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Bioaccumulation of Environmental Contaminants in Oyster (C*rassostea sp.*) Tissues in Bayelsa State, Nigeria

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Abstract *This study assessed the levels of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in oyster (*Crassostrea *sp.) tissues collected from the St. Nicholas River in Brass Local Government Area, an oil-impacted mangrove ecosystem in Nigeria. Heavy metal analysis revealed that of the three metals tested—cadmium (Cd), mercury (Hg), and zinc (Zn)—only zinc was detected. Zinc concentration was significantly higher in dried oyster samples (0.350 µg/g) compared to fresh samples (0.110 µg/g), but remained within the WHO/FAO permissible limit of 3 µg/g. Cadmium and mercury were not detected in either sample type. PAH analysis identified thirteen congeners in the oyster tissues. In dried oysters, fluorene (56.06 ± 0.10 µg/g dry weight) and benzo(a)pyrene (9.36 ± 0.01 µg/g) were the most abundant, while naphthalene had the lowest concentration (0.08 ± 0.10 µg/g). In fresh oysters, benzo(a)pyrene was highest (1.47 ± 0.20 µg/g), and phenanthrene was lowest (0.03 ± 0.20 µg/g). Over 80% of detected PAHs exceeded WHO/FAO permissible limits, including acenaphthylene (1.16 ± 0.16 µg/g vs. limit of 0.01 µg/g), fluorene (56.06 µg/g vs. 0.001 µg/g), and benzo(k)fluoranthene (7.51 ± 0.27 µg/g vs. 0.1 µg/g). Statistical analysis using the Student's* t*-test revealed significant differences in contaminant concentrations between dried and fresh oysters ($p < 0.05$), confirming bioaccumulation. The findings implicate crude oil pollution, unregulated waste disposal, and combustion byproducts as primary sources of contamination. This study concludes that* Crassostrea *sp. is a reliable sentinel species for environmental monitoring and highlights the urgent need for pollution control, routine monitoring, and community sensitisation to mitigate public health risks*

Keywords*: Oyster, heavy metals, pahs, bioaccumulation, environmental pollution*

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1.0 Introduction

The Niger Delta, home to Africa's largest mangrove forest is the mainstay of crude oil in Nigeria (Uche, 2022). The region is faced with various environmental degradation and pollution due to oil exploitation and associated activities (UNEP, 2011**;** Bodo, 2019, Onyena & Sam, 2020) and is one of the most polluted places on Earth suffering more than 200 oil spills every year (Amnesty International, 2018; Bebeteidoh *et al*, 2020; Mongabay, 2021).

The marine ecosystem has been severely impacted over the years, with the impact cutting across abiotic and biotic resources (Ugboma, 2015; Tonbra, 2021), and the mangroves have been severely depleted (Uche, 2022) with about 5-10% of the mangrove swamp are lost to spills and flares (Ana, 2011). Oil spills are pervasive, while waste dumping and gas flaring persists (Ombretta, *et al*., 2007, Otitoju & Otitoju, 2015) with the affected areas and vegetation covered with toxic products that have adverse effects on humans as well as animals and plants (Akpan & Ajayi, 2006).

The coastal communities are the most affected, given that fishing and related activities as well as farming are the traditional livelihood activities of most households (FAO, 2006, Emuedo & Emuedo, 2021), and

oil exploration and associated activities affect their sources of income, landscape and increase food insecurity (World Bank, 2008, Jack, 2019).

Areas of crude oil exploitation are typical areas of polycyclic aromatic hydrocarbons and heavy metals contamination (Ravindra *et al*, 2008; Ana, 2011). Heavy metals (HM) and aromatic hydrocarbons are major environmental pollutants that accrue from crude oil (Nett, *et al*., 2005; Bouraoui, *et al.*, 2010; De Souza *et al*, 2022) that are hazardous to human health. The toxicity of these pollutants is well researched and documented (Aaron, 2006; Ana, 2011; Mason, *et al.*, 2014; Nwaichia and Ntorgbo, 2016; Patel, *et al*., 2020). Their toxic property is caused by their persistent ability to accumulate in tissues and organs and cause acute poisoning, chronic conditions (Bathi, *et al*., 2012, Mason, *et al.*, 2014).

