PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 29 (2) 533-541 Feb. 2025

Concentration of Dietary Exposure and Health Risk Assessment of Ni, Cd and Pb in Periwinkles Clams and Nile tilapia Harvested from Selected Communities in the Niger Delta Region, Nigeria

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ABSTRACT: Niger Delta region is home to several seafood and a source of livelihood for the people; however, environmental pollution has exposed the marine ecosystem due to anthropogenic activities. Consequently, the objectives of this paper were to assess the concentration, dietary exposure and human health risk assessment of Ni, Cd and Pb in periwinkles (*Tympanotanum fuscatus*), clams (*Mya arenaria*), and Nile tilapia (*Oreochromis noliticus*) harvested from Egbormung, Krakrama and Bassambiri communities in the Niger Delta Region Nigeria using appropriate standard methods after HCl/HNO_3 (3:1) digestion and AAS model 210 VGP Buck scientific analysis. Data obtained showed that the concentration of Cd (0.004±0.001 – 1.283±0.197 mg/kg); Ni (0.047±0.007 – 5.220±0.276 mg/kg); Pb (0.200±0.000 – 20.822±0.094 mg/kg) for periwinkles, Cd (0.003±0.001 – 0.656±0.027 mg/kg); Ni (0.081±0.003 – 2.333±0.157 mg/kg); Pb (0.339±0.002 -16.763±0.071 mg/kg) for clams and Cd (0.002±0.001 – 2.362±0.139 mg/kg), Ni (0.064±0.004 – 1.639±0.067 mg/kg), Pb (1.250±0.019 – 41.237±0.374) for Nile tilapia. The results of the risk of consumption of the seafood from Egbormung samples are (5.51E-01, 2.15E-01, 9.13E-01); from Krakrama samples are (8.29E-01, 1.06E+00, 2.28E+00) from Bassambiri are (1.47E+00, 7.92E-01, 2.88E+00); from Kono, the control site are (1.28E-02, 2.08E-02, 7.54E-02) for periwinkles, clams and Nile tilapia respectively. High HI values were obtained for seafood samples from the coastal rivers in the order: Fish > clams > periwinkles and Bassambiri > Krakrama > Egbormung respectively. All three seafoods had high levels of Pb while Ni levels in periwinkles and Nile tilapia were higher than clams Cd in clam samples were higher than the other seafood samples.

DOI: https://dx.doi.org/10.4314/jasem.v29i2.24

Cite this Article as: KALAGBOR, A. I; MARTINS, B. W; OBELEMA, B. N; AKPOTAYIRE, S. I (2025). Concentration of Dietary Exposure and Health Risk Assessment of Ni, Cd and Pb in Periwinkles Clams and Nile tilapia Harvested from Selected Communities in the Niger Delta Region, Nigeria. *J. Appl. Sci. Environ. Manage.* 29 (2): 533-541

Dates: Received: 23 December 2024; Revised: 27 January 2025; Accepted: 09 February 2025; Published: 28 February 2025

Keywords: Coastal Rivers; human health risk assessment; periwinkle, clams and Nile tilapia

Seafood is typically regarded as a low-calorie protein source and offers vital elements that support children's and newborns' brain and visual development. They include polyunsaturated oil, such as omega-3 fatty acids, which the body is unable to create on its own and must instead be received from seafood (Jin and Makoto, 2016). Consuming seafood can lower the risk of cardiovascular illnesses, protect the heart, raise good cholesterol, and enhance blood flow, according to studies (Akshay *et al.*, 2018; Ajita

