Assessment of Heavy Metal Contamination and Health Risks in Crabs (*Scylla senrata*) from Oil and Non-Oil Producing Communities in Rivers State, Nigeria

Abstract

The study investigates the health risks associated with heavy metal contamination in *Scylla senrata* harvested from Abonnema (non-oil producing community, NOPC) and Kula (oil producing community, OPC) in the Niger Delta region, Nigeria, at both low and high tides. The metals analyzed include iron (Fe), lead (Pb), nickel (Ni), manganese (Mn), zinc (Zn), copper (Cu), cadmium (Cd), and chromium (Cr). The analyses were conducted using flame atomic absorption spectrophotometry. The results showed significant variation in metal concentrations. Results showed elevated levels of Fe (94.7–146.8 mg/kg), Pb (8.3–38.28 mg/kg), Ni (3.62–6.45 mg/kg), Mn (42.79–71.43 mg/kg), Cu (18.5–27.95 mg/kg), and Cd (1.25–2.00 mg/kg) above WHO/FEPA limits, particularly in Kula. Chromium (Cr) levels were relatively lower, with concentrations ranging from 0.21 to 0.28 mg/kg at low tide and <0.001 mg/kg at high tide. In addition, zinc (Zn) concentrations remained within the permissible limit. The Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ) calculations indicated that the concentrations of these metals are within safe limits for human consumption, with none of the THQ values exceeding the threshold of 1.0. In conclusion, these findings suggest that while anthropogenic activities, particularly oil exploration, contribute to metal contamination, the consumption of these crabs poses minimal health risk based on current metal exposure levels. Continued monitoring is recommended to assess long-term environmental and health impacts.

Keywords: *Scylla senrata*, heavy metals, WHO/FEPA limits, Estimated Daily Intake (EDI), Target Hazard Quotient (THQ)

INTRODUCTION

Heavy metal pollution in aquatic ecosystems has emerged as a critical environmental issue due to its ability to bioaccumulate in aquatic organisms, thereby posing significant risks to both human health and the environment. This contamination continues to draw global attention because of the widespread presence of heavy metals, their diverse sources, persistence in the environment, and toxic effects on living organisms [1]. Their non-biodegradable nature and propensity to accumulate in the tissues of plants and animals further exacerbate the problem [2].Consequently, the bioaccumulation of metals serves as a key pathway for the transfer of elevated pollutant levels through food chains and webs, leading to significant public health concerns when humans are part of the food chain. Hence, it is essential to routinely evaluate the bioaccumulation potential of heavy metals in organisms, particularly edible species, to assess the potential health risks to humans.

Assessing the levels of heavy metals in *Scylla senrata* and their potential health risks through indices such as Target Hazard Quotient (THQ) and Estimated Daily Intake (EDI) provides crucial insight into the safety of consuming seafood from these regions. These indices serve as benchmarks to evaluate the non-carcinogenic risks associated with dietary exposure to heavy metals [3]. Previous studies have highlighted varying levels of heavy metals in seafood from oil-producing areas, but comprehensive assessments comparing oil and non-oil-producing communities remain limited [4,5,20,21].

This study aims to evaluate the levels of heavy metals in *Scylla senrata* harvested from oil- and non-oil-producing communities in AKULGA, Rivers State, and to assess the associated health risks of their consumption using estimated daily intake (EDI) and total hazard quotient (THQ).

MATERIALS AND METHODS

Study Area

The study area encompasses Kula and Abonnema in the Akuku-Toru Local Government Area (Akulga) of Rivers State, Nigeria (Fig. 1). Akulgacomprises several communities namely; Abonnema, which is the head quarter, Idama, Kula, Obonoma, Abissa, Orusangama, Elem Sangama and Soku. Akulga is an economically significant region covering approximately 1,443 km² with a population of about 156,006 people (Fed. Rep. Nig. Gazette, 2015; Census, 2006).

The study area is situated between latitudes 04°44'09.6" N and 04°20'37.4" N, and longitudes 006°46'28.8" E and 006°38'39.9" E, within the Niger Delta region along the Sombrero River. It features fibrous clay mud, indicative of high compressibility and consolidation[6].The climate of the region is primarily tropical monsoon, with rainfall occurring throughout most of the year, except for the months of December, January, and February, which may still experience some rainfall in certain years.

