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Research Article

Seasonal Assessment of Bio-accumulation and Potential Human Health Risk of Heavy Metals in Periwinkle (*Typanotonus fuscatus var radula)* from the Great Kwa River, Nigeria

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ABSTRACT

Seasonal changes, anthropogenic and other natural processes, introduce waste and waste materials, including heavy metals, into the rivers of Niger Delta region of Nigeria. This study assessed the bioaccumulation of heavy metals in periwinkle and the potential health risk associated with consuming this seafood from the Great Kwa River, Nigeria. The mud and periwinkle samples were collected from four marked points along the water course to cover both wet and dry seasons. After wet digestion, the heavy metal analysis was carried out using an Atomic Absorption Spectrophotometer. The metal elements analyzed were cobalt, iron, copper, cadmium, and lead. The level of cadmium in the periwinkle was higher in the dry season than in the wet season and exceeded the World Health Organization/Food and Agriculture Organization permissible limit in seafood. Cobalt, iron, and copper concentrations were higher in the wet season than in the dry season. Cadmium had the highest bioaccumulation in the dry season, while copper had the highest bioaccumulation in the wet season. The Estimated Daily Intakes were lower than their upper tolerable limits. The Target Hazard Quotients did not exceed standard values. The Hazard Index was 0.0933 and 0.0619 for the dry and wet seasons, respectively. The incremental lifetime cancer risk of cadmium was 8.4×10^{-5}, and that of lead was 3.9×10^{-7}. These values were within the tolerable or acceptable range for cadmium and lead. Consumption of periwinkle from the Great Kwa River may not pose any significant human health risk due to heavy metal poisoning.

Keywords: *Periwinkle, Great Kwa River, heavy metals, bio-accumulation and, health risk assessment.*

INTRODUCTION

One major source of water available to mankind is the river estuary, which spreads across communities and settlements in small streams to brooks with ample support for aquatic life, to which rural dwellers can draw for sustainability. Rivers economically provide rural dwellers with abundant natural resources and opportunities; they form part of the immediate employment of the natives via fishing, diving for clams, boat making, and seafood trading. The United Nations nutrition report stated that seafood is not just a source of protein but also rich in omega-3 fatty acids and bioavailable micronutrients, which have attracted global recognition (HLPE, 2014; FAO, 2020). The World Health Organization reported that micronutrients in aquatic animals are highly bioavailable. As such, researchers incorporated this finding in dietary guidelines for consuming seafood. The recommendation was focused on balancing nutritional benefits with food safety concerns over the bioaccumulation of contaminants and pollutants (FAO/WHO, 2021; Willet *et al*., 2019). Owing to the role small aquatic animals like fish, periwinkle, shrimps, clams, and other gastropods play in nutrition, studies showed that these animals enhanced the absorption of micronutrients such as iron and zinc from plant-sourced foods when consumed together (Barrie *et al*., 2018). Despite its contribution as an abundant nutritional resource and sustainable health, water poses a fear and a threat to life if contaminated. Most of the severe contamination is due to unregulated human activities like oil spillage, discharge of untreated effluents, and to a larger extent, unregulated solid waste disposals into water bodies (Yeboah and Ameyaw, 2012). With many emerging studies on water pollution and water sediment contamination, research revealed that the natural presence of contaminants can impact water quality, even though no anthropogenic sources of pollution exist (Akpoveta *et al*., 2011; Atiemo *et al*., 2012). This finding necessitates periodic assessment of contaminant levels, especially heavy metals, in water bodies like rivers closer to municipal settlements.

