**Mathematical evaluation of Heavy Metals and Polycyclic Aromatic Hydrocarbons in Selected Commonly Consumed Seafood and Health Risk Implications in Akipelai Town, Ogbia, Bayelsa State**

**ABSTRACT**

This carried out the mathematical evaluation of health risk of heavy metals and polycyclic aromatic hydrocarbons in selected seafood in Akipelai, Bayelsa State. Seafood were collected from Akipelai River. Heavy metals, PAHs, estimated 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 Pb, Cd, Cr, and Ni levels in *Grapsidae* were 1.160±0.008mg/kg, 1.016±0.008mg/kg, 8.036±0.008mg/kg, and 12.125±0.008mg/kg respectively, were higher than the reference values for seafood as recommended and similar pattern were observed in *P. busungwe, C. armatum,* and *Oxudercinae*. The estimated daily intake of Pb, Cd, and Ni in *Cardisoma armatum* were 1.002mg/kg, 1.704mg/kg, and 1.526mg/kg respectively, were higher than the reference values for seafood as recommended and similar pattern were observed in *Oxudercinae, Atlantic silverside, Portunus armatus,* and *Catharanthus roseus.* The target hazard and hazard index of Ni, Pb, and Cd in *P. busungwe*were 1.014mg/kg, 8.504mg/kg, and 8.904mg/kg respectively, were higher than the reference values for seafood as recommended and similar trend were observed in *Atlantic silverside.* Life cancer risk and total life cancer risk of Pb, Cd, and Ni studied in *Cardisoma armatum* 1.75, 6.005, and 0.044 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*. Chronic consumption of these seafood could lead to cumulative toxic effects and other serious health conditions. Immediate action is required to prevent contamination of marine resources in Akipelai Town.

KEYWORDS*: Akipelai River, seafood, PAHs, heavy metals, EDI, LCR, TLCR, THQ, HI*

1. INTRODUCTION

The Niger Delta region of Nigeria is rich in crude oil making it a major economic hub for the country. The region is plagued by socio-economic and environmental challenges, one of which is illegal crude oil bunkering (Kalu and Ndubuisi, 2019; Zalik, 2011). The stolen crude is either sold in the black market or refined locally in makeshift refineries known as "artisanal refineries. These activities operate outside legal and regulatory frameworks and are often controlled by organized criminal networks (Okoli and Orinya, 2013). The process of bunkering often involves vandalizing pipelines results in oil spills that have devastating environmental impacts (Aghedo, 2013).

Bayelsa State, located in the heart of Nigeria's oil-rich Niger Delta region, and is one of the most affected areas by oil bunkering activities (Okoli and Orinya, 2013). 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 (Ibaba and Olumati, 2009).

One of the damaging impacts of crude oil theft in Ogbia is environmental degradation (Kalu and Ndubuisi, 2019). This pollution has devastating effects on the local ecosystems, destroying farmlands, and rendering water sources unsafe for drinking (Orogun and Atu, 2018). The artisanal refineries, which use rudimentary methods to refine crude, contribute to environmental pollution by releasing toxic by-products into the air, water, and soil ((Ibaba and Olumati, 2009; Nwilo and Badejo, 2005).

A significant consequence of this pollution is the accumulation of heavy metals in aquatic ecosystems, particularly in seafood, which has to do with illegal refining are crude and release a plethora of toxic pollutants into the surrounding environment (Olawoyin, 2012). These pollutants are heavy metals and polycyclic aromatic hydrocarbons, leach into the soil, rivers, and other water bodies, contaminating aquatic ecosystem (Ibaba and Olumati, 2009; Nduka and Orisakwe, 2010). Seafood harvested from areas near illegal crude oil sites in Nigeria is heavily contaminated with heavy metals (Akande and Oni, 2015; Barakat, 2015). Pb, Hg, Cr, Cd, and As are the most prevalent heavy metals found in seafood from oil-polluted sites (Idodo-Umeh and Ogbeibu, 2010). Research conducted in the Niger Delta has reported elevated levels of Pb, Hg, Cr, Cd, and As in fish species such as Tilapia and Catfish as well as in crustaceans like shrimp and crabs. Chronic exposure to lead through seafood consumption can lead to neurological problems, particularly in children, as well as kidney damage and reproductive issues in adults (Okoro, 2011).

The consumption of seafood contaminated with heavy metals poses significant health risks to local populations. Given that seafood is a primary source 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 (Barakat, 2015; Idodo-Umeh and Ogbeibu, 2010). PAHs in areas affected by illegal oil refining are much higher than in non-polluted areas (Anyakora *et al.,* 2005; Numbere and Camilo, 2020). Seafood are exposed to PAHs through both direct contact with polluted water and sediments and through the food chain (Ikem *et al*., 2013).

