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Geochemical Assessment of Bottom Sediments of Water Bodies at Crude Oil Exploration Station in Delta State, Nigeria

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ABSTRACT

Understanding the occurrence, composition, and distribution patterns of aliphatic hydrocarbons (AHCs) are crucial signals for identifying the anthropogenic contributions and sources of AHCs present in the environment. Therefore, this study focused on analyzing the concentrations, distribution pattern, compositional patterns, and sources of AHCs found in crude oil and sediments collected from the Udu, Ethiope East, and Ughelli North Local Government Areas. A total of nine (09) crude oil samples and ten (10) sediment samples were obtained from the designated study area. The analysis of AHC concentrations in these identification was performed by gas chromatography with Flame Ionization Detector (GC-FID) using hexane/dichloromethane mixture and further purification in a column filled with silica gel and alumina. The AHC in the crude oil samples were observed to be between 450 and 43657 mg/kg, with an average of 12859.11+7884.68mg/kg. The sediment samples on the other hand contained concentrations of AHC that varied between 10.8 and 470mg/kg with a mean concentration of 102.74 +2.85 mg/kg. The UNEP guideline limit of AHCs in sediments is 10 mg/kg, yet they were greater than those. The AHCs of the crude in the Ethiope East Local Government Area were detected to be 3071 +53.3mg/kg. Udu Local Government Area on the other hand reported concentrations of 14999 +/-314.3 and 155027 +/-291.7mg/kg. AHCs of the Ughelli North Local Government Area were 1149±69.7, 21686±3352.8, 14099±147.7, 450±17.3, 1114±19.6, and 43657±2185.3 mg/kg. Regarding sediment, the AHCs recorded were 12.7±0.3 and 18.8±0.6 mg/kg for Ethiope East Local Government Area, while Udu Local Government Area presents recorded values of 17. The results of the ANOVA reveal a significant difference ($p<0.05$) in the levels of AHCs found in both crude oil and sediment samples. Furthermore, the regression analysis indicates a minimal or nonexistent correlation between AHC concentrations in crude oil and those in sediment. Notably, the predominant hydrocarbons (MH) identified in the samples of crude oil and sediment were characterized by even carbon numbers, including C8, C16, C18, C32, C34, C36, and C38.

Keywords: Aliphatic Hydrocarbons, Sediment, Crude, Oil, Nigeria

1. INTRODUCTION

Nigerian Bitumen Corporation is a German based firm that started the production of crude oil in Nigeria in 1908 through drilling of fourteen wells that are presently referred to as Lagos State. The company was brought to a halt by the First World War that saw Germany (the home country of the company) and Britain (the colonial power that ruled Nigeria) being so involved in it. The company returned to the search of crude oil after the war was over, however (Akinshola, 2006). Presently, numerous onshore and offshore wells are actively involved in the extraction of crude oil throughout the country. This has happened mainly because of the critical significance of petroleum as a significant energy source and as a transport fuel, and as a first or raw material in numerous products, such as plastics, paints, fertilizers, insecticides, and pharmaceuticals. In turn, petroleum is regarded as the most crucial resource, which is used in the modern society. The ancient of the petroleum dates back to the depths of earth where the remains of some of the ancient plants and animals have undergone combustion and intense pressure of millions of years. Moreover, petroleum has been identified in each of the three forms of matter. It exists in its liquid, solid, and gaseous states, respectively, as crude oil (Eyankware et al., 2016; Ancheyta, 2011). Crude oils are composed of a blend of various organic elements, which differ in appearance and composition from one oilfield to another. Worldwide, there are many sites involved in the extraction of crude oil. This substance is generally perceived as having a low market value at the time of extraction, as it is rarely in a form that can be immediately utilized. The crude oil, based on its source, can have a significant difference in terms of its physical properties and chemical composition (Ancheyta, 2011). The molecular properties of crude oil differ based on its type. In a computational approach for analyzing crude oil and its blends, the physical and chemical attributes of particular classes of hydrocarbon molecules are utilized to ascertain the segment type and the range of segment numbers for those molecules. As noted by Ghulam et al. (2013), a crude assay is an aggregation of laboratory data (both physical and chemical) that defines a particular crude oil. The main constituents of the main energy sources like crude oil, natural gas, and coal are hydrocarbons which are naturally occurring compounds. They are highly flammable and thus combustible to produce carbon dioxide, water, and heat (Eyankware et al., 2020; Carey, 2021). Hydrocarbons play the most critical role of providing energy to human beings and other forms of life (Ivwurie, 2004).

The term "hydrocarbon" refers to a mixture of rich fluids that are produced from kerogen through catagenesis, and metagenesis processes. The specific chemical compounds present in the kerogen structure affect both the amount and the composition of the hydrocarbons produced (Osisanya, et al., 2023; Wang et al., 2006). Nigeria is not a newcomer in the exploration and exploitation of crude oil, which has over the years had notable challenges in onshore and offshore oil producing and processing regions (Atunbi, 2011; Odesa et al., 2024). At the moment, the production of crude oil is being done in Ughelli North, Ughelli South, and Udu LGA, with flow stations and wellheads under exploratory activities. In the case of a spill, the primary recipients of crude oil pollutants are usually the soils and water bodies (Ozobeme et al., 2025). Petroleum hydrocarbons, which are organic pollutants, include both aliphatic hydrocarbons (both saturated and unsaturated) and cyclic hydrocarbons (comprising aromatic and alicyclic types). The growing presence of these substances in environmental settings can be linked to various human activities (Eyankware, et al., 2025; Eyankware, et al., 2018). Therefore, the environmental pollution caused by industrial and domestic activities can have a far-reaching implication on the agricultural productivity of the region with a multiplier on the socio-economic wellbeing of the population (Nwadinigwe et al., 2014a, Eyankware, et al., 2021; Odesa, et al., 2023; Blessing, et al., 2024; Nwadinigwe et al., 2014b). High levels of petroleum hydrocarbons in the environmental matrices are serious threats to the human body and aquatic life. As cited by Eyankware, et al., (2024), these pollutants may enter the body of a human being in various ways such as inhalation, ingestion, or dermal assimilation. This study will use geochemical proxies in evaluating the degree of crude oil contamination in the sediments of the water bodies within the areas of the territories of Udu, Ughelli North and Ethiope East Local Government Areas. The following are the objectives that will be used to achieve the objectives of this study.:i. Assess the levels of aliphatic hydrocarbons (AHCs) in crude oil and bottom water sediments from Udu, Ughelli North, and Ethiope East Local Government Areas. ii. Analyze the compositional and distributional patterns of aliphatic hydrocarbons (AHCs) in crude oil and bottom water sediments from Udu, Ughelli North, and Ethiope East.

Study Area

The study area host specific oil wells and flow stations and nine flow stations, which consist of Eriemu, Evwreni, Oweh, Oroni, Osioka, Kokori, Afiesere, Uzere, and Olomoro-Oleh. Furthermore, the Utorogu field is located roughly 42 kilometers southeast of Warri, currently producing about 10 Mbpd of oil and condensate, in addition to 300 MMscf/d of gas. The Utorogu Flow Station began its operations in 1968, with a processing capacity of 30 Mbpd. At present, it also includes a Field Logistics Base and a Non-Associated Gas (NAG) plant that has a capacity of 360 MMscf/d. The Delta Central Senatorial districts in Delta State comprise eight Local Government

Areas, which are Sapele, Okpe, Ughelli North, Ughelli South, Udu, and Uvwie. Importantly, Ethiope East, Udu, and Ughelli North are the primary Local Government Areas of significance in this context. An assessment was conducted on selected flow stations and oil wells in OML 30 and 34. OML 30 comprises nine flow stations, which are Eriemu, Evwreni, Oweh, Oroni, Osioka, Kokori, Afiesere, Uzere, and Olomoro-Oleh. The village of Afiesere is located at a distance of 90.65 kilometers of Warri North at Kokori, the village is located in the Ethiope East locality in Ughelli North Local Government Area. Likewise, the Ughelli North Local Government Area also has Eruemukowharien that stands at 68.26 kilometers of Warri North. Evwreni on the other hand lies 119 km in the same reference point.

Geology of the Study Area

The geology of the study area falls under the sedimentary zone of the Niger-Delta Basin. Niger-Delta geology includes three different lithostratinomies, Benin, Agbada and Akata formations that are covered with Quaternary deposits (Short and Stauble, 1967). It is characterized by the typical sedimentary sequence of the Niger Delta Basin. At its center is the Agbada Formation, famous for its sandstone composition and remarkable hydrocarbon reservoir potential, which is positioned above the marine shales of the Akata Formation. Furthermore, the region is distinguished by the continental deposits of the Benin Formation, which comprises sands and clayey sands, as illustrated in Fig. 1.

