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Evaluation of Heavy Metals and Health Risk Assessment of Shellfish Contaminated in Santa Barbara River, Niger Delta, Nigeria

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Abstract

Heavy metals are metal with relative high density known to cause adverse effects on humans health through the food chain. Edible parts of different shellfish species Crab (Cardisoma crassum), Prawn (Macrobrachium rosenbergii), Crayfish (Decapoda reptania) and Shrimp (Penaeus notalis) were analyzed using atomic absorption spectrophotometer (AAS) for various concentrations of Pb, Cr, Ni and Hg. Concentrations of Pb and Cr in all shellfish species were above the Food and Agriculture Organization/World Health Organization permissible limit, while Ni and Hg were below detection limit. The heavy metal concentration in shellfish arranged in increasing order were Cardisoma crassum > Macrobrachium rosenbergii > Decapoda reptania > Penaeus notalis. The dangers to human health of eating shellfish from the Santa Barbara River in Nembe Bayelsa State were assessed. With the exception of Ni and Hg, the target hazard quotient (THQ) showed significant concern for ingestion of these shellfish. The hazard index (HI) suggests a high risk of human carcinogenesis. According to the life cancer risk (LCR) and total life cancer risk (TLCR) values, Pb and Cr levels were notably high in youngsters. In conclusion, the very high quantity of these metals may be hazardous to shellfish directly or indirectly to people who regularly eat contaminated seafood. The consumption of fish from the Santa Barbara River in the Niger Delta may be hazardous to human health.

Keywords: Heavy metal, Shellfish, Human health, Hazard index, Niger Delta

1 Introduction

The numerous species of crustaceans and molluscs that make up shellfish are aquatic invertebrates with a hard outer shell. Eating edible seafood, especially shellfish, is good for one's health and one of the main sources of nutrient-rich food for humans, supplying a significant percentage of dietary protein and fat intake in many nations. (Moruf, Ogunbambo, and Moruf 2020). The ecology is threatened by trace metals from the environment, which are typically found in extremely high concentrations and pose a harm to aquatic life. Due to a number of anthropogenic activities over the past two decades, significant amounts of metals and their compounds—both inorganic and organic—have been released into the environment (Yousif *et al.* 2021). Many marine organisms (fish, shrimp, and crab) at the highest point of the natural feeding ground items and aggregates high levels of metals from the water and sediment (Arulkumar, Paramasivam, and Rajaram 2017; Daellenbach *et al.* 2017; Adimalla and Wang 2018). Consumption of contaminated fish and other aquatic organisms can cause heavy metals to accumulate in aquatic organisms and have an impact on humans, deteriorating human health (Yousif *et al.* 2021; Abarshi, Dantala, and Mada 2017). These metals are very soluble and easily absorbed by fish and other aquatic life. As a result, metals build up in many aquatic ecosystems and are then gradually absorbed by a wide range of microbes, flora, and fauna. Trace elements can later return to the aquatic medium after being absorbed to sediment particles in the aquatic environment. For example, trace metals can be released in reaction to pH and redox potential changes. Long-term exposure to these trace metals threatens human health because they infiltrate the food chain (Ahmed *et al.* 2022; Ahmed *et al.* 2019; Omorotionmwan and Ighariemu 2022; Ighariemu, Belonwu, and Wegwu, 2019a). Crabs, lobsters, and shrimp are examples of benthos organisms that can gather food, water, and sediment-traced metal (Baki *et al.* 2018). Crabs in particular may be a helpful indicator for determining the level of contamination in the surface sediment since they function as a typical benthic organism, which is thought to be an entirely different aquatic species. (Ololade *et al.* 2011). As a result, bacteria, shellfish, and other aquatic creatures may eat trace metal residues from the contaminated habitats, which could enter the food chain and risk human health. Additionally, shellfish (crabs, lobster and shrimp) are mobile, and their tissue concentration of trace metals present can be used as biomarkers or bio-monitors that accumulate in different body parts (Baki *et al.* 2018). The general population's primary source of exposure to heavy metals, which are known to have negative toxicological effects on individuals, is thought to be dietary food products. (Gall, Boyd, and Rajakaruna 2015; Agency 2012). On the Hazards Priority List of the Agency for Toxic Substances and Disease Registry (ATSDR), Cr(VI) is ranked 17th as a group 1 human carcinogen by the International Agency for Research on Cancer (IARC) (USEPA 2017). The immune system, nervous system, motor system, kidney, cardiovascular system, and other systems have all been found to be adversely affected by mercury (Hg), even at low concentrations. Lead (Pb) has a negative effect on the haematological, renal, cardiovascular, reproductive, and skeletal systems. As they can be found in maritime settings that may be contaminated by these ubiquitous substances, which are likely present in fish and shellfish, fish and shellfish are thought to be one of the main food sources of these three contaminants. independent of their anthropogenic or natural origins to have a high distribution, and they can even accumulate significant levels of Cd, Hg, and Pb in their tissue (Castilhos *et al.* 2006). The preservation of the maritime environment and its biodiversity is essential for human survival, whether directly or indirectly. Goal 9 of the Sustainable Development Goals (SDGs), which has undersea life as one of its seventeen key emphases, serves as further confirmation of this. Since the ocean currently contains 97% of human life, the two have converged. On the other hand, maritime contamination, such as oil spills, are frequently made worse by the presence of offshore businesses. One of the main sources of dangerous pollutants for marine ecosystems are accidental and deliberate spills of a mixture of complex hydrocarbon molecules (Singh *et al.* 2020). In 2020, there were documented oil spills totaling about 1000 tonnes, with three medium-scale accidents (between 7 and 700 tonnes) and zero large-scale incidents (more than 700 tonnes). Between 1970 and 2020, it is predicted that more than 5 million tonnes of oil escaped into the sea (ITOPF 2020). Marine life will continue to be threatened as long as the oil spill is present, including the possibility of their vital organs growing larger and the impediment to fish and marine mammals' growth, development, digestion, respiration, and reproduction (Arum *et al.* 2021; NOAA 2018). Coral reef devastation is a given as the oil leak sinks deeper and deeper into the ocean. Oil spills may limit fishing opportunities for fisherman, which will have a substantial impact on the economy (Pascoe and Innes 2018). In the coastal hamlet of Nembe, Bayelsa State, the goal of this study is to estimate the level of metal pollution in various shellfish affected by oil spill.

