



Assessment of Polycyclic Aromatic Hydrocarbons in the Biophysical Environment of Anya-Ogologo River, Rivers State, Nigeria

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ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) pose significant environmental and health risks in the Niger Delta, where oil pollution has degraded aquatic ecosystems. This study assessed Polycyclic aromatic hydrocarbons (PAHs) contamination in the Anya-Ogologo River, Rivers State, Nigeria, focusing on water, sediments, and periwinkles (*Tympanotonus fuscatus*) to evaluate pollution levels, sources, and human health risks. The study findings revealed severe Polycyclic aromatic hydrocarbons (PAHs) contamination, with total concentrations in water ranging from 0.72 to 8.65 mg/L (exceeding moderate pollution thresholds) and sediments from 1.76 to 8.47 mg/kg. Periwinkles showed bioaccumulation of low-molecular-weight Polycyclic aromatic hydrocarbons (PAHs) (0.34 mg/kg). Diagnostic ratios indicated pyrogenic dominance (Phen/Anth >1, Flth/Py >1), with negligible petrogenic input (BaA/Chry = 0). Probabilistic risk assessment estimated elevated cancer risks, particularly for children (ILCR >10⁻⁶), via dermal and inhalation pathways. Conclusively, the study highlights severe Polycyclic aromatic hydrocarbons (PAHs) pollution in the Anya-Ogologo River, primarily from combustion sources, posing significant ecological and health risks. Urgent remediation and policy interventions are needed to mitigate exposure.

1. INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) represent a class of persistent organic pollutants of critical global concern due to their carcinogenic, mutagenic, and teratogenic properties (Montano *et al.*, 2025).

These compounds originate primarily from incomplete combustion of organic matter (pyrogenic sources) and petroleum products (petrogenic sources) (Orecchio *et al.*, 2008), posing

severe threats in hydrocarbon-rich regions like Nigeria's Niger Delta. In this region, decades of oil extraction, illegal bunkering, pipeline vandalism, and inadequate wastewater management have elevated PAH pollution to catastrophic levels (Abdulai *et al.*, 2025), driving mangrove degradation, biodiversity loss, and contamination of aquatic food chains (Montano *et al.*, 2025), (Smetanová *et al.*, 2025). The concentration of PAHs pollutants may be used to categorize the level of pollution. It is regarded as low PAH contamination when the level is between 0 and 0.1 mg/l. The PAH pollution level is considered to be moderate when it is between 0.1 and 1 mg/l. High PAH pollution is defined as anything between 1 and 5 mg/l, while extremely high PAH pollution is defined as anything above 5.1 mg/l (Minikova *et al.*, 2017). According to Dong *et al.* (2012), the availability of some major combustion products from either a low temperature petrogenic process or low temperature pyrolytic process is reflected in the presence of low and high molecular weight PAHs in sediments. The presence of high molecular weight PAHs in sediments suggest the existence of some major combustion products from a high temperature pyrolytic process or petrogenic activity. Consequently, communities face elevated risks of cancers, respiratory diseases, and reproductive disorders, yet site-specific data quantifying ecosystem contamination and human health risks remain critically limited, especially for tidal ecosystems like Rivers State's Anya-Ogologo River experiencing multi-pathway pollution inputs.

Within Rivers State, crude oil exploitation has triggered severe environmental deterioration through inevitable leaks during exploration, extraction, transportation, and processing (Onwurah *et al.*, 2007). Aquatic ecosystems are particularly vulnerable, where oil spills diminish dissolved oxygen, cause eutrophication, disrupt food chains and induce pathologies like hemorrhagic septicemia in aquatic life via PAH

exposure (Blenkinsopp *et al.*, 2019). Terrestrially, hydrocarbons alter soil physicochemical properties (pH, structure, temperature), inhibit seed germination, and reduce agricultural productivity (Smith, 2021), though aquatic contamination remains the dominant crisis in the oil-rich Niger Delta. Despite recognition of these impacts, region-specific studies quantifying PAH transfer across biophysical matrices (water, sediment, biota) are scarce, hindering risk assessment and remediation planning for critical ecosystems like the Anya-Ogologo River.

This study addresses these gaps by conducting a comprehensive assessment of PAH contamination in the Anya-Ogologo River's biophysical environment. It focused on:

1. Quantifying PAH concentrations across water, sediments, and periwinkles (*Tympanotonus fuscatus*) to characterize cross-matrix transfer;
2. Apportioning pollution sources (pyrogenic vs. petrogenic) using diagnostic ratios;
3. Evaluating ecological and human health risks for local communities. By integrating these dimensions, we deliver urgently needed evidence to guide remediation and policy interventions in one of the world's most oil-impacted regions.

