Bioaccumulation of heavy metals in Oreochromis niloticus from Ngamo Dam, Zimbabwe

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ABSTRACT

Background: Environmental pollution from heavy metals poses a global public health concern, especially in developing countries with intensive mining and poor waste management. In Zimbabwe, freshwater bodies such as Ngamo Dam are at risk of contamination, affecting aquatic organisms and human consumers. This study aimed to investigate the levels of cadmium (Cd), copper (Cu), lead (Pb), manganese (Mn), and zinc (Zn) in Oreochromis niloticus (O. niloticus) and water samples from Ngamo Dam to assess their safety for human consumption.

Methods: Water and fish samples were collected from three sites in Ngamo Dam between January and February 2024. Fish gills and muscles were prepared using wet acid digestion, while water samples were digested with nitric acid. Metal concentrations were analyzed using Atomic Absorption Spectrophotometry (AAS). Statistical analysis was performed using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test to determine significant differences among sampling sites ($p < 0.05$).

Results: Water samples showed heavy metal concentrations exceeding World Health Organization (WHO) and Standards Association of Zimbabwe (SAZ) permissible limits: Pb (5.21–10.30 mg/L), Cu (5.67–8.56 mg/L), Mn (2.96–4.34 mg/L), Zn (2.15–3.67 mg/L), and Cd (1.34–3.23 mg/L). In O. niloticus gills, the order of accumulation was Cu > Zn > Pb > Cd > Mn, with Cu reaching 11.44 mg/kg. Muscles showed lower but significant accumulation, with Cu (5.87–12.62 mg/kg) and Pb (1.39–4.19 mg/kg) being prominent. Pb levels in water exceeded WHO limits by up to 10 times, while Cd exceeded permissible limits by approximately 6 times. Both water and fish samples contained heavy metal concentrations above recommended safety thresholds. A summary of all concentrations is provided in Table 1.

Conclusion: The findings reveal high levels of heavy metal bioaccumulation in Ngamo Dam water and fish, rendering them unsafe for human consumption. Continuous monitoring, implementation of remediation strategies, and strict regulation of anthropogenic activities around the dam are necessary to protect public and ecological health. Authorities should consider bioremediation and improved waste management practices to reduce contamination.

Keywords: Pollution, Bioaccumulation of heavy metal, Environmental health, Carcinogenic heavy metals, Water pollution

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BACKGROUND

Heavy metals are naturally occurring elements with high atomic weight, density, and melting point, known for their toxicity even at low concentrations (1).

They are chemically stable and non-biodegradable, enabling them to persist in the environment, accumulate in biological tissues, and biomagnifies along the food chain. Their persistence in aquatic ecosystems leads to bioaccumulation in fish and other organisms, posing significant risks to both ecological and public health (2).

Globally, heavy metal contamination of freshwater systems has become a major environmental concern due to increasing industrialization, urbanization, and agricultural expansion. These pollutants can alter the physicochemical properties of water and affect aquatic biodiversity, particularly fish species that serve as an essential protein source for humans (3, 4).

Oreochromis niloticus (Nile tilapia) is one of the most widely distributed freshwater fish species and a vital component of human diets in many developing countries. Its global demand has increased due to its high nutritional value—it is rich in protein, omega-3 fatty acids, vitamins (D and B2), and essential minerals such as calcium, phosphorus, iron, zinc, iodine, magnesium, and potassium (3, 4). However, the species' wide distribution and feeding habits make it an effective bioindicator for assessing heavy metal pollution in aquatic environments.

Heavy metals enter aquatic ecosystems through both natural and anthropogenic processes. Natural sources include weathering of rocks and volcanic activity, whereas human activities such as mining, smelting, electroplating, agriculture, and improper waste disposal contribute the most significant inputs (5). Common contaminants include cadmium (Cd), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), lead (Pb), nickel (Ni), and zinc (Zn) (6). Exposure to elevated levels of these metals has been linked to enzyme inhibition, oxidative stress, DNA damage, endocrine disruption, organ dysfunction, and carcinogenic effects in both aquatic organisms and humans (7). The severity of these effects depends on metal type, concentration, bioavailability, and duration of exposure.