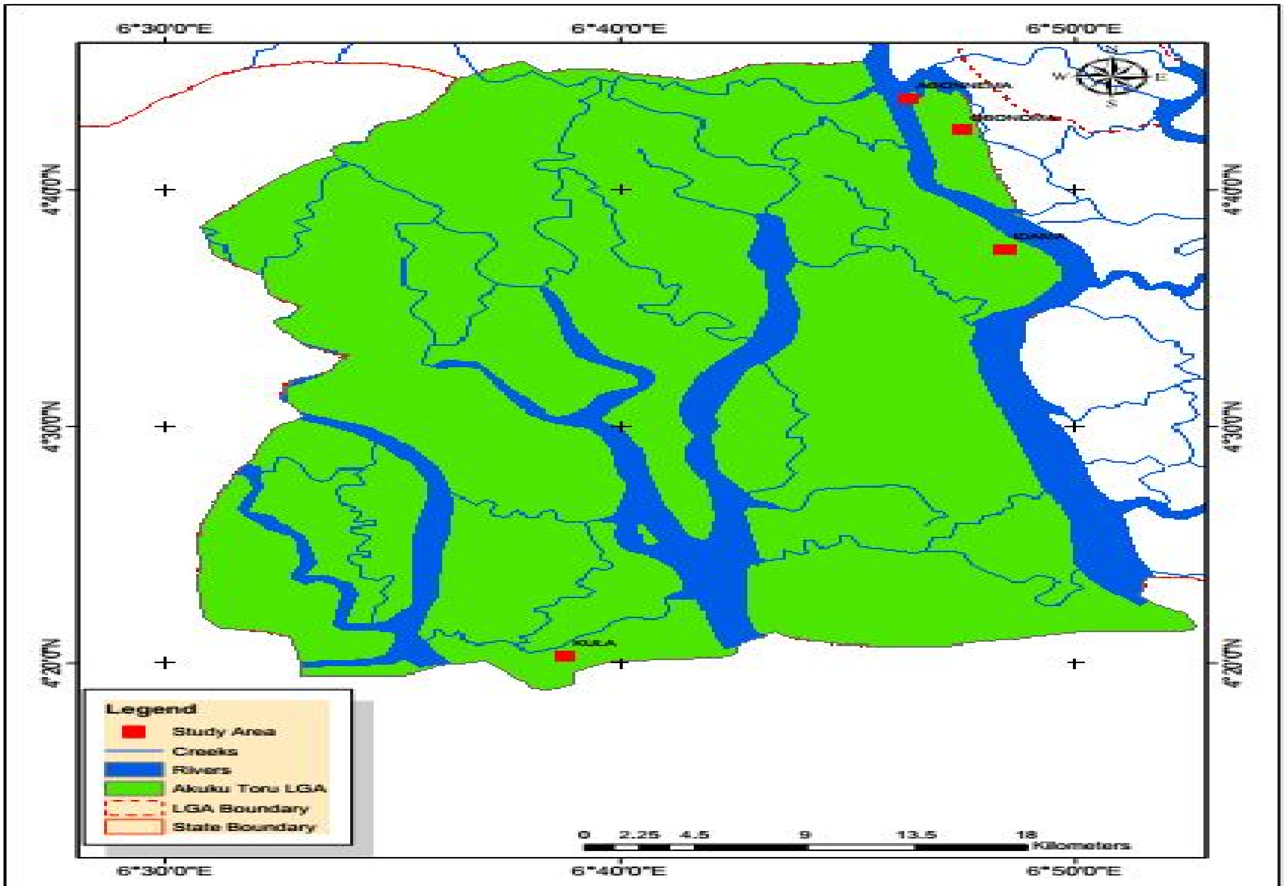

Figure1: MapofStudyArea showingsampling pointsand Rivers

Sample Collection and Preparation

Crab (*Scylla senrata*) samples were collected from Kula (oil-producing community) and Abonnema (non-oil-producing community) creeks during both low and high tide regimes. Sampling was conducted five times for each location. The crabs were placed in polythene bags immediately after collection and transported to the laboratory for processing. In the laboratory, the crab samples were oven-dried to a constant weight to remove moisture. The dried samples were then ground into a fine powder and sieved through a 2-mm mesh sieve to ensure uniform particle size. For digestion, 1 g of the powdered crab sample was treated with 5 mL of 65% nitric acid (HNO_3) and gently heated at 90°C for 1–2 hours. An additional 2.5 mL of 65% $HNO_3$was added, and the mixture was further digested until the solution became clear. The digested samples were then filtered to remove any residues, leaving a solution suitable for heavy metal analysis.

