Assessment of Selected Metals and Polycyclic Aromatic Hydrocarbons in the Gills and Muscles of *Oreochromis Niloticus* from Oyorokoto River, Andoni, Rivers State, Nigeria

[1]Tetam, Jack Gbenenee, [2]Nkin, Gift Kiisi and [3]Kpaanadee, Reward Mee-eeBari
[1] Department of Biochemistry, Rivers State University,
Port Harcourt, Nigeria
[2]Department of Chemistry, Rivers State University,
Port Harcourt, Nigeria
[3]Department of Biochemistry, University of Port Harcourt,
Port Harcourt, Nigeria
DOI: 10.56201/ijccp.vol.11.no6.2025.pg56.67

Abstract
Aquatic organisms such as tilapia fish are broadly consumed due to their nutritional value; however, their tendency to bioaccumulate environmental contaminants raises serious food safety concerns. This study investigated the metal and polycyclic aromatic hydrocarbon (PAH) concentrations in the muscles and gills of tilapia (Oreochromis sp.) obtained from the Oyorokoto River (n=18). Fish samples were collected from local fishermen, rinsed, placed in pre-cleaned polyethylene bags, and oven-dried prior to laboratory analysis. Selected metals and PAHs were quantified using atomic absorption spectrophotometry and gas chromatography-mass spectrometry, respectively. In the gills, the concentrations (mg/kg wet weight) of copper (187.05± 1.12), iron (160.75 ± 2.84), lead (284.00 ± 3.15), chromium (146.35 ± 1.06), nickel (69.55 ± 1.42), cadmium (97.65 ± 0.88), and zinc (275.10 ±1.75) exceeded WHO permissible limits, except magnesium (351.00 ± 0.00), which remained within guideline values. In the muscles, copper (58.75 ± 0.94), lead (128.00 ± 2.06), chromium (36.95 ± 0.78), nickel (32.95 ± 1.25), cadmium (98.00 ± 1.14), and zinc (186.71 ± 1.52) also exceeded permissible limits, whereas iron (59.75±0.00) and magnesium (308.55 ± 0.00) were within acceptable ranges. Sixteen PAHs were detected, including carcinogenic compounds. Phenanthrene showed the lowest concentration (0.03 ± 0.01 ppm), while chrysene recorded the highest (0.36 ± 0.04 ppm), and all PAH concentrations surpassed WHO guideline values. The findings reveal significant contamination and bioaccumulation of toxic metals and PAHs in tilapia from the Oyorokoto River, indicating they are unsafe for human consumption. These contaminants pose substantial public health risks, including metal poisoning and elevated cancer risk. Immediate environmental remediation and targeted public health interventions are strongly recommended.

Keywords: *Tilapia Fish, Selected Metals, PAHs Assessment, Oyorokoto River, Andoni LGA, Rivers State, Nigeria*

1. Introduction

Freshwater is naturally occurring water with a low concentration of dissolved salts typically below 0.05% (Adaka *et al.*, 2017). It is found in variety of forms including surface water in rivers, lakes and ponds as well as ground water and glaciers. Fresh water bodies like rivers and streams are vital for biodiversity, human consumption, and various economic activities. Numerous aquatic organisms including fishes live inside these water bodies. Tilapia (*Oreochromis niloticus*) is a common name for specie of cichlid fish primarily originating from Africa and the Middle East. They are predominantly herbivorous, feeding on a wide variety of plant and animal matter. It is a vital aquaculture species widely consumed in tropical and subtropical regions worldwide. In Nigeria, tilapia serves as an affordable and accessible source of animal protein, supporting both nutritional needs and livelihoods (Fagbenro, 2011). The rapid growth rate, adaptability to varying water conditions, and relatively low production costs has facilitated its popularity among fish farmers and consumers (FAO, 2020; Adewumi *et al.,* 2022). However, the sustainability of tilapia production is increasingly threatened by environmental contamination, particularly in areas affected by oil exploration and industrial activities (Ite *et al.,* 2013). Some popular farmed species include Nile tilapia, Mozambique tilapia, blue tilapia, red tilapia. Fish gills and muscles are crucial tissues for assessing pollutant uptake and accumulation. Gills, being the primary site of gaseous exchange, are in direct contact with the water and serve as an initial barrier and uptake route for waterborne contaminants.

