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Assessment of some Heavy Metals and Health Risks in Water and Shrimps from a Polluted Mangrove Swamp, Niger Delta, Nigeria

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ABSTRACT

The heavy metal concentrations of water and shrimp (*Penaeus monodon*) from Isaka Bundu swamp, Niger Delta were evaluated between January and June 2022. The non-carcinogenic health risk assessment was used to assess the water's suitability for recreation and the shrimps for consumption. Five heavy metals (Pb, Cu, Cd, Ni, and Zn) were assessed in both media using standard methods and compared with national and international standards. The Chronic daily intake (CDI) for Cd and Cu (in children) exceeded their respective reference doses while hazard quotients (HQs) for Cd and Cu (in children) and all the hazard indices were greater than 1 in the water. All the target hazard quotients (THQs) and total hazard index (THIs) were lower than 1 in the shrimps. The heavy metal concentrations, CDIs, HQ/THQs and HI/THIs were higher in the more impacted stations 1 and 3. Based on the heavy metal concentrations and health risk assessment, the waters of the Isaka Bundu swamp are unsafe for recreational purposes. However, shrimps are safe for human consumption. The high concentrations of heavy metals in the water influenced the concentrations in the shrimps. Anthropogenic activities in the area contributed to the heavy metal concentrations in the environment. The results also showed that the children were more prone to adverse health impacts.

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INTRODUCTION

Estuaries are the resultant water bodies where the freshwater bodies discharge into the ocean. They have been described as a receptacle of contaminants arising from both inland and coastal human activities (Tjahjono et al., 2018). These contaminants, including heavy metals, tend to pollute the water and accumulate in biota and sediments (Iwuoha & Onojake, 2016; Ebong & John, 2021). Heavy metal pollution is one of the major environmental problems globally (Zhu et al., 2020; Anyanwu et al., 2022a, b). It is becoming more severe and alarming. Recent studies in Nigeria have reported the accumulation of heavy metals in the blood of inhabitants using the Aba River, Aba, Abia State (Ali et al., 2022) and breast milk of postpartum mothers in Yenagoa, Bayelsa State (Philip-Slaboh et al., 2023). Accumulation of heavy metals in seafood especially shrimps has been variously reported in different regions of the world (El-Moselhy et al., 2014; Zhang et al., 2020; Mokarram et al., 2020; Markmanuel et al., 2022).

Shrimp (*Penaeus monodon*), family Penaeidae is a rich source of minerals, vitamins, antioxidants, essential amino acids, and unsaturated fatty acids (Omogbai et al., 2019; Davies et al., 2022a). The giant tiger prawn (*Penaeus monodon*) is an economically important species

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in the Niger Delta and most parts of the world (Komi & Francis, 2017; Eludoyin et al., 2018). The nutritional value of seafood products in the human diet has been receiving considerable attention in recent times (Pangestuti & Kim, 2011; Atef et al., 2017). Shrimp is one of the most beneficial shellfish foods for humans, and it has caused aquatic faunal communities to be the most unvoiced victims (Yap et al., 2019; Biswas et al., 2021).

In nature, heavy metals are toxic, persistent, and bioaccumulative, endangering human health and aquatic ecosystems (Zeng et al., 2020; Hembrom et al., 2020). Essential metals, such as iron, copper, zinc, and manganese, play an important role in biological systems, whereas non-essential metals, such as chromium, nickel, lead and cadmium are toxic even in trace amounts (Ali et al., 2019; Zoroddu et al., 2019; Okereafor et al., 2020; Davies and Efekemo, 2022; Davies et al., 2022a). However, essential metals can also be toxic at high concentrations (Davies & Ekperusi, 2021).

Heavy metals can migrate, undergo transformation, or form complexes in aquatic environments, resulting in adverse effects on human health and the environment (Sun et al., 2019; Nguyen et al., 2020; Bazzi et al., 2020). Humans are exposed to heavy metals via two major routes - direct ingestion (oral) and dermal absorption (Rahman et al., 2019; Mukherjee et al., 2020; Anyanwu and Chris, 2023).