1.1 Bioaccumulation of Heavy Metals in Shellfish

When compared to the amount of a chemical or toxin in the environment, bioaccumulation is the net buildup of that chemical or toxin in a biological organism over time (Varsha 2013).

Hazardous heavy metal bioaccumulation in riverine ecosystems biota may have detrimental effects on both animals and people (Malik and Maurya 2014). The ecological well-being of aquatic animal species can be harmed by higher metal concentrations with greater weight in biota, which may also contribute to population declines (Luo *et al.* 2014). Food, sediments, and water are just a few of the sources where heavy metals can find their way into aquatic biota. Freshwater fish are frequently exposed to dangerous heavy metals that come from both anthropogenic and natural sources. Since it affects fish and endangers consumers' health, heavy metal contamination of fish has become a major global issue (Rahman *et al.* 2012). The level of heavy metal bioaccumulation in diverse fish species and fish tissues must be evaluated for the management of aquatic ecosystems and human fish consumption (Yousafzai *et al.* 2017). Fish are high in unsaturated fatty acids and low in cholesterol. They are a significant source of protein (Malakootian, Mortazavi, and Ahmadi 2016). Eating fish that is edible to humans is favourable, hence it is suggested as part of a healthy diet. Consuming shellfish that contains toxic heavy metal contamination, however, is seen as a risk to human health and has sparked worry, particularly in more vulnerable demographics including mothers, children, and people who are prone to infections from other sources. Several factors, including the environment and the fish's genetic makeup, can affect how much heavy metals freshwater fish can bioaccumulate. Although the concentration and bioavailability of metals in the water column, the physicochemical properties of water, and other climatic factors are all external environmental factors that affect fish, age, size (length and weight), feeding habits, and body physiology are all internal factors that affect fish. The amount of heavy metal accumulation in various fish tissues normally varies depending on the shape and function of the tissues. In comparison to less metabolically active tissues like the skin and muscles, the liver, kidneys, and other metabolically active tissues like the gills tend to store more heavy metals. The majority of scientists think that the induction or development of metal-binding proteins called metallothioneins (MTs) in these tissues following exposure to heavy metals accounts for the substantially larger accumulation of heavy metals in fish metabolically active organs. Fish gills have been found to be the ideal tissue for the collection and removal of heavy metals like Ni (Mansouri, Ebrahimpour, and Babaei 2012). Since they are edible and most important to human health, fish muscles have been the focus of the majority of studies on the bioaccumulation of heavy metals in fish. The bioaccumulation of dangerous heavy metals in aquatic creatures has important environmental, ecological, and social implications on people and other fish that eat carnivorous species (Ali and Khan 2018; Ali *et al.* 2017). Fish have a wide range of bioaccumulation tendencies, and accumulation can take place in the flesh, head, liver, bones, kidney, stomach, heart, muscle, operculum, and kidneys of many fish species. Because of the different metals' solubilities in water, their bioavailability, and the different habitats, life cycles, eating habits, ecological aspects, and physiological characteristics of fish, it happens in different places and in different fish species (Anandkumar *et al.* 2017). Significant levels of heavy metals can have cytotoxic, mutagenic, and genotoxic effects on fish species, and large levels of heavy metal bioaccumulation in aquatic bodies can harm aquatic species genetically (Salam *et al.* 2019; Matos *et al.* 2017). Fish contain water-borne heavy metals that affect human health and enter the body through the food chain (Dwivedi, Tiwari, and Mayank 2015). Injurious heavy metals also have an effect on fish health and welfare. According to accounts, the freshwater fish Channa punctatus became feeble and more prone to illness due to stress brought on by the river's heavy metal-containing wastewater. Heavy metal pollution is one of the possible causes of the population declines of freshwater fish and other aquatic species in freshwater settings. According to reports, growing contamination has caused the amount and variety of freshwater fish and other aquatic species in Pakistan's River Indus to decline (Ali and Khan 2018). Heavy metals like cadmium (Cd), chromium (Cr), lead (Pb), iron (Fe), manganese (Mn), copper (Cu), nickel (Ni), arsenic (As), mercury (Hg), and zinc (Zn), however, have a high level of toxicity and persistence capacity after reaching a certain limit in the aquatic environment, with the potential for biomagnification, bioaccumulation, and incorporation into the food chain (M. Ahmed *et al.* 2015; Kibria *et al.* 2016). Fish bioaccumulate hazardous substances as a result of heavy metal pollution of rivers, lakes, and streams. Several mechanisms, including dietary intake and the absorption of sediment particles, can cause fish to absorb heavy metals (Liu *et al.* 2020). Numerous invertebrates serve as essential food for fish and other aquatic animals and provide a useful way to absorb lead, copper, zinc, and cadmium (Corrias *et al.* 2020). Another way to be exposed to these dangerous compounds is by drinking water right away (Malik and Maurya 2014; Ighariemu, Belonwu, and Wegwu, 2019b). Sediment is still another choice; in marine environments, it serves as the primary storehouse for trace elements. Water body pollution is typically assessed using the Bioaccumulation Factor (BAF), also known as the rate of element concentration between fish and the abiotic (sediment and water) environments. Significant and trace elements are transported from abiotic to biotic species in this environment, where they build up in the biota and contaminate the food chain (Ali and Khan 2018).