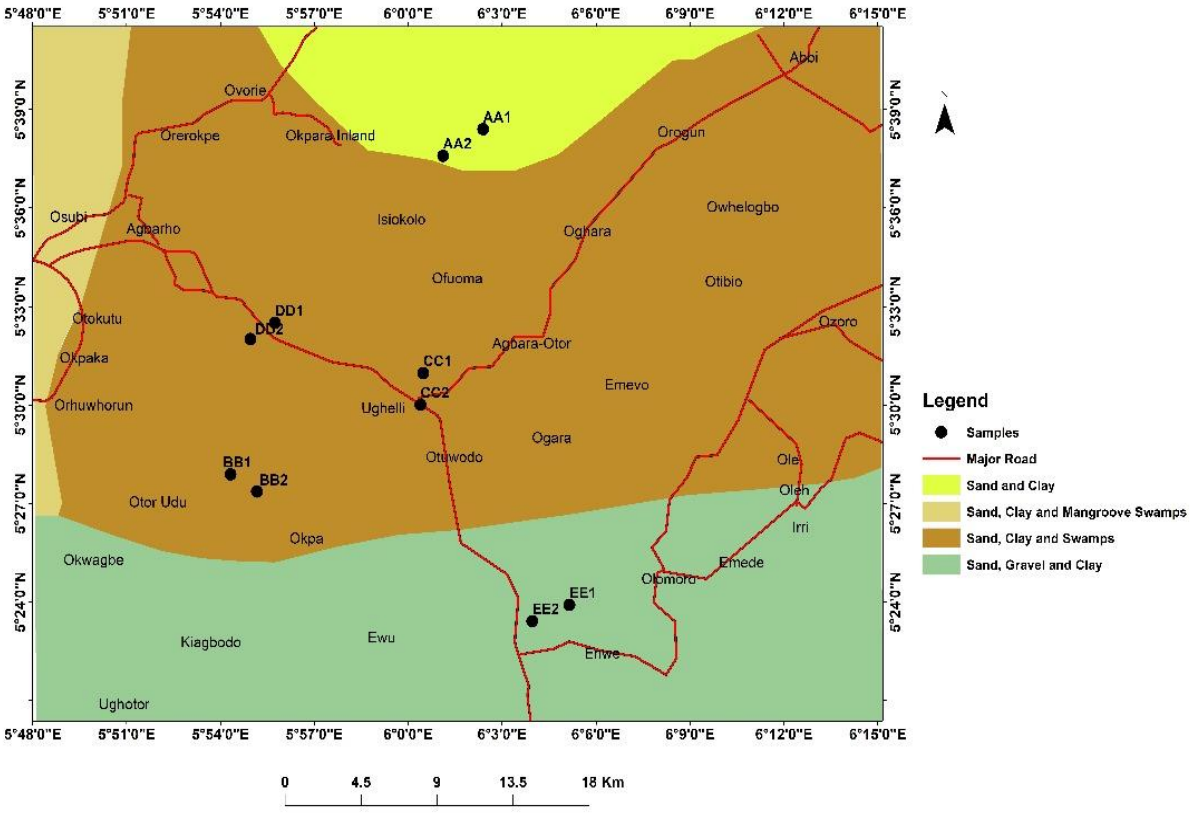

Fig. 1: Geologic Map of sample site location showing the sampling points.

2. MATERIALS AND METHODS

The materials that were used in this study include: The Agilent 6890 Gas Chromatophot, equipped with Flame Ionization Detector (GC-FID) is the equipment used, an S-Mettler FA210A model weighing balance (USA), a rotary evaporator (Search Tech Instrument RE52-2 model, USA), Teflon screw-cap vials, glass wool, a glass fractionating column, a 2 mL glass pipette., a 100 mL conical flask, a 100 mL beaker, a 100 mL measuring cylinder, and a Soxhlet extractor.

Sample Collection

Crude Oil Sample Collection

Two samples of crude oil were gathered from Utorogu, located in the southeast of Warri, along with an additional two samples from Afisere and Evwreni Eruemukowharien, both found in the Ughelli South Local Government Area of Delta State, as illustrated in Fig. 1. In a town situated 42 kilometers southeast of Warri within the Udu Local Government Area, two crude oil samples were also collected. Furthermore, two samples were acquired from each of the fields, namely Afisere and Evwreni Eruemukowharien, both located in the Ughelli South Local Government Area of Delta State, as depicted in Fig. 1. Additionally, one crude oil sample was taken from Kokori in the Ethiope East Local Government Area, which is in the southwestern region of the Niger Delta. These locations represent only a fraction of the numerous onshore oil field stations operated by the Nigerian Petroleum Development Company (NPDC) which is a subsidiary of the Nigerian National Petroleum Corporation (NNPCL td). In total, five unique oil fields and nine distinct oil wells were employed to obtain the crude oil samples. Prior to analysis, the samples were labelled with identifiers A, B1, B2, C1, C2, D1, D2, as well as E1 and E2 (refer to Table 1 and Fig. 1).

Collection of Bottom Sediments

Bottom sediment samples from the river were gathered utilizing a Van Veen grab, subsequently encased in aluminium foil, and conveyed to the laboratory for additional analysis. The samples were maintained at a cool and dry environment. A total of ten (10) bottom sediment samples were collected from the locations of Kokori, Utorogu, Afiesere, Eruemukowharien, and Evwreni (refer to Fig. 1). Before analysis, these sediments were designated with the following labels: AA1, AA2, BB1, BB2, CC1, CC2, DD1, DD2, EE1, and EE2, as illustrated in Table 1.

Table 1: Sample location for Bottom water Sediments

S/N	Sample code	Name of site	Latitude	Longitude
1	AA1	Kokori 1	$5^{0}38^{I}10.04712^{II}$	$6^{0}2^{I}3.61752^{II}$
2	AA2	Kokori 2	$5^{0}38^{I}10.04712^{II}$	$6^{0}2^{I}3.61752^{II}$
3	BB1	Utorogu 1	$5^{0}27^{I}41.47^{II}$	$5^{0}53^{I}49.31^{II}$
4	BB2	Utorogu 2	$5^{0}27^{I}41.47^{II}$	$5^{0}53^{I}49.31^{II}$
5	CC1	Afiesere 1	$5^{0}30^{I}34.18992^{II}$	$6^{0}0^{I}32.36544^{II}$
6	CC2	Afiesere 2	$5^{0}30^{I}34.18992^{II}$	$6^{0}0^{I}32.36544^{II}$
7	DD1	Eruemukowharien1	$5^{0}32^{I}19.99032^{II}$	$5^{0}55^{I}18.46344^{II}$
8	DD2	Eruemukowharien2	$5^{0}32^{I}19.99032^{II}$	$5^{0}55^{I}18.46344^{II}$
9	EE1	Evwreni 1	$5^{0}23^{I}34.044^{II}$	$6^{0}4^{I}34.482^{II}$
10	EE2	Evwreni 2	$5^{0}23^{I}34.044^{II}$	$6^{0}4^{I}34.482^{II}$

Methods

Sample Extraction

The Soxhlet extractor was used in extracting the n-alkanes in the sediment. The mixture of solvents was prepared in the form of hexane and dichloromethane 1:1. Sediment samples of 10 g were grounded and filtered using a syrupy sieve with a diameter size of 0.4 μm before the samples were placed in extractable thimbles. A 5 g of anhydrous sodium sulfate was added to each sample in order to remove all moisture. After this, 200 mL of the hexane-dichloromethane mixture was moved to the round-bottom flask connected to the Soxhlet extractor where it was left to reflux sufficiently to achieve quantitative extraction. Finally, the extract was condensed to 3 mL by using a rotary evaporator and a Teflon screw-cap vial, clearly labelled, was used to transfer it.

Preparation of Packed Fractionating Column

Glass wool was used to fill the column of the glass, and the silica gel Shaw (60-120 mesh grams) was weighed to 10 grams to prepare the column was activated overnight at 105ºC. This activated silica gel was then dissolved in dichloromethane (DCM) to form a slurry, which was subsequently packed into the column. Before the extraction process, 10 mL of DCM was utilized to condition the fractionating glass column, following the addition of 5 grams of anhydrous sodium sulfate for moisture absorption (US EPA, 1996). The extracts underwent a de-asphalting procedure by being precipitated in a dichloromethane-petroleum ether mixture (boiling point 40-60ºC) at a ratio of 1:30 for 20 minutes at 3000 rpm, in accordance with the methodologies provided by Teschner, (1981), Wehner and Teschner (1981) and Ekpo et al. (2012). The deasphalted extracts were separated into saturated compounds, aromatic compounds, and heterocompounds (resins or NSO) using liquid chromatography with silica gel (70/230 mesh, activated for 6 hours at 400°C) and alumina (neutral, activated for 2 hours at 700°C). The saturated fraction consists of aliphatic hydrocarbons, was eluted with 50 mL of n-hexane, while the monoaromatic and polycyclic aromatic hydrocarbon fractions were separated using 50 mL of dichloromethane. Subsequently, the heterocyclic fractions (resin or NSO) were extracted using a 50 mL mixture of methanol and dichloromethane in 1:2 proportion. Lastly, the evaporation of the solvents was done in a stream of nitrogen.

Sample Analysis Using Gas Chromatography (GC)

The total analysis of the oil samples took place with the help of Agilent 6890 chromatograph that had a 30 m x 0.25 mm x 0.25 m film thickness DB-5MS capillary column along with a flame ionization detector (FID). The oven's operational temperature was set to increase from 60ºC to 295ºC at a rate of 3ºC/min, with helium acting as the carrier gas at a flow rate of 300 mL/s.. This temperature profile included a five-minute hold at the initial temperature and a twenty-minute hold at the final temperature. Peak identification was achieved through electronic integration, retention time analysis, and comparison with standards maintained at 300ºC. The identification of specific compounds was facilitated by contrasting the obtained mass spectra with those of authentic standards and by examining the GC retention times (Ekpo et al., 2012).

3. RESULTS AND DISCUSSION

Analysis of the Distribution of Aliphatic Hydrocarbons (n-Alkanes) in Samples of Crude Oil is presented in Table 2.