Health risk assessment (HRA) of heavy metals in seafood typically involves calculating the estimated daily intake (EDI) of each metal and PAHs while comparing it to established reference doses (RfD) provided by regulatory agencies such as the US Environmental Protection Agency (EPA/WHO (2008). 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). 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 (Signa *et al*., 2017; Tomasello *et al*., 2012).

The Akipelai community is a small riverine settlement located in the Ogbia Local Government Area (LGA) of Bayelsa State, in the Niger Delta region of southern Nigeria (Briggs, 2020). This area is largely inhabited by the Ogbia people, who are of Ijaw ethnic origin, known for their cultural heritage and distinct language. Akipelai 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 located 40330N and 6033200E. The main occupation of the people of Akipelai is farming, fishing, and palm oil milling (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 Akipelai. 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 health risk assessment of some selected seafood, mostly consumed by the people of Akipelai.

1. **MATERIALS AND METHODS**

**1. Studied Area**

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

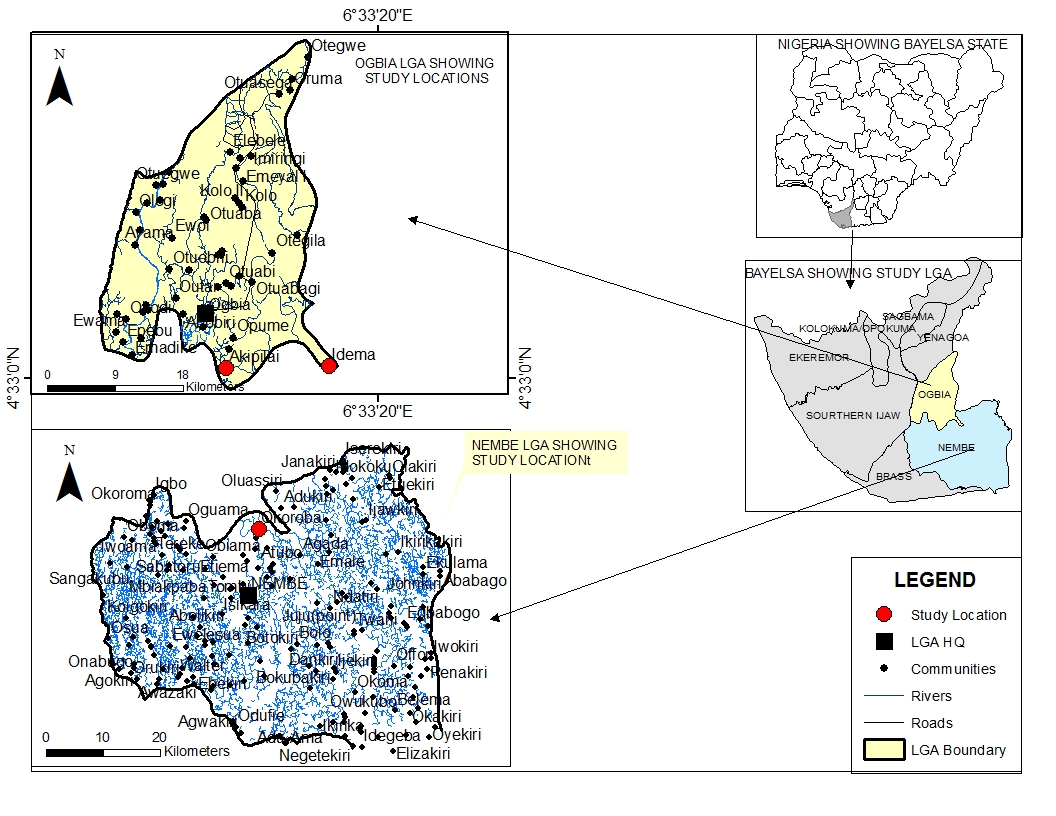
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Figure 1 GPS of Akipelai in Ogbia Local Government Area of Bayelsa State

**2. Collection of Seafood Samples**

Ten different types of shell and fin seafood were collected from sites 1 and 2 in June, 2024 in Akipelai 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

**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.

**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.* (1986). 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 (Miller, 1998).

**6. Human Health Risk Assessment of Heavy Metals in Seafood**

**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.

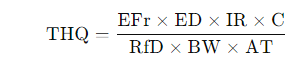
C = Concentration of the metal in seafood (µg/g or mg/kg)

IR = Ingestion rate of seafood (g/day)

BW = Body weight (kg)

**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)

**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, 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 [30].

1. **RESULTS**

**1.** **Heavy Metal Concentrations In Seafood From Akipelai Community**

Heavy metal contents in seafood collected from Akipelai community Ogbia Local Government Area of Bayelsa State, reported in mean and standard error of mean,

Table 1 Heavy metal concentrations in seafood from Akipelai community (N=3)

