**"Mathematical Assessment of Heavy Metals and Polycyclic Aromatic Hydrocarbons in Commonly Consumed Seafood: Health Risk Implications in Idema-Abureni Clan, Ogbia, Bayelsa State"**

ABSTRACT

This carried out the mathematical evaluation of health risk of heavy metals and polycyclic aromatic hydrocarbons in selected seafood in Idema-Abureni Clan, Bayelsa State. Seafood were collected from Idema River. Heavy metals, PAHs, estimated daily intake (EDI), life cancer risk (LCR), total life cancer risk (TLCR), target hazard quotient (THQ), and hazard index of hazardous (HI) [heavy metals](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/heavy-metal) were investigated based on standard methods of estimation. The Pb, Cd, and Ni in *Grapsidae* seafood were 6.16±0.08mg/kg, 2.94±0.07mg/kg, and 10.15±0.11mg/kg respectively, which were higher than the reference values for seafood as recommended and similar pattern were perceived in *P. busungwe, C. armatum, Bagrus bajad,* and *A. silverside.* The estimated daily intake of Pb, Cd, and Cr in *P. busungwe* were 0.026mg/kg, 0.05mg/kg, and 0.006mg/kg respectively, were higher than the reference values for seafood as recommended. The THQ and HI of Pb, Cd, Cr, and Ni in *Grapsidae* were 0.006mg/kg, 0.001mg/kg, 0.006mg/kg, and 0.002mg/kg respectively, were higher than the reference values for seafood as recommended and similar fashion were noticed in *Potamonautes busungwe, Cardisoma armatum, Oxudercinae, H. bivittatus, Mystus tengara, Bagrus bajad*, *Atlantic silverside, Portunus armatus,* and *C. roseus* seafood. LCR and TLCR of Pb, Cd, Cr, and Ni studied in *Grapsidae* were 1.007 mg/kg, 3.080 mg/kg, 0.005mg/kg, 0.056 mg/kg respectively, were significantly higher the reference values for seafood as recommended and similar occurrences were observed in *Oxudercinae, Bagrus bajad, Portunus armatus,* and *Catharanthus roseus.* Consumption of the studied seafood in Idema River could lead to cumulative toxic effects.

*Keywords: Idema River, seafood, PAHs, heavy metals, EDI, LCR, TLCR, THQ, HI*

1. **INTRODUCTION**

Southern Nigeria is depot of crude oil, hence it is regarded as the economic hub for Nigeria. The Southern region of Nigeria is plagued by socio-economic and environmental challenges, one of which is crude oil theft (Kalu and Ndubuisi, 2019). Illegal crude oil activities entails theft of crude oil through unauthorized access to pipelines, which operate outside legal and regulatory frameworks and are often controlled by organized criminal networks (Kalu and Ndubuisi, 2019; Zalik, 2011; Okoli and Orinya, 2013; Aghedo, 2013; Ibaba and Olumati, 2009).

Bayelsa State is located in the heart of Southern, is one of the most affected areas by illegal crude oil bunkering. The region is notorious for the widespread activities of oil theft, which involves unauthorized tapping of pipelines, and crude oil theft (Okoli and Orinya, 2013). Crude oil theft in Ogbia LGA is part of a larger pattern in the Niger Delta, where artisanal refining has become a booming underground economy. The stolen crude is refined using rudimentary methods in illegal refineries, often located deep in the creeks. These refineries produce low-quality petroleum products that are sold locally, while the process generates significant environmental pollution (Orogun and Atu, 2018).

Vandalism of oil pipelines leads to frequent oil spills, which contaminate water bodies, farmlands, and forests. This pollution has devastating effects on the local ecosystem, killing fish and other aquatic life, destroying farmlands, and rendering water sources unsafe for drinking (Asuni, 2019; Nwilo and Badejo, 2005).

Seafood are vital source of nutrition for the local population including the Idema-Abureni clan (Olawoyin, 2012). Seafood harvested from areas near illegal crude oil sites in Nigeria is heavily contaminated with heavy metals and PAHs (Nduka and Orisakwe, 2010). These heavy metals are of particular concern due to their toxicity and their tendency to bioaccumulate in organisms and concentrated as they move up the food chain (Akande and Oni, 2015). Consumption of seafood contaminated with heavy metals poses significant health risks to local populations. Given that marine organisms are primary sources of protein for many communities in Bayelsa State, the exposure to heavy metals through dietary intake is substantial result in neurological disorders, kidneys and liver, cancers, and increased risk of cardiovascular diseases (Akande and Oni, 2015; Barakat, 2015; Orogun and Atu, 2018).

PAHs in areas affected by illegal oil refining are much higher than in non-polluted areas (Idodo-Umeh and Ogbeibu, 2010; Okoro *et al.,* 2011). The creeks, rivers, and estuaries of the Niger Delta, where many illegal refineries are located, are particularly vulnerable to contamination (Anyakora *et al*., 2005). Seafood from areas impacted by illegal crude oil activities has been found to contain elevated levels of PAHs (Numbere and Camilo, 2020). Seafood exposed to PAHs through both direct contact with polluted water and sediments. The bioaccumulation of PAHs in seafood poses a significant health risk to human populations, particularly in the Niger Delta, where seafood is a major part of the diet. Bivalve mollusks, such as oysters and periwinkles, are vulnerable to PAH contamination (Okoro *et al*., 2011; Anyakora *et al.,* 2005; Numbere and Camilo, 2020).

Health risk assessment (HRA) of heavy metals in seafood involves calculating the estimated daily intake (EDI) of each metal and PAHs while comparing it to established reference doses (RfD) provided by (Ikem *et al.,* 2013). The target hazard quotient (THQ) is used to assess non-carcinogenic risks, while the cancer risk (CR) is used to evaluate potential carcinogenic risks (Clarkson and Magos, 2016). A THQ value above 1 indicates a potential health risk from long-term exposure to heavy metals and PAHs (Signa *et al.,* 2017). The Niger Delta, have reported THQ values for lead, mercury, and cadmium carcinogenic PAHs in seafood exceeding 1, suggesting a significant health risk for local populations, particularly for vulnerable groups like children and pregnant women (Anyakora *et al.,* 2005; Tomasello *et al.,* 2012).

The Idema-Abureni Clan is a small riverine settlement located in the Ogbia Local Government Area of Bayelsa State (Briggs, 2020). This area is largely inhabited by Ogbia people and Nembe people, who are of Ijaw ethnic origin. Idema-Abureni Clan is characterized by its proximity to waterways, which play a central role in the community's daily life, providing transport, sustenance, and economic opportunities. It is designated 40330N and 6033200E (Briggs, 2020). 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 Idema Town. Meanwhile, there are paucity of information regarding the health risk of consumption the famous seafood of the community. The aim of the study is to perform mathematical health risk assessment of heavy metals and PAHs in selected seafood, mostly consumed by the people of Idema-Abureni Clan.

1. **MATERIALS AND METHODS**

**2.1 Studied Area**

Collection of seafood was done in June 2024 from Idema River. Idema river originates from Kalabari river and it flows through Towns and villages in the Ogbia kingdom. The seafood serve as a source of livelihood for many people in Idema Town.