In Zimbabwe, several studies have reported bioaccumulation of heavy metals in fish from water bodies such as Lake Chivero, Lake Manyame, and Lake Kariba (8, 9). Elevated metal concentrations have been associated with mining and industrial activities, particularly in areas with poor waste management and limited environmental regulation (10). This situation raises concerns for smaller reservoirs and dams such as Ngamo Dam, located in Gweru, where similar anthropogenic pressures may exist.

The present study was therefore conducted to evaluate the bioaccumulation of selected heavy metals Pb, Cd, Mn, Cu, and Zn in *O. niloticus* and water from Ngamo Dam, Zimbabwe. The objective was to determine the concentrations of these metals in fish tissues and water and to assess their safety for human consumption according to the WHO and SAZ guidelines (11, 12).

MATERIALS AND METHODS

Sample collection

Water and fish sample were collected from Ngamo Dam which located between latitude 19° 31' 0" S and longitude 29° 43' 59" E. The dam is in agro-ecological region 3 which receives mean annual rainfall range 650 to 700 mm. The dam was built to provide water for domestic uses, irrigation, and wildlife consumption. Samples were collected between January and February 2024. The samples were collected from three sites within the Ngamo Dam. The first site was located at the upper course of the dam, the second sites at the middle course. and the third site at the lower course of the dam.

Water samples were collected 30 cm below the water surface. Three water samples were collected from each site. The samples were placed in sterile polythene bottles, acidified with 10% nitric acid (pH=2.5) to prevent metal crystallization, and keep metal ions in the dissolved state, and prevent microbial activities (13). The water samples were kept in an ice cooler-box to maintain them at a temperature below 4 °C during transfer from the field to the laboratory (14). Gill nets were used to catch fish samples. The nets were set over night at each site and five *O. niloticus* were selected at each site. A total of 15 fish samples were collected and transported to the laboratory in a cooler box. Upon arrival, the fish samples were cleaned using deionized water and stored in the refrigerator prior to heavy metal analysis (15).

Preparation of solutions

Stock solutions

Lead stock solution was prepared by dissolving 1.60 g of lead nitrate [Pb (NO3)2] in 100 ml of deionized water before diluting to 1Lt in a volumetric flask with deionized water forming a colorless solution. For copper, 2.52 g of CuSO4 $3H_2O$ was dissolved in 250 ml of deionized water and diluted to 1litter in a volumetric flask with deionized water to form a blue solution. For manganese, 1.45g of $MnCl_2$ was weighed using an analytical balance and transferred into a beaker. For Zn, 4.40 g of ZnSO4: 7H20 was mixed with deionized water in 100 ml standard flask and transferred to 1000 ml volumetric flask which was diluted to the mark using deionized water. Cadmium stock solution was prepared by dissolving 1.372 g of Cd (NO_3) in deionized water then diluting to 1 L in a volumetric flask (16).

Standard solution

Atomic Absorption Spectrophotometer (model number AA320N) was used in this experiment. The AAS instrument calibration standards were prepared by diluting standard (1000 ppm) which was prepared for all five metals. The stock solutions were used to calculate the required volumes for concentrations of 10, 20, 30 and 40 ppm in final volumes of 100 ml. the serial dilution formula was used as follows: $C_1V_1 = C_2 V_2$ where C_1 (standard concentration of 1000 ppm), V_1 is volume to be calculated, C_2 (different concentrations of 10, 20, 30, 40ppm, V_2 is the volume of the volumetric flask (100 ml). The calculated volumes of all metals were transferred into 100ml. volumetric flask which was later diluted using deionized water (17).