Table 2: AHCs concentrations (mg/Kg) in the crude oil samples

	A	B1	B2	C1	C2	D1	D2	E1	E2
C8	39.1	256	338	<0.001	18757	238	2.54	12.2	517
C9	32.5	479	188	<0.001	<0.001	232	<0.001	<0.001	60.5
C10	32.4	48.0	219	<0.001	<0.001	237	<0.001	32.0	<0.001
C11	47.3	712	270	<0.001	10.1	312	<0.001	21.5	<0.001
C12	58.3	108	265	<0.001	5.81	260	<0.001	50.7	<0.001
C13	75.4	808	463	<0.001	182	458	<0.001	34.2	71.2
C14	84.7	620	475	13.8	189	404	25.0	45.3	133
C15	123	1053	810	34.1	137	534	27.0	55.5	1136
C16	200	1130	844	13.3	46.6	522	11.2	45.0	1234
C17	142	835	858	18.3	50.3	528	4.38	49.8	1140
Pr	127	885	719	102	159	481	4.62	85.1	897
C18	154	831	979	38.3	58.4	678	8.61	47.0	1799
Ph	83.0	523	481	55.9	101	290	5.61	26.7	657
C19	144	766	861	76.2	129	637	5.11	51.5	2947
C20	134	602	664	30.1	103	561	7.00	43.8	3174
C21	143	571	615	6.51	144	581	6.11	37.5	2695
C22	140	461	531	4.64	42.6	508	5.19	28.8	1613
C23	138	412	503	2.54	76.7	409	5.47	27.2	782
C24	121	494	521	4.53	25.6	575	6.35	30.1	1657
C25	145	427	546	1.70	133	489	5.45	31.6	2006

C26	135	352	382	2.46	37.9	425	14.3	25.4	846
C27	122	452	470	14.2	36.1	555	7.21	32.9	1379
C28	126	100	409	16.8	96.9	439	10.0	36.4	853
C29	106	403	699	147	200	628	12.5	57.5	1011
C30	94.4	525	802	248	397	1015	29.6	72.6	2708
C31	98.0	222	894	258	396	1086	65.2	27.9	2009
C32	66.7	312	321	4.81	77.6	474	77.9	28.9	12123
C33	50.1	238	208	22.4	54.5	271	23.7	23.5	65.1
C34	28.3	170	105	20.4	19.7	181	22.8	21.7	74.1
C35	38.6	33.6	30.3	0.25	3.92	25.9	19.0	4.17	14.2
C36	15.3	79.3	28.6	7.07	9.75	61.7	18.3	12.6	43.8
C37	13.6	53.9	<0.001	<0.001	<0.001	<0.001	2.58	2.82	2.82
C38	0.95	9.7	1.04	<0.001	<0.001	<0.001	5.19	3.60	2.15
C39	5.01	22.9	3.88	1.30	2.95	2.77	5.08	4.76	2.19
C40	6.68	5.47	3.74	5.00	3.73	3.79	6.66	3.45	3.48
TOTAL	**3071**	**14999**	**15507**	**1149**	**21686**	**14099**	**450**	**1114**	**43657**

As shown in Table 2, the samples of crude oil under consideration contained aliphatic hydrocarbons (AHCs) in the most diverse amounts, between 450 and 43657 mg/kg. Plotting of the concentrations of the n-alkanes was found to be lowest in D2 and highest in E2. The AHC level is recorded in the Ethiope East Local Government Area as 3071.0±53.3 mg/kg, whereas in the Udu Local Government Area, the recorded values are 14999.0±314.3 and 15507±291.7 mg/kg. Conversely, the Ughelli North Local Government Area displayed AHC concentrations of 1149±69.7, 21686±3352.8, 14099±147.7, 450±17.3, 1114±19.6, and 43657±2185.3 mg/kg. Table 3 and Fig. 2.1 depict significant variations in the amounts and composition of AHCs present in crude oil from different sampling locations ($p < 0.05$). Frena et al. (2017) and Iwegbu et al. 2(2021) propose that the marked differences in crude oil concentrations at these sites may be due to variations in source input, degradation, and sedimentation processes.

Table 3: Overview of ANOVA findings regarding aliphatic hydrocarbons present in crude oils.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	44696021	8	5587003	3.412071	0.000897	1.968713
Within Groups	5.01E+08	306	1637423			
Total	5.46E+08	314				

In samples A and B1, n-C16 was identified as the most abundant n-alkane, while n-C38 and n-C40 displayed the lowest concentration levels, as illustrated in Fig. 2.1 to 2.3 respectively. In sample B2, n-C18 exhibited the highest concentration, whereas n-C37 was not present. For sample C1, n-C8 through n-C13, along with n-C37 and n-C38, were not detected, with n-C31 showing the highest concentrations, as depicted in Fig. 2.4 to 2.5 respectively. In sample C2, n-C9, n-C10, n-C37, and n-C38 were absent, while n-C8 recorded the highest concentrations. Lastly, in sample D1, n-C31 presented the highest concentrations, and n-C37 and n-C38 were undetected as illustrated in Fig. 2.4 to 2.5. In sample D2, the n-C32 compound was found to have the highest concentration see Fig. 2.6 to Fig. 2.7, whereas n-C9 through n-C13 were not detected at all. In the cases of samples E1 and E2, Pr and n-C32 displayed the highest concentrations respectively; however, n-C9 was not present in E1, and n-C10 to n-C12 were missing in E2 as shown in Fig. 2.8 to 2.9 respectively. Among the analyzed crude oil samples, the even carbon n-alkanes were identified as the most significant AHCs, with average concentrations of 450 mg/Kg, in comparison to the odd carbon n-alkanes, which showed an average concentration of 286 mg/Kg, as outlined in Table 3 and 4. Aside from samples C1, D1, and E1, the major AHCs discovered in the crude oil samples of this study were those characterized by even carbon numbers see Fig. 2.4 to 2.9 respectively.

Table 4: Results of the T-test conducted to compare even n-alkanes against odd n-alkanes present in crude oil.

	Even	*Odd*
Mean	450.0764	286.0415
Variance	345181	41709.33
Observations	17	16
Pooled Variance	198339.9	
Hypothesized Mean Difference	0	
D	31	
t Stat	1.057447	
P(T<=t) one-tail	0.149239	
t Critical one-tail	1.695519	
P(T<=t) two-tail	0.298479	
t Critical two-tail	2.039513	

