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Bioaccumulation and Health Risk Assessment of Lead, Cadmium, Arsenic, and Mercury in Blue Crabs Found in Creeks in Bayelsa State of Niger Delta Region of Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This research investigated the accumulation of four heavy metals: Pb, Cd, As, and Hg in male and female crabs obtained from four creeks in Bayelsa State and the potential health risks associated with their consumption. The heavy metals were analyzed using Micro-Wave Plasma Atomic Emission Spectrophotometer 4200 Agilent. The mean concentrations of Pb (mg/kg) in the male crabs obtained in Nembe, Taylor, Kolo and Nuno creeks were 41.13±0.17, 31.23±0.12, 38.70±0.33 and 11.63±0.37 respectively, whereas those of the female crabs were 45.63±0.25, 32.00±0.24, 40.00±0.08 and 12.20±0.08 respectively. The mean concentrations of Cd (mg/Kg) in the male crabs from the same creeks were 46.77±0.42, 37.23±0.17, 41.83±0.37 and 28.60±0.29

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respectively, whereas those of the female crabs were 47.73±0.37, 39.65±0.45, 45.03±0.25 and 29.40±0.08 respectively. The mean concentrations of As (mg/Kg) in the male crabs from the same creeks were 5.067±0.21, 4.83±0.21, 4.73±0.21 and 1.77±0.12 respectively, whereas those of the female crabs were 6.03±0.17, 5.13±0.17, 5.10±0.08 and 2.07±0.12 respectively. The mean concentrations of Hg (mg/Kg) in the male crabs from the same creeks were 7.87±1.37, 5.57±0.16, 6.80±1.14 and 5.93±0.90 respectively, whereas those of the female crabs were 9.20±0.99, 6.40±0.54, 9.23±1.01 and 6.17 ±0.09 respectively. The concentrations of all the heavy metals were generally higher than the permissible level by Food and Agriculture Organization and World Health Organization in seafood. Statistical analysis of the level of the studied metals showed there is a significant difference p< (0.05). The Total Hazard Quotient (THQ) in all the blue crab in all the creeks were less than 1. The Estimated Metal Intake, Health Risk Index, and Carcinogenic Risk indicated a risk of developing cancer over time due to the ingestion of Pb, Cd, and As. From the results, the health risks associated with exposure to the heavy metals through the consumption of the blue crabs for the inhabitants in the study area are in the order: Pb >Cd>Hg>As. Therefore, blue crabs from the creeks under study are considered unsafe for consumption.

Keywords: Heavy metal; blue crab; cadmium; lead; mercury; arsenic; health risk assessment.

1. INTRODUCTION

"Heavy metal pollution is a serious environmental issue across the globe. As the human population increases, it has been established that the intensities of the anthropogenic threats it exerts on the environment increase. The increase was attributed to industrialization and aqua-cultural activities" [1]. The discharge of industrial waste containing heavy metals into the aquatic ecosystem has been reported to represent a health risk if the metals accumulate in flora and fauna such as crabs which are mainly used as bio-indicator [2-5].

The aquatic environment contains seafood, and the Heavy metal pollution of this ecosystem is a cause of public health concern. Heavy metals are reported to be non-biodegradable and they tend to bio-accumulate in organisms [6-8]. These metals when ingested by humans could circulate in the bloodstream and accumulate in the target organ. Wang et al., [9], reported that heavy metals appeared in toxic form in both aquatic organism and human who consumed seafood; and as the heavy metals concentration in the environment increased, they explained that they can be transferred to another organism through the food chain with the resultant effect of damaging flora and fauna and ultimately causing death.

"The accumulation of heavy metals in an organism depends on various bio-organic and environmental factors such as size, age, feeding habits, temperature, and dissolved oxygen" [10]. The feeding habit plays a significant role in the accumulation of metals in organism tissues because metals tend to be bio-magnified through the food chain [11,12]. Most aquatic food chain begins with the invertebrates, however, the ability of invertebrates to accumulate contaminants varies from species to species [13-15]. For this reason, it is important to determine the chemical composition of marine organisms such as crabs, particularly the heavy metal content, to evaluate the possible health risk of this aquatic food to humans [16-20].

In recent years, more attention is given to toxic heavy metals because of their bio-accumulation and bio-magnification potentials and persistence in the environment. Some heavy metals like cadmium, arsenic, mercury, and lead are considered to be highly toxic to human and aquatic life. Therefore, it is important to determine the daily environmental exposure to these metals [21-24].