Unlike the lower Bonny River and New Calabar River estuaries that have been studied extensively, the Isaka-Bundu mangrove swamp has received little or no attention. It is being severely polluted from industrial and agricultural activities and constitutes a major contributor to the pollution load in the lower Bonny River estuary. Therefore, this study aims to evaluate the heavy metals contents and the health risks of swimming in waters and consuming shrimps of the Isaka-Bundu swamp, Niger Delta, Nigeria.

MATERIAL AND METHOD

Study area and sampling stations

Isaka-Bundu mangrove swamp, located along the Upper reaches of Bonny River Estuary has been subjected to pollution pressures (Davies et al., 2022b). The swamp receives domestic and industrial waste input from companies (Nigerian Ports Authority, OandO Oil and Gas, Conoil, Ibeto cement factory, dredging companies, etc.), adjoining creeks, and the densely populated coastal settlements on the banks. It is characterized by the wet season (May to October) and dry season (November to April).

Three sampling stations, about 500 meters apart were selected based on anthropogenic activities (Figure 1).

Station 1: Isaka (Latitude 04°45’03.05” N, Longitude 007°00’ 45.51” E), located near a heap of sediment, was a dump site marred with oil sheen, and the tidal currents dump off litter and other particulate contaminants. An abandoned bunkering site was also within the station.

Station 2: Bundu-Ama (Latitude 04˚44’ 55.35” N, Longitude 007˚00’ 38.40” E) was near the densely populated settlement lining the tidal-swept mangrove swamp. The station witnessed a massive discharge of human, animal, and domestic wastes and runoff that was visible on the shorelines.

Station 3: Dockyard (Latitude 04˚45’ 03.58” N, Longitude 007˚00’57.75” E) and close to the popular Creek Road market. Maintenance fluid and other associated liquid and solid wastes are discharged from the Dockyard while sewage, refuse and other large quantities of commercial wastes from the market are dumped around the station.

Samples collection and analyses

Water samples were collected monthly from the stations between January and June 2022. Water samples for heavy metal analysis were collected from below the water surface (20 cm) near shore in new, clean well-labelled screw-capped bottles and acidified. The determination

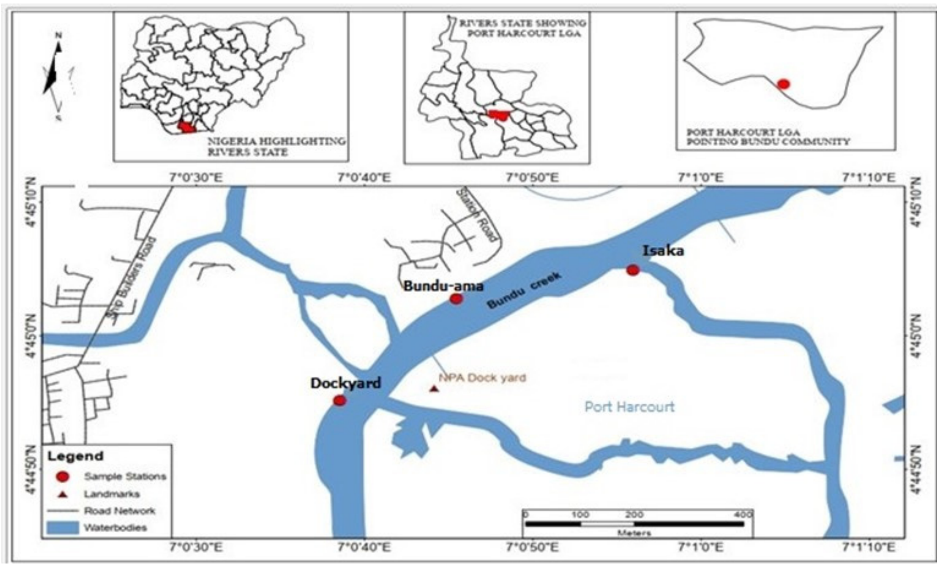

Fig. 1. Map of Port Harcourt, Rivers State, Nigeria showing the study area

Plate 1. Shrimp (*Penaeus monodon*) samples

of heavy metal (Pb, Cu, Cd, Ni, and Zn**)** concentrations in the water was carried out with UNICAM Solaar 969 atomic absorption spectrometer (AAS) that uses acetylene-air flame.