By bridging these scientific and contextual gaps, this study delivered urgently needed evidence to guide remediation, policy interventions, and public health protection in one of the world's most oil-impacted regions.

2. MATERIALS AND METHOD

2.1. Study/ Sampling Area

The Anya-Ogologo River is a significant tidal channel flowing through central Port Harcourt,

Nigeria, known for its history of pollution and flooding. Its course runs through densely populated residential and commercial areas like D/Line and Diobu, and it passes under the Ikoku Flyover before connecting to the Port Harcourt Creek system (The Tide, 2022; Nwido *et al.*, 2023). The geographic coordinates for a central point of the river are approximately Latitude 4.8015° N, Longitude 7.0195° E.

2.2. Determination of PAHs in Water Sample from Anya-Ogolo River.

Water Sample Collection and Pre-Treatments

Surface water samples were collected in triplicate from three stations (Stations 1–3) along Anya-Ogolo River on 26 November 2021 (Figure 1). Amber glass bottles, pre-cleaned with 2.5% nitric acid to eliminate trace metal contamination, were used for collection. Samples were immediately stored below 4°C during transport to preserve chemical integrity prior to laboratory analysis.

Extraction and Analysis of PAHs in Water Sample Prior to analysis, water samples were sequentially filtered through a cellulose filter (Quanta, 8.0 µm pore size, 90 mm diameter) followed by a glass fiber prefilter (0.45 µm, 47 mm diameter), with 800 mL of filtrate then processed using preconditioned Strata C18-E cartridges (Phenomenex; 3 mL volume, 200 mg C18 adsorbent) that were first rinsed with 3 mL each of dichloromethane, methanol and deionized water (5 mL·min⁻¹ flow rate) and dried with clean air for 20 min before PAH elution using 3 mL dichloromethane. The extracts were then spiked with 50 µL of binaphthyl-2,2-dihydrogenphosphate internal standard (1000 µg·L⁻¹ in acetonitrile), concentrated to dryness under nitrogen, and reconstituted in 500 µL acetonitrile for triplicate injection (20 µL aliquots) into an HPLC system (Shimadzu Model 20A with SIL-20AC autosampler, SPD-M20A detector, and Lichrospher PAH column [Agilent, C18, 250×3 mm, 5 µm] at 40°C) using an acetonitrile/water gradient (60:40 for 5 min → 85:15 over 10 min → 95:5 over 10 min [held 9 min] → 60:40 over 4 min [held 2 min]) at 0.6 mL·min⁻¹ flow rate, with detection at

compound-specific λ_{max}: Nap (254 nm), Acy (220 nm), Ace/Flu (226 nm), Phe/Ant (250 nm), Flt (235 nm), Pyr (240 nm), BaA (285 nm), Chr (266 nm), BbF/BkF (254 nm), and BaP (295 nm). (Nwido, N.J, *et al.*, 2023).

2.3. Estimation Of PAHs in Sediments Samples from Anya-Ogolo River

Sediment Samples Collection and Pre-Treatments

Three sample of the intertidal sediments were collected from three different location in Anya-Ogolo River with a clean shovel from the top layer of about 10-20cm, avoiding the water-sediment interface to minimize contamination and was emptied into a laboratory sampling bottle labelled station 1, 2, and 3. It was then placed into ice-filled cooler, and transported to the laboratory for analysis. At the laboratory, the sediment sample was dried with freeze-drying techniques.

2.4. Extraction and analysis of PAHs in Sediment Samples

10g of soil sediment was weighed, and 10 ml of dichloromethane (DCM) extraction solvent was added, and the mixture was stirred (thoroughly mixed). About 30 minutes were given for the mixture to settle so that the organic and aqueous phases could be separated. To get rid of any impurities, the separated aqueous layer was filtered. The above processes were carried out using n-pentane to ensure that only PAHs and not any other hydrocarbons present in the samples were extracted. An Agilent 7890B Gas Chromatograph (GC-MS from Agilent Technologies, Inc. Santa Clara, California, USA), was used to measure the PAH concentration (U.S. EPA, 2014).