Large quantities of inorganic and organic compounds are introduced annually into various rivers and creeks in the Niger Delta region as a result of the discharge of sewage and illegal oil bunkering which have rendered the aquatic ecosystem polluted [29]. Therefore, the Assessment of Lead, Cadmium, Arsenic, and Mercury Pollution of Selected Creeks in the Nigerian Niger Delta, Using Blue Crabs as Markers is important.

Bayelsa State in the Niger Delta region of Nigeria hosts a lot of upstream activities of the Nigerian petroleum industry. Heavy engineering construction and oil spillages are common occurrences in that area. Yet, majority of the local population depends on the aquaculture for livelihood. Therefore, this research is aimed at monitoring the pollution of the creeks by the four heavy metals and the health risks they portend on the population due to the consumption of blue crabs common the aquatic environment of the area. This research is of environmental health importance, due to the changing pollution dynamics in the oil-rich Bayelsa State of Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

The study areas, Nembe, Taylor, Kolo, and Nuno creeks as shown in (Plate 1). Nembe Creek is a distributary and it is 8 meters above sea level. This is one of the three giant oil reservoirs in the Niger Delta with a potential of one-billion-barrel production and it is where Nembe Creek Trunk Line was constructed by the Royal Dutch Shell PLC. The truck line evacuates crude from the Niger Delta to the Atlantic coast for export. Nembe Creek is located at latitude 5.532813 and longitude 6.403743.

Taylor Creek (called Gbaraintoru by indigenes), Yenagoa Local Government Area of Bayelsa State. The study area stretched from Koroama to Polaku along Taylor Creek. The Lower Taylor Creek is situated between 5º 01ˈN; 6º 17ˈE and 5º 02ˈN; 6º 18ˈE. Several creeks and flood channels interconnect freshwater swamp forests, linking the Nun River and Taylor Creek at various points and forming a mass of water bodies during the high flood. These creeks and swamps with their associated floodplain lakes and fishing ponds constitute the main fishing systems. Okoso Creek is at present the most prominent creek connected to Taylor Creek which subsequently empties into the Nun River at its confluence at Polaku. In the dry and low water period, Taylor Creek in the Zarama axis reduces to disjointed series of pools linked by sections of shallow water. Taylor Creek is subject to mild tidal influence in the dry season. Water flows in one direction during the flood period but it is gentle in the low water period. At the peak of the dry season, the direction of flow is slightly reversed in Taylor Creek during the rising tide, while at full tide, the flow almost stagnates

“The Kolo Creek area as defined by this study included all those communities around Kolo Creek where oil exploration and exploitation activities are ongoing in the Ogbia Local Government Area of Bayelsa State Nigeria. It is located within longitudes 4 55 52.25 N and 4 55 31.92N and latitudes 6 20 11.94 E and 6 24 50.70 E including the towns of Imiringi, Otuasega, Elebele, Orom, and Ayon. The Kolo Creek oil and gas field is located within the Imiringi town area and situated about 10 km east of Yenagoa, the capital city of Bayelsa State. The Kolo Creek Field hosts some oil facilities including 46 oil wells, one flow station (Kolo Creek), one manifold, and one SPDC campsite. The other economic activities include subsistence agriculture, artisanal fishing, palm wine tapping and processing, and basic commerce” (Ezekiel et al., 2008).

Nuno River is located at Latitude 5.1833329 and longitude 6.316667 and is the longest (160 km) continuation of the Niger River. The Nuno River begins near the village of Aboh, where the Niger River splits in two, forming Nuno and Forcados, flows through the rain forests, swamps, and mangroves, and empties into the Gulf of Guinea. Flooding from monsoon rains lasts from June to September, then the water level drops, and in February, with the arrival of the flood waters from the Niger River, rises again. Forest rivers and streams of the Nuno River basin are home to many species of fish and other aquatic organisms.

2.2 Sample Collection

By using a random sampling technique, three samples, each, of male and female *Callinectes sapidus* (blue crabs) were collected in February 2023 from the study sites in Bayelsa State, Nigeria.

2.3 Sample Preparation and Metal Determination

The blue crabs were washed with distilled water, air-dried for three days and pulverized. Exactly 1 g of the sample was digested with a mixture of HNO_3 and $HClO_4$, and the filtrate made up to 100 mL. The metal concentration in the samples was analyzed using Micro-Wave Plasma Atomic Emission Spectrophotometer 4200 Agilent.

2.4 Health Risk Assessment

The potential health risk of heavy metal consumption through *Callinectes Sapidus* were assessed based on the Estimated daily intake of metal (EDI) (Chary *et al.,* 2008), health risk Index (HRI) [30] and the target hazard quotient (H/Q) [9,32].

