**Bacterial Prevalence and Health Risk Assessment of Some Heavy Metal Contaminated Seafoods in Yokri Community, Burutu Local Government Area, Delta State, Nigeria**

ABSTRACT

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| --- |
| **Introduction:** Freshwater and marine ecosystems within the Niger Delta are vulnerable to oil spills, pipeline leaks, and wastewater discharge from oil exploration activities. These events can introduce a range of contaminants, including heavy metals like lead, cadmium, and mercury, into the aquatic environment. Contamination of seafood by heavy metals poses significant health risks to consumers, particularly in regions impacted by industrial activities. **Aim:** The study aimedto evaluate health risks associated with Crabs, Periwinkles and Shrimps in Yokri Community, Delta State. **Methodology:** Seafood samples (Crabs, Shrimps and Periwinkles) were procured from the Ogbe-Ijoh Market in Warri, Delta State, Nigeria, on September 26th, 2023, representing the wet season samples, while dry season samples were collected on the 19th of March 2024. Aseptic techniques, including the use of sterilised tools and equipment, were employed to handle and transfer the samples during microbiological analysis. Heavy metals and microbiological assessment were done following standard methods. Health risk assessment was done using the United States Environmental Protection Agency risk assessment framework. **Results:** The results showed that mercury, lead, cadmium, and arsenic varied among seafood species with significant implications for human health. Mercury and arsenic levels were below the detection level (<0.001 mg/kg) in all samples during both seasons. Cadmium concentrations in Crabs were 0.16 mg/kg (wet) and 0.41 mg/kg (dry), while in Periwinkles, values were 0.32 mg/kg (wet) and 0.16 mg/kg (dry). Lead levels were 1.33 mg/kg (wet) and 1.63 mg/kg (dry) in Crabs; 1.04 mg/kg (wet) and 1.24 mg/kg (dry) in Periwinkles. Potential *Vibrio* population in Shrimps were 2.0 x 104 CFU/g and potential *Salmonella-Shigella* in Crabs was 1.3 x 104CFU/g in the wet season, indicating faecal contamination and associated health risks. Human health risk assessment showed that lead posed the highest risk, with Target Hazard Quotient values exceeding the reference doses in both seasons for Crabs (wet: 0.224, dry: 0.274) and Periwinkles (wet: 0.121, dry: 0.144). Cadmium posed a risk in Periwinkles (wet: 0.0642, dry: 0.0321) and Crabs (wet: 0.0447, dry: 0.112). However, Estimated Daily Intake values did not exceed Provisional Tolerable Daily Intake for cadmium or lead, suggesting minimal health risks. **Conclusion:** Health Risk Index analysis confirmed negligible health risks associated with cadmium and lead intake from seafood. However, continuous monitoring and mitigation efforts to ensure seafood safety and protect public health in Yokri and its environs are vital as findings will serve as a warning to local authorities, fishing communities and consumers, emphasising the need for sustainable practices in this ecologically vital region. |

*Keywords: Heavy metals, Marine products, Daily metal intake, Non-cancer risk, Hazard index*

1. INTRODUCTION

The Niger Delta, an expansive wetland region nestled in the southern expanse of Nigeria, stands as a testament to the country's rich biodiversity and flourishing fishing industry [1,2]. The Niger Delta has vast natural resources, particularly oil and gas, which account for more than 90% of Nigeria’s export earnings and approximately 80% of government revenue. Since the discovery of oil in the region in 1956, oil production has played a crucial role in Nigeria’s economic development (Ewim et al., 2023). However, beneath this veneer of natural splendour lies a pressing concern fueled by ongoing oil exploration endeavours [3]. These activities, though crucial for economic growth, pose significant threats to the delicate ecological balance of the Niger Delta. With oil extraction comes the looming spectre of environmental degradation, manifesting in the form of heavy metal contamination and the proliferation of pathogenic microorganisms within aquatic ecosystems [4,5].

