The University of Tehran Press

Pollution

Print ISSN: 2383-451X
Online ISSN: 2383-4501

https://jpoll.ut.ac.ir/

Health Risk Index of Trace Metals in Wild and Pond-Raised African Catfish from Wudil, Kano State, Nigeria

Rasheed Olatunji Moruf✉ | Idris Uba Muhd | Zahrau Rabiu Mudi | Salisu Ibrahim

Department of Fisheries and Aquaculture, Faculty of Agriculture, Bayero University, Kano, Nigeria

Article Info

Article type:
Research Article

Article history:
Received: 22 March 2025
Revised: 30 May 2025
Accepted: 6 September 2025

Keywords:
Risk Assessment
Trace Metal. African Catfish
Wudil Town
Nigeria

ABSTRACT

The research evaluated the concentration of trace metals and the associated human health risk in muscle tissue of wild and pond-raised African Catfish (Clarias gariepinus) using different standard analytical methods. The results detailed the metal concentrations with significant higher values of Cr (0.041 mg kg^{-1}) and Mn (0.113 mg kg^{-1}) observed in the wild fish, while Cu (0.024 mg kg^{-1}), Pb (0.015 mg kg-1) and Fe (3.301 mg kg^{-1}) were significantly higher ($P < 0.05$) in pond-raised C. gariepinus. Furthermore, all metals except Fe were below the FAO/WHO recommended permissible levels. Notably, Fe levels in wild C. gariepinus (2.615±0.10 mg kg^{-1}) and pond-raised (3.301±0.31 mg kg^{-1}) were higher than the recommended 0.05 mg kg^{-1}, potentially influenced by sediment Fe content and pond water sources. Analysis of daily metal intake (DIM) and health risk index (HRI) revealed that consumers of wild and pond-raised C. gariepinus in Wudil were not exposed to high doses of trace metals (Cd, Co, Cr, Cu, Mn, Pb, and Zn) across all age categories, with levels consistently below FAO/WHO acceptable limits. For instance, DIM results indicated daily Cd intake ranging from 0.0006 to 0.0016 mg kg^{-1} day^{-1} for wild C. gariepinus consumers and 0.0008 to 0.0010 mg kg^{-1} day-1 for pond-raised ones, resulting in HRI ratios below one (1) for each age category. These findings suggest that, despite elevated Fe concentrations, the consumption of C. gariepinus from the studied sources poses minimal health risk related to trace metal exposure.

Cite this article: Moruf, R.O., Uba Muhd, I., Rabiu Mudi, Z., & Ibrahim, S. (2025). Health Risk Index of Trace Metals in Wild and Pond-Raised African Catfish from Wudil, Kano State, Nigeria. *Pollution*. 11(4), 1384-1392. https://doi.org/10.22059/poll.2025.392469.2856

DOI: https://doi.org/10.22059/poll.2025.392469.2856

INTRODUCTION

Fish remains the most affordable source of animal protein for the average Nigerian, contributing approximately 50% of the total animal protein intake, and with the growing global population and rising demand for protein sources, aquaculture emerges as a pivotal industry in meeting nutritional needs (Fakoya et al., 2021). Amid growing concerns about food safety and environmental sustainability, aquaculture practices are coming under increasing scrutiny (Onyidoh et al., 2018). Alongside the expansion of aquaculture, questions arise regarding the potential health implications associated with consuming farmed fish compared to their wild counterparts

The increasing industrialization, urbanization, and agricultural activities in the study area have resulted in the release of various pollutants, including industrial effluents and toxic discharges containing trace metals into surrounding aquatic ecosystems, raising significant concerns about the safety of consuming fish from both wild and pond-raised sources (Verdegem et al., 2023). In addition, there has been growing concern over the presence of trace metal contaminants

*Corresponding Author Email: *tunjimoruf@gmail.com*

in aquatic environments and their potential impacts on human health and the environment. For instance, studies in Nigeria have reported elevated levels of heavy metals such as lead, cadmium, and mercury in water bodies and fish, particularly in industrial and urban areas (Moruf et al., 2022; Ajiboye *et al*., 2025), aligning with global trends of rising trace metal pollution and its associated ecological and public health risks (Kolarova and Napiórkowski, 2021; USEPA, 2022). Trace metals such as lead, cadmium, mercury, and arsenic can become toxic when accumulated in aquatic environments, where they bioaccumulate in organisms especially fish, posing serious human health risks (e.g., neurological and kidney damage, developmental issues, and cancer) and causing ecological harm through food chain disruption, water chemistry alteration, sediment contamination, and biodiversity loss (Onyidoh et al., 2018). The presence of trace elements in aquatic environments, arising from both natural sources and anthropogenic activities, underscores the necessity of assessing their concentrations in fish species intended for human consumption, as these elements occur in various chemical forms (e.g., free ions, complexes with organic/inorganic ligands, or adsorbed onto particles) (Dey et al., 2024).