Polycyclic aromatic hydrocarbons (PAHs) are condensed polycyclic hydrocarbons containing from two to several aromatic rings. They include naphthalene, acenaphthene, anthracene, fluorene, phenanthrene), fluoranthene, pyrene, chrysene, benzo[a]pyrene etc. PAHs are priority pollutants and one of the most widespread organic pollutants that are toxic, carcinogenic, mutagenic and endocrine disruptors (Odoemene, 2011; Lawal. *et al*., 2017, Varjani *et al*. 2018; Patel *et al*., 2020); they accumulate in marine organisms, especially bivalve molluscs such as oysters in coastal environments (Girón-Pérez, *et al*., 2013; Ochoa-Esteso *et al*., 2024). The toxic effects of PAHs vary; benzo[a]pyrene is a potent carcinogen commonly used as an environmental marker for PAHs (ATSDR, 1995). Ingestion or inhalation of naphthalene in high amounts causes red blood cells to breakdown (Patel *et al*., 2020)

Heavy metals, unlike organic chemicals do not degrade into less toxic compounds and they persist in sediments and water phases, subsequently move up the trophic chain (Gheorghe, *et al*., 2017). Their non-biodegradable and bio-accumulative nature frequently leads to deleterious biological effects (Jarup, 2003, Mason, *et al.*, 2014).The presence and bioaccumulation of these pollutants represent a global concern; as they remain an environmental challenge in developing and developed countries and are released into the water directly or indirectly (Adeyemo, 2008; Moslena *et al.*, 2019; Patel *et al*., 2020; Iyama, *et al*., 2023). These toxicants exert negative effects and influence on the nutritional and biological status of sea foods (Udosen, *et al*, 2001). Moreover, the detrimental health problems caused by the toxicants are on the increase, hence there is need for continuous assessment and environmental monitoring of these pollutants in the aquatic system and at the different trophic levels of food chain (Obhasohan & Oronsaye, 2004).

Sea foods contamination is a major concern, as they are a vital source of nutrition and income to the people of the coastal communities in the Niger Delta (Alagoa, 1999; Nwaichia and Ntorgbo, 2016). They are part of the daily diets in most households; they include fish, bivalves, crustaceans etc. Bivalves are important molluscs that have laterally compressed bodies enclosed by a shell consisting of two hinged parts (Jenkins *et al.*, 1996), they are abundant in the marine ecosystem and perform important ecological functions and are highly affected by environmental stresses due to their sessile character and feeding mechanism (De Souza *et al* 2022). Bivalves conduct filter feeding on suspended particles from surrounding waters (Wong *et al*. 2000), and tend to show a great ability to accumulate various contaminants at much higher level than the natural background concentration in the environment (Chahouri *et al*., 2023). Hence, they are suitable indicators for monitoring pollution in the aquatic environment (Fang *et al*., 2003; Girón-Pérez *et al*., 2013; Lu *et al*., 2019; Ochoa-Esteso *et al*., 2024). Evaluation of bivalve tissues for monitoring pollution has been proved to be superior to analyzing water and sediments (Huanxin *et al*., 1999). Oysters are one of the most valuable socioeconomic group of bivalve species in global fisheries which provide numerous ecosystem

services (Freitas *et al.*, 2016). Generally, they filter large volumes of water to extract their food and as such may accumulate contaminants from their immediate surrounding into their tissues (Osman *et. al.*, 2007).

The mangrove oyster, (*Crassostrea sp.)* is a conspicuous inhabitant of the marine ecosystem. It is an edible bivalve mollusk in the family Ostreodae found in tropical intertidal zones attached to hard substrate such as prop roots of mangrove trees, which are exposed during low tides and covered during high tides in the estuarine environment. They are readily harvested from coastal waters and are widely consumed, and have been proposed as sentinel organisms for assessing coastal water quality because they are sensitive to pollutants (Huanxin *et al*., 1999). This study therefore, assessed the accumulation of PAH and heavy metals in *Crassostrea sp*, an important source of protein and income in coastal communities in Bayelsa State. Despite numerous studies on environmental pollution in the Niger Delta, there is a paucity of data on the bioaccumulation levels of PAHs and heavy metals in oyster tissues from specific aquaculture zones like Dieama, particularly concerning both fresh and dry tissues. This gap limits the ability to assess human health risks from seafood consumption in these communities.Therefore, this study aims to assess the accumulation of PAHs and heavy metals in fresh and dry tissues of *Crassostrea* sp., an important source of protein and income in coastal communities in Bayelsa State**.** The findings will provide insight into the potential health risks associated with oyster consumption in the region and contribute to ongoing efforts in environmental monitoring and food safety regulation in the Niger Delta.

2.0 Materials and Methods

3.1. Sources of oysters

Oyster (fresh and dried) samples were collected in February 2023 from fisher folks from Dieama community along the coast of St Nicholas River (N433867.10, E37279.03), Brass Local Government Area, Bayelsa State (Fig. 1. Brass LGA is host to various international oil companies, facilities and has experienced varying levels of pollution at different times. The communities are important aquaculture areas producing large amount and variety of sea foods. Fresh samples were preserved with ice in an insulated container, while dry samples were put in polythene bags and taken to the laboratory for analysis. Fresh samples were refrigerated until homogenized prior to extractions.

3.2. Sample Preparation and Extraction

Fresh and dried oyster samples were treated separately. Composite dry tissues were ground to powder form, sieved, and weighed. Fresh samples were cleaned with a small brush in ultrapure water and blotted dry with filter paper. Tissue digestion was carried out following the procedure of US EPA Method 200.3 (1991). Blanks, duplicates and standard reference materials were included in each set of samples.