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic compounds formed during the incomplete combustion of organic matter, originating from sources such as petroleum spills, industrial emissions, domestic waste burning, and vehicle exhausts (Ravindra*et al.,* 2008;Nkin, 2025;Aigberua*et al.,* 2018). Exposure to PAHs can induce various toxic effects in fish, including DNA damage, immune suppression, reproductive disorders, and carcinogenic effects (Vondracek *et al.,* 2017). The presence of PAHs in fish muscles and gills is particularly relevant as these organs are directly involved in respiration, osmoregulation, and are consumed by humans. The impact of PAHs on human health depends mainly on the length and route of exposure, the amount or concentration of PAHs one is exposed to, as well as the relative toxicity of the PAHs. A variety of other factors can also affect health impacts including subjective factors such as pre-existing health status and age (Tetam *et al.,* 2021). Exposures to high levels of pollutant mixtures containing PAHs have resulted in symptoms such as eye irritation, nausea, vomiting, diarrhoea and confusion. Mixtures of PAHs are also known to cause skin irritation and inflammation. Anthracene, benzo(a)pyrene and naphthalene are direct skin irritants. But, anthracene and benzo(a)pyrene are reported to be skin sensitizers, i.e. cause an allergic reaction in skin in animals and humans (Wangboje*et al.,* 2022).

Metals are generally defined as substances characterized by relatively high densities, high electrical and thermal conductivity (Tetam *et al.,* 2021; Wokoma *et al.,* 2019;Nwineewii& Marcus,2021). Some metals are either essential nutrients (typically iron, cobalt, and zinc), or relatively harmless (such as ruthenium, silver, and indium), but can be toxic in larger amounts or certain forms (Adewole &Uchegbu, 2010; Tetam *et al.,* 2025).

Metals are significant environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional and environmental reasons (Jaishankar *et al.,* 2014;Nwineewii& Marcus,2021). Metal-induced toxicity and carcinogenicity involves many mechanistic aspects, some of which are not clearly elucidated (Tetam *et al.,* 2025). However, each metal is known to have unique features that confer to its specific toxicological mechanisms of action (Tchounwou*et al.,* 2012; Wokoma&Agbozu, 2019; Tetam *et al.,* 2025).

The Oyorokoto river serves as a source of livelihood for residents of Andoni LGA in Rivers State and despite the ecological and economic significance of the river, there is no documented data on metal and PAH content, in tilapia fish obtained from this river. This knowledge gap hinders proper environmental risk assessment, regulatory policy formulation, and public health awareness. Given the potential for chronic exposure in the human population that depends on the oyorokoto river for food and livelihood, it is imperative to investigate the concentrations of selected metals and PAHs in the gills and muscles of tilapia from this ecosystem. Hence, the study will provide scientific data on the metal and PAH content, the extent of contamination, and identifying pollution sources in the river.

Literature Review

Numerous studies across Nigeria have reported the presence of various metals in the tissues of different fish species, reflecting the pervasive nature of metal pollution in aquatic environments. These metals, being non-biodegradable, tend to bioaccumulate in aquatic organisms and bio magnify up the food chain (Mansour &Sidky, 2002; Emoyoma*et al.,* 2023). Gills, due to their direct exposure to water and their role in respiration, are often found to accumulate higher concentrations of certain metals compared to muscle tissue (Maxwell *et al.,* 2016). However, the accumulation in muscle is of greater concern for human consumption.

Davies *et al.* (2025) through their research in Rivers State highlighted varying concentrations of metals like cadmium (Cd), lead (Pb), and chromium (Cr) in *Tilapia guineensis*, with some areas showing concentrations exceeding regulatory limits. Their findings also emphasized the correlation between heavy metal levels in water, sediment, and fish bioaccumulation, noting arsenic as having particularly high bioaccumulation factors.

Similarly, another study in Atuka Creek, a crude oil-contaminated site, revealed elevated levels of Pb, Fe, Ni, and Zn in Redbelly tilapia (*Coptodonzillii*) that surpassed recommended limits for human consumption (Davies *et al*., 2024). PAHs are hydrophobic organic pollutants formed mainly through incomplete combustion of fossil fuels and the release of crude oil into the aquatic systems (Neff,1979). These compounds can enter into the fish through ingestion of contaminated food and water at direct absorption through the gills (Anyakora*et al.,*2010). Studies have shown that PAHs tend to accumulate in lipid- rich tissues, through detection in muscles and gill tissues is common and of toxicological relevance. (Tongo *et al.,*2010).