Freshly caught live shrimp samples were collected from the catch of local fisher folks in the three sampling stations and identified as *Penaeus monodon* using Powell (1983). A total of sixty representative shrimp samples (mean length: 6.03±0.62cm; mean weight: 8.22±0.18g) from each station were used for the study (Plate 1).

The dissected dried tissues (about 0.5g each) were weighed and digested in concentrated nitric acid (AnalaR grade, BDH 69%). The sample was digested by heating the nitric acid-treated samples at 40°C for 1 hour and then raised to 140°C for at least 3 hours to achieve full digestion. After digestion, the samples were topped up with DDW to 40 ml before filtering them with Whatman No.1 (filter speed: medium) filter papers into acid-washed plastic containers. The digested samples were also analysed for Pb, Cu, Cd, Ni, and Zn concentrations with UNICAM Solaar 969 atomic absorption spectrometer (AAS).

Quality Control and Assurance

All glassware and equipment used were acid- washed and procedural blanks were analyzed once for every five samples during analysis to ensure consistency in data collection. Standard solutions for all five metals were prepared and analyzed occasionally during the analysis for heavy metal recoveries. The heavy metal recoveries were satisfactory with recoveries between 90-110%. The quality of the analytical procedures used for the shrimp samples was verified by using CRM for Dogfish Liver (DOLT-3, National Research Council Canada). The recoveries for the CRMs were satisfactory between 80-120%

Statistical Analysis

The data were summarized with Microsoft Excel while one-way ANOVA was used to test for significant differences in the concentrations of the metals in water and shrimps among the stations. The source of significant difference at $p<0.05$ was determined with Tukey pairwise posthoc test. Pearson correlation coefficient was used to test for a significant ($p<0.05$) association between the concentrations of the heavy metals in the water and shrimps.

Health Risk Assessment

The heavy metal content of the water and shrimps exceeded their respective regulatory limits hence the need for health risk assessment. Health risk assessment was carried out for water (dermal) since the inhabitants of area only swim in the water due to its highly saline nature and ingestion for the shrimps.

Health Risk Assessment for water (Dermal)

Chronic Daily Intake (CDI)

The chronic daily intake (CDI) of heavy metals in Isaka-Bundu mangrove swamp water was calculated for dermal exposure using formula 1 (Moldovan et al., 2020):

$$CDI = \frac{CwxSAxK_p xETxEFxEDxCF}{BWxAT} \tag{1}$$

Where,

CDI is the daily dose of heavy metals in mg/L, the users are susceptible to through dermal exposure; Cw is the heavy metal concentration (mg/l); SA is the skin surface area – 18000 cm^2 (adult) and 6600 cm^2 (children); Kp is the permeability coefficient – Pb (0.0001cm/h), Ni (0.0002 cm/h), Cd, Cu (0.001 cm/h) and Zn (0.0006 cm/h); ET is the exposure time – 0.58 H/event (adult) and 1 H/event (children); EF is the exposure frequency (350 days/year); ED is the exposure duration – 70 years (adult) and 6 years (children); CF is the conversion factor (0.001 l/cm^3); BW is the average body weight of the consumers - 70kg (adult) and 15kg (children) and AT (ED x EF) is the average time of the exposure – 24500 days (adult) and 2100 days (children) (USEPA, 2001, 2004).

