**Mathematical Modelling of Heavy Metals and PAH Contaminations in Seafood from Okoroba, Nembe of Bayelsa State: Implications for Public Health**

**ABSTRACT**

This study is based on the health risk assessment of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in selected seafood from Okoroba, Bayelsa State. Seafood were collected from Okoroba River. Heavy metals, PAHs, Daily Intake, Life Cancer Risk, Total Life Cancer Risk, Target Hazard Quotient, and Hazard Index of hazardous [heavy metals](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/heavy-metal) were investigated based on standard methods of estimation. The Ni, Cr, Pb, and Cd level in *Calcinuselegans* were 29.79±0.01mg/kg, 2.49±0.01, 2.49±0.01mg/kg, 1.19±0.01mg/kg, and 2.19±0.01mg/kg respectively, were significantly higher than the reference values which were 5.5mg/kg, 0.05mg/kg, 0.2mg/kg, and 1.0mg/kg respectively and similar differences were observed in *Catharanthus roseus*, *Oxudercinae,* and*Sesamumindicum.* The estimated daily intake of Ni, Cd, and Pb in *Calcinuselegans* were 10.032mg/kg, 2.160mg/kg, and 0.301mg/kg respectively, were significantly higher than the reference values 0.5mg/kg, 0.00mg/kg respectively and similar trends occurred in *Catharanthus roseus,Sesamumindicum, Gecarcinidae,* and Atlantic silverside. The target hazard and hazard index of Ni, Pb, and Cd in*Halichoeres bivittatus* were 3.600mg/kg, 1.380mg/kg, 6.010mg/kg, and 2.050mg/kg respectively, which were significantly higher than the reference values 1mg/kg and similar trends occurred in *Schilbemystus, Bagrus bajad, Atlantic*silverside, *Portunus armatus,* and *Catharanthus roseus*. The estimated daily intake of Ni, Cd, and Pb in the studied seafoodwere higher than the Recommended Tolerable Daily Intake levels of heavy metals in sea food. The estimated daily intake, target hazard quotient and hazard index of Ni, and Pb evaluated is suggestive of possible health risk on the indigenous people of Okoroba community upon consumption for period of time.

*Keywords: Seafood, heavy metals, PAHs, EDI, LCR, TLCR, RTDI*

1. **1NTRODUCTION**

Environmental pollution arising from oil exploration and industrial waste has led to contamination of aquatic ecosystems in the Niger Delta, Nigeria. This includes Okoroba in Nembe LGA, Bayelsa State, where seafood, a primary protein source is vulnerable to pollutants such as heavy metals (HMs) and polycyclic aromatic hydrocarbons (PAHs). Mathematical risk assessments are essential to evaluate human health implications. Oguguah *et al.* (2016) showed that heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), chromium (Cr), arsenic (As), copper (Cu), zinc (Zn), and iron (Fe) have been widely detected in fish, shrimp, and mollusks from polluted waters. According to Oguguah *et al.* (2016), these metals bioaccumulate and biomagnify through the food chain. Heavy metals are important aquatic pollutants with non-biodegradable and bioaccumulation properties, high toxicity, and long-time persistence (Varol *et al.,* 2017;Uysal *et al.,* 2019). The major source of heavy metalpollution into the river is the [earth's crust](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/earth-crust). Additionally, heavy metals are known to be transmitted into the river through [industrial effluents](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/industrial-effluent) and bunkering activities directed (Uysal *et al.,* 2019).

PAHs, which are lipophilic and persistent organic pollutants, originate from crude oil spills and combustion. They pose carcinogenic and mutagenic risks. Nwaichi *et al*., (2017) reported that PAHs such as benzo[a]pyrene, fluoranthene, and pyrene have been reported in aquatic species in the Niger Delta. Polycyclic aromatic hydrocarbons (PAHs) are a large fragments of all-pervasive organic compounds which possess the capacity to be widely disseminated in terrestrial and aquatic ecosystems (Boisa *et al.,* 2019; Lawal, 2017). The level of toxicity of these organic compounds is largely dependent on theirmolecular weight as the larger molecular weight PAHs (high MW PAHs) having four to seven aromatic rings are not acutely toxic but possess a greater capacity for carcinogenicity(Srogi, 2007). PAHs also possess the tendency of eliciting oxidative stress alongside the consequence of cytotoxic effects (Padula *et al.,* 2015). Vulnerability in children has been shown to be associated with the expression of several pathological results such as symptoms of asthma and poor cognitive development as well as the occurrence of lower pulmonary function and wheezing symptoms in adults (Padula *et al.,* 2015).

Seafood accumulate contaminants primarily by uptake through the skin and gills, surface contacts with sediments, industrial effluent, wastewater, and food consumed (Soltani *et al*., 2019), thus serving as a secondary source of exposure to humans (Dang *et al.,* 2016). Results from studies have confirmed that heavy metals may enter into the food chain through the natural and anthropogenic processes and cause toxicity in the [aquatic organisms](https://www.sciencedirect.com/topics/pharmacology-toxicology-and-pharmaceutical-science/aquatic-species) even at low concentrations (Gwimbi *et al.,* 2020). The long period of intake of cytotoxic heavy metals through foodstuffs lead to chronic accumulation, which consequently can cause damages to organs and tissues. Consequential effects of metal accumulation are [mutagenesis](https://www.sciencedirect.com/topics/pharmacology-toxicology-and-pharmaceutical-science/mutagenesis), carcinogenesis, [teratogenesis](https://www.sciencedirect.com/topics/pharmacology-toxicology-and-pharmaceutical-science/teratogenesis), deformation, and breakdowns of organs (Dang *et al.,* 2016).

Communities under Nembe Local Government Area, of Bayelsa State, is a hub of fishing activities. The Atlantic coastline, brackish mangroves, and creeks surrounding Nembe make it rich in aquatic biodiversity, contributing to the availability of seafood such as fish, shrimp, crab, periwinkle, and oysters, which are vital to the local diet and economy. However, oil exploration and exploitation by multinational companies in the region have resulted in environmental degradation that has affected seafood safety and sustainability. Nwaichi *et al.* (2017) showed that PAHs are formed from incomplete combustion of organic matter, crude oil spills, and gas flaring. Umeoguaju *et al*. (2023), detected PAHs in seafood samples from the Niger Delta, showing potential carcinogenic and mutagenic risks. Akeju and Gbekeloluwa (2023) studied the molecular Characterization of Bacteria Isolated from Some Seafood in Nembe Community while Markmanuel *et al.* (2022) evaluated the Tin concentrations and human health risk assessment for children and adults in seafood and canned fish commonly consumed in Nembe, Bayelsa State.

The seafood in the Okoroba River are consumed as the main protein source by the residents of the community as well as the other cities in the Southern parts of Nigeria. Therefore, the assessment of PAHs and hazardous heavy metals in seafood is considered highly very vital as they are highly bio-accumulated biological systems and pose significant health risks over prolonged exposure (Justice-Alucho *et al.,* 2021; Akeju and Gbekeloluwa, 2023).

Health risk assessment is a quantitative and qualitative evaluation of the risk posed to human health by the actual or potential presence of specific pollutants. It is thus an evaluation of the hazardous properties of environmental pollutants, the dose-response relationship of these pollutants and the extent of human exposure to them (Ephraim-Emmanuel and Ordinioha, 2021). Despite broader studies in the Niger Delta, Okoroba-specific data is scarce. The unique hydrology and proximity to oil facilities may influence local pollution levels. A localized study ensures context-specific data accuracy, tailored public health interventions, and grounded environmental policy recommendations. Mathematical models such as Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), and Incremental Lifetime Cancer Risk (ILCR) allow quantification of risk levels, identification of populations at risk (e.g., children, pregnant women), and assessment of long-term implications of continuous seafood consumption (Tanhan *et al*., 2023; Odey *et al.,* 2024; Nobile *et al*., 2024).).