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and Jayakumat, 2019; Bo *et al.,* 2020). Bivalve molluscs, or seafood, include clams, periwinkles, oysters, and cockles. They can be found in mangroves and on sandy beaches (Ahina *et al.,* 2012; Bo *et al.,* 2020). There are several of these in the Niger Delta, along with small and medium-sized fish, which are good sources of calcium for the growth of bones when consumed whole. The bioavailability of certain heavy metals in these marine foods has been attributed to increased anthropogenic activity along the Niger Delta region's shoreline and waterways. Anthropogenic activities and rising coastal pollution from increasing urbanization have led to an increase in the presence of these metals in the marine environment. Because they are higher tropic level species that are frequently consumed by humans, fish, shrimp, crab, and other bivalves are utilized in assessments of metal buildup (Ahina *et al.,* 2012; Lais *et al.,* 2013; Aytekin *et al.,* 2019; Ukwo *et al.,* 2020). Consumption of food particles enhanced with heavy metals from seafood can be traced back down the food chain, indicating their bioaccumulation, and has been associated with a number of health problems (Nishijo *et al.,* 2017; Engwa *et al.,* 2019). By their diet, shellfish can absorb heavy metals like Pb and Cd, which can then accumulate within their tissues and contaminate seafood (Yap *et al.,* 2009). Eating seafood contaminated with heavy metals can be harmful to one's health. As bio-indicators, they have been employed to track the contamination caused by heavy metals (Ndome *et al.,* 2010). Hence, the objectives of this paper is to assess concentration In this study the tissues of periwinkles, clams and small fishes from Egbormung, Krakrama and Bassambiri rivers were used to assess the concentration, dietary exposure and human health risk assessment of Ni, Cd and Pb in periwinkles (*Tympanotanum fuscatus*), clams (*Mya arenaria*), and Nile tilapia (*Oreochromis noliticus*) harvested from Egbormung, Krakrama and Bassambiri communities in the Niger Delta Region, Nigeria.

MATERIALS AND METHODS

Description of the Study areas: The Egbormung River is located between the New Calabar River and Imo River. The river flows from Bonny through Isioum, Agama, Ngo and Ikuru heading to Opobo. Krakrama Creek is located at Opudegema-Degema at Degema LGA. The creek originated from Tuma and KaluTuma and is connected to Buguma creek through Krakrama. It finally connects to the new Calabar River. Bassambiri is a community located at Nembe Kingdom at Brass LGA in Bayelsa State. The creek flows from Nembe creek through Tubopiri and Oruama to Bassambiri down to Odema creek all in Nembe, Brass LGA. Kono River is situated on the coast of Ogoni in Khana LGA, Rivers State.

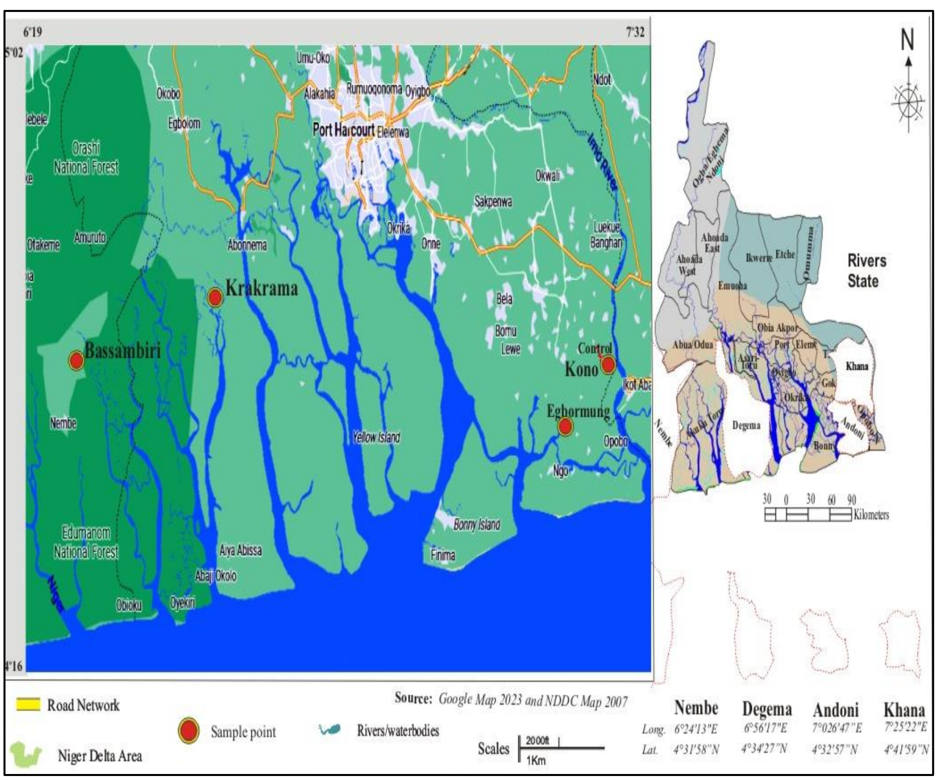

Fig.1: Geological map of the study areas

(Source: Geographic Information System, 2023)