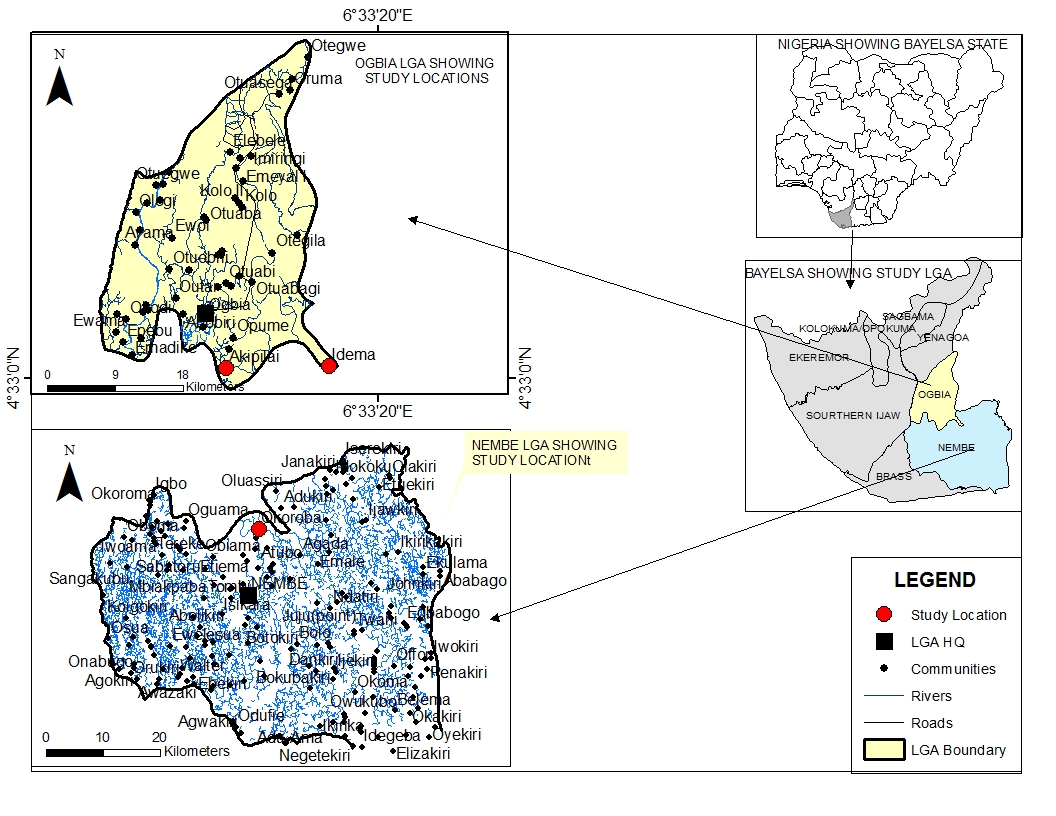
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Figure 1 GPS of Idema Town in Ogbia Local Government Area of Bayelsa State.

**2.2 Collection of Seafood Samples**

Ten different types of shell and fin seafood were collected from sites 1 and 2 in June, 2024 in Idema Town. Upon collection, the seafood were immediately transferred into the icebox and conveyed into the laboratory. Before dissection, 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.* [22]. 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 based on the method as described by Allen *et al*. (1996). 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 (AOAC, 1995; Miller, 1998)

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**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 [27] :



Where.

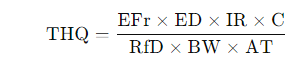
C = Concentration of the metal in seafood (µg/g or mg/kg)

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 *et al*., 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 (Ferguson, J.E. (1990; EFSA, 2008).

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 (US EPA, 1989).

1. **RESULTS**

**3.1 Heavy Metal Concentrations in Seafood From Idema-Abureni Clan River**

Table 1 shows the heavy metal concentrations in seafood from Idema-Abureni Clan river. Results for each heavy metals were reported in triplicate. Heavy metals in the studied seafood were compared to that of the reference values for each of the heavy metals assayed.

Table 1 Heavy metal concentrations in seafood from Idema-Abureni Clan River (n=3)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb | Cd | Cr | Ni | Zn | | Mn | | Fe | |
| *Grapsidae* (mg/kg) | 6.16±0.08b | 0.43±0.06 | 2.94±0.07 b | 3.15±0.11 b | 5.62±0.06 | 1.95±0.08 | | 31.86±0.43 | | |
| *P. busungwe*(mg/kg) | 8.06±0.06 b | 1.38±0.13 | 1.86±0.06 b | 3.61±0.16 b | 8.06±0.10 | 0.15±0.05 | | 19.68±0.12 | | |
| *C. armatum* (mg/kg) | 3.43±0.07 b | 0.59±0.12 b | 7.15±0.10 b | 2.73±0.17 b | 1.59±0.08 | 0.53±0.06 | | 27.82±0.10 | | |
| *Oxudercinae* (mg/kg) | 3.18±0.09 b | 0.23±0.15 | 3.05±0.12 b | 1.06±0.09 b | 2.73±0.07 | 0.10±0.07 | | 33.72±0.07 | | |
| *H. bivittatus* (mg/kg) | 7.64±0.05 b | 0.07±0.11 b | 5.13±0.09 b | 1.75±0.09 b | 1.21±0.06 | 2.01±0.12 | | 26.57±0.10 | | |
| *Mystus tengara* (mg/kg) | 5.81±0.13 b | 0.03±0.09 | 1.39±0.07 b | 4.43±0.08 b | 0.38±0.08 | 1.20±0.08 | | 21.52±0.14 | | |
| *Bagrus bajad* (mg/kg) | 4.02±0.04 b | 1.02±0.09 b | 1.11±0.09 b | 1.19±0.03 b | 0.43±0.10 | 3.63±0.12 | | 18.82±0.21 | | |
| *A. silverside* (mg/kg) | 4.91±0.09 b | 0.54±0.06 b | 3.93±0.10 b | 4.52±0.06 b | 1.84±0.10 | 0.25±0.08 | | 17.52±0.08 | | |
| *P. armatus* (mg/kg) | 8.02±0.09 b | 0.15±0.08 b | 6.58±0.06 b | 3.84±0.10 b | 2.31±0.09 | 0.82±0.09 | | 28.93±0.11 | | |
| *C. roseus* (mg/kg) | 3.63±0.12 b | 0.32±0.08 b | 3.05±0.08 b | 10.02±0.09 b | 5.89±0.07 | 1.16±0.08 | | 20.21±0.11 | | |
| Standard permissible limits of heavy metals in fish | | | | | | | | | | |
| WHO/FAO(2011)  MPL (mg/kg) | 1.0 | 0.5 | 0.6 | 0.05 | 30 | 5.5 | | | | 43 |
|  |  |  |  |  |  |  | | | |  |

Data were reported in mean and standard error of mean (M±EM). Values bearing superscript (“b”) were significantly higher than the reference values at p≤ 0.05 down the group. Values with no superscript were significantly lower than the reference values at p≤ 0.05 down the group.