Hazard Quotient

The hazard quotient (HQ) is the ratio used in risk characterization and also to evaluate the level of the significant impact of a particular risk (Sharif *et al*., 2016). The Hazard Quotient (HQ) for non-carcinogenic risk for dermal route determined by equation 2 from USEPA (1999):

$$HQ = \frac{CDI}{RfD} \tag{2}$$

Where,

CDI in mg/kg/day is the daily dose of heavy metals to which a consumer might be exposed;

RfD represents the dermal reference dose (mg/kg/day) of each of the metals under consideration. It is the daily dosage that enables the individual to sustain this level of exposure over a long period of time without having any deleterious effects. If, HQ > 1, it is an indication of adverse non-carcinogenic effects of concern while HQ < 1 indicate acceptable level.

Health Risk Assessment for Shrimps

Target hazard quotient (THQ) for each heavy metal was calculated in order to assess the potential health risk of consuming *Penaeus monodon* collected from the study area (Biswas *et al*., 2021). It was calculated using equation 3:

$$THQ = \frac{ED\,x\,IR\,x\,EF\,x\,CW}{RfD\,x\,BW\,x\,AT} x10^{-3} \quad (3)$$

Where ED is the Exposure duration – of70 years (adults) and 10 years (children); IR is the daily ingestion rate – 0.3 mg/kg/person/day (adults) and 0.15 mg/kg/person/day (children) (Markmanuel *et al*., 2022); EF is the exposure frequency (365 days/year); CW is the concentration of respective heavy metal (mg/kg) in the shrimps; RFD is the reference oral dose in mg/kg/day (0.001 for Cd, 0.004 for Pb, 0.3 for Zn, 0.02 for Ni and 0.04 for Cu); BW is body weight - 70 kg (adult) and 25 kg (children) and AT (ED x EF) is the average time of the exposure – 25550 days (adult) and 3650 days (children) (USEPA, 2001, 2004).

Hazard Index (HI)

Hazard index (HI) is the cumulative potential for non-carcinogenic effects from more than one heavy metals through dermal or ingestion (shrimps) pathways and can be estimated from equation 4 (Sharma, 2020).

$$HI = \sum_{i=1}^{n} HQ\,/\,THQ \quad (4)$$

Where, HI is the hazard index for the overall toxic risk and n equals the total number of metals under consideration. If HI for non-carcinogenic adverse effect due to dermal and ingestion (shrimps) exposures is lower than one (HI < 1.0), then no chronic risks are expected to occur but if HI is greater than one (HI > 1.0), possible chronic risk arising from the dermal and ingestion (shrimps) exposures could manifest (Moldovan et al., 2020).

RESULTS AND DISCUSSION

Heavy Metal content in water

The summary of the heavy metal concentrations in the water are presented in Table 1. Lead (Pb) values ranged between 3.16 and 9.21 mg/L. The lowest value was recorded in station 2 while the highest value was recorded in station 1. All the recorded values exceeded the acceptable limit (0.01 mg/L) set by NESREA (2011) and SON (2015) for aquatic life and drinking water respectively. The 3 stations were significantly different ($F = 192.20$, $p > 0.05$). Copper (Cu) values ranged between 57.03 and 99.72 mg/L. The lowest value was recorded in station 2 and the highest in station 1. All the recorded values exceeded the acceptable limits of 0.001 mg/l and 1mg/l set by NESREA (2011) and SON (2015) for aquatic life and drinking water respectively. Stations 1 and 3 were significantly ($F = 25.30$, $p < 0.05$) higher than station 2. Cadmium (Cd) values ranged between 5.16 and 9.07 mg/L. The lowest value was also recorded in station 2 while the highest value was also recorded in station 1. All the recorded values exceeded the acceptable limits of 0.005 mg/l and 0.003mg/l set by NESREA (2011) and SON (2015) for aquatic life and drinking water respectively. The 3 stations were significantly different ($F = 15.85$, $p < 0.05$). Nickel (Ni) values ranged between 1.12 and 1.98 mg/L. The lowest value was also recorded in station 2 while the highest value was also recorded in station 1. All the recorded values exceeded the acceptable limits of 0.01 mg/l and 0.02mg/l set by NESREA (2011) and SON (2015) for aquatic life and drinking water respectively. Station 3 was also significantly ($F = 4.52$, $p < 0.05$) higher than station 2. Zinc (Zn) values ranged between 19.21 and 29.32 mg/L. The lowest value was also recorded in station 2 while the highest value was also recorded in station 1. All the recorded values exceeded the acceptable limits of 0.01 mg/l and 3.0 mg/l set by NESREA (2011) and SON (2015) for aquatic life and drinking water respectively. The 3 stations were significantly different ($F = 41.32$, $p < 0.05$).