Sample collection: Seafood samples were harvested from three different points for each river and labelled appropriately. Periwinkles and clams were de-shelled at points of collection and transported together with Nile tilapia in an ice box to the laboratory freezer for preservation. This collection was carried out for three consecutive months.

Sample preparation: The de-shelled periwinkles, clams and Nile tilapia were put in distinctively labelled dry crucibles and put in the oven at 120 ^{o}C until a constant dry weight was obtained for each sample. The dried samples were ground using a porcelain mortar and pestle to fine powder and labelled accordingly.

Wet digestion: The samples were digested by weighing 2 g of each sample into clean beakers. 20 mL of the *aqua regia* was added, stirred and heated for 1 hr. The resulting solution after digestion was complete was allowed to cool. Thereafter, they were filtered into 100 mL volumetric flasks using the Whatsman filter paper and made up to volume using deionised water.

Heavy metal analysis: The samples were analysed using air-acetylene flame atomic absorption spectrophotometer; AAS model 210 VGP Buick Scientific for nickel (Ni), cadmium (Cd) and lead (Pb).

Health risk assessment study of heavy metals: Calculation for the health risk assessment was done using Estimated Daily Intake (EDI), Chronic Daily Intake (CDI), True Metal Intake (TMI), Daily True Metal Intake (DTMI), Target Hazard Quotient (THQ) and Hazard Index (HI) (Akien-Alli *et al.,* 2021) as presented in Equations 1-6.

True metal intake

$$TMI = \frac{C_{metal} \text{ x } D_{seafood\ intake}}{B_{(average\ wt)}} \quad (1)$$

Where C_{metal} is heavy metal concern (mg/kg); $D_{(seafood\ intake)}$is daily intake (≤5kg/year); and $B_{(average\ wt)}$ adult body weight (60.7kg for Africa) (Walpole *et al.*, 2012).

Estimated daily intake: For purposes of this study, TMI is equivalent to the Estimated Daily Intake (EDI) which is expressed in Equation 2

$$EDI = \frac{C \text{ x } IR}{B_{(average\ wt)}} \quad (2)$$

Where: EDI is the estimated daily intake; C is the concentration of the metal; IR is the ingestion rate; and B is the average adult body weight (60.7kg).

Daily true metal intake (DTMI): The daily TMI for the metals in seafood samples was calculated from the formula presented in equation 3.

$$DTMI = \frac{TMI\ (per\ year)}{365\ days} \quad (3)$$

Where: DTMI is the daily true metal intake; TMI is the true metal intake.

Target hazard quotient (THQ: The level of health risk assessment for non-carcinogenic exposure of toxic heavy metals through consumption of seafood samples from the respective rivers was determined using the equation 4.

$$THQ = \frac{CDI}{R_f D} \quad (4)$$

Where: THQ is the target hazard quotient; CDI is the Chronic Daily Intake of a heavy metal (a carcinogen) and R_fD is the reference oral dose. For purposes of this study, CDI was substituted with EDI. Reference dose (mg/kg/day) ingestion (oral) for Cd, Ni, and Pb are 1E-03, 2E-02, and 5E-03 respectively as stated by (US EPA, 2011).