Okoroba community is one of the prominent communities in Nembe Local Government Area. It is located 40330N and 6033200E, which occupy same geographical location with Opume, Akipilai, Nembe, Otuabagi, Agrisaba, Emago, Otuakeme, Kolo, Oloibiri, and Emeyal communities. Okoroba community is endowed with crude oil, hence one of the crude oil producing communities in Ogbia Local Government Area of Bayelsa State. The main occupation of the people of Okoroba include; farming, fishing, and palm oil milling. Periwinkle, blue swimming crab, mud keeper, slipper fish, butter catfish, silver side, sesema crab, land crab, and elegant crab remain the main source of protein to the people of Okoroba. More so, there are paucity of information regarding the health risk of consumption the famous seafood of the community.We evaluated the concentration of PAHs and heavy metals as well as performed the health risk associated with the seafood collected from the Okorobariver in Nigeria (Fig. 1).

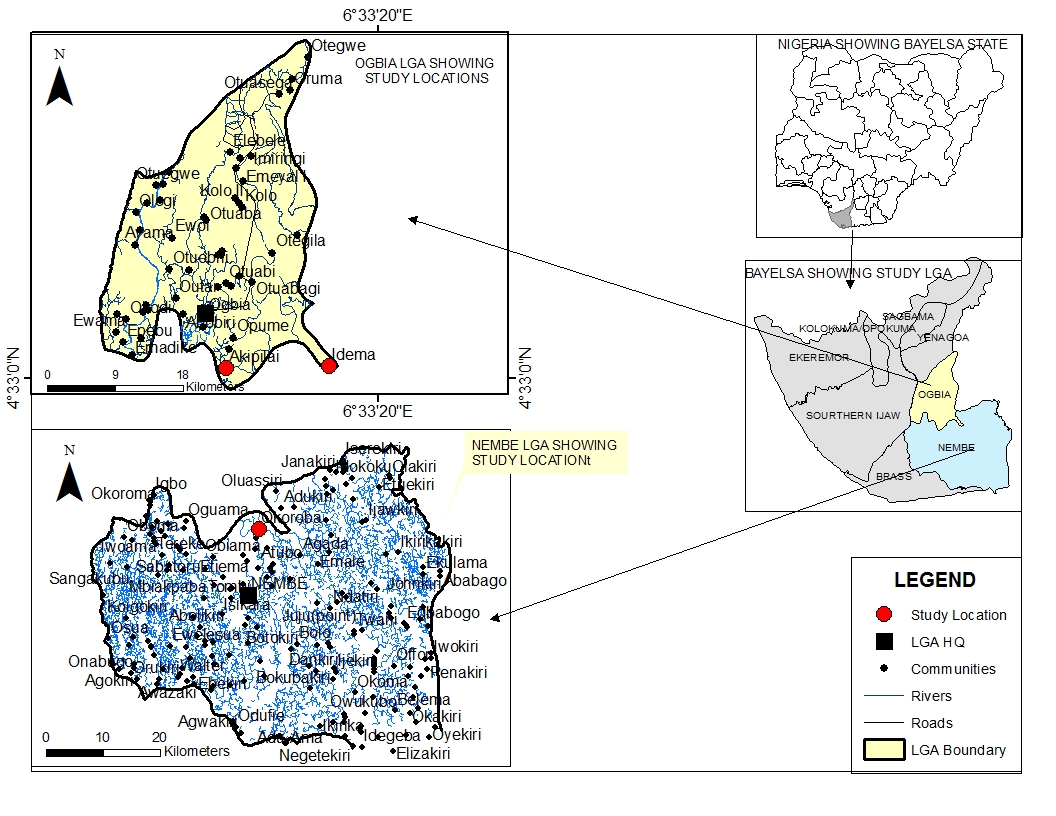
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Figure 1 GPS of Okoroba Town, Ogbia Local Government Area of Bayelsa State

**2. MATERIALS AND METHODS**

**2.1 Studied Area**

Collection of seafood was done in June 2024 from Okoroba River. Okoroba River originates from Nembe, Idema and it flows through Idema community through the Nembe rivers. The seafood serve as a source of livelihood for many people in Okoroba community.

**2.2 Collection of Seafood Samples**

Ten different types of shell and fin seafood were collected from sites 1 and 2 in June, 2024. Upon collection, the seafood were immediately transferred into the icebox and conveyed into the laboratory. Beforedissection, they were allowed to thaw and [anthropometric measurements](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/anthropometric-measurement) were taken. The seafood were harvested and prepared for PAHs and hazardous metal analysis. Each of the seafood was oven-dried at 80 °C and was monitored until a constant weight was reached.

**2.3 Determination of Heavy Metal ion Concentration of Seafood**

The heavy metal ion concentrations of seafood (finfish) were determined using AAS, following the modified method as described by Rohan *et al.* (2014). AAS technique makes use of the atomic absorption spectrum of a sample in order to assess the concentration of specific analytes within the sample. It requires using a standard with known analyte concentration to establish the relation between the measured absorbed absorbance and the analyte concentration and relies therefore on the Beer-Lambert Law. Digestion/preparation of the sample and estimation of heavy metals were carried out based on standard methods.

**2.4 Determination of PAHs Concentrations Seafood (Shellfish)**

Polycyclic aromatic hydrocarbon (PAHs) concentrations in seafood (shellfish) using gas chromatography and HPLC, following the modified method of determination of PAHs in seafood (shellfish) as described by Bhupander *et al.* (2014). In this method, 50 mL of the sample was measured into a bottle seal via a separatory funnel. Then, 50 mL of methylene chloride was added into the bottle seal containing the sample (shell fish sample) and it was shaken for 30 seconds to rinse the surface. The mixture was allowed to stand and the organic layer is separated from the water phase for a minimum of 10 minutes. Ten millilitre (10 mL) of the methylene chloride was delivered into 250 mL flask. A second 60 mL of the methylene chloride was again added to the sample (shell seafood) and both the sample and the separatory funnel were rinsed with 20 mL of the solvent into the extract. This extraction procedure was then repeated a second time with both the sample and solvent combined in an Erlenmeyer flask. The combined extract was then poured into a dried column containing packed cotton wool. Repeat the extraction procedure a second time, combine the extracts in the Erlenmeyer flask. Perform the third extraction in the same manner. Pour the combined extract through a drying column containing sodium sulphate and silica packed with cotton wool which collect the extract into vial and concentrated it by boiling it down with 1.0 mL nitrogen steam. The remaining extract was then mixed with 1.0 mL of the solvent and 1.0µL of the mixture was injected into flame ionization detector gas chromatograph for the analysis of PAHs.

**2.5 Wet Digestion Method**

In this method, a total volume of 100 mL of H2SO4, HNO3, and HClO4 in the ratio of 40%:40%:20% were mixed together. Exactly 1 g of the sample was delivered into a conical flask. Then, 2 mL of the H2SO4, HNO3, and HClO in the ratio of 40%:40%:20% the acid were added to the sample in the conical flask. Digestion of the sample was commenced until the appearance of white fumes was clearly observed or noticed. The mixture was then cooled and filtered into a 100ml volumetric flask and was made up to using distilled water. The hollow cathode lamp for the desired metal was installed. The wavelength dial as specified by the analytical methodology was set. Then, the slit width was set or prepared according to manufacturer’s suggested setting. Turn on the instrument was switched on and the hollow cathode lamp current as suggested by the manufacturer and while the instrument was made to warm up until energy sources stabilizes within about 10 to 20 minutes. The current was adjusted after been warmed-up while the wavelength was also adjusted until optimum energy gain is obtained. The align lamp was then fixed in accordance with manufacturer’s instructions. The burner head was installed and adjust its position. A 10cm, single-slot burner head was recommended for air-acetylene flames. The flow rate was adjusted according to manufacturer’s instructions to give maximum sensitivity for the metal being measured. The acetylene was adjusted to a specified value. The flame was Ignited and allowed to stabilized for 10 minutes. The blank was the aspirated and the instrument was zeroed. The standard solution was aspirated and the aspiration was adjusted to a standard solution until the aspiration rate of nebulizer to obtain a maximum sensitivity. The blank was aspirated again into and re-zero instrument. The standard was aspirated using standard with a concentration near the middle of the linear range and record absorbance while the instrument is now ready to operate.