* 1. **Estimated Daily Intake of Metals in Seafood From Idema-Abureni Clan River**

Table 2 indicates the estimated daily intake of metals in seafood from Idema (Abureni Clan) River. The estimated daily intake for each of the heavy metals was compared to the reference values as shown in Table 2.

Table 2 Estimated daily intake of metals in seafood from Idema (Abureni Clan) River

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb | Cd | Cr | Ni | Zn | Mn | Fe |
| *Grapsidae* (mg/kg) | 0.020 | 0.001 | 0.010 | 0.033 | 0.018 | 0.006 | 0.103 |
| *P. busungwe* (mg/kg) | 0.026 | 0.005 | 0.006 | 0.012 | 0.026 | 0.964 | 0.064 |
| *C. armatum* (mg/kg) | 0.011 | 0.002 | 0.023 | 0.041 | 0.005 | 0.002 | 0.090 |
| *Oxudercinae* (mg/kg) | 0.010 | 7.504 | 0.010 | 0.029 | 0.009 | 0.304 | 0.109 |
| *H. bivittatus* (mg/kg) | 0.025 | 2.104 | 0.017 | 0.035 | 0.004 | 0.007 | 0.086 |
| *M. tengara* (mg/kg) | 0.019 | 9.705 | 0.005 | 0.024 | 0.001 | 0.004 | 0.070 |
| *Bagrus bajad* (mg/kg) | 0.013 | 0.003 | 0.004 | 0.017 | 0.001 | 0.061 | 0.061 |
| *A.. silverside* (mg/kg) | 0.016 | 0.002 | 0.010 | 0.028 | 0.006 | 1.980 | 0.057 |
| *P. armatus* (mg/kg) | 0.026 | 4.914 | 0.021 | 0.022 | 0.008 | 0.003 | 0.094 |
| *Catharanthus. roseus* (mg/kg) | 0.012 | 0.001 | 0.010 | 0.033 | 0.019 | 0.004 | 0.066 |
| TDI (FDA, 2001; Garcia – Rico et al., 2007) | 0.00 | 0.000 | 0.1 | 0.5 | 8 | 0.4-10 | 0.8 |
|  |  |  |  |  |  |  |  |

Recommended tolerable intake (TDI) and upper tolerable each day intake (UTDI) level of heavy metals sea food (FDA, 2001; Garcia – Rico *et al.,* 2007).

**3.3 Target Hazard Quotient and Hazard Index (HI) Of Metals in Seafood From Idema-Abureni River**

Table 3 presents the target hazard quotient and hazard index (HI) of metals in seafood from Idema-Abureni River. The Target hazard quotient and hazard index (HI) of metals in seafood from Idema-Abureni River were discussed and compared to the reference values stated in Table 3.

Table 3 Target hazard quotient and hazard index (HI) of metals in seafood from Idema-Abureni River

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb | Cd | Cr | Ni | Zn | Mn | Fe | HI |
|  |  |  |  |  |  |  |  |  |
| *Grapsidae* (mg/kg) | 0.006 | 0.001 | 0.006 | 0.002 | 0.006 | 0.040 | 0.001 | 0.010 |
| *Potamonautes busungwe*(mg/kg) | 0.008 | 0.005 | 0.004 | 0.005 | 0.073 | 0.062 | 0.0789 | 0.014 |
| *Cardisoma armatum* (mg/kg) | 0.003 | 0.002 | 0.015 | 0.002 | 0.017 | 0.002 | 0.0013 | 0.007 |
| *Oxudercinae* (mg/kg) | 0.003 | 0.076 | 0.007 | 0.002 | 0.003 | 0.002 | 0.013 | 0.006 |
| *Halichoeres bivittatus* (mg/kg) | 0.007 | 0.021 | 0.001 | 0.002 | 0.013 | 0.047 | 0.108 | 0.010 |
| *Mystus tengara* (mg/kg) | 0.005 | 0.009 | 0.003 | 0.001 | 0.004 | 0.028 | 0.087 | 0.007 |
| *Bagrus bajad* | 0.004 | 0.003 | 0.024 | 0.840 | 0.005 | 0.084 | 0.076 | 0.009 |
| *Atlantic silverside* (mg/kg) | 0.005 | 0.002 | 0.006 | 0.001 | 0.019 | 0.057 | 0.076 | 0.008 |
| *Portunus armatus* (mg/kg) | 0.007 | 0.049 | 0.014 | 0.001 | 0.025 | 0.019 | 0.012 | 0.009 |
| *Catharanthus roseus* (mg/kg) | 0.003 | 0.001 | 0.006 | 0.002 | 0.063 | 0.027 | 0.082 | 0.006 |
| Mohammed *et al*. (2022), Bat et., (2018) | 0.3-0.5 | 0.1-0.5 | 0.1-0.05 | 0.1-0.2 | 100 | 20 | 0.1-5.0 | 1 |

**3.4 Life Cancer Risk And Total Life Cancer Risk (TLCR) Of Metals In Seafood from Idema-Abureni Clan River**

Table 4 shows the 4 life cancer risk and total life cancer risk (TLCR) of metals in seafood from Idema-Abureni Clan River. The life cancer risk and total life cancer risk (TLCR) of metals in seafood from Idema-Abureni Clan River evaluated in this study were discussed and compared to the reference values reported in Table 4.

Table 4 Life cancer risk and total life cancer risk (TLCR) of metals in seafood from Idema-Abureni Clan River

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb | Cd | Cr | Ni | Zn | Mn | Fe | TLCR |
| *Grapsidae* (mg/kg) | 1.007 | 3.080 | 0.005 | 0.056 | - | - | - | 0.062 |
| *P. busungwe*(mg/kg) | 0.021 | 0.002 | 0.003 | 0.020 | - | - | - | 0.025 |
| *C. armatum* (mg/kg) | 0.009 | 0.760 | 0.012 | 0.070 | - | - | - | 0.083 |
| *Oxudercinae* (mg/kg) | 0.085 | 0.288 | 0.005 | 0.049 | - | - | - | 0.054 |
| *H. bivittatus* (mg/kg) | 0.213 | 0.080 | 0.009 | 0.060 | - | - | - | 0.070 |
| *Mystus tengara* (mg/kg) | 0.162 | 0.019 | 0.003 | 0.041 | - | - | - | 0.044 |
| *Bagrus bajad* (mg/kg) | 0.111 | 0.001 | 0.002 | 0.029 | - | - | - | 0.032 |
| *Atlantic silverside* (mg/kg) | 0.136 | 0.760 | 0.005 | 0.048 | - | - | - | 0.054 |
| *P. armatus* (mg/kg) | 0.221 | 0.189 | 0.011 | 0.037 | - | - | - | 0.048 |
| *C. roseus* (mg/kg) | 0.102 | 0.380 | 0.005 | 0.056 | - | - | - | 0.062 |
| (FAO,WHO,1998 | to | to | to | to | - | - | - | to |

**3.5 Polycyclic Aromatic Hydrocarbon (PAHS) Concentration Of Seafood Samples in Idema-Abureni Clan River**

Table 5 shows the polycyclic aromatic hydrocarbon (PAHS) concentration of seafood samples in Idema-Abureni Clan River. The cancer risk of the detected and evaluated PAH in seafood harvested from Idema-Abureni Clan river were estimated and discussed in comparison to standard values (Table 5).