The Great Kwa River is one of the main sources of seafoods ranging from fresh fish, shrimps, prawns, crabs, clams, periwinkle, and other shellfish in Calabar and its environs. The river drains the east side of the city, and it is subject to seasonal uncontrolled pollution from both natural and anthropogenic sources. It belongs to the Cross-River System, which comprises major tributaries, notably the Calabar River, Akpayafe River, and Mbo River. These tributaries drain to the North, and freshwater/mangrove swamps to the south. Major Creeks are formed as the river and its tributaries drain and sculpt their routes through the freshwater and mangrove terrain of the south. Two such Creeks are Mbat-Abbiati and Oberekkai Creeks. These Creeks are located in the present-day Akamkpa Local Government Area of Cross River State, Nigeria. Concerns have risen about solute pollution, heavy metal contamination, and the potential impact on food systems and human health associated with these Creeks (Ephraim and Ajayi, 2015). The Great Kwa River is subject to continuous and unabated natural and anthropogenic pollution occasioned by its association with the municipal and urban development of the Calabar metropolis. With no absolute waste management system, flooding carries waste and wastewater into the river from many outlets. During flooding, potentially toxic elements in the soil dissolve in the floodwater and are transported into the river as the season changes.

The fact that the Great Kwa River is susceptible to such pollution problems, and the people draw most of their livelihood from it, brings the people and the possible pollution crisis together. This therefore creates a need for continuous monitoring of the river and its resources, using available biomonitors, such as periwinkle. This study was therefore embarked to assess the bio-accumulation and potential human health risk of heavy metals in periwinkle (a mud feeder) from the Great Kwa River, Nigeria.

MATERIALS AND METHODS

Description of the study area

This study was conducted at the Esuk Atu beach of the Great kwa River drainage located between 8° 15E and 8° 30E latitude and longitude 4° 45N and 5⁰ 15N. it is about 56km long and 2.8km wide at the mouth where it meets the Cross River estuary, both of which drain Calabar (Okoroafor *et al*., 2015). The river coordinates were taken for each sampling point, about 300 to 400 meters apart. Station 1 was between latitude 4.9479 and longitude 8.36002; station 2 was latitude 4.94813 and longitude 8.35672; station 3 was latitude 4.94813 and longitude 8.35809; station 4 was latitude 4.9409 and longitude 8.35406.

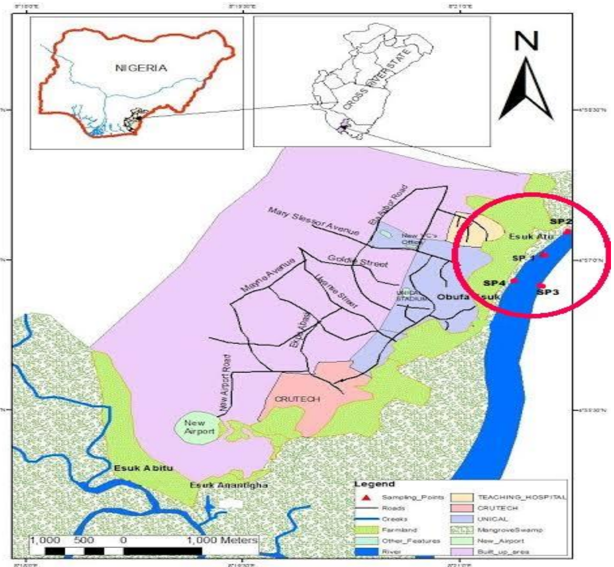

Figure 1: Map of the study area

Sample collection and preparation

The periwinkle samples and the mud sediment were collected from the study area at the mapped sampling points. The breadth of the river at these points was crossed using a canoe and the distance between points was taken by a measuring tape and the GPS taken. The periwinkle from their muddy habitat was collected into black nylon bags labeled p1 to p4 for proper identification. The mud sediment from the four stations was also collected into another polythene bag and labeled m1 to m4. The samples were collected in August 2022 for the wet season and January 2023 for the dry season, between 7.00 am and 10.00 am. The samples were transported to the laboratory in ice chest containers for subsequent preparation and analysis. In the laboratory, the samples were processed following the method described by Udiba *et al*., (2020). The periwinkle was washed thoroughly to remove the mud from its hard shell. It was boiled and the soft tissue was removed from the shell with a stainless needle. The mud sediment was allowed to dry at room temperature. An equal weight of 1.0g of both the dried mud sediment and the processed periwinkle was weighed using an electronic weighing balance (CS 200, Ohaus Corporation, USA).