Determination of Heavy Metal Levels in Crab

The concentrations of heavy metals (Pb, Cd, Cr, Fe, Ni, Mn, Cu, and Zn) in the crab samples were analyzed using a flame atomic absorption spectrophotometer (FAAS). Prior to the analysis, the instrument was calibrated using a calibration blank and a series of five working standard solutions for each target metal. This calibration ensured the accuracy and reliability of the heavy metal measurements. The digested crab samples were analyzed in accordance with the manufacturer's guidelines and standard analytical protocols. To maintain the precision and accuracy of the results, quality control measures were implemented throughout the process. These measures included the analysis of blanks, the use of certified reference standards, and the inclusion of duplicate samples. These steps ensured the reliability and validity of the heavy metal concentration data obtained.

Health Risk Assessment of Crab (*Scylla senrata*)

The human health risks assessment was prepared using the estimated daily intakes (EDI) and target hazard quotient (THQ).

Estimation of Dietary Intake

Estimated daily intake (EDI) of heavy metals through crab consumptions were calculated using the formula:

$$EDI\ (mg/Kg - bw/day) = \frac{IRxC}{ABW}$$

Where

Where EDI = Estimated daily intake; IR = ingestion rate is 105 g/person/ day for fish and 8.3 g/person/ day for crab; C = heavy metal concentration in muscle; and ABW = average body weight is 55.9 kg [7].

Target Hazard Quotient (THQ)

The Target Hazard Quotient (THQ) represents the non-carcinogenic health risk associated with the consumption of heavy metals [8].The Target Hazard Quotient (THQ) for the heavy metals from the consumption of catfish in the study area was calculated following the guidelines recommended by USEPA[9], using the specified formula.

$$\mathrm{THQ} = 10^{-3} \mathrm{x} \frac{\mathrm{EF\ x\ ED\ x\ MI\ x\ CM}}{\mathrm{ORD\ x\ BW\ x\ AT}}$$

Where EF = Exposure frequency (365 days/year);

ED is the exposure duration (51.86 years), which corresponded to average life expectancy of a Nigerian;

AT = averaging exposure time for non-carcinogens(365 days/year x ED). The oral reference dose (ORD) is an estimate of daily exposure to human population (including sensitive sub-group) that is likely to be without an appreciable risk of deleterious effect during life time. 10^{-3} is the unit conversion factor.

The oral reference doses (ORDs) (mg/kg/day) utilized in the study were as follows: Cd (0.001), Cu (0.04), Zn (0.3), Ni (0.02), Pb (1.5), and Fe (0.7), as established by Osakwe *et al.*[10] and USEPA, [9].The Target Hazard Quotient (THQ) has a benchmark value of 1. A calculated THQ value of less than 1 indicates minimal or no non-carcinogenic health risk, whereas a value equal to or greater than 1 suggests a potential for non-carcinogenic adverse health effects from fish consumption [11].

Statistical Analysis of Experimental Data

Data were analyzed using SPSS software (version 21.0). Descriptive statistics were presented as mean ± standard deviation.