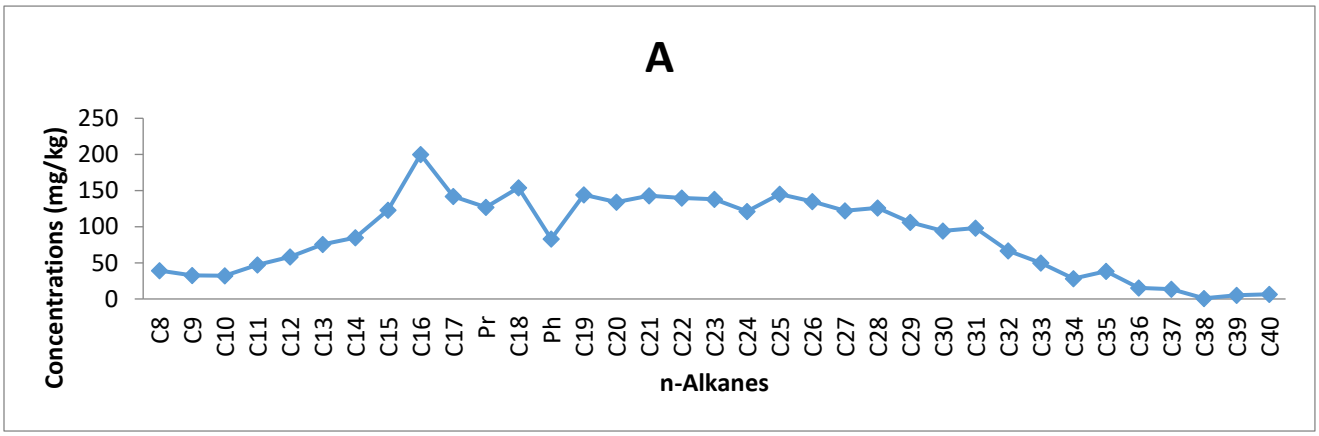

Fig. 2.1: Plot of concentration mg/kg against n-Alkanes at A

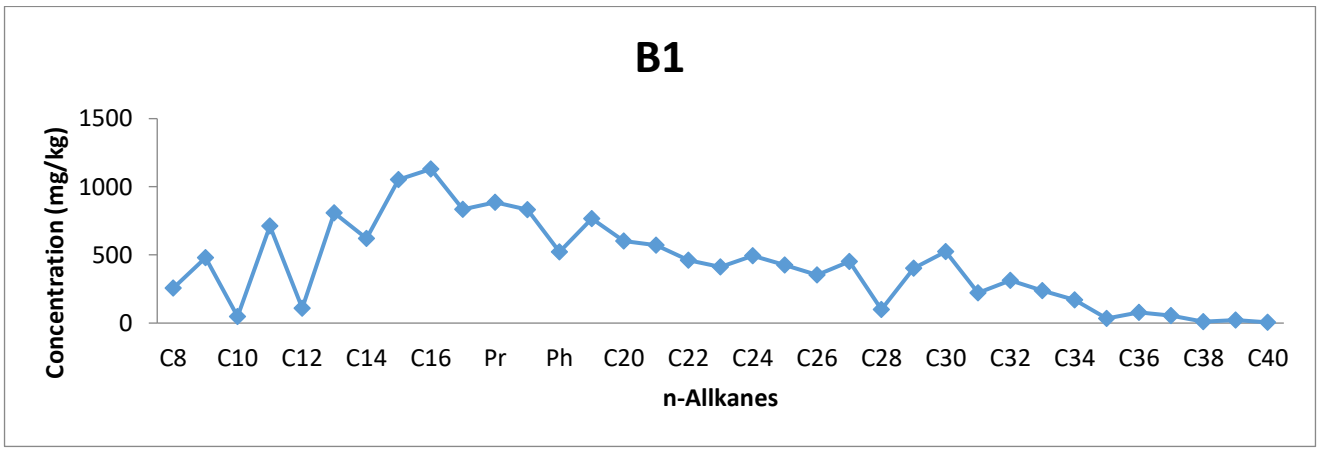

Fig. 2.2: Plot of concentration mg/kg against n-Alkanes at B1

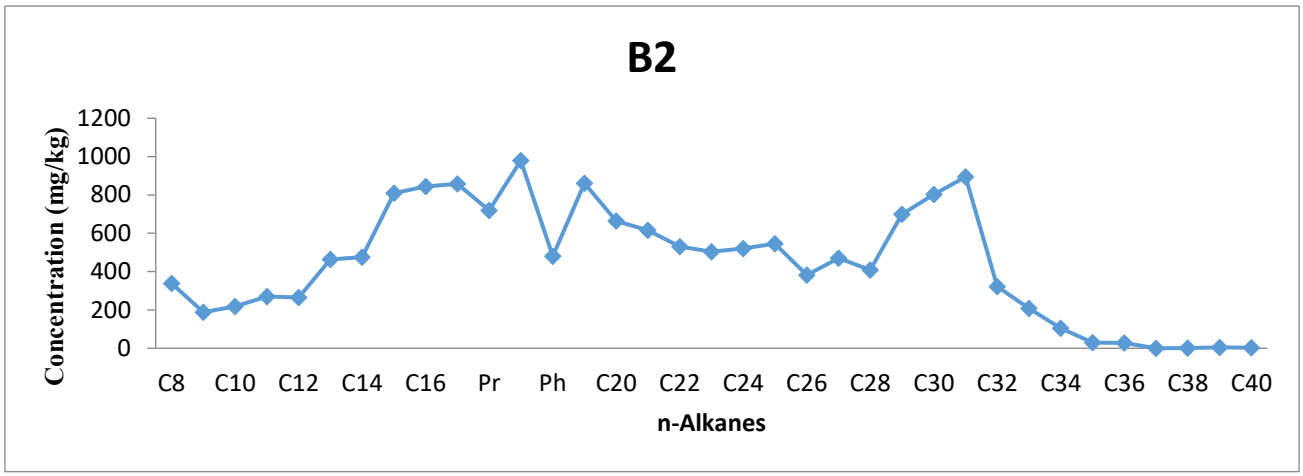

Fig. 2.3: Plot of concentration mg/kg against n-Alkanes at B2

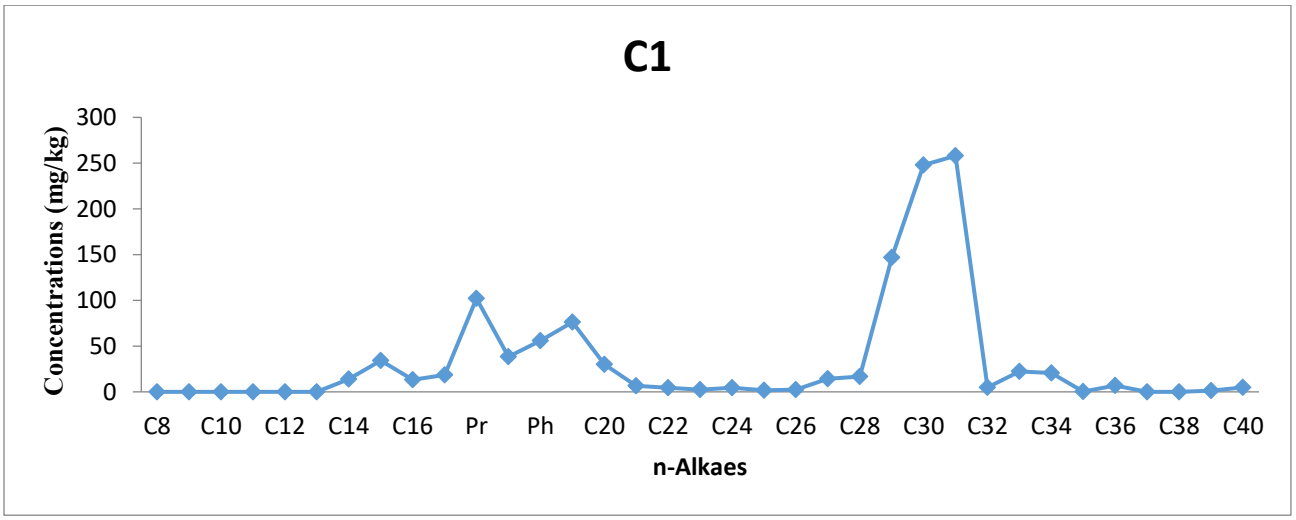

Fig. 2.4: Plot of concentration mg/kg against n-Alkanes at C1

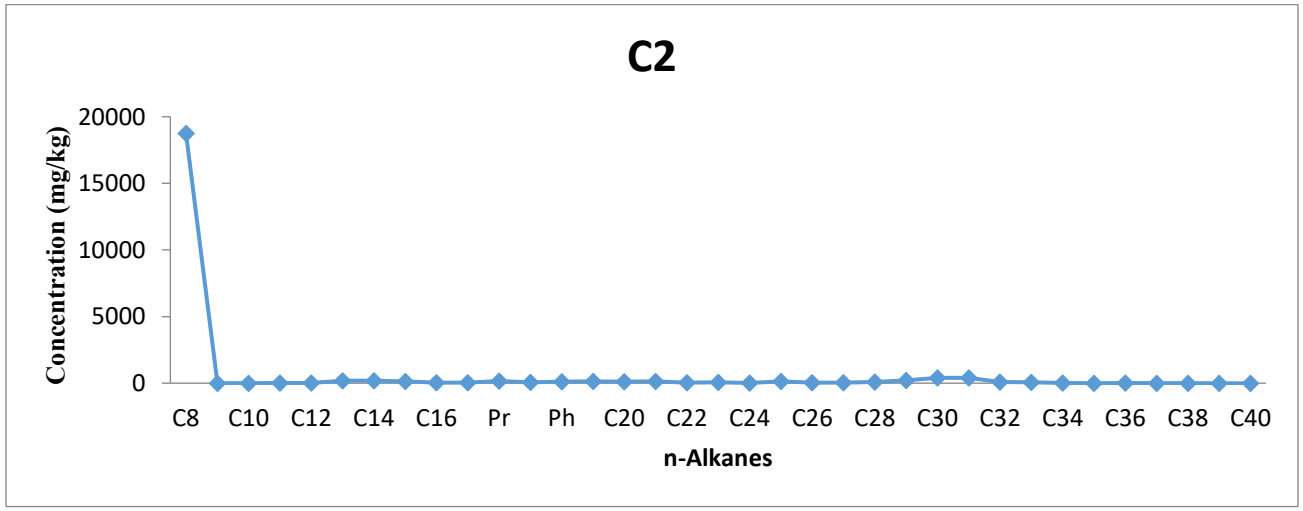

Fig. 2.5: Plot of concentration mg/kg against n-Alkanes at C2

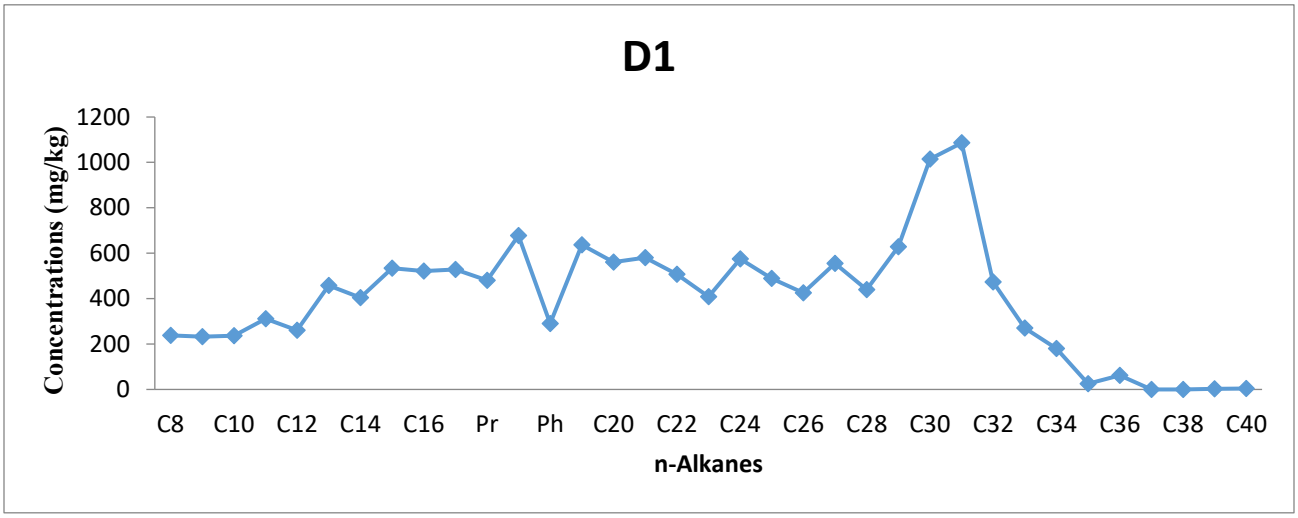

Fig. 2.6: Plot of concentration mg/kg against n-Alkanes at D1

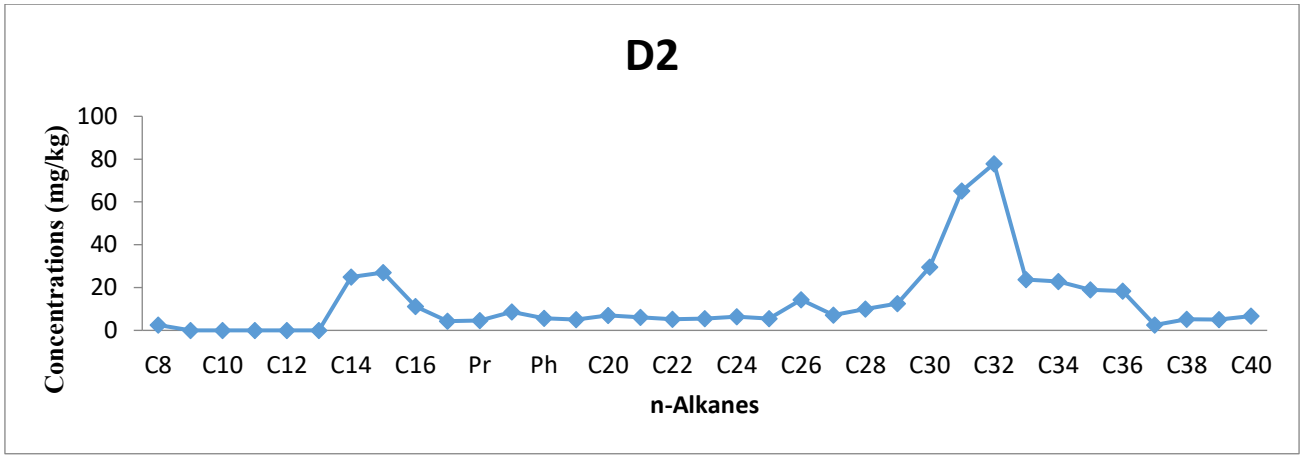

Fig. 2.7: Plot of concentration mg/kg against n-Alkanes at D2

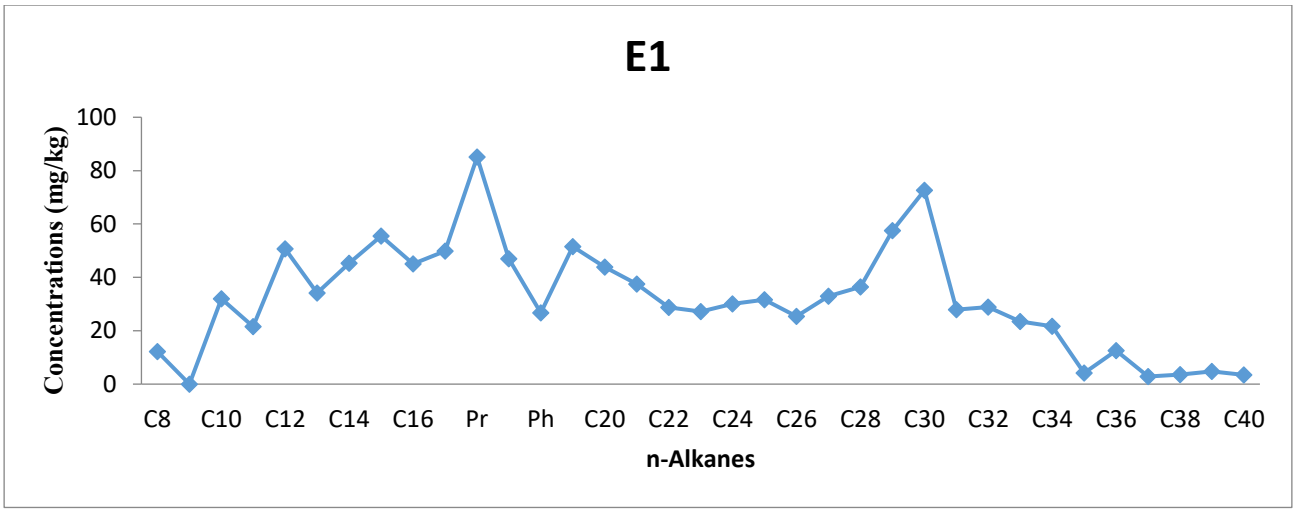

Fig. 2.8: Plot of concentration mg/kg against n-Alkanes at E1

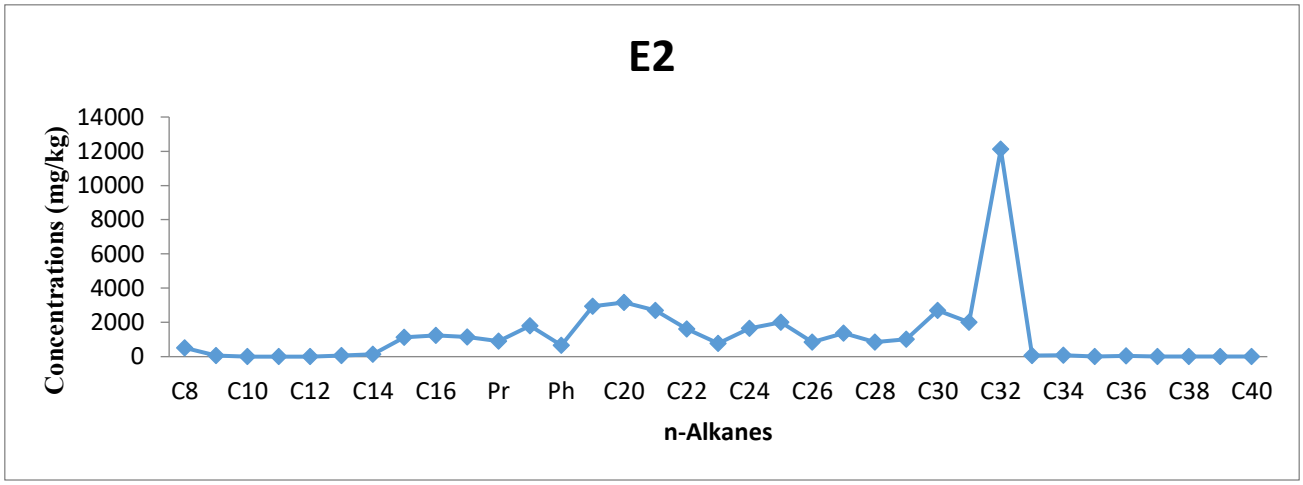

Fig. 2.9: Plot of concentration mg/kg against n-Alkanes at E2

Distribution of Aliphatic Hydrocarbons (N-Alkanes) in Sediment Samples

Table 5: presents the concentrations of aliphatic hydrocarbons (AHCs) found in sediment samples collected from the study areas.

Table 5*:* AHCs concentrations (mg/Kg) in the sediment samples

	AA1	AA2	BB1	BB2	CC1	CC2	DD1	DD2	EE1	EE2
C8	0.26	0.52	<0.001	<0.001	0.45	<0.001	0.97	1.00	8.09	37.8
C9	0.52	0.16	<0.001	0.52	0.15	0.48	0.18	0.20	1.49	4.45
