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Petroleum-Related Contaminants in Edible Biota: A Case Study of Bioaccumulation in the Bille Coastal Region, Rivers State, Nigeria

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ABSTRACT

Aquatic environments in the Niger Delta region of Nigeria are increasingly threatened by petroleum-related pollution resulting from oil exploration, transportation, and artisanal refining activities. This study assessed petroleum hydrocarbon contamination in biota from Bille Creek, Rivers State, Nigeria. Sediment and biota (periwinkle and crab) samples were collected and analyzed using standard analytical and microbiological methods. The results showed that total petroleum hydrocarbons (TPH) were detected in all samples, with mean concentrations of 40.08 ± 7.68 mg/kg in sediment, 164.90 ± 0.50 mg/kg in periwinkle, and 224.05 ± 1.25 mg/kg in crab, indicating increasing accumulation in biota. Several polycyclic aromatic hydrocarbons (PAHs) were detected at low concentrations, with naphthalene recording 0.02 ± 0.01 mg/kg in sediment, 0.19 ± 0.01 mg/kg in periwinkle, and 0.92 ± 0.01 mg/kg in crab. High-molecular-weight polycyclic aromatic hydrocarbons were mostly below detectable limits, although crab samples showed a wider range of detectable compounds. Heavy metals such as cadmium, chromium, and lead were below detectable limits in all samples, while zinc was present at 0.49 ± 0.02 mg/kg in sediment, 0.54 ± 0.01 mg/kg in periwinkle, and 0.88 ± 0.00 mg/kg in crab. Hydrocarbon-utilizing bacteria were recorded at 0.45 × 10^2 cfu/g, whereas fungi were less than 0.01 × 10^2 cfu/g. Thus, petroleum-related contaminants are present in the Bille aquatic environment and are accumulating in edible biota. Hence, continuous monitoring, strengthened pollution control, and public awareness are recommended to reduce environmental and health risks.

1. INTRODUCTION

Marine and terrestrial ecosystems around the globe have, over the last few decades, been bearing the brunt of the persistent organic pollutants, a burden which has resulted to a greater extent through the escalation of human and industrial activities (Raheem *et al.,* 2025). This is especially worrying in the developing world whereby, the rapid urbanization and industrial growth are accompanied by a poor environmental governance (Yu *et al.,* 2024). Though these environments are crucial to the economic growth and the security of livelihoods, particularly along the coastlines, they are also facing continuous degradation that questions the ecological stability and human health (Nwaichi and Ntorgbo, 2016).

The development of industrial areas with great population density has also increased the ecological pressure with cumulative and often irreversible environmental consequences. The release of crude oil and refined petroleum products into water bodies is a leading source of marine pollution (Arghiropol *et al.,* 2025). Spills, be it exploration, transportation or refining- pose both short term and long term risks to marine life. Acute toxicity is caused by a short-term or a single exposure event, and chronic toxicity is caused by repeated or prolonged exposure, causing less dramatic but long-term ecological effects (Holth *et al.,* 2014). The level and nature of the effects of petroleum hydrocarbons is strongly determined by the chemical structure, solubility, viscosity, and toxicity of the compound, thus different petroleum products impact marine environments in different ways (Rajak *et al.,* 2024; Holth *et al.,* 2014).

Even the crude oils of neighbouring wells in the same geological formation can have significantly different chemical profiles, which can significantly change their environmental behaviour and toxicity (Zhan et al., 2015). The issue of hydrocarbon pollution of the aquatic ecosystems in the Niger Delta region of Nigeria has continued to be a growing and acute environmental issue in the region. It can be explained by the fact that the oil exploration, production, transportation, and refining activities dominate the economy of the region (Ite *et al.,* 2018; Adeniran *et al.,* 2023). Polycyclic aromatic hydrocarbons (PAHs) and total petroleum hydrocarbons (TPH) are the most urgent of all the petroleum-related contaminants due to their toxicity, persistence and bioaccumulative properties. These pollutants are petrogenic (crude oil spillages and petroleum discharges) and pyrogenic (gas flaring and incomplete combustion) (Aigberua, 2020; Okedere and Elehinafe, 2022). When discharged into water bodies, petroleum hydrocarbons are subjected to a series of physical, chemical, and biological reactions that determine their movement and retention in the bodies of water, sediments, and organisms (Thornton *et al.,* 2024). Aquatic sediments are also involved in this process in a dual way; as repositories and secondary sources of hydrocarbon pollution. As a result, the quality of sediments can be used as an effective measure of persistent pollution and possible hydrocarbon bioavailability in the waters (British Geological Survey, 2024). Their buildup in aquatic organisms, especially fish and benthic organisms, creates serious concerns in terms of human health because of their mutagenicity, carcinogenicity, and endocrine-disrupting effects (when passed on through the food chain) (Nwaichi *et al.,* 2014; Ekpo *et al.,* 2012).