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb (mg/kg) | | Cd (mg/kg) | | Cr (mg/kg) | Ni(mg/kg) | Zn (mg/kg) | | Mn (mg/kg) | | Fe (mg/kg) |
| *Grapsidae* | 1.160±0.008b | | 1.016±0.008b | | 8.036±0.008 b | 12.125±0.008b | 5.400±0.015 | | 3.188±0.006 | | 13.720±0.011 |
| *P. busungwe* | 3.756±0.010 b | | 0.262±0.009 | | 0.518±0.006 | 5.491±0.010 b | 1.700±0.01 | | 0.458±0.014 | | 24.013±0.013 |
| *C. armatum* | 0.535±0.008 | | 0.053±0.011 | | 1.531±0.011 b | 8.026±0.011 b | 1.211±0.010 | | 1.972±0.010 | | 28.923±0.011 |
| *Oxudercinae* | 3.184±0.009 b | | 0.179±0.008 | | 1.932±0.008 b | 7.313±0.011 b | 3.204±0.006 | | 3.529±0.010 | | 21.183±0.008 |
| *H. bivittatus* | 6.020±0.008 b | | 0.762±0.008 b | | 3.197±0.007 b | 5.312±0.012 b | 0.667±0.060 | | 0.632±0.012 | | 17.376±0.049 |
| *Mystus tengara* | 2.616±0.020 | | 0.055±0.010 | | 0.525±0.009 | 3.016±0.009 b | 0.580±0.016 | | 0.184±0.009 | | 25.055±0.007 |
| *Bagrus bajad* | 1.549±0.011 b | | 0.485±0.014 | | 2.154±0.009 b | 6.188±0.014 b | 2.764±0.015 | | 1.533±0.011 | | 34.134±0.008 |
| *Atlantic silverside* | 1.914±0.015 b | | 0.090±0.005 | | 0.913±0.009 b | 2.572±0.012 b | 6.182±0.021 | | 2.045±0.013 | | 14.386±0.058 |
| *P. armatus* | 2.688±0.007 b | | 0.375±0.007 | | 0.671±0.009 b | 5.838±0.008 b | 4.890±0.010 | | 0.416±0.006 | | 23.927±0.010 |
| *C. roseus* | 3.411±0.011 b | | 0.837±0.013 | | 4.321±0.012 b | 4.074±0.016 b | 1.914±0.014 | | 3.904±0.031 | | 20.034±0.009 |
| Standard permissible limits of heavy metals in fish | | | | | | | | | | | |
| WHO/FAO, 2011 1  MPL (mg/kg) | |  | | 0.5 | 0.6 | 0.05 30 | |  | 5.5 | 43 | |
| FAO/WHO, 1998 1 | |  | | |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | 1.0 | 1.0 | 43.40 | 22.70 | 40 | - | - | | 43.40 | 22.70 40 | |  | - | - | |

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.

**2. Estimated Daily Intake of Metals In Seafood From Akipelai Community**

Table 2 shows the estimated daily intake of metals in seafood from Akipelai community.

Table 2 Estimated daily intake of metals in seafood from Akipelai community

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb | Cd | Cr | Ni | Zn | Mn | Fe |
| *Grapsidae* (mg/kg) | 1.004 | 0.613 | 2.026 | 3.039 | 0.018 | 0.010 | 0.045 |
| *P. busungwe* (mg/kg) | 2.003 | 0.203 | 0.002 | 2.518 | 0.006 | 0.002 | 0.078 |
| *Cardisoma armatum* (mg/kg) | 1.002 | 1.704 | 0.305 | 1.526 | 0.004 | 0.006 | 0.094 |
| *Oxudercinae* (mg/kg) | 0.610 | 5.804 | 0.210 | 1.024 | 0.010 | 0.011 | 0.069 |
| *Halichoeres bivittatus* (mg/kg) | 0.020 | 0.803 | 0.150 | 2.017 | 0.002 | 0.002 | 0.056 |
| *Mystus tengara* (mg/kg) | 0.309 | 1.784 | 0.202 | 0.610 | 0.002 | 0.059 | 0.081 |
| *Bagrus bajad* (mg/kg) | 1.005 | 0.002 | 0.307 | 3.020 | 0.009 | 0.005 | 0.111 |
| *Atlantic silverside* (mg/kg) | 0.706 | 2.924 | 0.203 | 0.308 | 0.020 | 0.007 | 0.047 |
| *Portunus armatus* (mg/kg) | 0.419 | 1.001 | 1.002 | 3.009 | 0.016 | 0.001 | 0.078 |
| *Catharanthus roseus* (mg/kg) | 2.011 | 0.703 | 1.014 | 2.013 | 0.006 | 0.013 | 0.065 |
| TDI (WHO, 2011 | 0.001 | 0.000 | 0.1-1.2\* | 0.5 | 8 | 0.4-10\* | 0.8\* |
| UTDI (1998) | 0.240 | 0.064 | - | 1.00 | 40 | - | - |

Prescribed middle of the road day by day admission (TDI) and upper fair day by day consumption (UTDI) levels of heavy metals in nourishment stuffs. Middle of the road Daily Intake of overwhelming metals by human as endorsed