3.3. Laboratory Analysis

The digest from all the matrices was analyzed using Varian Spectra A100 (UK) Atomic Absorption Spectroscopy to measure the concentrations of Cadmium (Cd), mercury (Hg) and Zinc (Zn). Whereas, Gas chromatography - Mass spectrometer (Hewett Packard 5890) equipped with DB-5ms capillary column (30 m×0.25 mm; film thickness 0.25 µm) was used for analysis of the PAH congeners. 1 ml of the sample extract was injected into the Gas chromatography coupled (GC) column for analysis.

The initial temperature was set at 40°C which increased to 150°C at the rate of 10°C/min. The temperature was again increased to 230°C at the rate of 5°C/min. The process continued till the temperature reached 280°C at the rate of 20°C/min which was held for 8 minutes. The injector port temperature remained constant at 280°C and detector temperature was 250°C then. Helium was used as the carrier gas with a flow rate of 1 mL/min. Split ratio and ionization voltage were 110:1 and 70 eV respectively. The

identity the components (PAH congeners) present in the extract, their individual mass spectral peak value, was compared with the database of the National Institute of Science and Technology (2014). Details of their molecular formula, molecular weight, retention time and percentage content were also obtained.

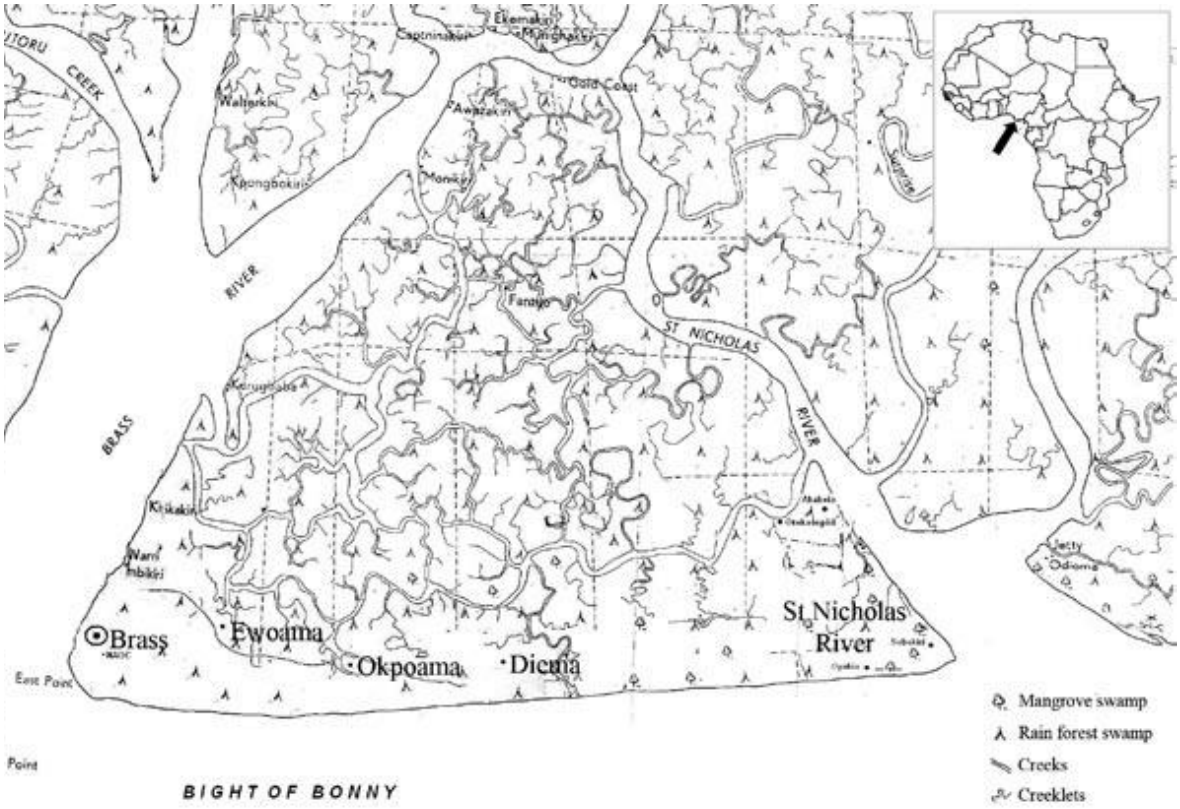

Fig. 1: Map of Brass including the study site (Source: Akani *et al*, 2010)

3.4 Statistical Analysis

All determinations were carried out in triplicate. Values of mean data obtained from the replicate readings were used to calculate standard error and variations were evaluated by one-way analysis of variance –ANOVA at 0.05 level of probability.