In addition to oil activities, there are other anthropogenic activities that lead to PAH contamination in coastal areas. Among them, there are the utilisation of creosote-treated wood in the aquaculture plants, burning of bush, careless disposal of industrial effluents, intensive vehicular emission, and the artisanal petroleum refining processes regularly found in the Niger Delta (Ashraf et al., 2013). Environmental impacts of such activities are usually measured by the observed alterations in the physical, chemical, and biological properties of the impacted ecosystems (Delgado and Gomez, 2024).

Because of their low vapour pressure and poor solubility in sea water, PAHs are easily adsorbed on suspended organic particles and then accumulate in bottom sediments where they may last many years (Lu *et al.,* 2024). The sediments support a broad diversity of benthic organisms, *Tympanotonus fuscatus* (periwinkle) and *Goniopsis pelii* (crab). These creatures are specifically applicable in biomonitoring research due to their wide distribution throughout the coastal areas, sessile habit, ease of harvesting, and philtre-feeding habits, which simplify the storage of contaminants with little metabolic degradation (Rajak *et al.,* 2024). Biota such as *Tympanotonus fuscatus* and *Goniopsis pelii* are considered nutritious seafood, especially in terms of protein and vitamins. The average seafood intake in most of the communities of the Niger Delta coastline is approximated to be about 370g/per week (dry weight), which indicates that there is the possibility of high human exposure to the accumulated contaminations (Nwaichi and Ntorgbo, 2016).

The accumulation of petroleum hydrocarbons in these organisms and its further passing on to human beings in their diets is a major concern to the public health. Reported negative effects are growth disruption, reproductive development, and sex differentiation in aquatic organisms and increased risks of cancer and genetic mutation in exposed population (Ossai *et al.,* 2022). In addition, exposure to crude oil has a high toxicity that is highly dependent on the stage of the development of the organisms. Eggs and larvae are particularly susceptible due to their low locomotor ability and lack of capacities to leave polluted environments in comparison with juvenile or adult life (Carroll *et al.,* 2018). Increased lipid concentrations and surface-volume ratios of lipid during early development increase the vulnerability to lipophilic contaminants (Mahfouz *et al.,* 2020). During these developmental stages, exposure may interfere with the key processes underlying development, such as organ formation and physiological patterning, with long-term ecological effects (Incardona, 2017; Pasparakis et al., 2019; Sorhus et al., 2017). It is on this background that assessing petroleum hydrocarbon contamination in biota of Bille Creek, Rivers State, in order to estimate the level of environmental pollution, the possible ecological hazards, and human health implication in the Niger Delta region. The aim of this research is to assess the petroleum hydrocarbons on biota in Bille, Rivers State, Nigeria.

2. MATERIALS AND METHODS

2.1. Sample Collection and Preparation

Samples of sediment, crab, and periwinkle were collected at Bille in Rivers State, Nigeria. Five (5) composite sediment samples were collected from different sampling stations in Bille Creek. Twenty (20) crabs **(***Callinectes* sapidus) were collected from the study area, while approximately two hundred (200) periwinkles (*Tympanotonus fuscatus*) were randomly picked across the sampling stations to obtain a representative pooled sample for homogenisation. The samples were prepared in accordance with established laboratory protocols. The samples were individually homogenized with a mortar and pestle. The homogenized samples were stored individually in clearly labeled sterile containers until needed for heavy metal analysis, while the groups designated for PAHs analysis were wrapped in aluminum foil to shield them from light exposure (Ogbonna and Tebira, 2021).

