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Research Article

Forensic Identification of Sources and Ecological Risk Assessment of Polycyclic Aromatic Hydrocarbons in an Aquatic Ecosystem

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Abstract

Background and Objective: Polycyclic Aromatic Hydrocarbons (PAHs) are environmental pollutants formed at high temperatures and under pyrolytic conditions during the incomplete combustion of organic matter. This paper reports sources and ecological risk assessment of PAHs in sediment and specimens of *Pachymelania aurita* in a Nigerian Coastal aquatic ecosystem. **Materials and Methods:** The study involved six months collection of water, sediment and macrofauna samples from five study locations. Sixteen priority PAHs pollutants described by the USEPA were analyzed to determine variation in concentration and distribution in the study area. The sources of these pollutants in the study area was investigated using the diagnostic ratio method. Ecological risk factors were computed to determine the risk posed by these pollutants and statistical analyses were performed to evaluate the relationship between PAH concentrations in samples and to determine variation in risk parameters. **Results:** Values of $\Sigma 16$ PAHs were highest in sediment with a range of 4.7-13.0 $\mu\text{g kg}^{-1}$. Among the PAHs, chrysene and benz[a]anthracene occurred in relatively higher concentrations in the collected samples. Polycyclic aromatic hydrocarbons in the area may have originated majorly from pyrolytic sources, with some elements of petrogenic input in sediment samples. Hazard Index was highest for sediment samples. Values of BAF were higher than BSAF in all the sampling points. **Conclusion:** The concentrations of individual and $\Sigma 16$ PAHs at the sampling points were below regulatory limits in most cases, however, the growing anthropogenic activities may result in the aggravation of risk parameters for the study area which may lead to general threat to ecological integrity.

Key words: Source, ecological risk, sediment, macrofauna, coastal, PAH

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

All over the world, the environmental danger posed by Polycyclic Aromatic Hydrocarbons (PAHs) has been widely reported^{1,2}. Polycyclic aromatic hydrocarbons, belong to a group of organic chemicals that have two or more condensed aromatic rings and are ubiquitous pollutants in air, water and soil and are known to be environmentally harmful³. According to Tonge *et al.*⁴ they are widely detected in the aquatic environment and are mainly classified into four major types depending on their sources. They include: (a) PAHs from fuels (petrogenic), (b) PAHs derived from an incomplete combustion process (pyrogenic), (c) PAHs generated by organic metabolism (biogenic) and (d) PAHs from the transformation process in sediment (diagenetic). Of these four types, petrogenic and pyrogenic sources are mainly generated anthropogenically and are significant contributors to environmental PAH pollution in aquatic ecosystems^{5,6}.

Hydrocarbons are major components of crude oil and are classified as; aliphatic saturated hydrocarbons, aliphatic unsaturated hydrocarbons and alicyclic saturated hydrocarbons⁷. The impact of these categories on the environment is due mainly to their specific toxicity⁸. The toxicity of PAHs and their widespread distribution has led to more attention to the presence of these compounds in the aquatic environment⁹. Petrogenic PAHs enter aquatic environments through a number of sources such as; natural oil seeps from erosion of coal, peat and oil shale deposits; oil and coal spills; release of treated and untreated ballast and bilge water from ships and discharge from oil refineries, oil/water separators on oil production platforms, coal-fired power plants, stormwater runoff and municipal sewage treatment plants¹⁰. Domestic and industrial activities, as well as natural events such as forest fires, produce PAHs by pyrolysis/pyrosynthesis^{2,11}.

Coastal ecosystems in Nigeria are under serious environmental degradation arising from inefficient waste management systems and poor land use management practices within and around their catchment areas¹². Direct release of untreated domestic wastes, wood waste, detrital materials from sundry sources, organic effluents from industrial operations and other human activities into the lagoon systems threaten the ecological integrity of these water bodies¹³. These waste ends up in the benthic region, which is the ultimate sink for all materials discharged into the aquatic environment¹².

The benthic genus, *Pachymelania*, is one of the most common and most dominant gastropod molluscs in the southwestern lagoon system of Nigeria¹⁴. It is endemic to West Africa and harvested by natives of coastal communities as staple source of protein. The production and population

dynamics as well as the ecology and natural food components of *P. aurita* in the brackish water Lagos Lagoon have been reported¹⁴. A major gap in the study of the ecology of this genus, is the dearth of knowledge regarding its response to and interaction with specific pollutants in natural environmental conditions. This has made it difficult to determine the ecological risk faced by this important taxon in polluted coastal ecosystems of Nigeria. This present study therefore, is aimed at forensic identification of the sources and assessment of the ecological risk posed by PAH to this organism and its habitat.