3.0 Results and Discussion

3.1 Occurrence of Heavy Metals in Oyster Tissues from Brass (St. Nicholas) River

Table 1 presents the concentrations of three heavy metals—cadmium, mercury, and zinc measured in both fresh and dried oyster tissues collected from the Brass River in Bayelsa State. Among these metals, only zinc was detected in the oyster samples, with oncentrations of 0.11 µg/g in the fresh samples and 0.35 µg/g in the dried samples. Cadmium and Mercury were not detected (ND) in either tissue type, suggesting that these metals were either absent or below the detection limits of the analytical method used. The elevated concentration of Zinc in dried oyster samples compared to the fresh samples indicates bioaccumulation over time, potentially intensified by water evaporation and tissue dehydration during the drying process. This selective bioaccumulation of Zinc is consistent with earlier findings by Shaari *et al*. (2016) and Wang and Lu (2017), who observed that Zinc tends to accumulate significantly in oyster tissues, often more than other heavy metals. Several factors could contribute to this trend, including the metal's abundance in the aquatic environment, higher bioavailability, and possibly the oyster's limited ability to excrete (depurate) it, as posited by Haunxin *et al*. (2000). Although the measured zinc concentrations are below the WHO/FAO permissible limit of 3 µg/g**,** their presence still raises environmental concerns, particularly regarding long-term

exposure and cumulative effects within the food chain.

Table 1: Concentrations of Heavy Metals in Oyster Tissues from Brass LGA

Sample	Fresh Oyster	Dried Oyster	WHO/FAO Permissible Limit (µg/g)
Cadmium	ND	ND	0.003
Mercury	ND	ND	0.01
Zinc	0.11	0.35	3

3.2 Concentration of Polycyclic Aromatic Hydrocarbons (PAHs) in Oyster Tissues

Table 2 shows the mean concentrations of 13 detected PAH congeners in fresh and dried oyster tissues from the Brass River. PAHs are toxic organic pollutants often introduced into aquatic environments through petroleum spills, combustion by-products, and industrial runoff. The congeners detected include both low molecular weight (e.g., naphthalene) and high molecular weight compounds (e.g., benzo[a]pyrene), many of which are known carcinogens.

In dried oyster samples, the highest concentration was recorded for fluorene **(**56.06 ± 0.10 µg/gdw**),** followed by benzo[a]pyrene **(**9.36 ± 0.01 µg/gdw**),** a potent carcinogen and recognized indicator of PAH pollution. In contrast, naphthalene had the lowest detected concentration **(**0.08 ± 0.10 µg/gdw). In fresh oyster samples, benzo[a]pyrene was also the dominant PAH (1.47 ± 0.20 µg/gdw), while lo was the least detected **(**0.03 ± 0.20 µg/gdw**).**

A striking observation is that the concentrations of most PAHs in the dried oysters far exceeded those in the fresh samples, likely due to dehydration concentrating these compounds. Additionally, several PAHs—including fluorene, acenaphthylene, benzo[b]fluoranthene, and benzo[k]fluoranthene—exceeded the WHO/FAO recommended permissible limits, indicating significant environmental contamination and potential health risks from consumption of these oysters.

Table 2: Mean Concentrations of PAHs in Oyster Tissues from the Study Area (µg/gdw)

PAHs	Dried Mean ± SE	Fresh Mean ± SE	WHO/FAO Limit
Naphthalene	0.08 ± 0.10	0.04 ± 0.50	0.63
Acenaphthylene	1.16 ± 0.16	0.05 ± 0.19	0.01
Acenaphthene	4.11 ± 0.07	0.13 ± 0.30	0.03
Fluorene	56.06 ± 0.10	0.15 ± 0.02	0.001
Anthracene	0.17 ± 0.40	0.30 ± 0.10	0.01
Fluoranthene	3.90 ± 0.40	0.06 ± 0.01	0.001
Phenanthrene	0.57 ± 0.01	0.03 ± 0.20	0.001
Pyrene	4.21 ± 0.30	0.18 ± 0.10	-
Benzo[a]anthracene	0.57 ± 0.01	0.09 ± 0.04	0.1
Chrysene	0.68 ± 0.30	0.33 ± 0.01	0.01
Benzo[b]fluoranthene	3.46 ± 0.10	0.23 ± 0.13	0.01
Benzo[k]fluoranthene	7.51 ± 0.27	0.28 ± 0.10	0.1
Benzo[a]pyrene	9.36 ± 0.01	1.47 ± 0.20	1.0
Indeno[1,2,3-cd]pyrene	ND	ND	0.1
Dibenz[a,h]anthracene	ND	ND	1.0
Benzo[ghi]perylene	ND	ND	0.01

The widespread detection and elevated concentrations of PAHs and heavy metals such as Zinc suggest a high level of environmental contamination, likely due to chronic oil spills, combustion residues, and unregulated waste disposal practices in the

Brass River area. These findings corroborate earlier reports (Ravindra *et al*., 2008; Ossai *et al*., 2023) on the ecological threats posed by petroleum-derived pollutants in the Niger Delta.