**2.6 Human Health Risk Assessment of Heavy Metals in Seafood**

**2.6.1 Estimated Daily Intake of Metals in Seafood**

The daily intake of hazardous [heavy metals](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/heavy-metal) were estimated based on the concentration in the samples of the seafood species. The daily intake by consuming the fish sample was estimated using equation 1 below (Matouke and Abdullahi, 2020):



Where.

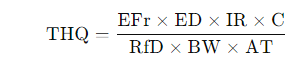
C = Concentration of the metal in seafood (µg/g or mg/kg)

IR = Ingestion rate of seafood (g/day)

BW = Body weight (kg)

**2.6.2 Target Hazard Quotient and Hazard Index of Metals in Seafood**

The estimation of the Target Hazard Quotient (THQ) and Hazard Index (HI) of metals in seafood is a crucial aspect of assessing the potential health risks associated with the consumption of contaminated seafood. The Target Hazard Quotient is calculated using the formula below (Matouke and Abdullahi, 2020):



Where:

EFr = Exposure frequency (days/year)

ED = Exposure duration (years)

IR = Ingestion rate (kg/day)

C = Concentration of the contaminant (mg/kg)

RfD = Reference dose (mg/kg/day)

BW = Body weight (kg)

AT = Averaging time (days, ED × 365 days/year for non-carcinogens)

**2.6.3 Life Cancer Risk and Total Life Cancer Risk of Metals in Seafood**

The estimation of Life Cancer Risk (LCR) and Total Life Cancer Risk (TLCR) of metals in seafood is an important process to assess the potential carcinogenic risks posed by consuming seafood contaminated with carcinogenic metals.

Daily Intake of Metal was calculated or estimated using the formula:



Where:

C = Concentration of the metal in seafood (mg/kg)

IR = Ingestion rate of seafood (kg/day)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Body weight (kg)

AT = Averaging time (days, usually lifetime expectancy in days for carcinogens)

The Life Cancer Risk (LCR) was calculated using the formula:

Where:

DIM = Daily intake of the metal (mg/kg/day)

CSF = Cancer Slope Factor (mg/kg/day)^(-1), which is a measure of the risk of cancer associated with exposure to a carcinogen over a lifetime

The estimation of Life Cancer Risk (LCR) and Total Life Cancer Risk (TLCR) of metals in seafood is an important process to assess the potential carcinogenic risks posed by consuming seafood contaminated with carcinogenic metals.

**3. RESULTS**

**3.1 Heavy metal concentrations in seafood from Okoroba, Nembe River**

Table 1 shows the heavy metal concentrations in seafood from Okoroba, Nembe river of Bayelsa. The heavy metal levels in the selected seafood were reported in mean and standard deviation. The values of each heavy metals assayed were compared with the references for significance.

Table 1 Heavy metal concentrations in seafood from Okoroba, Nembe River

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb (mg/kg) | | Cd(mg/kg) | | | Cr(mg/kg) | Ni(mg/kg) | | | Zn(mg/kg) | Mn(mg/kg) | | Fe(mg/kg) |
| *Grapsidae* | 2.19±0.01 a | | 1.19±0.01a | | | 2.49±0.01 a | 29.79±0.01a | | | 3.19±0.01 | 0.18±0.01 | | 18.62±0.0a |
| Potamonautes busungwe | 4.03±0.01 a | | 1.36±0.01 | | | 6.07±0.00 a | 23.13±0.01a | | | 2.30±0.01 | 1.26±0.01 | | 23.10±0.0a |
| *Cardisoma armatum* | 1.67±0.01 a | | 0.17±0.01 | | | 0.83±0.01 | 6.46±0.01 a | | | 0.58±0.01 | 0.35±0.01 | | 12.72±0.01 |
| *Oxudercinae* | 3.22±0.01 a | | 0.04±0.01 | | | 5.16±0.01a | 10.29±0.01a | | | 0.91±0.01 | 2.63±0.01 | | 19.13±0.0a |
| *Halichoeres bivittatu* | 1.19±0.00 a | | 0.47±0.01 | | | 1.56±0.01 | 8.18±0.01a | | | 1.83±0.01 | 2.48±0.01 | | 21.18±0.0a |
| *Mystus tengara* | 0.36±0.01 | | 0.19±0.01 | | | 4.19±0.01a | 6.40±0.01a | | | 0.62±0.01 | 0.15±0.04 | | 10.01±0.01a |
| *Bagrus bajad* | 1.22±0.01 a | | 0.56±0.01 | | | 10.05±0.01a | 3.19±0.01 | | | 4.18±0.01a | 0.56±0.01 | | 17.16±0.01a |
| *Atlantic silverside* | 2.19±0.01a | | 0.80±0.01 | | | 5.05±0.01a | 1.38±0.01 | | | 4.95±0.01a | 1.21±0.01 | | 0.04±0.01 |
| *Portunus armatus* | 3.14±0.01 a | | 1.05±0.01 a | | | 3.19±0.01 a | 2.82±0.02 | | | 2.10±0.01 | 2.35±0.01 | | 15.16±0.01a |
| *Catharanthus roseus* | 4.01±0.00 a | | 1.36±0.01 a | | | 6.04±0.01 | 7.39±0.02 a | | | 3.89±0.01 | 0.80±0.01 | | 18.06±0.01 |
| Standard permissible limits of heavy metals in seafood | | | | | | | | | | | | | |
| WHO/FAO, 2011 | 1.0 | 0.2 | | 0.6 | 0.05 | | |  | 5.5 | | | 43 | |

Data are reported in mean and standard error of mean (M±SE). Values bearing similar superscript ‘’a’’were significantly higher than the reference values down the groups.

**4.2 Estimated daily intake of metals in shellfishes from Okoroba, Nembe River**

Table 2 presents the estimated daily intake of metals in shellfishes from Okoroba community, Bayelsa State. The estimated daily intake of cytotoxic heavy metals were compared to the reference values in Table 2.

Table 2 Estimated daily intake of metals in shellfishes from Okoroba, Nembe River

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb (mg/kg) | Cd (mg/kg) | Cr  (mg/kg) | Ni  (mg/kg) | Zn (mg/kg) | Mn(mg/kg) | Fe (mg/kg) |
| *Grapsidae* | 0.301 | 2.160 | 0.208 | 10.032 | 0.010 | 5.920 | 0.060 |
| *Potamonautes busungwe* | 0.016 | 1.201 | 0.270 | 15.043 | 0.008 | 0.004 | 0.075 |
| *Cardisoma armatum* | 0.701 | 2.200 | 0.203 | 7.281 | 0.002 | 0.001 | 0.041 |
| *Oxudercinae* | 0.013 | 1.230 | 0.017 | 14.033 | 0.002 | 0.009 | 0.062 |
| *Halichoeres bivittatus* | 1.010 | 0.002 | 0.305 | 3.827 | 0.006 | 0.008 | 0.069 |
| *Mystus tengara* | 0.001 | 2.290 | 0.514 | 10.021 | 0.002 | 4.960 | 0.033 |
| *Bagrus bajad* | 0.020 | 0.002 | 0.133 | 16.010 | 0.014 | 0.002 | 0.056 |
| Atlantic silverside | 0.573 | 2.690 | 0.416 | 13.900 | 0.016 | 0.004 | 1.360 |
| *Portunus armatus* | 0.826 | 1.750 | 0.110 | 2.009 | 0.007 | 0.008 | 0.049 |
| *Catharanthus roseus* | 1.816 | 1.001 | 0.520 | 26.724 | 0.013 | 0.003 | 0.059 |
| EC, 2005  (mg/kg) | 0.00 | 0.000 | 0.1-1.2\* | 0.5 | 8.0 | 0.4-10\* | 0.8\* |
| UTDI (mg/kg) | 0.5 | 1.0 | 43.40 | 22.70 | 40 | - | - |

Recommended tolerable daily intake (TDI) and upper tolerable daily intake (UTDI) levels of heavy metals in sea food (WHO, 2011).