MATERIALS AND METHODS

This study was conducted in the western part of the Lagos Lagoon, which houses many industries located along the shoreline. These industries discharge their waste into the lagoon. The study lasted for six months, from November, 2021 to April, 2022, during which collection of samples and analyses of PAHs in the samples (water, sediment and macrofaunal) were carried out.

Description of research area: The Lagos Lagoon is located on a low-lying coast and oriented parallel to the coastline, between Latitudes 60° 26' and 60° 38' N and Longitudes 30° 23' and 30° 43' E. The overall characteristics of the area reflect the basin morphometry as determined by anthropogenic alteration, marine and watershed influences¹⁴.

The lagoon is under serious environmental perturbation arising from inefficient waste management system in the metropolitan city of Lagos¹⁴. Direct discharge of untreated domestic waste, wood waste, detrital materials from adjoining vegetated lands, organic effluents from industrial operations and the introduction of petroleum products from sundry sources into the lagoon system threaten the ecological integrity of the study area¹². Five sampling points, four of which are major points for one anthropogenic activity or the other, and the fifth was relatively free from human activity, were sampled for this study.

Collection of water, sediment and *P. aurita*

Water: Water samples were collected in two amber-coloured 250 mL bottles from the five study stations. Samples were stored in a refrigerator with the addition of 0.05% (w/v) Sodium Azide (NaN₃) prior to analysis.

Sediment: Three replicates of sediment samples were collected from each sampling point, using a van Veen grab of size 0.1 m². The top 5 cm layer of each haul was collected and placed in a labeled polythene bag and taken to the laboratory for analysis.

Specimens of *P. aurita*: Three grab hauls for macrofauna were taken from each station, the collected material was washed through a 0.5 mm mesh sieve. The residue in the sieve was kept in labeled plastic containers for laboratory investigation. Samples were kept in the refrigerator prior to analysis.

Laboratory investigation

Identifications of specimens of *P. aurita*: Preserved macrofauna samples were sorted on a white tray and specimens of *P. aurita* were selected using previous studies¹⁵ as guide.

Species of PAHs investigated: Sixteen PAHs identified as priority pollutants by the the (United States Environmental Protection Agency) USEPA due to their toxic, mutagenic and carcinogenic characteristics were investigated. These include; low molecular weight (LMW) compounds (152-178 g mol⁻¹): Naphthalene (N, 2-rings), acenaphthene (Ace, 3-rings), acenaphthylene (Acy, 3-rings), anthracene (Ant, 3-rings), fluorine (Fl, 3-rings) and phenanthrene (Phe, 3-rings); medium molecular weight (MMW) compounds (202 g mol⁻¹): Fluoranthene (Flu, 4 rings) and pyrene (Pyr, 4-rings) and high molecular weight (HMW) compounds (228-278 g mol⁻¹): Benz[a]anthracene (BaA, 4-rings), benzo[b]fluoranthene (BbF, 5-rings), benzo[k]fluoranthene (BkF, 5-rings), benzo[g,h,i]perylene (BghiP, 6-rings), benzo[a]pyrene (BaP, 5-rings), chrysene (Chry, 4-rings), dibenz[a,h]anthracene (DBA, 5-rings) and indeno[1,2,3-c,d]pyrene (IP, 6-rings)¹⁶.

Extraction procedure for PAHs in water, sediment and *P. aurita*: A liquid-liquid extraction methodology using dichloromethane (DCM) followed by Gas Chromatography Mass Spectrometry (GC/MS) was used for the extraction of PAHs in water, sediment and *P. aurita* samples. Detail procedures^{16,17} followed recommendations and methods well known for hydrocarbon analysis.

Source Identification of PAHs: Diagnostic ratios as described in Liu *et al.*¹⁸, were used for differentiating petrogenic and pyrogenic sources of PAHs in water, sediment and *P. aurita*.

Ecological risk assessment and characterization: Ecological risk assessment and characterization were carried out by computations of bioaccumulation factors (BAFs), hazard quotient (HQ) and hazard index (HI) for the different PAHs.

Computation of bioaccumulation parameters: Two parameters, bioaccumulation factors (BAFs) and biota sediment accumulation factors (BSAF) were investigated using recommended methods^{19,20}.

$$BAF = \frac{C_b}{C_w} \quad (1)$$

Where:

C_b = PAH concentration in the organism ($\mu\text{g g}^{-1}$)
 C_w = Concentrations of PAH in water ($\mu\text{g L}^{-1}$)

$$BSAF = \frac{C_{org}}{C_s} \quad (2)$$

Where:

C_{org} = Actual concentration of PAH in the organism
 C_s = True concentration of PAH in sediment

Values of these parameters (BAF and BSAF) less than or equal to 1 indicate that adverse effects are not likely to occur, whereas values >1 indicates possibility of adverse health effects^{21,22}.