Fish exposed to PAHs may suffer from genotoxic effects, developmental abnormalities, and increased cancer risk. In humans, the consumption of PAH- contaminated fish is associated with increased risk of carcinogenesis and immune suppression (WHO, 2011). According to (Farkas *et al.,* 2002) Tilapia is an important freshwater species in tropical and subtropical aquaculture and wild capture fisheries. Its widespread availability, ease of sampling, and ability to accumulate pollutants makes it a suitable bio-indicator for monitoring pollution. (Adams *et al.,* 2003) in his research demonstrated the effectiveness of tilapia in reflecting both acute and chronic contamination by metals and hydrocarbons in freshwater and estuarine environments. This review highlights these gaps and underscores the importance of an integrated approach to environmental monitoring and risk assessment.

2. Materials and Methods

2.1. Description of the Study Area

Oyorokoto River is located in Andoni Local Government Area of Rivers State, Nigeria, in the Niger Delta region (Akinrotimi& Gabriel, 2012). Geographically, Andoni lies approximately between latitudes 4°28′ and 4°45′ North and longitudes 7°25′ and 7°45′ East. The Town is bordered by the Atlantic Ocean to the south and the Bonny and Opobo Rivers to the west and east correspondingly (Nwankwoala, & Ngah, 2014). Oyorokoto is one of the major coastal fishing settlements in the area and is approachable by water and partly by land using the Ogoni-

Andoni route (Abowei, 2010). The Oyorokoto River forms part of the broad brackish and estuarine ecosystems of the Niger Delta, marked by a system of creeks, mangrove swamps, and tidal flats (Uwadiae&Uyi, 2014). The river experiences both tidal controls from the Atlantic Ocean and freshwater inflows from inland rivers and creeks, ensuing in a lifely aquatic environment (Awoyemi *et al.,* 2017). The climatic condition of the area is generally tropical, with two different seasons: the rainy season (April–October) and the dry season (November–March). Average annual rainfall spans between 2,000 and3,500 mm**,** whereas temperatures range from 25°C to 33°C during the year (NIMET, 2020).

Figure 1: Map of the study area showing sampling points

The flora of the Oyorokoto River environment is preponderantly mangroveforest**,** scattered with spots offreshwater swamp vegetation andsalt-tolerant plant species such as *Rhizophora racemosa*, *Avicennia africana*, and *Nypafruticans* (Ugbomeh&Obire, 2012). These plant species perform a crucial ecological role by fixing the shoreline, offering breeding grounds for aquatic fauna, and assisting as filters for suspended particulates and nutrients (Ugbomeh&Obire, 2012). Limnologically, the Oyorokoto River displays varied tidal and fluvial features**,** with recurrent saline interference from the Atlantic Ocean and freshwater input from inland origins (Nwankwoala& Ngah, 2014). The tidal regime affects the salinity inclination, water depth, and sediment structure, all of which affect the allocation and diversity of marine organisms (Abowei, 2010). The river helps a wealthy ecological arrangement, including different species of finfish, shellfish, plankton, and benthic creatures (Akinrotimi& Gabriel, 2012). It functions as a fundamental habitat for both resident and itinerant fish breeds, helping the high artisanal fishing operations in the area (Ugbomeh&Obire, 2012).

Nevertheless, the ecological honesty of this environment is progressively threatened by anthropogenic influences which include oil exploration, domestic effluent discharge, and indiscriminate waste dumping, which have led to habitat transformation and contamination of marine biota (UNEP, 2011). Oyorokoto is believed to be one of the biggest fishing settlements in

West Africa (Owhonda&Ologeh, 2018). The main occupation of the residents is artisanal fishing, which helps as the principal source of livelihood and protein for the native population (FAO, 2020). Fish species such as *Oreochromis niloticus*, *Clarias gariepinus*, *Chrysichthysnigrodigitatus*, and different shellfish are frequently caught and sold in native and urban markets (Akinrotimi& Gabriel, 2012). In extension to fishing, the community engages in fishprocessing, boat building, trivial trading, and transportation. Nevertheless, the area is steadily affected by oil and gas exploration activities**,** given its nearness to offshore oil fields operated by multinational companies (Nwilo*et al., 2020;* Akinrotimi& Gabriel, 2012). These activities, alongside marine transportation, household waste discharge, and artisanalrefining activities, contribute tremendously to the anthropogenic input of pollutants into the marine environment (Nwilo*et al.,* 2020;Akinrotimi& Gabriel, 2012). The combination of these socioeconomic activities has elevated concerns about environmental degradation and contamination of marineresources**,** specifically, through the introduction of heavy metals and polycyclic aromatic hydrocarbons (PAHs) into the water and biota. Nevertheless, assessing the concentrations of these contaminants in economically vital fish types such as *Oreochromis niloticus* from the Oyorokoto River is crucial for environmental management and public health protection (Nwilo*et al.,* 2020; Akinrotimi& Gabriel, 2012; FAO, 2020).