Digestion procedure

Water samples were filtered through 0.45 mm Whattman membrane filter paper. The filtrate was then acidified with concentrated HNO_3 to a pH of < 0.05). The filtrate was heated using hotplate at 120 ^oC until the volume was reduced to 5 ml. The concentrated solution was transferred into a 100 ml volumetric flask and diluted to the mark using deionized water)18). The wet acid digestion method was used for fish samples. A combination of sulfuric acid, nitric acid, and perchloric acid was used. Muscles and gills of each fish sample were separately dissected using stainless steel, then dried in hot air oven until no mass change and finally ground using pestle and mortar. The sample was sieved after grinding and packed in labelled sample plastics (19). One gram (1g) of each fish sample was measured into 250 ml conical flask and mixed with 10 ml of sulfuric acid. The mixture was left in fume hood for 16 h, then heated at 120 ^oC until brown color evolved. The sample was cooled before adding 5 ml of nitric acid and heated for 60 min. After cooling to room temperature, 3 ml of perchloric acid was added, followed by heating. Then it was heated until its volume was reduced to 5 ml .Finally, it was filtered into 100 ml volumetric flasks which were diluted to the mark using deionized water. The same procedure was done on all the samples (20).

Statistical analysis

Data were analysed using IBM SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA). Metal concentration data were expressed as mean ± standard deviation (SD). Differences in metal concentrations among the three sampling sites were tested using one-way ANOVA. When significant differences were detected ($p < 0.05$), Tukey's Honestly Significant Difference (HSD) post hoc test was applied for pairwise comparisons. Pearson correlation analysis was conducted to assess relationships between metal concentrations in water and fish tissues (gills and muscles). All statistical analyses were performed at a 95% confidence level, and graphical presentations were prepared using Microsoft Excel 2021.

RESULTS

Concentration of heavy metals in the Ngamo Dam water

Lead recorded the highest concentration at all sites ranging from 5.21 mg/L to 10.30 mg/L (Figure 1). The highest concentration was recorded at site 3. There was a significant difference in the concentration of lead found in the different site ($p< 0.05$). Cadmium and zinc recorded low concentrations in all the studied sites compared to other metals. The highest concentration of cadmium was recorded at site 3 with a concentration of 3.2 ppm and the lowest concentrations at site with a concentration of 1.34ppm. Zinc concentration ranged from 2.15 ppm to 3.67 ppm with site 2 recording the highest concentrations. The concentrations of copper and manganese were high at site 3 and 2, respectively. Site 1 had low concentrations of both metals. There were significant differences in metal concentrations at different sites. Lead had the highest concentration and cadmium recording the lowest in the following order Pb>Cu>Mn>Zn>Cd.

Table 1: Concentrations of heavy metals (mg/L for water; mg/kg for fish tissues) in water and *Oreochromis niloticus* from Ngamo Dam, Zimbabwe

Metal	WHO/SAZ Limit (mg/L or mg/kg)*	Water (mg/L)	Gills (mg/kg)	Muscles (mg/kg)	Exceedance Factor (Water)**
Pb	0.01	5.21–10.30	3.04–4.53	1.39–4.19	520–1030×
Cu	2.00	5.67–8.56	8.50–11.44	5.87–12.62	2.8–4.3×
Mn	0.50	2.96–4.34	1.02–2.15	0.84–1.56	5.9–8.7×
Zn	3.00	2.15–3.67	2.74–5.66	2.51–4.64	Within–1.2×
Cd	0.005	1.34–3.23	0.36–0.85	0.36–0.85	268–646×

**WHO-World Health Organization and SAZ- Standards Association of Zimbabwe permissible limits for drinking water (WHO, 2011; SAZ, 2009); **Exceedance factor = measured concentration ÷ permissible limit*