Computation of hazard quotient and hazard index: Hazard quotient (HQ) is calculated using the following equation:

$$HQ = \frac{(\text{PAH})_{sol}}{\text{Chronic value or reference concentration}} \quad (3)$$

Where:

(PAH)_{sol} = Exposure concentration

Chronic value or reference concentration is an estimate of a continuous exposure to the *P. aurita* population that is likely to be without an appreciable risk of deleterious effects during a lifetime²². Hazard index (HI) is given as:

$$\sum HQ = HI \quad (4)$$

An HI value >1 indicates that the environmental medium contains a concentration of PAHs that may be harmful to macrofauna populations or the PAHs concentrations are in excess of its estimated chronic toxicity to macrofauna populations^{2,22}.

Statistical analysis: Comparative analysis was carried out between the concentration of PAHs in sediment and recommended values of effect range low (ERL) and effect range median (ERM) using the United States National Oceanic sediment quality guidelines²³⁻²⁶. The ERL is the concentration in bulk sediment below which toxicity to benthic organisms is unlikely, while the ERM is the concentration above which effects are likely.

The relationships between the concentration of PAHs in water, sediment and *P. aurita* and between BSAFs/BAFs for each PAH were determined using Spearman rank correlations and Pearson's correlations coefficient. Regression analysis ($p < 0.05$) was performed to determine the nature of these relationships. All statistical analyses were performed with SPSS 10 and Excel 2003; 2007 for Windows.

RESULTS AND DISCUSSION

Concentrations of PAHs in water, sediment and *P. aurita*

samples: The values of PAHs in water, sediment and macrofauna are summarized in Table 1. Concentrations of PAHs in water varied among sampling stations. Group total concentrations ($\Sigma 16$ PAHs) fluctuated between $2.0 \mu\text{g L}^{-1}$, which was recorded in station B and $7.0 \mu\text{g L}^{-1}$ observed in station A. Among the PAHs, chrysene and benz[a]anthracene occurred in relatively higher concentrations in water samples. The highest concentration ($2.5 \mu\text{g L}^{-1}$) of chrysene occurred in A and lowest ($0.9 \mu\text{g L}^{-1}$) at point B, while the concentration of benz[a]anthracene was highest ($2.0 \mu\text{g L}^{-1}$) at sampling point D and the lowest ($0.1 \mu\text{g L}^{-1}$) was recorded at point B.

Values of PAHs in sediment also varied remarkably among sampling stations. Group total concentrations fluctuated between $4.7 \mu\text{g L}^{-1}$, which was recorded in station B and $13.0 \mu\text{g kg}^{-1}$ observed in stations A and D. Chrysene, benz[a]anthracene and anthracene occurred in relatively higher concentrations. The concentration of chrysene was highest ($3.8 \mu\text{g kg}^{-1}$) at sampling point D and the lowest ($2.6 \mu\text{g kg}^{-1}$) at point B. Benz[a]anthracene recorded highest concentration ($3.0 \mu\text{g kg}^{-1}$) at sampling points A and D and

the lowest ($0.52 \mu\text{g kg}^{-1}$) was recorded at point B, while anthracene recorded lowest ($0.11 \mu\text{g kg}^{-1}$) and the highest ($1.7 \mu\text{g kg}^{-1}$) concentrations at station B and D, respectively.

The concentrations of PAHs in the body mass of *P. aurita* collected from the different sampling points also varied considerably. Group total concentrations fell between $0.5 \mu\text{g kg}^{-1}$, which was recorded in station B and $2.2 \mu\text{g kg}^{-1}$ observed in stations A and C. Chrysene, benz[a]anthracene and benzo[a]pyrene were the major representatives of PAHs. The concentration of chrysene was highest ($0.9 \mu\text{g kg}^{-1}$) in sampling point C and lowest ($0.24 \mu\text{g kg}^{-1}$) at point B, while a range of 0.099 - $0.4 \mu\text{g kg}^{-1}$ was observed for benz[a]anthracene with the lowest recorded at point B and highest score at sampling point A. Another PAH species that occurred in relatively significant concentrations is benzo[a]pyrene, its highest concentration ($210 \mu\text{g kg}^{-1}$) occurred in specimens collected from station C and the lowest concentration ($0.1 \mu\text{g kg}^{-1}$) was observed in station B. In the overall analysis, $\Sigma 16$ PAHs was highest in sediment compared to those of water and *P. aurita* samples. Representations of the 16 US-EPA priority PAHs in water, sediment and *P. aurita* samples recorded in this study shows a clear dominance of medium and high molecular weight PAHs.