RESULTS AND DISCUSSION

Heavy Metal Distribution in crab (*Scylla senrata*)

The levels of heavy metals in crab(*Scylla senrata)* collected from Abonnema (non-oil producing community, NOPC) and Kula (oil producing community, OPC) at both low and high tides were compared to the World Health Organization (WHO) and Federal Environmental Protection Agency (FEPA) guidelines for fish are presented in Table 1. The observed levels of heavy metals in *Scylla senrata* from both oil-producing (Kula) and non-oil-producing (Abonnema) communities reveal significant environmental and health implications. From the results, ron (Fe) concentrations were highest at low tide in Kula (146.8 ± 0.4 mg/kg) compared to Abonnema (125.6 ± 0.3 mg/kg), with similar trends at high tide. These values exceed the permissible limits set by WHO [12] and FEPA [13], highlighting potential risks of iron overload, which can lead to oxidative stress and organ damage in humans [14]. Lead (Pb) concentrations were alarmingly high, particularly in Kula at low tide (38.28 mg/kg), far exceeding the 2.0 mg/kgWHO [12] and FEPA [13] limit. Even at high tide, lead levels remained substantially elevated, reflecting significant environmental pollution likely linked to oil activities. Nickel (Ni) concentrations ranged from 3.62 ± 0.1 mg/kg in Abonnema (high tide) to 6.45 ± 0.3 mg/kg in Kula (low tide), also exceeding the WHO [12] and FEPA [13] permissible limit of 2.0 mg/kg. Elevated nickel levels pose risks of allergic reactions, respiratory issues, and potential carcinogenic effects with prolonged exposure [15]. Manganese (Mn) concentrations were higher in Kula (71.43 ± 0.6

mg/kg) than in Abonnema (65.27 ± 0.5 mg/kg) at low tide, surpassing the safe limit of 0.5 mg/kg. Elevated manganese levels suggest anthropogenic influences, potentially from industrial discharge and oil exploration activities. Zinc (Zn) levels were within permissible limits of of 3.0 mg/kg, with the highest concentration recorded at high tide in Kula (13.98 ± 0.3 mg/kg). Although zinc is an essential micronutrient, excessive accumulation can disrupt homeostasis and cause gastrointestinal disturbances [16]. Copper (Cu) concentrations exceeded the recommended WHO [12] and FEPA [13] safe limit (3.0 mg/kg) in all samples, with the highest value observed at low tide in Kula (27.95 ± 0.5 mg/kg). Elevated copper levels can lead to liver and kidney damage, with bioaccumulation further magnifying the risks [17]. Cadmium (Cd) levels in Kula crabs (2.00 ± 0.05 mg/kg at high tide) far exceeded the permissible limit of 0.5 mg/kg.Chromium (Cr) levels were relatively lower, with concentrations ranging from 0.21 to 0.28 mg/kg at low tide and <0.001 mg/kg at high tide. While these values appear minimal compared to other metals, the cumulative effects of multi-metal contamination cannot be overlooked.

Table 1: Heavy Metals Level of Crab (*Scylla senrata*) obtained at Low and High Tide

Sample ID	**Fe (mg/kg)**	**Pb (mg/kg)**	**Ni (mg/kg)**	**Mn (mg/kg)**	**Zn (mg/kg)**	**Cu (mg/kg)**	**Cd (mg/kg)**	**Cr (mg/kg)**
LOW TIDE								
ABO (NOPC)	125.6 ± 0.3	8.3 ± 0.1	5.43 ± 0.2	65.27 ± 0.5	11.68 ± 0.1	25.69 ± 0.4	1.25 ± 0.03	0.21 ± 0.01
KUL (OPC)	146.8 ± 0.4	38.28 ± 0.5	6.45 ± 0.3	71.43 ± 0.6	12.66 ± 0.2	27.95 ± 0.5	1.71 ± 0.05	0.28 ± 0.02
HIGH TIDE								

ABO (NOPC)	94.7 ± 0.2	16.04 ± 0.3	3.62 ± 0.1	42.79 ± 0.4	13.48 ± 0.2	18.5 ± 0.2	1.29 ± 0.03	<0.001 ± 0.001
KUL (OPC)	111.9 ± 0.3	16.55 ± 0.2	6.26 ± 0.2	45.27 ± 0.3	13.98 ± 0.3	26.23 ± 0.3	2.00 ± 0.05	<0.001 ± 0.001
MaximumLimitWHO/ FEPA (mg/kg)	0.5	2.0	2.0	0.5	30	3.0	0.5	-

Key:NOPC:Non-oilproducingcommunity.OPC:Oilproducingcommunity.ABO=Abonnema;KUL=Kula

From the findings, the heavy metal contamination in crabs from the oil-producing community (Kula) was more pronounced compared to the non-oil-producing community (Abonnema), with significantly higher levels observed during low tide. This trend highlights the impact of oil exploration and other anthropogenic activities on aquatic ecosystems.