**3. Target Hazard Quotient and Hazard Index Of Metals in Seafood From Akipelai Town**

Table 3 shows the target hazard quotient and hazard index of metals in seafood from Akipelai Town, Ogbia Local Government Area of Bayelsa State

Table 3 Target hazard quotient and hazard index of metals in seafood from Akipelai Town

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb | Cd | Cr | Ni | Zn | Mn | Fe | Hazard index |
| *Grapsidae*(mg/kg) | 0.001 | 0.003 | 1.745 | 0.002 | 5.805 | 7.384 | 5.565 | 0.007 |
| *P. busungwe*(mg/kg) | 1.014 | 8.504 | 1.126 | 8.904 | 1.805 | 1.064 | 9.705 | 0.003 |
| *Cardisoma armatum* (mg/kg) | 4.964 | 1.704 | 3.36 | 0.001 | 1.305 | 4.574 | 1.104 | 0.002 |
| *Oxudercinae* (mg/kg) | 0.003 | 5.804 | 4.186 | 0.001 | 3.465 | 8.174 | 5.805 | 0.006 |
| *H. bivittatus* (mg/kg) | 0.006 | 0.003 | 6.916 | 8.604 | 7.216 | 1.464 | 7.405 | 0.010 |
| *Mystus tengara* (mg/kg) | 0.002 | 1.784 | 1.146 | 4.804 | 6.276 | 4.265 | 1.004 | 0.003 |
| *Bagrus bajad* (mg/kg) | 0.001 | 0.002 | 4.106 | 0.001 | 2.995 | 3.554 | 1.404 | 0.005 |
| *Atlantic silverside* (mg/kg) | 7.695 | 2.924 | 1.976 | 4.174 | 6.605 | 4.744 | 5.805 | 0.001 |
| *Portunus armatus* (mg/kg) | 0.008 | 0.001 | 1.456 | 4.604 | 5.295 | 9.605 | 9.705 | 0.010 |
| *C. roseus* (mg/kg) | 0.003 | 0.003 | 9.316 | 6.614 | 2.075 | 9.044 | 8.125 | 0.007 |
| Mohammed et al. (2022), Bat et., (2018) | 0.3-0.5 | 0.1-0.5 | 0.1-0.05 | 0.1-0.2 | 1 | 1 | 1 | 1 |

**4. Life Cancer Risk and Total Life Cancer Risk (TLCR) Of Metals in Seafood From Akipelai Town**

Table 4 indicates the life cancer risk and total life cancer risk (TLCR) of metals in seafood from Akipelai Town, in Ogbia Local Government Area of Bayelsa State

Table 4 Life cancer risk and total life cancer risk (TLCR) of metals in seafood from Akipelai Town

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | Pb | Cd | Cr | Ni | Zn | Mn | Fe | TLCR |
| *Grapsidae* (mg/kg) | 3.405 | 0.004 | 0.013 | 0.066 | - | - | - | 0.083 |
| *Potamonaute* *busungwe*(mg/kg) | 2.505 | 0.001 | 3.001 | 0.031 | - | - | - | 0.033 |
| *Cardisoma armatum* (mg/kg) | 1.75 | 6.005 | 0.003 | 0.044 | - | - | - | 0.047 |
| *Oxudercinae* (mg/kg) | 2.150 | 2.204 | 2.005 | 0.041 | - | - | - | 0.046 |
| *Halichoeres bivittatus* (mg/kg) | 1.714 | 0.001 | 3.005 | 0.029 | - | - | - | 0.035 |
| *Mystus tengara* (mg/kg) | 4.605 | 3.705 | 0.001 | 0.017 | - | - | - | 0.018 |
| *Bagrus bajad* (mg/kg) | 4.205 | 3.604 | 0.004 | 0.034 | - | - | - | 0.039 |
| *Atlantic silverside* (mg/kg) | 3.105 | 1.114 | 0.002 | 0.014 | - | - | - | 0.016 |
| *Portunus armatus* (mg/kg) | 1.624 | 3.804 | 1.001 | 0.015 | - | - | - | 0.017 |
| *Catharanthus roseus* (mg/kg) | 3.305 | 0.001 | 3.007 | 0.022 | - | - | - | 0.030 |
| Ref. EFSA (2015). | to | to | to | to | - | - | - | to |

1. **Polycyclic Aromatic Hydrocarbon (PAHS) Concentration of Seafood Samples in Akipelai Community**

Table 5 shows the polycyclic aromatic hydrocarbon (PAHS) concentration of seafood samples in Akipelai community in Ogbia Local Government Area of Bayelsa State.