In the Nigerian context, oil was discovered in the Niger Delta Region (NDR) in 1956. With the oil boom of the 1970s, excessive exploitation of the region’s environmental resources began (Amakama et al., 2021; Anyanwu et al., 2023). Freshwater and marine ecosystems within the Niger Delta are vulnerable to oil spills, pipeline leaks, and wastewater discharge from oil exploration activities [6,7]. These events can introduce a range of contaminants, including heavy metals like lead, cadmium, and mercury, into the aquatic environment [8,9]. These metals can bioaccumulate in the bodies of fish and shellfish, ultimately reaching consumers through the food chain [10,11]. Similarly, oil exploration practices may increase the presence of harmful bacteria like *Escherichia coli* and *Salmonella* in the water, leading to the contamination of seafood with these pathogens [12,13,14].

Previous studies have documented the presence of elevated heavy metal concentrations in various environmental components of the Niger Delta, including sediments and aquatic biota, linked to oil exploration activities [15,16]. It has been reported that during the dry season, there is increased physiological activity by the aquatic biota as well as higher exploration rates, hence, the increased concentrations of heavy metals in the shellfish [17]. Research suggests these contaminants can bioaccumulate in fish and shellfish, raising concerns about human health risks associated with seafood consumption [18,19]. Additionally, studies have identified increased levels of faecal coliform bacteria in waterways near oil exploration sites, potentially leading to the contamination of seafood with pathogenic microorganisms [20,21]. However, limited data exists on the combined health risk assessment specifically considering both heavy metal contamination and microbiological hazards in seafood from the Niger Delta.

Understanding the ecological risks associated with consuming contaminated seafood is crucial for safeguarding public health and the integrity of the Niger Delta ecosystem [22,23]. This report will contribute valuable information to inform local authorities, fishing communities and consumers about the potential risks and recommend mitigation strategies to ensure a sustainable future for this ecologically vital region.

This study evaluated the health risks associated with the consumption of seafood harvested near oil exploration sites in the Niger Delta. We will employ the framework established by the United States Environmental Protection Agency (USEPA) for ecological risk assessment. Analysing seafood samples for heavy metal concentrations and microbial contamination, we can identify potential ecological hazards posed by the consumption of these resources.

2. materialS and methods

**2.1 Sample Collection**

Seafood samples (Crabs, Shrimps and Periwinkles) were procured from the Ogbe-Ijoh Market in Warri, Delta State, Nigeria, on September 26th, 2023, representing the wet season samples, while dry season samples were collected on the 19th of March 2024. The origin of these samples was traced through vendor interviews, indicating that they were sourced from fishermen operating in Yokri, an area known for its association with ongoing oil exploration activities conducted by Shell Petroleum Development Company (SPDC).

**2.2 Preparation of Samples**

The method of Esteves and Anibal [24] was adopted with slight modifications. The preparation of samples involved several steps to ensure the integrity of the analysis. Firstly, each seafood sample, including Crabs, Shrimps, and Periwinkles, underwent a thorough rinsing process with deionised water to eliminate any potential surface contaminants (sand, sediment and dirt) for chemical analysis only. Subsequently, the samples were carefully dissected or shelled to obtain representative portions for further analysis.

Following dissection, each portion was precisely weighed and then transferred into clean, labelled containers to maintain traceability and prevent cross-contamination. To ensure the homogeneity of the samples, each seafood type was divided into three representative subsamples. These subsamples were then homogenised using a mortar and pestle to create a uniform sample. Special care was taken during the transfer process to minimise the risk of contamination.

Aseptic techniques, including the use of sterilised tools and equipment, were employed to handle and transfer the samples during microbiological analysis. These measures were implemented to uphold the accuracy and reliability of the subsequent analytical procedures.

**2.3 Analysis of Heavy Metals**

The analysis of heavy metals in the samples was conducted with standardised spectrophotometric and atomic absorption spectrophotometry techniques to ensure precision and reproducibility. Quality assurance and control measures were rigorously followed throughout the process.

Initially, the samples underwent acid digestion to break down organic components and release the metals for analysis. Specifically, two grams of dried, homogenised tissue samples were digested using an XT-9912 model microwave system (Xintuo, China) with a solution comprising 15 ml hydrochloric acid, 5 ml nitric acid, and 5 ml perchloric acid (3:1:1 ratio). Hydrochloric acid was used for preliminary digestion. Nitric acid, an oxidising acid, was used as the dominant acid of digestion, commonly used for the oxidation of organic matter. Perchloric acid (a strong inorganic acid) was used for the rapid digestion of biological tissues. This digestion was performed under controlled conditions, with heating continued until the expulsion of brown fumes indicated complete tissue dissolution and the formation of a colourless solution. The digested samples were then cooled and diluted to a final volume of 50 ml with distilled water to achieve consistent sample concentrations [25].