Health risk assessment plays a crucial role in evaluating the potential risks posed by trace metal contaminants in fish and informing regulatory measures to protect public health. According to Sobhanardakani et al. (2018), the health risk index serves as a crucial metric for evaluating the potential health hazards posed by trace element exposure through fish consumption. Incorporating factors such as metal accumulation levels, bioavailability, and toxicological thresholds, this index provides valuable insights into the safety of consuming aquatic products, while the total health quotient offers a comprehensive assessment of nutritional quality and safety by integrating multiple trace elements into a single metric for comparative analysis (Moruf, 2021).

Several studies have highlighted the accumulation of trace metals in captured fish as a significant concern, primarily due to the associated risks to food safety, public health, and the integrity of aquatic ecosystems (Abalaka, 2015; Abdulrahman et al., 2018; Sani et al., 2020). This issue is particularly relevant for African catfish (*Clarias gariepinus*), a freshwater species that is widely consumed across many regions of Africa. Its popularity—especially in West Africa (e.g., Nigeria), East Africa (e.g., Kenya), and Southern Africa (e.g., South Africa)—is driven by its rapid growth rate, resilience, and high market demand (FAO, 2018; Ogunbambo, 2020). Given its widespread consumption, the contamination of *C. gariepinus* by trace metals poses a direct threat to human health and calls for continuous monitoring and regulation. However, there is a scarcity of information on safety assessments of trace metals accumulation in wild and pond raised catfish in Nigeria. The present work seeks to compare the levels of trace metal contamination and associated health risks between wild-caught and pond-raised African catfish, highlighting potential human exposure pathways through fish consumption and emphasizing the roles of bioaccumulation and biomagnification in trace metal transfer within the aquatic food web.

MATERIALS AND METHODS

Sample collection and preparation

Live specimens of *C. gariepinus* were collected from River Wudil (wild) and a commercial fish farm (pond-raised) in Wudil Town (11°49’N, 8°5’E), Kano State, Nigeria. The area is located approximately 44 km southeast of Kano city (Isma’il and Abubakar, 2015).

The fish were captured using gill nets from the river and harvested manually from concrete ponds at the farm. Sampling focused on minimizing post-mortem changes that could alter tissue metal levels. The collected fish were carefully handled to minimize stress and contamination during transport. Once captured, the specimens were washed thoroughly with distilled deionized water to remove any adhering debris or surface contaminants. Proper species identification