2.2. Sample collection

Fish samples were obtained from fishermen in Oyorokoto basin. Sampling was conducted during the early hours of the day to ensure the freshness of the specimens. The Samples were rinsed, placed in pre-cleaned polyethylene bags and were transported on ice to the laboratory and stored at -20°C until analysis.

2.3. Sample Preparation

Tissue Dissection and Thawing

Frozen fish samples were thawed at room temperature, and biometric measurements (total length, weight) were recorded. Under clean laboratory conditions, muscles and gills were dissected using stainless steel instruments pre-cleaned with 10% nitric acid and deionized water to avoid cross-contamination. Approximately 10-20 g of each tissue per fish was obtained, homogenized using an electric blender (Model BX 300). The homogenates were divided into aliquots for heavy metal and PAH analysis.

2.4. Determination of Heavy Metals

Sample Digestion Procedure

Approximately 0.5 g of the dried and homogenized fish samples were accurately weighed into digestion flasks in three analytical replicates**,** prepared by taking three separate aliquots from the same homogenized composite sample. Each aliquot was treated with 20 mL of aqua regia, prepared by mixing concentrated hydrochloric acid (HCl) and nitric acid (HNO_3) in a 3:1 ratio (v/v). The mixture was heated on a hot plate inside a fume cupboard for about 2 hours until a clear solution was obtained, indicating complete digestion of organic matter. The digested solutions were allowed to cool and then filtered through Whatman No. 1 filter paper. Each filtrate was transferred into a 50 mL volumetric flask and made up to the mark with distilled water for metal analysis.

Metal Quantification and Instrumental Analysis

Metal concentrations were quantified using atomic absorption spectrometry (AAS) for specific elements. All measurements were carried out in triplicates and as well, analytical blanks and standard reference materials were included for data quality and accuracy of the instrument.

2.5. Determination of Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs Extraction

PAHs were extracted using the Soxhlet extraction method. Approximately 5g of tissue was weighed into a thimble and extracted with n-hexane/dichloromethane (1:1 v/v) for 6–8 hours.

Gas Chromatography- Mass Spectrometry (GC-MS) Analysis

PAHs were analyzed by gas chromatography-mass spectrometry (GC-MS, e.g., Agilent 7890A/5975C) with a DB-5ms capillary column (30 m × 0.25 mm × 0.25 µm). Injection was split less at 280°C, with a temperature program starting at 60°C (hold 1 min), ramping to 300°C at 10°C/min (hold 5 min). Helium carrier gas flowed at 1 mL/min. Mass spectrometry operated in selected ion monitoring (SIM) mode for target ions. Calibration used a 16-PAH standard mix (0.1-100 µg/L), with detection limits of 0.01-0.1 µg/kg.

2.6. Quality Control and Quality Assurance (QC/QA)

All reagents used were of standard analytical grades and as well, glass wear was acid-washed using 10 percent Nitric Acid and rinsed with deionized water. Other QC/QA practices were also maintained.

2.7. Data Analysis

Descriptive statistics such as mean ± standard deviation was computed for all parameters. Correlation analyses and significance tests ($p < 0.05$) were performed using SPSS (version 25.0) to evaluate relationships among contaminants and between tissues.

3. Results

Table 1: Selected metal concentration in gills of tilapia fish obtained from Oyorokoto River (mg/kg, Wet Weight Basis)

S/N	Selected Metals	Concentration (mg/kg)	WHO standard (mg/kg)
1	Copper	187.05±1.12	30
2	Iron	160.75±2.84	43-100
3	Lead	248.00±3.15	0.3
4	Chromium	146.35±1.06	0.15
5	Nickel	69.55±1.42	0.5-0.7
6	Cadmium	97.65±0.88	0.05–0.3
7	Magnesium	351.00±0.00	200-400
8	Zinc	275.10±1.75	100

Values are expressed as mean ± standard deviation

Table 2: Selected metal concentration in muscle of tilapia fish obtained from Oyorokoto River (mg/kg, Wet Weight Basis)

