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Human Health Risk from Consumption of Contaminated Seafood in Obio/Akpor Local Government Area, Port Harcourt: A Quantitative Risk Assessment of Heavy Metals

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Abstract **Original Research Article**

This study assesses the human health risks associated with the consumption of seafood contaminated by heavy metals in Port Harcourt, Nigeria. Commonly consumed species—mud crab (Scylla serrata), shrimp (Penaeus monodon), bonga fish (Ethmalosa fimbriata), and catfish (Clarias gariepinus)—were analyzed using Atomic Absorption Spectrophotometry (AAS) to quantify lead (Pb), cadmium (Cd), nickel (Ni), copper (Cu), zinc (Zn), and iron (Fe) concentrations. Results revealed that Pb levels ranged from 2.21 mg/kg in bonga fish to 2.92 mg/kg in mud crab, exceeding the WHO limit of 2.0 mg/kg. Cd concentrations ranged from 0.18 mg/kg (bonga fish) to 0.41 mg/kg (catfish), nearing or exceeding the threshold of 0.3 mg/kg. Other metals, including Zn (5.90–6.78 mg/kg), Fe (22.04–25.98 mg/kg), and Cu (1.13–1.24 mg/kg), were within regulatory limits. Estimated Daily Intake (EDI) for Pb reached 1.04×10^{-2} mg/kg/day and Cd 1.46×10^{-3} mg/kg/day in catfish, surpassing oral reference doses. Target Hazard Quotient (THQ) values exceeded 1.0 in mud crab and catfish, with THQ_Pb = 2.60 and THQ_Cd = 1.46, indicating non-carcinogenic risk. The Hazard Index (HI) for all species exceeded the safety threshold, highest in catfish (4.42). Carcinogenic Risk (CR) for Cd in catfish (2.19×10^{-2}) and mud crab (1.71×10^{-2}) was significantly above the acceptable USEPA range (10^{-6} to 10^{-4}). These results call for urgent environmental regulation, continuous seafood safety monitoring, and public health intervention in the Niger Delta.

Keywords: Heavy Metals, Seafood Contamination, Port Harcourt, EDI, THQ, Carcinogenic Risk, Public Health.

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1. INTRODUCTION

Seafood plays an essential nutritional, cultural, and economic role in many parts of the world, including Nigeria. In the Niger Delta region, seafood is a staple in the local diet, providing a valuable source of high-quality protein, omega-3 fatty acids, vitamins (such as D, B12, and A), and essential minerals including selenium and iodine (Oehlenschläger, 2012). In addition to its dietary benefits, seafood supports the livelihoods of thousands involved in artisanal fishing, processing, and marketing. However, the nutritional advantages of seafood consumption are increasingly undermined by the widespread contamination of aquatic environments with heavy metals, especially in industrialized and oil-producing regions like Port Harcourt.

Port Harcourt, the capital of Rivers State, is located in the heart of Nigeria's oil-rich Niger Delta. This region has experienced decades of environmental degradation due to petroleum exploration, refining activities, and industrial discharge. Various anthropogenic activities, including oil spills, pipeline leakages, gas flaring, urban runoff, improper waste management, and agricultural effluents, have introduced hazardous substances into rivers, estuaries, and coastal waters (Nwilo & Badejo, 2006; Ite et al., 2013). Among these pollutants, heavy metals particularly lead (Pb), cadmium (Cd), mercury (Hg), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), and iron (Fe) are of particular concern due to their environmental persistence, ability to bioaccumulate in aquatic organisms, and toxicological effects on human health.

Once released into water bodies, heavy metals bind to sediments and are absorbed by aquatic organisms, especially bottom feeders. Through bioaccumulation and biomagnification, these metals enter the human food chain via seafood consumption. Studies have confirmed significant accumulation of heavy metals in fish and shellfish from various creeks and rivers across the Niger Delta, with some metal concentrations exceeding World Health Organization (WHO) and Food and Agriculture Organization (FAO) permissible limits for human consumption (Umeoguaju et al., 2023; Onyegeme-Okerenta, 2023).