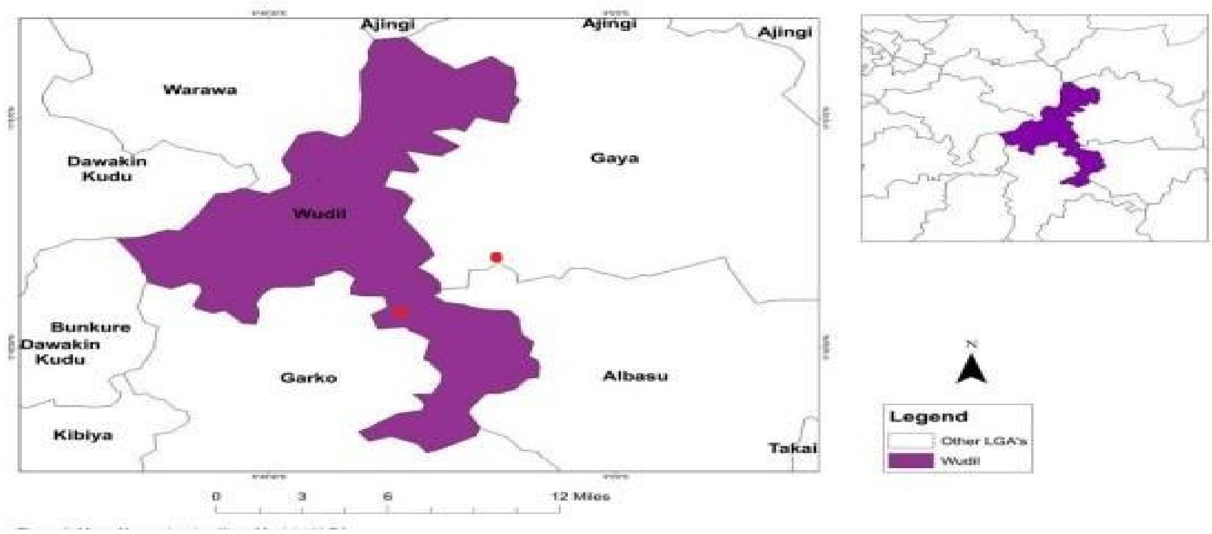

Fig. 1. Map of the study area (Wudil Town), showing sampling location (on red)

was conducted using the FAO identification guide (Schneider, 1990) to confirm taxonomic accuracy. The fish were then placed in aerated containers or transported in water-filled containers, maintaining their physiological state before laboratory processing. Upon arrival at the Department of Fisheries and Aquaculture, Bayero University, the fish were either sacrificed ethically using humane procedures, such as stunning or anesthesia, to minimize suffering before tissue sampling.

Analytical procedures

In this study, the muscle tissue of *C. gariepinus* was analyzed for trace metal concentrations, as muscle is the primary edible portion consumed by humans and serves as an indicator of potential health risks. Fish samples were first dissected to isolate muscle tissue, which was then oven-dried at 105°C until a constant weight was obtained. The dried samples were homogenized into a fine powder using a clean mortar and pestle to ensure uniformity before digestion. Tissue digestion was performed using concentrated nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) in a 3:1 ratio, following AOAC (2005) guidelines. Approximately 1.0 g of homogenized tissue was digested on a hot plate at 120 °C until a clear solution was obtained. The mixture was heated gradually on a hot plate at 120°C until complete digestion was achieved, as indicated by a clear solution. The digested samples were then cooled, filtered using Whatman No. 42 filter paper, and diluted to a final volume with deionized water before metal analysis.

Trace metal concentrations were determined using an Atomic Absorption Spectrometer (AAS) (Model: CELiL, CE2021, U.K.), calibrated with certified standard solutions to ensure accuracy. Instrumental conditions were optimized for each metal, including appropriate lamp currents, slit widths, and wavelength settings, following standard analytical guidelines. To maintain quality control and quality assurance, reagent blanks were prepared and analyzed alongside samples to account for potential contamination. Additionally, certified reference materials (CRM) were used to validate the accuracy and precision of the analytical procedure, and all measurements were conducted in triplicate to ensure reproducibility. Standard operating procedures were followed throughout to minimize errors and maintain data integrity. Daily intake of metals (DIM) and health risk index (HRI) for all the trace metals were determined using the formula specified in equations (I)– (IV) as described by Akinsorotan *et al.* (2022)

$$Daily\,intake\,of\,metals\left(DIM\right)=\frac{\left(\text{Cmetal}\times\ \text{Dfish}\times\ \text{Cfactor}\right)}{Bo} \tag{1}$$

Where C_{metal} = Concentration of heavy metal in Fish, D_{fish} = Daily nutritional intake of fish, B_o = Average Body Weight. C_{factor} = Conversion of fresh fish to dry constant weight factor calculated as,

$$\text{Cfactor} = \text{IRww} - \text{IRdw} \tag{II}$$

$$IRww=\frac{\text{IRdw}\left[\left(100-\ \text{W}\right)\right]}{100} \tag{III}$$

Where IR_{dw} = Dry weight intake rate, IR_{ww} = Wet weight intake rate, W = Percentage of water content in raw muscles (where 64.8% for *C. gariepinus* was used in this study). Thus, the C_{factor} was calculated as 0.352 using the above formulas, where the daily nutritional requirement was 100 g for adults (18 years and above with average body weight of 70 kg), 80 g for teenagers (6 – 18 years, with mean body weight of 48 kg) and 60 g for children (less than 6 years, with average body weight of 19 kg), as recommended by Portier *et al*. (2007).

$$Health\,Risk\,Index\left(HRI\right)=\frac{\text{DIM}}{\text{RfD}} \tag{IV}$$

Where RfD is the reference daily dose (mg $kg^{-1}d^{-1}$) while Bo is the mean bodyweight of the population. A HRI value of one (1) and less depicts a safe level and considered acceptable, however, any value above 1 is a potential heavy metal risk.