S/N	Metals	Concentration (mg/kg)	WHO standard (mg/kg)
1	Copper	58.75±0.94	30
2	Iron	59.75±0.00	43-100
3	Lead	128.00±2.06	0.3
4	Chromium	36.95±0.78	0.15
5	Nickel	32.95±1.25	0.5-.07
6	Cadmium	98.00±1.14	0.05–0.3
7	Magnesium	308.55±0.00	200-400
8	Zinc	186.71±1.52	100

Values are expressed as mean ± standard deviation

Table 3: Polycyclic aromatic hydrocarbon concentration in muscles of tilapia fish obtained from Oyorokotoriver

S/N	PAHs	Concentration (ppm)	WHO standard (ppm)
1	Naphthalene	0.11±0.01	0.002
2	Acenaphthylene	0.05±0.03	0.002
3	Fluorene	0.05±0.11	0.002
4	Phenanthrene	0.03±0.01	0.002
5	Anthracene	0.09±0.10	0.002
6	Fluoranthene	0.07±0.01	0.002
7	Pyrene	0.04±0.00	0.002
8	Benz[a]anthracene	0.13±0.00	0.002
9	Chrysene	0.36±0.04	0.002
10	Benzo[b]fluoranthene	0.22±0.20	0.002
11	Benzo[h]fluoranthene	0.29±0.01	0.002
12	Benzo[a]pyrene	0.16±0.00	0.002
13	Indeno[1,2,3-cd] pyrene	0.04±0.04	0.002
14	Dibenz[a,h]anthracene	0.18±0.00	0.002
15	Benzo[gh]perylene	0.11±0.01	0.002
16	Acenaphthene	0.06±0.00	0.002

Values are expressed as mean ± standard deviation

4. Discussion

The selected metal concentrations in gills of tilapia fish obtained from Oyorokoto river are presented in Table 1 and the result showed that heavy metals such as copper (187.05±1.12), iron (160.75±2.84), lead (248.00±0.3.15), chromium (146.35±1.06), nickel (69.55±1.42), cadmium (97.65±0.88), and zinc (275.10±1.75) mg/kg were detected for their different concentrations and they were above WHO permissible limits except magnesium (351.00±0.00) that was detected within limit. Among the heavy metals analyzed, lead, chromium, cadmium and nickel are not essential heavy metals while copper, iron, and zinc are the essential heavy metals. The high concentrations of heavy metals in the gills of the tilapia fish indicate severe water contamination in the Oyorokoto river. Fish gills are in constant contact with the surrounding water for respiration and osmoregulation, making them primary sites for the absorption of dissolved metals. This direct exposure explains why the gills often exhibit higher concentrations of heavy metals compared to other tissues like the muscle. The levels of all detected metals, with the exception of magnesium, exceed the permissible limits set by the World Health Organization (WHO). Heavy metal contamination has remained a persistent global environmental problem over the past several decades due to its widespread ecological impacts and detrimental effects on aquatic ecosystems and public health (Adewole &Uchegbu, 2010). This is a matter of serious concern, particularly for the non-essential and highly toxic metals like lead, chromium, cadmium, and nickel. Their presence in such high amounts suggests significant industrial and anthropogenic inputs into the river. The elevated levels of essential metals like copper, iron, manganese, and zinc, while necessary for the fish's metabolic processes in trace amounts, are toxic at such high concentrations and indicate a significantly polluted environment. The Oyorokoto River, situated in the Niger Delta, is likely subjected to pollution from various sources, including oil and gas exploration activities, industrial effluents, agricultural runoff containing pesticides and fertilizers, and municipal waste. These activities are known to release significant quantities of heavy metals into aquatic ecosystems. The findings of this study are in consonance with the findings of Adaka *et al.,* (2017) who reported high metal contents in fish species from Oguta Lake.

Table 2 presents the selected metal concentration in muscle of tilapia fish obtained from Oyorokoto river and the result showed that heavy metals such as copper (58.75±0.94), lead (128.00±2.06), chromium (36.95±0.78), nickel (32.95±1.25), cadmium (98.00±1.14), and zinc (186.71±1.52) mg/kg were detected for their different concentrations and they were above WHO permissible limits except iron (59.75±0.00) and magnesium (308.55±0.00) that were detected within limit. The presence of high concentrations of heavy metals in the muscle tissue of the tilapia fish, the primary part consumed by humans, raises serious public health concerns. Although the levels are generally lower than in the gills, they still exceeded WHO's safety limits for most of the detected metals. The bioaccumulation of these metals in fish muscle tissue means that they can be transferred up the food chain, ultimately affecting human consumers. Lead and cadmium are particularly dangerous, as they are cumulative toxins that can cause severe health problems. Chronic exposure to lead can lead to neurological damage, developmental issues in children, and kidney problems. Cadmium is a known carcinogen and can cause kidney, bone, and lung diseases. The consumption of fish from the Oyorokoto River, therefore, poses a significant risk of heavy metal poisoning to the local population who rely on it as a source of protein. The result of the study is in tandem with the findings of Wangboje*et al.*, (2018) who reported that the metal content of the fish harvested from Obotie river in Niger Delta region exceeded WHO standards.