Target hazard quotient (THQ): The target hazard quotient for the metals in seafood samples was calculated from the formula presented in equation 5.

$$THQ = \frac{DTMI}{R_f D} \quad (5)$$

Where: THQ is the target hazard quotient; DTMI is the daily true metal intake and R_fD is the reference oral dose

Hazard index: Hazard index is utilized to evaluate the collective non-carcinogenic health risk exposure of dictated heavy metals emanating from different pathways. For the purpose of this study the potential hazard index (HI) posed by these metals was obtained using the sum of the target hazard quotients (THQ) of each heavy metal computed.

$$HI = (THQ_{Cd} + THQ_{Ni} + THQ_{Pb}) \quad (6)$$

Where: HI is the hazard index; THQ_{Cd} is the target hazard quotient for Cd; THQ_{Ni} is the target hazard quotient for Ni and THQ_{Pb} is the target hazard quotient for Pb. HI < 1 implies insignificant non-carcinogenic risk to the exposed public health but when the permissible value of HI > 1 there is tendency of non-cancer effect which might require further inspection of the surface and ground water of the study area (US EPA, 2011).

Statistical analysis: This data obtained from this study was subjected to statistical analysis using SPSS v.23.

RESULTS AND DISCUSSION

The mean concentrations of Cd, Ni, and Pb in periwinkles (*Tympanotanum fuscatus*) are presented in Table 1. Pb had the highest concentration from all the sampling sites, with Bassambiri recording the highest (20.822±0.094 mg/kg). Ni had concentrations of 4.430±0.165 mg/kg and 5.220±0.276 mg/kg for Egbormung and Bassambiri respectively while lower concentrations were obtained from Krakrama (0.047±0.007 mg/kg) and Kono (0.052±0.002 mg/kg). From the three metals analysed, Cd had the lowest concentrations of 0.004±0.001 mg/kg (Kono), 0.013±0.003 mg/kg (Egbormung) and 1.280±0.118 mg/kg (Bassambiri) except those harvested from Krakrama whose value was higher than that obtained for Ni. The general trend is Pb > Ni > Cd. From Table 2, the metal with the highest concentration in the Clams (*Mya arenaria*) samples was Pb. The result from Krakrama was 16.763±0.071 mg/kg compared to 13.407±0.009 mg/kg and 11.123±0.135 mg/kg from Bassambiri and Egbormung respectively. The concentrations of Ni from Bassambiri and Krakrama were 2.333±0.157 mg/kg and 1.735±0.071 mg/kg respectively. Lower concentrations of 0.081±0.003 mg/kg and 0.081±0.003 mg/kg were obtained from the samples harvested from Kono and Krakrama respectively. With respect to the metals analysed, Cd had the least concentration of 0.003±0.001 mg/kg (Kono), 0.041±0.009 mg/kg (Bassambiri) and 0.432±0.155 mg/kg (Krakrama) with an exception for Clams harvested from Egbormung whose value was higher than that obtained for Ni. A similar trend in the order of concentration of the metals is observed; Pb > Ni > Cd. Table 3 showed the mean concentrations of Cd, Ni and Pb in Nile tilapia (*Oreochromis noliticus*) from the three sampling sites. Pb had the highest concentration in Nile tilapia harvested from all the sampling sites with Bassambiri recording the highest (41.237±0.374 mg/kg). Concentration of Ni ranged from 1.290±0.046 mg/kg to 1.639±0.067 mg/kg for Bassambiri and Egbormung samples respectively. Concentrations of Ni obtained from Krakrama (0.073±0.009 mg/kg) and Kono (0.064±0.004) were lower than the others. Cd had the lowest values of 0.002±0.001 mg/kg (Egbormung) and 0.017±0.002 (Kono); except Krakrama and Bassambiri samples which were higher than that obtained for Ni. Results from Egbormung and Kono showed the same trend in the order of concentrations as follows: Pb > Ni > Cd while Krakrama and Bassambiri showed a different trend: Pb > Cd > Ni.

