

Post-spill Assessment of Polycyclic Aromatic Hydrocarbons, Total Petroleum Hydrocarbons and Volatile Organic Compounds in Surface Water from Aleto River, Southern Nigeria

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Abstract

This study was designed to assess the level of Polycyclic Aromatic Hydrocarbons (PAHs), Total Petroleum Hydrocarbon (TPH) and Volatile Organic Compounds (VOCs) in surface water collected from Aleto river located within the pollution-prone Niger Delta Region of Nigeria. Surface water samples were collected from River Aleto, 12 months after a crude oil spill that spread to the River, at upstream and downstream locations while surface water samples collected midstream from Ogharefe River served as Control samples. Surface water samples were analyzed for PAH, TPH and VOCs using standard analytical methods. The level of sixteen (16) USEPA-recognized PAH compounds, C₄ – C₄₀ hydrocarbon chain lengths and BTEX were investigated. Results obtained showed that PAH concentration was higher in upstream surface water samples (94.30±0.08 mg/l) while TPH (954.78 ± 0.03 mg/l) and VOC (41.35±0.03ppm) concentrations were higher in the surface water samples collected at downstream locations along the Aleto River. Varying levels of PAH compounds were found to be present in the surface water samples. TPH compounds and BTEX showed significance presence when values for downstream and upstream surface water samples were compared with results for control surface water samples. Findings from this study suggest that surfacewater from Aleto river contain substantial amount of hydrocarbon pollutants associated with deleterious environmental and epidemiological effects, thus residents of Aleto Eleme are exposed to health risks associated with direct contact or consumption of water and seafood from the Aleto River.

Keywords: Polycyclic Aromatic Hydrocarbons; Total Petroleum Hydrocarbon; Volatile Organic Compounds; Surface Water; Assessment

1. Introduction

Most hydrocarbon-dependent economies, such as Nigeria are constantly facing an epidemic of crude and refined oil spills from conventional and artisanal processes, thus the environment and public health are exposed to unquantifiable risk levels [1, 2]. Hydrocarbon released into the environment exists in different forms (they could be volatile organic compounds or semi-volatile organics) [3, 4], and possess variable potentials to threaten environmental media, including soil and water. Increased crude oil activities have resulted in extensive environmental pollution by oil spills involving blowouts, leakages from tanks or tanker trucks and dumping of waste petroleum products into the environment [5]. This has made hydrocarbon pollution of such ecosystems a widespread environmental issue, especially in developing nations. Water pollution caused by aromatic and aliphatic hydrocarbons is a significant environmental concern with far-reaching consequences. Aromatic hydrocarbons, such as benzene, toluene, and xylene, are commonly found in petroleum-based fuels and solvents [6].

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Polycyclic Aromatic Hydrocarbons (PAHs) are a class of ubiquitous organic compounds consisting of two or more fused aromatic rings. PAH is one of the several pollutants released into the environment during crude oil exploration and production. PAHs, which are classified as persistent organic pollutants commonly occurring in the environment are considered to be the most challenging organic contaminants to remediate [7 -9]. This may be due to their toxic, mutagenic and carcinogenic properties; they pose a significant environmental risk to public health [10, 11]. When PAHs enter into an aquatic environment, they may remain in water or accumulate in organisms and migrate as water flows [12].

Total Petroleum Hydrocarbons (TPH) are a large family of several hundred chemical compounds that originally come from crude oil. They are found in the range of C₆ through C₃₅ as mixture containing hundreds to thousands of hydrocarbons including aliphatic (straight carbon chain) and aromatic (carbon ring) compounds. TPH measures the gross quantity of individual petroleum hydrocarbon components present in the environment. Some hydrocarbon mixtures may also contain priority pollutants including volatile organic compounds (VOCs), semi-volatile compounds (SVOCs) and metals, each of which have their own specific toxicity information (ATSDR, 1999). The presence of chemical contaminants in the coastal environments from many anthropogenic sources is a major threat to the marine water [5, 13].