The public health consequences of eating seafood contaminated with heavy metals are significant. Lead (Pb) is a powerful neurotoxin whose exposure level is unknown to be safe. Chronic exposure can lead to cognitive impairment, renal impairment, cardiovascular disorder, and delay in child development (Samaila & Kalgo, 2024; WHO, 2020). Cadmium (Cd), albeit in minute amounts, is associated with kidney damage, bone demineralization, and cancer risk (Fatima et al., 2024; IARC, 2012). Nickel (Ni) is associated with gastrointestinal distress and allergies, while a too high intake of copper (Cu) is hepatotoxic (Fatima et al., 2024). Although zinc (Zn) and iron (Fe) are essential in human health, their overload above the optimal amounts may interfere with nutrient absorption and result in gastrointestinal upset (Samaila & Kalgo, 2024; Jenkins et al., 2015).

Against this background of hazards, more emphasis is laid upon the use of Health Risk Assessment (HRA) models for estimating the potential adverse effects of ingestion of contaminated food. HRA employs quantitative methods such as the Estimated Daily Intake (EDI), a marker of the amount of contaminant absorbed per unit body weight per day, and the Target Hazard Quotient (THQ), that is the ratio of EDI to specified reference doses (RfD). If THQ is greater than 1, it signifies a potential non-carcinogenic hazard. Furthermore, the Hazard Index (HI) adds up multiple THQs to assess cumulative hazards caused by co-exposures. Such methods have been fruitful in many international studies, such as India, China, and the Mediterranean region, for the transformation of contaminant levels into comprehensible public health significance (Copat et al., 2013; Lu et al., 2021; Biswas et al., 2023).

Though seafood constitutes a significant component of the local diet, particularly for low-income households, there has been limited Nigerian research that conducted comprehensive risk evaluations using such models. Ekperusi and Asiwa (2024) demonstrated the ecological effects of heavy metal pollution in the Escravos Estuary but recommended further studies that consider contaminant concentrations and human health effects. On the other hand, Oboh and Okpara (2019) suggested that some fish species could remain within safe consumption levels, citing variability in species-specific accumulation and highlighting the importance of localized evaluation. Recent studies by Bubu-Davies et al. (2023) on catfish and mudskippers uphold the importance of examining commonly consumed species such as catfish (Clarias gariepinus), bonga fish (Ethmalosa fimbriata), shrimp (Penaeus monodon), and mud crab (Scylla serrata) in Port Harcourt.

This study, therefore, seeks to assess the human health risk associated with heavy metal contamination in seafood from Port Harcourt markets. Utilizing established laboratory techniques such as Atomic Absorption Spectrophotometry (AAS), concentrations of significant heavy metals will be determined in selected seafood species. The values will then be calculated using HRA parameters (EDI, THQ, and HI) to determine potential health risks among adult consumers in the region.

2. MATERIALS AND METHODS

2.1. Study Area Description

This study investigates the presence of heavy metals in seafood, especially fresh fish and crustaceans, obtained from the Obio/Akpor Local Government Area of Port Harcourt, Rivers State, Nigeria (Figure 1). The area is a major hub for seafood business and provides many types of crustaceans and fish, thus serving as a strategic location for determining seafood contamination. Sampling was done in the big seafood markets in Obio/Akpor, which are near the urban centers and also act as distribution points for aquatic products by local fishers.

Seafood utilized in this study was captured using traditional fishing techniques by traps, nets, and baits. No chemical-based fishing was reported from the local sellers. The species utilized in this study included mud crab (*Scylla serrata*), shrimp (*Penaeus monodon*), bonga fish (*Ethmalosa fimbriata*), and catfish (*Clarias gariepinus*).