Plate 1. Map of Bayelsa state showing the sample creeks

2.4.1 Estimated Daily Intake of metal (EDI)

The Estimated daily intake of metal (EDI) was calculated to averagely estimate the daily metal landing in the body system specified body weight of a consumer. This does not take into cognizance the possible metabolic ejection of the metal but can easily tell the possible ejection rate of a particular metal. The estimated daily intake of metal in this study was calculated based on the formula

$$EDI = \frac{(Metal\ x\ C\ factor\ x\ Cfood\ intake}{WAB}$$

Where:

EDI is the Estimated Daily Intake
C metal = Concentration of the metal in mg/kg
C factor = Conversion factor. The C factor as reported by Ricciardi and Bourget, (1998) for blue crabs is 20.5
C is the food intake = This is the daily intake of crab. The daily intake of crab was 60 g/day while the WAB = Average body weight = 60 kg

Then, the Health Risk Index was calculated using $HRI = \frac{EDI}{RfD}$

RfD = Oral reference dose of the metal of interest are as follows:
Pb = 0.0035 mg/kg/day
Cd = 0.001 mg/kg/day
As = 1.5 mg/kg/day
Hg = 0.0003 mg/kg/day

Reported by USEPA IRIS, [33]

2.4.2 Non – carcinogenic health effect

2.4.2.1 Target hazard quotient

"Non- carcinogenic hazard estimation of heavy metals intake was determined using THQ values. THQ is a ratio of the determined dose of a pollutant to a reference level which was taken into consideration. THQs were calculated consistent with the technique defined by the Environmental Protection Agency (EPA) in the USA" (USEPA, 1989; Singh et al., 2010; USEPA, 2011).

The $THQ = \frac{EF\ x\ ED\ x\ FIR\ x\ C}{RFD\ x\ WAB\ x\ TA} x\ 10^{-3}$

EF = Exposure frequency (350 days) 1 year
ED = Exposure duration 54 years, equivalent to the average lifetime of the Nigerian population.
FIR = Food Ingestion Rate = 60 g/person/day which is 0.06 kg/day
C = Concentration of the metal
WAB = Average body weight = 60kg
TA = Average exposure time for non-(carcinogens ED x 365 days/year) (54 x 1 year) which is 19,345. Therefore, if THQ is greater than 1, the exposure is likely to cause adverse health effects (Adedokun *et al.,* 2016).

2.4.3 Carcinogenic health Effect

2.4.3.1 Carcinogenic Risk (CR)

USEPA distinguishes between the cancer-causing agents by a load of proof characterization of the compound. The evaluated everyday portion and the malignant slope factor were multiplied together to determine the lifetime cancer chance presented by the metal hazard. Malignancy slope factors are evaluations of cancer-causing intensity and are utilized to relate the day portion of a substance over a lifetime. Ingestion malignancy incline factors are communicated in units of (mg/kg/day) [34].

The lifetime likelihood of reaching disease due to cancer-causing synthetic substances is determined as follows:

Carcinogenic Risk = EDI x CSFing

Where:

EDI is the estimated daily intake of each heavy metal (mg/kg/day)
CSFing is the ingestion cancer slope factors (mg/kg/days)-1

Pb = 0.0085 $(mg/kg/days)^{-1}$
Cd = 0.38 $(mg/kg/days)^{-1}$
As = 1.50 $(mg/kg/days)^{-1}$
Hg = NA
NA= Not Applicable.

2.5 Statistical Analysis

The single-factor analysis of variance (one-way ANOVA) and paired sample t-test were used to determine differences in the accumulation and distribution of heavy metals in crabs. A statistically significant difference was set at p < (0.05).

3. RESULTS AND DISCUSSION

3.1 The Metals Concentrations in Crab

The results revealed that the concentration of Pb, Cd, As, and, Hg exceeded the various USEPA and FAO/WHO permissible limits. From the results, Nembe Creek is the most contaminated. This could be attributed to the recent oil spill which was one of the worst in recent times. The oil spill was reported to have caused extensive environmental damage. This study further revealed that sexual changes are a factor in metal accumulation and distribution in Molluscs. This study further revealed that metals values were larger in the female of the species than the male as shown in Figs. 1, 2, 3,4, 5, and 6. The result is in line with the report of Beltframe et al., (2010), but in contrast with that of Ubong et al., [35] which revealed that metal values were larger in the male crabs than the female.