Table 5 Polycyclic aromatic hydrocarbon (PAHS) concentration of seafood samples in Akipelai community

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Compound |  | *Grapsidae* | *P. busungwe* | *C.*  *armatum* | *Oxudercinae* | *H. bivittatus* | *M.*  *tengara* | *B. bajad* | *A.*  *Silverside* | *P. armatus* | *C. roseus* |
| Naphthalene(3) |  | 1.014 | 0.284 | ND | 0.847 | ND | 0.085 | 0.003 | 0.847 | 1.014 | ND |
| Acenapthylene(3) |  | 0.004 | ND | ND | 0.270 | ND | 0.194 | ND | 0.270 | 0.004 | ND |
| Acenaphthene(3) |  | 0.029 | ND | ND | 0.082 | ND | 0.032 | ND | 0.812 | 0.029 | ND |
| Fluorene(3) |  | 0.184 | 0.055 | 0.249 | 1.219 | 0.006 | ND | 0.006 | 1.219 | 0.184 | 0.249 |
| Phenanthrene(3) |  | 1.053 | 0.768 | 0.186 | 1.804 | 0.695 | 0.819 | 1.059 | 1.804 | 1.053 | 0.186 |
| Anthracene(3) |  | 0.043 | 0.011 | 0.074 | 0.026 | 0.158 | ND | 0.006 | 0.026 | 0.043 | 0.074 |
| Fluoranthene(3) |  | 1.281 | 1.349 | 0.860 | 0.541 | ND | 1.260 | 0.036 | 0.541 | 1.281 | 0.860 |
| Pyrene(3) |  | 0.033 | ND | 0.032 | 0.086 | 0.092 | ND | ND | 0.086 | 0.033 | 0.032 |
| Benz(a) anthracene(2A) |  | ND | ND | ND | 0.414 | ND | 0.369 | 0.002 | 0.414 | ND | ND |
| Chrysene(2B) |  | 0.039 | 0.005 | ND | ND | 0.454 | 0.852 | ND | ND | 0.039 | ND |
| Benzo(b) fluoranthene(2B) |  | ND | ND | ND | ND | 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 |  | 3.680 | 2.473 | 1.402 | 5.288 | 1.306 | 3.611 | 1.112 | 5.288 | 3.680 | 1.402 |
| Total carcinogenic PAHs |  | 0.039 | 0.005 | 0 | 0.414 | 0.454 | 1.221 | 0.002 | 0.414 | 0.039 | 0 |
| % Carcinogenic PAHs |  | 1.060 | 0.202 | 0 | 7.892 | 34.763 | 33.813 | 0.180 | 7.829 | 1.060 | 0 |

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

1. **DISCUSSION**

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 and Li, 2014). The concentration of heavy metals in seafood collected from Akipelai 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. Among the most cytotoxic heavy metals, the Ni level in *Grapsidae* was highest followed by Cr, Pb while the least was Cd. The Ni level in *P. busungwe* was noticed to be highest followed by Pb, Cd while the least was Cr, which were higher than the reference values as recommended by WHO (2011).

However, from the less toxic heavy metals, Fe level in *Grapsidae* was highest followed by Zn while the least was Mn, which lesser than the reference values for seafood as recommended by WHO (2011). The concentration of Fe inspected in *P. busungwe*was to be highest followed by Zn while the least was Mn, which lesser than the reference values for seafood as recommended by WHO (2011). The level of Fe Scrutinized in *C. armatum* was highest followed by Mn while the least was Zn, which lesser than the reference values for seafood as recommended by WHO (2011). The concentration of Fe perceived in *Oxudercinae* was highest followed by Mn while the least was Zn and similar trends occurred in *H. bivittatus* seafood, which lesser than the reference values for seafood. The Fe level in *Mystus tengara* was significantly highest followed by Zn while the least was Mn and same developments arose in *Bagrus bajad* and *Atlantic silverside,* which lesser than the reference values for seafood*.* The level of Fe surveyed in *Portunus armatus* was significantly highest followed by Zn while the least was Mn and similar progressions materialized in *C. roseus,* which lesser than the reference values for seafood(Table 1).

The Ni level in *C. armatum* was seen to be highest followed by Cr, Pb while the least was Cd, which higher than the reference values for seafood (WHO, 2011) The concentration of Ni examined in *Oxudercinae* was significantly highest followed by Pb, Cr while the least was Cd and similar trends occurred in *H. bivittatus,* which higher than the reference values for seafood (WHO, 2011). The level of Ni detected in *Mystus tengara* was significantly highest followed by Pb, Cr while the least was Cd and similar patterns Happened in *Bagrus bajad* and *Atlantic silverside,* which higher than the reference values for seafood. The concentration of Ni discerned in *Portunus armatus* was significantly highest followed by Pb, Cr while the least was Cd. Also, the level of Ni inspected in *C. roseus* was highest followed by Cr, Pb while the least was Cd, which higher than the reference values for seafood (Table 1). The significantly high Ni, Pb, Cr, and Cd level observed in *Grapsidae, P. busungwe, C. armatum, Oxudercinae, H. bivittatus, Mystus tengara, Bagrus bajad*, *Atlantic silverside, Portunus armatus,* and *C. roseus* seafood is reflective of heighten degree of environmental contamination arising from crude oil spill and illegal bunkering activities in Akipelai Town. Also, the predominance of Ni, Pb, Cr and Cd scrutinizedin seafood in this study could possibly lead a serious public health concern due to the potential for bioaccumulation and biomagnification in seafood. Chronic exposure to heavy metals through seafood consumption could result in adverse health effects, including neurotoxicity, organ damage, and increased cancer risk.