The low-MW PAHs (2-3 rings) AZU, IND and DIB, were most abundant in water samples, while 4-ringed PAHs (ANT, FLU and PYR) were predominant in water and sediment than in *P. aurita* samples. Higher concentrations of PAHs recorded in sediment samples is expected, this is because, PAH compounds are removed from the water column by volatilization to the atmosphere, by binding to suspended particles or sediments or by being accumulated or absorbed

Table 1: Summary of values of PAHs in water, sediment and macrofauna

PAH	Water ($\mu\text{g L}^{-1}$)		Sediment ($\mu\text{g kg}^{-1}$)		Macrofauna ($\mu\text{g kg}^{-1}$)	
	Range	Mean	Range	Mean	Range	Mean
Naphthalene	0.00086-0.1	0.039	0.14-0.68	0.422	0.00028-0.012	0.045
Acenaphthylene	0.011-0.3	0.108	0.23-0.65	0.46	0.00013-0.0057	0.0025
Acenaphthene	0.0023-0.074	0.134	0.0031-0.9	0.2832	0.00021-0.011	0.003
Fluorene	0.0037-0.43	0.158	0.031-0.63	0.4362	0.0079-0.13	0.05
Phenanthrene	0.0076-0.37	0.168	0.02-0.55	0.318	0.0028-0.22	0.077
Anthracene	0.058-0.92	0.488	0.11-1.7	1.024	0.016-0.13	0.07
Fluoranthene	0.013-0.06	0.05	0.022-0.085	0.0574	0.0031-0.024	0.01
Pyrene	0.16-1.4	0.476	0.06-0.53	0.344	0.0075-0.024	0.09
Benz[a]anthracene	0.1-2.0	1.048	0.52-3.0	1.914	0.098-0.42	0.311
Chrysene	0.9-2.5	1.78	2.6-3.8	3.34	0.24-0.9	0.588
Benzo[b]fluoranthene	0.04-0.06	0.06	0.082-0.4	0.1724	0.0037-0.015	0.001
Benzo[k]fluoranthene	0.17-0.37	0.264	0.4-0.87	0.616	0.015-0.057	0.043
Benzo[a]pyrene	0.15-0.3	0.238	0.16-0.36	0.276	0.1-0.21	42.122
Indeno[1,2,3-cd]pyrene	0.00017-0.0013	0.001	0.001-0.0025	0.002	0.000022-0.001	0.0003
Dibenzo[a,h]anthracene	0.00034-0.0015	0.0009	0.00093-0.0021	0.002	0.000025-0.0008	0.0002
Benzo[ghi]perylene	0.00008-0.0008	0.004	0.00028-0.00044	0.005	0.000025-0.0008	0.00007

Table 2: Diagnostic ratios between PH/AN and FL/PY in water, sediment and macrofauna

Diagnostic ratio	Sampling points				
	A	B	C	D	E
Water					
PH/AN	0.4	0.40	0.20	0.60	0.19
FL/PY	0.15	0.12	0.08	0.03	0.25
Sediment					
PH/AN	0.32	0.18	0.22	0.26	0.40
FL/PY	0.15	0.81	0.09	0.14	0.13
<i>Pachymelania aurita</i>					
PH/AN	0.20	0.40	0.18	1.75	0.19
FL/PY	0.42	0.40	0.41	0.04	0.38

PH/AN: Phenanthrene/anthracene and FL/PY: Fluorene/pyrene

onto aquatic biota^{9,27}. Sediments are major sinks for PAHs, because of the low solubility of these compounds and their strong affinity for organic carbon in particulate matter. Hence, PAH concentrations in sediment are usually higher than those detected in surface water^{9,22}. The quality and composition of sediment have been implicated as major factors affecting the levels of PAH in sediment. High mud content of sediment in the study area as reported by Uwadiae¹⁴, may be a factor contributing to high PAH levels recorded. Mud tends to bind PAHs more strongly.

Forensic diagnostic ratios: The result of diagnostic ratios between PH/AN and FL/PY in water, sediment and *P. aurita* are depicted in Table 2. The ratio of PH to AN in water ranged from 0.19 observed in station E to 0.60 in station D, while FL/PY fluctuated between 0.03 in station D and 0.25 at station E. In sediment, PH/AN varied between 0.18 recorded in station B to 0.4 observed in station E. The FL/PY ranged between 0.09 in station D and 0.81 in station B. In tissue of *P. aurita*, PH/AN ranged from 0.18 in station C and 1.75 in station D. The PH/AN fluctuated from 0.42 in station A to 0.38 in station E.