C10	0.15	<0.001	<0.001	0.16	<0.001	0.17	0.07	<0.001	3.79	7.74
C11	0.11	0.27	<0.001	<0.001	0.24	<0.001	<0.001	<0.001	<0.001	24.4
C12	0.27	0.13	0.14	0.26	<0.001	0.21	0.14	0.18	0.11	1.42
C13	<0.001	0.15	<0.001	<0.001	0.30	<0.001	0.13	0.14	<0.001	<0.001
C14	0.28	0.21	0.25	0.25	0.21	0.30	0.26	0.36	1.19	<0.001
C15	0.21	0.42	0.22	0.21	0.66	0.21	0.23	0.22	8.43	<0.001
C16	0.40	0.42	0.60	0.69	0.42	0.66	0.50	0.55	15.4	2.33
C17	0.42	0.36	0.32	0.43	0.36	0.33	0.44	0.44	6.02	1.57
Pr	0.33	0.79	0.44	0.33	0.74	0.44	0.34	0.35	12.9	3.53
C18	0.70	0.40	0.72	0.77	0.40	0.76	0.90	1.00	5.85	3.48
Ph	0.42	0.41	0.42	0.41	0.41	0.41	0.40	0.44	10.1	1.40
C19	0.42	0.43	0.41	0.40	0.58	0.41	0.40	0.42	0.72	1.61
C20	0.42	0.51	0.41	0.66	0.47	0.71	0.41	0.47	5.62	3.73
C21	0.51	0.57	0.48	0.48	0.52	0.51	0.49	0.55	12.3	2.05
C22	0.56	0.50	0.53	0.55	0.49	0.56	0.61	0.68	13.7	2.48
C23	0.50	0.60	0.49	0.49	0.57	0.52	0.52	0.53	9.92	2.56
C24	0.60	1.32	0.58	0.58	1.20	0.61	0.62	0.64	12.2	4.28
C25	1.26	0.56	1.12	<0.001	0.55	1.26	1.38	1.65	36.7	21.1
C26	0.53	0.63	0.53	1.18	0.63	0.56	0.53	0.57	13.3	3.18
C27	0.63	0.62	0.63	0.63	<0.001	0.64	0.64	0.65	14.5	4.78
C28	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.61	0.61	14.2	3.64
C29	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.69	0.70	16.1	4.62
C30	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.68	0.68	13.9	10.2
C31	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	15.0	30.0