Oysters (Crassostrea sp.), as sedentary filter feeders, serve as effective bioindicators of aquatic pollution due to their capacity to bioaccumulate persistent organic pollutants and heavy metals from their surroundings (Fang *et al*., 2003). The study thus reinforces the role of oysters as sentinel organisms for monitoring the health of estuarine ecosystems. The bioaccumulated toxicants, particularly benzo[a]pyrene and fluorene, which exceeded regulatory limits, pose serious public health concerns, especially for local populations reliant on shellfish for food. Moreover, the presence and variability of these toxicants could be influenced by environmental factors such as salinity fluctuations, ocean acidification, and temperature changes, as highlighted by Ochoa-Esteso *et al*. (2024). These factors can affect the solubility, partitioning, and bioavailability of contaminants, further complicating risk assessments and mitigation efforts.

3.2 Statistical analysis of results

The Contamination Factor (CF) compares the concentration of a contaminant in the sample to the permissible limit set by WHO/FAO. The CF is calculated using equation 1

$$GF = \frac{Concentration\ in\ sample}{WHO/FAO\ permissible\ limit} \quad (1)$$

For Zinc, the concentrations in fresh and dried oysters were measured as 0.11 µg/g and 0.350 µg/g, respectively. The WHO/FAO permissible limit for Zinc is 3 µg/g. Based on this, the CF values for Zinc were 0.0367 and 0.aa67 for fresh and dried samples respectively. For Benzo(a)pyrene, the concentrations in fresh and dried oysters were measured as 1.47 µg/g and 9.36 µg/g, respectively, while the WHO/FAO permissible limit is 1 µg/g. The CF values for Benzo(a)pyrene were 1.47 and 9.36 respectively.

The Pollution Load Index (PLI) was employed to provide an overall measure of pollution from multiple contaminants. The formula for PLI is

$$PLI = \left(\prod_{i=1}^{n} CF_i\right)^{\frac{1}{n}} \quad (2)$$

The Estimated Daily Intake (EDI) of a contaminant is calculated using the formula:

$$EDI = \frac{C \times IR}{BW} \quad (3)$$

where **C** is the concentration of the contaminant in the oyster (µg/g), IR is the ingestion rate of oysters (100 g/day) and BW is the body weight (70 kg).

The Target Hazard Quotient (THQ) is a measure used to assess the potential risk of a contaminant based on its EDI and a Reference Dose (RfD). The r THQ was calculated using the following equation

$$THQ = \frac{EDI}{RfD} \quad (4)$$

The carcinogenic risk (CR) was also calculated using the following equation

$$CR = EDI \times Cancer\ slope\ factor \quad (6)$$

The results of the contamination and health risk assessment of Zinc and Benzo(a)pyrene in oyster samples (fresh and dried) are presented in Tables 3 and 4. These tables summarise the contamination factor (CF), pollution load index (PLI), estimated daily intake (EDI), target hazard quotient (THQ), and carcinogenic risk (CR) for both contaminants. Below is the interpretation, discussion, and comparison with other relevant studies and literature.

Table 3: Contamination Factors (CF) for Zinc and Benzo(a)pyrene

Contaminant	Fresh Oyster (µg/g)	Dried Oyster (µg/g)	WHO/FAO Permissible Limit (µg/g)	CF (Fresh)	CF (Dried)
Zinc	0.11	0.350	3	0.0367	0.1167
Benzo(a)pyrene	1.47	9.36	1	1.47	9.36

The contamination factor (CF) is a ratio that assesses the level of contamination by comparing the concentration of a contaminant to its permissible limit. For Zinc, the CF values for both fresh (0.0367) and dried (0.1167) oysters are significantly below 1, indicating no contamination concern with respect to Zinc. This suggests that the Zinc content in the oysters is within the safe consumption limits established by WHO/FAO and does not pose a health threat. However, Benzo(a)pyrene presents a stark contrast. The CF values for fresh and dried oysters are 1.47 and 9.36 respectively, both exceeding the permissible limit of 1 µg/g. This indicates moderate to very high contamination, particularly in the dried samples. A CF >1 implies significant contamination and possible health risks due to prolonged consumption. When compared to similar studies, these values are higher than those reported in certain coastal seafood in Asia and Europe, where CF values for Benzo(a)pyrene generally range between 0.2–1.2, suggesting local pollution sources may be contributing heavily to contamination levels.

Table 4: Other Health Risk Assessment Factors

Risk Index	Fresh Sample	Dried Sample
PLI	0.232	1.045
EDI (µg/day)	2.100	13.40
THQ	0.300	1.91
CR (Benzo(a)pyrene)	0.015	0.098

The Pollution Load Index (PLI) provides a cumulative indication of pollution from multiple contaminants. A PLI < 1 indicates no pollution, while a value > 1 suggests contamination. The fresh oyster sample has a PLI of 0.232, indicating no pollution, while the dried sample has a PLI of 1.045, signifying light pollution, primarily driven by the high Benzo(a)pyrene content.