2.2. Sampling Metadata and Logistical Protocols

For sampling locations and coordinates, five distinct sampling stations were established along the Bille Creek in Rivers State. While specific GPS coordinates are often provided in a supplemental map, the stations represent the upper, middle, and lower reaches of the creek (Ogbonna and Tebira, 2021). Five (5) composite samples were collected. Each composite was formed by pooling sub-samples from different points at each station to ensure a representative matrix. For the periwinkles (*Tympanotonus fuscatus*), approximately 200 individuals were randomly picked and pooled per station. For crabs (*Callinectes amnicola*), 20 individuals were collected. This pooling strategy was used to obtain sufficient biomass for homogenization and to average individual biological variability (Ogbonna and Tebira, 2021). The entire soft tissue (edible portion) of the periwinkles was extracted after a brief boiling process to loosen the shells. For crabs, the edible muscle tissue and hepatopancreas were homogenized for analysis. Following collection, samples were stored in ice chests at approximately during transit to the laboratory. Once at the facility, homogenized samples for heavy metal analysis were kept in sterile containers, while those for PAH analysis were wrapped in aluminum foil and stored in a freezer at to prevent photodegradation and microbial transformation of hydrocarbons (Ogbonna and Tebira, 2021). Collections were typically timed to capture seasonal variations, covering both the dry and wet seasons within the Rivers State climatic cycle.

2.3. Sample Normalization and Total Petroleum Hydrocarbon Determination

The study utilized Gas Chromatography with Flame Ionization Detection (GC-FID), specifically employing an Agilent 6890N system. The extraction followed the EPA 8015 modified method for extractable petroleum hydrocarbons. Results for sediments and biota (crab and periwinkle) are reported on a dry weight (dw) basis to handle sample moisture and ensure accurate dry weight reporting. After collection and boiling (for periwinkle unshelling), samples were homogenized and large quantities of anhydrous sodium sulphate were added (typically a 1:1 ratio, such as 10g of salt to 10g of sample) to chemically dehydrate the tissue before solvent extraction. Samples were often air-dried or oven-dried at low temperatures to a constant weight, then sieved to remove moisture interference. TPH concentrations were normalized using a calibration curve derived from a certified TPH standard mixture. Recovery was validated by the addition of a surrogate standard (1-chlorooctadecane) at a concentration of to the samples prior to extraction to monitor the efficiency of the solvent recovery process.

2.4. Sample Digestion and Heavy Metal Determination

Two (2) grams of each prepared sediment, crab, and periwinkle sample were separately weighed using a precision balance and transferred into a 250 ml beaker. Ten milliliters of aqua regia, a mixture of hydrochloric acid (HCl) and nitric acid (HNO3), were added to each beaker containing the different samples. The mixtures were heated on a hot plate until the entire sample was dissolved, resulting in a clear solution. The solution was allowed to chill prior to being transferred into a 50 ml volumetric flask and brought to the calibration mark with distilled water. The concentrations of heavy metals (Zn, Cd, Pb, Ni, and Cr) in the sample were determined through Atomic Absorption Spectrophotometry (Ogbonna and Tebira, 2021).

2.5. Determination of the Polycyclic Aromatic Hydrocarbon Content

2.5.1. Sample extraction

Ten grams of each sample were placed in an amber glass bottle and mixed with 10 g of anhydrous sodium sulphate to remove moisture. The sample was spiked with 1-chlorooctadecane surrogate standard at 300 µg/ml and extracted with 30 ml of dichloromethane. The bottle was sealed and shaken mechanically for 5 to 6 hours at room temperature. The extract was allowed to stand for 1 hour, filtered through 110 mm filter paper, and concentrated to 1 ml overnight in a fume cabinet.

2.5.2. Sample clean-up

The sample extracts were cleaned using a glass column packed with silica gel and anhydrous sodium sulphate. The concentrated extract was mixed with cyclohexane and transferred into the column. Elution was carried out using pentane, followed by dichloromethane. The eluate was collected in a clean beaker and evaporated overnight in a fume cabinet at room temperature (Ogbonna and Tebira, 2021).

2.5.3. Separation and detection

An Agilent 6890N Gas Chromatograph equipped with a Flame Ionisation Detector was used for the separation and detection of PAHs. Three microlitres of the cleaned and concentrated extract were injected into the GC-FID system. The separated compounds were detected using the flame ionisation detector, and PAH concentrations were quantified from the chromatogram and expressed in mg/kg.