2 Materials and Methods

2.1 Sampling Area

The below Figure 1 map representing the sampling sites of the present study.

Sample collection

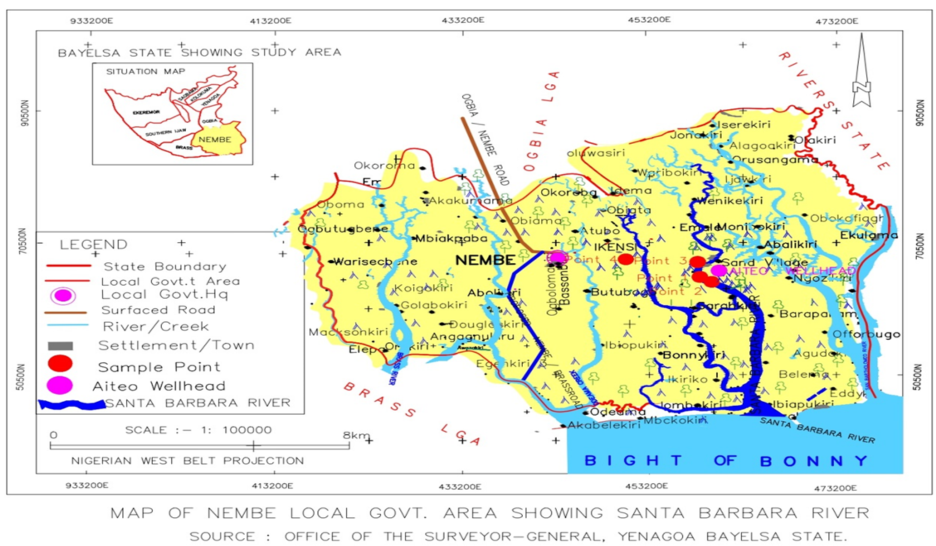

Figure 1. Map representing the sampling sites of the present study

Shellfishes *(Cardisoma crassum, Macrobrachium rosenbergii, Decapoda reptania and Penaeus notalis)* sample were purchased from artisanal fishermen from Sonikiri I community in Nembe local government area of Bayelsa state after the oil spill incident that occurred in December 2021.

Standards and Reagents

The quality of each and every reagent was quite high. De-ionized water was used for all dilutions. At least 65% of the sample was nitric acid, with a density of 1.4 g/mL. Merck Millipore's element standard solutions, which were created by diluting mg/L stock solutions, were used for the calibrations.

Sample Preparation

The fresh shellfish samples were transported using an ice chest to the lab. The shellfish samples were washed with water and drained. They were further placed in the oven and oven dried at 70%C for 36 hrs. The shellfish was then taken out of the oven and ground with a mortar and pestle until powdery. Atomic Absorption Spectrophotometer (AAS) (GBC Avanta AAS model: PM ver 2.02 Avanta) measurements of heavy metal contents in fish were performed.

Heavy Metal determination in shellfishes

Processing

The samples were thoroughly dried in an oven for three days before being ground into powder in a silimic mortar. A crucible container containing 2 grams of the sample was weighed, and it was then placed in a furnace for 6 hours to produce ash. The crucible was taken out of the furnace and put into a desiccator where it could cool after six hours using a crucible thug. The ash content was dissolved or heated to a virtually dry state after cooling using 5ml of 10% HCL. Then, it was filtered into a funnel and measuring cylinder, made up to 20ml with pure water, and exposed to metal analysis using atomic absorption spectroscopy.