Statistical analysis

Data were tested for normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test). Where assumptions were met ($P > 0.05$), independent sample t-tests were used to compare metal concentrations between wild and pond-raised groups at $\alpha = 0.05$. Statistical analyses were performed using SPSS version 20.

RESULTS AND DISCUSSION

Concentration of Trace Metal

The concentration of trace metal in wild and pond-raised Africa Catfish (*C. gariepinus*) is presented in Table 1. The wild fish had 0.011 ± 0.75 mg kg^{-1} Cd while the same pond-raised species contained 0.009 ± 0.31 mg kg^{-1} of Cd concentration. The difference in Cd level of wild and pond-raised counterpart showed no statistically significant difference ($P > 0.05$). A similar trend was observed for Co and Zn, which also recorded higher concentrations in pond-raised *C. gariepinus*, with respective values of 0.029 mg kg^{-1} and 0.255 mg kg^{-1}. Significant higher values of Cr (0.041 mg kg^{-1}) and Mn (0.113 mg kg^{-1}) were observed in the wild fish, while Cu (0.024 mg kg^{-1}), Pb (0.015 mg kg^{-1}) and Fe (3.301 mg kg^{-1}) were significantly higher in pond-raised *C. gariepinus.* The difference might be as a result of variety of factors including environmental conditions, dietary sources and human activities (Ahmadi et al., 2015; Radwan et al., 2022). Wild-caught fish mainly eats debris, plankton, invertebrate and smaller fish, whereas pond-reared fish is mostly fed with man-made diets and commercial fish feed. According to Khawar et al. (2024), these dietary habits of fish play a crucial role in the accumulation of nutrients and trace metals within the fish, as different food sources can have varying levels of these elements. The result is comparable to the report of Onyidoh et al. (2018), on the heavy metal concentration in wild and farmed catfish from Kaduna State, Nigeria.

Table 1. Mean concentration of trace metal (mg kg^{-1}) in wild and pond-raised African catfish, *Clarias gariepinus*

Heavy metal	Wild Fish	Pond-Raised Fish	*P-Value*
Cadmium (Cd)	0.011±0.75	0.009±0.31	0.1046
Cobalt (Co)	0.004±0.23	0.029±0.51	0.8273
Chromium (Cr)	0.041±0.31[a]	0.006±0.23[b]	0.0495*
Copper (Cu	0.024±0.22[a]	0.113±0.10[b]	0.0463*
Manganese (Mn)	0.113±0.50 [a]	0.098±0.12[b]	0.0495*
Lead (Pb)	0.008±0.03[a]	0.015±0.50[b]	0.0495*
Zinc (Zn)	0.146±0.52	0.255±0.13	0.8248
Iron (Fe)	2.615±0.10[a]	3.301±0.31[b]	0.0463*

Table 2. Daily intake of metal (DIM) and health risk index (HRI) of individual's responses for trace metals in muscle tissue of wild African Catfish, *Clarias gariepinus*

Trace Metal	Mean±SD (mg.kg^{-1})	Individual Category	DIM (mg.kg-1 day^{-1})	HRI
Cd	0.011±0.75	Adult (18 years and above)	0.0016	0.9128
		Teenager (6-17years)	0.0013	0.9274
		Children (1-5 years)	0.0010	0.9557
Co	0.004±0.23	Adult (18 years and above)	0.0006	0.0193
		Teenager (6-17years)	0.0005	0.0154
		Children (1-5years)	0.0003	0.0116
Cr	0.041±0.31	Adult (18 years and above)	0.0059	0.0040
		Teenager (6-17years)	0.0047	0.0032
		Children (1-5years)	0.0036	0.0024
Cu	0.024±0.22	Adult (18 years and above)	0.0035	0.0869
		Teenager (6-17years)	0.0028	0.0695
		Children (1-5years)	0.0021	0.0521
Mn	0.113±0.50	Adult (18 years and above)	0.0164	0.1169
		Teenager (6-17years)	0.0131	0.0935
		Children (1-5years)	0.0098	0.0701
Pb	0.008±0.03	Adult (18 years and above)	0.0012	0.2896
		Teenager(6-17years)	0.0009	0.2317
		Children (1-5years)	0.0007	0.1738
Zn	0.146±0.52	Adult (18 years and above)	0.0211	0.0705
		Teenager (6-17years)	0.0169	0.0564
		Children (1-5years)	0.0127	0.0423
Fe	2.615±0.10	Adult (18 years and above)	0.3786	0.5409
		Teenager (6-17years)	0.3029	0.4327
		Children (1-5years)	0.2272	0.3246