The weighed sample was each placed in a beaker and 30ml aqua rega solution (20ml HNO_3 and 10ml HCL) was added. The product was gently boiled for 30 to 45 min to ensure complete dissolution and allowed to cool. After cooling, the solution was filtered through Whatman filter paper and poured into a volumetric flask, and distilled water was added to make up to 50 ml. The digest was kept in a labeled plastic bottle with a lid and was used for metal analysis. The samples were analyzed using a Buck 211VGP Atomic Absorption Spectrophotometer.

Human health risk assessment

The United States EPA recommended that the health risk assessment model (US-EPA, 2017) be adopted for the estimation of toxicity indicators. Estimated Daily Intake (EDI) was calculated by dividing the product of the mean metal concentration of the metal and the fish ingestion rate of an average Nigerian (0.02kg or 20g) by the average body weight of an adult (60.7kg) (Udiba et al., 2020). Target Hazard Quotient (THQ) was computed for metals that can cause non-carcinogenic health risk by finding the ratio of the EDI for the metal at the mean concentration by the Oral Reference Dose (RFD) value of the metal. Hazar Index (HI) was the summation of the respective THQ of all the metals. Incremental Lifetime Cancer Risk (ILCR) was computed for carcinogenic heavy metals with known Cancer Slope Factor (CSF) values. ILCR was determined by using the product of the EDI and the CSF for Pb and Cd.

Analytical quality assurance

To evaluate the accuracy and precision of the analytical procedure employed, standard reference material, lichen coded (International Atomic Energy Agency IAEA-A-336) was analyzed in like manner to the samples. Results of the analysis of standard reference material show that the analyzed values of the metal were close to the certified reference values (Table 1), suggesting the reliability of the method.

Bio-sediment accumulation factor

The bio-sediment accumulation factor is the ratio of the mean concentration in biota (periwinkle) to the mean concentration in sediment. It is used to describe the rate of metal uptake of periwinkle from the mud, from which they are harvested (Obirikorang, 2010).

Statistical analysis

An independent Student T-test was done using a graph pad prism to detect significant differences in the concentration of heavy metals in both the soft tissues of periwinkle and the mud sediment. The mean and SD for each metal were computed using Microsoft Excel. Results were presented as mean ± SD and values at $p \leqslant 0.05$ were considered significant.

RESULTS

Table 1. Results of the Analysis of Reference Material (Lichen International Atomic Energy Agency Code, IAEA-336) Compared to the Certified Reference value (Mg/Kg).

Element (mg/kg)	Pb	Cd	Cu	Mn	Zn
A Value	5.25	0.14	4.00	55.78	29.18
R Value	4.2 - 5.5	0.1 - 2.34	3.1 - 4.1	56 - 70	33.8 - 37

A Value = Analyzed value
R Value = Reference value

Table 2. The Mean Concentration of Heavy Metals in the Periwinkle and Mud from the Great Kwa River

	Wet season		Dry season	
	Periwinkle	Mud sediment	Periwinkle	Mud sediment
Metal (mg/kg)				
Co	0.440±0.221[a]	0.550±0.348*	0.075±0.014	0.061±0.013
Fe	2.124±0.304[a]	2.113±0.345*	00.682±0.091	0.602±0.144
Cu	0.432±0.068[a]	0.312±0.182*	0.082±0.003	0.155±0.176
Cd	0.042±0.022	0.034±0.013	0.185±0.078[a]	0.126±0.055*
Pb	0.140±0.043	0.295±0.058*	0.144±0.068	0.114±0.046

Values are in mg/kg or ppm, and are presented as Mean ± SD
*= Significant increase in mud sediment across the seasons
a= significant increase in periwinkle across the seasons