Atomic Absorption Spectroscopy Analysis

Atomic absorption spectroscopy was calibrated for each metal using a standard metal, which is listed below as Cr $(\lambda) = 357.90nm$, Pb $(\lambda) = 283.30nm$,Using 20ml of 10% hydrochloric acid (HCL) and a heating mantle, 2 grammes of the materials were digested to almost dryness. In a Flame atomizer AAS, Cr, Hg, and Ni were examined using a Hollow Cathode Lamp (HCL), whereas Pb was examined using an Electrode Less Discharge Lamp (EDL). The extract was inhaled right into the instrument for measuring atomic absorption.

Atomic Absorption Spectroscopy Conditions

GBC Avanta pm ver 2.02 Avanta was used for the atomic absorption spectroscopy (AAS). Acetylene and air at 70 psi were the carrier gases. The carrier gases used were acetylene and air at 70 psi. The materials were atomized, and their atomic makeup was checked. The atomizer used was a flame atomizer. Then, an element-specific line radiation source's optical light was shone on the atoms. After passing through a monochromator to separate the element-specific radiation from any additional radiation that the radiation source may have generated, the radiation is eventually detected by a detector.

Quality assurance and quality control

Double-distilled, deionized water that was impurity-free was used for all study processes. Used glass and plasticware (Merck, Germany) was thoroughly rinsed with 10% HNO3, then washed with deionized distilled water. To ensure data quality and quality control, each sample was inspected three times. Metal analysis was performed using a GBC Avanta AAS (model: PM ver 2.02 Avanta). Analytical blanks were treated in the same way as the samples, and concentrations were determined using standard solutions produced in the same acid matrix based on the monoelement certified reference solution ICP, as stated by (Yesudhason *et al.* 2013). Standards for the calibration of the instrument were created (Merck, Germany).

Statistical analysis

The calculated metal concentration data were tabulated and validated for normality and homogeneity of variance prior to statistical analysis. Using one-way variance of analysis, it was determined whether there were significant changes in metal levels among several species of shellfish (ANOVA).

Health risk assessment

The potential risks to human health from the discovered metals in fish species that can be consumed were calculated using the estimated daily intake (EDI) of metals, the target hazard quotient (THQ), the hazard index (HI), the life cancer risk (LCR), and the total life cancer risk (TLCR). A summary of data on numerous danger parameters can be seen in Table 1.

Table 1. Description of the metal indices utilized in study of the present fish samples

Items	N	Percent(%)	Min
Estimated daily intake (EDI)	The EDI was assessed using the metal concentrations in the studied fish and their consumption characteristics	$$EDI = \frac{Cn \times IGr}{Bwt} \quad (1)$$ where, Cn represents the determined concentrations of heavy metal in the fish tissues (mg/kg dry-wt); IGr represents the ingestion rate (55.5 g/day for adults and 52.5 g/day for children); Bwt represents the body weight: (70 kg for adults and 15 kg for children).	Rakib et al. (2021); Varol et al. (2017); Rahmani et al. (2018)
Target hazard quotient (THQ)	THQ was calculated from the ratio of EDI to the oral reference dose (RfD)	$$THQs = \frac{ED \times EP \times EDI}{At \times RfD} \times 10^{-3} \quad (2)$$ where, ED is the exposure duration (65 years), EP is exposure frequency (365 days/year); AT is the average time for non-carcinogens (ED × EP). RfD (mg/person/day) of metals viz. Cr, Hg, Pb and Mn is 0.003, 0.0001, 0.004 and 0.046 respectively.	Traina et al. (2019); Rahmani et al. (2018)
Hazard index (HI)	The HI can be used to assess the additive effects from various heavy metals taken via fish consumption	$$HI = \sum_{i=k}^{n} THQ \quad (3)$$ where, HI > 1 refers for consumers experiencing significant health hazards due to non-carcinogenic metals exposure.	Resma et al. (2020); Khandaker et al. (2021)
Cancer risk(CR)	Carcinogenic risk describes the incremental probability of cancer in an individual over a lifetime, due to exposure to a substantial carcinogen.	$$CR = \frac{ED \times EP \times EDI \times CSF}{AT} \times 10^{-3} \quad (4)$$ where, CSF is the oral slope factor of carcinogens (mg/kg/day) provided by USEPA (2010), CSF values are available only for Cr (0.003 mg/kg/day) and Pb (0.0085 mg/kg/day). The probability of the development of cancer in a consumer would be > 1 in 100,000, when CR values are above 10^{-5}.	Vu et al. (2017); FAO (2014); Wirnkor et al. (2021)

Source: Rakib et al., 2021

Table 2. Approximate value of dry weight converted from the wet weight recommended by FAO