For heavy metal quantification, an Atomic Absorption Spectrophotometer (SOLAAR 969AA UNICAM, Spectronic Unicam, Cambridge, UK) was used. Calibration curves for mercury, cadmium, lead, and arsenic were generated from standard solutions of known concentrations. The limits of detection (LOD) and limits of quantification (LOQ) for each metal were as follows: mercury (LOD: 0.01 mg/L; LOQ: 0.05 mg/L), cadmium (LOD: 0.005 mg/L; LOQ: 0.02 mg/L), lead (LOD: 0.02 mg/L; LOQ: 0.1 mg/L), and arsenic (LOD: 0.01 mg/L; LOQ: 0.05 mg/L).

To validate the accuracy of the method, recovery experiments were conducted by spiking known concentrations of each metal into the samples before analysis, achieving recovery percentages within 95-105% for all metals. Quality control involved analysing blanks and replicates for each batch of samples to monitor and minimise potential contamination. Standard reference materials (SRMs) were also analysed alongside samples to ensure analytical consistency.



**2.4 Bacteriological Analysis**

The bacteriological analysis in this study followed standard spread plate techniques on selective media tailored to target specific microorganisms. Serial dilution was done with 1g of the various blended/crushed samples, and 0.1mL aliquot of the different dilutions was plated out. Enumeration of potential pathogens was done using MacConkey agar and *Salmonella-Shigella* agar for *Enterobacteriaceae* and *Salmonella-Shigella* counts, respectively, with incubation at 37°C. Potential *Vibrio* species were enumerated on thiosulfate citrate bile salts sucrose agar (TCBS) at 35°C for 24-48 hours. Total viable bacterial counts were determined by spreading diluted samples onto nutrient agar plates and incubating them at a temperature of 35°C for 24 hours. Results were quantified as colony-forming units per gram (CFU/g) [26]. The dilution factor of 10-2 was inoculated for enumeration and representation of bacterial densities.

**2.5 Human Health Risk Assessment**

**2.5.1 Estimated Daily Intake (EDI)**

The estimated daily intake (EDI) method by Ullah et al. [27] and Saha and Zeman [28] for estimating heavy metal concentration in foodstuffs was employed in this study. The estimated daily intake (EDI) of each heavy metal in this exposure pathway was determined by the equation:

$EDI=\frac{Ef x ED x CF x CM}{WAB x TA}$

Where EF represents the exposure frequency (365 days/year); ED signifies the exposure duration, equivalent to an average lifetime (52 years for the Nigerian population); FIR denotes the fresh food ingestion rate (kg/person/day), set at 5 for all seafoods [27]; Cf is the conversion factor (0.208) for converting fresh weight (FW) to dry weight (DW); Cm indicates the heavy metal concentration in foodstuffs (mg/kg DW); WAB represents the average body weight (bw) (with the average adult body weight set at 70 kg); and TA signifies the average exposure time for non-carcinogens (equal to EF × ED).

**2.5.2 Target Hazard Quotient (THQ)**

The THQ method, derived from the United States EPA Region III Risk-based concentration USEPA [29], was employed. Dosage estimation was determined as follows:

$THQ=\frac{Efr x ED\_{tot }x FIR x C x 10^{-3}}{Rfd\_{0 }x BW\_{a }x AT\_{n }}$

Where EFr represents exposure frequency (365 days/year); EDtot signifies the total exposure duration (52 years, average lifetime); FIR denotes the food ingestion rate (5g/day), assuming local inhabitants consume at least 5g of seafood daily; C stands for the concentration of heavy metals in Crabs/Shrimps/Periwinkles (mg/kg); RFDos indicates the oral reference dose (mg/kg/day), and ATn signifies the average exposure time for non-carcinogens in days. The following reference doses were utilised: Ar=2.0 x 10-2 (mg/kg/day), Pb=4.0 x 10-3 (mg/kg/day), and Cd=1.0 x 10-3 (mg/kg/day). The BWa represents the average adult body weight (70 kg), and ATn is the average exposure time for non-carcinogens (365 days/year × number of exposure years, assuming 52 years). Since exposure to two or more pollutants may result in additive and/or interactive effects, the total THQs in this study were treated as the arithmetic sum of the individual metal THQ values, derived by the method of Ullah et al. [27].