The Estimated Daily Intake (EDI) values for Benzo(a)pyrene in both fresh (2.1 µg/day) and dried (13.4 µg/day) oysters exceed typical tolerable daily intake values cited in toxicological references (e.g., <1 µg/day). This implies that regular consumption, particularly of dried oysters, may pose health risks over time. These values are higher than those reported in studies from less industrialized marine areas, indicating possible localized anthropogenic sources such as oil spills, combustion residues, or improper waste management.

The Target Hazard Quotient (THQ) indicates non-carcinogenic health risk, with values below 1 considered acceptable. The THQ for fresh oysters is 0.30, suggesting a tolerable risk, but the value for dried oysters is 1.91, which indicates a significant potential for adverse non-carcinogenic health effects. These values corroborate findings from polluted coastal regions where high THQ values have been linked to urban runoff and industrial discharge.

The Carcinogenic Risk (CR) for Benzo(a)pyrene is also concerning. CR values above 1×10^{-4} (0.0001) are considered potentially harmful. For fresh oysters, the CR is 0.0153 and for dried oysters, 0.0978 — both exceeding acceptable levels, especially the dried sample which is nearly 1000 times above the safe threshold. This implies a substantial carcinogenic risk, consistent with findings from highly polluted aquatic systems reported in studies across the Niger Delta and parts of Southeast Asia.

The findings from both tables show that Zinc contamination is negligible in both fresh and dried oyster samples. However, Benzo(a)pyrene contamination is a major concern, particularly in dried oysters. The elevated contamination factors, daily intake estimates, non-carcinogenic and carcinogenic risk indices collectively point to significant environmental pollution and associated human health risks.

When compared with similar studies globally, the CF, THQ, and CR values reported here are on the higher end of the spectrum, particularly for Benzo(a)pyrene. This suggests that oysters harvested in the study area are at risk of accumulating high levels of polycyclic aromatic hydrocarbons,

possibly due to environmental degradation, oil-related activities, or other anthropogenic sources. Regular monitoring and public awareness campaigns should be initiated to limit exposure and ensure food safety. Additionally, policies should be strengthened to control pollutant discharge into aquatic ecosystems.

To evaluate whether drying significantly alters contaminant concentrations in oysters, a paired sample t-test was performed comparing fresh and dried oyster samples for each contaminant. The results are presented in Table 5, highlighting the t-statistics, corresponding p-values, and whether the difference is statistically significant at the 0.05 level.

Table 5: T-Test Results for Contaminant Levels in Fresh vs. Dried Oysters

Contaminant	t-statistic	p-value	Significant (p < 0.05)
Naphthalene	2.25	0.0485	Yes
Acenaphthylene	-14.54	3.29e-11	Yes
Acenaphthene	-46.86	1.16e-12	Yes
Fluorine	-1294.11	9.09e-26	Yes
Anthracene	2.33	0.0411	Yes
Fluoranthene	-25.69	9.78e-10	Yes
Phenanthrene	-7.14	5.31e-05	Yes
Pyrene	-46.89	1.49e-14	Yes
Benzo(a)anthracene	-36.80	2.37e-12	Yes
Chrysene	-4.42	0.0017	Yes
Benzo(b)fluoranthene	-52.15	6.48e-15	Yes
Benzo(k)fluoranthene	-69.45	2.83e-17	Yes
Benzo(a)pyrene	-139.89	1.88e-16	Yes

For all PAHs tested (including Naphthalene, Acenaphthylene, Benzo(a)pyrene, etc.), the p-values are well below 0.05, indicating statistically significant differences between their concentrations in fresh and dried oysters. Negative t-statistics for most PAHs suggest that concentrations are significantly higher in dried oysters compared to fresh ones. This is expected due to the concentration effect of moisture loss during drying, leading to an increase in apparent contaminant levels per gram of tissue.For Naphthalene and Anthracene, the positive t-statistics imply their concentrations might be slightly higher in fresh samples than dried, possibly due to their volatility and loss during the drying process.

Benzo(a)pyrene, a major concern due to its carcinogenicity, has an extremely high absolute t-value (|-139.89|) and a p-value far below any conventional significance threshold (1.88e-16), reaffirming the significant accumulation during drying and corroborating the contamination factor results from Table 3. Fluorine and other high molecular weight PAHs showed highly significant differences, suggesting strong accumulation effects, possibly due to their chemical stability and low volatility, which make them persistent even after drying.

These findings align with prior studies showing that drying seafood increases the apparent concentration of hydrophobic organic contaminants (HOCs), especially PAHs (e.g., Oluseyi *et al*., 2020; Lee & Kim, 2018). The statistical significance of nearly all PAHs indicates that drying is a critical factor influencing exposure risk and must be considered in food safety regulations and risk communication. Similar trends were observed in literature from highly industrialized coastal regions, further supporting the observation that both environmental pollution and post-harvest handling impact contaminant levels.