Recommended organization	Metal name	Value (wet weight)	Value (dry weight)
FAO, (1983)	Cr	0.15 to 1.0 mg/kg	0.65–4.35
	Hg	0.5	2.17
	Pb	0.5	2.17
	Ni	80	347.82

Source: Rakib et al. (2021)

Table 3. Result of Heavy Metals in Shellfish

Shellfish	Scientific name	Pb (mg/kg)	Cr (mg/kg)	Ni (mg/kg)	Hg (µg/kg)
Crab	Cardisoma crassum	1.80 ± 0.06[a]	1.23 ± 0.07[a]	BDL	BDL
Prawn	Macrobrachium rosenbergii	1.83 ± 0.09[a]	1.63 ± 0.09[a]	BDL	BDL
Crayfish	Decapoda reptania	1.00 ± 0.11[a]	1.23 ± 0.03[a]	BDL	BDL
Shrimp	Penaeus notalis	0.53 ± 0.03[a]	2.76 ± 0.03[a]	BDL	BDL
*FAO/WHO Limit (2004)		0.5	0.15		0.5

3 Results

Values represent Mean ± Standard Error of Mean (SEM). Mean in the same column with the same superscript alphabet are significantly different, While mean with different alphabet are not significantly different at $P \geq 0.05$, $n = 3$, BDL – Below Detectable Limit. Tukey post-hoc test was used to determine the observed significant difference *FAO/WHO- Food and Agriculture Organization/World Health Organization (2004).

Table 4. Bioaccumulation Factor of Shellfish

Shellfish	Scientific name	Pb (mg/kg)	Cr (mg/kg)	Ni (mg/kg)	Hg (µg/kg)
Crab	Cardisoma crassum	1.61	0.07	-	-
Prawn	Macrobrachium rosenbergii	0.92	0.09	-	-
Crayfish	Procambarus clarkii	0.89	0.07	-	-
Shrimp	Penaeus vannamei	0.47	0.16	-	-

Human Health Risk Assessment of Shellfish

Table 5. Estimated daily intake (EDI) of Shellfish

Shellfish	Scientific name	Pb (mg/kg)		Cr (mg/kg)		Ni (mg/kg)		Hg (μ g/kg)	
		ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD
Crab	Cardisoma crassum	5.837E-03	1.368E-03	3.989E-03	9.348E-03	-	-	-	-
Prawn	Macrobrachium rosenbergii	3.340E-03	7.828E-03	5.286E-03	1.239E-03	-	-	-	-
Crayfish	Decapoda reptania	3.243E-03	7.6E-03	3.989E-03	9.348E-03	-	-	-	-
Shrimp	Penaeus notalis	1.719E-03	4.028E-03	8.95E-03	2.098E-02	-	-	-	-

USEPA, 2000 Maximum acceptable risk level (ARL) (Values in bold denote the above Maximum acceptable risk level). 1×10^{-5}

Table 6. Target Hazard Quotient (THQ) of Shellfish

Shellfish	Scientific name	Pb (mg/kg)		Cr (mg/kg)		Ni (mg/kg)		Hg (μ g/kg)	
		ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD
Crab	Cardisoma crassum	1.67E+00	3.91E+00	2.66E-03	6.23E-03	-	-	-	-
Prawn	Macrobrachium rosenbergii	9.54E-01	2.24E+00	3.52E-03	8.26E-03	-	-	-	-
Crayfish	Decapoda reptania	9.27E-01	2.17E+00	2.66E-03	6.23E-03	-	-	-	-
Shrimp	Penaeus notalis	4.91E-01	1.15E+00	5.97E-03	1.40E-02	-	-	-	-

Maximum Permissible Limit (Values in bold denote the above Maximum Permissible limit).HQ: 1

Table 7. Life Cancer Risk (LCR) of Shellfish

Shellfish	Scientific name	Pb (mg/kg)		Cr (mg/kg)		Ni (mg/kg)		Hg (μ g/kg)	
		ADULT	CHILD	ADULT	CHILD	ADULT	CHILD	ADULT	CHILD
Crab	Cardisoma crassum	1.67E+00	3.91E+00	2.66E-03	6.23E-03	-	-	-	-
Prawn	Macrobrachium rosenbergii	9.54E-01	2.24E+00	3.52E-03	8.26E-03	-	-	-	-
Crayfish	Decapoda reptania	9.27E-01	2.17E+00	2.66E-03	6.23E-03	-	-	-	-
Shrimp	Penaeus notalis	1.46E-05	3.42E-05	4.48E-03	1.05E-02	-	-	-	-

USEPA, 2011. Maximum Permissible Limit (Values in bold denote the terrible Cancer Risk (CR) exposure). $LCR : 1 \times 10^{-6}\ to\ 1 \times 10^{-4}$