“The difference in the concentration results from the accumulation between the genders which can be attributed to a difference in diet or habitat. The male crab feeds more on fish and bivalves, while the female crab feeds more on shrimp, plants, and detritus. It is known that certain forms of metal can readily accumulate within crustacean tissue at much higher levels. Shrimp has been reported as a vector of the transfer of mercury to top marine predators of the food chains” [36] (Bu-Dayan and Subrahmanyam, 1998). “Therefore, female crabs feed more on shrimps and plants and receive a high level of metals which increases the concentration of the heavy metals present in them” [10]. “Molluscs, especially filter-feeding animal bivalves, are well-known for their active ingestion of heavy metal-bound organic and inorganic matter. These bivalves can also be highly exposed to heavy metals during feeding and accumulate a wide range of metals from sediments” [37].

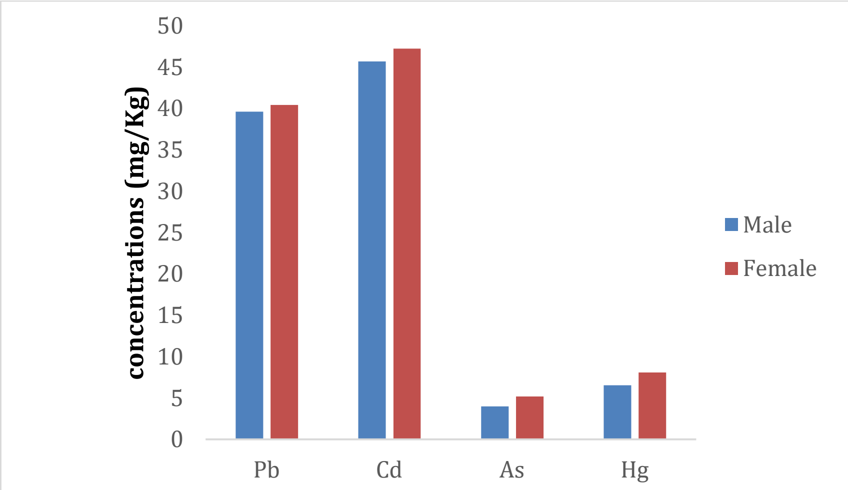

Fig. 1. Comparison of metal concentrations in male and female blue crabs in Nembe Creek

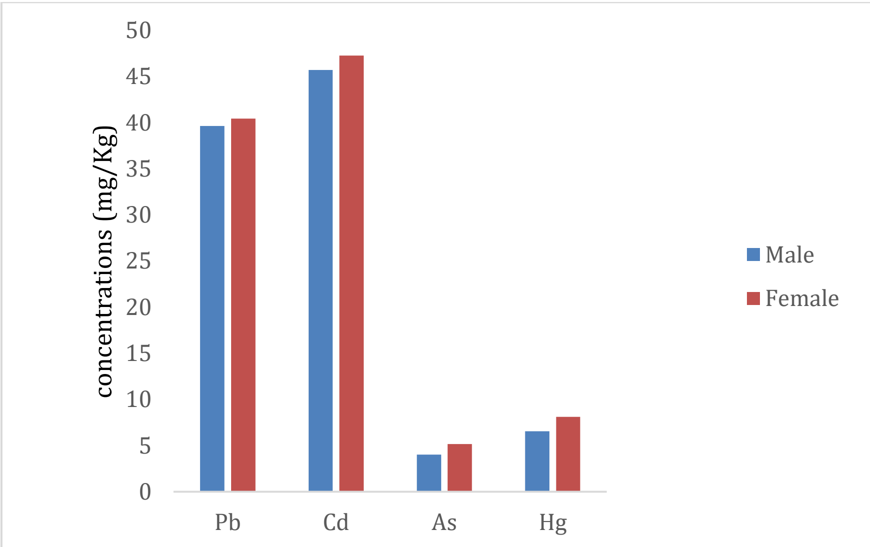

Fig. 2. Comparison of metal concentrations in male and female blue crabs in Taylor Creek