Petroleum hydrocarbons are one of the major pollutants which are frequently discharged into the coastal waters in Niger Delta region of Nigeria, which is a major hydrocarbon deposit [14, 15]. Oil spillage is a form of pollution; it is a process whereby liquid petroleum hydrocarbon is discharged or released into the environment [16]. UNEP [17] reported that in recent years, there has been series of devastation brought about by accidental spills in the Niger Delta Region which has led to wide-ranging ecological pollution. Oil theft, operations, illegal refining, mystery spills and sabotage are amongst major causes of oil spills in our environment. Illegal petroleum activities are not governed by petroleum exploration laws that are designed to manage environmental issues [15, 16].

In this study, we report the post-crude oil spill levels of Polycyclic Aromatic Hydrocarbons, Total Petroleum Hydrocarbon and Volatile Organic Compounds in surface water of Aleto River located in Rivers State, Nigeria, aimed at establishing its pollution status.

2. Materials and methods

2.1. Study Area

Aleto Community is located in Eleme Local Government Area (L.G.A.) of Rivers State, Nigeria. Eleme L.G.A is located between latitude 4°44' N and longitude 7°15'E, to the east, lies Tai, to the west, Okrika and Port Harcourt Local Government Areas, and to the North, Obio/Akpor and Oyigbo. It is a crude oil producing L.G.A. with presence of oil and gas, petrochemical, and fertilizer industries. Apart from major oil companies like SPDC, Mobil etc., the L.G.A. also hosts Port Harcourt Refinery Company, Alesa Eleme, Indorama Eleme Petrochemical Company Limited, Notore Chemicals Limited and Indorama Fertilizer Chemicals Ltd. Eleme has a mean annual rainfall of 160–298 mm, a relative humidity of above 90%, and a mean temperature of 27°C. It undergoes alternating rainy and dry seasons [18]. Convectional rains are known to occur in the dry season months of November through March, whereas the rainy season typically lasts from April to October. Eleme is home to Aleto surface water, which empties into the Imo River. Runoffs into the Aleto surface water banks are caused by a number of adjacent activities, including sand mining, roasting cow-skins, oil spills, vehicle repairs, illicit refining operations, and catchment areas [18]. A crude oil spill was reported to have occurred in an oil facility located at Aleto Eleme in June 2023 [19].



Figure 1 Map of Eleme communities showing the sampling location (Aleto)

2.2. Water Sample Collection

Water samples were collected from the Aleto River in plastic vials at a depth of 25 cm under water at upstream and downstream locations, and the vials immediately capped. Sampling was done in triplicates at each sampling point and was done between the months of July and August, 2024. The samples were placed in ice-cold chest packs and transported to the laboratory, where they were stored at a temperature of 4°C. Midstream surface water samples (Control) were collected from a location over 232km away from the study area and without any known history of hydrocarbon pollution (Ogharefe River in Delta State, Nigeria).

Table 1 Sampling locations and their coordinates

Sampled Surface Water	Location	Elevation	Distance	Coordinates
Aleto surface water (Upstream)	Aleto Community, Eleme LGA, Rivers State	427m	69.2m	N-4°43'23.2" E-7° 06'10.6"
Aleto surface water (Downstream)	Aleto Community, Eleme LGA, Rivers State	465m	115.0m	N-4°43'23.2" E-7° 01'26.5"
Ogharefe surface water (Control)	Ogharefe Community, Okpe LGA, Delta State	178m	232.0m	N-5° 56' 47.27" E-5° 37' 57.32"

2.3. PAH, TPH and BTEX Analysis

Water samples were analyzed using Gas Chromatograph (GC) equipped with flame ionization detector and HP-5 fused silica capillary column (30m × 0.32 mm ID × 0.25 µm film thickness) (GC model: Agilent 6890N).

2.4. Statistical Analysis

All values were expressed as mean ± SD and then subjected to analysis of variance (ANOVA) using the Statistical Package for Social Sciences (SPSS) version 17.0 (SPSS Inc., Chicago Illinois). Statistical significance was considered at P=0.05.