Table 1. Summary of heavy metal concentrations in water

Heavy Metals	Station 1	Station 2	Station 3	F- Value	SON 2015	NESREA 2011
Pb	8.73 ± 0.18^{a} (8.01 – 9.21)	3.77 ± 0.18^{c} (3.16 – 4.23)	5.75 ± 0.18^{b} (5.26 – 6.42)	192.20 $p < 0.05$	0.01	0.01
Cu	91.08 ± 2.52^{a} (84.61 – 99.72)	68.92 ± 3.70^{b} (57.03 – 76.52)	93.29 ± 1.22^{a} (89.59 – 96.54)	25.30 $p < 0.05$	1	0.001
Cd	7.60 ± 0.33^{a} (6.79 – 9.07)	5.51 ± 0.13^{c} (5.16 – 5.93)	6.69 ± 0.29^{b} (6.03 – 7.97)	15.85 $p < 0.05$	0.003	0.005
Ni	1.62 ± 0.11^{a} (1.28 – 1.98)	1.35 ± 0.06^{b} (1.12 – 1.52)	1.66 ± 0.06^{a} (1.54 – 1.94)	4.52 $p < 0.05$	0.02	0.01
Zn	27.13 ± 0.68^{a} (25.21 – 29.32)	20.20 ± 0.38^{c} (19.21 – 21.52)	24.14 ± 0.52^{b} (23.12 – 26.51)	41.32 $p < 0.05$	3	0.01

a, b, c = Means with different superscripts across the rows are significantly different at $p < 0.05$; SON = Standard Organisation of Nigeria; NESREA = Nigeria Environmental Standard and Regulatory Enforcement Agency

All the heavy metals evaluated highly exceeded the limits set by NESREA (2011) and SON (2015) for aquatic life and drinking water respectively which could be attributed to cumulative impacts. Human activities could produce effects that accumulate over time and space to the detriment of the environment (Emenike *et al*., 2020). Anaero-Nweke *et al*. (2018) recorded relatively lower values (<0.001 – 0.008 mg/l) in other parts of Upper Bonny Estuary, Niger Delta. Elsewhere in the Niger Delta, Udoinyang *et al*. (2022) recorded Pb values within the range recorded in this study, lower Cu, Cd and Zn values and higher Ni values in Iko River Estuary, Akwa Ibom State. Spatial analysis showed that stations 1 and 3 had significantly higher values throughout the study. This could be attributed to anthropogenic activities in the area. Illegal bunkering and artisanal refining activities in station 1 could be responsible (Nwankwoala et al. 2017; Bebeteidoh et al., 2020) while wastes from dockyard activities and market could be responsible for the higher values recorded in station 3. Environmental pollution from dockyard activities have been reported (Chukwu & Akinyanmi, 2018; Ashari et al., 2021) and different types of wastes generated from markets located by waterways are usually discharged into the waterways (Oketola & Fagbemigun, 2013).