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 metals such as mercury (Hg), cadmium (Cd), lead (Pb), and arsenic (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. The Estimated Daily Intake (EDI) of these metals through seafood is a key parameter for assessing the risk associated with metal exposure via diet (Burger *et al.*, 2002; Storelli *et al.*, 2005). In this study, the Ni level in *Grapsidae* was scrutinized to be highest followed by Cr, Pb while the least was Cd and simulacrum of such development unfolded in *P. busungwe*seafood (Table 2). The Cd in *Cardisoma armatum* was examined to be apex in concentration followed by Ni, Cr while the least was Pb and same fashion transpired in *Mystus tengara* seafood (Table 2). The Ni in *Bagrus bajad* was perceived to be topmost in level followed by Pb, Cr while the least was Cd (Table 2). The Cd in *Atlantic silverside* seafood was detected to be ultimate in level followed by Pb, Ni while the least was Cr. Also, the Ni in *Portunus armatus* seafood was surveyed to be maximum in concentration followed by Cr, Cd while the least was Pb and their values. More so, the Ni in *Catharanthus roseus* seafood was discerned to peak in level followed by Pb, Cr while the least was Cd (Table 2). The values of Ni, Cd, Cr, and Pb inspected in *Grapsidae, P. busungwe, Cardisoma armatum, Mystus tengara, Bagrus bajad, Atlantic silverside, Portunus armatus* and *Catharanthus roseus* seafood were higher than the tolerable daily intake (TDI) and upper tolerable daily intake (UTDI) reference values as reported by WHO (2011).

Chronic exposure of the people of Akipelai to Pb *from Grapsidae, P. busungwe, Cardisoma armatum, Mystus tengara, Bagrus bajad, Atlantic silverside, Portunus armatus* and *Catharanthus roseus* seafood, particularly at levels exceeding the TDI or UTDI, could lead to severe neurological damage, cognitive deficits, learning disabilities, reduced IQ, memory loss especially in children, memory loss and mood disorders in adults. Prolong ingestion of Ni and Cr through *Grapsidae, P. busungwe, Cardisoma armatum, Mystus tengara, Bagrus bajad, Atlantic silverside, Portunus armatus* and *Catharanthus roseus* seafood at elevated levels of Cr(VI) by the people of Akipelai, might increase the risk of developing gastrointestinal cancers, respiratory and skin toxicity, chronic bronchitis and asthma, dermatitis, oxidative stress and DNA damage, increases the risk of mutagenesis and chronic diseases including cancer. Uptake of Cd through *Grapsidae, P. busungwe, Cardisoma armatum, Mystus tengara, Bagrus bajad, Atlantic silverside, Portunus armatus* and *Catharanthus roseus* seafood exceeding the TDI/UTDI recommendations by the indigenous people of Akipelai might result in kidney dysfunction, leading to proteinuria, renal failure, bone demineralization in older adults and increases the risk of cancers including lung, prostate, and kidney cancers.

Consumption of seafood has long been associated with numerous health benefits, including high-quality protein and omega-3 fatty acids. However, the accumulation of heavy metals such as mercury (Hg), lead (Pb), cadmium (Cd), and arsenic (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 of Cr in *Grapsidae* was studied to be apex in level followed by Cd, Ni while the least was Pb (Table 3). The target hazard quotient and hazard index Ni in *P. busungwe* seafood was highest next was Cd, Cr, while the least was Pb. The target hazard quotient and hazard index Pb in *Cardisoma armatum* seafood was surveyed to ultimate in level next was Cr, Cd while the least was Ni. The target hazard quotient and hazard index of Cd in *Oxudercinae* seafood was observed to be maximum in concentration next was Cr, Pb while the least was Ni. The target hazard quotient and hazard index of Ni in *H. bivittatus* seafood was observed to be topmost in concentration next was Cr, Pb while the least was Cd. Also, target hazard quotient and hazard index of Ni in *Mystus tengara* seafood was examined to be peak in concentration next was Cd, Cr while the least was Pb (Table 3). The target hazard quotient and hazard index of Cr in *Bagrus bajad* seafood was observed to be topmost in concentration next was Cd, Pb while the least was Ni. The target hazard quotient and hazard index of Pb in *Atlantic silverside* seafood was examined to be peak in concentration next was Ni, Cd while the least was Cr (Table 3). More so, the target hazard quotient and hazard index of Ni in *Portunus armatus* seafood was examined to be peak in concentration next was Cr, Pb while the least was Cd (Table 3). The target hazard quotient and hazard index of Cr in *Atlantic C. roseus* seafood was observed to be uppermost in level next was Ni, Cd while the least was Pb (Table 3).