**2.5.3 Health Risk Index (HRI)**

The health risk index (HRI) method by Hu et al. [30] was adopted for this study. Below is the equation:

$$HRI=\frac{EDI}{Rfd}$$

An HRI less than 1 means the exposed population is unlikely to experience obvious adverse effects, whereas an HRI above 1 means that there is a chance of carcinogenic effects, with an increasing probability as the value increases. Where reference oral doses (RfD) for Ar, Pb, and Cd are 3.5 x 10-3, 1.4 x 10-1 and 1.0 x 10-3 mg/kg/ day, respectively [31].

**2.6 Data Analysis**

All data and charts were computed using Microsoft Excel version 16.

3. results and discussion

**3.1 Concentrations of Heavy Metals in Seafood Samples**

The heavy metal analysis of seafood samples from Ogbe Ijoh market revealed varying levels of cadmium, lead, mercury, and arsenic in Crabs, Shrimps, and Periwinkles in both wet and dry seasons. For Crabs, cadmium levels were 0.16 mg/kg (wet) and 0.41 mg/kg (dry season), and lead levels were notably higher at 1.33 mg/kg (wet season) and 1.63 mg/kg (dry season). Both mercury and arsenic were below detectable levels (<0.001 mg/kg) in Crab samples. Shrimp samples showed no detectable cadmium (<0.001 mg/kg) in both wet and dry seasons, while lead was present at 0.672 mg/kg (wet season) and 0.88 mg/kg (dry season). Mercury and arsenic in Shrimps were below detectable levels as observed in Crabs. Periwinkle samples contained 0.32 mg/kg (wet season) and 0.16 mg/kg (dry season) of cadmium, with lead levels at 1.04 mg/kg (wet season) and 1.24 mg/kg (dry season). Again, mercury and arsenic levels in Periwinkles were below detectable limits. The results indicated that lead was the most prevalent heavy metal in all seafood types, particularly in the dry season, while cadmium was present in varying amounts, especially in Crabs and Periwinkles. Our results were in agreement with those of Akintade et al. [32], who reported the presence of lead and cadmium in shrimps from three different markets in Lagos. Also, they stated that arsenic values were within WHO standards. Lastly, the mean values of Cd and Pb exceeded the permissible limits set by the World Health Organisation and Food and Agriculture Organisation (0.3mg/kg) for shrimp.

Slight variations in heavy metal concentrations may be attributed to environmental factors such as water quality and pollution levels in the Yokri River, which has a flow station where oil and gas activities take place. These industrial activities likely contribute to the presence of heavy metals in the water, subsequently affecting the seafood collected from this area. Weather conditions, including rainfall and river flow rates, may also influence the distribution and concentration of these contaminants. Furthermore, amplified heavy metal concentrations are attributed to higher physiological activities, higher exploration of oil/industrial activities, as well as increased growth rates of these sea biota during the dry season [17]. These findings suggested variations in heavy metal accumulation among different seafood species, with potential implications for human health and environmental quality.

Fig.1: Concentrations of heavy metals (mg/kg) in fresh Crabs, Shrimps, and Periwinkles

\* Results are in mean ± standard deviation

Possible sources of heavy metals that might have accumulated in the seafood could be attributed to various anthropogenic activities, particularly those related to oil exploration in the community. Oil exploration activities often involve the release of heavy metals into the environment through processes such as drilling, production, transportation, and accidental spills or possible accidental discharge of drilling muds. In the Niger Delta region, where oil exploration is prevalent, the discharge of wastewater containing heavy metals from oil drilling operations, as well as erosion and runoff from contaminated sites or farmlands where pesticides are being used, can contribute to the accumulation of heavy metals in aquatic ecosystems [33,34].

The environmental significance of these concentrations to public health raises concerns about potential health risks associated with the consumption of contaminated seafood. Lead and cadmium, even at relatively low concentrations, can pose serious health threats, particularly with chronic exposure. These heavy metals are known to accumulate in the human body over time, potentially leading to adverse health effects such as neurological disorders, kidney damage, and developmental abnormalities, especially in vulnerable populations such as children and pregnant women [35,36,37,38]. Therefore, even if some heavy metal concentrations fall below regulatory limits, continuous monitoring and mitigation efforts are necessary to ensure the safety of seafood consumption and protect public health in communities reliant on these resources.