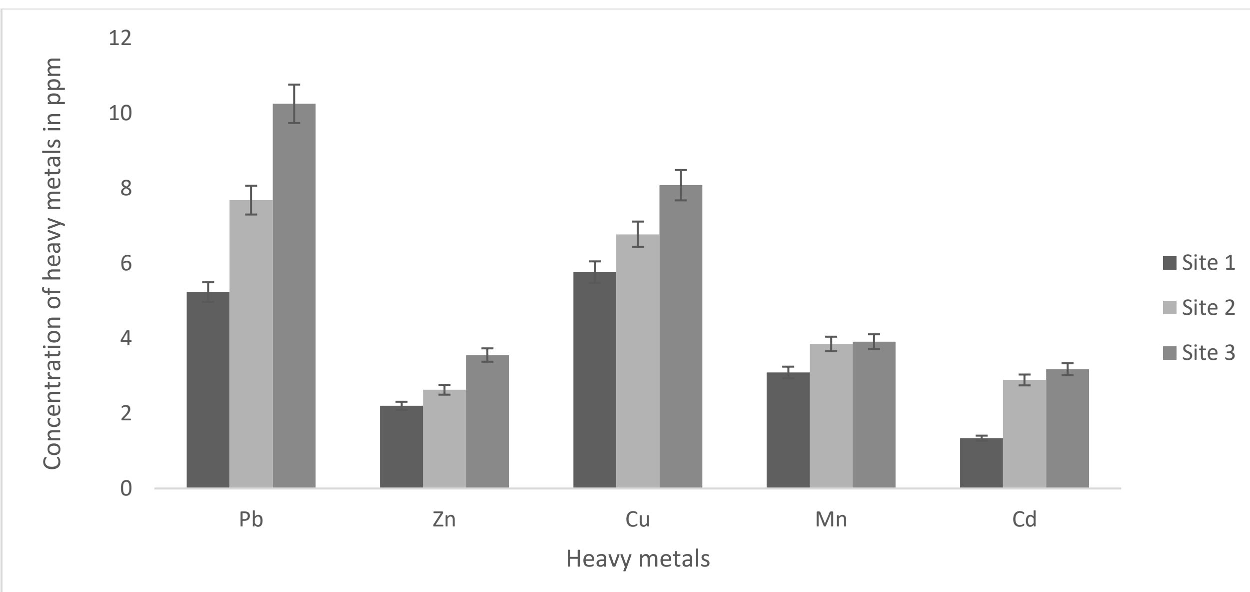

Figure 1: The concentration of heavy metals in Ngamo Dam sampled at three different sites in the dam measured in part per million (ppm) using an AAS machine

Concentration of heavy metals in fish gills

O. niloticus gills had high concentrations of copper ranging from 8.5mg/kg to11.43mg/kg. The highest concentration was recorded at Site 1 while the lowest was recorded at Site 3. There was no significant difference in the concentrations at Site 2 and Site 3 ($p<0.05$). Lead concentrations ranged from 3.04-4.53mg/kg across the three sites. There was no significant difference in zinc concentration among the three sites. Manganese and cadium had the least concentrations recorded in the *O. niloticus* gills (Fig 2).

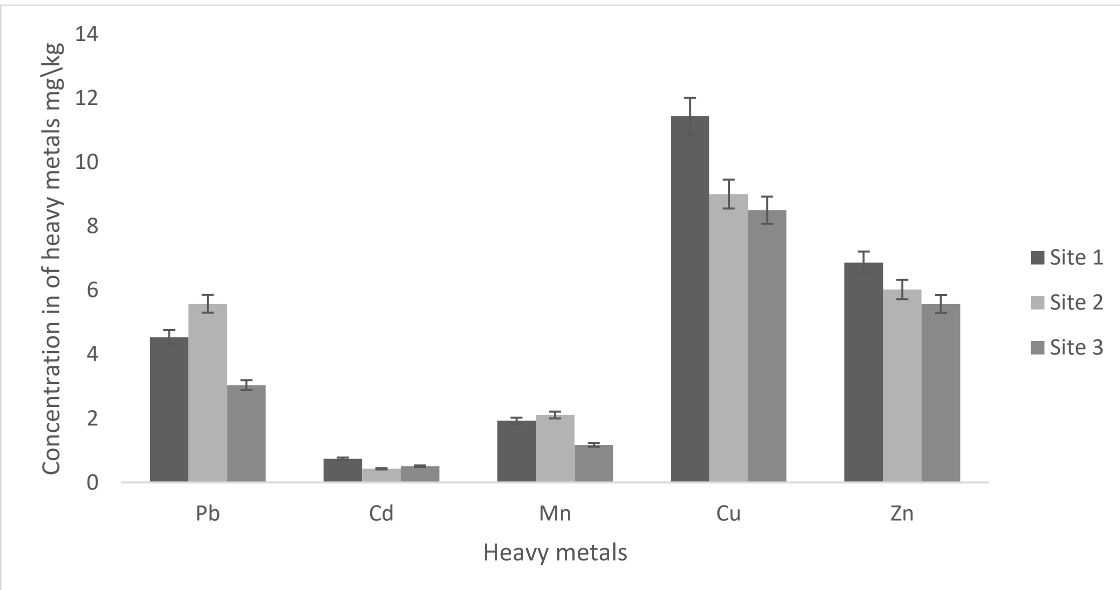

Figure 2: The concentration of heavy metals in the gills of *O. niloticus* fish harvested at three different sites in the Ngamo Dam measured in mg/kg using an AAS machine