**3.3** **Target Hazard Quotient and Hazard Index of Metals in Seafood FromOkoroba Nembe River, Bayelsa**

Table 3 shows the target hazard quotient and hazard index of metals in seafood from Okoroba Nembe River, Bayelsa. The target hazard quotient of each of the evaluated cytotoxic heavy metals calculated were compared to the reference values in table 3.

Table 3 Target hazard quotient and hazard index of metals in seafood from Okoroba Nembe River, Bayelsa

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples |  |  | Pb (mg/kg) | Cd (mg/kg) | Cr (mg/kg) | Ni (mg/kg) | Zn (mg/kg) | Mn(mg/kg) | Fe  (mg/kg) | Hazard index |
| *Grapsidae* |  |  | 0.103 | 6.160 | 0.390 | 4.002 | 1.450 | 0.260 | 0.550 | 0.006 |
| *Potamonautes busungwe* |  |  | 0.205 | 3.010 | 1.310 | 2.010 | 2.700 | 1.930 | 1.370 | 0.008 |
| *Cardisoma armatum* |  |  | 1.000 | 2.210 | 1.800 | 3.010 | 0.006 | 8.060 | 1.160 | 0.009 |
| *Oxudercinae* |  |  | 0.107 | 1.230 | 0.110 | 2.010 | 1.790 | 1.610 | 1.760 | 0.008 |
| *Halichoeres bivittatus* |  |  | 2.050 | 6.010 | 1.380 | 3.600 | 1.980 | 0.750 | 1.590 | 0.009 |
| *Mystus tengara* |  |  | 3.390 | 3.290 | 0.907 | 1.201 | 6.750 | 1.540 | 1.060 | 0.002 |
| *Bagrus bajad* |  |  | 1.406 | 0.620 | 1.017 | 3.160 | 4.520 | 1.310 | 0.960 | 0.009 |
| *Atlantic*silverside |  |  | 2.001 | 2.690 | 4.009 | 2.230 | 1.310 | 0.810 | 0.70 | 0.003 |
| *Portunus armatus* |  |  | 1.008 | 1.750 | 2.890 | 1.570 | 2.540 | 0.450 | 1.140 | 0.009 |
| *Catharanthus roseus* |  |  | 2.007 | 2.010 | 1.310 | 3.001 | 4.210 | 1.840 | 7.320 | 0.009 |
| Garcia-Rico (2007). |  |  | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**3.4 Life Cancer Risk and Total Life Cancer Risk of Metals in Seafood FromOkoroba Nembe River, Bayelsa**

Table 4 shows the life cancer risk and total life cancer risk of metals in seafood from Okoroba. The life cancer risk and total life cancer risk of Pb in *Grapsidae* was highest next was Cd, Cr while the least was Ni.

Table 4 Life cancer risk and total life cancer risk of metals in seafood from Okoroba Nembe River, Bayelsa

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb  (mg/kg) | Cd  (mg/kg) | Cr  (mg/kg) | Ni  (mg/kg) | Zn | Mn | Fe | TLCR |
| *Grapsidae* | 3.500 | 2.004 | 1.104 | 1.054 | - | - | - | 0.058 |
| *Potamonautes busungwe* | 1.340 | 3.804 | 2.001 | 1.073 | - | - | - | 0.084 |
| *Cardisoma armatum* | 7.250 | 8.650 | 5.002 | 6.036 | - | - | - | 0.038 |
| *Oxudercinae* | 1.094 | 2.065 | 1.009 | 1.056 | - | - | - | 0.065 |
| *Halichoeres bivittatus* | 8.104 | 7.640 | 8.003 | 3.046 | - | - | - | 0.050 |
| *Mystus tengara* | 2.560 | 2.340 | 0.007 | 0.036 | - | - | - | 0.043 |
| *Bagrus bajad* | 1.040 | 1.004 | 0.017 | 0.017 | - | - | - | 0.035 |
| *Atlantic*silverside | 8.005 | 7.004 | 5.008 | 7.009 | - | - | - | 0.017 |
| *Portunus armatus* | 6.004 | 6.650 | 7.005 | 5.015 | - | - | - | 0.020 |
| *Catharanthus roseus* | 8.004 | 9.840 | 6.01 | 4.041 | - | - | - | 0.052 |
| Reference | to | to | to | to | - | - | - | to |

**3.5 Polycyclic Aromatic Hydrocarbon Concentration of Fresh Seafood Samples Harvested From Okoroba, Nembe River, Bayels.**

Table 5 shows the PAH levels of fresh seafood in Okoroba river harvested from Okoroba river, Bayelsa.

Table 5 Polycyclic aromatic hydrocarbon concentration of fresh seafood samples harvested from Okoroba, Nembe River, Bayelsa

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Compound | *Grapsidae* | *Potamonautes busungwe* | *Cardisoma armatum* | *Oxudercinae* | *Halichoeres bivittatus* | *M. tengara* | *Bagrus bajad* | *A.*  silverside | *P.armatus* | *C.*  *roseus* |
| Naphthalene(3) | 10.737 | 8.776 | 0.085 | 2.113 | 8.406 | 10.653 | 1.260 | 10.138 | 8.206 | 10.58 |
| Acenapthylene(3) | ND | ND | 0.194 | ND | ND | ND | 0.895 | 1.523 | ND | ND |
| Acenaphthene(3) | 5.402 | 6.416 | 0.032 | ND | 5.622 | 4.205 | 0.575 | 4.740 | 3.053 | 4.263 |
| Fluorene(3) | 4.197 | ND | ND | ND | 1.402 | 2.098 | 0.952 | 5.551 | 2.394 | 3.318 |
| Phenanthrene(3) | 6.218 | 10.183 | 0.819 | 4.762 | 6.366 | 11.463 | 1.182 | 8.476 | 10.841 | 5.188 |
| Anthracene(3) | ND | 5.503 | ND | ND | ND | ND | ND | ND | ND | ND |
| Fluoranthene(3) | 3.510 | ND | 1.260 | ND | 2.740 | 1.852 | 1.562 | 4.843 | 3.744 | 2.871 |
| Pyrene(3) | 2.830 | 5.505 | ND | 2.275 | 4.741 | 1.215 | 0.189 | 2.677 | 4.420 | 2.110 |
| Benz(a) anthracene(2A) | ND | ND | 0.369 | ND | ND | ND | ND | ND | ND | ND |
| Chrysene(2B) | 3.671 | 2.057 | 0.852 | 1.143 | ND | 2.107 | 0.036 | 1.427 | ND | ND |
| Benzo (b) fluoranthene(2B) | ND | ND | ND | 1.928 | ND | ND | ND | ND | ND | ND |
| Benzo (k) fluoranthene(2B) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Benzo(a) pyrene(1) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Indeno(1,2,3-cd) pyrene(2B) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Dibenz (a,h) anthracene(2A) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Benzo(g,h,i) perylene(3) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Total | 36.565 | 38.440 | 3.611 | 12.222 | 29.276 | 33.591 | 6.650 | 39.375 | 32.657 | 28.309 |
| Total carcinogenic PAHs | 3.671 | 2.057 | 1.221 | 3.071 | 0 | 2.107 | 0.036 | 1.427 | 0 | 0 |
| % Carcinogenic PAHs | 10.040 | 5.351 | 33.813 | 25.127 | 0 | 6.273 | 23.94 | 3.624 | 0 | 0 |

1 = cancer-causing polycyclic sweet-smelling hydrocarbon to people; 2A = most likely cancer-causing polycyclic fragrant hydrocarbon; 2B = perhaps cancer-causing polycyclic fragrant hydrocarbon; (3) =Non-cancer-causing polycyclic sweet-smelling hydrocarbon; ND = Not Detected .