Table 8. Hazard Index for Shellfish

Shellfish	Scientific name	HI	
		ADULT	CHILD
Crab	Cardisoma crassum	1.67E+00	3.91E+00
Prawn	Macrobrachium rosenbergii	9.54E-01	2.24E+00
Crayfish	Decapoda reptania	9.27E-01	2.17E+00
Shrimp	Penaeus notalis	4.91E-01	1.15E+00

USEPA, 2011 Maximum Permissible (Values in bold denote the above Maximum Permissible limit). HI: 1

Table 9. Total life cancer risk (TLCR) of Shellfish

Shellfish	Scientific name	$\sum$LCR	
		ADULT	CHILD
Crab	Cardisoma crassum	2.04E-03	4.79E-03
Prawn	Macrobrachium rosenbergii	2.67E-03	6.26E-03
Crayfish	Decapoda reptania	2.02E-03	4.74E-03
Shrimp	Penaeus notalis	4.49E-03	1.05E-02

USEPA, 2011 Maximum Permissible Limit (Values in bold denote the terrible Cancer Risk (CR) exposure).
$LCR: 1 \times 10^{-6}\ to\ 1 \times 10^{-4}$

4 Discussion

Metal concentrations

According to the study, the concentration of heavy metals in Table 3 varied correspondingly among the various species of shellfish. The highest value was discovered to be chromium (Cr), followed by lead (Pb), with no levels of nickel (Ni) or mercury (Hg) present. Levels of Cr were 1.23 ± 0.03mg/kg, 1.23 ± 0.07mg/kg, 1.63 ± 0.09mg/kg, 2.76 ± 0.03mg/kg respectively for crayfish (Decapoda reptania), crab (Cardisoma crassum), prawn (Macrobrachium rosenbergii) and shrimp (Penaeus notalis). There were observed significant difference within the values except crayfish (Decapoda reptania) in this study. The values were above WHO permissible limit for seafood. However, in increasing order, Cr level in shellfish ranged from shrimp > prawn > crab > crayfish. Cr toxicity in humans varies depending on the chemical form of the compound, its oxidation state, and the route of exposure (Moffat *et al.* 2018). Hexavalent (Cr [VI]) toxicity has been linked to neurotoxicity and induce DNA damage in many different ways that can influence the formation of DNA adducts, chromosomal aberrations, sister chromatid exchanges, alterations in replication and transcription of DNA (J. Wise *et al.* 2022; Jaishankar *et al.* 2014). Pb levels were 0.53± 0.03 mg/kg, 1.00 ± 0.11 mg/kg, 1.03 ± 0.09 mg/kg, and 1.80 ± 0.06 mg/kg respectively for shrimp (Penaeus notalis), crayfish (Decapoda reptania), prawn (Macrobrachium rosenbergii) and crab (Cardisoma crassum). The results for the shellfish were found to be statistically significant, and the significant difference was identified using a Tukey post-hoc test. Additionally, the levels exceeded the World Health Organization (WHO) permissible limit. Excess Pb levels in the aquatic system may cause generative damage and alteration in blood and nerve cells of fishes and other aquatic organisms (Kumar *et al.* 2020). However, in increasing order, Pb level in shellfish ranged from crab > prawn > crayfish > shrimp. In the hemopoietic system, Pb affect heme synthesis thereby inhibiting three important enzymes participating in the process, i.e. delta aminolevulinic acid dehydratase, delta aminolevulinic acid synthase, and ferrochelatase (Papanikolaou *et al.* 2005). One of the most pervasive metals, it is detected in all stages of the inert environment and biological systems and has no recognised biological function in humans. (Castro-González and Méndez-Armenta 2008). In addition, Pb has been reported to cause neurotoxicity in humans nephrotoxicity, hepatotoxicity and many others adverse health effects (Abarshi, Dantala, and Mada 2017). Morever, the concentrations of nickel (Ni) and mercury (Hg) in this study were below the detectable limit (BDL). The high concentration of heavy metals like Cr and Pb in shellfish, however, may be due to the enormous amount of crude oil that was spilled into Santa Barbara River in Nembe Bayelsa State.