2.5. Determination of PAH in Periwinkle from Anya-Ogolo River

Periwinkle Sampling and Pre-Treatment

The periwinkle Samples were collected in three different locations (station1 (Runnuolumeni Town,

located near the NNS Pathfinder in the Mgbosimini Community area), station 2 (Eagle Island, located near Kidney Island on the Bonny River and station 3 (Google Earama (located near the Saipem Base) in triplicate each on 26th November 2021, from the swamp surface in Anya-Ogologo River (Figure 1). Samples were wrapped in aluminum foil and transported to the laboratory for analysis. They were then washed with deionized water to remove all dirt particles, and also shelled and kept in an oven at 65 °C for 2 days after which they were grounded to powdered form. After sampling, they were maintained below 4 °C and were taken to the laboratory immediately for analysis.

2.5. Extraction and Analysis of PAHs in Periwinkle Sample

1.0g of the powdered sea food sample was digested in 6 ml of HCl and made up to 30ml with distilled water. Filtration was carried out using an acid wash filter paper (Whatman) and stored in sample bottles. The filtrate was passed through 3mL Strata C₁₈-E cartridges (Phenomenex) containing 200mg of C₁₈ adsorbent, previously conditioned by passing 3mL of dichloromethane, methanol and deionized water at a flow rate of 5mL min⁻¹.

Clean ambient air was then passed through the cartridge for 20min, and the PAHs were eluted with 3mL of dichloromethane. An aliquot of 50µL of solution (1000µg·L⁻¹ 1000 µg·L⁻¹ binaphthyl-2,2-dihydrogenphosphate in acetonitrile) was added to the extracts, the solvent was evaporated to dryness with nitrogen gas, and the extract was resuspended in 500 µL of acetonitrile. Aliquots (20µL) of the extract were injected, in triplicate, into a liquid chromatography system (Model 20A, Shimadzu) equipped with an automatic injection module (Model SIL-20AC) and a UV-Vis-DAD detector (Model SPM-M20A). The column (Lichrospher PAH, C₁₈, 250mm × 3mm, 5µm, Agilent) was maintained at 40 °C. The mobile phase was acetonitrile/water, with an initial concentration of

60:40 for 5 min, followed by a change to 85:15 over 10 min, then to 95:05 over 10min, with a hold for 9 min, then to 60:40 over 4min, with a hold for 2min. The mobile phase flow rate was 0.6 mL·min⁻¹. The chromatograms were obtained using the maximum absorbance wavelength of each PAH: Nap (254nm), Acy (220nm), Ace and Flu (226nm), Phe (250nm), Ant (250nm), Flt (235nm), Pyr (240nm), BaA (285nm), Chr (266nm), BbF (254nm), BkF (254nm) and BaP (295nm). (Agilent technology 2015).

2.6. Source apportionment and statistical evaluation

To quantify the contribution of each potential source to the PAH contamination in the water surface, sediment, and periwinkle samples based on the statistical analysis, Reference values for diagnostic ratios of PAHs compound were adopted as the major sources of PAHs in each sample type to examine the sixteen (16) PAHs that USEPA considers priority as shown in table 1 below.

The hydrocarbon source is considered pyrogenic if the predicted ratio of phenanthrene to anthracene is less than 10. The presence of petrogenic sources is assumed when the value is more than 10 (Boehm and Saba, 2008). In addition, it is generally accepted that a ratio of fluoranthene to pyrene (Flth/Py) of less than one (1) is the point to a source of hydrocarbon contamination (Anyakora *et al.*, 2011). More than one (>1.0) was the FLth/PY ratio of PAHs. If the Flth/Py ratio is less than one (<1.0), then the PAHs likely to originate from a petrogenic source, whereas if it is more than one (>1.0), then the PAHs likely originated from a pyrogenic or pyrolytic source

Table 1. Reference values for diagnostic ratios of PAHs compound

PAH ratio	Value range	Source	Reference
Phen/Ant h	< 10	Pyrogenic	or Boehm and Saba, 2008
	>10	pyrolytic Petrogenic	
BaA/Chy	<0.5	Petrogenic	Yunker <i>et al.</i> , 2002
	>0.5	Pyrogenic pyrolytic	
Flth/Py	<1.0	Petrogenic	Anyakora <i>et al.</i> , 2011
	>1.0	Pyrogenic pyrolytic	
ANT/(ANT + PHE)	<0.1	Petrogenic	Pies <i>et al.</i> , 2008
	>0.1	Pyrogenic	

2.7. Method of data analysis

The laboratory data were analyzed using IBM SPSS Statistics (version 25.0). Results were presented in tables as mean \pm standard error of the mean (SEM). Differences between sample means were assessed using one-way analysis of variance (ANOVA), with statistical significance set at $p < 0.05$.