The heavy metal concentration in the mud sediment and the soft tissues of periwinkle is presented in Table 2. The cobalt level was 0.550±0.348 mg/kg in the wet season and was significantly higher ($p<0.05$) than the 0.061±0.013 mg/kg recorded in the dry season. The iron (Fe) level in the mud sediment in the wet season was 2.113±0.345 mg/kg and was significantly higher at $p<0.05$ than the level in the dry season which was 0.602±0.144 mg/kg Copper level of 0.312±0.182 mg/kg in the wet season was also significantly higher than the dry season level of 0.155±0.176 (figure 2). Cadmium (Cd) level in the mud was 0.034±0.013mg/kg in the wet season and significantly decreased ($p<0.05$) compared to the dry season, 0.126±0.055 mg/kg The lead (Pb) level in the wet season was 0.295±0.058 mg/kg and was significantly higher ($p<0.05$) than the 0.114±0.046 mg/kg level in the dry season.

The heavy metals concentration in the soft tissues of periwinkle from the Great Kwa River is presented in Table 2, and Figure 3. The cobalt level in the wet season was

0.440±0.211 mg/kg and significantly higher at $p<0.05$ than the 0.075±0.014 mg/kg dry season level. The iron and copper levels in periwinkle are also presented in Figure 3. Iron level in the wet season was 2.134±0.304 mg/kg and was significantly higher ($p<0.05$) than dry season 0.682±0.091 mg/kg. Copper level in the wet season was 0.432±0.068 mg/kg and was significantly higher at $p<0.05$ compared to dry season 0.08±0.003 mg/kg. The level of Cadmium in the wet season was 0.042±0.022 and was significantly lower ($p<0.05$) than the dry season 0.185±0.078. Lead level in the soft tissues of periwinkle was 0.140±0.068 mg/kg in the dry season and 0.140±0.043 mg/kg in the wet season.

The comparative lead and Cadmium levels are presented in Figure 4. The lead level in mud was 0.295±0.058 mg/kg while the level in periwinkle was 0.140±0.043 mg/kg for the wet season. Mud concentration in the dry season was 0.114±0.046 mg/kg, and 0.144±0.068 mg/kg for periwinkle. A significant difference at $p<0.05$ was observed in mud and periwinkle values in the wet season. However, no significant difference at $p<0.05$ was seen for lead values in mud and periwinkle in the dry season.

Cadmium levels in mud and periwinkle for dry and wet seasons had no significant difference ($p<0.05$). the level in mud was 0.034±0.013 mg/kg and that of periwinkle was 0.042±0.022 mg/kg for the wet season. Cadmium level in the dry season for mud was 0.126±0.055 mg/kg, and 0.185±0.078 mg/kg for periwinkle.

The cobalt level for periwinkle was 0.440±0.211 mg/kg, and 0.550±0.348 mg/kg for mud in the wet season. No significant difference was seen at $p<0.05$. The cobalt level in periwinkle in the dry season was 0.075±0.014 mg/kg, while that of mud was 0.061±0.013 mg/kg. There was no significant difference at $p<0.05$. The Iron and Copper levels are presented in Figure 5. Iron level in mud was 2.113±0.345 mg/kg against 2.134±0.304 mg/kg level in periwinkle for dry season with no significant difference ($p<0.05$). Copper level in the wet season for mud was 0.312±0.182 mg/kg against periwinkle 0.432±0.008 mg/kg. The copper level in mud in the dry season was 0.155±0.176 mg/kg, while that of periwinkle was 0.082±0.003 mg/kg. the iron level in periwinkle in the dry season was 0.682±0.091 mg/kg, while that in mud was 0.602±0.144 mg/kg. There was no significant difference in the concentration of the metals in mud compared to that of the periwinkle.