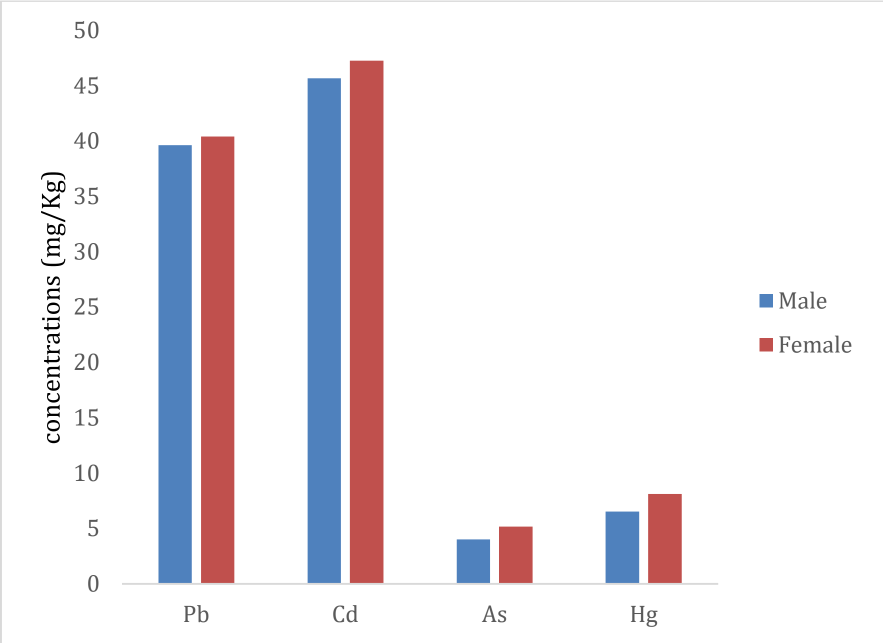

Fig. 3. Comparison of metal concentrations in male and female blue crabs in Kolo Creek

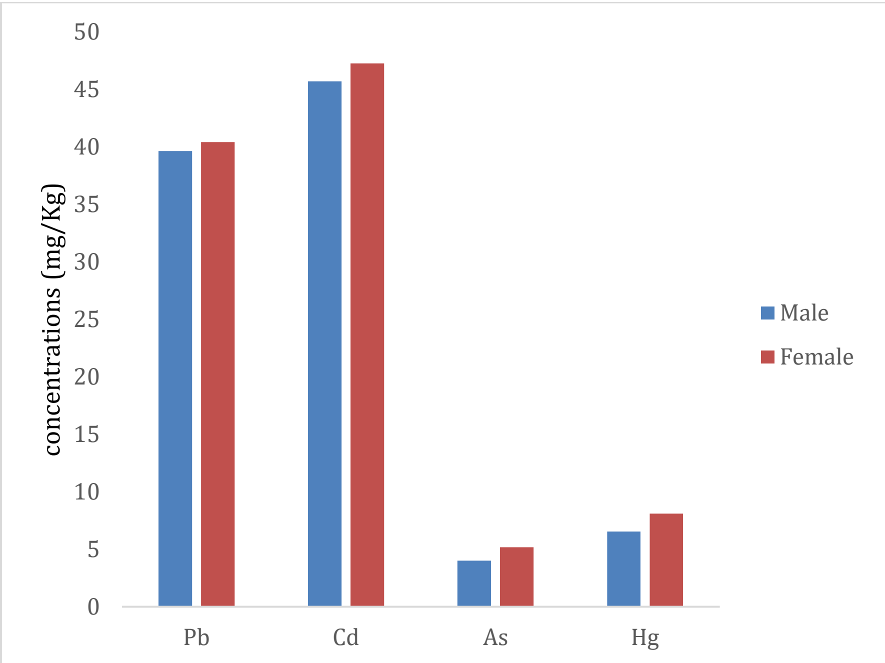

Fig. 4. Comparison of metal concentrations in male and female blue crabs in Nuno Creek

Mehdi et al., [10] and Shojaei et al [38], reported that "plants have a relationship with sediment and receive more sediment-associated metals. The root of the plant has an important role in depurating the water and sediment, retaining large quantities of organic material and trace metals brought by the tides. Metal is closely bound to plant cell walls, slowing its translocation from roots to buds. Because plants are salt-excluders, it hinders the entry of metals through their root system. Larger organisms generally exhibit higher contaminant levels in their bodies and crabs that are higher on the food chain also accumulate more contaminants when compared to crabs that eat a range of different foods or eat smaller organisms". This revealed that higher metals level in the organs of the female crabs because they are larger and can eat larger food items. This agreed with Cogun et al., [39] which revealed differences in heavy metal concentration on the same species from a different site. This difference in heavy metals concentration depends on the availability of metal and the source of pollution in the different habitats. Jenyo-Oni and Oladele, [40], attributed the differences in concentration to that rapid urbanization and industrialization which are associated with the production and deposition of hazardous waste in aquatic environments. The report further attributed heavy metals as the major components of these wastes which have been implicated in several metal-related diseases and food poisoning in man.