3. Results and discussion

The levels of sixteen (16) USEPA-recognized PAH compounds (Naphthalene, Benzo[k]fluoranthene, Acenaphthylene, Acenaphthene, Benzo[a]anthracene, Fluorene, Benzo[b]fluoranthene, Phenanthrene, Anthracene, Dibenz[a,h]anthracene Pyrene, Chrysene, Benzo[a]pyrene, Indeno[1,2,3-cd]pyrene, Fluoranthene, and Benzo[g,h,i]perylene), C₄ – C₄₀ hydrocarbon chain lengths and BTEX in surface watersamples were analysed and are presented in Tables 2, 3 and 4 respectively. Varying levels of PAH compounds were found to be present in the surface water samples. Results obtained showed that overall level of PAH compounds was higher in the upstream surface water samples (94.30±0.08 mg/l) than in downstream surface water samples (71.03±0.05 mg/l) when compared with Control surface water sample which recorded 0.45±0.03 mg/l. Carcinogenic PAH compounds detected by GCMS analysis in upstream surface water samples are Benzo[a]pyrene, benzo[a]anthracene, chrysene, benzo[k]fluoranthene, benzo(g,h,i) perylene and benzo(a)pyrene, while Benzo[a]Pyrene, Benzo[b]fluoranthene, Benzo(a)pyrene, Indeno(1,2,3-cd) pyrene and Dibenz(a,h)anthracene were found to be present in downstream surface water samples. TPH (954.78 ± 0.03 mg/l) and VOC (41.35±0.03ppm) concentrations were higher in the surface water samples collected at downstream locations along the Aleta River. Upstream and downstream surface water samples showed predominant presence of C₁₅ hydrocarbon chain length. Similarly, BTEX showed significance presence when values for downstream and upstream surface water samples were compared with results for control surface water samples.

Table 2 Polycyclic aromatic hydrocarbon (PAHs) in surface water samples

Polycyclic Aromatic Hydrocarbon (mg/l)	Upstream Surface Water	Aleta	Downstream Surface Water	Aleta	Ogharefe Surface Water
Non-Carcinogenic					
Benzene-1,2,3-trimethyl-	1.56±0.00 ^b		3.46±0.00 ^c		BDL ^a
2-methylnaphthalene	8.48±0.01 ^c		5.66±0.00 ^b		BDL ^a
Acenaphthylene	6.83±0.01 ^c		BDL ^a		0.04±0.00 ^b
Acenaphthene	12.33±0.01 ^c		9.50±0.00 ^b		BDL ^a
Naphthalene	6.42±0.00 ^c		5.28±0.01 ^b		0.01±0.00 ^a
Fluorene	2.78±0.01 ^c		1.88±0.01 ^b		BDL ^a
Phanthrene	10.26±0.01 ^c		6.28±0.00 ^b		BDL ^a
Anthracene	BDL ^a		BDL ^b		0.05±0.01 ^c
Fluoranthene	8.56±0.00 ^b		10.96±0.01 ^c		BDL ^a
Carcinogenic					
Benzo[a]Pyrene	7.30±0.01 ^c		4.16±0.01 ^b		0.31±0.01 ^a
Benzo[a]anthracene	9.59±0.00 ^c		BDL ^a		BDL ^b
Chrysene	1.75±0.01 ^c		BDL ^a		BDL ^b
Benzo[b]fluoranthene	BDL ^a		5.58±0.00 ^c		0.04±0.01 ^b
Benzo[k]fluoranthene	6.55±0.01 ^b		BDL ^a		BDL ^a
Benzo(g,h,i)perylene	3.65±0.00 ^b		BDL ^a		BDL ^a
Benzo(a)pyrene	8.24±0.01 ^b		10.27±0.00 ^c		BDL ^a
Indeno(1,2,3-cd) pyrene	BDL ^a		4.55±0.00 ^c		BDL ^b
Dibenz(a,h)anthracene	BDL ^a		3.45±0.01 ^b		BDL ^a
Total PAHs	94.30±0.09 ^c		71.03±0.05 ^b		0.45±0.03 ^a
ΣCarcinogenic PAHs	37.08±0.03 ^c		28.01±0.02 ^b		0.35±0.01 ^a
%Carcinogenic PAHs	39.32		39.43		77.77

Values represent mean ± SEM. Values in the same row with different superscript alphabets are significantly different at p≤0.05 (n=3). BDL implies below detection limits of 0.01mg/l.