Bioaccumulation/ Rate of uptake of Heavy Metals from the Mud Sediment to the Soft Tissues of the Periwinkle

Table 3. Shows the mean Concentration of Heavy Metals in Periwinkle Compared to the Standard Permissible Range/Limits

Metal (mg/kg)	Periwinkle (dry season)	Periwinkle (wet season)	WHO/FAO	JECFA PMTDI
Cobalt	0.075	0.440	-	0.005-1.8
Iron	0.682	2.134	263	0.8
Copper	0.082	0.432	30.0	0.05-1.8
Cadmium	0.185	0.042	0.06	-
Lead	0.144	0.140	0.03-0.24	-

WHO/FAO= permissible limit in seafood (2009), JECFA= Joint Food and Agricultural Organization/WHO Expert Committee on Food Additives PMTDI (2000)

Table 4. Shows the Bio–sediment Accumulation Factor for Heavy Metals from the Great Kwa River

Heavy metal	BSAF (dry season)	BSAF (wet season)
Cobalt	1.23	0.80
Iron	1.13	1.00
Copper	0.53	1.38*
Cadmium	1.47*	1.24
Lead	1.26	0.47

*Highest rate of uptake by the periwinkle

Human health risk assessment

Estimated daily intake: The estimated daily intake is presented Table 5. In the dry season, the estimated daily intake (EDI) for iron was 0.007, cobalt was 0.0088, cadmium was 0.000061, copper was 0.0014, and lead was 0.000047. Also, in the wet season, the recorded EDI for iron was 0.00023, cobalt was 0.00002, cadmium was 0.000014, copper was 0.000027, and lead was 0.000046

Table 5. Estimated Daily Intake of Metals in the Soft Edible Tissue of Periwinkle Harvested from the Great Kwa River Calabar, Cross River State

	Dry season		Wet season			
Metal	Mean conc.	EDI	Mean conc.	EDI	UL	RDI
Fe	2.134	0.0007	0.682	0.00023	-	-
Co	0.440	0.0088	0.075	0.00002	-	-
Cd	0.185	0.000061	0.042	0.000014	0.064	0.00
Cu	0.432	0.0014	0.082	0.000027	-	-
Pb	0.144	0.000047	0.140	0.000046	0.24	0.00

EDI = Estimated daily intake
UL = upper tolerable daily intake
RDI = Recommended daily intake
Values are expressed as mg/kg body weight/day

Target hazard quotient: The target hazard quotient is presented in Table 6. In the dry season, the target hazard quotient (THQ) for lead was 0.012, cadmium was 0.0609, iron was 0.0136, and copper was 0.0068. Also, in the wet season, the THQ for lead was 0.0115, cadmium was 0.01384, iron was 0.0010, and copper was 0.0356.

Table 6. Target Hazard Quotient of Metals in the Soft Edible Tissues of Periwinkle Harvested from the Great Kwa River, Calabar, Cross River State

Metal	RFD	THQ (dry season)	THQ (wet season)
Lead (Pb)	0.004	0.012	0.0115
Cadmium (Cd)	0.001	0.0609	0.01384
Iron (Fe)	0.7	0.0136	0.0010
Copper (Cu)	0.04	0.0068	0.0356
Cobalt (Co)	N/A	-	-
		HI = 0.0933	HI = 0.0619

RFD=oral reference dose for the metal in mg/kg/day
(USEPA Regional Studies, 2017). THQ values (mg/kg wet weight/day)

Relative contribution to aggregated risk

The relative contribution to the aggregated risk was 12.9% for Pb, 65% for Cadmium, 14.6% for Fe and 7.2% for copper in the dry season, and 18.9%, 22.2%, 1.61%, and 57.4% for Pb, Cd, Fe, and Cu respectively in the wet season.

Incremental lifetime cancer risk (ILCR)

The ILCR value of Pb was 3.9×10^{-7} and that of Cd was 8.4×10^{-5}

DISCUSSION

The exposure routes of toxic heavy metals to humans are numerous, but the daily consumption of food from the river habitat polluted with a wide range of toxicological and hazardous metals has increased by the day and it is a subject of global concern. Urbanization, unregulated solid waste disposal, oil exploration, and a host of natural and anthropogenic causes pose pollution problems, especially in the Niger Delta region of Nigeria (Chinedu and Chukwuemeka, 2018). It has been assessed that the continuous pollution of the water bodies poses a threat to both seafood and consumers, due to bioaccumulation and biomagnification along the food chain. This study assessed the extent of pollution of the Great Kwa River and predicted the possible health effects that can occur over prolonged exposure to heavy metals such as Fe, Cu, Pb, Cd, and Co. Heavy metals like Pb and Cd are very toxic and have no recognized biological function. However, Co, Fe, and Cu are trace elements, yet very toxic when concentration exceeds the upper tolerable limits.