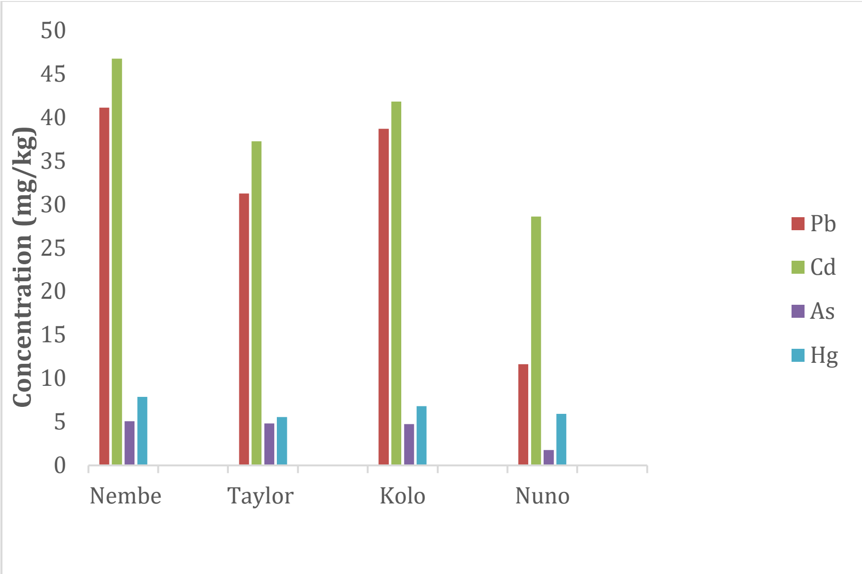

Fig. 5. Comparison of metal concentrations in male blue across the study creek in Bayelsa State

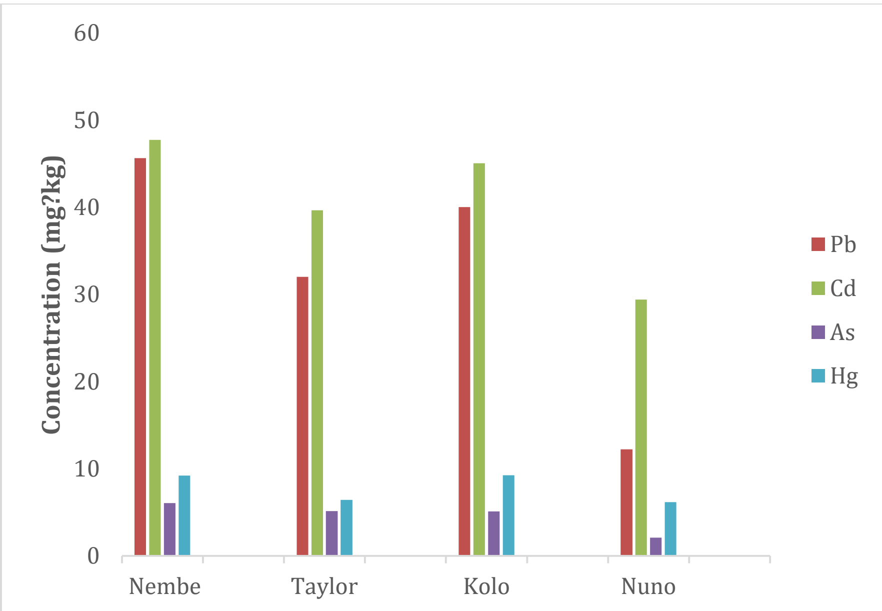

Fig. 6. Comparison of metal concentrations in female blue across the study creek in Bayelsa State

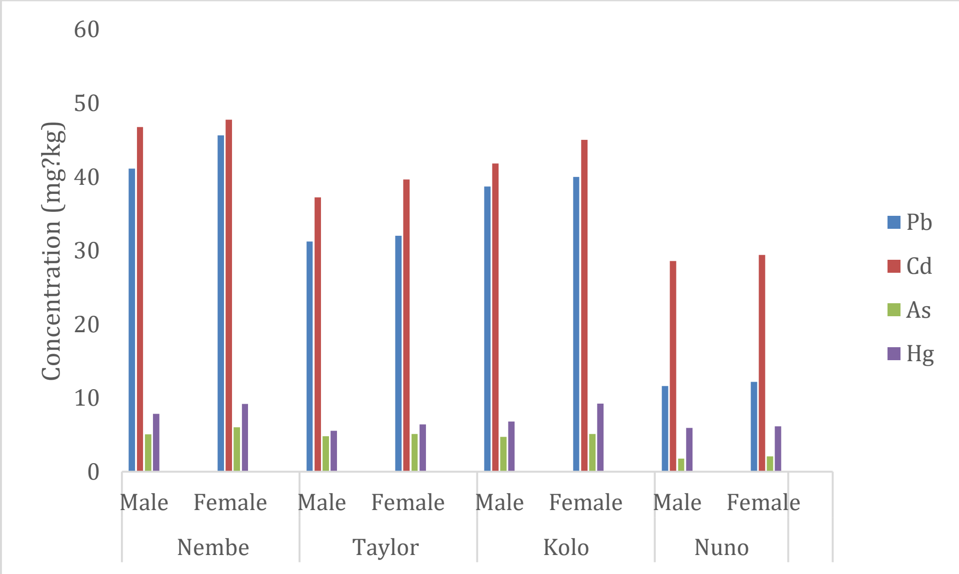

Fig. 7. Comparison of metal concentrations in male and female blue across the study creek in Bayelsa State