Table 1: Mean concentrations (mg/kg) of Cd, Ni and Pb in periwinkle (*Tympanotanum fuscatus*) from the sampling sites

Location	Cd	Ni	Pb
Egbormung	0.013±0.003	4.430±0.165	8.825±0.077
Krakrama	1.283±0.197	0.047±0.007	9.539±0.098
Bassambiri	1.280±0.118	5.220±0.276	20.822±0.094
Kono (control)	0.004±0.001	0.052±0.002	0.200±0.000

Table 2: Mean concentrations (mg/kg) of Cd, Ni and Pb in clams (*Mya arenaria*) from the sampling sites

Location	Cd	Ni	Pb
Egbormung	0.656±0.027	0.374±0.008	11.123±0.135
Krakrama	0.432±0.155	1.735±0.071	16.763±0.071
Bassambiri	0.041±0.009	2.333±0.157	13.407±0.009
Kono (control)	0.003±0.001	0.081±0.003	0.339±0.002

Table 3: Mean concentrations of Cd, Ni and Pb in Nile tilapia (*Oreochromis noliticus*) from the sampling sites

Location	Cd	Ni	Pb
Egbormung	0.002±0.001	1.639±0.067	15.835±0.056
Krakrama	0.477±0.120	0.073±0.009	38.405±0.105
Bassambiri	2.362±0.139	1.290±0.046	41.237±0.374
Kono (control)	0.017±0.002	0.064±0.004	1.250±0.019

Tables 4 and 5 showed that the daily true metal intake (DTMI) for periwinkles for Cd, Ni and Pb were 3.00E-07, 1.00E-03 and 1.99E-03 respectively for Egbormung samples. The samples from Krakrama showed that the DTMI was least for Ni (1.06E-05) while Cd and Pb were 2.89E-04 and 2.22E-03 respectively. Bassambiri samples had DTMI values of 2.89E-04, 1.20E-03 and 4.70E-03 for Cd, Ni and Pb respectively. It was observed that the values obtained for these heavy metals were higher than the values from the control samples; 9.48E-07, 1.17E-05 and 4.52E-05 for Cd, Ni and Pb respectively. Pb concentrations from Egbormung were high compared to Ni and Cd concentrations. Samples from Krakrama had higher values for Pb followed by Cd while Ni had the lowest concentration. Bassambiri samples had the highest concentration of Pb. The concentration of Ni was also the highest when compared to Egbormung and Krakrama. The levels of Cd were similar to that obtained for Krakrama samples. The order of the metals concentration followed the sequence of Pb > Ni > Cd except Krakrama samples whose order is Pb > Cd > Ni. These results are in close proximity with those reported by Onyegeme-Okerenta *et al*. (2023), which stated that the EDI values obtained from seafood samples harvested from Elebele River in Bayelsa State exceeded the reference doses given by the regulatory bodies, they attributed these high values in the seafood samples to the illegal bunkering activities and indiscriminate disposal of toxic substances into the water body. Furthermore, the high values of Pb obtained from seafood samples in this study also corroborates the finding reported by Ihunwo *et al.,* (2022); Ighariemu *et al.,* (2023) who reported high values of Pb in seafood samples analyzed and attributed it to the waste deposition, anthropogenic activities and the presence of metal scrapings deposited in the river.

Table 4: True Metal Intake (TMI) for metals in periwinkle (*Tympanotanum fuscatus*) samples (mg/kg/year) from the sampling sites

Metals	Egbormung	Krakrama	Bassambiri	Kono
Cd	1.10E-03	1.06E-01	1.06E-01	3.50E-04
Ni	3.65E-01	3.90E-03	4.30E-01	4.30E-03
Pb	7.27E-01	7.27E-01	1.72E+00	1.65E-02

Table 5: Daily True Metal Intake (DTMI) for the metals in periwinkles (*Tympanotanum fuscatus*) (mg/kg/day) from the sampling sites

Metals	Egbormung	Krakrama	Bassambiri	Kono
Cd	3.00E-07	2.89E-04	2.89E-04	9.48E-07
Ni	1.00E-03	1.06E-05	1.20E-03	1.17E-05
Pb	1.99E-03	2.22E-03	4.70E-03	4.52E-05