Comparison of metal concentration

The heavy metal concentration of shellfish in this study was higher when compared with other studies related to oil spill impact on rivers in the Niger Delta region. There were profound variation in values for Pb and Cr which is classified as a known human carcinogen by United State Environmental Protection Agency (USEPA), International Agency for Research on Cancer (IARC) and Agency for Toxic Substances and Disease Registry (ATSDR) (Monga, Fulke, and Dasgupta 2022; Oskarsson and Alexander 2022). For instance shellfishes (U. tangeri, C. amnicola, T. fuscatus, P. monodon), along the Opuro-Ama Creek in Rivers State (Chris and Oghenetekevwe 2022), Senilia senilis (Blood Cockle) and Crassostrea gasar (Oyster) from Bonny Estuary, Rivers State (Dike *et al.* 2022), Sarotherodon melanotheron (Blackchin tilapia) from Woji creek, Rivers State (Ihunwo *et al.* 2022), three different species of catfishes Chrysichthys nigrodigitatus (marine catfish),Clarias gariepinus (african catfish), and Schilbe mystus (silver catfish) in Ikoli Creek, Yenagoa, Bayelsa State (Ighariemu, Belonwu, and Wegwu 2019c), three selected fin fish species; Oreochromis niloticus, Synodontis clarias, and Hepsetus odoe from Oguta lake (Ogueri, Adebayo, and Nwaiwu 2018), fish samples from six Rivers in Delta state viz: Egbokodo River in Warri, River Ethiope in Sapele, Urie River in Igbide Isoko, Asaba-Ase creek, Aragba River in Abraka, and Uzere Creek (Ubiogoro and Adeyemo 2017). Genyonamus lineatus (Croaker fish) from Bonny and Finima, Rivers State (Abarshi, Dantala, and Mada 2017), Callinectis amnicola (swimming crabs) from Azuabie estuarine creek, Rivers State (Moslen and Miebaka 2017), Tympanotomus fuscatus (Periwinkle) from Iko river estuary, Akwa Ibom State (Abiaobo, Udi, and Obot 2016), seafoods from Ethiope river, Warri Delta State (Uhegbu *et al.* 2012), Seafoods (T. guineensis, L. falcipinis, C. pallidus, and P. notialis) from Ogoniland, Rivers State (Nkpaa *et al.* 2016). This study showed higher values of heavy metal concentrations than all compared scholarly research cited within the Niger region with an exception of (Ubiogoro and Adeyemo 2017) study on multiple rivers and creek that has high level of Iron (Fe) bioconcentrated in different fishes and (Ihunwo *et al.* 2022) study on Woji Creek that has high level of Pb in Sarotherodon melanotheron due to waste deposition and other anthropogenic activities on the intertidal creek.

Bioaccumulation Factor (BAF) of Shellfish

The bioaccumulation factor is essential for determining both the efficacy of any particular pollutant's accumulation in the entire body of the fish as well as the proportional contributions of abiotic media as a source of heavy metals accumulation in fish. According to (Eneji, Sha'Ato, and Annune 2011). Several elements influence the rate of heavy metal bioaccumulation in fish, including the concentration of a metal in a body of water or the sediment nearby, a fish's dietary preferences, and its ability to digest the metal. Sediment serves as a natural sink for heavy metals in aquatic ecosystems, lowering the amount of bioavailable metals in the water. (Gilbert and Avenant-Oldewage 2014), and eventually passing on to fish (Eneji, Sha'Ato, and Annune 2011). Benthic species, which are omnivorous fish that feed by tunnelling into mud or sediment and remaining there for a long time, include shellfish as an example (Poucher 2022). In addition, (Chaudhary *et al.* 2022; Dirisu and Edwin-Wosu 2022) noted that benthic macrofauna such as Cardisoma crassum, Macrobrachium rosenbergii, Decapoda reptania and Penaeus notalis depending on availability, as affected by season or water hydrology, feed on both aquatic and terrestrial plant and animal components. Due to their habitat and preferred diet, they also frequently bioconcentrate heavy metals from the bottom sediments. Heavy metal bioaccumulation factor in Cardisoma crassum, Macrobrachium rosenbergii, Decapoda reptania and Penaeus notalis were evaluated with respect to sediment as the medium. Table 4 shows Bioaccumulation factor (BAF) of this study, the highest BAF value of Pb were seen in Cardisoma crassum followed by Macrobrachium rosenbergii, Decapoda reptania and Penaeus notalis respectively. While Cr level was highest in the following order Penaeus notalis, Macrobrachium rosenbergii, Decapoda reptania and Cardisoma crassum respectively. Ni and Hg, however, were not found. Because they are dangerous pollutants in our water bodies and bioaccumulate even at low exposure levels, these heavy metals present a threat to aquatic life. (Amadi, Frazzoli, and Orisakwe 2022; Ubiogoro and Adeyemo 2017), heavy metal bioaccumulation may have both carcinogenic and non-carcinogenic effects on human health (2011). The fundamental problem with a high concentration of heavy metals in the aquatic ecosystem is that they are extremely dangerous. Humans and aquatic biotas may all be affected by the toxin level (Yadav *et al.* 2018). In this study, BAF in the shellfishes showed possible accumulation of Pb and Cr which may be due to contamination effects and anthropogenic activities in the study area. Other study on freshwater fishes reported lesser bioaccumulation on different species of freshwater fishes (Ashamo and Raheem 2017). Moreover, when compared with scholarly work of (Olayinka-Olagunju, Dosumu, and Olatunji-Ojo 2021), the BAFs in all fish organs revealed no probability of accumulation.