Heavy Metal content in shrimps

The summary of the heavy metal concentrations in the shrimps (*Penaeus monodon*) are presented in Table 2. Lead (Pb) values ranged between 2.31 and 4.92 mg/kg. The lowest value was recorded in station 2 while the highest value was recorded in station 1. All the recorded values exceeded the limit (0.3 mg/kg) set by FAO/WHO (2021) for contaminants in foods. The 3 stations were significantly different ($F = 28.0$, $p < 0.05$). Copper (Cu) values ranged between 57.01 and 89.52 mg/kg. The lowest value was recorded in station 1 and the highest in station 3. All the recorded values exceeded the limit of 0.5 mg/kg set by FAO/WHO (2021) for contaminants in foods. Stations 1 and 2 were significantly ($F = 7.03$, $p < 0.05$) lower than station 3. Cadmium (Cd) values ranged between 3.38 and 4.73 mg/kg. The lowest value was recorded in station 2 while the

Table 2. Summary of heavy metal concentrations in shrimps (*Penaeus monodon)*

Heavy Metal	Station 1	Station 2	Station 3	F-Value	FAO/WHO 2021
Pb (mg/kg)	3.87±0.29[a] (3.22 - 4.92)	2.85±0.18[c] (2.31 - 3.29)	3.28±0.15[b] (2.70 - 3.61)	28.0 P<0.05	0.3
Cu (mg/kg)	65.87±2.79[b] (57.01 - 71.83)	65.23±0.63[b] (64.16 - 68.21)	74.49±3.11[a] (68.23 - 89.52)	7.03 P<0.05	0.5
Cd (mg/kg)	4.33±0.13[a] (4.01 - 4.73)	3.82±0.15[b] (3.38 - 4.20)	4.15±0.09[a] (3.89 - 4.39)	28.1 P<0.05	2.0
Ni (mg/kg)	1.37±0.11[a] (1.08 - 1.82)	1.18±0.06[b] (1.01 - 1.42)	1.34±0.10[a] (1.12 - 1.79)	10.7 P<0.05	-
Zn (mg/kg)	20.00±0.52[a] (18.12 - 21.43)	18.24±0.49[b] (16.96 -19.81)	19.42±0.33[a] (18.39 - 20.45)	24.9 P<0.05	1.0

a, b, c = Means with different superscripts across the rows are significantly different at p < 0.05; FAO = Food and Agriculture Organisation; WHO = World Health Organisation.

highest value was recorded in station 1. All the recorded values exceeded the limit of 0.025 mg/kg set by FAO/WHO (2021) for contaminants in foods. Stations 1 and 3 were significantly higher ($F = 28.1$, $p < 0.05$) than station 2. Nickel (Ni) values ranged between 1.01 and 1.82 mg/kg. The lowest value was recorded in station 2 while the highest value was also recorded in station 1. FAO/WHO (2021) has no limit for nickel. Stations 1 and 3 were significantly ($F = 10.7$, $p < 0.05$) higher than station 2. Zinc (Zn) values ranged between 16.96 and 21.43 mg/kg. The lowest value was also recorded in station 2 while the highest value was also recorded in station 1. All the recorded values exceeded the acceptable limit of 1.0 mg/kg set by FAO/WHO (2021), Stations 1 and 3 were significantly ($F = 24.9$, $p < 0.05$) higher than station 2.

All the heavy metals values recorded in the shrimps (*Penaeus monodon*) exceeded the values set by FAO/WHO (2021) for contaminants in foods. However, FAO/WHO (2021) has no limit for nickel. The values were higher than values of Cd and Cu but lower than Pb, Ni and Zn recorded in shrimps in Benin River, Niger Delta (Ezemonye et al., 2019). However, related studies in the Niger Delta recorded lower values in some of the heavy metals evaluated (Solomon et al., 2020; Opuogulaya et al., 2022). Spatially, all the metals were significantly higher in station 1 except Cu that recorded the highest value in station 2. As observed in the water, station 2 recorded the lowest values in all the metals. This is an indication of effect of human activities in the stations. Accumulation of heavy metals in crustaceans including shrimps have been extensively reported in related studies (Yasin et al., 2020; Pandiyan et al., 2021; Yousif et al., 2021; Markmanuel et al., 2022). The relationship between the concentrations of heavy metals in the water and biota was confirmed by the moderate to high correlation co-efficients recorded. Three metals (copper, nickel and zinc) had positive correlations with the shrimps (station 1), four metals (lead, cadmium, nickel and zinc) in station 3 and only two in station 2. The correlations were moving in the same direction; showing that the concentrations in the water influenced the concentrations in the shrimp (Schober et al., 2018). Ali et al. (2022) recorded similar correlations between heavy metal concentrations in water and blood in Aba River stations where heavy metal concentrations were higher.