The presence of many possible sources could affect PAHs prior to their deposition in the environment. The molecular patterns generated by each source however, are like fingerprints, which make it possible to hypothesize processes which generate PAHs and their distribution in environmental media²⁷. These values indicate pyrolytic pollution in the whole study stretch^{28,29}.

Generally, FLU/PYR ratios above 1 indicate a pyrogenic origin, whereas values below 1 are typical of petroleum hydrocarbons²⁷. The low FLU/PYR (≤ 0.81) ratio observed in sediment of station B indicates PAHs of petroleum origin²⁸. Results from both PH/AN and FL/PY ratios indicate that PAHs in the area may have originated majorly from pyrolytic diffuse sources, with some petrogenic input in sediment samples.

Hazard quotient and hazard index: Variations in HQ recorded for the different species of PAH in water, sediment and *P. aurita* samples are shown in Figs. 1-3. Chrysene recorded the highest (1.1) HQ for water samples which occurred in station A, whereas naphthalene recorded the least (0.00000089) in station C. Other PAHs with relatively high HQ include; pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene and benzo[a]pyrene. In the sediment sample, phenanthrene recorded the highest (909) HQ, this occurred in station A. The lowest value (0.011) of HQ was recorded in station C by acenaphthene. Also, relatively higher HQ was observed for benz[a]anthracene and chrysene in sediment samples. Naphthalene recorded the lowest (0.0003) HQ in *P. aurita* in station C, while the highest occurred in station A by benzo[ghi]perylene. The values of HI varied between 0.804 (B) and 2.5 (D) for water, 194.3 (B) and 288.04 (A) for sediment and 23.9 (B) and 182.8 (A) for *P. aurita*.

The trend demonstrated in the HQ indicates a higher preponderance of medium and higher molecular weight PAHs in collected samples, especially for sediment and *P. aurita*. Values of HI were higher for sediment and macrofauna samples (Fig. 4). Comparative analysis between concentrations of PAHs in sediment with the recommended effect range low (ERL) and effect range median (ERM) shows that the values obtained in this present study were generally lower (Table 3).

Bioaccumulation and biota-sediment accumulation factors:

Table 4 illustrates variations in BAF and BSAF of PAH species at the sampling stations. Bioaccumulation factor for the individual PAHs fluctuated between 0.0008 and 6.15. Acenaphthylene recorded lowest BAF in station B and dibenzo[a,h]anthracene was the highest in station A. Indeno[1,2,3-cd]pyrene, benzo[a]pyrene, fluoranthene, pyrene, benz[a]anthracene, chrysene and phenanthrene were among the PAHs with the relatively higher values of BAF. Group total BAF was highest (16.65) in station C, while the lowest (2.96) was found in station E.