Table 5 Polycyclic aromatic hydrocarbon (PAHS) concentration of seafood samples in Idema-Abureni Clan River

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| PAHs | *Grapsidae* | *P. busungwe* | *C. armatum* | *Oxudercinae* | *H.*  *bivittatu* | *M.*  *tengara* | *B.*  *bajad* | *A.*  silverside | *P. armatus* | *C.*  *roseus* |
| Naphthalene(3) | 4.821 | 2.813 | 3.181 | 1.585 | 2.904 | ND | 3.104 | 3.872 | 2.831 | 10.558 |
| Acenapthylene(3) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Acenaphthene(3) | ND | ND | 2.373 | 3.916 | 1.619 | ND | 2.559 | 1.287 | 2.392 | 4.263 |
| Fluorene(3) | 2.207 | ND | ND | 1.418 | ND | 5.154 | ND | ND | ND | 3.318 |
| Phenanthrene(3) | 5.308 | 6.181 | 6.591 | 4.193 | 3.138 | 2.935 | 6.243 | 5.739 | 4.125 | 5.188 |
| Anthracene(3) | ND | ND | ND | ND | ND | 1.533 | ND | ND | ND | ND |
| Fluoranthene(3) | ND | ND | 1.262 | ND | 2.614 | ND | 2.938 | ND | 1.743 | 2.871 |
| Pyrene(3) | ND | 4.289 | 2.942 | 3.173 | 1.534 | 1.126 | 3.352 | 2.753 | 2.162 | 2.111 |
| Benz(a) anthracene(2A) | ND | ND | 3.727 | ND | ND | ND | ND | ND | ND | ND |
| Chrysene(2B) | 3.216 | 3.361 | 7.585 | 2.282 | 2.190 | 3.241 | 4.430 | 2.628 | 3.760 | ND |
| Benzo(b) fluoranthene(2B) | 4.943 | 2.105 | ND | 1.579 | 1.762 | ND | 2.539 | 1.774 | 2.101 | 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 | 2.338 | 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 | 20.496 | 21.086 | 24.661 | 18.146 | 15.761 | 13.989 | 23.165 | 18.054 | 19.114 | 28.309 |
| Total carcinogenic PAHs | 8.159 | 7.804 | 11.312 | 3.861 | 3.952 | 3.241 | 6.969 | 4.402 | 5.861 | 0 |
| %carcinogenic PAHs | 39.808 | 37.010 | 45.870 | 21.277 | 25.075 | 23.168 | 30.084 | 24.382 | 30.663 | 0 |

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

**4. DISCUSSION OF FINDINGS**

Table 1 shows the heavy metal concentrations in seafood in river from Idema community Abureni Clan. Results for each heavy metals were reported in triplicate. Heavy metals in the studied seafood were compared to that of the reference values for each of the heavy metals assayed. 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; Gu, *et al.,* 2017). While many of these metals have industrial, agricultural, or technological applications (Needleman *et al*., 2002; Pacyna *et al.,* 2006; Rice *et al.,* 2014), their persistence, bioaccumulation, and toxicity of heavy metals make them a significant public health concern. Exposure to metals like lead, mercury, cadmium, and arsenic through contaminated water, food, and air continues to pose risks, especially in industrialized and agricultural regions (Lanphear *et al*., 2005; Satarug *et al.,* 2010; Song *et al.,* 2014). The concentration of heavy metals in seafood collected from Idema river was reported in Table 1. The Ni level among the most cytotoxic heavy metals in this study studied in *Grapsidae* was perceived to highest next was Pb, Cr while the least was Cd. The Pb concentration in *P. busungwe*seafood was topmost followed by Ni, Cr while the least was Cd. Ni predominated in level in *C. armatum* seafood followed by Cr, Pb while the least was Cd and similar trends was examined in *Oxudercinae* seafood (Table 1). The Ni scrutinized in *H. bivittatus* seafood was ultimate in level followed by Pb, Cr while the least was Cd and similar fashion was noticed in *Mystus tengara* and *Bagrus bajad* seafood (Table 1). Ni examined in *A. silverside* seafood was observed to be highest in level followed by Pb, Cr while Cd was the least. Also, the Pb levels in *P. armatus* seafood was higher than the Ni, Cr, and Cd while Ni predominated in concentration in *C. roseus* seafood followed by Pb, Cr and the least was Cd (Table 1). The levels of Pb, and Ni, Cr observed in *Grapsidae,* *P. busungwe, C. armatum,* *Oxudercinae*, *H. bivittatus, Mystus tengara*, *Bagrus bajad, A. silverside, P. armatus*  and *C. roseus* were higher than the reference values as recommended by WHO (2011). The levels of Pb, Ni, Cr, and Cd estimated in *Grapsidae,* *P. busungwe, C. armatum,* *Oxudercinae*, *H. bivittatus, Mystus tengara*, *Bagrus bajad, A. silverside, P. armatus*  and *C. roseus* seafood in this study were similar to the values reported by Mohammed *et al*. (2022) on heavy metals in four marine fish and shrimp species from a subtropical coastal area: accumulation and consumer health risk assessment as well as Athanasia *et al*. (2023) on detection of arsenic, chromium, cadmium, lead, and mercury in fish: effects on the sustainable and healthy development of aquatic life and human consumers.

The Fe concentration among the least toxic heavy metals in *Grapsidae* was highest followed by Zn while the least was Mn. The Fe in *P. busungwe* seafood was ultimate in level next was Zn while the Mn was the least. Fe predominated in *C. armatum* seafood followed by Zn while the least was Mn and same pattern occurred in *Oxudercinae* seafood (Table 1). The level of Fe estimated in *H. bivittatus* seafood was highest followed by Mn while the least was Zn and same was trends was perceived in *Bagrus bajad* seafood (Table 1). The Fe evaluated in *A. silverside* seafood predominated in level followed by Zn while the least was Mn and same pattern occurred in *P. armatus* and *C. roseus* respectively (Table 1). The levels of Fe, and Zn, and Mn observed in *Grapsidae,* *P. busungwe, C. armatum,* *Oxudercinae*, *H. bivittatus, Mystus tengara*, *Bagrus bajad, A. silverside, P. armatus*  and *C. roseus* were lower than the reference values as recommended by WHO (2011). The Fe, Zn, and Mn estimated in *Grapsidae,* *P. busungwe, C. armatum,* *Oxudercinae*, *H. bivittatus, Mystus tengara*, *Bagrus bajad, A. silverside, P. armatus*  and *C. roseus* seafood were far much lower than the values reported by Emmanuel *et al.* (2022) on heavy metal bioaccumulation in highly consumed pelagic and benthic fish and associated health risk as well as Bat *et al*. (2018) on human health risk assessment of heavy metals in the black sea: evaluating mussels.