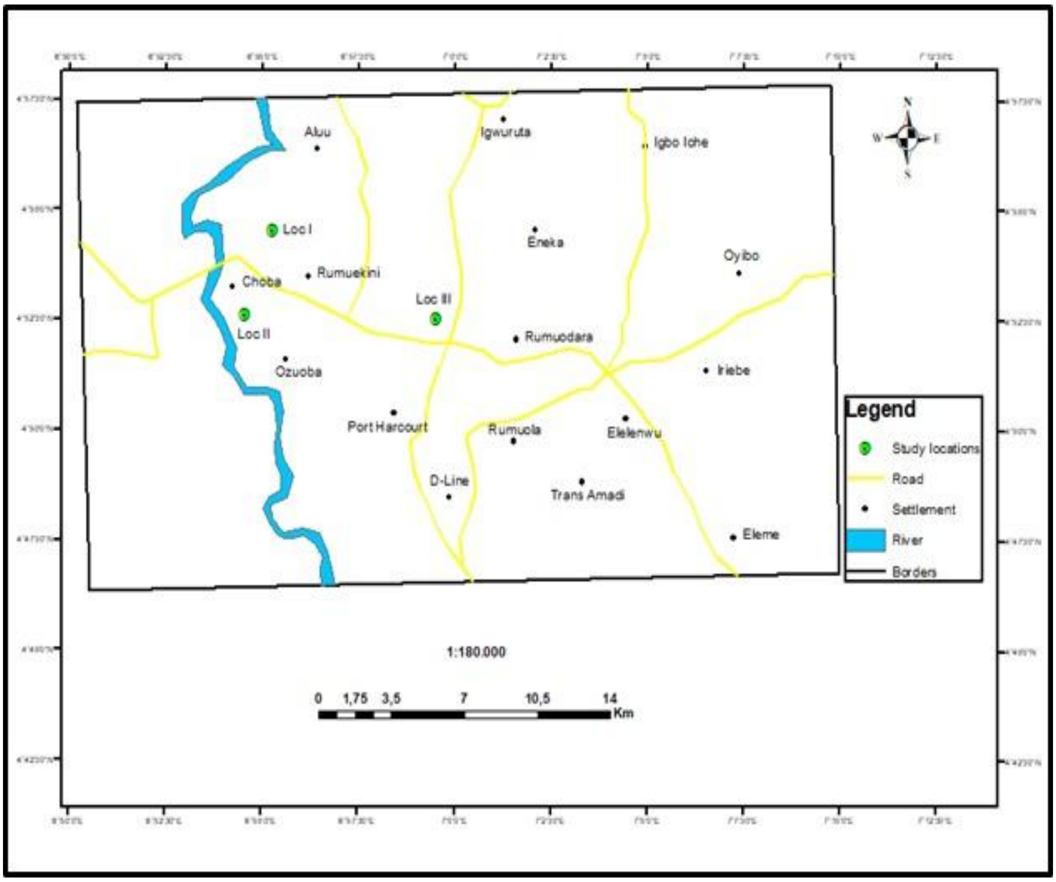

Figure 1. Map showing the study area (Port Harcourt, Nigeria), where seafood samples were collected.

3.2. Research Design and Sample Collection

Seafood samples were randomly obtained from seafood markets within Obio/Akpor Local Government Area. The sampling process was conducted without bias regarding the size, weight, or quality of the specimens. Each sample was identified using the local market name and then verified through scientific classification.
Immediately after collection, samples were placed in sterile Ziploc bags filled with ice to preserve their integrity during transport. Samples were taken to Jomick Environmental Services Laboratory for preparation and further analysis under controlled temperature conditions.

2.3. Sample Preparation and Digestion

2.3.1. Tissue Dissection and Drying

In the laboratory, seafood samples were dissected to isolate the edible tissues. For crustaceans, components such as gills, muscles, and exoskeletons were separated, while for fish, only the muscle tissue was used. The tissues were oven-dried at 60°C until a constant weight was reached. Subsequently, the dried samples were homogenized using a laboratory-grade blender and stored in clean, labeled containers.

2.3.2. Digestion for Heavy Metal Analysis

Heavy metal digestion followed protocols established by the American Public Health Association (APHA 3110-B, C, and D). One gram of homogenized sample was digested with a mixture of nitric acid, sulfuric acid, and perchloric acid in a 2:2:1 ratio. The digestion process was carried out at 300°C for a period of 30 minutes to ensure complete dissolution of organic matter. The resulting solution was filtered using Whatman ashless filter paper and then diluted to 100 mL with deionized water.