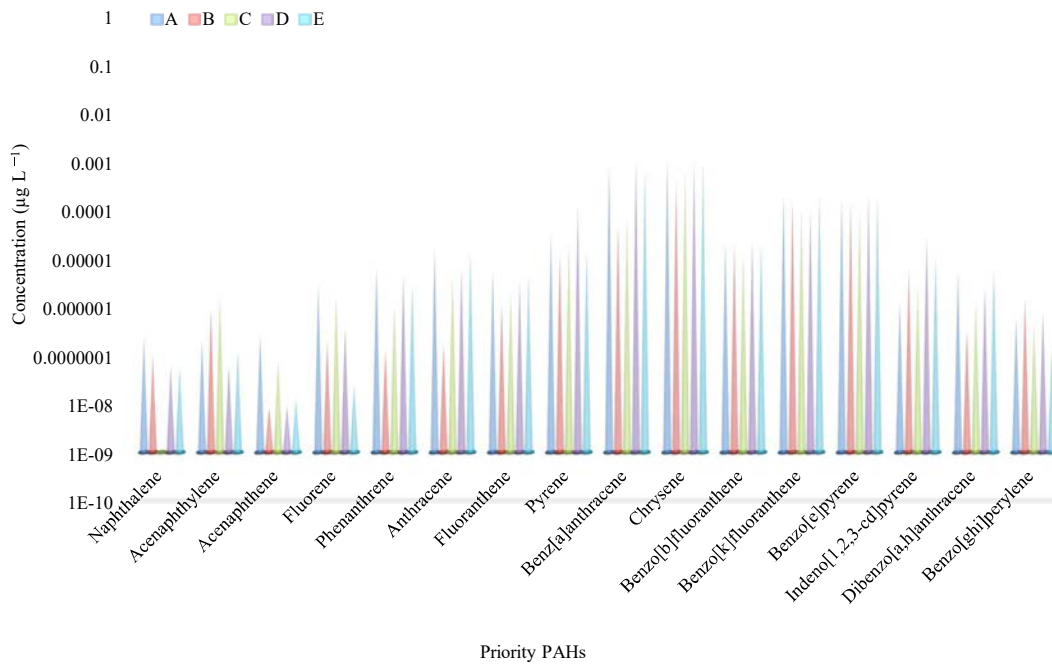


Fig. 1: Hazard quotients for the different PAHs in water

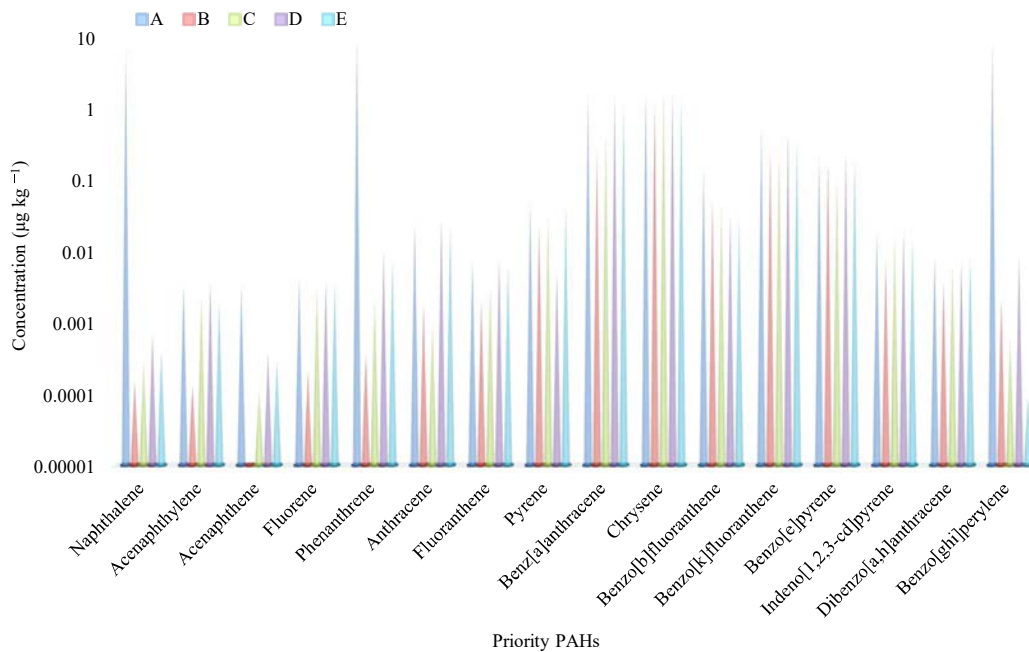


Fig. 2: Hazard quotients for the different PAHs in sediment

Biota-sediment bioaccumulation factor for the individual PAHs ranged between 0.0004 g kg^{-1} recorded for acenaphthylene in station E and 1.31 g kg^{-1} observed for benzo[a]pyrene in station C. Generally, benzo[a]pyrene,

fluoranthene, pyrene, benz[a]anthracene, chrysene and phenanthrene recorded relatively higher values of BSAF. Group total BSAF was highest (5.92 g kg^{-1}) in station C, while the lowest (1.54 g kg^{-1}) was found in station E.