Table 3. Daily intake of metal (DIM) and health risk index (HRI) of individual's responses for trace metals in muscle tissue of pond-raised African Catfish, *Clarias gariepinus*

Trace Metal	Mean±SD ($mg.kg^{-1}$)	Individual Category	DIM (mg.kg-1 day^{-1})	HRI
		Adult (18 years and above)	0.0008	0.7903
Cd	0.009±0.31	Teenager (6-17years)	0.0010	0.9425
		Children (1-5 years)	0.0008	0.7819
		Adult (18 years and above)	0.0025	0.0849
Co	0.029±0.51	Teenager (6-17years)	0.0034	0.1120
		Children (1-5years)	0.0025	0.0840
		Adult (18 years and above)	0.0005	0.0004
Cr	0.006±0.23	Teenager (6-17years)	0.0007	0.0005
		Children (1-5years)	0.0005	0.0003
		Adult (18 years and above)	0.0099	0.2481
Cu	0.113±0.10	Teenager (6-17years)	0.0131	0.3272
		Children (1-5years)	0.0098	0.2454
		Adult (18 years and above)	0.0086	0.0615
Mn	0.098±0.12	Teenager (6-17years)	0.0114	0.0811
		Children (1-5years)	0.0085	0.0608
		Adult (18 years and above)	0.0013	0.3293
Pb	0.015±0.50	Teenager(6-17years)	0.0017	0.4344
		Children (1-5years)	0.0013	0.3258
		Adult (18 years and above)	0.0224	0.0746
Zn	0.255±0.13	Teenager (6-17years)	0.0295	0.0985
		Children (1-5years)	0.0222	0.0738
		Adult (18 years and above)	0.2899	0.4141
Fe	3.301±0.31	Teenager (6-17years)	0.3824	0.5463
		Children (1-5years)	0.2868	0.4097

Health Risk Assessment

The associated human health risk of wild and pond-raised *C. gariepinus* for adults, teenagers and children are presented in Tables 2 and Table 3. All the metals except iron were below the permissible level recommended by FAO/WHO (Food, and Agricultural Organization/World Health Organization, 2011). Specifically, Fe in wild *C. gariepinus* (2.615±0.10 mg kg^{-1}), and pond-raised (3.301±0.31 mg kg^{-1}) were lower than the recommended 30 mg kg^{-1} (wet weight). The lower level of Fe may be attributed to the sediment Fe content and the water supplying the ponds. *C. gariepinus* can bioaccumulate trace metals in bottom sediments being bottom dwellers (Sani et al., 2020). Despite potential bioaccumulation of trace metals by *C. gariepinus,* the Fe levels recorded were lower than those reported for other catfish species in the region. The Fe content recorded in this study was not up to 68.7 mg kg^{-1} reported in sharp-tooth catfish in River Niger, Nigeria (Ekere et al., 2018). Iron, essential for various physiological functions, showed elevated levels possibly due to its role in oxygen transport. However, excessive Fe intake can lead to adverse health effects such as increased pulse rate and blood coagulation.