Target Hazard Quotient (THQ)

The estimated Target Hazard Quotient (THQ) of heavy metals through the consumption of crabs collected from non-oil producing and oil producing communities in Rivers state are shown in Table 2. A THQ value below 1 indicates no significant health risk, whereas a value exceeding 1 suggests potential health risks [3]. For iron (Fe), the THQ values were the lowest among the metals, ranging from 0.00109 (high tide, Abonnema) to 0.00171 (low tide, Kula). Lead (Pb), despite its high concentration, showed relatively low THQ values, with the highest being 0.01826 at low tide in Kula. This indicates that Pb, while present at concerning levels, does not individually constitute a significant health risk through dietary exposure.Nickel (Ni) exhibited THQ values higher than Pb, ranging from 0.01642 (high tide, Abonnema) to 0.02929 (low tide, Kula), reflecting a slightly higher risk but still below the threshold of 1.0. Cadmium (Cd) showed notable THQ values, particularly in Kula during high tide (0.03364), consistent with its elevated concentration levels.

Table 2: Target Hazard Quotient (THQ) values for heavy metals in crab samples (Low and High Tide)

Sample ID	**Fe**	**Pb**	**Ni**	**Zn**	**Cu**	**Cd**	**Cr**
LOW TIDE - ABO (NOPC)	0.00144	0.00398	0.02461	0.00044	0.00129	0.02106	0.00007
LOW TIDE - KUL (OPC)	0.00171	0.01826	0.02929	0.00048	0.00140	0.02878	0.00010
HIGH TIDE - ABO (NOPC)	0.00109	0.00764	0.01642	0.00052	0.00092	0.02172	<0.001
HIGH TIDE - KUL (OPC)	0.00129	0.00788	0.02839	0.00054	0.00131	0.03364	<0.001

Target hazard quotient > 1 poses threat for consumers of the species.

Although chromium (Cr) had the lowest THQ values (<0.001), the cumulative health risk of multi-metal exposure must be considered. Manganese (Mn) was not quantified in terms of THQ, but its elevated concentrations (as discussed in Table 1) warrant further investigation into its potential impacts. Zinc (Zn) and copper (Cu) exhibited minimal THQ values, all well below 1, with Zn showing the lowest risk contribution (0.00044 to 0.00054) across all samples.

Notably, none of the THQ values for the metals studied exceeded 1, suggesting that, individually, the concentrations of these metals do not pose significant non-carcinogenic risks to consumers based on current exposure scenarios [3]. The results from this study suggest that the heavy metals in crab samples from the low and high tide zones in these oil-producing and non-oil-producing communities do not pose a significant health risk to consumers.

Estimation of Dietary Intake (EDI)

The Estimated Daily Intake (EDI) values of heavy metals in Crab are presented in Table 3. The findings show that the EDI for iron (Fe) in the crab samples ranges from 0.01406 to 0.02178 mg/kg-bw/day, which is well below the Tolerable Upper Intake Level (UL) of 45 mg/kg/day for adults [18]. Iron is an essential nutrient, and while excessive intake can cause toxicity, the levels observed in this study are within safe limits, suggesting that iron intake from these crabs does not pose a risk. Lead (Pb) levels in the samples range from 0.00123 to 0.00568 mg/kg-bw/day. These values are considerably lower than the recommended ADI of 0.21 mg/kg/day for lead [19]. While lead is a potent neurotoxin, the EDI values from the crabs indicate that the consumption of these crabs does not pose a significant risk from lead exposure. Nickel (Ni) concentrations in the crabs range from 0.00054 to 0.00096 mg/kg-bw/day, which is well below the recommended ADI of 0.074 to 0.100 mg/kg/day for nickel [19]. These values suggest that nickel exposure from crab consumption is within safe limits and poses no significant health risk.Copper (Cu) levels in the crab samples range from 0.00274 to 0.00415 mg/kg-bw/day, which is far below the Tolerable Upper Intake Level (UL) of 10 mg/kg/day for adults. Copper is an essential element, and while toxicity can occur at high levels, the concentrations found in the present study are significantly lower than the UL, indicating that the copper intake from these crabs poses no risk to health.