2.6. Enumeration of Hydrocarbon Utilizing Microorganisms

The vapor phase transfer method developed by Mills et al. (1978) and updated by Ogbonna et al. (2020) was employed to estimate the population of hydrocarbon-utilizing microorganisms by spread plate techniques on mineral salt medium (MSM). The approach utilized sterile filter paper discs, saturated with 2 ml of sterilized crude oil, which were aseptically positioned on the inner cover of inverted Petri dishes before to incubation. One milliliter (1 ml) of the composite soil samples underwent serial dilution from 10^{-1} to 10^{-7}. Aliquots of 0.1 milliliters from 10^{-2} dilutions were inoculated into the medium in duplicate. To enumerate hydrocarbon-degrading bacteria, the medium was augmented with Miconazole Nitrate to inhibit fungal contamination. The mineral salts medium, augmented with streptomycin to suppress bacterial contamination, was employed to facilitate the enumeration of oil-degrading fungi. The plates were incubated at ambient temperature for five days before to enumeration.

2.7. Quality Control and Assurance

For each step of the experiment, Standard Operating Procedures (SOPs) were outlined. The SOPs included rules for preparing samples, calibrating equipment, collecting data, and analyzing it. The equipment was calibrated according to the manufacturer's instructions or standard procedures. Samples were carefully prepared and handled to keep them from becoming dirty or going bad. There were rules on how to store, label, and keep track of items.

2.8. Data Analysis

The data obtained from the study were meticulously entered and coded utilizing Microsoft Excel (2019). The coded data were evaluated utilizing IBM SPSS version 21. One-way analysis of variance (ANOVA) was employed to ascertain significant means at a 5% significance level. LSD and Tukey's post-hoc test were employed for multiple group comparisons. The experiments were carried out in duplicate.

3. Results and Discussion

The concentrations of total petroleum hydrocarbons (TPH) in sediment, periwinkle, and crab samples from Bille Creek, Rivers State, Nigeria, are presented in Table 1. The results in Table 1 show that TPH were detected in all analysed samples. The lowest concentration was recorded in sediment, while higher concentrations were recorded in the biota. Crab had the highest TPH concentration of 224.05 ± 1.25 mg/kg, followed by periwinkle with 164.90 ± 0.50 mg/kg, while sediment recorded 40.08 ± 7.68 mg/kg. This trend suggests greater accumulation of petroleum hydrocarbons in edible biota than in sediment. The higher concentrations observed in crab and periwinkle may be linked to their feeding behaviour, close contact with sediment, and exposure to petroleum-related contaminants in the aquatic environment.

Table 1: Standard error of mean total for petroleum hydrocarbon in sediment and biota

Parameter	Concentration (mg/kg)		
	Sediment	Periwinkle	Crab
TPH	40.08 ± 7.68	164.90 ± 0.50	224.05 ± 1.25

The accumulation of TPH in edible biota is important because aquatic organisms may serve as pathways through which petroleum-related contaminants enter the human food chain. Similar observations have been reported in petroleum-impacted environments in the Niger Delta, where sediment-biota transfer of hydrocarbons is influenced by chronic petroleum inputs, oil spill events, pipeline leakage, and artisanal refining activities (Ogbonna and Tebira, 2021; Ogbaji *et al.,* 2025; Chris and Onyena, 2026). The relatively higher TPH concentration in crab compared with periwinkle may also reflect differences in mobility, feeding strategy, sediment contact, and tissue accumulation capacity. This agrees with reports that mobile benthic organisms may show higher hydrocarbon accumulation because of frequent interaction with contaminated sediments and food sources (Ikpe *et al.,* 2023). The result therefore indicates possible bioaccumulation of petroleum hydrocarbons in edible organisms from Bille Creek. The concentrations of polycyclic aromatic hydrocarbons (PAHs) in sediment, periwinkle, and crab samples are presented in Table 2. The results in Table 2 show that PAHs were detected at relatively low concentrations across the samples, although the pattern of detection varied among sediment, periwinkle, and crab. Naphthalene was detected in all samples, with the highest concentration recorded in crab at 0.92 ± 0.01 mg/kg, followed by periwinkle at 0.19 ± 0.01 mg/kg and sediment at 0.02 ± 0.01 mg/kg. This indicates that naphthalene was the most consistently detected PAH in the study.

Crab samples showed the widest range of detectable PAH compounds. Acenaphthylene, fluorene, fluoranthene, benzo(b)fluoranthene, benzo(k)fluoranthene, and benzo(a)pyrene were detected in crab but were below detectable limits in sediment and periwinkle. This suggests that crab may have a greater capacity to accumulate a wider range of PAH congeners, possibly because of its feeding pattern, mobility, and contact with contaminated sediment. Species-specific differences in PAH accumulation have also been reported in Niger Delta aquatic environments, where periwinkles, crabs, and other benthic organisms show different PAH profiles depending on feeding behaviour, lipid content, and exposure route (Bonte *et al.,* 2022; Oka *et al.,* 2025).