However, Table 2 indicates the estimated daily intake of metals in seafood in from Idema-Abureni Clan. The estimated daily intake for each of the heavy metals was compared to the reference values as shown in Table 2. Seafood consumption is a major source of essential nutrients like omega-3 fatty acids, protein, and various minerals (Maher *et al.,* 2012). However, it is also a potential source of exposure to toxic Hg, Cd, Pb, and As, among others (Zhao *et al.,* 2016). Metals can accumulate in marine organisms due to natural geochemical processes and anthropogenic pollution, raising concerns about their potential health effects on humans. In this study, the Zn level in *Grapsidae* seafood was highest followed by Fe while the least was Mn and the Mn level examined in *P. busungwe* seafood was topmost next was Fe while the least was Zn. The Fe in *C. armatum* seafood was ultimate in concentration followed by Zn while the least was Mn and same trend occurred in *Oxudercinae, H. bivittatus, M. tengara,* and *Bagrus bajad* seafood. The level of Mn in *A. silverside* seafood was next was Zn while the least was Fe. More so, the concentration of Fe in *P. armatus* seafood was highest followed by Zn while the least was Mn and similar fashion occurred in *Catharanthus. roseus* seafood (Table 2). Having Zn, Mn, and iron Fe in seafood lower than the Recommended tolerable intake level of heavy metals sea food (Garcia-Rico *et al*., 2007; Burger *et al*., 2002), might not negatively impact on the nutrition and overall health of the indigenous people of Idema Town.

The Estimated Daily Intake (EDI) of these metals through seafood is a key parameter for assessing the risk associated with metal exposure via diet (Storelli *et al.,* 2005; Ghosn *et al.,* 2019). The estimated daily intake of Pb and Cd in *Grapsidae* and *P. busungwe* seafood harvested from Idema river were higher than those of Ni and Cr. The Cd and Pd in *C. armatum*, *Oxudercinae,* and *H. bivittatus* seafood were much more higher those of Ni and Cr (Table 2). The Cd in *M. tengara* seafood was topmost in levels followed by Pb, Ni while the least was Cr. The levels of Pb and Cd scrutinized in *Bagrus bajad* and *A. silverside* seafood were higher than of Ni and Cr. Also, the Cd in *P. armatus* seafood estimated was highest in level followed by Pb, Ni while the least was Cr. The Pb in *Catharanthus. roseus* seafood was supreme in level next was Cd, Ni while the least was Cr (Table 2). The levels of Pb and Cd estimated in *Grapsidae,* *P. busungwe, C. armatum,* *Oxudercinae*, *H. bivittatus, Mystus tengara*, *Bagrus bajad, A. silverside, P. armatus* and *C. roseus* seafood were higher than the Recommended tolerable intake level of heavy metals sea food (FDA, 2001; Garcia-Rico *et al.,* 2007).

Having levels of lead (Pb) and cadmium (Cd) in *Grapsidae,* *P. busungwe, C. armatum,* *Oxudercinae*, *H. bivittatus, Mystus tengara*, *Bagrus bajad, A. silverside, P. armatus* and *C. roseus* seafood that exceed the Estimated Daily Intake (EDI) values might cause serious health implications to the indigenous people of Idema Town. Pb and Cd are toxic even at low concentrations, and prolonged exposure through food consumption the studied seafood from Idema-Abureni Clan River could lead to bioaccumulation in the body that might precipitate acute and chronic health effects. According to Mohammed *et al*. (2022), Cd exposure primarily affects the kidneys, where it accumulates over time, potentially leading to kidney dysfunction and damage, while chronic exposure can also cause bone demineralization, leading to conditions like osteoporosis. While Ghosn *et al*. (2019) in their study on levels of Pb, Cd, Hg and As in fishery products from the eastern mediterranean and human health risk assessment due to their consumption reported that long-term exposure to cadmium has also been linked to an increased risk of cancer, particularly lung and prostate cancer. Additionally, cadmium can cause damage to the liver and may interfere with calcium metabolism, exacerbating bone loss.

Meanwhile, Table 3 presents the target hazard quotient and hazard index (HI) of metals in seafood from Idema-Abureni Clan River. Intake of seafood has long been associated with numerous health benefits, including high-quality protein and omega-3 fatty acids. However, the accumulation of Hg, Pb, Cd, and As in marine organisms poses significant health risks to humans (Miyazaki *et al*., 2015; Eme *et al.,* 2020). The target hazard quotient (THQ) and hazard index (HI) are crucial risk assessment tools used to evaluate the potential health risks associated with the consumption of contaminated seafood. Liu *et al.* (2016) examined the THQ of heavy metals in fish species from the Yangtze River in China. They found that THQ values for mercury exceeded 1 for certain fish, indicating significant health risks to consumers. Karami *et al*. (2020) studied the THQ of heavy metals in seafood from the Persian Gulf. Their results indicated that the THQ for cadmium was above 1 for several species, suggesting a potential risk to human health. In this study, the target hazard quotient and hazard index (HI) of Pb and Cr were topmost in *Grapsidae* seafood followed by Ni while the least was Cd and similar pattern were noticed in *Potamonautes busungwe* and *Cardisoma armatum.* The target hazard quotient and hazard index (HI) of Cd in *Oxudercinae* seafood was ultimate in level next was Cr, Pb while the least was Ni and same pattern occurred in *Halichoeres bivittatus,* and *Mystus tengara,* seafood. The target hazard quotient and hazard index (HI) of Ni in *Bagrus bajad* seafood was ultimate in level next was Cr, Pb while the least was Cd. The target hazard quotient and hazard index (HI) of Cr in *Atlantic silverside* seafood was ultimate in level next was Pb, Cd while the least was Ni and same trends were examined in *Portunus armatus* and *Catharanthus roseus* seafood (Table 3). The Pb, Cd, Cr, and Ni levels estimated in *Grapsidae,* *P. busungwe, C. armatum,* *Oxudercinae*, *H. bivittatus, Mystus tengara*, *Bagrus bajad, A. silverside, P. armatus* and *C. roseus* seafood in this study were lower than the reference values of Pb, Cd, Cr, and Ni in seafood reported by Mohammed *et al*. (2022) and Bat *et al.* (2018). Having target hazard quotient (THQ) and hazard index (HI) values for Pb, Cr, Ni, and Cd that are lower than the established reference values generally indicates a lower risk to human health from consuming contaminated *Grapsidae,* *P. busungwe, C. armatum,* *Oxudercinae*, *H. bivittatus, Mystus tengara*, *Bagrus bajad, A. silverside, P. armatus* and *C. roseus* seafood by the indigenous people of Idema-Abureni Clan.