C32	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	14.8	28.0
C33	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	21.7	61.4
C34	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	22.1	125
C35	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	20.1
C36	1.45	2.56	<0.001	1.6	<0.001	<0.001	1.33	1.62	21.3	13.68
C37	0.34	2.10	<0.001	1.8	<0.001	<0.001	2.04	2.62	19.2	0.43
C38	0.23	1.61	6.75	2.13	<0.001	2.33	0.65	0.14	20.4	10.9
C39	0.47	1.50	1.94	0.81	0.54	0.42	0.69	0.70	29.4	15.7
C40	0.69	1.04	0.79	0.71	0.89	1.25	0.78	0.89	30.8	12.3
TOTAL	**12.7**	**18.8**	**17.7**	**16.1**	**10.8**	**13.7**	**17.6**	**19.0**	**431**	**470**

The levels of AHCs detected in the sediments ranged from 10.8 mg/kg at site CC1 to a maximum of 470 mg/kg at site EE2. In particular, the AHC concentrations for Ethiope East Local Government Area were recorded at 12.7±0.3 and 18.8±0.6 mg/kg, while for Udu Local Government Area, the measurements were 17.7±1.4 and 16.1±0.5 mg/kg. In the Ughelli North Local Government Area, the concentrations included 10.8±0.2, 13.7±0.4, 17.6±0.4, 19.0±0.5, 431±8.8, and 470±24.2 mg/kg. Similar to crude oil, there were notable differences in both the concentrations and composition of AHCs across the various sites ($p < 0.05$), as depicted in Fig. 3.2 and Table 5. At sites AA1 and AA2, n-C36 showed the highest concentrations (Figs. 3.1 to 3.2), while at BB1 and BB2, n-C38 was found to have the greatest concentration, as indicated in Table 6 and Figs. 3.3-3.4, respectively. At CC1 (Fig. 3.5), n-C24 reached the highest concentration, whereas CC2 (Fig. 3.6) recorded the peak concentration for n-C38 (refer to Figs. 3.5 to 3.6, respectively). Furthermore, the highest concentration of n-C37 was observed at both DD1 and DD2, as illustrated in Figs. 3.7–3.8, respectively. In contrast, the maximum concentration of n-C34 was noted at EE2, while n-C25 was found in the highest concentration at EE1. It is important to highlight that the higher n-alkanes (C28 to C35) were generally absent in these sediments, with exceptions observed at sites EE1 and EE2 (see Figs. 3.9 and 3.10, respectively). The notable differences in sediment concentrations observed at various locations could be attributed to a range of factors, including the physicochemical characteristics of the sediments, the biological and chemical interactions occurring within them, the sources of input, processes of degradation, circulation patterns, and sedimentation rates (Frena et al., 2017; Osisanya, et al., 2025; Iwegbue et al., 2021).

Table 6: A summary of the ANOVA findings regarding aliphatic hydrocarbons present in sediments.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	8661.413	9	962.3793	15.10167	1.12E-20	1.907453
Within Groups	21667.07	340	63.72666			
Total	30328.48	349				

In 1992, United Nations Environment Programme (UNEP) established a guideline amount of 10 mg/kg of AHCs in sediments. Scientists believe that AHCs do not pose a danger to the environment when the levels are lower than this level, but levels that are higher than this threshold are dangerous to the environment (UNEP, 1992). The content of the n-alkanes that was present in the sediments exceeded the limit suggested by the UNEP, 1992. The sediment samples of the studied sites demonstrated high AHC levels that were significantly high, which means that petroleum hydrocarbon contamination is widespread in these areas. This pollution could be associated with oil leakage and oil spills associated with oil mining and transportation systems, unlawful bunkering and oil refining (Iwegbue et al., 2021).