Table 2: Standard error of mean for concentration of PAHs in sediment and biota

Parameter	Concentration (mg/kg)		
	Sediment	Periwinkle	Crab
Naphthalene	0.02 ± 0.01	0.19 ± 0.01	0.92 ± 0.01
Acenaphthylene	BDL	BDL	0.18 ± 0.01
Acenaphthene	BDL	0.01 ± 0.00	0.02 ± 0.00
Fluorene	BDL	BDL	0.08 ± 0.01
Anthracene	BDL	0.13 ± 0.02	0.02 ± 0.00
Phenanthrene	0.01 ± 0.01	0.20 ± 0.10	BDL
Fluoranthene	BDL	BDL	0.03 ± 0.01
Pyrene	0.02 ± 0.02	BDL	0.13 ± 0.02
Benzo (a) anthracene	0.01 ± 0.01	BDL	0.08 ± 0.00
Chrysene	0.01 ± 0.01	BDL	0.01 ± 0.00
Benzo (b) fluoranthene	BDL	BDL	0.06 ± 0.00
Benzo (k) fluoranthene	BDL	BDL	0.07 ± 0.00
Benzo (a) pyrene	BDL	BDL	0.02 ± 0.00
Dibenz(a,h)anthracene	BDL	BDL	BDL
Indeno(1,2,3-cd) pyrene	BDL	BDL	BDL
Benzo (g,h,i) perylene	BDL	BDL	BDL

BDL = Below detection limit

Periwinkle samples showed detectable levels of naphthalene, acenaphthene, anthracene, and phenanthrene. Phenanthrene was higher in periwinkle than in sediment, suggesting possible uptake and retention in edible tissues. However, several high-molecular-weight PAHs were below detectable limits in periwinkle. In sediment, only a few PAHs were detected, including naphthalene, phenanthrene, pyrene, benzo(a)anthracene, and chrysene. The low sediment PAH values may reflect site-specific variation, contaminant degradation, sediment composition, or differences in the availability of PAHs at the time of sampling.

The detection of PAHs in edible biota is significant because PAHs are persistent organic contaminants of environmental and public health concern. Their presence in periwinkle and crab indicates that petroleum-related contaminants in Bille Creek may be entering the aquatic food chain. Previous studies in Niger Delta environments have reported PAH contamination in water, sediment, and fish, with strong evidence linking contamination to petroleum activities and combustion-related sources (Asagbra *et al.,* 2015; Nwaichi *et al.,* 2014). The detection of PAHs in biota, even where some sediment values are low, also agrees with the view that PAHs can partition into lipid-rich tissues and persist in edible aquatic organisms after release from sediment-associated pools (Bonte *et al.,* 2022).

Although most high-molecular-weight PAHs were below detectable limits, the presence of compounds such as benzo(a)pyrene in crab is noteworthy because some PAHs are associated with toxic, mutagenic, and carcinogenic effects. Similar concerns have been raised in studies on edible biota from petroleum-contaminated coastal regions, where PAH bioaccumulation may contribute to non-carcinogenic and carcinogenic health risks among consumers of seafood from affected environments (Odesa and Olannye, 2025). These findings support the need for continuous monitoring of edible aquatic organisms harvested from petroleum-impacted coastal environments.

The concentrations of selected heavy metals in sediment, periwinkle, and crab samples from Bille Creek are presented in Table 3. The results in Table 3 show that cadmium, chromium, and lead were below detectable limits in all samples. Nickel was detected only in sediment, with a concentration of 0.16 ± 0.01 mg/kg, but was below detectable limits in periwinkle and crab. Zinc was detected in all samples, with the highest concentration recorded in crab at 0.88 ± 0.00 mg/kg, followed by periwinkle at 0.54 ± 0.01 mg/kg and sediment at 0.49 ± 0.02 mg/kg.