Table 4 shows the 4 life cancer risk and total life cancer risk (TLCR) of metals in seafood from Idema-Abureni Clan River. The life cancer risk and total life cancer risk (TLCR) of metals in seafood from Idema-Abureni Clan River evaluated in this study were discussed and compared to the reference values reported in Table 4. Consumers of seafood, are exposed to these metals, leading to potential long-term health effects, including cancer (Chen *et al*., 2018). Cadmium is known to accumulate in shellfish and can cause lung, prostate, and kidney cancers with long-term exposure (Maher *et al*., 2012). Chromium is a carcinogen that may be present in seafood due to industrial pollution. While its primary concern is neurotoxicity, lead exposure has also been associated with potential cancer risks (Chen *et al*., 2018). Wang *et al.* (2013) assessed the LCR and TLCR for multiple heavy metals, including arsenic, cadmium, and lead, in shellfish harvested from coastal China and result obtained from their study revealed that the LCR for cadmium was estimated at 1.5 × 10⁻⁵, and the TLCR for all metals was 1.8 × 10⁻⁴, indicating a combined risk that exceeded acceptable cancer risk levels. **Zhang *et al*. (2016)** also evaluated the cancer risk associated with hexavalent chromium in fish from rivers affected by industrial pollution and result gathered from the study indicated that the LCR for Cr was calculated to be 4.5 × 10⁻⁴, which was significantly above acceptable levels. Table 4 shows the Life cancer risk and total life cancer risk (TLCR) of metals in seafood from IdemaAbureni River.

The Life cancer risk of Cd and Pb in *Grapsidae* seafood were higher than the TLCR (0.062mg/kg) while those of Pb, Cd, Cr, and Ni in *P. busungwe*seafood were lower than the TLCR (0.025mg/kg) (Table 4). The Life cancer risk of Cd in *Oxudercinae* seafood was higher than the TLCR (0.083mg/kg) while the Pb and Cd were higher than the TLCR (0.054mg/kg). The Life cancer risk of Pb and Cd in *H. bivittatus* seafood was higher than the TLCR (0.07mg/kg) while the Pb in *Mystus tengara* seafood were higher than the TLCR (0.044mg/kg). The Life cancer risk of Pb in *Bagrus bajad* seafood was higher than the TLCR (0.032mg/kg) while the Pb and Cd in *Atlantic silverside* seafood were higher than the TLCR (0.054mg/kg).

The Life cancer risk of Pb and Cd in *P. armatus* seafood was higher than the TLCR (0.048mg/kg) while the Pb and Cd in *C. roseus* seafood were higher than the TLCR (0.062mg/kg). Mathematically quantified life cancer risk and total life cancer risk (TLCR) of metals in seafood from Idema-Abureni River revealed that Pb, Cd, Cr, and Ni predominates in *Grapsidae, Potamonautes busungwe, Cardisoma armatum, Oxudercinae, Halichoeres bivittat, Mystus tengara, Bagrus bajad, Atlantic silverside, Portunus armatus* and *Catharanthus roseus* seafood and their respective values scrutinized were higher than the reference values as reported by the European Food Safety Authority (EFSA, 2015). The examined values of Pb, Cd, Cr, and Ni in *Grapsidae, Potamonautes busungwe, Cardisoma armatum, Oxudercinae, Halichoeres bivittat, Mystus tengara, Bagrus bajad, Atlantic silverside, Portunus armatus* and *Catharanthus roseus* seafood collected from Idema-Abureni River were similar to the values same heavy metals reported by Wang *et al.* (2013) on health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish and **Zhang *et al.* (2016) on** cancer risk from lead, Cadmium, and chromium in fish from heavily polluted rivers. The high level of Pb, Cd, Cr, and Ni estimated in seafood collected from Idema-Abureni River is reflective of severe contamination of her aquatic lives. Consumption *Grapsidae, Potamonautes busungwe, Cardisoma armatum, Oxudercinae, Halichoeres bivittat, Mystus tengara, Bagrus bajad, Atlantic silverside, Portunus armatus* and *Catharanthus roseus* seafood could pose significant long-term cancer risks. The estimated levels of Pb, Cd, Cr, and Ni in seafood obtained from Idema-River River calls for stricter regulations to limit illegal oil pipeline vandalization and bunkering activities that could lead to the release of Pb, Cd, Cr, and Ni as well as other carcinogenic substances into aquatic ecosystems.

Polycyclic aromatic hydrocarbons (PAHs) gets into aquatic ecosystems through various routes such as crude oil spills, illegal bunkering activities, and atmospheric deposition (Zhao *et al.,* 2014; Diercks *et al.,* 2010). Industrial activities near coastal regions, illegal bunkering activities and the burning of fossil fuels release PAHs, which can bind to particles in the water and settle in sediments, where they are taken up by benthic organisms, such as shellfish, or accumulate in the tissues of pelagic species (Wang *et al.,* 2016). Perugini *et al*. (2007) measured PAHs in seafood from the Adriatic Sea and found elevated levels, especially in shellfish, which were correlated with proximity to urban and industrial sites. In this study, naphthalene was detected in *Grapsidae, P. busungwe, C. armatum, Oxudercinae, H. bivittatu, B. bajad, A. silverside*, *P. armatus,* and *C. roseus* while *a*cenaphthene was detected in *C. armatum, Oxudercinae, H. bivittatu, B. bajad, A. silverside,* *P. armatus,* and *C. roseus.* Fluorene was examined in *Grapsidae, Oxudercinae, M. tengara,* and *C. roseus* (Table 5). Phenanthrene was perceived in *Grapsidae, P. busungwe, C. armatum, Oxudercinae, H. bivittatu, B. bajad, A. silverside,* *P. armatus,* and *C. roseus* while Fluoranthene was uncovered in *C. armatum, H. bivittatu, B. bajad, P. armatus,* and *C. roseus* (Table 5). Pyrene was identified in *P. armatus, C. armatum, Oxudercinae, H. bivittatu, M.tenga, B. bajad, A. silverside*, *P. armatus,* and *C. roseus* while chrysene was noticed in *Grapsidae, P. busungwe, C. armatum, Oxudercinae, H. bivittatu, B. bajad, A. silverside*, *P. armatus,* and *C. roseus* seafoodwhile *a*cenaphthene was detected in *C. armatum, Oxudercinae, H. bivittatu, B. bajad, A. silverside*, and *P. armatus* seafood (Table 5). Also, benzo(b) fluoranthene was observed in *Grapsidae, P. busungwe, Oxudercinae, H. bivittatu, A. silverside*, and *P. armatus* (Table 5).

The total PAHs detected in *C. roseus,* topmost in concentration next was *C. armatum, B. bajad, Grapsidae, P. armatus, A. silverside*, *Oxudercinae, H. bivittatu* while the least was *M. tengara* (Table 5). The total carcinogenic PAHs in *C. armatum* was the ultimate in level next was *Grapsidae, P. busungwe, B. bajad, A. silverside, H. bivittatus,* *Oxudercinae, M. tengara* while the least was *C. roseus* (Table 5). Also, percentage carcinogenic PAHs was topmost in *C. armatum* followed by *Grapsidae, P. busungwe, P. armatus, B. bajad, A. silverside, H. bivittatus,* while the least was *M. tengara* (Table 5).