In several studies conducted in coastal areas and estuaries worldwide, similar trends in heavy metal concentrations have been observed, albeit with differences in magnitudes. For instance, Mbeh et al. [39] conducted a study in Limbe, Cameroon, quantifying heavy metals (Cd, Pb, Fe, Mg, Cu, and Zn) in seafood, including fish and crabs, and evaluating health risks to consumers. Their findings indicated that crustaceans were more contaminated with trace elements, with Crabs and fish species from Down Beach exhibiting higher metal contamination. The most abundant metals in the samples were zinc and iron, with zinc posing a potential health risk to children. Additionally, O’Mara et al. [40] reported standard levels of metals in fish, highlighting the influence of factors such as species characteristics, exposure period, and environmental conditions on heavy metal absorption. Similarly, Emenike et al. [41] emphasised the role of abiotic factors in influencing fish absorption of heavy metals. Despite the fact the concentrations of heavy metals detected in the current study's seafood samples from the Niger Delta appear to align with findings from other studies conducted in regions experiencing similar anthropogenic pressures such as oil exploration activities; regional disparities in environmental conditions and pollution sources may lead to divergent results.

**3.2 Bacteriological Analysis of Seafood Samples**

The bacteriological concentrations in the seafood samples from Ogbe Ijoh market during the wet and dry seasons, as shown in Fig.2, indicated the presence of bacterial populations. For Crabs, there were no significant bacterial counts enumerated on the selected microbiological media in either wet or dry season samples. Potential *Salmonella-Shigella* counts were detected only in Crabs collected during the dry season at a concentration of 1.3 x 104 ± 0.05 CFU/g. The total viable bacterial counts were 2.1 x104 ± 0.34 CFU/g in Crabs from the wet season and 1.5 x 104 ± 1.08 CFU/g in the dry season. For Shrimp samples recovered during the dry seasons, *Enterobacteriaceae* populations were not detected; however, potential *Salmonella-Shigella* populations were enumerated in both wet (1.5 x104 ± 0.02 CFU/g) and dry (1.2 x104 ± 0.03 CFU/g) seasons. Potential *Vibrio* counts were detected (2.0 x104 CFU/g) in Shrimp samples in the dry season. Total viable bacterial counts in Shrimps were higher, with wet season samples having 2.3 x 104 CFU/g and dry season samples 2.2 x 104 CFU/g ± 1.03. Periwinkle samples showed the presence of *Enterobacteriaceae* populations in the dry season (1.5 x104 ± 0.03 CFU/g) and were not present in the wet season. The potential *Salmonella-Shigella* population was absent in Periwinkle samples, and potential *Vibrio* counts were also not detected. The total viable bacterial counts were 2.0 x104 ± 0.04 CFU/g in wet season Periwinkles and 1.5 x 104 ± 0.07 CFU/g in dry season Periwinkles. Our reports substantiate the results of other researchers [42,43,44]. The study by Effiong & Adeyemi [43] revealed total viable bacterial counts ranging from 2.10 x 104 CFU/g to 7.30 x 104 CFU/g in prawns from wetlands in Akwa Ibom State. Again, Peter et al. [44] reported high numbers of total heterotrophic bacteria, faecal coliforms, *E. coli* and *Salmonella* from shrimps in Ibadan. Our results indicated that Shrimps generally had higher viable bacterial counts, particularly in the wet season, and that seasonal variations appear to influence the presence and concentration of bacterial pathogens in these seafood samples. International Commission on Microbiological Specification for Food (ICMSF) and United States Food Drugs Administration (USFDA) has suggested total viable bacterial counts of not greater than 5 ×105 CFU/g in shellfish for consumers’ safety [45] while National Agency for Food and Drug Administration (NAFDAC) suggests that viable counts not greater than 5.0x105 CFU/g and 1.0 × 106 CFU/g for consumers safety [46]. Again, our results were below the limits suggested by these regulatory agencies.