Polycyclic Aromatic Hydrocarbons are a group of chemical compounds that consist of multiple fused aromatic rings. They are a common by-product of the incomplete combustion of organic materials and are also found in fossil fuels like coal and petroleum (Tetam *et al.,* 2021). Table 3 shows the polycyclic aromatic hydrocarbon concentration in muscles of tilapia fish obtained from Oyorokoto river and the result showed that 16 PAHs were detected in the sample including carcinogenic PAHs such as benzo[a]pyrene, indeno[1,2,3cd pyrene], Dibenz[a,h]anthracene, benzo[gh] perylene, Benzo[b]fluoranthene and Benzo[k]fluoranthene. It was also recorded that phenanthrene had the least concentrations (0.03±0.01) ppm while chrysene had the highest concentration (0.36±0.04) ppm and concentrations of the PAHs were all above the permissible limits recommended by WHO. The detection of 16 different PAHs, including several known carcinogens, in the muscle of tilapia fish from the Oyorokoto River is another critical finding with serious health implications. The presence of potent carcinogens such as benzo[a]pyrene, indeno[1,2,3-cd]pyrene, dibenz[a,h]anthracene,benzo[g,h,i]perylene, benzo[b]fluoranthene, and benzo[k]fluoranthene, all at levels exceeding WHO recommendations, is particularly concerning. PAHs are organic pollutants that are formed from the incomplete combustion of organic materials. In the Niger Delta, their presence in the aquatic environment is strongly linked to oil spills, gas flaring, and the activities of both industrial and artisanal oil refineries. The fact that chrysene showed the highest concentration (0.36±0.04 ppm) while phenanthrene had the lowest (0.03±0.01 ppm) provides some insight into the potential sources and weathering of the PAHs in the river. Regardless of the specific concentrations, the presence of any level of these carcinogenic compounds in a food source is a significant health risk. PAHs are lipophilic, meaning they accumulate in the fatty tissues of fish, and can be passed on to humans upon consumption (Alomirah*et al.,* 2011). Long-term exposure to carcinogenic PAHs is associated with an increased risk of developing various forms of cancer. The findings from this study suggests the urgent need for pollution control measures in the Oyorokoto River and for public health advisories to be issued to the local communities regarding the consumption of fish from this water body.

5. Conclusion

This study clearly demonstrates that tilapia fish collected from the Oyorokoto River are heavily contaminated and pose a significant risk to human health. The findings show elevated concentrations of toxic heavy metals, particularly lead and cadmium, in both gill and muscle tissues, with levels exceeding established safety thresholds. The presence of these metals indicates substantial and direct pollution of the river's ecosystem. Furthermore, the detection of 16 polycyclic aromatic hydrocarbons (PAHs), including several known carcinogens, highlights the widespread influence of anthropogenic activities, likely associated with oil-related pollution in the area. Consequently, consumption of these fish presents serious health risks to the local population, including potential heavy metal toxicity and an increased likelihood of cancer, underscoring the urgent need for environmental remediation and public health intervention. While the study provides valuable baseline evidence of contamination, it is constrained by the use of analytical rather than biological replicates, limiting the ability to capture variability among individual fish. Additionally, sampling was restricted to a single location and did not account for seasonal differences. Addressing these limitations in future research will enable a more comprehensive evaluation of ecological and human health risks.

References

Abowei, J. F. N. (2010). Salinity, dissolved oxygen, pH and surface water temperature conditions in Nkoro River, Niger Delta, Nigeria. *Advance Journal of Food Science and Technology*, 2(1), 16–21.

Adaka, G., Ajima, M., Ezeafulugwe, C., Osuigwe, D., &Nlewadim, A. (2017). Assessment of heavy metals in fish tissues of some fish species in Oguta Lake south eastern Nigeria. *Federal University of Technology Owerri Journal Series*, 3(1), 249–257.

Adams, S. M., Brown, A. M., & Goede, R. W. (2003). A quantitative health assessment index for rapid evaluation of fish condition in the field. *Transactions of the American Fisheries Society*, 132(3), 626–632.