Benzo[a]pyrene (BaP), benzo[a]pyrene, benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene, chrysene, Dibenzo[a,h]anthracene, Benzo[k]fluoranthene, Indeno[1,2,3-cd]pyren are recognized as the most potent carcinogenic PAHs while anthracene, pyrene, fluoranthene, and phenanthrene are considered possibly carcinogenic or contribute to the overall toxicity of PAH mixtures (Wang *et al*., 2016). In this study, benz(a)anthracene, chrysene, fluorene, and phenanthrene were detected in *Grapsidae, P. busungwe, C. armatum, Oxudercinae, H. bivittatus, B. bajad, A. silverside.* *P. armatus* and *C. roseus* seafood collected from Idema River and are recognized as carcinogenic PAHs. Long-term exposure to these carcinogenic PAHs in the studied seafood could possibly lead to increases cancer incidences and given the bioaccumulative nature of benz(a) anthracene, chrysene, fluorene, and phenanthrene, the indigenous people of Idema populations who rely heavily on such seafood for protein might be at higher risk of cancers of various types.

1. **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 Idema 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 seafood were significantly higher the reference values for seafood. Chronic consumption of these examined seafood for the presence of heavy metals and PAHs by residents of Idema River could lead to cumulative toxic effects. Immediate action is required to prevent the contamination of marine resources in Idema River. This includes implementing more stringent regulations on illegal crude oil or bunkering activities and conducting regular environmental monitoring. Public health interventions, including raising awareness about the risks of consumption of the contaminated studied seafood is necessary.

**Data Availability Statement:** All data used or developed is contained within the paper.

**REFERENCES**

Kalu, K. N., & Ndubuisi, A. (2019). Environmental Degradation in the Niger Delta Region:

Implications for Sustainable Development in Nigeria. *International Journal of Energy Economics and Policy, 9*(1), 274-282.

Zalik, A. (2011). Oil ‘futures’: Shell’s Scenarios and the social constitution of the global oil market. Geoforum, 42(3), 316-324.

Okoli, A. C., & Orinya, S. (2013). Oil pipeline vandalism and Nigeria’s national security. *Global*

*Journal of Human Social Science Political Science, 13*(5), 67-75.

Aghedo, I. (2013). Winning the War, Losing the Peace: Amnesty and the Challenges of Post-

Conflict Peace-Building in the Niger Delta, Nigeria. *Journal of Asian and African Studies, 48*(3), 267-280.

Ibaba, S. I., & Olumati, S. E. (2009). Sabotage Induced Oil Spillage and Human Rights Violation

in Nigeria’s Niger Delta. *Journal of Sustainable Development in Africa, 11*(4), 51-71.

Orogun, P. S., & Atu, S. B. (2018). Corruption and Oil Theft in Nigeria: Implications for National

Development. *International Journal of African Development, 5*(2), 45-59.

Asuni, J. B. (2019). Blood Oil in the Niger Delta. United States Institute of Peace. Special Report,

229

Nwilo, P. C., & Badejo, O. T. (2005). Oil spill problems and management in the Niger Delta.

*International Oil Spill Conference Proceedings, 1*(1), 567-570.

Olawoyin, R. (2012). Human Health Risk Associated with Heavy Metals in Soil and Groundwater

of Oil-Impacted Area in the Niger Delta, Nigeria. *International Journal of Environmental Research and Public Health, 9*(5), 2109-2123.

Nduka, J. K., & Orisakwe, O. E. (2010). Heavy Metal Levels and Health Risk Assessment of

Artisanal Crude Oil Refining: A Case Study of the Niger Delta, Nigeria. Journal of Environmental Science and Health, Part A, 45(6), 631-637.

Akande, M. G., & Oni, I. (2015). Assessment of Heavy Metal Contamination in Water and

Sediments from a Coastal Area of the Niger Delta. *Journal of Marine Pollution, 72*(3), 385-395.

Barakat, A. O. (20150. Environmental Impacts of Oil Spills on Aquatic Systems in the Niger Delta.

*Water, Air, & Soil Pollution, 160*(1-4), 149-166.

Idodo-Umeh, G., & Ogbeibu, A. E. (2010). Bioaccumulation of Heavy Metals in Fish from Oil-

Polluted Waters of the Niger Delta. *African Journal of Environmental Science and Technology, 4*(11), 726-735.

Okoro, D., Ikolo, F., & Obed, R. (2011). Concentration of Polycyclic Aromatic Hydrocarbons in

Some Seafood from Oil Polluted Waters of the Niger Delta. *Journal of Environmental Chemistry and Ecotoxicology, 3*(13), 367-373.

Anyakora, C., Ogbeche, A., & Palmer, P. 2005). GC/MS analysis of polynuclear aromatic

hydrocarbons in sediment samples from the Niger Delta. *Chemosphere, 60*(7), 990-997.

Numbere, A. O., & Camilo, G. R. (2020). Oil pollution effects on mangrove forest structure and

aquatic animal abundance in the Niger River Delta, Nigeria. *Regional Studies in Marine Science, 33,* 100909.

Ikem, A., Egiebor, N. O., & Nyavor, K. (2013). Trace Elements in Water, Fish, and Sediment from

Tuskegee Lake, Southeastern USA. *Water, Air, & Soil Pollution, 149*(1), 51-75.

Clarkson, T. W., & Magos, L. (2016). The Toxicology of Mercury and Its Chemical Compounds.

*Critical Reviews in Toxicology,* 36(8), 609-662.

Signa, G., Mazzola, A., Tramati, C.D., Vizzini, S. (2017). Diet and habitat use influence Hg and

Cd transfer to fish and consequent biomagnification in a highly-contaminated area: Augusta Bay (Mediterranean Sea). *Environ Pollut, 230*, 394–404.

Tomasello, B., Copat, C., Pulvirenti, V., Ferrito, V., Ferrante, M., & Renis, M. (2012).

Biochemical and bioaccumulation approaches for investigating marine pollution using Mediterranean rainbow wrasse, Coris julis (Linneaus 1798). *Ecotoxicol Environ Saf, 86*, 168–75.

Briggs, J. (2020). Environmental Challenges in the Niger Delta," Journal of Nigerian

Environmental Studies, 2020,

Rohan, R., Khan, I., & Pandit, J.U. (2014). Heavy metal analysis in water, fish and vegetative

samples of Iakha-Banjara Lake, Sagar, Madhya Pradesh, India.*Journal of Environmental* *research and Development, volume 8.* Nigeria Delta Development Commission, 31.

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**.**

Allen, S.E**.**, Grimshaw, H.M., & Rowland, A.P. (1986). *Chemical Analysis*. In: Methods in Plant Ecology. *Blackwell Scientific Publications*, 285–344).

AOAC (1995). International. *Official Methods of Analysis of AOAC International* (16th Edition).

Method, 975.03.

Miller, R.O. (1998). "Wet Digestion of Plant Tissue in an Open Vessel". In: Kalra, Y.P. (Ed.),

*Handbook of Reference Methods for Plant Analysis*. CRC Press.

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, 2020.

Ferguson, J.E. (1990). The Heavy Elements: Chemistry, Environmental Impact and Health Effects.