From Tables 6 and 7**,** the concentration for Ni (8.44E-05) was the least compared to Cd (1.48E-05) and Pb (2.51E-03) for Egbormung samples. Cd concentration was lower in Krakrama (9.75E-05) and Bassambiri (9.26E-06) while Ni concentrations were 3.92E-04 and 5.27E-04 for Krakrama and Bassambiri respectively. DTMI values for Pb for these two locations (Krakrama and Bassambiri) were 3.78E-03 and 3.03E-03 respectively. These values are similar to that obtained from Egbormung samples but higher than those from the control samples. Clam samples from Egbormung had high values of Pb when compared to values obtained for Cd and Ni. These results are in agreement with the assertions of Vincent-Akpu and Yanadi, (2014) who reported similar mean concentration of Pb and Cd metals in seafood samples harvested from Iwofe site on New Calabar River, Rivers State. Samples from Krakrama recorded the highest concentrations of Pb when compared to Basambiri and Egbormung samples. Cd concentrations were the least in Bassambiri when compared to the other two locations.

Table 6: True Metal Intake (TMI) for the metals in Clams (*Mya arenaria*) samples (mg/kg/year) from the sampling sites

Metals	Egbormung	Krakrama	Bassambiri	Kono
Cd	5.41E-02	3.56E-02	3.40E-03	2.47E-04
Ni	3.08E-02	1.43E-01	1.92E-01	6.67E-03
Pb	9.17E-01	1.38E+00	1.10E+00	2.80E-02

Table 7: Daily True Metal Intake (DTMI) for the metals in Clams (*Mya arenaria*) samples (mg/kg/day) from the sampling sites

Metals	Egbormung	Krakrama	Bassambiri	Kono
Cd	1.48E-05	9.75E-05	9.26E-06	6.77E-07
Ni	8.84E-05	3.92E-04	5.27E-04	1.83E-05
Pb	2.51E-03	3.78E-03	3.03E-03	7.68E-05

The metals concentration in clams followed the order: Pb >Ni > Cd except Egbormung samples whose order was Pb > Cd > Ni. Onyegeme-Okerenta *et al.* (2022) reported that fecal matter, domestic and industrial effluents, wastes from illegal refining activities, soot, and debris from the destruction of the illegal refineries are continuously emptied into the Krakrama river; and this could be the reason for the high levels of the heavy metals in the seafood samples analyzed. Tables 8 and 9 showed that Nile tilapia from Egbormung had the least DTMI values for Cd (3.83E-07) while Ni and Pb were 3.70E-04 and 3.58E-03 respectively. These values are lower than the value obtained from the control sample which was 3.84E-06. Concentration for Cd from Krakrama and Bassambiri samples were close, 1.08E-04 and 5.33E-04 respectively and these values are higher than the control (3.84E-06). Pb concentrations for Krakrama and Bassambiri were also close. The DTMI value obtained for Nile tilapia harvested from Krakrama was 8.67E-03 while the value recorded for Bassambiri was 9.31E-03. Both values were higher than the control (2.83E-04). Ni concentrations obtained were 1.65E-05 and 2.91E-04 respectively for these two locations. The value for seafood samples harvested from Krakrama river compares with the value from the control (1.44E-05). Nile tilapia samples from Egbormung recorded very high concentrations of Pb followed by Ni when compared to other sea foods. Cd had the least concentration. However, the seafood samples from Krakrama had high Pb concentration followed by Cd, and then Ni. Bassambiri samples had the highest Pb concentrations which is also the highest metal concentration recorded from the seafood followed by Cd then Ni. The metal concentration in Nile tilapia follows the trend; Pb > Cd > Ni except for samples from Egbormung whose order is Pb > Ni > Cd. The findings derived from this study agree with that of Akien-Alli *et al.* (2021); high concentration values of Pb, Cd and Ni in periwinkle for TMI and DTMI were reported. The source of the high Pb found to be present in the seafood samples is as a result of the corrosion of the pipelines that are laid across the river bodies Anarado *et al.* (2024). The observed Pb levels in the seafood samples can be attributed to the disposal of metal scrapings into the river (Cai *et al.*, 2019), surface runoffs and municipal waste discharges into the water bodies which enters into the body system of the seafood through the food chain (Olele *et al.*, 2013).