The mean concentration of Cadmium in periwinkle was higher in the dry season compared to the wet season. The dry season value was higher than reported by Nwakwo and Nlemanya (2018), for Cawtbone channel, Okrika, and Udiba *et al*. (2020), for Cawtbone channel, Okrika, and Bodo, as well as (Udiba *et al*., 2020), for periwinkle sold in major markets in Calabar Municipality, (Babula *et al*., 2008), for periwinkle along Forcados river in Delta state. Also, Cadmium in periwinkle in the dry season exceeded the WHO/FAO permissible limit in seafood, a potential threat to average and chronic consumers. Cd toxicity is seen by its ability to interact with essential nutrient metabolism such as iron in hemoglobin. It has been seen to affect both liver and kidney functions in long-term exposure (Oguguah *et al*., 2017). The significant difference in concentration observed may be attributed to dilution due to the high volume of water in the wet season. The mean concentrations of Co, Fe, and Cu were higher in the wet season than in the dry season. Generally, river water pollution is higher in the wet season than in the dry season. The wet season is characterized by a flood of solid waste and industrial chemicals washed into the water body. This makes the water turbid. The Pb level for dry and wet seasons exceeded the WHO permissible limit for seafood. According to (WHO, 2011), Fe rarely contaminates seafood but the study reveals the concentration of iron in periwinkle is higher than the PMTDI for humans. Co and Cu were within the PMTDI. The mean Cd concentration in this study agrees with the report of Udiba *et al*., (2020). However, the baseline study by Udiba *et al*., (2020) concluded that there was no safe level of concentration for lead as it persists and causes toxicity.

The uptake of heavy metal from the mud and bioaccumulation in the soft tissues of periwinkle from the Great Kwa River increases the chance of human health risk to an average Nigerian in the catchment area, with a moderate consumption rate. The degree of uptake is seen in the bio-sediment accumulation factor of each of the metals (Table 3). From the findings, it was observed that the availability of the heavy metals in the mud sediment of the river indicated its pollution, and periwinkle bioaccumulated these metals effectively in the soft tissues in descending order of Cd>Pb>Co>Fe>Cu. The use of the accumulation factor provides information on the actual pollution load aids in the estimation of the metals' biotransfer to the seafood from the sediment, and indicates significant bioaccumulation. From the results, Cd was taken up at a higher rate, even though its concentration in the mud was lower than Fe for the dry season. However, uptake may be affected by seasons, salinity of the environment, organic matter in the mud sediment, and location of the mud (Ansari *et al*., 2004), as the wet season data revealed. Metal enrichment in the soft tissues of the periwinkle for the wet season was in the order of Cu>Cd>Fe>Co>Pb. This suggests an explanation that water acts as an additional source of contamination to the sediment.

Consumption of seafood from contaminated water can pose a range of human health risks, which are grouped into two classes: carcinogenic and non-carcinogenic effects. The estimation is based on calculation and assumptions that cooking does not have any effect on the concentration of the metal absorbed and bioavailability in the body. Some heavy metals have no biological function and are toxic at low concentrations. Some of them have no recommended daily allowance to prove their menace in toxicity. Others have known biochemical functions but above their recommended or upper tolerable limits will bring about human health diseases on exposure. Human health risk therefore is imperative to establish the possibility of this metal causing any health effect be it cancer or human diseases apart from cancer and metastasis (Christian *et al*., 2020).

The indicators of toxicity for non-carcinogenic health effects are the computation of the estimated daily intake (EDI). The EDI of all the metals was low (<1). This indicates a safe consumption rate in comparison to the recommended daily intake (RDI) and the upper tolerable limit of the metal in seafood as established by (FAO/WHO, 2011).