2.7.1. PAH diagnostic ratios analysis

The Anth/ (Anth + Phen) Ratio, BaA/Chry Ratio, Flth/py Ratio, and Phen/ (Anth + Phen) Ratio were only a few of the diagnostic ratios utilized to pinpoint the sources of the PAHS discovered in this inquiry.

2.7.2. Probabilistic model of human health risk assessment

The risk-based approach takes into account the exposure pathways including inhalation exposure and dermal contact. Three age groups are considered: child (1–11 years), adolescent (12–17 years), and adult (18–70 years). The incremental lifetime cancer risk (ILCR) for incidental inhalation is defined with the formula below (Goudarzi *et al.*, 2021):

$$R_I = \frac{C_a \left(CSF_i \left(\frac{BW}{70} \right)^{1/3} \right) IR_{air} \cdot EF \cdot ED}{BW \cdot AT} \times cf \quad (1)$$

Where R_I is the incremental individual lifetime cancer risk associated with inhalation, CSF_i is the inhalation carcinogenic slope factor ($\text{mg kg}^{-1} \text{d}^{-1}$), IR_{air} is the inhalation rate ($\text{m}^3 \text{d}^{-1}$), C_a is the air concentration of PAHs (ng m^{-3}), EF is the exposure frequency (d year^{-1}), ED is the exposure duration (year), AT is the averaging time for carcinogens (d), BW is the body weight (kg), and cf is the conversion factor (106). In the equation, C_a , IR_{air} , CSF_i , BW , and EF were treated probabilistically.

The ILCR for dermal contact pathway is defined as:

$$R_D = \frac{C_{pa} \left(CSF_d \left(\frac{BW}{70} \right)^{1/3} \right) AB \cdot SA \cdot EV \cdot AF_d \cdot EF \cdot ED}{BW \cdot AT} \times cf \quad (2)$$

Where R_D is the incremental individual lifetime cancer risk associated with dermal contact, C_{pa} is the particle bound PAH concentration ($\mu\text{g g}^{-1}$), CSF_d is the carcinogenic slope factor for dermal contact ($\text{mg kg}^{-1} \text{d}^{-1}$), AB is the dermal adsorption fraction (dimensionless), SA is the dermal surface area exposed (cm^2), EV is the event frequency (event d^{-1}), and AF_d is the particle-to-skin adherence factor ($\text{mg cm}^{-2} \text{event}^{-1}$). C_{pa} , BW , AB , SA , AF_d , and EF were treated in the equation probabilistically.

The total risk is the sum of risks associated with each exposure route. The ILCRs for adult, adolescent, and child were calculated respectively as:

$$\text{For adult:} \quad ILCR = \sum_{i=18}^{70} Ri / 53$$

$$\text{For adolescent:} \quad ILCR = \sum_{i=12}^{17} Ri / 6$$

$$\text{For child:} \quad ILCR = \sum_{i=1}^{11} Ri / 11$$

A 70-year lifetime exposure period (equivalent to

(AT) 25,550 days at 365 days/year) was used for cancer risk assessment calculations, utilizing the benzo[a]pyrene (B[a]P) potency factor derived from the 95% upper confidence limit of the linearized multistage model (OEHHA, 1993). The cancer slope factors are normalized to account for extrapolation to a different body weight from standard of 70 kg (Equations 1 and 2). The acceptable risk distribution was assigned by constraints on percentiles. As shown in Table 2 below. Anthracene and phenanthrene (Phen/Anth), fluoranthene and pyrene (Flth/Py), benzo (a) anthracene and chrysene (BaA/Chry), and Anthracene and phenanthrene (Anth/ (Anth + Phen)) were all determined by calculations.

Cancer evidence and potency equivalency factor for PAHs used in this study PAHs were classified according to IARC (1987) criteria Potency equivalency factors (PEFs) were derived from Malcolm and Dobson (1994).

3. RESULTS AND DISCUSSION

3.1. PAHs in water of Anya-Ogolo River

The levels of PAHs in the water samples from the various locations is shown in Table 3. Naphthalene levels were found to be below the detectable limit (DBL) at every location (stations 1, 2 and 3). Acenaphthylene, acenaphthene, chrysene, benzo(b) fluoranthene, benzo(k) fluoranthene, benzo(g,h,i) perylene, benzo(a) pyrene, Dibenz (a, h) anthracene and indeno (1,2,3 -cd) pyrene were below detectable limit across all the stations (station 1, 2 and 3). At stations 1, 2, and 3, fluorene was found with mean values of 0.14±0.02 mg/L, 0.04±0.00 mg/L, and 0.05±0.00 mg/L respectively. Phenanthrene, Anthracene, and Fluoranthene were also found in water samples from all sites, and their mean concentrations were significantly different from controls at all stations, with a statistical significance level of 0.05. Pyrene was found in water samples from stations 2 and 3 with mean values of 0.28±0.00 mg/L, and 0.05±0.00 mg/L