**4. DISCUSSION OF FINDINGS**

The toxic metals arsenic (As), mercury (Hg), cadmium (Cd), and lead (Pb) are the most common heavy metals that induce human poisoning. Fish and aquatic product consumption is the major pathway for human exposure to Hg and As and, to a lesser extent, Cd and Pb (Goyanna *et al.,* 2023). The exposure of water shelfish to As, Cd, Pb, and Cr result in bioaccumulation, mainly in liver and kidney tissues. Cd and Pb have been widely recognized as pollutants in waters worldwide and as a threat to aquatic organisms (Gu *et al.,* 2017).

The concentration of heavy metals in seafood collected from Okoroba river was reported in Table 1. The heavy [metal concentration](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/metal-concentrations)s in the seafood were estimated in mg/kg/ dry weight. Ni level in *Grapsidae* was highest followed by Fe, Zn, Cr, Pb, Cd while the least was Mn (Table 1). The Ni, Cr, Cd, and Pb levels observed in *Grapsidae* were higher than the reference values as reported by WHO/FAO (2011). The Fe concentration in *Potamonautes busungwe*was noticed to be highest followed by Ni, Cr, Pb, Zn, Cd while the least was Mn (Table 1). The level of Ni, Cr, Cd, and Pb seen characterized in *Potamonautes busungwe*were higher than the reference values as reported WHO/FAO (2011).

The Fe estimated in *Cardisoma armatum* seafood was highest in concentration next was Ni, Pb, Cr, Zn, Mn while the least was Cd. The level of Cr, and Cd were lower than the reference values shown in Table 1. The level of Ni and Pb in observed in *Cardisoma armatum* could lead to health risk to the people of Okoroba community upon consumption over a period of time, which in line with the report of Pastorelli *et al.*(2012) on Human exposure to lead, cadmium and mercury through fish and seafood product consumption in Italy: A pilot evaluation.

The Ni level determined in *Oxudercinae* was highest followed by Cr, Pb while the least among the hazardous heavy metals in Table 1 was Cd. The Ni, Cr, and Pb concentration evaluated in *Oxudercinae* were significantly higher than the reference values (Table 1). The Ni estimated among the cytotoxic heavy metals in *Halichoeres bivittatu* was highest in concentration next to it was Cr, Pb, Cd, while the least was Cd. The level of Ni, Cr, and Pb observed in *Halichoeres bivittatu* were higher that the reference values (Table1). Ni and Cr levels in *Mystus tengara* were significantly high when compared to those of the reference values in Table 1. The Ni level in *Mystus tengara* was higher than that of Cr.

More so, among the cytotoxic heavy metals estimated in *Bagrus bajad,* Cr was highest in concentration followed by Ni, Pb, while the least was Cd (Table 1). The Cr, Ni, and Pb levels were higher than the references values reported by FAO (2008). Also, the Pb, Cd, Cr, and Ni levels determined in *Atlantic silverside* were higher than the reference values (Table 1). The Cr estimated was highest in level followed by Pb, Ni while the least was Cd.

The level of Cr in *Portunus armatus* was noticed to be highest next was Pb, Ni while the least was Cd. The concentration of Cr, Pb, Ni, and Cd characterized in *Portunus armatus* were higher than the reference values on Table 1. The concentration of Ni determined in *Catharanthus roseus* was highest followed by Cr, Pb, while the least was Cd. But the levels of these metals were significantly higher than the reference values reported by WHO/FAO (2011)

The levels of Ni, Cr, Cd, and Pb estimated from *Grapsidae, Potamonautes busungwe,Cardisoma armatum, Halichoeres bivittatu, Bagrus bajad,Atlantic silverside*,*Portunus armatus,*and *Catharanthus roseus,* is suggestive that consumption of these seafood for protein might pose potential risk to the Okoroba indigenous people. The level of Ni, Cr, Cd, and Pb estimated in *Grapsidae, Potamonautes busungwe,Cardisoma armatum, Oxudercinae, Halichoeres bivittatu, Bagrus bajad,Atlantic silverside*,*Portunus armatus,*and *Catharanthus roseus* seafood from this study is similar to the values reported by Ali *et al.*(2023) on Human biomonitoring of heavy metals exposure in different age- and gender-groups based on fish consumption patterns in typical coastal cities of China and Turdiyeva and Lee (2023) on Comparative analysis and human health risk assessment of contamination with heavy metals of Central Asian rivers.

The estimated daily intake of Ni in was highest in *Grapsidae* followed by Mn, Cd, Pb, Cr, Fe, while the least was Zn. The Recommended Tolerable Daily Intake (TDI) of Pb, Cd, Cr, and Ni level in *Grapsidae* were higher than the Recommended Tolerable Daily Intake (TDI) but were lower than the Upper Tolerable Daily Intake (UTDI) levels of heavy metals in sea food (Garcia-Rico *et al*., 2007) except for Cd, Cr, and Ni, which were higher. The estimated daily intake of Ni in *Gecarcinidae* was noticed to be highest followed by Cd, Pb, and Cr. The estimated daily intake of Ni, Cd, and Pb were higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in sea food (Table 2).

The higher levels of Cd, Cr, and Ni when compared to the Recommended Tolerable Daily Intake (TDI) but were lower than the Upper Tolerable Daily Intake (UTDI) levels of heavy metals in sea food is suggestive *Grapsidae, Gecarcinidae,* may pose health risk upon consumption for a period of time. The Estimated Daily Intake for Pb and Cd were higher than the estimated daily intake of Ni, Cd, and Cr were higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in sea food(Table 2). Sen *et al*. (2022) reported similar results on the heavy metal level in seafood.The estimated daily intake of Ni, Cd, and Cr in *Grapsidae, Gecarcinidae*, *Oxudercinae,* were higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood while those of Zn, Mn, and Fe were lower than Recommended Tolerable Daily Intake (TDI) but were lower than the Upper Tolerable Daily Intake (UTDI) levels of heavy metals in sea food(Table 2).

However, the estimated daily intake of Ni in *Oxudercinae* was highest followed by Cd, Cr, while the least was Pb regarding the cytotoxic heavy metals. The estimated daily intake of Ni, Cd, Cr, and Pb in this study were significantly higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood but lower than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood(Table 2). The estimated daily intake of Ni, Cd, Cr, and Pb observed in *Oxudercinae* is indicative that it could be unsafe for consumption. The estimated daily intake of Ni in *Halichoeres bivittatus* was highest in level next was Pb,Cr while the least was Cd. The estimated daily intake of Pb in *Halichoeres bivittatus* was higher than both the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood but lower than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood. The estimated daily intake of Cr and Ni in *Halichoeres bivittatus* were higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood (Table 2).

The estimated daily intake of Ni in *Mystus tengara* was noticed to be highest followed by Mn, Cd, Cr, Fe, Zn while the least was Pb. The estimated daily intake of Ni, Pb, Cd, Cr, and Mn in *Mystus tengara* were higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood but lower than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood (Table 2). Meanwhile, the estimated daily intake of Ni in *Bagrus bajad* was highest next was Cr, Pb while the least among the cytotoxic heavy metals in this study was Cd. The estimated daily intake of Ni, Pb, Cr, and Cd in *Bagrus bajad* were higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood but lower than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood (Table 2).