Pergamon Press.

EFSA (European Food Safety Authority) (2008). Polycyclic Aromatic Hydrocarbons in Food:

Scientific Opinion of the Panel on Contaminants in the Food Chain. EFSA Journal, 724, 1-114.

US EPA (1989). Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation

Manual (Part A), EPA/540/1-89/002.

Goyanna, F.A.A., Fernandes, M.B., de Silva, G.B., & de Lacerda, L.D. (2023). 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

Needleman, H.L., McFarland, C., Ness, R.B., Fienberg, S.E., Tobin, M.J. (2002). "Bone lead levels

in adjudicated delinquents: A case control study." Neurotoxicology and Teratology, 24(6), 711-717.

Pacyna, E.G., Pacyna, J.M., & Fudala, J. (2006). Global emissions of mercury to the atmosphere

from anthropogenic sources in 1995 and 2000." Atmospheric Environment, 40(22), 4048-4063.

Rice, K.M., Walker Jr., E.M., Wu, M., Gillette, C., Blough, E.R. (2014). Environmental mercury

and its toxic effect. Neurotoxicology and Teratology, 12(3), 11-17.

Lanphear, B.P., Hornung, R., &Khoury, J. (2005). Low-level environmental lead exposure and

children's intellectual function: An international pooled analysis." Environmental Health Perspectives, 113(7), 894-899.

Satarug, S., Garrett, S.H., Sens, M.A., & Sens, D.A. (2010). Cadmium, environmental exposure,

and health outcomes." Environmental Health Perspectives, 118(2), 182-190.

Song, Q., & Li, J. (2014). Environmental effects of heavy metals derived from the e-waste

recycling activities in China." Journal of Environmental Science and Health, Part A, 49(4), 321-328.

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

Mohammed, A. T., Sarker, T., Hasan, M. N., Ahammad, B., & Khandaker, M. U. (2022). Heavy

Metals in Four Marine Fish and Shrimp Species from a Subtropical Coastal Area: Accumulation and Consumer Health Risk Assessment. Biology, *11*(12), 1780.

Athanasia, P., Gounari, E., & Katsoulakos, G. (2023). Detection of Arsenic, Chromium, Cadmium,

Lead, and Mercury in Fish: Effects on the Sustainable and Healthy Development of Aquatic Life and Human Consumers. Sustainability, 15(23), 16242.

Emmanuel, E., Aliyu, U., Hammed, O., & Abubakar, A. (2022). Heavy Metal Bioaccumulation in

Highly Consumed Pelagic and Benthic Fish and Associated Health Risk. Biological Trace Element Research, *200*(5), 1943-1954.

Bat, L., Arici, E., & Öztekin, A. Human Health Risk Assessment of Heavy Metals in the Black

Sea: Evaluating Mussels. Curr World Environ, 13(1).

Maher, W.A., Foster, S.D., Krikowa, F., Apte, S.C., & Hales, L.T. (2012). Arsenic and selenium

speciation and bioavailability in fish from Lake Macquarie, NSW, Australia. Environmental Chemistry, 9(6), 513-523.

Zhao, Y., Xia, L., & Yang, Y. (2016). Assessment of human health risks of heavy metals in Bohai

Sea seafood, China. PLoS ONE, 11(6), e0157640.

Food and Drug Administration (2001). 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, 2001.

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

Burger, J., Gaines, K.F., Boring, C.S., Stephens, W.L., Snodgrass, J., & Dixon, C. (2002). "Metal

levels in fish from the Savannah River: Potential hazards to fish and other receptors." Environmental Research, *89*(1), 85-97.

Storelli, M.M., Barone, G., Garofalo, R., & Marcotrigiano, G.O. (2005). Trace metals in tissues

of mugilids (Mugil auratus, Mugil capito, and Mugil labrosus) from the Mediterranean Sea. Bulletin of Environmental Contamination and Toxicology, 74(5), 837-844.

Ghosn, M., Osta, J., Salamé, H., & Saab, E. (2019). Levels of Pb, Cd, Hg and As in Fishery

Products from the Eastern Mediterranean and Human Health Risk Assessment due to their Consumption. Environmental Science and Pollution Research, *26*(22), 22626-22634

Miyazaki, N., Yamaguchi, Y., & Iwasaki, S.(2015). Health risk assessment of heavy metals in

seafood consumed in Japan. Food Chemistry, 185, 318-324.

Eme, J. O., Emenike, M. A., & Okwor, N. J. (2020). Health risk assessment of heavy metals in

seafood from the coastal waters of Nigeria. Environmental Monitoring and Assessment, 192(4), 1-13.

Liu, J., Geng, Y., Wang, Q., Song, X., & Li, Z. (2016). Health Risk Assessment of Heavy Metals

in Fish Species Collected from the Yangtze River, China. Environmental Science and Pollution Research, 23(13), 13053-13065.

Karami, M., Khosravi, M., Gholami, M., Bahaodini, R., Gholami, N., & Zare, M. (2019). Health

Risk Assessment of Heavy Metal Contamination in Seafood from the Persian Gulf: A Case Study of the Target Hazard Quotient (THQ). Environmental Monitoring and Assessment, 192(1), 1-12

Chen, W., Liu, X., Shen, C., & Chuang, Y. H. (2018). Life cancer risk assessment of inorganic

arsenic exposure through seafood consumption in Taiwan. Journal of Environmental Science and Health, Part C, **36**(3), 179-197.

Wang, X., Sato, T., Xing, B., & Tao, S. (2013). Health risks of heavy metals to the general public

in Tianjin, China via consumption of vegetables and fish. Science of the Total Environment, ***350***(1-3), 28-37.

European Food Safety Authority (EFSA) (2015). Statement on the benefits of fish/seafood

consumption compared to the risks of methylmercury in fish/seafood.

Zhang, Y., Xu, J., Fang, Z., & Wang, Y. (2016). Cancer risk from lead, Cadmium, and chromium

in fish from heavily polluted rivers. Environmental Monitoring and Assessment, ***188*(**1), 42.

Zhao, X., Chen, L., & Shen, H. (2014). Bioaccumulation and distribution of polycyclic aromatic

hydrocarbons in different tissues of fish from Taihu Lake, China. Environmental International, 73, 72–78.

Diercks, A. R., Highsmith, R. C., Asper, V. L., Joung, D., Zhou, Z., Guo, L., & Shiller, A. M.

(2010). Characterization of subsurface polycyclic aromatic hydrocarbons at the Deepwater Horizon oil spill site. Geophysical Research Letters, 37(20).

Wang, C., Liu, S., Zhao, Q., Liu, B., & Zhang, G. (2016). Levels of polycyclic aromatic

hydrocarbons in seafood from Chinese Bohai Sea: Risk assessment for human health. Environmental Pollution, 213, 14–22

Perugini, M., Visciano, P., Giammarino, A., Manera, M., Di Nardo, W., & Amorena, M. (2007).

Polycyclic aromatic hydrocarbons in marine organisms from the Adriatic Sea, Italy. Chemosphere, *66*(10), 1904–1910.