The present study corroborated the study of Umuannakwe and Agumba, (2013), revealing "the mean concentration of the heavy metal from the four samples of stations. The concentration of chromium, copper, Barium, nickel, arsenic, and vanadium exceeded the standard limit of USEPA, WHO, and Nigeria Industrial Standard (NIS) for drinking water quality. The report suggested that activities in the area had contributed to the high sediment-contribution of these contaminants". Therefore, the consumption of the crabs may be considered unsafe. Also, the concentrations of Pb from the present study were higher than that reported by Agwu et al. [41].

Olowu et al., (2009), revealed that consumption of prawns from the Ojo River in the Lagos metropolis may be considered safe for consumption while the crabs from the same river unsafe, but needed continuous monitoring to identify possible bioaccumulation. Generally, there was an increase in the level of Cd in the crabs across the study creeks, maybe due to the increase in anthropogenic waste disposal.

3.2 Estimated Daily Intake of Metals in Crab for Adult Population

The average daily intake of metals in the adult population was compared to the recommended daily intake level (DIL) of metals and their upper tolerable daily intake (UTDI) set up by the Institute of Medicine for people aged 19 to 79 years [10,11]. The Pb, Cd, As, and Hg through EDI was UTDI as shown in Table 2. This showed that Pb, Cd, As, and Hg ingestion may pose a health risk through the consumption of crabs.

3.3 Health Risk Index

"An HRI of less than 1 means the exposed population is unlikely to experience obvious adverse effects; whereas an HRI above 1 means that there is a chance of non-carcinogenic effects, with an increasing probability as the value increases" [20,21]. Therefore, Table 3 shows that all the values of HRI exceeded 1. Thus, there is a chance of non-carcinogenic effects.

3.4 Target Hazard Quotient (THQ) in Crabs for Adult Population

THQ values of Pb, Cd, As, and Hg were below 1 (THQ < 1) as shown in Table 4. This simply indicates that the population of the study area may not be exposed to a non-carcinogenic health risk due to the consumption of the examined seafood samples. These results suggest that there may be no risk or toxicity associated with non-carcinogenic ingestion of the metals through crab intake.

3.5 Lifetime Cancer Risk (LCR) of Heavy Metals in Crabs for Adult Population

The U.S. Environmental Protection Agency reported that 10^{-6} to 10^{-4} is the range of allowable lifetime risk expected for carcinogens. The LCR of Pb, Cd, and As was outside the permissible limit in the adult population of the study area. This indicates that there may be a risk of developing cancer over time due to the carcinogenic ingestion of Pb, Cd, and As.

3.6 Statistical Test for Significance

The statistical test for significance showed that there was a significant difference between the Pb concentrations for male and female crabs across the creeks for t-test as [t-stat (-0.42165)0.05 ≤ t-Cri (1.734064) 0.05]; for one-tail, and [t-stat (-0.42165)0.05 ≤ t-Cri (2.100922) 0.05] in two-tail, assuming equal variance. The observations for unequal variance were [t-stat (-0.42165)0.05 ≤ t-Cri (1.734064)0.05]; for one-tail and [t-stat (-(-0.42165]0.05 ≤ t-cri (2.100922) 0.05] for two-tail. The trend was similar for Cd, As and Hg. The P-value (1.4×10^{-13}) was less than 0.05.