The next indicator of toxicity is the Target Hazard Quotient (THQ). THQ is estimated to show the effects of a single metal on the food consumed and the possible human risk expected. For the study, THQ of individual heavy metals through periwinkle consumption by average adult followed a descending order Cd> Fe>Pb>Cu in both seasons since Co has no oral reference dose. THQ <1 is considered safe for consumption without expecting potential risk from consumption. The exposed population is unlikely to experience any adverse health implications. Conversely, THQ>1 or 1 indicates a potential health risk and will require related intervention and protective measures taken. In this study, the THQ of all the metals was less than 1 in both seasons, (Table 5).

The exposure to one toxicant is expressed by THQ but during the consumption of periwinkle, all metals are consumed at once leading to additive and interactive effects (Barrie *et al*., 2018). The toxicity of more than one element is indicated by the Total THQ or Hazard Index (HI).

A high consumption of copper has been linked to Alzheimer's disease, together with zinc and lead. Iron, in close interaction with zinc, has been implicated in Parkinson’s disease (Soghra *et al*., 2018). From a nutritional point of view, THQ and TTHQ <1 indicate food quality and nutritional benefits. Above the unity, value presupposes potential threat in consumption and probability of an adverse effect (Odey *et al*., 2024; Ahmed *et al*., 2016). The hazard index of the metals was less than 1 for both seasons suggesting minimal or no potential health risk.

The relative contribution of each of these metals to the potential of developing non-carcinogenic health risks as a result of exposure was only high for Cadmium and copper, supporting the increased pollution of the river through anthropogenic sources such as flooding during heavy downpours, and washing of industrial chemicals and effluents into the water body.

The possibility of developing any type of cancer is indicated by calculating the Incremental Lifetime Cancer Risks (ILCR). This represents an incremental probability of an individual developing cancer over a lifetime due to exposure. The duration of time used was the average life expectancy of a Nigerian, 55 years, which was applied in the study to compute the EDI and the average body weight of an adult, 60.7kg (UN-WPP, 2022; Oguguah *et al*., 2017). The product of the EDI and the CSF of the metal resulted in the ILCR value (Udiba *et al*., 2020). The ILCR value for Cd was within the tolerable and acceptable range of 10^{-6} to 10^{-4}. The ILCR value of Pb was lower than the standard tolerable range value of 10^{-6}.Values less than this are considered negligible. This suggests that consumers are not at risk of developing cancer due to the consumption of periwinkle, for Pb poisoning. This finding is consistent with the findings of Udiba *et al*. (2020), where Pb ILCR values were negligible for periwinkle sold in the Watt market and Marian market. The negligibility of the value of lead does not negate the possible risk of cancer. Therefore, continuous biomonitoring of the river is essential since lead can be very persistent in the environment.

CONCLUSION

Periwinkle is an inexpensive yet rich source of protein and micro-nutrients that are consumed in large quantities in Calabar, Cross River State, and other parts of the Niger Delta Region of Nigeria. yet, contamination with heavy metals can pose toxicological risks to man. The study investigated the bioaccumulation and potential health risks of selected heavy metals (Cd, Fe, Cu, Co, and Pb) in periwinkle from the Great Kwa River in Nigeria. The results showed that consumption of periwinkle in the dry season may predispose Cadmium toxicity, while in the wet season, it may predispose Copper toxicity. Though these may not cause immediate adverse human health risks for the studied metals, consumption should be limited, to prevent possible bioaccumulation and toxicity. Regular biomonitoring, controlled anthropogenic activities and enforcement of environmental and safety management laws.

DATA AVAILABILITY

Data will be made available on request

AUTHORS’ CONTRIBUTIONS

Conceptualization, MOO and SOE; methodology, MOO, IAI and EOE; validation, MOO, EOM and EAA; formal analysis, CIU and PBE; investigation, MOO, SOE and EOO; resources, MOO and SOE; data curation, EOO, EOE and BO; writing—original draft preparation, SOE, CUI and PBE; writing—review and editing, MOO, IAI and EAA; supervision, MOO and EOM; project administration, SOE and EAA. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest

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