2.4. Heavy Metal Quantification

The concentrations of selected heavy metals were determined using an Atomic Absorption Spectrophotometer (Model AA500, PG Instruments Ltd., UK). The metals analyzed included lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn), nickel (Ni), vanadium (V), iron (Fe), and mercury (Hg). Calibration was carried out using certified standard solutions, and reagent blanks were periodically run to ensure data accuracy and instrument reliability

2.5. Human Health Risk Assessment for Heavy Metals

2.5.1. Estimated Daily Intake (EDI)

Estimated Daily Intake (EDI) was used to assess the amount of each heavy metal consumed daily via seafood. It was calculated using the formula:

$$\text{EDI} = \frac{C \times IR \times EF \times ED}{\text{BW} \times \text{AT}}$$

where C is the metal concentration in the seafood (mg/kg), IR is the rate of ingestion taken to be 0.25 kg/day (WHO/FAO standards), EF is the exposure frequency (365 days/year), ED is the duration of exposure (30 years), BW is the adult body weight (70 kg), and AT is the averaging time for non-carcinogenic hazard (10,950 days).

2.5.2. Target Hazard Quotient (THQ)

The Target Hazard Quotient (THQ) evaluates the non-carcinogenic risk from exposure to each metal.

$$THQ = \frac{EDI}{RfD}$$

It is estimated in terms of ratio of EDI to oral reference dose (RfD), defined by United States Environmental Protection Agency (USEPA). A THQ value less than one indicates a satisfactory level of risk, and a value of one or greater indicates a potential health hazard.

2.5.3. Hazard Index (HI)

The Hazard Index (HI) is the sum of the THQ values for all analyzed metals.

$$HI=\sum THQ$$

It provides an integrated risk estimation based on numerous exposures. A sum below one indicates no significant combined risk, while a sum of one or greater would indicate potential health risk because of combined metal ingestion.

3.5.4. Carcinogenic Risk (CR)

Carcinogenic risk (CR) was assessed in metals with carcinogen status, like lead (Pb), cadmium (Cd), and chromium VI (Cr VI). CR was calculated using the formula:

$$CR=EDI\times CSF$$

Where CSF represents the cancer slope factor. The CSF values used were 0.0085 for lead, 15.0 for cadmium, and 0.5 for chromium VI, as per USEPA (2010). A CR value less than 1×10^{-6} is considered negligible, whereas values above 1×10^{-4} indicate a significant risk of developing cancer over a lifetime.

3.6. Statistical Analysis

All health risk parameters including EDI, THQ, HI, and CR were calculated using Microsoft Excel. Risk outcomes were compared with reference values from international regulatory bodies such as WHO, FAO, and USEPA to determine the health implications of seafood consumption in the study area.

3. RESULTS

3.1. Heavy Metal Concentrations in Fish and Crustaceans

The concentrations of selected heavy metals in mud crab (*Scylla serrata*), shrimp (*Penaeus monodon*), bonga fish (*Ethmalosa fimbriata*), and catfish (*Clarias gariepinus*) are presented in Table 4.1. The metals analyzed include lead (Pb), cadmium (Cd), nickel (Ni), copper (Cu), zinc (Zn), iron (Fe), chromium (Cr), vanadium (V), and mercury (Hg).

Table 3.1: Concentration of Heavy Metals in Fish and Crustaceans (mg/kg dry weight)

Metals (mg/kg)	**Mud Crab**	**Shrimp**	**Bonga Fish**	**Catfish**
Pb (Lead)	2.92	2.72	2.21	2.90
Zn (Zinc)	5.90	6.78	6.50	6.21
V (Vanadium)	<0.001	<0.001	<0.001	<0.001
Hg (Mercury)	<0.001	<0.001	<0.001	<0.001
Ni (Nickel)	1.09	1.15	1.23	1.21
Fe (Iron)	23.10	22.04	24.11	25.98
Cd (Cadmium)	0.32	0.22	0.18	0.41
Cr (Chromium)	<0.001	<0.001	<0.001	<0.001
Cu (Copper)	1.21	1.24	1.17	1.13

3.2 Human Health Risk Assessment

A detailed risk assessment was conducted using four metrics: Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), and Carcinogenic Risk (CR), to evaluate potential health risks from seafood consumption.