The target hazard quotient and hazard index of Ni in *P. busungwe, H. bivittatus, Mystus tengara, Atlantic silverside, Portunus armatus* and *C. roseus* seafood obtained from Akipelai River were higher than the reference hazard index values (HI > 1) as reported by Mohammed *et al*. [49] and Bat *et al.* (2018). The target hazard quotient and hazard index of Cr predominate in *Grapsidae, P. busungwe, Cardisoma armatum, Oxudercinae*, *H. bivittatus, Mystus tengara,* *Bagrus bajad, Atlantic silverside, Portunus armatus* and *C. roseus* seafood obtained from Akipelai River were higher than the reference hazard index values (HI > 1) as reported by European Commision/WHO [39]. The target hazard quotient and hazard index of Cd in *P. busungwe, Cardisoma armatum, Oxudercinae*, *Mystus tengara,* *and Atlantic silverside* seafood obtained from Akipelai River were higher than the reference hazard index values (HI > 1) as reported by Mohammed *et al*. (2022) and Bat *et al.*  (2020). The target hazard quotient and hazard index of Pb in *Cardisoma armatum* and *Atlantic silverside* seafood obtained from Akipelai River were higher than the reference hazard index values (HI > 1) as reported by Mohammed *et al* (2020) and Bat *et al.* (2018). The target hazard quotient and hazard index of Pb, Cr, Cd, Cr, and Ni predominate in *Grapsidae, P. busungwe, Cardisoma armatum, Oxudercinae*, *H. bivittatus, Mystus tengara,* *Bagrus bajad, Atlantic silverside, Portunus armatus* and *C. roseus* seafood obtained from Akipelai River, hence these seafood might not be safe for consumption.

Heavy metals enter marine environments through industrial activities, mining, agricultural runoff, and improper disposal of waste (Chien *et al*., 2002), while, over time, these metals bioaccumulate in marine organisms, including fish and shellfish (Chen *et al*., 2018). Humans, as consumers of seafood, are exposed to these metals, leading to potential long-term health effects, including cancer. Cd is known to accumulate in shellfish and can cause lung, prostate, and kidney cancers with long-term exposure. Hexavalent chromium Cr (VI) is a known 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 (Maher *et al.,* 2012; Wang *et al.,* 2013; Mohammed *et al.,* 2022). 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 (Cr(VI)) in fish from rivers affected by industrial pollution and result gathered from the study indicated that the LCR for Cr(VI) was calculated to be 4.5 × 10⁻⁴, which was significantly above acceptable levels.

The life cancer risk of Pb inspected in *Grapsidae* seafood was higher than the TLCR (0.083mg/kg) while the Cd and Cr in *Potamonaute* *busungwe*seafood higher than the TLCR (0.033mg/kg). The life cancer risk of Pb and examined in *Potamonautes busungwe* seafood 2.505mg/kg while that of Cr was 3.001mg/kg (Table 4). The life cancer risk of Pb and Cd perceived in *Cardisoma armatum* seafood were higher than the TLCR (0.047mg/kg) while the Pb, Cd, and Cr in *Oxudercinae* seafood were higher than the TLCR (0.046mg/kg) (Table 4). Also, the life cancer risk of Pb and Cr scrutinized in *Halichoeres bivittatus* seafood were higher than the TLCR (0.035mg/kg) while the Pb and Cd in *Mystus tengara* seafood were higher than the TLCR (0.018mg/kg) (Table 4). More so, the life cancer risk of Pb and Cd studied in *Halichoere Bagrus bajad* seafood were higher than the TLCR (0.039mg/kg) while the Pb and Cd in *Atlantic silverside* seafood were higher than the TLCR (0.016mg/kg) (Table 4). The life cancer risk of Pb, Cd, and Cr in studied in *Portunus armatus* seafood were higher than the TLCR (0.017mg/kg) while those of Pb and Cr in *Catharanthus roseus seafood* were higher than the TLCR (0.0303mg/kg) (Table 4).

Mathematically estimated life cancer risk (LCR) and total life cancer risk (TLCR) of cytotoxic metals in seafood obtained from Akipelai River reflected 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 estimated 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 Akipelai 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 Akipelai River is reflective of high degree of contamination her marine environment. Consumption of *Grapsidae, Potamonautes busungwe, Cardisoma armatum, Oxudercinae, Halichoeres bivittat, Mystus tengara, Bagrus bajad, Atlantic silverside, Portunus armatus* and *Catharanthus roseus* seafood could elicit considerable long-term cancer risks, thereby warranting regulatory intervention to control the sources of metal pollution. The quantified levels of Pb, Cd, Cr, and Ni in the studied seafood in Idema River calls for stricter regulations to limit illegal oil pipeline vandalization and bunkering activities that lead to the release of Pb, Cd, Cr, and Ni as well as other carcinogenic substances into aquatic ecosystems.