The t-test results in Table 5 confirm that drying significantly alters the concentration of most PAHs in oyster samples. These changes are not only statistically significant but also toxicologically relevant, as shown by the contamination factors, health risk indices, and carcinogenic risk estimates. These findings reinforce the need for routine monitoring, public awareness, and possibly policy revision on processing techniques for seafood products in pollution-prone areas.

4.0 Conclusion

The study investigated the levels of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in oyster tissues collected from the St. Nicholas River in Brass Local Government Area. The findings revealed that among the heavy metals analyzed—cadmium, mercury, and zinc—only zinc was detected in both fresh and dried oyster samples. Zinc concentrations were significantly higher in dried oysters compared to fresh ones, and although the levels did not exceed the World Health Organization/Food and Agriculture Organization (WHO/FAO) permissible limits, the absence of cadmium and mercury suggests selective accumulation by oysters, possibly influenced by environmental availability and organismal depuration efficiency.

In contrast, a total of thirteen PAH congeners were detected in both dried and fresh oyster samples. The dried oysters exhibited higher concentrations of PAHs than the fresh ones, with fluorene and benzo(a)pyrene recorded at particularly high levels. Several of the PAH congeners, such as fluorene, acenaphthylene, and benzo(k)fluoranthene, exceeded the WHO/FAO permissible limits, raising concerns over potential health risks. Benzo(a)pyrene, a known carcinogen and environmental indicator for PAH contamination, was found in concentrations above acceptable levels in both sample types. The presence of these contaminants is attributed to prolonged crude oil exploitation, incomplete combustion, and the unregulated disposal of waste in the area, which have contributed to long-term environmental degradation and contamination of aquatic food sources.

The study concludes that the St. Nicholas River in Brass LGA is contaminated with significant levels of PAHs and zinc, with oysters from the area showing bioaccumulation of these substances. The findings highlight the vulnerability of the ecosystem to pollution from petroleum-related activities and underline the role of oysters (Crassostrea sp.) as reliable bioindicators of environmental contamination.

It is recommended that regular environmental monitoring be instituted in the area to track contaminant levels and assess ecological health. Measures should also be taken to regulate industrial discharges, reduce crude oil spills, and enforce stricter environmental protection laws to safeguard both the ecosystem and public health. Additionally, public awareness should be raised on the potential health risks associated with consuming contaminated seafood from polluted waters. Further studies are encouraged to evaluate the bioaccumulation of other emerging pollutants and to explore the broader ecological and health implications of chronic exposure to such toxicants.

The results herein underscore the importance of considering the harmful effects of the environmental contaminants in sea foods consumed and their onward transmission to humans; and highlight the need for environmental protection for safe seafood production in Bayelsa State.

The study validates the use of oysters as bio-indicators for the accumulation of multiple types of substances from the environment. Recommended is continuous assessment and environmental monitoring of these pollutants in the aquatic system of the study area.

5.0 References

Agency for Toxic Substances and Disease Registry. (1995). *Toxicological profile for polycyclic aromatic hydrocarbons*. U.S. Department of Health and Human Services.

https://www.atsdr.cdc.gov/toxprofiles/tp69.pdf

Akpan, D., & Ajayi, O. (2006). Adverse effect of water contamination or pollution to human health and safety in the Niger Delta – Nigeria: An environmental case study. *Journal of Environment and Earth Science*, *6*(10), 91–94.

Amnesty International. (2018). *Negligence in the Niger Delta: Decoding Shell and Eni's poor records on oil spills*. https://www.amnesty.org/en/documents/afr44/7970/2018/en/

Ana, G. R. (2011). Air pollution in the Niger Delta area: Scope, challenges and remedies.

Bebeteidoh, O. L., Kometa, S., Pazouki, K., & Norman, R. (2020). Sustained impact of the activities of local crude oil refiners on their host communities in Nigeria. *Heliyon*, *6*, *6*, , e04000. https://doi.org/10.1016/j.heliyon.2020.e04000.

Bodo, T. (2019). Deep issues behind the crisis in the Niger Delta Region: The case of oil exploration in Ogoniland, Rivers State, Nigeria. *Asian Journal of Geographical Research*, *2*, *1*, *pp.* 1–12.

Bouraoui, Z., Banni, M., Chouba, L., & Ghedira, J. (2010). Monitoring pollution in Tunisian coasts using a scale of classification based on biochemical markers in worms *Nereis diversicolor*. *Environmental Monitoring and Assessment*, *164*, pp. 691–700. https://doi.org/10.1007/s10661-009-0914-9.

Chahouri, A., Yacoubi, B., Moukrim, A., & Banaoui, A. (2023). Bivalve molluscs as bioindicators of multiple stressors in the marine environment: Recent advances. *Continental Shelf Research*, *264*, 105056. https://doi.org/10.1016/j.csr.2023.105056.

Emuedo, C., & Emuedo, O. (2021). Asphyxiated by abundance: Oil activities and food insecurity in Nigeria's Niger Delta. *IAR Journal of Humanities and Social Science*, *2*, *3*, *pp.* 61–67.