Table 3 Total petroleum hydrocarbons (TPHs) in surface water samples

Total Hydrocarbon (mg/l)	Petroleum Hydrocarbon (mg/l)	Upstream Aleto Surface water	Downstream Aleto Surface water	Ogharefe Surface water
C ₈		92.43±0.006 ^b	102.13±0.00 ^c	BDL ^a
C ₉		BDL ^a	11.00±0.00 ^b	BDL ^a
C ₁₀		63.95±0.01 ^c	15.02±0.00 ^b	BDL ^a
C ₁₁		94.80±0.01 ^b	BDL ^a	BDL ^a
C ₁₂		50.14±0.01 ^b	BDL ^a	BDL ^a
C ₁₃		35.72±0.01 ^b	56.24±0.00 ^c	BDL ^a
C ₁₄		57.23±0.00 ^b	81.74±0.00 ^c	BDL ^a
C ₁₅		132.16±0.00 ^b	157.01±0.00 ^c	BDL ^a
C ₁₆		14.35±0.00 ^b	108.06±0.00 ^c	BDL ^a
C ₁₇		BDL ^a	127.90±0.00 ^b	BDL ^a
Pristane		BDL ^a	14.43±0.00 ^b	BDL ^a
C ₁₈		70.68±0.00 ^b	91.02±0.00 ^c	BDL ^a
Phytane		BDL	BDL	BDL
C ₁₉		6.48±0.00 ^b	BDL ^a	BDL ^a
C ₂₀		40.91±0.01 ^b	BDL ^a	BDL ^a
C ₂₁		24.25±0.01 ^b	71.66±0.00 ^c	BDL ^a
C ₂₂		10.29±0.00 ^b	17.10±0.00 ^c	BDL ^a
C ₂₃		9.05±0.00 ^b	33.20±0.00 ^c	BDL ^a
C ₂₄		26.01±0.00 ^c	18.33±0.00 ^b	BDL ^a
C ₂₅		9.22±0.01 ^b	BDL ^a	BDL ^a
C ₂₆		BDL	2.61±0.00	BDL
C ₂₇		BDL ^a	13.48±0.00 ^b	BDL ^a
C ₂₈ -C ₃₀		BDL	BDL	BDL
C ₃₁		57.06±0.00 ^b	BDL ^a	BDL ^a
C ₃₂		27.20±0.00 ^b	BDL ^a	BDL ^a
C ₃₃		12.46±0.00 ^b	19.83±0.00 ^c	BDL ^a
C ₃₄		8.01±0.00 ^b	11.19±0.00 ^c	BDL ^a
C ₃₅		BDL ^a	2.84±0.00 ^b	BDL ^a
C ₃₆ -C ₃₈		BDL	BDL	BDL
C ₃₉		2.00±0.00	BDL	BDL
C ₄₀		5.59±0.00 ^b	BDL ^a	BDL ^a
Total TPH		850.14±0.08 ^b	954.78±0.03 ^c	BDL ^a

Values represent mean ± SEM. Values in the same row with different superscript alphabets are significantly different at p<0.05 (n=3). BDL implies below detection limits of 0.01mg/l.

Table 4 Volatile organic compounds (BTEX) in surface water samples

Volatile Organic Compounds (ppm)	Upstream Aleto Surface Water	Downstream Aleto Surface Water	Ogharefe Surface Water
Benzene	5.23±0.00 ^b	8.53±0.00 ^c	BDL ^a
Toluene	11.27±0.22 ^b	14.57±0.01 ^c	BDL ^a
Ethylbenzene	8.20±0.00 ^b	9.32±0.01 ^c	BDL ^a
Para-Xylene	5.22±0.00 ^c	4.90±0.01 ^b	BDL ^a
Ortho-Xylene	3.31±0.01 ^b	4.03±0.01 ^c	BDL ^a
BTEX	33.24±0.23 ^b	41.35±0.03 ^c	BDL ^a

Values represent mean ± SEM. Values in the same row with different superscript alphabets are significantly different at $p \leq 0.05$ (n=3). BDL implies below detection limits of 0.01ppm.