The analysis of daily intake of metal (DIM) and health risk index (HRI) showed that the population of wild and pond- raised *C. gariepinus* consumers in Wudil are not exposed to high doses of trace metals (Cd, Co, Cr, Cu, Mn, Pb and Zn) in all individual age category, as they were all below the FAO/WHO acceptable limits. For instance, the DIM results showed individuals' daily loading of Cd to be 0.0006 - 0.0016 $mg.kg^{-1}$ and 0.0008 - 0.0010 $mg.kg^{-1}$ for the wild and pond-raised *C. gariepinus* respectively. These recordings corresponded to HRI ratio of less than one (1) in each of the age category. Relative to the recommended daily intake values, as specified in this study, the results justify that the individuals are not exposed to any high dosage of cadmium with the consumption of fish muscles. Same is applicable to other trace metals investigated in this study. However, the DIM and HRI recorded in this study were higher than the results reported in farmed *C. gariepinus* (Burchell, 1822) in Zaria, Kaduna State, Nigeria (Onyidoh *et al*., 2018). Similarly, the present result corresponds to the report of Kortei et al. (2020), where human health risk assessment from trace metal exposure through the consumption of *C. anguillaris* from Ankobrah and Pra basins for both children and adults showed no significant non-carcinogenic adverse health risk to humans since all calculated values for Hazard Quotient (HQ) were <1.

CONCLUSION

The levels of all examined trace metals (Cd, Co, Cr, Cu, Mn, Pb, Zn, excluding Fe) in both wild and pond-raised *C. gariepinus* were found to be below the permissible limits. The risk assessment of human health concerning trace metal exposure indicated no significant risk from consuming *C. gariepinus* within the FAO/WHO limits. However, it is recommended to improve aquaculture practices for pond-raised fish in the region, and environmental regulations should enforce proper treatment of industrial wastes before discharge into water bodies to further reduce contamination risks.

COMPLIANCE WITH ETHICAL STANDARDS

This study was not funded. There are no conflicts of interest that are relevant to the content of this article that the authors must disclose.

DATA AVAILABILITY

This published article contains all of the data generated.

AUTHORS' CONTRIBUTIONS

All the authors Moruf Rasheed Olatunji, Muhd Idris Uba, Mudi Zahrau Rabiu and Salisu Ibrahim contributed equally to the manuscript.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

Abalaka, S. E. (2015). Heavy metals bioaccumulation and histopathological changes in *Auchenoglanis occidentalis* fish from Tiga dam, Nigeria. *Journal of Environmental Health Science and Engineering*, 13, 1-8.

Abdulrahman, M. B., Abdullahi, N. S., Mustapha, M., & Dansista, R. H. (2018). Assessment of some heavy metals accumulation in some fish species consumed in Kano metropolis. *International Journal of Advanced Academic Research | Sciences, Technology & Engineering*, 4(4), 120-126.

Ahmadi, Z., Yazdi, A., & Akrami, R. (2015). Seasonal Variation of Heavy Metal (Pb) in Fish (*Liza aurata*), Sediment and Water Samples from the Gomishan Wetland. *Environmental Sciences*, 13(2), 49-56.

Ajiboye, O. R., Lawal-Are, A. O., Obiakara-Amaechi, A. I., & Moruf, R. O. (2025). Preliminary ecological risk assessment of toxic elements in fish cage culture sites within the interconnected Epe and Badagry Lagoons, Nigeria. *Acta Natura et Scientia*, 6(1), 1-11.

Akinsorotan, A. M., Jimoh, J. O., Omobepade, B. P., Adene, I. C., & Olasunkanmi, J. B. (2022). Health risk assessment of heavy metals in earthen pond raised African catfish (*Clarias gariepinus*) in Lagos State, Nigeria. *International Journal of Innovation and Sustainable Development*, 16(1), 49-60.

AOAC (2005). Official methods of analysis. 18th Ed., International, Gaithersburg, MD, Chapter 49, Method. 959.08, pp 79–80.

Dey, S., Rajak, P., & Sen, K. (2024). Bioaccumulation of metals and metalloids in seafood: A comprehensive overview of mobilization, interactive effects in eutrophic environments, and implications for public health risks. *Journal of Trace Elements and Minerals*, 100141.

Ekere, N. R., Yakubu, N. M., & Ihedioha, J. N. (2018). Assessment of levels and potential health risk of heavy metals in water and selected fish species from the Benue-Niger River Confluence, Lokoja, Nigeria. *Journal of Aquatic Food Product Technology*, doi: org/10.1080/10498850.2018.1499061.

Fakoya, K. A., Abiodun-Solanke, A. O., & Mangai, E. O. (2021). Implications of production, post-harvest and consumption of fish on food and nutrition security: Nigeria as a focal country. Food Security and Safety: African Perspectives, 355-374..