Heavy metals in the muscles of *O. niloticus*

In the *O. niloticus* muscles, copper had the highest concentrations, and canadium showed the lowest. Copper had concentrations ranging from 5.87-12.62mg/kg, whereas canadium concentrations ranging from 0.36-0.85 mg/kg. Significant differences were noted among the site (p<,0.05), for all heavy metals, except for manganese, which showed no significant differences between site 1 and site 2. Lead had concentrations ranging from 1.39-4.12mg/kg and zn concentrations ranged from 2.51-4.64mg/kg (Fig 3).

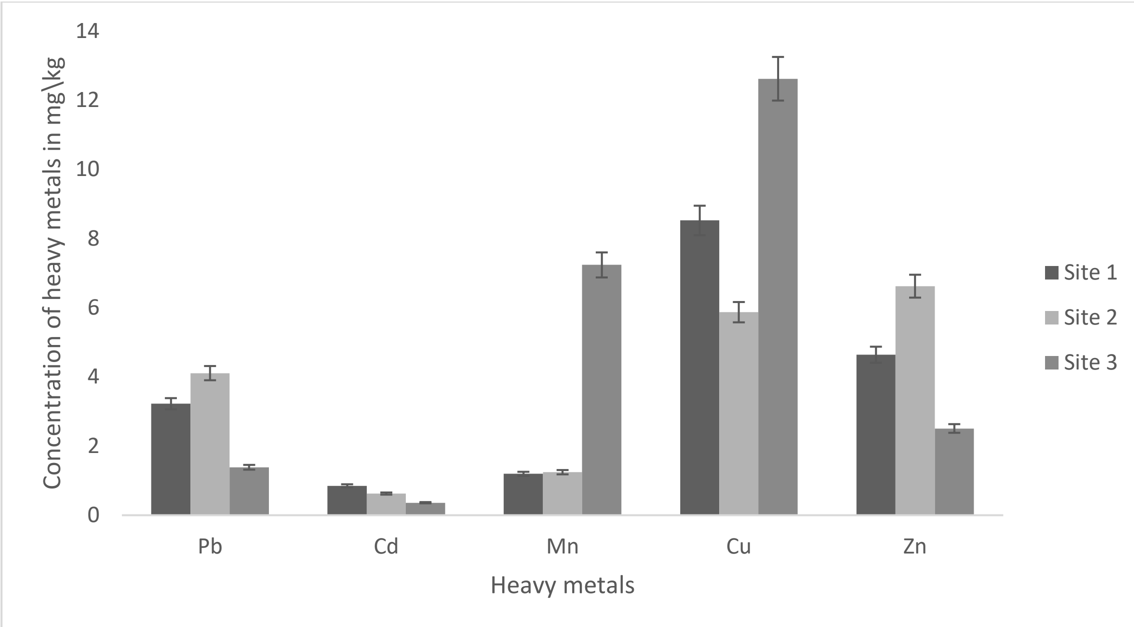

Figure 3: The concentration of heavy metals in the muscles of *O. niloticus* fish harvested at three different sites in the Ngamo Dam measured in mg/kg using an atomic absorption spectroscopy (AAS) machine

DISCUSSION

Fish are valuable nutritional resources, providing high-quality protein, omega-3 fatty acids, and essential minerals such as calcium, phosphorus, iron, and zinc. However, their nutritional benefits can be compromised by environmental contamination, particularly heavy metal pollution. Due to their non-biodegradable nature and tendency to bioaccumulate and bio-magnify, heavy metals pose serious ecological and health threats (21).