Crude oil pollution of water bodies by PAHs is usually caused by petroleum spills and other man-made activities such as discharges and seepages, industrial and municipal waste water, urban and suburban surface runoffs and atmospheric deposition. Crude oil production activities generally pollute both surface and groundwater with benzene, toluene, ethylene and xylene (BTEX) as well as other toxic chemicals including toxic PAH compounds. Total Petroleum Hydrocarbon (TPH) and Polycyclic aromatic hydrocarbon (PAH) concentrations can be potentially toxic and dangerous when they cross the food chain into biological systems [20].

Results obtained in this study revealed differences in the various hydrocarbon groups assayed in upstream and downstream surface water samples. Petroleum hydrocarbon compounds systematically undergo processes such as evaporation, dissolution, dispersion, photo-oxidation, and biodegradation when they are released into aquatic environments, at different rates depending on the carbon makeup [21 – 23].

Carcinogenic PAH compounds detected by GCMS analysis in upstream and downstream surface water samples. Specifically, Benzo[a]pyrene was detected in upstream and downstream sources. Polycyclic Aromatic Hydrocarbons (PAHs) comprise of over 200 organic compounds containing two or more fused aromatic rings that are carcinogenic, mutagenic, and capable of disrupting hormonal functions [24 - 26]. Sixteen PAHs compounds are considered by the U.S. Environmental Protection Agency (EPA) as priority pollutants as they are the most toxic, carcinogenic, and commonly found PAHs in the environment. Benzo(a)pyrene (BaP) a known carcinogen, is often used as a benchmark compound when evaluating the potential carcinogenicity of PAH mixtures. Other PAHs compounds of interest are Naphthalene, Benzo[k]fluoranthene, Acenaphthylene, Acenaphthene, Benzo[a]anthracene, Fluorene, Benzo[b]fluoranthene, Phenanthrene, Anthracene, Dibenz[a,h]anthracene Pyrene, Chrysene, Benzo[a]pyrene, Indeno[1,2,3-cd]pyrene, Fluoranthene, and Benzo[g,h,i]perylene). These compounds are often used as markers for assessing PAH contamination and exposure [27]. Inhalation, ingestion and dermal contact are the primary routes of exposure of PAHs to humans. PAHs are extremely toxic with excellent capability to stimulate health effects such as nausea, vomiting, eye irritation, diarrhea and confusion (short term effects). Other health effects (long term) include immune function suppression, cataracts, kidney and liver damage, skin inflammation, asthma amongst others. Generally, mixtures of PAHs are known to cause carcinogenic, genotoxic, teratogenic effects and are potential immunosuppressant [28].

Previous studies noted that the trend of hydrocarbon susceptibility to microbial degradation is as follows: linear alkanes > branched alkanes > small aromatics > cyclic aromatics [29, 30]. In this study, low molecular weight hydrocarbons (C₈ – C₁₀) were detected in upstream and downstream surface water samples from Aleto River. This observation is at variance with the report by Ihunwo et al. [15] who noted that low molecular weight hydrocarbons (C₈ – C₁₀) were not detected in either surface water or sediment at different stations along Woji Creek in the Niger Delta Estuary of Rivers State, Nigeria. This could be due to the persistence and bioavailability of hydrocarbon compounds in the environment [31, 32].

In this study, the concentration of BTEX in analysed surface water samples is a confirmation that pollution could bioaccumulate in oil polluted areas. Volatile Organic Compounds (BTEX) content of surface water samples was

significantly high when compared with Control samples where the VOCs were below detection limits (BDL). Benzene is a known carcinogen. Water contaminated by oil leaks containing benzene can poison streams serving as drinking water sources and cause significant detrimental effects to human and aquatic life [18].

4. Conclusion

The assessment of Polycyclic Aromatic Hydrocarbons, Total Petroleum Hydrocarbons and Volatile Organic Compounds in surface water from Aleto River showed high concentrations of hydrocarbons in surface water. Findings from this study suggests that Aleto river is exposed to substantial amount of hydrocarbon pollutants associated with deleterious environmental and epidemiological effects, thus residents of Aleto Eleme are exposed to health risks associated with direct contact or consumption of water and seafood from the Aleto River. The study confirms that the reported crude oil spill that affected Aleto River poses ecological threat to surface water.

Compliance with ethical standards

Disclosure of conflict of interest

Authors have declared that no competing interests exist.