Fig.2: Bacterial counts in Seafood Samples

\* Results are in mean ± standard deviation

These bacterial populations may be indicative of faecal contamination and potential health risks associated with consuming contaminated seafood. Sources of pollution in the Yokri area, particularly near oil exploration sites, include runoff from agricultural activities, domestic sewage, and industrial effluents. Oil exploration activities may contribute to water pollution through the discharge of drilling fluids, oil spills and waste disposal. Faecal contamination from human and animal waste can introduce pathogens like members of *Enterobacteriaceae* (*E. coli* and *Salmonella*) into aquatic environments, leading to contamination of seafood. Consumption of seafood contaminated with these pathogens can result in gastrointestinal illnesses, including diarrhoea, vomiting and abdominal cramps, posing significant risks to public health, especially in communities reliant on seafood as a primary food source. *Vibrio* species found in different seafoods have been implicated in gastrointestinal diseases, posing a considerable public health threat, as agents of sporadic and epidemic foodborne infections when undercooked or raw seafoods are consumed [47].

Comparing these microbiological concentrations to findings from some selected studies revealed variations in contamination levels across different regions and environmental conditions. Studies conducted in the Buffalo creek [48], Pulicat lake, in North Chennai coastal region, India [49] and Mgbuoshimini creek, Port Harcourt, Rivers State [50], reported comparable levels of faecal indicators and bacterial counts in seafood samples, suggesting a widespread issue of microbial contamination in aquatic environments affected by anthropogenic activities. However, specific sources of contamination and their impacts on public health may vary depending on factors such as population density, sanitation infrastructure, and industrial activities. Further research and monitoring efforts are necessary to assess the extent of bacterial contamination in seafood and implement appropriate mitigation measures to safeguard public health and ensure the safety of seafood consumption in communities like Yokri.

**3.3 Human Health Risk Assessment**

**3.3.1 Estimated Daily Intake (EDI) of heavy metals**

The Estimated Daily Intake (EDI) of heavy metals, specifically Cd and Pb, in seafood samples (Crabs, Shrimps, and Periwinkles) is presented in Table 1.

Table 1: EDI of the heavy metals in this study.

|  |  |  |
| --- | --- | --- |
|  | **Cadmium** | **Lead** |
|  | **Wet** | **Dry** | **Wet** | **Dry** |
| **Crabs****Mean Concentration (mg/kg)**  | 0.16±0.02 | 0.41±0.01 | 1.33±0.03 | 1.63±0.04 |
| **EDI (mg/kg/day)** | 0.01 | 0.02 | 0.05 | 0.06 |
| **% of EDI to PTDI** | 0 | 0 | 0 | 0 |
| **Shrimps** |  |  |  |  |
| **Mean Concentration (mg/kg)**  | <0.001±0.00 | <0.001±0.00 | 0.672±0.02 | 0.88±0.02 |
| **EDI (mg/kg/day)** | 0 | 0 | 0.01 | 0.01 |
| **% of EDI to PTDI** | 0 | 0 | 0 | 0 |
| **Periwinkles** |  |  |  |
| **Mean Concentration (mg/kg)**  | 0.32±0.00 | 0.16±0.01 | 1.04±0.05 | 1.24±0.04 |
| **EDI (mg/kg/day)** | 0.01 | 0.008 | 0.03 | 0.04 |
| **% of EDI to PTDI** | 0 | 0 | 0 | 0 |

**Note:** Provisional tolerable daily intake (PTDI) values (in mg/kg body wt/day) of all the metals were based on the data suggested by the Joint FAO/ WHO Expert Committee on Food Additives (JECFA) [51].

The corresponding Estimated Daily Intake (EDI) values for Cadmium were 0.01 mg/day for Crabs and Periwinkles in both wet and dry seasons, while it was negligible for Shrimps due to the concentration below the detection limit in both conditions. Significantly, the percentage of EDI to Provisional Tolerable Daily Intake (PTDI) for Cadmium was 0% for all seafood types, suggesting that the estimated intake of Cadmium from these seafood samples does not exceed the Provisional Tolerable Daily Intake recommended by JECFA, regardless of the season. The EDI values for Lead was 0.05 mg/day in wet season and 0.06 mg/day in dry season (for Crabs); 0.01 mg/day in wet season and 0.01 mg/day in dry season (for Shrimps); 0.03 mg/day in wet season and 0.04 mg/day in dry season (for Periwinkles). Despite the variability in concentrations among seafood types and seasons, the percentage of EDI to PTDI for lead remained at 0% for all samples, indicating that its intake from these seafoods does not exceed the recommended tolerable daily intake levels. Our results corroborate the findings of Ahmed et al. [52]. Their findings revealed that the EDI values of lead, arsenic and cadmium were less than 1 for two species of shrimp and one species of crab, which indicated that the average consumption of the species in the coastal area would not result in a health risk.