The estimated daily intake of Ni in *Atlantic*silverside was highest followed by Cd, Pb while the least regarding hazardous heavy metals in this study was Cr. The estimated daily intake of Ni, Pb, Cr, and Cd in *Atlantic*silverside were higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood but lower than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood(Table 2). The estimated daily intake of Ni in *Portunus armatus* was highest next was Cd, Pb while the least was Cr. The estimated daily intake of Ni, Pb, Cr, and Cd in *Portunus armatus* were higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood only (Table 2). The estimated daily intake of Ni in *Catharanthus roseus* was highest next was Cd, Pb while the least was Cr. The estimated daily intake of Ni, Pb, and Cd in *Catharanthus roseus* were higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood but lower than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood (Table 2).

The estimated daily intake of Ni was observed to predominantly and significantly increased in *Grapsidae, Potamonautes busungwe, Gecarcinidae, Oxudercinae, Halichoeres bivittatus, Mystus tengara,Bagrus bajad,* Atlantic silverside,*Portunus armatus,* and *Catharanthus roseus* and was higher than the estimated daily intake of Ni, Pb, and Cd in *Catharanthus roseus* were higher than the Recommended Tolerable Daily Intake (TDI)levels of heavy metals in seafood (Table 2). This predominantly increased Ni estimated daily intake of Ni found in these seafood is suggestive Ni could induced toxicological consequences to vital organs in the body following prolonged consumption. Zodape *et al*. (2010) on contamination of heavy metals in seafood marketed from Vile Parle and Dadar markets of suburban areas of Mumbai reported similar results on Cd, Cr, and Pb level and Mokhtar *et al*. (2012) on assessment Level of Heavy Metals in *Penaeusmonodon and OreochromisSpp* in selected aquaculture ponds of high densities development area

Table 3 shows the target hazard quotient and hazard index of metals in seafood harvested from Okoroba of Bayelsa State. The target hazard quotient and hazard index of Cd and Ni was highest in *Grapsidae* followed by Ni, Cr while the least among the cytotoxic metals in this study was Pb. The target hazard quotient and hazard index of Cd and Ni in *Grapsidae* were higher than the reference values as reported by Garcia-Rico *et al*. (2007). The target hazard quotient and hazard index of Cdwas highest in *Potamonautes busungwe* next was Ni, Cr while the least was Pb among the hazardous heavy metals. The target hazard quotient of CdCr, and Ni observed in *Potamonautes busungwe* were higher than reference target hazard quotient of CdCr, and Ni observed in seafood.

Meanwhile, the target hazard quotient and hazard index of Niwas highest in *Gecarcinidae* next was Cd, Cr while the least was Pb. The target hazard quotient of CdCr, and Ni observed in *Gecarcinidae* were higher than reference target hazard quotient of CdCr, and Ni observed in seafood. Also, the target hazard quotient and hazard index of cytotoxic heavy metals in *Oxudercinae* showed that Ni had the highest target quotient hazardous index next was Cd, Cr while the least was Pb. The target hazard quotient and hazard index of Ni, Cd, and Pb were higher than the reference values (Table 3). The significant higher target hazard quotient and hazard index of Ni, Cd, and Pb observed in *Oxudercinae* is suggestive that it could not be safe for consumption.Estimation of the target hazard quotient and hazard index of cytotoxic heavy metals in *Halichoeres bivittatus* revealed that Cd had the highest target quotient hazardous index followed by Ni, Pb while the least was Cr. The target hazard quotient and hazard index of Ni, Cd, Cr, and Pb were higher than their references (Table 3). The target hazard quotient and hazard index of Ni, Cd, Cr, and Pb noticed in *Halichoeres bivittatus* is suggestive of possible health risk in consumption of the seafood by the indigenous people of Okoroba community.

Analysis of the target hazard quotient and hazard index of cytotoxic heavy metals in *Mystus tengara* revealed that Pb had the highest target quotient hazardous index followed by Cd, Ni while the least was Cr. The target hazard quotient and hazard index of Ni, Cd, and Pb were higher than their references (Table 3). The target hazard quotient and hazard index of Ni, Cd, and Pb noticed in *Mystus tengara* is suggestive of possible health risk in consumption of the seafood by the indigenous people of Okoroba community. Evaluation of the target hazard quotient and hazard index of cytotoxic heavy metals in *Bagrus bajad* revealed that Ni had the highest target quotient hazardous index followed by Pb, Cr while the least was Cd. The target hazard quotient and hazard index of Ni, and Pb were higher than their references (Table 3). The target hazard quotient and hazard index of Ni, and Pb noticed in *Bagrus bajad* is suggestive of possible health risk in consumption of the seafood from Okoroba community. The target hazard quotient and hazard index of Cr, Ni, and Pb evaluated in this study were higher than those reported by Esilaba *et al*. (2020) on human health risk assessment of trace metals in the commonly consumed fish species in Nakuru Town, Kenya.

The target hazard quotient and hazard index of cytotoxic heavy metals in *Atlantic*silverside indicated that Cr had the highest target quotient hazardous index followed by Cd, Ni while the least was Pb. The target hazard quotient and hazard index of Cr, Cd, Ni, and Pb were far much higher than their references (Table 3). Also, the target hazard quotient and hazard index of heavy metals characterized in *Portunus armatus* indicated that Cr had the highest target quotient hazardous index followed by Cd, Ni while the least was Pb. The target hazard quotient and hazard index of Cr, Cd, Ni, and Pb were far much higher than their references (Table 3).

The target hazard quotient and hazard index of these cytotoxic heavy metals noticed in *Atlantic*silverside, *Catharanthus roseus,* and *Portunus armatus* point to the possibility of threat to health upon consumption of *Atlantic*silverside,*Catharanthus roseus* and *Portunus armatus* as a sources of protein and nourishments**.** The target hazard quotient and hazard index of cytotoxic heavy metals in *Catharanthus roseus* indicated that Ni had the highest target quotient hazardous index followed by Pb, Cd while the least was Cr. The target hazard quotient and hazard index of Ni, Pb, Cd, and Pb were far much higher than their references (Table 3).The target hazard quotient and hazard index of Cd, Pb, and Ni in the selected seafood is suggestive that it could be unsafe depending on *Grapsidae*, *Potamonautes busungwe, Gecarcinidae, Oxudercinae, Halichoeres bivittatus, Mystus tengara, Bagrus bajad, Atlantic*silverside, *Portunus armatus,Catharanthus roseus*, and as sources of protein and mineral nourishments. Taiwo *et al*. (2018) reported similar heavy metal levels of carcinogenic and non-carcinogenic evaluations of heavy metals in protein foods from southwestern Nigeria.

The life cancer risk and total life cancer risk of Cd in *Potamonautes busungwe*was observed to be highest followed by Cr, Pb while the least was Ni. The life cancer risk and total life cancer risk of Cd in *Gecarcinidae* was highest next was Pb, Ni while the least was Cr. The life cancer risk and total life cancer risk of Cd in *Oxudercinae* was highest followed by Pb, Ni while the least was Cr. The life cancer risk and total life cancer risk of Pb in *Halichoeres bivittatus* was highest followed by Cr, Cd while the least was Ni. The life cancer risk and total life cancer risk of Pb in *Mystus tengara* was highest followed by Cd, Ni while the least was Cr. The life cancer risk and total life cancer risk of Pb in *Bagrus bajad* was highest followed by Cr, Ni while the least was Cr. The life cancer risk and total life cancer risk of Pb in *Atlantic*silverside was highest followed by Ni, Cd while the least was Cr. The life cancer risk and total life cancer risk of Cr in *Portunus armatus* was highest followed by Cd, Pb while the least was Ni. The life cancer risk and total life cancer risk of Cd in *Catharanthus roseus* was highest followed by Pb, Cr while the least was Ni. The life cancer risk and total cancer risk of Cd, Cr, and Ni in this study were higher than the those reported by Adowei *et al*. (2020).