Adewole, M. B., &Uchegbu, L. U. (2010). Properties of soils and plant uptake within the vicinity of selected automobile workshops in Ile-Ife, south western Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 3(3), 23–28.

Adewumi, J. R., Ede, P. N., & Okereke, J. C. (2022). Geochemical assessment of trace metals in Niger Delta sediments: Natural and anthropogenic influences. *Environmental Monitoring and Assessment*, 194(3), 155.

Aigberua, A. O., Ekubo, A. T., & Izah, S. C. (2018). Assessment of heavy metals in soil and groundwater around agricultural farmlands in the Niger Delta, Nigeria. *Journal of Environmental Treatment Techniques*, 6(2), 146–153.

Akinrotimi, O. A., & Gabriel, U. U. (2012). Environmental characteristics and fish species diversity of Andoni River, Niger Delta, Nigeria. *Continental Journal of Environmental Science*, 6(1), 35–45.

Alongi, D. M. (2014). Carbon cycling and storage in mangrove forests. *Annual Review of Marine Science*, 6(1), 195–219.

Alomirah, K., Chan, S. M. N., Luan, T., Wong, M. H., & Tam, N. F. Y. (2011). Removal and biodegradation of polycyclic aromatic hydrocarbons by *Selenastrumcapricornutum*. *Journal of Environmental Toxicology*, 25, 1772–1779.

Anyakora, C., Ehianeta, T., & Umukoro, O. (2010). Polycyclic aromatic hydrocarbons (PAHs) levels in water samples from Lagos Lagoon, Nigeria. *African Journal of Biotechnology*, 9(29), 4479–4484.

Awoyemi, O. M., Akinyemi, A. A., & Adeniji, A. O. (2017). Hydrographic dynamics and water quality assessment of the Niger Delta estuarine system. *Environmental Monitoring and Assessment*, 189(6), 284.

Davies, O. A., & Allison, M. E. (2007). Assessment of the impact of industrial effluents on water quality and fish of Elechi Creek, Rivers State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 11(3), 79–83.

Davies, O. A., Abowei, J. F. N., &Ogbowei, L. I. (2010). Heavy metals in water, sediment and periwinkle (*Tympanotonusfuscatus*) samples from the Okpoka Creek, Niger Delta, Nigeria. *International Journal of Animal and Veterinary Advances*, 2(1), 68–72.

Emoyoma, U. O., Ezejiofor, A. N., Frazzoli, C., Bocca, B., Ekhator, O. C., Onyena, A. P., Udom, G. J., &Orisakwe, O. E. (2024). Polycyclic aromatic hydrocarbons in fish (fresh and dried) and public health in Nigeria: A systematic review. *International Journal of Environmental Health Research*, 34(5), 2197–2212.

FAO. (2020). *The state of world fisheries and aquaculture 2020*. Food and Agriculture Organization of the United Nations.

Fagbenro, O. A. (2011). Tilapia aquaculture in Nigeria: Prospects and challenges. *African Journal of Agricultural Research*, 6(10), 2234–2240.

Farkas, A., Salanki, J., &Specziar, A. (2002). Relation between growth and the heavy metal concentration in organs of bream (*Abramis brama* L.) populating Lake Balaton. *Archives of Environmental Contamination and Toxicology*, 43(2), 236–243.

Ite, A. E., Ibok, U. J., & Udo, I. M. (2013). Environmental impact of oil exploration and production in the Niger Delta. *Environmental Development*, 7, 18–32.

Jaishankar, M., Mathew, B. B., Shah, M. S., & Gowda, K. R. S. (2014). Biosorption of few heavy metal ions using agricultural wastes. *Journal of Environment Pollution*, 45(2), 145–159.

Mansour, S. A., &Sidky, M. M. (2002). Ecotoxicological studies. 3. Heavy metals contaminating water and fish from Fayoum Governorate, Egypt. *Food Chemistry*, 78(1), 15–22.

Maxwell, O., Anuonye, J. C., & Ugwu, J. (2016). Heavy metal concentration in fish species from Ogba River, Benin City, Nigeria. *Journal of Applied Sciences and Environmental Management*, 20(4), 1183–1187.

Nagajyoti, P. C., Lee, K. D., Narayanan, P., & Sreekanth, T. V. (2010). Heavy metals, occurrence and toxicity for plants: A review. *Environmental Chemistry Letters*, 8(3), 199–216.