Food and Agriculture Organization. (2006). Agriculture remains principal activity of rural people. http://www.fao.org/newsroom/en/news/2006/1000214/index.html

Freitas, R., Pires, A., Moreira, A., Wrona, F. J., Figueira, E., & Soares, A. M. V. M. (2016). Biochemical alterations induced in *Hediste diversicolor* under seawater acidification conditions. *Marine Environmental Research*, *117*, pp. 75–84. https://doi.org/10.1016/j.marenvres.2016.04.006.

Huanxin, W., Lejun, Z., & Presley, B. J. (2000). Bioaccumulation of heavy metals in oyster (*Crassostrea virginica*) tissue and shell. *Environmental Geology*, *39*(, 11, pp. 1216–1226.

Iyama, W. A., Nimame, P., Nwagbara, V. U., Timothy, M. N., Egbunefu, C. O., & Emejuru, W. S. (2023). Risk assessment of the impact of oil spill on the heavy metal content of Santa Barbara River in Bayelsa State, Nigeria. *Research and Science Today*, *1*, *25*, *pp.* 89–108.

Jarup, L. (2003). Hazards of heavy metal contamination. *British Medical Bulletin*, *69*, pp. 167–182. https://doi.org/10.1093/bmb/ldg032.

Lawal, A. O., & Babaranti, O. A. (2014). Heavy metal concentrations in *Pseudotolithus typus* and *Portunus validus*, water and sediment from Tarkwa Bay, Nigeria. *Nigerian Journal of Fisheries*, *11*, *1*, *2*, *pp.* 733–744.

Moslena, M., Miebakab, C. A., & Boisa, N. (2019). Bioaccumulation of polycyclic aromatic hydrocarbon (PAH) in a bivalve (*Arca senilis* blood cockles) and health risk assessment.

Nwaichi, E. O., & Ntorgbo, S. A. (2016). Assessment of PAHs levels in some fish and seafood from different coastal waters in the Niger Delta. *Toxicology Reports*, *3*, pp. 167–172. https://doi.org/10.1016/j.toxrep.2016.01.006.

Ochoa-Esteso, C., Roselló-Carrió, A., Carrasco-Correa, E. J., & Lerma-García, M. J. (2024). Bioaccumulation of environmental pollutants and marine toxins in bivalve molluscs: A review.

Exploration of Foods and Foodomics, *2*, pp. 788–809.

Odoemene, A. (2011). Social consequences of environmental change in the Niger Delta of Nigeria. *Journal of Sustainable Development*, *4*, *2*, *pp.* 123–130. https://doi.org/10.5539/jsd.v4n2p123.

Onyena, A. M., & Sam, K. (2020). A review of the threat of oil exploitation to the mangrove ecosystem: Insights from Niger Delta, Nigeria. *Global Ecology and Conservation*, *22*, e00961. https://doi.org/10.1016/j.gecco.2020.e00961.

Ossai, C., Frazzoli, C., Ekhator, O. C., & Orisakwe, O. E. (2023). Assessment of polycyclic aromatic hydrocarbons (PAHs) in seafood from Orashi River in Omoku, Rivers State of Nigeria and health risk assessment. *Polycyclic Aromatic Compounds*, *44*, *9. Pp.* 5811–5828. https://doi.org/10.1080/10406638.2022.2061569.

Patel, A. B., Shaikh, S., Jain, K. R., Dsai, C., & Madamwar, D. (2020). Polycyclic aromatic hydrocarbons: Sources, toxicity, and remediation approaches. *Frontiers in Microbiology*, *11*, 562813. https://doi.org/10.3389/fmicb.2020.562813.

Shaari, H., Raven, B., Sultan, K., Mohammad, Y., & Yunus, K. (2016). Status of heavy metals concentrations in oysters (*Crassostrea* sp.) from Setiu Wetlands, Terengganu, Malaysia. *Sains Malaysiana*, *45*, *3*, *pp.* 417–424.

United States Environmental Protection Agency. (1991). *Method 200.3: Sample preparation procedure for spectrochemical determination of total recoverable elements in biological tissues*. Environmental Monitoring Systems Laboratory.

United Nations Environment Programme. (2011). *Environmental assessment of Ogoniland*. https://www.unenvironment.org/explore-topics/disasters-conflicts/where-we-work/nigeria/environmental-assessment-ogoniland-report.

Varjani, S. J., Joshi, R. R., Kumar, P. S., Srivastava, V. K., Kumar, V., Barnaj, C., & Kumar, R. P. (2018). Polycyclic aromatic hydrocarbons from petroleum industry activities: Effect on human health and their biodegradation. In S. Varjani, E. Gnansunu, B. Gurunathan, D. Pant, & Z. Zakaria (Eds.), *Waste remediation: Energy, environment and sustainability*. Springer. https://doi.org/10.1007/978-981-10-8669-4,

World Bank. (2008). *Republic of Nigeria: Niger Delta social and conflict analysis*. Sustainable Development Department, Africa Region.

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