Table 1. The concentrations of the heavy metals in blue crabs (mg/kg)

Creek	Sex	Pb	Cd	As	Hg
Nembe	Male	41.13±0.17	46.77±0.42	5.07±0.21	7.87±1.37
	Female	45.63±0.25	47.73±0.37	6.03±0.17	9.20±0.99
Taylor	Male	31.23±0.12	37.23±0.17	4.83±0.21	5.57±0.16
	Female	32.00±0.24	39.65±0.45	5.13±0.17	6.40±0.54
Kolo	Male	38.70±0.33	41.83±0.37	4.73±0.21	6.80±1.14
	Female	40.00±0.08	45.03±0.25	5.10±0.08	9.23±1.01
Nuno	Male	11.63±0.37	28.60±0.29	1.77±0.12	5.93±0.90
	Female	12.20±0.08	29.40±0.08	2.07±0.12	6.17±0.09

Permissible Limit	Pb	Cd	As	Hg
WHO/FAO (1989)	0.50	0.50	-	-
FAO/WHO (1993)	0.214	0.10	-	-
USEPA (Mishra *et al.,* 2007)	4.00	0.20	1.20	-
FAO/WHO (2011)	1.50	0.10	-	0.50

Table 2. Estimated Daily Intake (EDI) of metals in crab for adult population (kg/person/day)

Creek	Sex	Pb	Cd	As	Hg
Nembe	Male	0.86	0.97	0.12	0.164
	Female	0.95	0.99	0.13	0.19
Taylor	Male	0.65	0.78	0.10	0.12
	Female	0.67	0.83	0.12	0.13
Kolo	Male	0.82	0.87	0.10	0.14
	Female	0.83	0.94	0.12	0.19
Nuno	Male	0.24	0.60	0.04	0.12
	Female	0.25	0.61	0.04	0.13
Recommended tolerable daily intake (TDI)		0.00	0.00	6.3×10^{-8}	0.003
upper tolerable daily intake (UTDI)		0.24	0.06	0.002	

Recommended tolerable daily intake (TDI) and upper tolerable daily intake (UTDI) levels of heavy metals in foodstuffs [10,11]; Tolerable Daily Intake of heavy metals by humans as prescribed by JECFA [12]

Table 3. Health risk index of metals in crab for adult population $(kg/person/day)^{-1}$

Creeks	Sex	Pb	Cd	As	Hg
Nembe	Male	244.60	973.00	0.08	546.70
	Female	271.10	993.00	0.08	636.70
Taylor	Male	185.70	775.00	0.07	386.70
	Female	190.30	825.00	0.07	443.30
Kolo	Male	230.00	870.00	0.07	47.00
	Female	273.70	937.00	0.07	64.00
Nuno	Male	69.14	595.00	0.03	410.00
	Female	72.29	612.00	0.05	426.70

Table 4. Target Hazard Quotient (THQ) of metals in crab for adult population

Creeks	Sex	Pb	Cd	As	Hg
Nembe	Male	0.01	0.05	$3.32 x 10^{-6}$	0.03
	Female	0.13	0.05	$4.02 x 10^{-6}$	0.03
Taylor	Male	0.01	0.04	$3.2 x 10^{-6}$	0.02
	Female	0.01	0.04	$3.42 x 10^{-6}$	0.02
Kolo	Male	0.01	0.04	$3.16 x 10^{-6}$	0.02
	Female	0.01	0.05	$3.4 x 10^{-6}$	0.03
Nuno	Male	0.003	0.03	$1.1 x 10^{-6}$	0.02
	Female	0.004	0.03	$1.38 x 10^{-6}$	0.02
Recommended standard		1	1	1	1

Table 5. Life cancer risk of heavy metals in adult population via consumption of crab

Creek	Sex	Pb	Cd	As
Nembe	Male	0.01	0.37	0.16
	Female	0.01	0.38	0.19
Taylor	Male	0.01	0.30	0.15
	Female	0.01	0.31	0.16
Kolo	Male	0.01	0.33	0.15
	Female	0.01	0.36	0.16
Nuno	Male	0.002	0.23	0.06
	Female	0.002	0.24	0.0657
Recommended standard		10^{-6} - 10^{-4}	10^{-6} - 10^{-4}	10^{-6} - 10^{-4}

4. CONCLUSION

Numerous studies have linked excessive bioaccumulation of heavy metals to various health abnormalities. They possess both short and long-term environmental health risks. The accumulations of lead, cadmium, arsenic, and mercury in blue crabs in the creeks studied in the Niger Delta area of Nigeria are, to a considerable extent, more than those reported from other regions in the literature.

This is believed to be due to rigorous anthropogenic input of the contaminants into the aquatic environment. It was evident from the study that heavy metal accumulations in blue crabs were higher than almost all the international standard levels. Furthermore, the study revealed differences in the concentrations of heavy metals between the male and female crabs. Though THQ calculated showed that THQ in all the blue crabs in all the creeks were less than 1, the Estimated Metal Intake, Health Risk Index, and Carcinogenic Risk indicated a risk of developing cancer over time due to the carcinogenic ingestion of Pb, Cd, and As. Therefore, blue crabs from the creeks under study are considered unsafe for consumption.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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