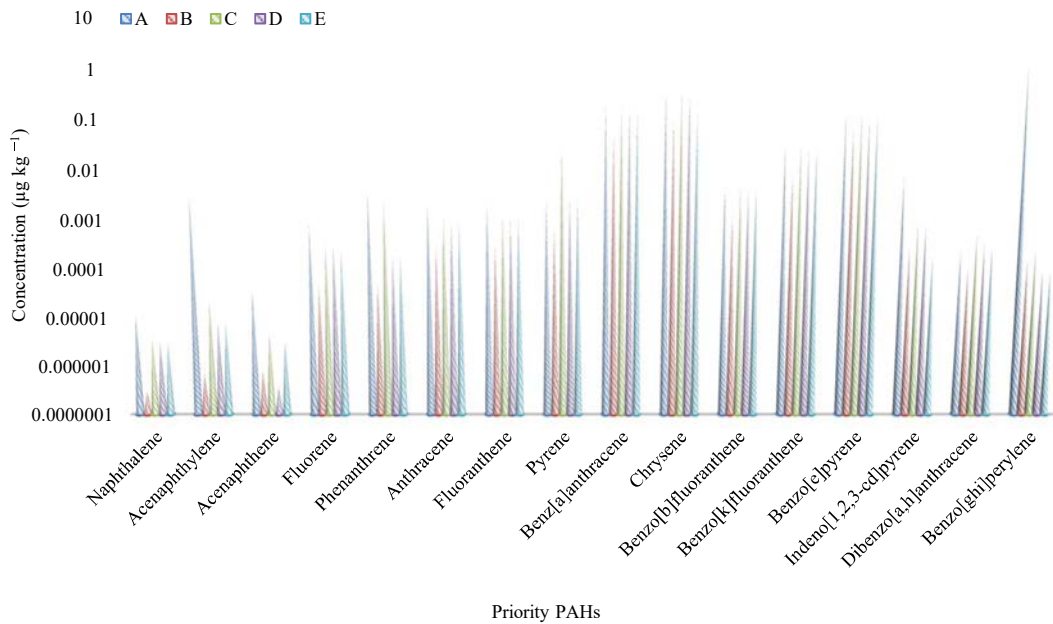


Fig. 3: Hazard quotients for the different PAHs in *Pachymelania aurita*

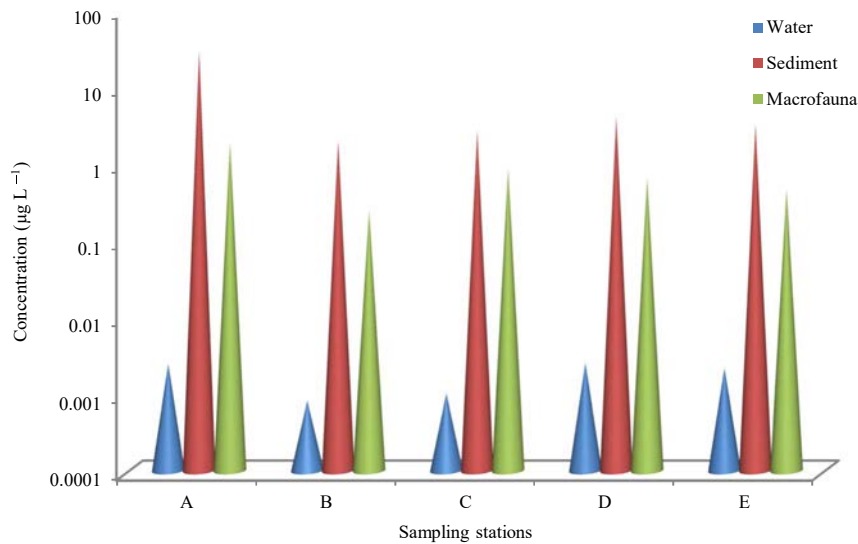


Fig. 4: Hazard index recorded for the different study stations

Values observed for both BAF and BSAF indicate higher BAF values than those of BSAF. Correlation analysis between the two shows a positive relationship in all the study locations and a significant association in stations A ($r = 0.53, p < 0.05$) and E ($r = 0.71, p < 0.05$).

Relationship between concentration of PAHs in water sediment and *P. aurita* samples: Spearman's correlations

between values of PAHs in sediment and *P. aurita* samples ($r_s = 0.98, p < 0.01$), sediment and water ($r_s = 1.0, p < 0.01$), animal and water ($r_s = 0.98, p < 0.01$) indicate a significant positive relationship. Generally, concentrations of PAHs in water had very strong influence on the concentration levels recorded in sediment and animal samples. Linear analysis using Pearson's correlation shows that, PAHs values in water, sediment and animal samples also established the same trend.

Table 3: Concentrations of PAHs in sediment compared with US National Oceanic Sediment Quality Guidelines

PAH	ERL ($\mu\text{g kg}^{-1}$)	EMR ($\mu\text{g kg}^{-1}$)	Sediment ($\mu\text{g kg}^{-1}$)	
			Range	Mean
Naphthalene	160	2100	0.14-0.68	0.422
Acenaphthylene	44	640	0.23-0.65	0.46
Acenaphthene	16	500	0.0031-0.9	0.2832
Fluorene	19	540	0.031-0.63	0.4362
Phenanthrene	240	1500	0.02-0.55	0.318
Anthracene	85.3	1100	0.11-1.7	1.024
Fluoranthene	600	5100	0.022-0.085	0.0574
Pyrene	665	2600	0.06-0.53	0.344
Benz[a]anthracene	261	1600	0.52-3.0	1.914
Chrysene	384	2800	2.6-3.8	3.34
Benzo[b]fluoranthene	-	-	0.082-0.4	0.1724
Benzo[k]fluoranthene	-	-	0.4-0.87	0.616
Benzo[a]pyrene	430	1600	0.16-0.36	0.276
Indeno[1,2,3-cd]pyrene	-	-	0.001-0.0025	0.002
Dibenzo[a,h]anthracene	63.4	260	0.00093-0.0021	0.002
Benzo[ghi]perylene	-	-	0.00028-0.00044	0.005