The present study revealed that water samples from Ngamo Dam contained Pb, Cd, Cu, Mn, and Zn concentrations exceeding the WHO and SAZ permissible limits for drinking water. Lead recorded the highest concentrations (5.21–10.30 mg/L), exceeding the WHO limit by up to 1030 times, followed by copper (5.67–8.56 mg/L) and manganese (2.96–4.34 mg/L). The high levels of Pb and Cd are indicative of contamination from anthropogenic activities, such as agricultural runoff, mining, sewage discharge, and industrial effluents, all of which have been identified as major pollution sources in Zimbabwean freshwater systems (22, 25).

The elevated metal levels in Ngamo Dam are consistent with findings from other contaminated water bodies in Zimbabwe, such as Lakes Chivero and Manyame, where Pb and Cd were reported to exceed WHO standards (23, 24). Continuous discharge of untreated waste into the dam likely contributes to the accumulation of these metals, threatening both aquatic life and human health.

Fish readily absorb and bio-accumulate metals through their gills, skin, and alimentary tract. In this study, *O. niloticus* gills exhibited the highest accumulation of Cu (8.50–11.44 mg/kg), followed by Zn, Pb, Cd, and Mn. The high Cu and Pb concentrations in gills can be attributed to direct exposure to dissolved metals in water during respiration. This finding agrees with (13), who reported similar accumulation patterns in tilapia from industrial regions of China.

Muscle tissues showed comparatively lower metal concentrations, but Pb and Cu still exceeded WHO/FAO recommended safety limits for fish consumption. These results mirror those of (21), who observed elevated Cu and Pb levels in fish from Lake Kariba, and (15), who reported significant bioaccumulation in edible fish tissues in Rwanda. The order of accumulation observed in this study (Cu > Zn > Pb > Cd > Mn) reflects the bioavailability and essentiality of certain metals Cu and Zn being essential micronutrients that tend to accumulate more readily than non-essential toxic metals such as Pb and Cd.

The bioaccumulation of toxic metals such as Pb and Cd in *O. niloticus* poses serious risks to both aquatic ecosystems and human consumers. Chronic exposure to these metals has been linked to neurological, renal, cardiovascular, and developmental disorders (10). Lead exposure, even at low levels, can cause developmental impairments in children and increase the risk of miscarriage in pregnant women, while Cd is a known carcinogen associated with kidney and bone damage (9, 14).

The concentrations found in this study indicate that fish and water from Ngamo Dam are not safe for human consumption. Continuous consumption of such contaminated fish could lead to long-term bioaccumulation in humans, increasing the risk of chronic diseases. From an ecological perspective, elevated heavy metal levels can reduce fish growth, impair reproduction, and disrupt trophic balance in the aquatic food web (27).

Compared with other Zimbabwean dams, Ngamo Dam exhibits similar pollution profiles but with notably higher Pb and Cd levels, suggesting localized contamination sources. Its proximity to agricultural and peri-urban settlements likely contributes to metal runoff, similar to patterns observed in other mining-influenced catchments (7, 26).

The findings underscore the urgent need for regular monitoring, enforcement of waste management regulations, and adoption of bioremediation technologies such as phytoremediation and microbial detoxification, which have proven effective in reducing heavy metal loads in aquatic systems (8).

CONCLUSION

This study revealed that both Ngamo Dam water and *O. niloticus* contain heavy metal concentrations far exceeding the WHO (2011) and SAZ (2009) permissible limits. Lead (Pb) and cadmium (Cd) were particularly elevated, exceeding allowable concentrations by up to 1030× and 646×, respectively. The pattern of bioaccumulation in fish tissues followed the order Cu > Zn > Pb > Cd > Mn, with gills accumulating higher concentrations than muscles due to their role in respiration and direct contact with water. The results demonstrate that Ngamo Dam is heavily contaminated with potentially toxic metals derived mainly from anthropogenic activities such as agricultural runoff, domestic effluents, and industrial discharges. Consequently, fish and water from the dam are not safe for human consumption without proper treatment. Continuous monitoring and control of pollution sources are essential to safeguard public health and the ecological integrity of the dam ecosystem. The concentration of heavy metals in fish and water can vary and change over time and it is difficult to provide the exact metal levels. It is necessary to carry out further studies in different seasons, different locations, different species including plants and identify possible sources to contain and reduce toxic waste emissions into the dam. Regular monitoring is necessary and identification of other metal elements such as Arsenic, Mercury, Iron, and Chromium. etc. The development of heavy metal management framework is necessary as it proved to be efficient in other countries such as the USA and Canada.