The naphathalene level in *Grapsidae* was highest followed by *Mystus tengara,C. roseus*, A. silverside,*Potamonautes busungwe, H*. *bivittatus, Oxudercinae* while the least was *Gecarcinidae*. The acenaphthylene level in A. silverside was highest next was *B. bajad*, *Gecarcinidae,* while it was undetected in *Grapsidae,Mystus tengara,Oxudercinae,H*. *bivittatus,P. armatus* and *C. roseus.* The acenahthrene level in *S. indicum*was observed to be highest followed by *Grapsidae,H*. *bivittatus,*A. silverside,*C. roseus,Mystus tengara,P. armatus,P. armatus* while it was not detected in *Oxudercinae.* The fluorene concentration in A. silverside was seen to be highest next was *Grapsidae,C. roseus, P. armatus,Mystus tengara,H*. *bivittatus* it was not detected in *Potamonautes busungwe, Gecarcinidae*, and *Oxudercinae.* Phenanthrene level in *Mystus tengara* was noticed to be highest followed by *Potamonautes busungwe,*A. silverside, *H*. *bivittatus*,*Grapsidae,C. roseus,Oxudercinae, B. bajad* while the least was *Gecarcinidae* (Table 5). The fluoranthene concentration in A. silversidewas observed to be highest next was *P. armatus, Grapsidae, C. roseus,H*. *bivittatus, B. bajad, Gecarcinidae* while Fluoranthene was not detected in *Mystus tengara*and *Oxudercinae.* The level of naphathalene, acenaphthylene, acenahthrene and fluorene estimated in this study in *Grapsidae,Potamonautes busungwe,Mystus tengara,Oxudercinae,H*. *bivittatus,P. armatus* and *C. roseus* is higher than the those reported by Nwaichi *et al*. (2016)

The pyrene level in *Potamonautes busungwe* was highest next was *H*. *bivittatus, P. armatus, Grapsidae,*A. silverside, *Oxudercinae,C. roseus,Mystus tengara,B. bajad* while it was not detected in *Gecarcinidae.* Also, Chrysene level observed in *Grapsidae* was higher followed by *Mystus tengara, Potamonautes busungwe,* A. silverside, *Oxudercinae, Gecarcinidae, B. bajad* while it was not detected in *Mystus tengara,P. armatus,* and *C. roseus.*Benzo (k), Benzo(a) pyrene, Indeno(1,2,3-cd) pyrene, Dibenz (a,h) anthracene, and Benzo(g,h,i) perylene were below detection limit in all the seafood used for this study. Chrysene is perhaps cancer-causing polycyclic fragrant hydrocarbon and its presence in *Grapsidae, Mystus tengara, Potamonautes busungwe,* A. silverside, *Oxudercinae, Gecarcinidae,* and *B. bajad* is suggestive of the possibility of cancer risk upon consumption of *Grapsidae, Mystus tengara, Potamonautes busungwe,* A. silverside, *Oxudercinae, Gecarcinidae,* and *B. bajad* seafood by the indigenous people of Okoroba community. Silva *et al*. (2011) reported estimated similar pyrene and chrysene in their study on polycyclic aromatic hydrocarbons (PAHs) in some locally consumed fishes in Nigeria.

The total concentration of carcinogenic PAHs in A. silverside was highest followed by *S. indicum, Grapsidae, Mystus tengara, P. armatus, H*. *bivittatus, C. roseus,Gecarcinidae.* The total carcinogenic PAHs in *Potamonautes busungwe* was highest next was that of *Oxudercinae, Mystus tengara,* A. silverside,*Gecarcinidae* while the least were *H*. *bivittatus, P. armatus,* and *C. roseus.* The percentage of carcinogenic PAHs in *Gecarcinidae*was highest followed by *Oxudercinae, B. bajad, Grapsidae,, Mystus tengara, Potamonautes busungwe,* A. silverside while *H*. *bivittatus, P. armatus,* and *C. roseus* have the lowest percentage of PAHs (Table 5). The acenaphthylene, acenahthrene, fluorine,phenanthrene, pyrene, acenahthrene, chrysene, fluoranthene, level in *Grapsidae, Mystus tengara,C. roseus*, A. silverside,*Potamonautes busungwe, H*. *bivittatus,Oxudercinae* and *Gecarcinidae, P. armatus* and *C. roseus* were higher than the values reported by Nwaichi and Ntorgbo (2016) on assessment of PAHs levels in some fish and seafood from different coastal waters in the Niger Delta.

**5. CONCLUSION**

Cytotoxic Pb, Cd, Cr, and Ni as well as benz(a) anthracene, chrysene, fluorene, and phenanthrene were mathematically evaluated in the studied seafood collected from Okoroba River. High levels Pb, Cd, Cr, Ni, benz(a)anthracene, chrysene, fluorene, and phenanthrene were observed in seafood collected from Idema River. LCR and TLCR of Pb, Cd, Cr, and Ni studied in the studied seafoodwere significantly higher the reference values for seafood.Chronic consumption of these examined seafood for the presence of heavy metals and PAHs by residents of Okoroba River could lead to cumulative toxic effects. Immediate action is required to prevent the contamination of marine resources in Okoroba River. Public health interventions, including raising awareness about the risks of consumption of the contaminated studied seafood is necessary. This research is both urgent and vital for safeguarding human health, preserving local biodiversity, and promoting sustainable living in Okoroba and similar coastal communities.

**Data Availability**

The data that support the findings of this study are available on request from the corresponding

author.

**REFERENCES**

Varol, M., Kaya,  G.K., & Alp, A. (2017). Heavy metal and arsenic concentrations in rainbow

trout (Oncorhynchus mykiss) farmed in a dam reservoir on the Firat (Euphrates) River: risk-based consumption advisories. *Sci. Total Environ*, 1288-1296.

Oguguah, Ngozi M., M. Onyekachi, J.. & Ikegwu. (2016). Concentration and Human Health

Implications of Trace Metals in Fish of Economic Importance in Lagos Lagoon, Nigeria." Journal of Health and Pollution 7.13 (2017), 66–72.

Uysal, K., Köse, E., Bülbül, M., Dönmez, M., Erdoğan, Y., Koyun, M., Ömeroğlu, C., & Özmal,

F.(2019). The comparison of heavy metal accumulation ratios of some fish species in Enne Dame Lake (Kütahya/Turkey). *Environ. Monit. Assess*, 157, 355-362.

Nwaichi, E. O., Ntorgbo, S.A.M., and J. O., & Osuoha, J.O. (2017). Occurrence and risk

assessment of PAHs in edible seafood from the Niger Delta, Nigeria." Environmental Science and Pollution Research, 24(2), 13626–13633.

Boisa, N., Ideriah, T.J.K., & Okehie, C.S (2019). Evaluation of polycyclic aromatic

hydrocarbons and total petroleum profiles in some Nigerian crude oils. *J. Sci Res Rep*, 23, 1-14.

Lawal, A.T (2017). Polycyclic aromatic hydrocarbons- A review. *Congent Environ. Sci*, 71, 1-8

Padula, A.M., Balmes, J.R., Eisen, E.A., Mann, J., & Noth, E.M. (2015) Ambient polycyclic

aromatic hydrocarbons and pulmonary function in children. *J Exp Sci Environ Epidemiol ,25*, 295-302.

Srogi, K. (2007). Monitoring of environmental exposure to polycyclic aromatic hydrocarbons: A

review. *Environ Chem Letters*, 5, 169-195.

Soltani, N., Moore, F., Keshavarzi, B., Sorooshian, A., & Javid, R. (2019). Potentially toxic

elements (PTEs) and polycyclic aromatic hydrocarbons (PAHs) in fish and prawn in the Persian Gulf. *Iran Ecotoxicology and Environmental Safety*, 173: 251-265.