Compositional pattern of aliphatic hydrocarbons in the sediment samples

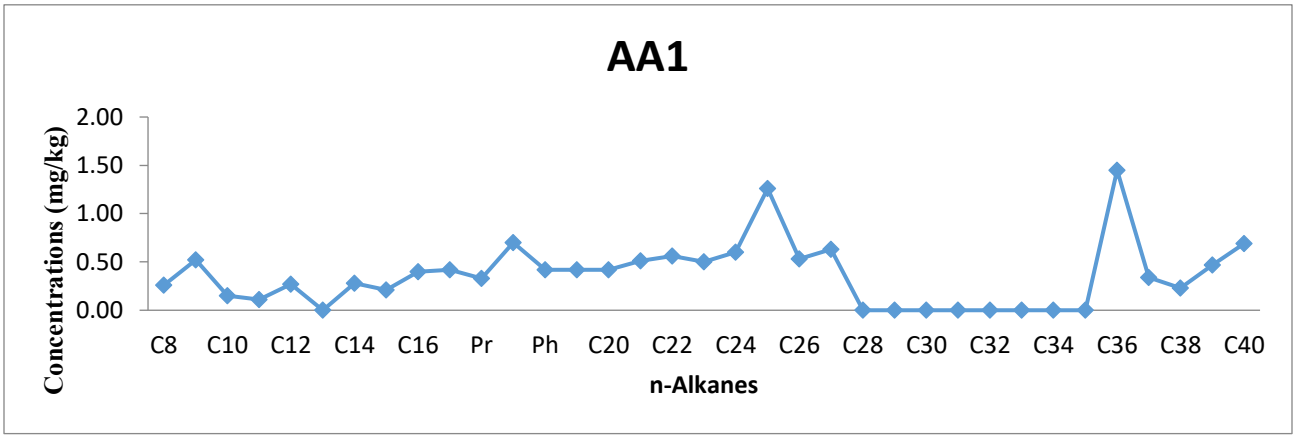

Fig. 3.1: Plot of Concentrations (mk/kg) against n-Alkanes at AA1

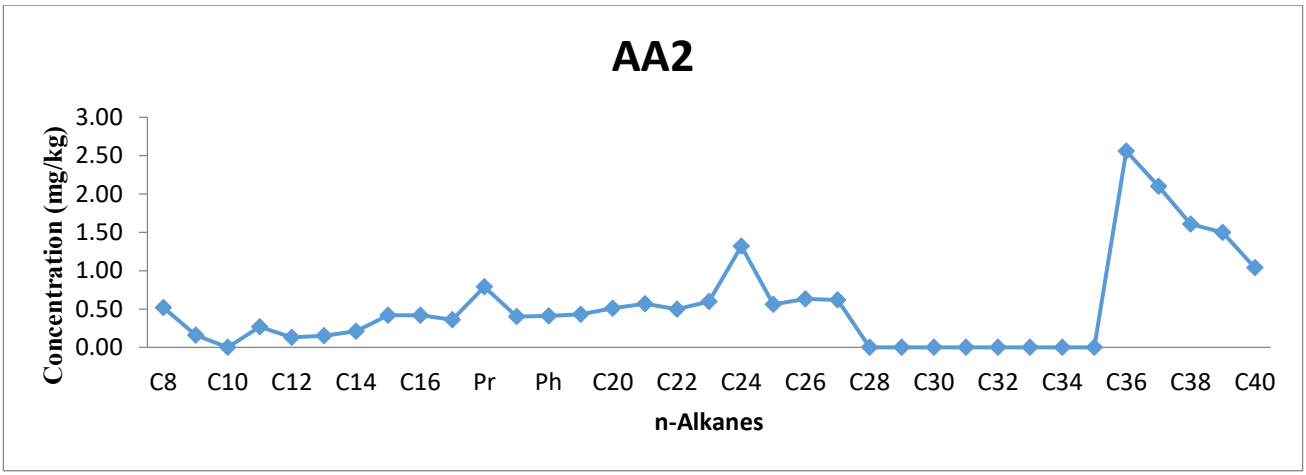

Fig. 3.2: Plot of Concentrations (mk/kg) against n-Alkanes at AA2

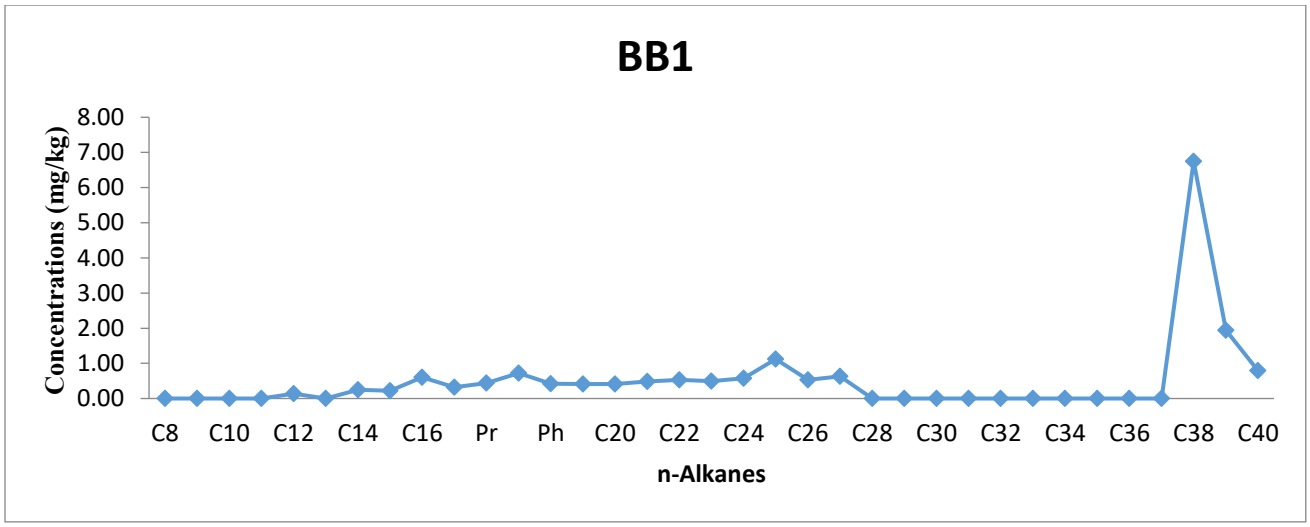

Fig. 3.3: Plot of Concentrations (mk/kg) against n-Alkanes at BB1

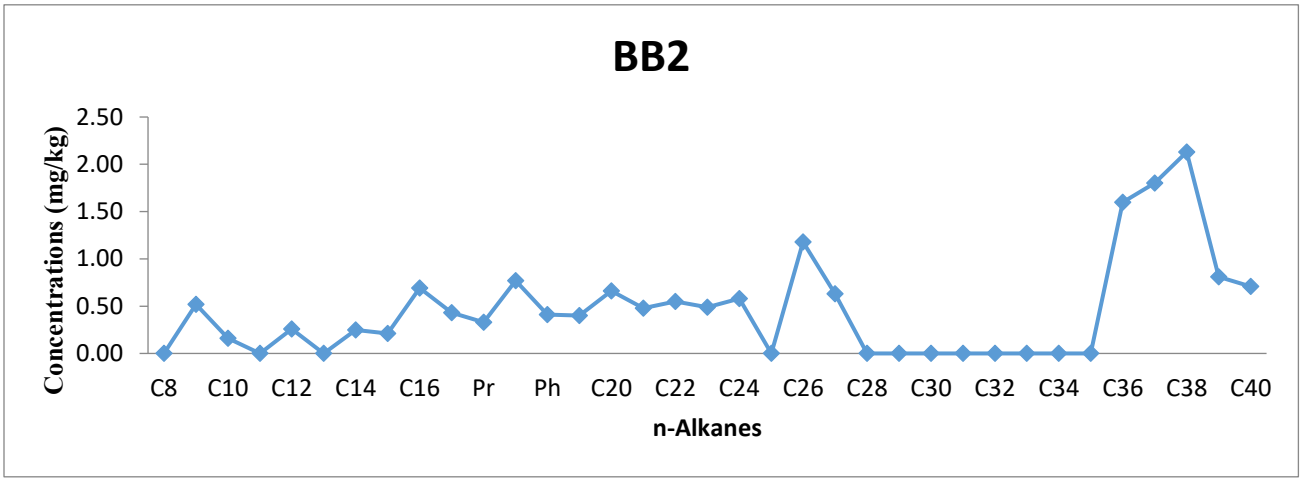

Fig. 3.4: Plot of Concentrations (mk/kg) against n-Alkanes at BB2

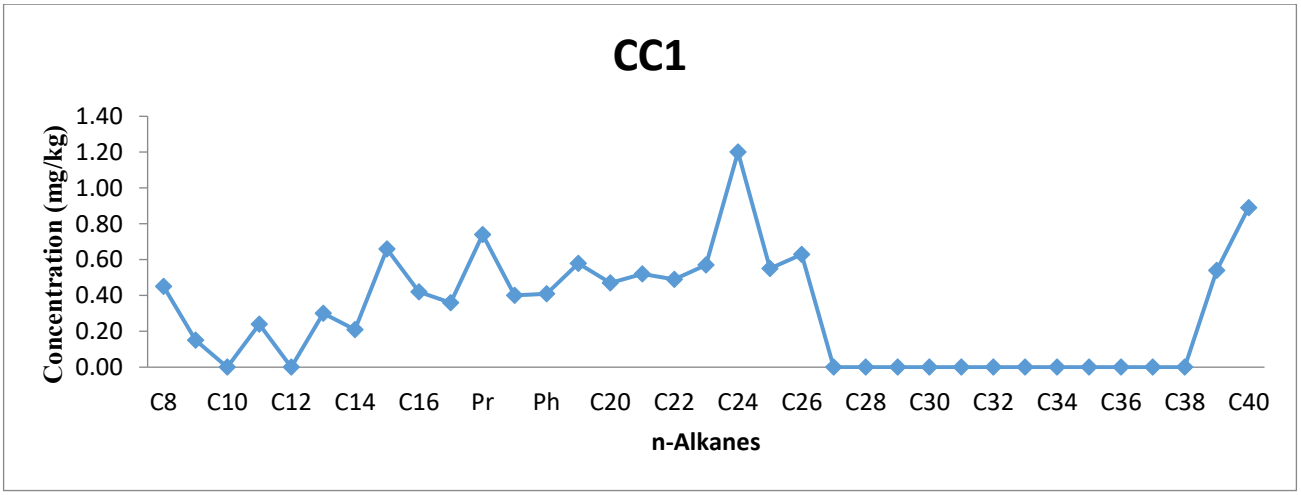

Fig. 3.5: Plot of Concentrations (mk/kg) against n-Alkanes at CC1

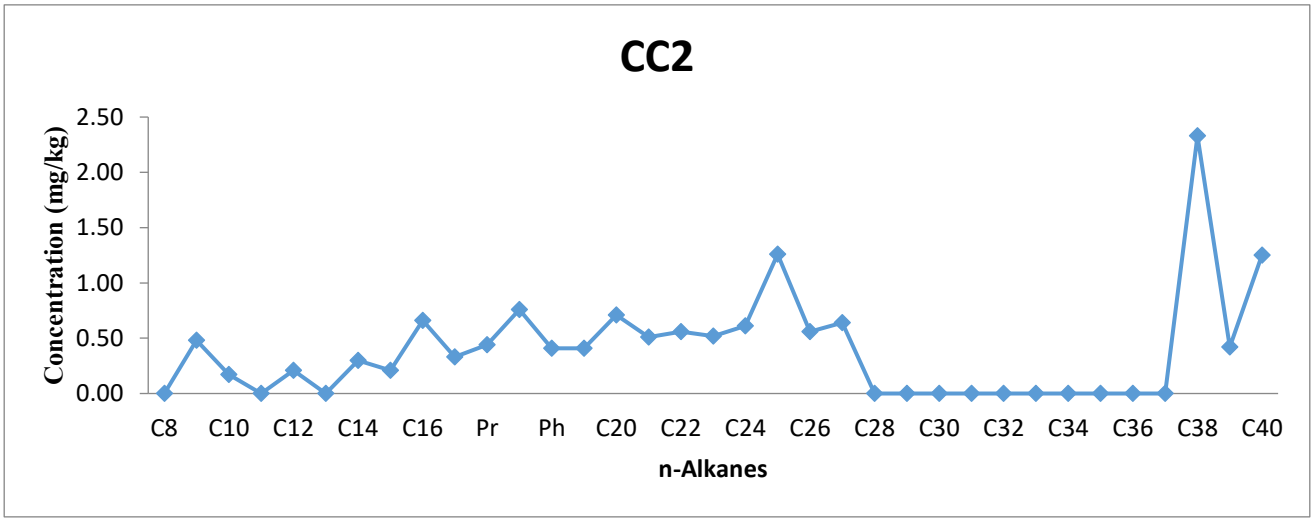

Fig. 3.6: Plot of Concentrations (mk/kg) against n-Alkanes at CC2

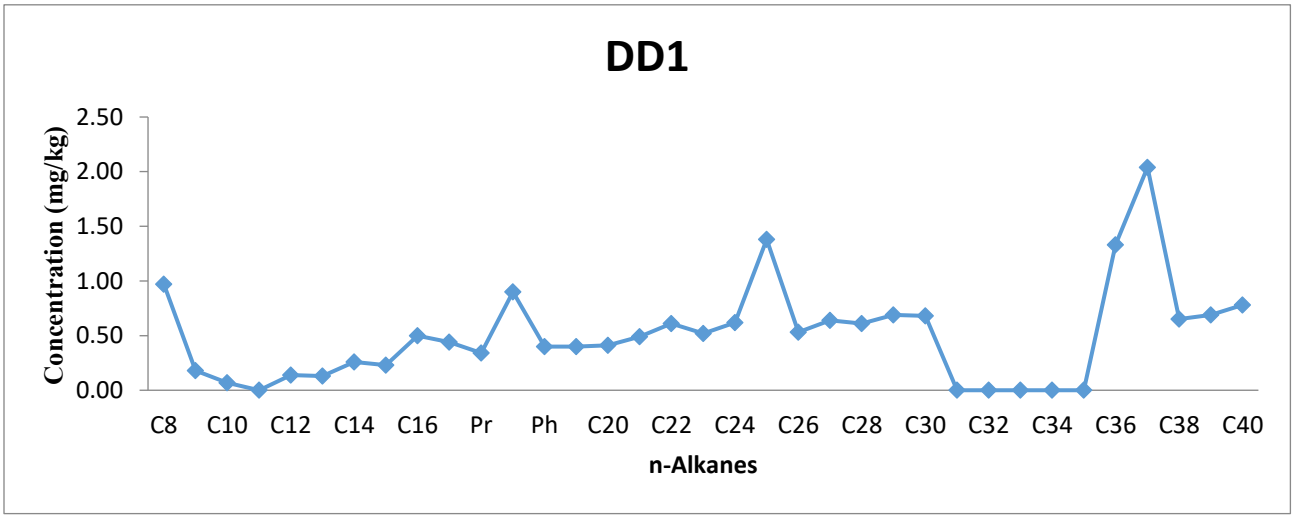

Fig. 3.7: Plot of concentrations (mk/kg) against n-Alkanes at DD1

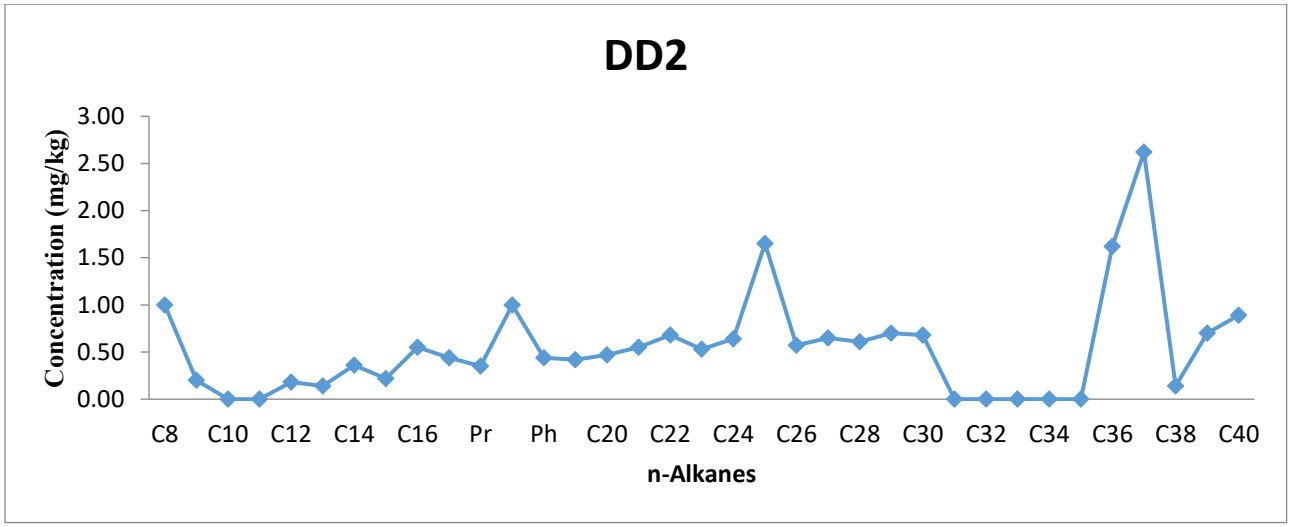

Fig. 3.8: Plot of Concentrations (mk/kg) against n-Alkanes at DD2

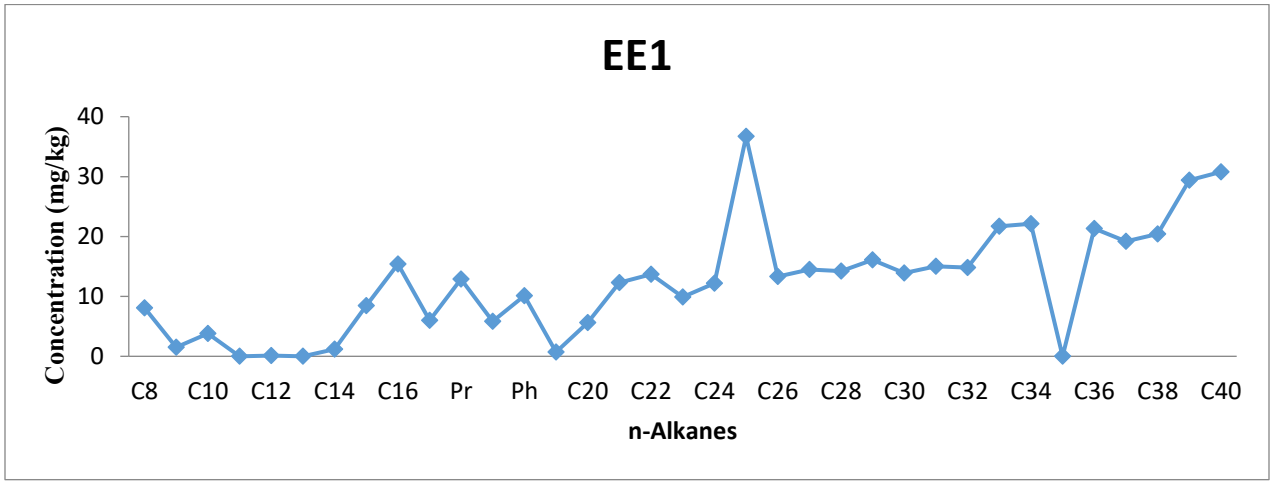

Fig. 3.9: Plot of concentrations (mk/kg) against n-Alkanes at EE1

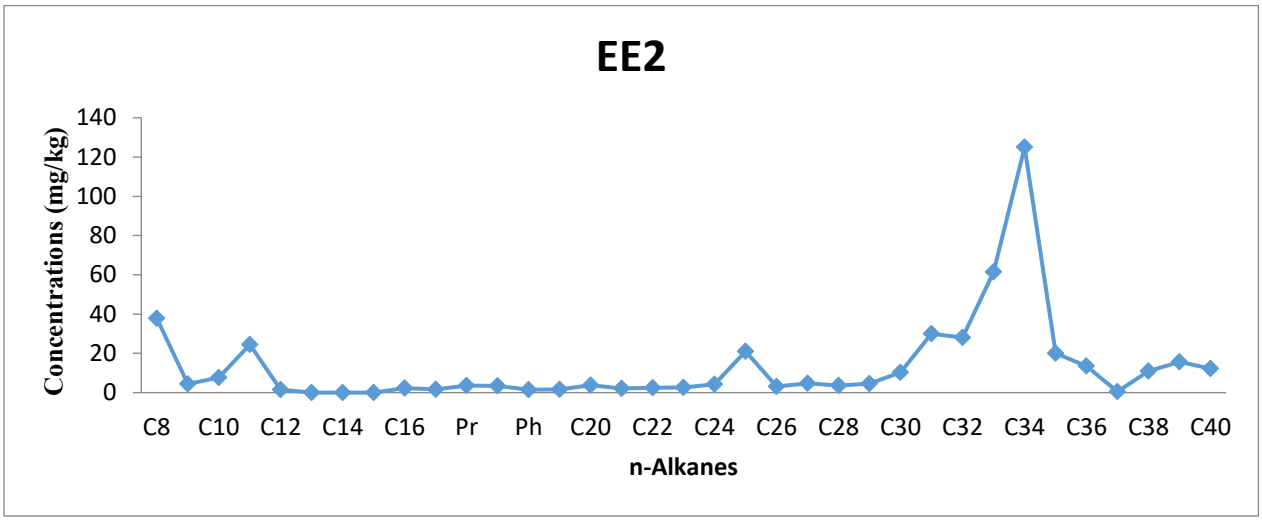

Fig. 3.10: Plot of concentrations (mk/kg) against n-Alkanes at EE2

Summary of Major Findings

i. There was significant variation in the concentrations of aliphatic hydrocarbons in the crude oil and sediments from the study area.
ii. The sediments from the study areas were highly contaminated by aliphatic hydrocarbons, as the concentrations of aliphatic hydrocarbons obtained in the sediments were above the UNEP 1992 guideline value.

4. CONCLUSION