PAHs enter marine ecosystems by various pathways, including oil spills, urban runoff, and atmospheric deposition (Zhao *et al.,* 2014; Diercks *et al.,* 2010). 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 Table 5, naphthalene was detected in *Grapsidae, P. busungwe, Oxudercinae, M. tengara, B. bajad, A. silverside* and *P. armatus*. The level of Naphthalene in *Grapsidae* was topmost followed by *P. armatus, Oxudercinae, A. silverside*, *P. busungwe* while the least was *B. bajad* (Acenapthylen level was scrutinized in *Grapsidae, Oxudercinae, M. tengara, A. silverside* and *P. armatus* and it presence was ultimate in concentration *M. tengara,* next was *A. silverside*, *P. armatus,* and *Grapsidae* (Table 5). Acenaphthene was observed in *Grapsidae, Oxudercinae, M. tengara, A. silverside* and *P. armatus* and was highest in concentration in *A. silverside,* *Grapsidae, P. armatus, Oxudercinae* while the least was *M. tengara* (Table 5). Fluorene was studied in *Grapsidae, P. busungwe, C. armatum, Oxudercinae, H. bivittatus, B. bajad, A. silverside.* *P. armatus* and *C. roseus.* The concentration of fluorene in *Oxudercinae* and *A. silverside* next was *Grapsidae, C. armatum, C. roseus, P. armatus, P. busungwe* while the least was *H. bivittatus* (Table 5). Phenanthrene was scrutinized in *Grapsidae, P. busungwe, C. armatum, Oxudercinae, H. bivittatus, M. tengara, B. bajad, A. silverside*, *P. armatus* and *C. roseus.* The level of phenanthrene was ultimate in *A. silverside* and *Grapsidae* followed by *P. armatus, C. armatum, M. tengara, P. busungwe* while the least was in *B. bajad* (Table 5). Anthracene was also examined in *Grapsidae, P. busungwe, C. armatum, Oxudercinae, H. bivittatus, B. bajad, A. silverside*, *P. armatus* and *C. roseus.* The value of anthracene in *H. bivittatus* was supreme in level followed by *C. roseus, C. armatum, Grapsidae, P. armatus, Oxudercinae, P. busungwe* while the least was seen in *A. silverside* and similar pattern of occurrence were perceived in pyrene (Table 5). Benz(a) anthracene was inspected in *Oxudercinae, M. tengara, B. bajad,*  and *A. silverside* in which it concentrated more in *Oxudercinae* and *A. silverside* while the least was *B. bajad*. Chrysene was detected in *Grapsidae, P. busungwe, H. bivittatus, M. tengara, P. armatus,* and *C. roseus* in which it accumulated mmore in *M. tengara* next was *H. bivittatus, Grapsidae, P. armatus* while the least was *P. busungwe* (Table 5).

The total PAHs detected in *Oxudercinae* topmost in concentration next was *A. silverside*, *Grapsidae, P. armatus, M. tengara, P. busungwe, C. armatum, C. roseus, H. bivittatus* while the least was *B. bajad* (Table 5). The total carcinogenic PAHs in *M. tengara* was the ultimate in level next was *H. bivittatus,* *Oxudercinae, A. silverside, Grapsidae, P. busungwe, P. armatus* while the least was *C. roseus.* Also, percentage carcinogenic PAHs was topmost in *H. bivittatus* next was *M. tengara, Oxudercinae, A. silverside, Grapsidae, P. armatus, B.* bajad while the least were *P. busungwe* and *C. roseus* (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 [54] (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 Akipelia 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 Akipelai 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 Akipelai River could lead to cumulative toxic effects. Immediate action is required to prevent the contamination of marine resources in Akipelai 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**

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

author.

**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. (2015). Environmental Impacts of Oil Spills on Aquatic Systems in the Niger Delta.

*Water, Air, and 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, *5,* 71-84

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).

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. *African Scientific Journal, 16,* 59-71

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.

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. (2000). "Global emissions of mercury to the atmosphere

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

Rice, K.M., Walker, 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.

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.

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.

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

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. (2020). 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

Mohammed, A. T., Sarker, T., Hasan, M. N., Ahammad, B., & Khandaker, M. U. (2020). Heavy

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

Bat, L., Arici, E., & Öztekin, A. (2018). Human Health Risk Assessment of Heavy Metals in the

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

Chien, L. C., Hung, T. C., Choang, K. Y., Yeh, C. Y., Meng, P. J., Shieh, M. J., & Han, B. C.

(2020). Daily intake of TBT, Cu, Zn, Cd, and As for fishermen in Taiwan. Environmental Toxicology and Pharmacology, ***13***(2), 79-86.

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.

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.

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.

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.

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

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

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.