respectively. However, it was below the detectable limit in samples from station 1. Benz (a) anthracene was furthermore found in station 2 with a mean value of 0.32±0.01 mg/L, however it was below the detectable limit in stations 1 and 3. In stations where PAHs were discovered, statistical comparisons of the concentrations with the controls revealed a significant difference at $p < 0.05$.

The PAHs found in water were below detectable limit according to the data shown in Table 3.

Table 2. Probabilistic model of human health risk assessment

Name Abbreviation	with	IARC Classifica tion	US EPA Classificati on	PEF
Benzo[a]pyrene (BaP)		2A	B2	1
PAHs				
Acenaphthene (Acp)		3	D	0.001
Acenaphthylene (AcPy)		3	D	0.001
Anthracene (Ant)		3	D	0.01
Benzo[a]anthracene (BaA)		2A	B2	0.1
Benzo[b]chrysene (BbC)		-	-	NA
Benzo[b]fluoranthene (BbFT)		2B	B2	0.1
Benzo[k]fluoranthene (BkFT)		2B	B2	0.1
Benzo[e]pyrene (BeP)		3	-	0.01
Benzo[g,h,i]perylene (BghiP)		3	D	0.01
Chrysene (CHR)		3	B2	0.01
Coronene (COR)		3	-	0.001 c
Cyclopenta[c,d]pyrene (C[c,d]P)		3	-	0.1c
Dibenzo[a,h]anthracene (DahA)		2A	B2	1c
Fluoranthene (FL)		3	D	0.001
Fluorene (Flu)		3	D	0.001
Indeno[1,2,3-c,d]pyrene (Inc[d]P)		2B	B2	0.1
Naphthalene (Nap)		2B	-	0.001
Perylene (PER)		3	-	0.001 c
Phenanthrene (PA)		3	D	0.001
Pyrene (Pyr)		3	D	0.001

Acenaphthene, fluorene, anthracene, phenanthrene, fluoranthene, pyrene, and benz(a)anthracene were found in the water samples. The PAH concentrations in the tested water samples range from 0.04 to 0.34, 0.04 to 4.08, and 0.05 to 0.66 mg/l, with total values for stations 1, 2, and 3 of 0.72, 8.65, and 1.08 mg/l, respectively. Also, there were no values of the two ringed PAHs in the distribution of PAHs in the water samples. Three ring PAHs concentrations in the water samples were 0.68, 5.83, and 1.03 mg/l for stations 1, 2, and 3, respectively. Station 2 had the highest concentration of four ring PAHs (2.50 mg/l) in the water sample; and Only station 2 had the water sample with a concentration of 0.32 mg/l contained five-six ring PAHs. Low molecular weight PAHs were detected at low amounts in stations 1 and 3, whereas high molecular weight PAHs were identified in stations 2 and 3 at values of 0.68, 5.83, and 1.03 mg/l in the water samples, respectively.

In this investigation, the total concentration of PAHs in the water were 0.72, 8.65, and 1.08 mg/l from stations 1, 2, and 3, respectively. The standard deviation was 0.05, 0.14, and 0.02 for stations 1, 2, and 3, respectively. This is an obvious indication that the Anya-Ogologo River is heavily contaminated with both low and high molecular weight PAHs. HMW PAHs had standard deviations of zero, while LMW PAHs had standard deviation in the following order: 0.09 (station 2) > 0.05 (station 1) > 0.02 (station 3).