Neff, J. M. (1979). *Polycyclic aromatic hydrocarbons in the aquatic environment: Sources, fates and biological effects*. Applied Science Publishers.

NIMET. (2020). *Climate of Nigeria: Annual rainfall and temperature data (1990–2020)*. NIMET Publications.

Nkin, G. K. (2025). Microplastics as silent invaders: A multiscale review of their toxicological effects and contaminant interactions in terrestrial and aquatic environments. *Magna Scientia Advanced Research and Reviews*, 14(2).

Nwankwoala, H. O., & Ngah, S. A. (2014). Geomorphology and hydrology of the Andoni coastal area, Rivers State, Nigeria. *Journal of Geography and Earth Sciences*, 2(2), 117–130.

Nwineewii, J. D., & Marcus, A. C. (2021). Bioaccumulation of heavy metals in fish species from the Niger Delta and associated human health risk assessment. *Journal of Applied Sciences and Environmental Management*, 25(6), 1079–1088.

Nwilo, P. C., Olayinka, D. N., &Adzandeh, A. E. (2020). Environmental impacts of oil exploration and exploitation in the Niger Delta of Nigeria. *Environmental Monitoring and Assessment*, 192(4), 254.

Owhonda, K. N., &Ologeh, I. O. (2018). Socioeconomic characteristics of artisanal fishing communities in coastal Rivers State, Nigeria. *Journal of Fisheries and Aquatic Science*, 13(1), 22–30.

Ravindra, K., Sokhi, R., & Van Grieken, R. (2008). Atmospheric polycyclic aromatic hydrocarbons: Source attribution, emission factors, and regulation. *Atmospheric Environment*, 42(13), 2895–2921.

Tchounwou, P. B., Clement, G. Y., Patlolla, A. K., & Dwayne, Y. S. (2012). Heavy metal toxicity and the environment. *Journal of Molecular, Clinical and Environmental Toxicology*, 4(5), 133–164.

Tetam, J. G., Wegwu, M. O., &Ikewuchi, C. C. (2021). Selected metal contents and phytochemical profiling of *Ficus capreifolia* and *Mangifera indica* commonly used antidiabetic plants from oil producing region of Nigeria. *Asian Journal of Environment and Ecology*, 16(4), 247–253.

Tetam, J. G., Nkin, G. K., & Briggs, O. N. (2025). Bioaccumulation potential and phytochemical profiling of Coffea arabica and Pueraria montana leaves obtained from Eyaa Community in Eleme Local Government Area of Rivers State, Nigeria. *International Journal of Chemistry and Chemical Processes, 11*(6), 20–33.

Tongo, I., Ezemonye, L., &Akpeh, K. (2017). Distribution, characterization and human health risk assessment of polycyclic aromatic hydrocarbons (PAHs) in Ovia River, Southern Nigeria. *Environmental Monitoring and Assessment*, 189, 247.

Ugbomeh, A. P., &Obire, O. (2012). Diversity and abundance of benthic macroinvertebrates in the Lower Niger Delta, Nigeria. *Continental Journal of Environmental Science*, 6(2), 1–10.

UNEP. (2011). *Environmental assessment of Ogoniland*. United Nations Environment Programme.

Uwadiae, R. E., &Uyi, H. O. (2014). Ecology and biodiversity of brackish water ecosystems of the Niger Delta, Nigeria. *International Journal of Ecosystem*, 4(4), 156–162.

Vondráček, J., Machala, M., & Svobodová, Z. (2017). Polycyclic aromatic hydrocarbons and their toxicological effects in fish. *Environmental Toxicology and Pharmacology*, 53, 148–155.

Wang, K., Skupinska, K., Misiewicz, I., & Kasprzycka-Guttman, T. (2011). Polycyclic aromatic hydrocarbons: Physicochemical properties, environmental appearance and impact on living organisms. *Acta Pollution Pharmacology*, 61, 233–240.

Wangboje, O. M., Osaigbovo, P. O., Atiwe, P., Erhayimwen, M., &Efenudu, I. (2022). Heavy metals in some fish species from Obotie rivers in the Niger Delta zone of Nigeria, West Africa. *[Journal name missing]*.

Wokoma, A. O. F., &Agbozu, I. E. (2019). Assessment of heavy metals in surface water, sediments, and aquatic organisms in the Niger Delta region of Nigeria. *Journal of Environmental Protection*, 10(2), 241–253.

World Health Organization. (2011). *Guidelines for drinking-water quality* (4th ed.). WHO Press.