Table 3: Standard error of mean for concentration of heavy metals in sediment and biota

Parameter	Concentration (mg/kg)		
	Sediment	Periwinkle	Crab
Cadmium (Cd)	BDL	BDL	BDL
Chromium (Cr)	BDL	BDL	BDL
Lead (Pb)	BDL	BDL	BDL
Nickel (Ni)	0.16 ± 0.01	BDL	BDL
Zinc (Zn)	0.49 ± 0.02	0.54 ± 0.01	0.88 ± 0.00

BDL = Below detection limit

The absence of detectable cadmium, chromium, and lead suggests that contamination by these metals was low or below the detection capacity of the analytical method at the time of sampling. This pattern partly differs from some Niger Delta studies that have reported broader heavy metal contamination in sediments and biota, often linked to oil exploration, pipeline leakage, industrial discharge, and urban runoff (Onyena *et al*., 2024). The differences may be due to site-specific pollution inputs, sampling season, sediment chemistry, hydrological conditions, or the analytical detection limits used in the present study.

The detection of zinc in sediment and biota shows that trace metal exposure exists in the study area. Zinc is an essential trace element required by living organisms, but elevated concentrations may indicate anthropogenic input or sediment-biota transfer. The higher zinc concentration in crab compared with sediment and periwinkle suggests possible accumulation in crab tissues. Similar studies have reported that zinc may accumulate in aquatic organisms because of its relative mobility and biological role in metabolism (Onyena *et al*., 2024). Therefore, although the selected heavy metals were generally low in the present study, continuous monitoring remains necessary because metal concentrations in aquatic environments can vary spatially and seasonally.

The microbial population of hydrocarbon-utilising microorganisms in sediment from Bille Creek is presented in Table 4. The results in Table 4 show that hydrocarbon-utilising bacteria were present in the sediment at 0.45 × 10^2 cfu/g, while hydrocarbon-utilising fungi were recorded at less than 0.01 × 10^2 cfu/g. The presence of hydrocarbon-utilising bacteria indicates that the sediment microbial community may have been exposed to petroleum hydrocarbons and may contain bacterial populations capable of utilising hydrocarbons as a carbon and energy source.

Table 4: Standard error of mean for microbial population in sediment

Parameter	Sediment
Hydrocarbon-utilizing bacteria x10^2cfu/g	0.45 X10^2
Hydrocarbon-utilizing fungi x10^2cfu/g	<0.01X10^2

BDL = Below detection limit

The low population of hydrocarbon-utilising fungi suggests that bacterial populations were more prominent than fungal populations in hydrocarbon utilisation within the sampled sediment. This may be due to differences in microbial adaptation, environmental conditions, nutrient availability, or the type and concentration of hydrocarbons present. The microbial results support the chemical findings, particularly the detection of TPH and PAHs, by indicating biological response to hydrocarbon contamination in the sediment environment. Previous studies have shown that hydrocarbon contamination can exert selective pressure on microbial communities, favouring the growth of hydrocarbon-utilising bacteria capable of degrading petroleum compounds (Abu and Chikere, 2006; Oka *et al.,* 2025).

Overall, the results show that petroleum-related contaminants were present in sediment and edible biota from Bille Creek. TPH concentrations were higher in biota than in sediment, PAHs were detected in both sediment and biota, zinc was present in all sample types, and hydrocarbon-utilising bacteria were detected in sediment. These findings suggest petroleum-related contamination and possible bioaccumulation in edible aquatic organisms from the study area. The observed pattern agrees with previous reports that petroleum-impacted Niger Delta environments may support contaminant transfer from sediment to edible aquatic organisms, thereby raising ecological and public health concerns for communities that depend on such resources for food and livelihood (Ogbonna and Tebira, 2021; Bonte *et al.,* 2022; Odesa and Olannye, 2025).

4. CONCLUSION

In conclusion, this study revealed that sediments and biota in Bille, Rivers State are affected by petroleum-related contaminants. While heavy metal contamination is generally low, the accumulation of zinc in biota and the presence of hydrocarbon-utilizing microorganisms indicate ongoing environmental exposure related to oil exploration and transportation activities in the Niger Delta. The bioaccumulation of hydrocarbons and PAHs in edible biota such as periwinkle and crab raises concerns about ecological integrity and potential human health risks for local communities dependent on these resources. Although several toxic heavy metals were absent, indicating limited pollution at the time of sampling, continuous monitoring is crucial due to the dynamic environmental contamination in the area. In all, these findings reenact the contamination challenges in Bille aquatic environment, which call for sustained environmental management and pollution control measures in the Niger Delta.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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