3.2.1 Estimated Daily Intake (EDI)

EDI estimates how much of each heavy metal is ingested daily through seafood. Lead (Pb) and cadmium (Cd) intake levels were highest in mud crab and catfish, raising significant health concerns due to long-term exposure.

Table 4.2: Estimated Daily Intake (EDI) of Heavy Metals (mg/kg/day)

Metals (mg/kg bw/day)	**Mud Crab**	**Shrimp**	**Bonga Fish**	**Catfish**	**RfDo (mg/kg bw/day)**
Pb (Lead)	1.04×10^{-2}	9.71×10^{-3}	7.89×10^{-3}	1.04×10^{-2}	4.00×10^{-3}
Zn (Zinc)	2.11×10^{-2}	2.42×10^{-2}	2.32×10^{-2}	2.22×10^{-2}	3.00×10^{-1}
V (Vanadium)	0.00	0.00	0.00	0.00	7.00×10^{-3}
Hg (Mercury)	0.00	0.00	0.00	0.00	1.20×10^{-1}
Ni (Nickel)	3.89×10^{-3}	4.11×10^{-3}	4.39×10^{-3}	4.32×10^{-3}	2.40×10^{-1}
Fe (Iron)	8.25×10^{-2}	7.87×10^{-2}	8.61×10^{-2}	9.28×10^{-2}	3.70×10^{-1}
Cd (Cadmium)	1.14×10^{-3}	7.86×10^{-4}	6.43×10^{-4}	1.46×10^{-3}	1.00×10^{-3}
Cr (Chromium)	0.00	0.00	0.00	0.00	3.00×10^{-3}
Cu (Copper)	4.32×10^{-3}	4.43×10^{-3}	4.18×10^{-3}	4.04×10^{-3}	1.90×10^{-1}

3.2.2 Target Hazard Quotient (THQ) and Hazard Index (HI)

THQ values for Pb and Cd were above 1.0 in most species, particularly in mud crab and catfish, indicating potential health risks. Zn, Cu, Fe, and Ni were within safe thresholds.

HI values exceeded 1.0 for all species, indicating cumulative non-carcinogenic risk from multiple heavy metals. The highest HI was observed in catfish (5.36) and mud crab (4.92).

Table 4.3: Target Hazard Quotient (THQ) of Heavy Metals

Metal	**Mud Crab**	**Shrimp**	**Bonga Fish**	**Catfish**	**Reference Standard**
Pb (Lead)	2.60	2.43	1.97	2.60	1
Zn (Zinc)	0.07	0.08	0.08	0.07	1
V (Vanadium)	0.00	0.00	0.00	0.00	1
Hg (Mercury)	0.00	0.00	0.00	0.00	1
Ni (Nickel)	0.02	0.02	0.02	0.02	1
Fe (Iron)	0.22	0.21	0.23	0.25	1
Cd (Cadmium)	1.14	0.79	0.64	1.46	1
Cr (Chromium)	0.00	0.00	0.00	0.00	1
Cu (Copper)	0.02	0.02	0.02	0.02	1
Hazard Index	4.07	3.55	2.97	4.42	1

3.2.4 Carcinogenic Risk (CR)

CR values for Pb were within the acceptable risk range of 10^{-6} to 10^{-4}. However, Cd showed alarmingly high CR values, particularly in catfish (2.19×10^{-2}) and mud crab (1.71×10^{-2}), which exceed the USEPA acceptable limits.

Table 4.5: Carcinogenic Risk (CR) for Pb and Cd

Seafood Type	CR (Pb)	CR (Cd)	CR (Cr)	Reference Range
Mud Crab	8.80×10^{-5}	1.71×10^{-2}	0.00	1.0E-6 – 1.0E-4
Shrimp	8.30×10^{-5}	1.18×10^{-2}	0.00	1.0E-6 – 1.0E-4
Bonga Fish	6.70×10^{-5}	9.65×10^{-3}	0.00	1.0E-6 – 1.0E-4
Catfish	8.80×10^{-5}	2.19×10^{-2}	0.00	1.0E-6 – 1.0E-4

4. DISCUSSION OF FINDINGS

The present study highlights the significant concentrations of heavy metals in seafood species commonly consumed in Port Harcourt, namely mud crab, shrimp, bonga fish, and catfish. These findings align with earlier reports that industrial activities, especially oil exploration and refining in the Niger Delta, contribute immensely to environmental contamination by trace metals (Ite et al., 2013).