Table 3: Estimated Daily Intake (EDI) of Heavy Metals in Crab Samples (Low and High Tide)

Sample ID	Fe (mg/kg-bw/day)	Pb (mg/kg-bw/day)	Ni (mg/kg-bw/day)	Mn (mg/kg-bw/day)	Zn (mg/kg-bw/day)	Cu (mg/kg-bw/day)	Cd (mg/kg-bw/day)	Cr (mg/kg-bw/day)

LOW TIDE								
ABO (NOPC)	0.01865	0.00123	0.00081	0.00969	0.00173	0.00382	0.00019	0.00003
KUL (OPC)	0.02178	0.00568	0.00096	0.01060	0.00188	0.00415	0.00025	0.00004
HIGH TIDE								
ABO (NOPC)	0.01406	0.00238	0.00054	0.00635	0.00200	0.00274	0.00019	<0.00001
KUL (OPC)	0.01656	0.00246	0.00093	0.00672	0.00208	0.00389	0.00030	<0.00001

Manganese (Mn) concentrations, ranging from 0.00635 to 0.01060 mg/kg-bw/day, was found to be lower than the Tolerable Upper Intake Level of 11mg/kg/day for an adult.However, the levels in this study are within safe ranges, suggesting no significant health risk from manganese exposure.Cadmium (Cd) levels in the crab samples range from 0.00019 to 0.00030 mg/kg-bw/day, which is well below the recommended Average Daily Intake of 0.06 mg/kg/day. As cadmium is a toxic metal that can cause kidney damage and other health issues at higher concentrations, the observed levels in these crabs indicate that there is no significant risk associated with cadmium consumption. Finally, chromium (Cr) concentrations in the samples are very low, with values approaching detection limits, and in some cases, below detectable levels. The EDI for chromium is negligible, suggesting that there is no risk of chromium exposure from consuming these crabs. Chromium is typically toxic only at high concentrations, which were not observed in this study.

From the results, the EDI values for heavy metals in the crab samples from Abonnema and Kula creeks indicate that the levels of metals such as iron, lead, nickel, copper, manganese, cadmium, and chromium are well below the safety thresholds set by health authorities. As such, the consumption of these crabs poses no significant health risk from heavy metal exposure.

Conclusion

This study reveals concerning levels of heavy metal contamination in crabs (*Scylla senrata)*from Kula, an oil-producing community, with metals such as iron, lead, nickel, manganese, cadmium, and copper significantly exceeding the WHO/FEPA limits, especially at low tide while zinc and chromium were within permissible limits. Despite these elevated concentrations, the Target Hazard Quotient (THQ) values for all metals remained below 1, indicating no immediate non-carcinogenic health risks. Furthermore, the Estimated Daily Intake (EDI) values were well within safe limits, suggesting that, at present, consumption of these crabs does not pose a significant health threat. However, the persistent presence of toxic metals in the environment raises alarms about the long-term ecological and health implications, particularly in areas influenced by industrial activities like oil exploration. Continued monitoring is recommended to assess long-term environmental and health impacts.

Conflict of interest: The authors declares that there is no conflict of interest.

Disclaimer (Artificial intelligence)
Option 1:
Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.
Option 2:
Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology
Details of the AI usage are given below:
1.

2.
3.