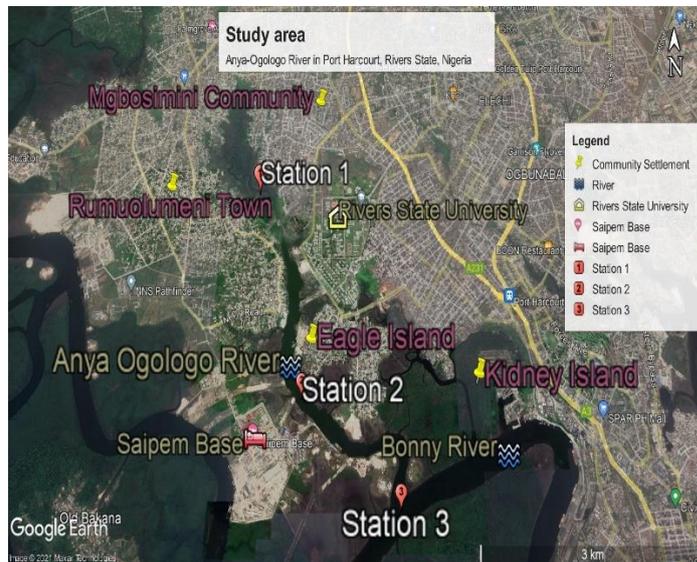


Figure 1: Map of Anya-Ogologo River in Port Harcourt, Rivers State, Nigeria



Figure 2: Map of Omuechi stream, Aluu in Port Harcourt, Rivers State, Nigeria

Table 3. Mean concentration and standard deviation of PAHs in the Water samples

Parameter	Concentration (mg/L)			
	Control	Station 1	Station 2	Station 3
Naphthalene	BDL	BDL	BDL	BDL
Acenaphthylene	BDL	BDL	BDL	BDL
Acenaphthene	0.001±0.001	BDL	BDL	BDL
Fluorene	0.0001±0.0001	0.14±0.02 ^a	0.04±0.00 ^a	0.05±0.00 ^a
Phenanthrene	0.0002±0.0002	0.34±0.03 ^a	4.08±0.07 ^a	0.05±0.00 ^a
Anthracene	0.0002±0.00013	0.21±0.00 ^a	1.70±0.01 ^a	0.66±0.017 ^a
Fluoranthene	BDL	0.04±0.01 ^a	2.21±0.04 ^a	0.26±0.09 ^a
Pyrene	BDL	BDL	0.28±0.00 ^a	0.05±0.00 ^a
Chrysene	BDL	BDL	BDL	BDL
Benz (a) anthracene	BDL	BDL	0.32±0.01	BDL
Benzo (b) Fluoranthene	BDL	BDL	BDL	BDL
Benzo (k) Fluoranthene	BDL	BDL	BDL	BDL
Benzo (g, h, i) perylene	BDL	BDL	BDL	BDL
Benzo (a) pyrene	BDL	BDL	BDL	BDL
Dibenz (a, h) anthracene	BDL	BDL	BDL	BDL
Indeno (1, 2, 3, -cd) pyrene	BDL	BDL	BDL	BDL

BDL = Below Detectable Limit; ^aThe mean difference is significant at the 0.05 level when compared to control.

Estimation of PAHs in sediment from Anya-Ogologo River

The quantity of PAHs in the sediment samples from various sites as shown in Table 4. It shows that Naphthalene levels were below the detectable limit at every location (stations 1, 2 and 3). Chrysene, Benzo (b) Fluoranthene, Benzo (k) Fluoranthene, Benzo (g, h, I) Perylene, Benzo (a) Pyrene, Dibenz (a, h) Anthracene, and Indeno (1, 2, 3, -cd) Pyrene were all found to exhibit this pattern at all stations (1, 2 and 3). In sediment samples from stations 1 and 2, acenaphthylene and acenaphthene were below the detectable limit, but they were present in

sediment sample from station 3, with a mean value of 0.110.00 and 0.250.02 for acenaphthylene and acenaphthene respectively. Sediment samples from all sites has the following PAHs: Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, and Benz (a) anthracene (1, 2 and 3).

The finding showed total values of 1.76, 8.47, and 5.71 mg/kg for sediments 1, 2, and 3, respectively, indicated that the evaluated sediment samples had PAHs concentrations ranging from 0.04 to 1.16 mg/kg, from 0.05 to 4.69 mg/kg, and from 0.04 to 4.64 mg/kg respectively. The PAHs in sediment samples include acenaphthylene, acenaphthene, fluorene, anthracene, phenanthrene, fluoranthene, pyrene, and benz(a)anthracene. Among all the PAHs found, Station 2 had the highest overall PAH concentration (8.47 mg/kg). It was clear from Table 4.2 that the sediment sample showed relatively modest levels of the two ringed PAHs. Three ring PAH concentrations were found in the sediment samples to be 0.06, 0.09, and 0.02 mg/kg for stations 1, 2, and 3, respectively, with standard deviations of 0.03, 0.02, and 0.13 mg/kg for stations 1, 2, and 3 respectively. The soil samples from Station 2 had the greatest levels of four ringed PAHs (2.07 mg/kg). In the sediment samples from the three distinct locations, five to six ringed PAHs were found. Stations 1 and 3 both had relatively modest quantities of high molecular weight PAHs. It is abundantly obvious from the higher values assigned to low molecular weight PAHs and the lower values assigned to high molecular weight PAHs that the Anya-Ogologo River. Station 2 was found to have the greatest levels of both HMW and LMW PAHs. Both (LMW) and (HMW) PAHs were found and identified in the sediment samples from the three distinct Anya-Ogologo River sites used in this investigation. This demonstrates that both low temperature and high temperature processes contributed to the PAHs found in the Anya-Ogologo River. In contrast to the light-weight n-alkanes, the PAHs levels in Anya-Ogologo River

sites as presented in table 4 are in significant quantities.