Correlation coefficient ($r_{8, 005} = 0.632$) showed that some metals in the water had moderate to strong positive correlations with their respective metals in the shrimps. Copper, nickel and zinc had correlation values of 0.696, 0.652 and 0.944 respectively with the shrimps in station 1 while in station 2, lead and cadmium had values of 0.774 and 0.702 respectively with the shrimps. On the other hand, lead, cadmium, nickel and zinc had values of 0.790, 0.740, 0.739 and 0.826 respectively with the shrimps in station 3.

Health Risk Assessment

Water for dermal exposure

Chronic Daily Intake (CDI)

The Chronic daily intake (CDI) of the heavy metals for dermal route exposure and their respective reference doses are presented in Table 3. The health risk assessment showed varying CDI values among the metals. The CDI values for Pb, Ni and Zn were lower than their respective reference doses while all the CDI values for Cd and Cu (except 1) exceeded their reference doses. The Cu CDI for adults in station 2 did not exceed the reference dose. The CDI values lower than their respective reference doses do not pose any health risks to people swimming in the swamp. Generally, higher CDI values were recorded for all the metals in all the stations among the children. On the other hand, higher CDI values recorded in stations 1 or 3 or both could be attributed to anthropogenic activities there.

These CDI values indicate a potential health risk from these metals to people swimming in the swamp. Huang et al. (2014) reported that an exposed individual will experience adverse health effect from that pollutant level, whenever the CDI value of the particular pollutant exceed the reference dose of the pollutant through any exposure route.

Table 3. The Chronic Daily Intakes and Reference Doses of the Heavy Metals (mg/kg/day)

Metals	**Station 1**		**Station 2**		**Station 3**		**Dermal**
	Adult	**Children**	**Adult**	**Children**	**Adult**	**Children**	**RfD***
Pb	1.30E-04	2.30E-04	5.60E-05	9.90E-05	8.60E-05	1.50E-04	5.25E-04
Ni	4.80E-05	9.00E-05	4.00E-05	7.10E-05	5.00E-05	8.80E-05	5.40E-03
Cd	1.10E-03	2.00E-03	8.20E-04	1.50E-03	1.00E-03	1.80E-03	1.00E-05
Cu	1.40E-02	2.40E-02	1.00E-02	1.80E-02	1.40E-02	2.50E-02	1.20E-02
Zn	2.40E-03	4.30E-03	1.80E-03	3.20E-03	2.20E-03	3.80E-03	6.00E-02

*USEPA = United States Environmental Protection Agency (2004); RfD = Reference Dose

Hazard Quotients (HQs)

The hazard quotients (HQs) are presented in Table 4. The HQ values for Pb, Ni and Zn were also lower than the threshold value (1) while all the Cd and Cu HQ values were higher than the threshold value (1). However, Cu recorded one HQ value that did not exceed 1 in station 2 (adult). The HQ values lower than the threshold value do not pose any health risks to people swimming in the swamp. Generally, HQ values followed the trend of CDI; higher values were recorded for all the metals in all the stations among the children.

The exposed individuals are more susceptible when HQs are high (Sharma, 2020). Higher HQ values recorded in stations 1 or 3 or both could also be attributed to anthropogenic activities. Generally, higher values of CDI and HQ were recorded among the children. The uptake of contaminants is usually higher among children due to their higher age-dependent dose coefficients and metabolism (WHO, 2017). The vulnerability of children to heavy metal contamination has been extensively reported (Zhang et al., 2021; Anyanwu et al., 2022a; Odo et al., 2022; Jonah et al., 2023).