References

- [1] Sam K, Zabbey N, Onyena AP. Implementing contaminated land remediation in Nigeria: Insights from the Ogoni remediation project. *Land Use Policy*. 2022; 115 (106051).
- [2] Sam K, Onyena AP, Zabbey N, Odoh CK, Nwipie GN, Nkeeh DK, Osuji LC, Little DI. Prospects of emerging PAH sources and remediation technologies: insights from Africa. *Environ Sci Pollut Res Int*. 2023; 30:39451-39473.
- [3] Colabuono FI, Taniguchi S, Cipro CVZ, da Silva J, Bicego MC, Montone RC. Persistent organic pollutants and polycyclic aromatic hydrocarbons in mosses after fire at the Brazilian Antarctic Station. *Mar. Pollut. Bull*. 2015; 93 (1-2):266-269.
- [4] Hoang SA, Sarkar B, Seshadri B, Lamb D, Wijesekara H, Vithanage M, Liyanage C, Kolivabandara PA, Rinklebe J, Lam SS, Vinu A. Mitigation of petroleum-hydrocarbon-contaminated hazardous soils using organic amendments: a review. *J. Hazard. Mater*. 2021; 416 (125702).
- [5] Inyang, SE; Aliyu, AB; Oyewale, AO. Total Petroleum Hydrocarbon Content in Surface Water and Sediment of Qua-Iboe River, Ibeno, Akwa-Ibom State, Nigeria. *J. Appl. Sci. Environ. Manage*. 2018; 22 (12):1953-1959.
- [6] Odesa GE, Eyankware MO, Elozona OE. Assessing the total petroleum hydrocarbon content in groundwater in parts of Eleme, Southern Nigeria. *World Scientific News*; 2024; 189:63-75.
- [7] Edwards NT. Polycyclic aromatic hydrocarbons (PAH's) in the terrestrial environment - a review. *Journal of Environmental Quality*. 1983; 12:427-441.
- [8] Cerniglia CE. Biodegradation of polycyclic aromatic hydrocarbons. *Biodegradation*. 1992; 3:351-358.
- [9] Weissenfels WD, Klewer HJ, Langhoff J. Adsorption of polycyclic aromatic hydrocarbons (PAHs) by soil particles: influence on biodegradability and biotoxicity. *Applied Microbiology and Biotechnology*. 1992; 36:689-696.
- [10] Chen SC, Liao CM. Health risk assessment on human exposed to environmental polycyclic aromatic hydrocarbons pollution sources. *Science of the Total Environment*. 2006; 366:112-123.
- [11] Mekuleyi GO, Aderinola OJ, Whenu OO. Total and Polyaromatic hydrocarbon in water, sediment, fin and shellfishes from badagary creek and ologe lagoon, Lagos, Nigeria. *Journal of Applied Science and Environmental Management*. 2018; 22(5):675-680.
- [12] Agbozu I, Edjere O, Asibor G, Otolo S, Bassey U. Source predictions of polycyclic aromatic hydrocarbon (PAHs) concentration in water, sediment, and biota (Fishes) from Ethiopie River, Delta State, Southern Nigeria. *Journal of Ecology and The Natural Environment*. 2020; 12(4), 140-149.
- [13] Charriau A, Bodineau L, Ouddane B, Fischer CJ. Polycyclic aromatic hydrocarbons and n-alkanes in sediments of the Upper Scheldt River Basin: contamination levels and source apportionment. *J. Environ. Monit*. 2009; 11(5):106- 1093.