Table 4. Concentration and standard deviation of PAHs in the sediment samples

Parameter	Concentration (mg/kg)			
	Control	Station 1	Station 2	Station 3
Naphthalene	BDL	BDL	BDL	BDL
Acenaphthylene	0.002±0.00	BDL	BDL	0.11±0.00 ^a
Acenaphthene	0.01±0.01	BDL	BDL	0.25±0.02 ^a
Fluorene	0.003±0.00	0.13±0.00 ^a	0.05±0.00 ^a	0.13±0.01 ^a
Phenanthrene	0.004±0.00	1.16±0.02 ^a	4.69±0.12 ^a	4.64±0.13 ^a
Anthracene	0.03±0.033	0.21±0.01 ^a	1.33±0.01 ^a	0.35±0.02 ^a
Fluoranthene	0.004±0.00	0.13±0.01 ^a	1.63±0.02 ^a	0.12±0.00 ^a
Pyrene	BDL	0.09±0.00 ^a	0.44±0.00 ^a	0.08±0.01 ^a
Chrysene	BDL	BDL	BDL	BDL
Benz (a) anthracene	BDL	0.04±0.00 ^a	0.34±0.02 ^a	0.04±0.00 ^a
Benzo (b) Fluoranthene	BDL	BDL	BDL	BDL
Benzo (k) Fluoranthene	BDL	BDL	BDL	BDL
Benzo (g, h, i) perylene	BDL	BDL	BDL	BDL
Benzo (a) pyrene	BDL	BDL	BDL	BDL
Dibenz (a, h) anthracene	BDL	BDL	BDL	BDL
Indeno (1, 2, 3, -cd) pyrene	BDL	BDL	BDL	BDL

BDL= Below Detectable Limit; ^aThe mean difference is significant at the 0.05 level when compared to control

Concentration of PAHs in periwinkle from Anya-Ogologo River

Periwinkle samples which contain; Fluorene, Phenanthrene, and Anthracene, with mean concentrations of 0.080.01, 0.180.05, and 0.080.04 for each compound, respectively shown in Table 5 revealed that the PAHs contents in the periwinkle sample from the Anya-Ogologo River ranged from 0.08 to 0.18 mg/kg with a total value of 0.34 mg/kg. Fluorene (0.08 mg/kg), phenanthrene (0.18 mg/kg), and anthracene (0.08 mg/kg) were also found in the periwinkle sample, with standard deviations of 0.01, 0.05, and 0.04, respectively. Three ringed PAHs were present in biota (periwinkle) samples at a concentration of 0.34 mg/kg; However, no PAH concentrations were found for two, four, five or six ring PAHs. In addition, only LMW PAHs with a standard deviation of 0.10 were found in the biota sample, with no HMW PAHs present. value of 0.48 was obtained from the bio-concentration factor for the biota. It is estimated by dividing the levels of PAHs present in the biota itself by the levels of PAHs present in the water sample where the biota is present. The bio-concentration factor from our investigation, however, produced a value (0.48) that is below 1.

Table 5. Concentration and standard of PAHs in the periwinkle samples

Sample	Station	Phen/Anth Ratio	BaA/Chry Ratio	Flth/py Ratio	Anth/(Anth + Phen) Ratio
Water	1	1.62	0	0.00	0.38
Water	2	2.40	0	7.89	0.29
Water	3	2.44	0	0.00	0.29
Sediment	1	5.52	0	1.44	0.15
Sediment	2	3.53	0	3.70	0.22
Sediment	3	13.26	0	1.50	0.07
Periwinkle sample	-	2.25	0	0.00	0.31

BDL = below detectable limit.