Table 4. Hazard Quotients (Dermal) and Total Hazard Index of the Heavy Metals

Metals	**Station 1**		**Station 2**		**Station 3**	
	Adult	**Children**	**Adult**	**Children**	**Adult**	**Children**
Pb	2.48E-01	4.38E-01	1.07E-01	1.90E-01	1.60E-01	2.86E-01
Ni	8.90E-03	1.70E-02	7.40E-03	1.30E-02	9.30E-03	1.60E-02
Cd	1.10E+02	2.00E+02	8.20E+01	1.50E+02	1.00E+02	1.80E+02
Cu	1.17E+00	2.00E+00	8.30E-01	1.50E+00	1.17E+00	2.08E+00
Zn	4.00E-02	7.20E-02	3.00E-02	5.30E-02	3.60E-02	6.30E-02
HI	**1.11E+02**	**2.03E+02**	**8.30E+01**	**1.52E+02**	**1.01E+02**	**1.82E+02**

Table 5. Target Hazard Quotients (Shrimps) and Total Hazard Index of the Heavy Metals

Metal	Station 1		Station 2		Station 3	
	Adult	Children	Adult	Children	Adult	Children
Pb	4.00E-03	6.00E-03	3.00E-03	4.00E-03	4.00E-03	5.00E-03
Ni	3.00E-04	4.00E-04	3.00E-04	4.00E-04	3.00E-04	4.00E-04
Cd	2.00E-02	3.00E-02	2.00E-02	2.00E-02	2.00E-02	3.00E-02
Cu	7.00E-03	1.00E-02	7.00E-03	1.00E-02	8.00E-03	1.00E-02
Zn	3.00E-04	4.00E-04	3.00E-04	4.00E-04	3.00E-04	4.00E-04
THI(∑THQ)	**3.16E-02**	**4.68E-02**	**3.06E-02**	**3.48E-02**	**3.26E-02**	**4.58E-02**

Hazard Index

The hazard indices (HI) recorded are also presented in Table 4. All the values recorded in the 3 stations for both adults and children were greater than the threshold value (1). The children recorded higher values, especially in station 1.

HI greater than 1 indicates that the level of contamination could result in adverse human health effects (Yi et al., 2011; Tripathee et al., 2016). In line with CDI and HQ, higher values were also recorded among the children, especially in station 1. Higher HI values were also recorded in stations 1 and 3; attributable to higher metal concentrations from anthropogenic impacts. Anyanwu et al (2022) recorded HI dermal values greater than 1 in two stations with higher heavy metal contamination.

Target Hazard Quotients and Total Hazard Index (Shrimps)

The target hazard quotients (THQs) and total hazard index (THIs) for the consumption of shrimp are presented in Table 5. All the THQs and THIs were lower than the threshold value of 1 and does not pose any health risks to the consumers of the shrimps. As observed in the water, THQs and THIs were also higher among the children but varied spatially. The THQs recorded for Ni, Cu and Zn were high in the 3 stations. Pb was only high in station 1 while Cd was high in stations 1 and 3. THIs was also high in stations 1 and 3.

All the THQs (shrimps) were lower than the threshold value (1) and do not pose any health risks to the consumers of the shrimps (Sharma, 2020). However, the values were higher among the children. Sarker et al. (2020) also recorded THQs of less than 1 in *Penaeus monodon* from the Meghna River estuary in Bangladesh. THIs (shrimps) were lower than the threshold value of 1 and does not pose any health risks to the consumers of the shrimps. Sarker et al. (2020) also recorded THIs less than 1 in *Penaeus monodon* from the Meghna River estuary in Bangladesh.

The dermal (HIs) and shrimp (THIs) were also generally higher among the children and more impacted stations 1 and 3.

CONCLUSION

The waters of Isaka Bundu swamp are not safe for recreational purposes based on the heavy metal concentrations and health risk assessment. However, the shrimps are safe for human consumption. The high concentrations of heavy metals in the water influenced the concentrations in the shrimps. Anthropogenic activities in the area contributed to the heavy metal concentrations in the environment. The results also showed that the children were more prone to adverse health impacts.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript.

LIFE SCIENCE REPORTING

No life science threat was practised in this research.

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