Evaluation of Human Health risk

Estimation of Daily Intake of Metals

The estimated daily intake (EDI) (mg/day) of shellfish contaminated with heavy metals as a result of consumption by both adults and children is shown in Table 5. For this investigation, a health risk assessment was conducted in light of human exposure to heavy metals through ingestion of shellfish from the Santa Barbara River, with the metals' EDI values typically being smaller than their respective oral reference doses. (RFD) - Cr, Ni, and Pb, are 1.5 x 10-3, 2.0 x 10- 2 and 3.5 x 10-3 respectively (USEPA 2009), suggesting minimal risk of human exposure. The EDI values obtained in this study were generally less compared to the findings of (Nkpaa *et al.* 2016) who worked on seafood (T. guineensis, L. falcipinis, C. pallidus, and P. notialis) from Ogoniland, Rivers State Nigeria. They stated that between 0.003 to 0.017 mg kg1 body weight (bw) of these seafood were consumed, with seafood from three research areas having the highest intake of Cr. This amount fell below the Table 2 FAO/WHO-established acceptable daily consumption guideline (1.5 mg kg1 bw) (1993), (USEPA, 2011a; USDOE 2011). For Pb consumption of these seafood ranged between 0.012 and 0.053 mg kg-1. This EDI value far exceeds the established EDI of Pb by FAO/WHO (1993), (USEPA, 2011a; USDOE 2011) Additionally, the EDI values found in this investigation were comparable to those found in (Markmanuel, Amos-Tautau, and Songca 2022; Ighariemu, Belonwu, and Wegwu 2019c). The amounts of Cr and Pb in this investigation were over the maximum tolerable risk threshold, but as their EDI values were lower than their respective RFD values, they might not represent a concern to human health. However, ongoing monitoring is required to identify increases in metal accumulation. In addition, this study demonstrated that ordinary adults and children in the Nembe village would consume more Cr and Pb than the recommended dietary limit (USEPA 2009). Consumers of such fish from the Santa Barbara River in Nembe Bayelsa State may be concerned about contamination as a result of the estimated daily intakes (EDI) of shellfish.

Non-Carcinogenic Risk Effects

As indicated in Tables 6 and 8, the target hazard quotient (THQ) and hazard index (HI) in this study both had values above the standard limit of 1 set by the (USEPA 2011). Children were thought to be most at risk for non-carcinogenic health concerns. Overt signs of acute Pb toxicity include dullness, restlessness, irritability, poor attention span, headaches, muscle tremor, abdominal cramps, kidney damage, hallucinations, and loss of memory with encephalopathy, according to reports by (Monga, Fulke, and Dasgupta 2022; Saha, Nandi, and Saha 2011; Papanikolaou *et al.* 2005). These symptoms all occur at blood lead levels of 100-120 g/dl in adults and 80 Signs of chronic lead toxicity, including tiredness, sleeplessness, irritability, headaches, joint pain, and gastrointestinal symptoms, may appear in adults at blood lead levels of 50 – 80 μg/dl. The biological half-life of lead may be considerably longer in children than in adults. Acute effect of hexavalent chromium [Cr(VI)] can lead to respiratory disease (S. Wise *et al.* 2018), While chronic oral exposure of humans to high doses of hexavalent chromium may have an impact on their immunological, gastrointestinal, liver, and kidney systems as well as perhaps their blood. Hexavalent chromium exposure through the skin can result in contact dermatitis, skin sensitivity, and skin ulceration.

Carcinogenic Risk effects

The exposure of adults and children to carcinogenic health risks, as revealed in Tables 7 and 9, was alarmingly high. The high metal concentration of Pb and Cr may be the cause of this. All socioeconomic categories are impacted by the hazard that significant lead exposure poses to young children's physical development and optimal health (Papanikolaou *et al.* 2005; Roper *et al.* 1991). While hexavalent chromium [Cr(VI)] is a widely acknowledged environmental contaminant with the potential to cause cancer teratogenic, and mutagenic effects, it is also becoming understood to be a neurotoxicant (J. Wise *et al.* 2022). In this study, the life cancer risk (LCR) and total cancer risk (TLCR) for shellfish were above the maximum permitted limit (MPL) set by the (USEPA 2011), which ranged from 1 10-6 to 1 10-4 for Pb and Cr, respectively.

5 Conclusion

According to the findings of this study, eating shellfish from the Santa Barbara River in the Niger Delta's Nembe Local Government Area of Bayelsa State poses a serious health risk. In terms of safeguarding human health and preventing disease, mussels from the Santa Barbara River of Nembe in particular Cardisoma crassum, Macrobrachium rosenbergii, Decapoda reptania and Penaeus notalis mainly because of Pb and Cr contaminations, may not be suitable for human consumption. Decision-makers, policy-makers, and other interested parties should work together to adopt policies and mitigation measures in light of the aforementioned conclusions.

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Data Availability

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

Conflict of interest

The authors affirm that they have no known financial or interpersonal conflicts that would have appeared to have an impact on the research described in this publication.

Consent for Publication

The paper has been read and approved for publishing by all authors.

Author Contributions Statement

Victor Ighariemu, Matthew Owhonda Wegwu, and Lawrence Chijoke Chuku all made significant contributions to the idea, planning, and careful revision of the study's paper. The manuscript was written by Victor Ighariemu, who also helped with revisions and final approval.

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