Source apportionment of polycyclic aromatic hydrocarbons in the study area using different diagnostic ratio

The diagnostic ratios in Table 6 uniformly indicate pyrogenic PAH sources (Phen/Anth: 1.62-13.26 >1; Flth/Py: 0.00-7.89 with detectable values >0.6; Anth/[Anth+Phen]: 0.07-0.38 <0.5), show negligible petrogenic input (BaA/Chry = 0 throughout), demonstrate strongest combustion signals in sediments (Station 3 Phen/Anth = 13.26), and reveal periwinkle ratios (Phen/Anth = 2.25) consistent with waterborne rather than sedimentary PAH uptake.

The approach that seems to be the most effective for distinguishing between pyrogenic and petrogenic hydrocarbons is the examination of the sixteen (16) PAHs that USEPA considers priority pollutant, which were studied.

Table 6. Diagnostic ratios of PAHs in test samples

Group name	Average
Naphthalene	BDL
Acenaphthylene	BDL
Acenaphthene	BDL
Fluorene	0.08±0.01
Phenanthrene	0.18±0.05
Anthracene	0.08±0.04
Fluoranthene	BDL
Pyrene	BDL
Chrysene	BDL
Benz (a) anthracene	BDL
Benzo (b) Fluoranthene	BDL
Benzo (k) Fluoranthene	BDL
Benzo (g, h, i) perylene	BDL
Benzo (a) pyrene	BDL
Dibenz (a, h) anthracene	BDL
Indeno (1, 2, 3, -cd) pyrene	BDL

The use of a Phen/Anth ratio that was lower than ten and a Flth/Py ratio that was greater than one to suggest pollution sources of process combustion was also observed. This is in-line with Barakat *et al.*, 2001. With the exception of W1, W3, and P, all of the samples had Flth/Py values greater than 1.0. The implication is that in addition to being petrogenic, the sources of hydrocarbons could also be

pyrogenic or come from other sources in addition to being petrogenic. No sample has a BaA/Chry ratio that is larger than zero. A high BaA/Chry ratio indicates that there are more pyrogenic sources present, while a low BaA/Chry ratio indicates that there are more petrogenic sources present (Nwaichi and Ntorgbo, 2015). The phen to anthocyanin ratios

in the different samples vary from 1.62 to 13.26. (less than 10 for all samples except for S3). This shows that the PAHs discovered in the samples came from an additional source, such as combustion

operations in the study region. The research region would have been exposed to nearby agricultural property that underwent bush combustion, and the components realized from the bush burning were washed into the river immediately before the occurrence of oil spills, even though there was an oil spill that resulted in a petrogenic source of PAHs. The PAH diagnostic ratios demonstrate this, indicating that there was a petrogenic source of PAHs despite having been an oil spill. An anthracene-phenanthrene ratio value of less than 0.1 indicates a petrogenic source, while a value of more than 0.1 indicates a pyrogenic source. The findings for the ratio of anthocyanins to total anthocyanins and phenanthrene are, 0.38, 0.29, and 0.29 respectively. The values found in the sediment samples are as follows: for sediments from stations 1, 2, and 3, 0.15, 0.22, and 0.67 respectively. After analysis, the river biota sample produced a value of 0.31. All of the findings are compatible with petrogenic origins since they all fall within a range that is smaller than 1.

4. CONCLUSION

The results and values from the four (4) different diagnostic ratios used for source apportionment indicate and confirm that the total petroleum hydrocarbons and PAHs found in the periwinkle, sediment, and water samples that were analyzed were produced by pyrogenic and petrogenic sources.

This study revealed severe polycyclic aromatic hydrocarbon (PAH) contamination in the Anya-Ogologo River ecosystem, with concerning levels detected across water (0.72-8.65 mg/L), sediments (1.76-8.47 mg/kg), and periwinkles (0.34 mg/kg). The diagnostic ratio analysis demonstrated that pyrogenic combustion processes were the predominant pollution sources, with Phen/Anth ratios ranging from 1.62 to 13.26 and Flth/Py ratios between 0.00-7.89. The probabilistic health risk assessment identified significant carcinogenic risks,

particularly for children through dermal exposure pathways, with incremental lifetime cancer risk values exceeding acceptable thresholds (ILCR >10⁻⁶).

The findings highlight the urgent need for remediation strategies targeting combustion-related pollution sources in the Niger Delta region. The multi-matrix assessment approach provided comprehensive insights into PAH distribution patterns and bioaccumulation dynamics in this tropical aquatic ecosystem. Future studies should incorporate longitudinal monitoring to track contamination trends and evaluate the effectiveness of mitigation measures. The results serve as critical baseline data for environmental policymakers and public health officials to develop targeted interventions that protect both ecosystem integrity and human health in oil-impacted communities. information about funding sources.

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