ERL: Effect range low and ERM: Effect range median

Table 4: Variations in BAF and BSAF of PAH species at the sampling stations

PAH (mg kg^{-1})	A		B		C		D		E	
	BAF	BSAF	BAF	BSAF	BAF	BSAF	BAF	BSAF	BAF	BSAF
Naphthalene	0.43	0.18	0.0028	0.0019	4.65	0.15	0.27	0.0046	0.05	0.008
Acenaphthylene	0.15	0.009	0.0008	0.0006	0.013	0.01	0.14	0.002	0.07	0.0004
Acenaphthene	0.15	0.012	0.088	0.068	0.06	0.05	0.43	0.0098	0.26	0.012
Fluorene	0.30	0.21	0.26	0.025	0.20	0.12	0.69	0.07	0.10	0.07
Phenanthrene	0.60	0.44	0.37	0.14	2.33	1.27	0.04	0.018	0.007	0.027
Anthracene	0.14	0.09	0.28	0.15	0.31	0.16	0.14	0.03	0.06	0.038
Fluoranthene	0.40	0.3	0.24	0.14	0.6	0.4	0.30	0.13	0.25	0.18
Pyrene	0.07	0.06	0.05	0.28	1.42	0.89	0.002	0.5	0.18	0.065
Benz[a]anthracene	0.24	0.13	0.98	0.19	3.00	0.5	0.17	0.11	0.24	0.14
Chrysene	0.31	0.22	0.30	0.09	0.70	0.24	0.04	0.18	0.15	0.11
Benzo[b]fluoranthene	0.21	0.033	0.06	0.025	0.38	0.12	0.18	0.12	0.23	0.17
Benzo[k]fluoranthene	0.15	0.06	0.05	0.038	0.34	0.12	0.26	0.45	0.13	0.08
Benzo[a]pyrene	0.70	0.56	0.50	0.38	1.4	1.31	0.57	0.5	0.60	0.5
Indeno[1,2,3-cd]pyrene	5.88	0.43	0.37	0.025	0.32	0.06	0.03	0.04	0.02	0.011
Dibenzo[a,h]anthracene	6.15	0.38	0.03	0.027	0.38	0.09	0.12	0.033	0.05	0.036
Benzo[ghi]perylene	0.17	0.13	0.09	0.07	0.55	0.43	0.11	0.11	0.61	0.1

BAF: Bioaccumulation factor and BSAF: Biota sediment accumulation factor

The $\Sigma 16\text{PAHs}$ in study locations indicate a potential risk to aquatic and human health according to the USA guidelines and regulations applicable to PAHs for drinking water, domestic water supply and fish consumption²⁹. In this study, $\Sigma 16\text{PAHs}$ exceeded 1000 ng g^{-1} dry weight at all sampling points, meaning, aquatic organisms in the area could be at severe health and environmental risk in line with the guideline. According to Zhang *et al.*³⁰, risk associated with polycyclic aromatic hydrocarbon concentrations in sediment can be classified according to the following categories: $>1.0 \text{ mg kg}^{-1}$ for high risk, $0.001-1.0 \text{ mg kg}^{-1}$ for medium risk and $<0.001 \text{ mg kg}^{-1}$ for low risk. In the present study, the $\Sigma 16\text{PAHs}$ from all sampling points were $0.002-0.007 \text{ mg L}^{-1}$ in water, $0.0047-0.013 \text{ mg kg}^{-1}$ in sediment and $0.0005-0.0022 \text{ mg kg}^{-1}$ in *P. aurita*

samples, indicating the possibility of some level of risk exposure.

CONCLUSION

In this study, low and high molecular weights PAHs were present in all the environmental samples investigated. Although the concentration of total PAHs recorded was below regulatory limits in most samples, the growing anthropogenic activities in the study area, pose a general threat to the ecological integrity. Also, there is the likelihood of increased accumulation of PAHs in the environment with time, suggesting that the environment may pose serious human health and environmental risks. Therefore, regular monitoring and more detailed and elaborate studies to cover other parts of the study area for PAHs pollution is recommended.

SIGNIFICANCE STATEMENT

The study is the first forensic identification of the sources of PAH in the study area. The study shows that, PAH in the area may have originated majorly from pyrolytic diffuse sources, with some elements of petrogenic input in sediment samples. It also revealed that, concentrations of individual and $\Sigma 16$ PAHs at the sampling points were below regulatory limits in most cases. However, the study noted that, the growing anthropogenic activities in the study area may result in the aggravation of risk parameters, which may lead to a general threat to ecological integrity.

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