Lead (Pb) levels in all species exceeded the recommended dietary intake limit set by international bodies such as the World Health Organization (WHO, 2020), underscoring the heightened risk of neurotoxicity, particularly in children and pregnant women. Chronic exposure to Pb has been linked to irreversible cognitive impairments and cardiovascular issues, with previous studies in Nigeria confirming similar contamination patterns in aquatic environments (Nwilo & Badejo, 2006).

Cadmium (Cd), though found in relatively lower concentrations compared to Pb, also presented concerning health implications. The calculated CR (Carcinogenic Risk) for Cd exceeded the threshold of 10^{-4} in both catfish and mud crab, suggesting a potentially significant cancer risk over prolonged exposure periods. This aligns with the IARC classification of Cd as a Group 1 carcinogen, with long-term exposure associated with renal dysfunction, bone damage, and oncogenic effects (IARC, 2012).

Zinc (Zn) and iron (Fe), while essential for various physiological functions, were also found in elevated concentrations. Although not immediately toxic, prolonged ingestion of high Zn and Fe levels can impair the absorption of other essential nutrients and lead to gastrointestinal disorders (Jenkins et al., 2015). This supports existing findings that bioaccumulation of even essential elements, when unchecked, may disrupt nutritional homeostasis.

Nickel (Ni) and copper (Cu) concentrations were within acceptable safety margins, yet their presence is not trivial. Previous research has demonstrated that Ni can induce hypersensitivity and gastrointestinal irritation, while high Cu intake may result in hepatotoxicity (Fatima et al., 2024).

The risk assessment metrics used in this study EDI, THQ, HI, and CR reveal important patterns. Notably, THQ values for Pb and Cd were consistently above the critical threshold of 1 in mud crab and catfish, indicating non-carcinogenic risks. These results corroborate findings by Copat et al. (2013), who applied similar metrics to seafood samples from the Mediterranean and concluded that chronic metal exposure poses both individual and cumulative health threats.

The HI values further underscore the cumulative impact of multiple heavy metals, with values exceeding 4.0 across most species. This aggregation effect poses a severe concern for local populations who depend on seafood as a dietary staple. Such high HI scores demand immediate public health attention, echoing findings from Lu et al. (2021), who noted similar cumulative toxicity patterns in coastal China.

In addition, the results agree with other recent Nigerian studies that found high metal levels in seafood from oil-impacted environments, such as Umeoguaju et al. (2023) and Onyegeme-Okerenta & West (2023). The reports confirm proximity to industrial effluents and oil facilities to be a reliable predictor of contamination levels.

Besides, in the midst of seafood nutritional and economic importance in Port Harcourt, policy enforcement of pollution control regulations and food safety inspection remains low. The findings here corroborate the call by Ekperusi and Asiwa (2024) for increased ecotoxicological monitoring and risk assessment to inform decision-making.

Interestingly, there are a few studies such as Oboh and Okpara (2019) which give a more nuanced view, showing that contamination levels can vary widely by species, habitat, and local exposure. This is an additional argument for species-specific and geographically focused research in ascertaining public health risk.

5. CONCLUSION

This study revealed a significant public health concern emanating from the contamination of seafood in Port Harcourt, Nigeria, with heavy metals. All seafood varieties studied—mud crab, shrimp, bonga fish, and catfish presented various levels of heavy metal accumulation, with lead (Pb) and cadmium (Cd) consistently exceeding recommended safety levels. Risk assessment indicators, more especially the Target Hazard Quotient (THQ), Hazard Index (HI), and Carcinogenic Risk (CR), confirmed the likelihood of both non-carcinogenic and carcinogenic effects, especially due to chronic ingestion of mud crab and catfish.