- [14] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Total Petroleum Hydrocarbons (TPH). U.S. Department of Health and Human Services, Public Health Service, Washington, USA. 1999.
- [15] Ihunwo OC, Onyema MO, Wekpe VO, Okocha C, Shahabinia AR, Emmanuel L, Okwe VN, Lawson CB, Mmom PC, Dibofori- Orji AN, Bonnail E. Ecological and human health risk assessment of total petroleum hydrocarbons in surface water and sediment from Woji Creek in the Niger Delta Estuary of Rivers State, Nigeria. *Heliyon*. 2021;7(8).
- [16] Mba IC, Mba EI, Ogbuabor JE, Arazu WO. Causes and Terrain of Oil Spillage in Niger Delta Region of Nigeria: The Analysis of Variance Approach. *International Journal of Energy Economics and Policy*. 2019; 9(2):283-287.
- [17] UNEP Environmental Assessment of Ogoniland. Kenya, Nairobi; 2011.
- [18] Gbarakoro SL, Gbarakoro TN, Eebu WL. Impact of Industrial Effluent Discharge on the Physicochemical Properties of Aletto Stream, Eleme, Rivers State, Nigeria. *Annual Research & Review in Biology*. 2020; 35(1):79-89.
- [19] Shell Confirms Fresh Spill on Oil Facility in Eleme. Available at: <https://www.thisdaylive.com/index.php/2023/06/16/shell-confirms-fresh-spill-on-oil-facility-in-eleme/>
- [20] Sampaio GR, Guizzellini GM, da Silva SA, de Almeida AP, Pinaffi-Langley ACC, Rogero MM, de Camargo AC, Torres EAFS. Polycyclic Aromatic Hydrocarbons in Foods: Biological Effects, Legislation, Occurrence, Analytical Methods, and Strategies to Reduce Their Formation. *Int J Mol Sci*. 2021.
- [21] Clement TP. Spills, Sediment, and Shoreline Contamination [WWW Document]. *Eos*. 2018.
- [22] Gray ND, Sherry A, Hubert C, Dolfing J, Head IM. Methanogenic degradation of petroleum hydrocarbons in subsurface environments: remediation, heavy oil formation, and energy recovery. Laskin AI, Sariaslani S, GMBT-A. Gadd AM (Eds.), *Advances in Applied Microbiology*, Academic Press. 2010: pp. 137-161.
- [23] Zeneli A, Kastanaki E, Simantiraki F, Gidarakos E. Monitoring the biodegradation of TPH and PAHs in refinery solid waste by biostimulation and bioaugmentation. *J. Environ. Chem. Engin*. 2019; 7 (103054).
- [24] Odesa GE, Ozulu GU, Eyankware MO, Mba-Otike MN, Okudibie EJ. A holistic review of three-decade oil spillage across the Niger Delta Region, with emphasis on its impact on soil and water. *Reading Time*. 2024; 2024b:02-02.
- [25] Ibezue, VC, Odesa EG, Ndukwe JO, Nwabine EO. Hydrocarbon concentration levels in groundwater in Jesse and Environ, Ethiopie West LGA Delta State, Nigeria. *International Journal of Computer Applications Technology and Research*. 2018; 7(7):241-254.
- [26] Odesa GE, Eyankware MO, Elozona OE. Assessing the total petroleum hydrocarbon content in groundwater in parts of Eleme, Southern Nigeria. *Reading Time*. 2024; 01-05.
- [27] US Environmental Protection Agency (U.S.E.P.A.). Integrated Risk Information System: Benzo[a]pyrene (BaP) (CASRN 50-32-8), Available from: U.S. Environmental Protection Agency. 2001. <<http://www.epa.gov/iris/subst/0136.htm>>
- [28] Ogoko EC. Evaluation of Polycyclic Aromatic Hydrocarbons, Total Petroleum Hydrocarbons and Some Heavy Metals in Soils of Nnpc Oil Depot Aba Metropolis, Abia State, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology*. 2014; 8(5):21-27.
- [29] Brooijmans RJW, Pastink MI, Siezen RJ. Hydrocarbon-degrading bacteria: the oil-spill clean-up crew *Microbial biotechnology*. 2009; 2:587-594.
- [30] Leahy JG, Colwell RR. Microbial degradation of hydrocarbons in the environment *Microbiol. Rev*. 1990; 54:305-315.
- [31] Anyanwu IN, Beggel S, Sikoki FD. *et al*. Pollution of the Niger Delta with total petroleum hydrocarbons, heavy metals and nutrients in relation to seasonal dynamics. *Sci Rep*. 2023; 13:14079.
- [32] Kuppusamy S, Maddela NR, Megharaj M, Venkateswarlu K. An overview of total petroleum hydrocarbons. In: *total petroleum hydrocarbons*. Springer nature Switzerland AG, cham Switzerland. 2020; 1-27.