Table 8: True Metal Intake (TMI) for the metals in Nile tilapia (*Oreochromis noliticus*) samples (mg/kg/year) from the sampling sites.

Metals	Egbormung	Krakrama	Bassambiri	Kono
Cd	1.40E-04	3.93E-02	1.95E-01	1.40E-03
Ni	1.35E-01	6.00E-03	1.06E-01	5.27E-03
Pb	1.30E+00	3.16E+00	3.40E+00	1.03E-01

Table 9: Daily True Metal Intake (DTMI) for the metals in Nile tilapia (*Oreochromis noliticus*) samples (mg/kg/day) from the sampling sites

Metals	Egbormung	Krakrama	Bassambiri	Kono
Cd	3.84E-07	1.08E-04	5.33E-04	3.84E-06
Ni	3.70E-04	1.65E-05	2.91E-04	1.44E-05
Pb	3.58E-03	8.67E-03	9.31E-03	2.83E-05

Target hazard quotient THQ is used in evaluating the levels of ingesting heavy metals through these sea foods. For purposes of this study, CDI is substituted with DTMI (mg/kg/day). The reference dose for Cd, Ni and Pb are 0.001, 0.02 and 0.004 mg/kg/day. Therefore, the THQ for these metals is calculated using a modified form of equation 3 which is presented in equation 5. The THQ and HI values for the three study sites and the control site are presented in Tables 10, 11, 12 and 13. The HI values obtained for seafood samples from the study sites in Tables 10, 11 and 12 are in the order of Bassambiri > Krakrama > Egbormung. Nile tilapia samples recorded the highest HI valued followed by clams then periwinkles in the order; Nile tilapia > clams > periwinkles. This trend can be explained from their feeding habits, location and degree of bioaccumulation. Research has shown that sediments form the major repository of heavy metals in the aquatic body. Fish has been reported to accumulate large amounts of metals because of their surface area, and their position at the top of the aquatic food chain. Fish scavenges for food in sediments with the mouth and this might have increased the level of intake of heavy metals in their body (Mansour & Sidky, 2002). The finding of this study gives credence to the report published by Ifemeje and Destiny (2022) which observed that fishes had higher concentrations of heavy metals in their bodies' tissues when compared to crabs and shrimps harvested from Ekpan and Ogunu Rivers, located in Warri, Delta State. Results from Table 10 showed that samples from Egbormung had THQ values for Cd being least in Nile tilapia and periwinkle; 3.84E-04 and 3.0E-03 respectively, but high (1.48E-01) in clams which is higher than the THQ (6.77E-04) for the control sample presented in Table 13. However, THQ for Ni in clams was the least (4.20E-03) compared to Nile tilapia and periwinkles which were 1.85E-02 and 5.0E-02 respectively. This value for the clams samples was found to be 4.5 times higher than the control THQ value of 9.15E-04. Pb THQ values for sea food from this river were high compared to the THQ values of the control samples which are 1.13E-02, 1.92E-02 and 7.08E-02 for periwinkles, clams and Nile tilapia respectively. Periwinkles and Nile tilapia had higher levels of Ni than the clams while the clams had higher levels of Cd than these two. THQ values for samples from Krakrama are presented in Table 11, periwinkles were found to have higher values (2.90E-01) than clams (9.75E-02) and Nile tilapia (1.08E-01) for Cd concentrations. THQ values for Ni in periwinkles was 5.30E-04 and 8.24E-04 for Nile tilapia. These values were lower than that obtained for clams (1.96E-02). Their values compare favourably with the THQ for the control which was 7.2E-04. Pb was also found to be the metal with the highest THQ values in the seafood similar to the findings in Egbormung River samples in the same order of Nile tilapia > clams > periwinkles. These seafoods though had lower concentrations of Ni, the concentrations of Pb were very high, thus making them unfit for consumption as well as the Nile tilapia from the control (Kono River) whose THQ value was 7.08E-02.