Public health implications of these findings suggest that while the concentrations of cadmium and lead in the analysed seafood samples may be detectable, their estimated daily intake levels do not pose significant risks to human health. However, continuous monitoring of heavy metal concentrations in seafood, adherence to food safety regulations and dietary diversity are essential to minimise potential health risks associated with heavy metal exposure through seafood consumption.

**3.3.2 Target Hazard Quotient of Heavy Metals in Sampled Seafoods**

From the heavy metal concentrations determined in this study, it was revealed that the concentrations of the heavy metals ranked as Pb >Cd >Hg/As across all seafood samples. Human health risk was not calculated for mercury (Hg) and arsenic (As), considering their concentrations were below detectable limits. Table 2 shows the results of the target hazard quotients (THQs) of the seafood samples.

Table 2: THQs of the studied heavy metals in seafoods sampled.

|  |  |  |
| --- | --- | --- |
|  | **Cadmium** | **Lead** |
|  | **Wet** | **Dry** | **Wet** | **Dry** |
| **Mean Concentration of Heavy metals in Crabs** | 0.16±0.02 | 0.41±0.01 | 1.33±0.03 | 1.63±0.04 |
| **Mean Concentration of heavy metals in Shrimps** | <0.001±0.00 | <0.001±0.00 | 0.672±0.02 | 0.88±0.02 |
| **Mean Concentration of heavy metals in Periwinkles** | 0.32±0.00 | 0.16±0.01 | 1.04±0.05 | 1.24±0.04 |
|  RFDos | 0.02 | 0 | 0 | 0 |
| **THQ in Crabs** | 4.47E-02 | 1.12E-01 | 2.24E-01 | 2.74E-01 |
| **THQ in Shrimps** | 0 | 0 | 1.01E-01 | 1.32E-01 |
| **THQ in Periwinkles** | 6.42E-02 | 3.21E-02 | 1.21E-01 | 1.44E-01 |

**Note:** THQ: total hazard quotient, THQs: total hazard quotients and RFDos: reference dosage

Analysing the THQ values, it is evident that Pb poses the highest health risk among the studied heavy metals in both wet and dry seasons. For instance, the THQ values for lead in Crabs were 0.224 in the wet season and 0.274 in the dry season, while in Shrimps, the values were 0.101 in the wet season and 0.132 in the dry season. Periwinkles showed THQ values for lead were 0.121 in the wet season and 0.144 in the dry season. These values exceed the RFDos for lead, indicating that exposure to lead through the consumption of these seafood samples may potentially exceed safe levels and pose health risks to consumers.

Similarly, cadmium exhibits significant health risks, especially in Periwinkles samples, where the THQ value was 0.0642 in the wet season and 0.0321 in the dry season, surpassing the RFDos for cadmium. In Crabs, the THQ for cadmium was lower but still notable, with values of 0.0447 in the wet season and 0.112 in the dry season, indicating a considerable health risk over prolonged consumption. Although the THQ values for cadmium in Shrimps were not available due to concentrations being below the detection limit, it is crucial to acknowledge the potential risk associated with this heavy metal in seafood consumption. The seasonal analysis showed that the dry season tends to have higher concentrations of lead and cadmium in Crabs and Periwinkles, resulting in higher THQ values. This could be due to various environmental factors such as lower water levels concentrating pollutants or increased industrial activity during certain times of the year, as well as increased physiological activities of these aquatic animals. However, all the THQs were lower than the threshold value (1) and do not pose any health risks to the consumers. Again, our report supports the findings of different researchers [52,53,54,55]. Davies & Anyanwu [55], stated that THQ was less than 1 in shrimps from a mangrove swamp in the Niger Delta while Ahmed et al. [52] reported a THQ less than 1 in crabs. If the target hazard quotient (THQ) number is less than 1, it is unlikely that the exposed population would experience any discernible negative consequences [56,57], therefore, such food could be consumed successfully.

**3.3.3 Health Risk Index (HRI) of heavy metals**

In Table 3, the HRI of the heavy metals Cd and Pb in the analysed seafood samples is presented.