References

1. Sanyaolu VT, Omotayo AI, Adetoro FA. Potential health risk assessment of bioaccumulation of heavy metals in freshwater organisms from Ojo river, Lagos, Nigeria. *Journal of Applied Sciences and Environmental Management*. 2022 May 31;26(5):885-892.
2. Otitoloju AA, Don-Pedro KN. Bioaccumulation of heavy metals (Zn, Pb, Cu and Cd) by Tympanotonusfuscatus var. radula (L) exposed to sublethal concentrations in laboratory bioassay. *West African Journal of Applied Ecology*. 2002;3(1).
3. USEPA. Risk-based concentration table. Philadelphia PA:United States Environmental Protection Agency, 2000.
4. Otokunefor TV, Obiukwu C. Impact of refinery effluent on the physicochemical properties of a water body in the Niger delta. *Applied ecology and environmental research*. 2005 Dec 1;3(1):61-72.
5. Onuoha SC, Anelo PC, Nkpaa KW. Human health risk assessment of heavy metals in snail (*Archachatinamarginata*) from four contaminated regions in Rivers State, Nigeria. *Am Chem Sci J*. 2016;11(2):1-8.
6. Ideriah TJ, David-Omiema S, Ogbonna DN. Distribution of heavy metals in water and sediment along Abonnema Shoreline, Nigeria. *Resources and Environment*. 2012;2(1):33-40.
7. Liu Q, Liao Y, Xu X, Shi X, Zeng J, Chen Q, Shou L. Heavy metal concentrations in tissues of marine fish and crab collected from the middle coast of Zhejiang Province, China. *Environmental Monitoring and Assessment*. 2020 May;192:1-12.
8. Njoga EO, Ezenduka EV, Ogbodo CG, Ogbonna CU, Jaja IF, Ofomatah AC, Okpala CO.

Detection, distribution and health risk assessment of toxic heavy metals/metalloids, arsenic, cadmium, and lead in goat carcasses processed for human consumption in South-Eastern Nigeria. *Foods*. 2021 Apr 8;10(4):798.

9. United States Environmental Protection Agency (2021). Risk based concentration table. Available online: https://epa-prgs.ornl.gov/cgibin/chemicals/csl_search (accessed on 18 January 2021).
10. Osakwe JO, Adowei PE, Horsfall M. Heavy metals body burden and evaluation of human health risks in African catfish (*Clariasgariepinus*) from Imo River, Nigeria. *Acta Chimica&Pharmaceutica Indica*. 2014 Oct 8;4(2):78-89.
11. Adamu SG, Saidu AS, Adamu AI, Sadiq MA, Jajere SM, Mohammed S, Tijjani AO, Musa HI, Usman UB, Thaddeus AL. Detection, distribution, and health risk assessment of heavy metals in wild catfish sold in Maiduguri Metropolis of Borno State, Northeastern Nigeria. *NigerianVeterinary Journal*. 2023;44(2):48-58.
12. WHO (World Health Organization). (2003). Guidelines for Drinking Water Quality. Vol 1. Recommendation, WHO. Geneva 130p
13. Federal Government Protection Agency (FEPA). (2003). Guidelines and Standards for Environmental Pollution Control in Nigeria. 238p.
14. Chowdhury S, Mazumder MJ, Al-Attas O, Husain T. Heavy metals in drinking water: occurrences, implications, and future needs in developing countries. *Science of the total Environment.* 2016 Nov 1;569:476-488.
15. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*. 2014 Jun 1;7(2):60-72.

16. Prasad AS. Discovery of human zinc deficiency: its impact on human health and disease. *Advances in Nutrition*. 2013 Mar 1;4(2):176-190.

17. Sharma RK, Agrawal M. Biological effects of heavy metals: an overview. *Journal of Environmental Biology*. 2005 Jun 1;26(2):301-313.

18. Institute of Medicine, Food and Nutrition Board (2001). Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. NAP, Washington, USA.

19. Olufunmilayo, F., & Olubunmi, E. Target Cancer Risk And Other Potential Human Health Risk Assessments Of Heavy Metals Intake Via Consumption Of Catfish (*Clariabuthupogon*) Collected From River Oluwa And River Owena, Southwestern Nigeria. *International Research Journal of Modernization in Engineering, Technology and Science*. 2024;6(1): 1284-1292.

20. Tripathi, Kaushlendra Mani, Deo Kumar, and Suraj Mishra. 2024. "Effect of Contamination of Heavy Metals in Soil and Its Mitigation Strategies: A Review". International Journal of Plant & Soil Science 36 (7):135-46. https://doi.org/10.9734/ijpss/2024/v36i74715.

21. Sarma ,Hridesh Harsha, Arnab Rajkumar, Ankita Baro, Bikash Chandra Das, and Nilabh Talukdar. 2024. "Impact of Heavy Metal Contamination on Soil and Crop Ecosystem With Advanced Techniques to Mitigate Them". Journal of Advances in Biology & Biotechnology 27 (6):53-63. https://doi.org/10.9734/jabb/2024/v27i6865.