Results obtained for samples from Bassambiri are presented in Table 12. These clams have the lowest THQ value; 9.26E-03 for Cd. Periwinkles and Nile tilapia samples has values of 2.89E-01 and 5.33E-01 respectively. These values are high when compared to the value for the control ample (Kono) which was 6.77E-04. THQ values for Ni were 5.24E-04, 2.63E-02 and 1.46E-02 for periwinkles, clams and Nile tilapia respectively. These values were higher than their respective THQ values for the control samples presented in Table 13 which are; 5.85E-04, 9.15E-04 and 7.2E-04. The order of periwinkles > clams > Nile tilapia for the levels of Ni in these seafoods is the reverse for THQ values for Pb in which Nile tilapia has the highest value (2.33) followed by periwinkles (1.18) then clams (0.76) while THQ values for the control samples were 7.08E-02, 1.13E-02 and 1.92E-02 for Nile tilapia, periwinkles and clams respectively. The seafood from these rivers has high concentrations of Cd, Ni and Pb; therefore, are unfit for consumption as this can lead to acute toxicological risks to consumers. The hazard index (HI) computed for the heavy metals in the seafood samples from the sampling sites revealed that clams (1.06E+00) and Nile tilapia (2.28E+00) harvested from Krakrama river; periwinkles (1.47E+00) and Nile tilapia (2.88E+00) harvested from Bassambiri river exceeded the reference value (HI≤1) given by US EPA (2011), thus indicating that the consumption of these seafood from this sampling locations could pose a non-carcinogenic health risk which could adversely affect the normal body functioning of individuals who consume these seafood.

Table 10: Target Hazard Quotient (THQ) and Hazard index (HI) for the Metals in seafood samples harvested from Egbormung river.

Metals	Periwinkles	Clams	Nile tilapia
Cd	3.00E-03	1.48E-01	3.84E-04
Ni	5.00E-02	4.20E-03	1.85E-02
Pb	4.98E-01	6.28E-02	8.94E-01
HI	**5.51E-01**	**2.15E-01**	**9.13E-01**

Table 11: Target Hazard Quotient (THQ) and Hazard index (HI) for the Metals in seafood samples harvested from Krakrama river

Metals	Periwinkles	Clams	Nile tilapia
Cd	2.90E-01	9.75E-02	1.08E-01
Ni	5.30E-04	1.96E-02	8.24E-04
Pb	5.38E-01	9.46E-01	2.17E+00
HI	**8.29E-01**	**1.06E+00**	**2.28E+00**

Table 12: Target Hazard Quotient (THQ) and Hazard index (HI)for the Metals in seafood samples harvested from Bassambiri river

Metals	Periwinkles	Clams	Nile tilapia
Cd	2.89E-01	9.26E-03	5.33E-01
Ni	5.24E-04	2.63E-02	1.46E-02
Pb	1.18E+00	7.57E-01	2.33E+00
HI	**1.47E+00**	**7.92E-01**	**2.88E+00**

Table 13: Target Hazard Quotient (THQ) and Hazard index (HI)for the Metals in seafood samples harvested from Kono river

Metals	Periwinkles	Clams	Nile tilapia
Cd	9.48E-04	6.77E-04	3.84E-03
Ni	5.85E-04	9.15E-04	7.20E-04
Pb	1.13E-02	1.92E-02	7.08E-02
HI	**1.28E-02**	**2.08E-02**	**7.54E-02**

Conclusion: This study has shown that the high levels of Ni, Cd, and Pb in these seafoods can be attributed to the anthropogenic activities that release these and other heavy metals into the rivers. The high level of accumulation in the Nile tilapia when compared to the clams and periwinkles can be attributed to the size as they have larger bodies and surface area. Hence, the metals will tend to bio-accumulate more in them. The HI values have shown that the Bassambiri River in Nembe was more polluted with these potentially toxic elements than the other two rivers. These non-essential metals, Cd, Ni, and Pb are toxic even at low concentration and are not beneficial. They have been classified as category 1 carcinogens by the International Agency for Research in Cancer (IARC) therefore consumption of seafood from these rivers is not recommended.

Declaration of Conflict of Interest: The authors declare no conflict of interest.
Data Availability Statement: Data are available upon request from the first author or corresponding author or any of the other authors

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