Table 3: HRI of the studied heavy metals

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | **Cadmium** | **Lead** |
|  |  | **Wet** | **Dry**  | **Wet** | **Dry**  |
| **Crabs** | **EDI** | 0.01 | 0.005 | 0.05 | 0.006 |
|  | **HRI** | 0 | 0 | 0 | 0 |
| **Shrimps** | **EDI** | 0 | 0 | 0.01 | 0.01 |
|  | **HRI** | 0 | 0 | 0 | 0 |
| **Periwinkles** | **EDI** | 0.01 | 0.03 | 0.03 | 0.04 |
|  | **HRI** | 0 | 0 | 0 | 0 |
|  | **RFDos** | 0 | 0 | 0 | 0.001 |

**Note:** RFDos: reference dosage, HRI: health risk assessment and EDI: estimated daily intake

For Cd, the EDI varied among seafood types, with Crabs and Periwinkles exhibiting EDI values of 0.01 mg/day, while Shrimps had an EDI value of zero, irrespective of the wet or dry season. Despite these differences in EDI values, the corresponding HRIs for Cd were consistently calculated as zero for all seafood types and seasons. This consistent result indicates that the estimated daily intake of Cd from the seafood samples does not exceed the reference dosage, resulting in negligible health risks associated with Cd intake from these sources.

Similarly, for Pb, the EDI values ranged from 0.005 to 0.03 mg/day across seafood types and seasons. Despite these variations, the HRIs for Pb were also consistently calculated as zero for all seafood types and seasons. This uniform outcome suggests that the estimated daily intake of Pb from the seafood samples does not surpass the reference dosage, resulting in minimal health risks associated with Pb intake from these sources. The HRI analysis indicates that the consumption of Crabs, Shrimps, and Periwinkles from the studied area does not pose significant health risks in terms of Cd and Pb exposure during wet and dry seasons.

Shaheen et al. [58] have reported that if THQ is more than 1, there is a potential that it will have an adverse effect on health, and if the HRI value is less than 1, the exposed population is safe [59]. Our results were in line with the reports of other researchers [60,61]. However, some studies have confirmed THQ values above 1. Lima et al. [62] confirmed THQ(in lead) in the range of 1.75–3.60, which could pose a threat as lead contributes to lung cancer, brain and liver damage [63]. They further confirmed very high values of TTHQ in excess of 2.66 that they attributed to, inter alia, low water quality and lead contamination in bottom sediments.

Although the calculated risk factors indicated a negligible probability of health risk rising from the consumption of these seafoods, nonetheless, the limited amount of available literature, it is challenging to eliminate such risk occurring elsewhere, particularly in people based on these products.

4. Conclusion

This study assessed heavy metal concentrations and bacteriological quality of selected seafood samples from Yokri community, Burutu Local Government Area of Delta State, Nigeria, during wet and dry seasons (peak seasons), to ascertain the public health risks associated with the consumption of such foods. Analysis revealed varying levels of heavy metals, Pb and Cd, in the Crabs, Shrimps, and Periwinkles samples. While within regulatory limits, continuous monitoring of crude oil exploration activities by oil companies and domestic activities around the river by indigenes of the community should be done by appropriate regulatory authorities to prevent potential long-term health risks. Bacterial analysis identified appreciable populations of potential enteric pathogens (i.e. *Enterobacteriaceae*, *Salmonella-Shigella*, and *Vibrio*), counts indicating possible faecal contamination and potential health hazards. In spite of this, total viable counts enumerated in this study were within permissible limits stipulated by the International Commission on Microbiological Specifications for Food, United States Food and Drug Administration and National Agency for Food and Drug Administration (total viable bacterial counts not greater than 5.0 ×105 CFU/g and 1.0 × 106 CFU/g). Pollution sources, particularly from oil exploration activities, may have contributed to heavy metal contamination. Health risk assessment suggested low health risks associated with heavy metals in the seafood. Ongoing monitoring by environmental health workers, regulatory bodies and mitigation efforts (building sanitary facilities, proper treatment and disposal of industrial waste/effluent, amongst others) are crucial to ensure seafood safety, with emphasis on regulatory measures and public awareness campaigns to mitigate risks.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Details of the AI usage are given below:

1.

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3.

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