The geochemical evaluation of crude and bottom sediment of water bodies in the Udu, Ethiope East, and Ughelli North Local Government Areas of the Niger Delta Basin was carried out in this study. The results of the study revealed the concentration, compositional pattern, and sources of aliphatic hydrocarbons (AHCs) in crude oil and bottom sediments from water bodies in the study area. This study revealed mean concentrations of aliphatic hydrocarbons in crude oil and bottom water sediments as 102.74±2.85 mg/kg and 12859.11±7884.68 mg/kg, respectively. The AHCs for crude are 3071.0±53.3 mg/kg for Ethiope East Local Government Area and 14999.0±314.3 and 15507±291.7 mg/kg for Udu Local Government Area, while 1149±69.7, 21686±3352.8, 14099±147.7, 450±17.3, 1114±19.6, and 43657±2185.3 mg/kg are for Ughelli North Local Government Area. For sediment the AHCs are 12.7±0.3 and 18.8±0.6 for Ethiope East Local Government Area and 17.7±1.4 and 16.1±0.5 mg/kg for Udu Local Government Area; those of Ughelli North Local Government Area are 10.8±0.2, 13.7±0.4, 17.6±0.4, 19.0±0.5, 431±8.8, and 470±24.2 mg/kg.

Acknowledgement

The authors have no acknowledgments to disclose.

Informed consent

Not applicable.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

Conflicts of interests

The authors declare that they have no conflicts of interests, competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data and materials availability

All data associated with this study are present in the paper.

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