FAO (2011). The state of world review of fisheries and aquaculture. Part 1, 2012, http://www.fao.org/docrep/016/i2727e/i2727e01.pdf.

FAO (2018). Agriculture Organization of the United Nations. Fisheries Department. The state of world fisheries and aquaculture. Food and Agriculture Organization of the United Nations.

Isma'il, M., & Abubakar, S. (2015). Geospatial Analysis of Landuse/Landcover Change in Wudil Town of Kano State, Nigeria. *International Journal of Scientific Research in Environmental Sciences*, 3(5), 189-197.

Khawar, M., Masood, Z., Hasan, H., Khan, W., De los Ríos-Escalante, P. R., Aldamigh, M. A., & Said, M. B. (2024). Trace metals and nutrient analysis of marine fish species from the Gwadar coast. *Scientific Reports*, 14(1), 6548.

Kolarova, N., & Napiórkowski, P. (2021). Trace elements in aquatic environment. Origin, distribution, assessment and toxicity effect for the aquatic biota. *Ecohydrology & Hydrobiology*, 21(4), 655-668.

Kortei, N. K., Heymann, M. E., Essuman, E. K., Kpodo, F. M., Akonor, P. T., Lokpo, S. Y., & Tettey, C. (2020). Health risk assessment and levels of toxic metals in fishes (*Oreochromis noliticus* and *Clarias anguillaris*) from Ankobrah and Pra basins: Impact of illegal mining activities on food safety. *Toxicology Reports*, 7, 360-369.

Moruf, R. O. (2021). Target hazard quotient evaluation of selected trace elements in highly consumed crustacean species in Lagos, Nigeria. *Acta Scientiarum (Biological Sciences)*, 43, 1-9.

Moruf, R. O., Durojaiye, A. F., & Okunade, G. F. (2022). Metal contamination and health risks in West African Mud Creeper (*Tympanotonos fuscatus* var *radula*) from Abule-Agele Creek, Nigeria. *Bulletin of Environmental Contamination and Toxicology*, 108(2), 351-358.

Ogunbambo, M. M. (2020). Seasonal and Temperature Dependent Variations in Proximate Parameters and Mineral Elements of Smoke-Dried Catfish (*Clarias gariepinus*, Burchell, 1822) using Traditional and

Eco-Friendly Kilns in Lagos, Nigeria. *Journal of Applied Sciences and Environmental Management*, 24(4), 639 - 643.

Onyidoh, H. E., Ismail, F. M., Muhammad, A. M., & Idris, J. A. (2018). Risk assessment of heavy metals in wild and farmed *Clarias gariepinus* (Burchell, 1822) in Zaria, Kaduna state, Nigeria. *Greener J. of Agric. Sci,* 8, 12-21.

Portier, K., Tolson, R., & Roberts, S.M. (2007). Body weight distributions for risk assessment. *RiskAnalysis*, 27 (1): 11–26.

Radwan, M., Abbas, M. M. M., Afifi, M. A. M., Mohammadein, A., Al Malki, J. S. (2022). Fish parasites and heavy metals relationship in wild and cultivated fish as potential health risk assessment in Egypt. *Frontiers in Environmental Science*, 10, 890039.

Sani, A., Ahmad, M. I., & Abdullahi, I. L. (2020). Toxicity effects of Kano central abattoir effluent on *Clarias gariepinus* juveniles. *Heliyon*, 6(7): 1-7.

Schneider W. (1990). Field guide to commercial marine resources of the Gulf of Guinea. Food and Agricultural organization of the United, Rome, Italy. 186 p.

Sobhanardakani, S., Tayebi, L., & Hosseini, S. V. (2018). Health risk assessment of arsenic and heavy metals (Cd, Cu, Co, Pb, and Sn) through consumption of caviar of *Acipenser persicus* from Southern Caspian Sea. *Environmental Science and Pollution Research*, 25, 2664-2671.

USAID (2014). Markets, increasing competitiveness and food security in Nigeria. p78.

USEPA (2022). National Water Quality Inventory Report to Congress. U.S. Environmental Protection Agency. p86

Verdegem, M., Buschmann, A. H., Latt, U. W., Dalsgaard, A. J., & Lovatelli, A. (2023). The contribution of aquaculture systems to global aquaculture production. *Journal of the World Aquaculture Society*, 54(2), 206-250.