Pr/Ph	1.53	0.97	0.87	1.16	1.07	1.09	0.77

*∑LMW/ ∑HMW: sum of low molecular weight hydrocarbon to sum of high molecular weight hydrocarbon, E/O: even to odd hydrocarbons ratio, LHC/SHC: long chain to short chain hydrocarbons, CPI: carbon preference index, Pr/Ph: pristane over phytane ratio.

Some sources diagnostic ratios of hydrocarbons for the sampled sites are presented in Table 2. In the sediment of Ethiope River across the sampled sites, the ratio of sum of low molecular weight hydrocarbons to the sum of high molecular weight hydrocarbon (∑LMW/ ∑HMW) was higher than 1 in all. This indicated large amount of low molecular weight hydrocarbon were present than are high molecular weight hydrocarbons which suggests petrogenic source of contamination of the sediment. The dominance of even to odd hydrocarbons in Umuaja, Eku and Aghalokpe suggests anthropogenic source of contamination (Chokor, 2021). However, the low ratio (less than 1) of even to odd in Obinomba

abd Abraka suggests biogenic source of contamination (Sakari *et al.,* 2012; Adeniji *et al.,* 2017). The sediment of River Ethiope therefore has its contamination origin from both anthropogenic and natural sources.

According to Fagbote and Olanipekun (2013) and Adeniji *et al.*(2017), the ratio of long chain hydrocarbons to short chain hydrocarbons (LHC/SHC) was evaluated to determine other possible sources of contamination. This ratio has been used to infer whether the hydrocarbons are from aquatic plants source or terrestrial vascular plants. High ratio greater than 4 indicated dominance of terrestrial plant waxes. Ratio less than 2.38 suggests aquatic plant sources while values between 2.38 – 4.33 implies mixture of both sources. All the ratios evaluated from all sampling sites were less than 2.0 suggesting aquatic plant as source of contamination.

The nC31/nC19 ratio which ranged between 0.62 to 1.91 for all stations infer the predominance of hydrocarbons from terrestrial origin. The C31/C19 ratio, has been used to index source of n-alkanes in water. The presence of nC31 suggests biogenic hydrocarbons found on Earth, while nC19 indicate aquatic biogenic inputs. Hence, it is used to indicate the dominance of either hydrocarbon sources. Ratio below 0.4 represent aquatic sources while values above 0.4 is an indication of terrestrial derived hydrocarbons (Yusoff *et al.,* 2012; Fagbote and Olanipekun, 2013; Edori and Edori, 2021).

The carbon preference index (CPI) is a used in the assessment of the predominance of natural hydrocarbons over anthropogenic ones (Omayma *et al.,* 2015; Abdallah *et al.,* 2015). Values higher than one indicate biogenic sources such as hydrocarbons from aquatic algae or terrestrial vascular plants. However, values of CPI less than one suggest hydrocarbons from petroleum inputs (Maioli *et al.,* 2011; Onyema *et al.,* 2013). This study reveals CPI range of 1.45 - 2.53; an indication that the hydrocarbons had contributory source of anthropogenic origin.

Pristane and phytane hydrocarbons are not basic components of several terrestrial biotas but are of organisms and petroleum produced from the diagenesis of phytol and other isoprenoidyl (Wang *et al.,* 2012). Some uncertainties that are associated with pristane/phytane ratio used as a signature of petroleum hydrocarbon sources are that pristane can be produced from zooplankton, marine animals, and pristane and phytane presence in crude oils may be natural hydrocarbons of post-depositional transformation involving oxidation reactions of the phytol side chain or catalytic hydrogenation of phytadiene (Emoyan *et al.,* 2020). The dominance of Pristane over Phytane is an indication of of biogenic source of contamination. However, when this ratio is not equal to one, it is an indication of petrogenic source (Kaur *et al.,* 2017; Orta-Martínez *et al.,* 2018; Schwarz *et al.,* 2019; Chokor *et al.,* 2021). All the values in all the stations were greater than one pointing biogenic as the source of hydrocarbon contamination of the Sediment of Ethiope River.

Table 3: Physicochemical parameters (Mean±SD) of different sampling sites in Ethiope River.

Umuaja	Abraka	Eku	Aghalokpe	Sapele	p-Obinomb	Okpara-

		a				Waterside		valu e
pH	6.19±0.59[a]	5.94±0.81[b]	6.12±0.81[a]	6.63±0.42[c]	5.75±0.50[b]	5.55±0.50[b]	6.70±0.14[c]	0.00
TOC(%)	0.09±0.03[a]	0.14±0.19[b]	0.39±0.12[c]	0.25±0.11[d]	0.69±0.40[d]	0.33±0.26[c]	0.08±0.04[a]	0.00
EC (µs cm^{-1})	78.97±22.62[a]	94.8±8.12[b]	93.19±50.39[b]	80.67±21.72[a]	120.50±47.37[c]	78.00±59.40[a]	110.00±121.62[b]	0.00

*Means with the same superscript along the row are not significantly different.

The mean pH in the sediment samples of Ethiope River ranged from 5.55 – 6.70 for all sampling sites. The lowest (5.55) and highest (6.70) pH values obtained were observed in Okpara-waterside and Sapele's sediment respectively. This is similar with the 5.61 to 6.81 range reported by Emoyan *et al.* (2020). The mean total organic carbon (TOC) in the sediment ranged from 0.08 – 0.69% with the lowest and highest TOC levels occurring in the sediment of Sapele and Aghalokpe respectively. The mean electrical conductivity ranged between 78.00 – 120.50 µs cm^{-1} in all sites. The lowest and highest electrical conductivity was observed in the sediment of Umuaja and Aghalokpe respectively. The EC content depicts the presence of a high loading of inorganic mineral content (Iwegbue *et al.,* 2017). The pH levels are slightly acidic and neutral; this is common to anaerobic soils of the Niger Delta (Tesi *et al.,* 2016; Emoyan *et al.,* 2020). The range of pH, EC, and TOC values in this study are favorable for the adsorption of HAHCs over LAHCs on active soil surfaces (Pawar *et al.,* 2010; Okere and Semple, 2012). There was significant difference ($p<0.05$) in the physic-chemical parameters among the different sampling locations in River Ethiope.

Conclusion

The results obtained from this study reveals that the sediments from River Ethiope are contaminated with AHCs. The total concentrations of Aliphatic compounds at various site from sites ranged from 10897-316783 µg/kg in (C1-C39), with Okpara-waterside containing the highest concentration and Eku with the lowest concentration. The carbon preference index (CPI) reveals that the major source of hydrocarbon contamination is associated with petroleum activities.

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