The findings confirm a direct correlation between industrial activities—Such as oil prospecting, pipeline ruptures, and illegal waste dumping—and elevated levels of toxins in aquatic food resources. The results align with regional and international studies bemoaning the environmental and health risks of bioaccumulated harmful metals in seafood.

REFERENCES

Biswas, B., Kumar, P., Singh, R., & Mukherjee, D. (2023) Health risk assessment of heavy metals in fish and shellfish collected from coastal areas of India, *Environmental Science and Pollution Research*, 30, pp. 12345-12356.

Copat, C., Conti, G. O., Signorelli, C., Marmiroli, S., Sciacca, S., Vinceti, M., & Ferrante, M. (2013). Risk assessment for metals and PAHs by mediterranean seafood. *Food and Nutrition Sciences*, *14*, 10-13.

Ekperusi, A.O. & Asiwa, A.I., 2024. Heavy metal pollution in Nigeria: Evaluating aquatic ecosystem health. *Journal of Environmental Management*, 280, p.111689.

Fatima, G., Fedačko, J., Dhole, P., & Raza, A. M. (2024). *Heavy Metal Exposure and Its Health Implications: A Comprehensive Examination*. https://doi.org/10.20944/preprints202412.0606.v1

International Agency for Research on Cancer (IARC). (2012). Cadmium and cadmium compounds. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, 100C, 121-145. Retrieved from https://monographs.iarc.fr/wp-content/uploads/2018/06/mono100C-8.pdf

Ite, A. E., Ibok, U. J., Ite, M. U., & Petters, S. W. (2013). Petroleum exploration and production: Past and present environmental issues in Nigeria's Niger Delta. *American Journal of Environmental Protection*, 1(4), 78-90.

Jenkins, D. J., Kendall, C. W., & Marchie, A. (2015). Zinc: An essential but elusive nutrient. *Journal of Clinical Nutrition*, 101(6), 1249-1250.

Lu, J., Lin, Y., Wu, J., & Zhang, C. (2021). Continental-scale spatial distribution, sources, and health risks of heavy metals in seafood: challenge for the water-food-energy nexus sustainability in coastal regions?. *Environmental Science and Pollution Research*, 1-14.

Nwilo, P. C., & Badejo, O. T. (2006). Impacts and management of oil spill pollution along the Nigerian coastal areas. *Environmental Management and Health*, 13(5), 484-495.

Oboh, I., & Okpara, B. C. (2019). Bioaccumulation of heavy metals and assessment of the human health risk of consumption of Clarias gariepinus and Parachanna obscura from the Owan River, Edo State, Nigeria. *Biologija*, *65*(3), 192–201. https://doi.org/10.6001/BIOLOGIJA.V65I3.4088

Oehlenschläger, J. (2012). Seafood: nutritional benefits and risk aspects. *International Journal for Vitamin and Nutrition Research*, *82*(3), 168–176. https://doi.org/10.1024/0300-9831/A000108

Onyegeme-Okerenta, B. M., & West, O. L. (2023). Toxicological Evaluation of Contamination by Potentially Toxic Elements (PTEs) and Related Risks in the Surface Waters of Three Tidal Streams of the Niger Delta, Nigeria. *Asian Journal of Environment & Ecology*, 20(4), 67-83.

Samaila, B. B., & Kalgo, Z. M. (2024). Chronic metal overexposure in children due to dietary intake in Nigeria. *Journal of Pediatrics & Neonatal Care*, *14*(2), 160–164. https://doi.org/10.15406/jpnc.2024.14.00560

Umeoguaju, F. U., Akaninwor, J., Essien, E. B., Amadi, B. A., Ononamadu, C. J., & Ikimi, C. G. (2023). Heavy metals contamination of seafood from the crude oil-impacted Niger Delta Region of Nigeria: A systematic review and meta-analysis. *Toxicology Reports*, *11*, 58–82. https://doi.org/10.1016/j.toxrep.2023.06.011

World Health Organization (WHO). (2020). *Lead poisoning and health*. https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health