Gwimbi, P., Kotelo, T., & Selimo, M.J. (2020). Heavy metal concentrations in sediments and

Cyprinus carpio from Maqalika Reservoir–Maseru, Lesotho: An analysis of potential health risks to Fish consumers. *Toxicol. Program Tech. Rep. Ser,*7: 475-479.

Dang, V.D., Kroll, K.J., Supowit, S.D., Halden, R.U., &  Denslow, N.D. (2016). Tissue

distribution of organochlorine pesticides in largemouth bass (Micropterus salmoides) from laboratory exposure and a contaminated lake. *Environ. Pollut*, 216, 877-883.

Umeoguaju, F.U., Akaninwor, J.O., Essien, E.B., Amadi, B.A., Igboekwe, C.O., 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. *Toxicol Rep, 11,* 58-82.

Akeju, F.B., & Gbekeloluwa B. O. (2023). Environmental Impact of Oil Exploration in

Nigeria: A Case Study of Nembe Local Government." International Journal of Research and Innovation in Applied Science, 8( 9), 75–89.

Markmanuel, D. P., Amos-Tautua, B. M. W., & Songca, S. P. (2022). Tin concentrations and

human health risk assessment for children and adults in seafood and canned fish commonly consumed in Bayelsa State, Nigeria. Journal of Applied Sciences and Environmental Management, 26(7), 1263–1269.

Justice-Alucho, C. H., Mike-Anosike, E. E., & Braide, W. (2021). Molecular characterization of

bacteria isolated from some seafoods in Nembe Community, Bayelsa State, Nigeria. Asian Journal of Applied Science and Technology, 5(3), 68–79.

Ephraim-Emmanuel, B.C., & Ordinioha, B. (2021). Exposure and public health effects of

polycyclic aromatic hydrocarbon compounds in Sub-Saharan Africa: A systematic review. *Int J Toxicol*, 40, 250-269.

Tanhan, P., Lansubsakul, N., Phaochoosak, N., Sirinupong, P., Yeesin, P., & Imsilp, K. (2023).

Human health risk assessment of heavy metal concentration in seafood collected from Pattani Bay, Thailand. Toxics, 11(1), 18.

Odey, M. O., Mgbe, P. T., Adindu, E. A., Osim, M. E., Ofutet, E. O., Ibor, M. E., Osoro, B.,

Waithanji, R., Itam, E. H., & Omoriri, M. A. (2024). Seasonal assessment of pollution status, bioaccumulation, and potential human health risk of heavy metals in shrimps (Penaeus monodon) and water from the Great Kwa River in Calabar, Nigeria. African Journal of Biomedical Research, 27(2), 407–414.

Nobile, M., Mosconi, G., Arioli, F., Chiesa, L., Peloso, M., Accurso, D., Butovskaya, E.,

Fedrizzi, G., Curci, D., & Panseri, S. (2024). Evaluation of the risk from potentially toxic elements (PTEs) in Italy’s most consumed processed fish products. Foods, 13(3), 456.

Bhupander, K.V.K.,Verna, R., Gaur, S.K., Kumar, C.S., & Akolkar, A.B. (2014). Validation of

HPLC method for determination of priority polycyclic aromatic hydrocarbons (PAHs) in waste water and sediments. *Advances in Applied Science Research*, *5*(1), 201-209**.**

Matouke, M.M., & Abdullahi, K.L. (2020). Assessment of Heavy Metals Contamination and

Human Health Risk in *Clarias gariepinus* [Burchell, 1822] Collected From Jabi Lake, Abuja, Nigeria. Scientific Afican, [10.1016/j.sciaf.2020.e00292](https://doi.org/10.1016/j.sciaf.2020.e00292)

Goyanna, F.A.A., Fernandes, M.B., de Silva, G.B., & de Lacerda, L.D. (2017). Mercury in

oceanic upper trophic level sharks and bony fishes-A systematic review. *Environ. Pollut*, 318, 120821.

Gu, Y.-G., Lin, Q., Huang, H-H., Wang, L-G., Ning, J-J., & Du, F-Y. (2017). Heavy metals in

fish tissues/stomach contents in four marine wild commercially valuable fish species from the western continental shelf of South China Sea. *Mar. Pollut. Bull*, 114, 1125–1129

World Health Organization (WHO). Guidelines for Drinking-water Quality, Fourth Editio, 2011.

Pastorelli, A.A., Baldini, M., Stacchini, P., Baldini, G., Morelli, S., Sagratella, E., Zaza, S; &

Ciardullo, S. (2019). Human exposure to lead, cadmium and mercury through fish and seafood product consumption in Italy: A pilot evaluation. *Food Addit. Contam. Part A Chem. Anal. Control Expo. Risk Assess*, 29, 1913–1921

Food and Drug Administration (FDA) (2008). Fish and Fisheries Products Hazards and

Controls Guidance: Third Edition*.* U.S. Department of Health and Human Services, Food and Drug Administration, Center for Food Safety and Applied Nutrition, Office of Seafood.

.

Ali, M.U., Wang, C., Li, Y., Jin, X., Yang, S., Ding, L., Feng, L., Wang, B., & Li, P. (2023).

Human biomonitoring of heavy metals exposure in different age- and gender-groups based on fish consumption patterns in typical coastal cities of China. *Ecotoxicol. Environ. Saf*, 262,115316.

Turdiyeva, K., & Lee, W. (2023). Comparative analysis and human health risk assessment of

contamination with heavy metals of Central Asian rivers. *Heliyon,* 9, e17112.

Garcia-Rico, L., Tejeda-Valenzuela, L., & Jurado-Rodriguez, M. (2007). Tolerable Intake Levels

of Heavy Metals in Seafood**: Health Risk Assessment and** Recommendations. Environmental Toxicology and Chemistry, 26(1), 43-50.

Zodape, G.V., Dhawan, V.L., Wagh, R.R., & Sawant, A.S. (2010). Contamination of heavy

metals in seafood marketed from Vile Parle and Dadar markets of suburban areas of Mumbai (west coast of) India. *International Journal of Environmental Sciences*, 1(6), 1177-1185.

Sen, I., Shandil, A., & Shrivastava, V.S. (2022). Study for Determination of Heavy Metals in

Fish Species of the River Yamuna (Delhi) by Inductively Coupled Plasma- Optical Emission Spectroscopy (ICP-OES). *Advances in Applied Science Research, 2*(2), 161-166.

Mokhtar, M. B., Aris, A.Z., Munusamy, V., & Praveena, S.M. (2009). Assessment Level of

Heavy Metals in Penaeus Monodon and Oreochromis Spp in Selected Aquaculture Ponds of High Densities Development Area. *European Journal of Scientific Research,* 3(3), 348-360.

Esilaba, F., Moturi, W. N., Mokua, M., & Mwanyika, T. (2020). Human Health Risk Assessment

of Trace Metals in the Commonly Consumed Fish Species in Nakuru Town, Kenya. *Environmental health insights,* 14, 1178630220917128.

Taiwo, A.M.,  Oyebode, A.O., Salami, F. O., Okewole, I., Gbogboade, A.S., Agim, C., Oladele,

T.O., Kamoru, T.A., Abdullahi, K. L., & Davidson, D. (2018). Carcinogenic and noncarcinogenic evaluations of heavy metals in protein foods from southwestern Nigeria.

Adowei, P., Ebenezer, E., & Markmanuel, D. (2020).Concentrations and Human Health Risk

Assessment of Cd, Co, Cr, Ni, and Pb via Eating White Granulated Garri Produced in Nigeria. *American Journal of Environmental Protection, 9*(4), 77-85.

Silva, B.O., Adetunde, O.T., Oluseyi, T.O., Olayinka, K.O., & Alo, B.I. (2011). Polycyclic

aromatic hydrocarbons (PAHs) in some locally consumed fishes in Nigeria, *Afr. J. Food Sci,* 31, *5*(7), 384–391