List of abbreviations

AAS-Absorption Spectrophotometry; O. niloticus-Oreochromis niloticus; ANOVA-one-way analysis of variance; Cd-cadmium; Cu-copper, Pb-lead; Mn-manganese; Zn-zinc; SAZ-Standards Association of Zimbabwe; WHO-World Health Organization; SD-standard deviation; HSD-Honestly Significant Difference; ppm-part per million

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Author contributions

TM designed the study and supervised the work. NC, MC and TM carried out sample collection, laboratory analysis, and data processing. All authors contributed to manuscript drafting, critical review, and approved the final version for submission.

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Conflict of interest

The authors declare that they have no competing interests.

Ethical Approval

This study did not involve human participants. Ethical clearance for handling of fish samples was obtained from the Midlands State University Animal Care and Use Committee

REFERENCES

1. Jannetto, P., & Huang, Y. (2023). Toxic metals in food chains: mechanisms of accumulation and human health implications. *Critical Reviews in Environmental Science and Technology*, 53(14), 2451–2473.
2. Diaconu, D., Popescu, M., & Ionescu, G. (2020). Bioaccumulation of cadmium and lead in freshwater fish: A meta-analysis. *Ecotoxicology and Environmental Safety*, 190, 110136.
3. Tacon, A., Metian, M., & Hasan, M. (2020). Fish consumption, nutrition, and health: A global perspective. *Reviews in Fish Science & Aquaculture*, 28(2), 215–231.
4. Karageorgou, K., Petropoulos, S., & Antoniadis, V. (2023). Nutritional composition and heavy metal content of Nile tilapia (Oreochromis niloticus): A global synthesis. *Food Chemistry*, 411, 135507.
5. Jacob, J., Ndlovu, T., & Chikowore, G. (2018). Anthropogenic drivers of trace metal pollution in African inland waters. *Environmental Science and Pollution Research*, 25(23), 22764–22778.
6. Antoine, T., Collin, R., & Chowdhury, S. (2017). Toxicological effects of trace metals on aquatic organisms: A review of global case studies. *Environmental Toxicology and Chemistry, 36*(11), 2950–2963.
7. Dube, T., Manjengwa, F., & Nhiwatiwa, T. (2019). Spatial variation of heavy metals in sediments and fish from mining-impacted rivers of Zimbabwe. *Environmental Monitoring and Assessment*, 191(5), 320.
8. Ngwenya, B., Moyo, P., & Chirenje, T. (2023). Heavy metal contamination in African freshwater systems: Emerging trends and management strategies. *Environmental Research*, 231, 116028.
9. Antoine, T., Collin, R., & Chowdhury, S. (2017). Toxicological effects of trace metals on aquatic organisms: A review of global case studies. *Environmental Toxicology and Chemistry*, 36(11), 2950–2963.
10. Collin, R., Antoine, T., & Bridges, B. (2022). Human health risk assessment of heavy metal exposure through fish consumption in Sub-Saharan Africa. *Science of the Total Environment*, 832, 154980.
11. Manjengwa, F., Nhiwatiwa, T., Nyakudya, E., & Banda, P. (2019). Fish from a polluted lake (Lake Chivero, Zimbabwe): A food safety issue of concern. *Food Quality and Safety*, 3(3), 157–167.
12. Zaynab, T., Sharif, Y., & Khan, M. (2022). Current trends in heavy metal contamination of African freshwater resources. *Environmental Science and Pollution Research*, 29(45), 68244–68258.
13. Orr, M., & Bridges, B. (2017). Human exposure pathways to toxic metals through contaminated water sources. *Journal of Environmental Management, 200*, 168–177.
14. Utete, B., Nyamasoka, B., Dalu, T., & Cowden, P. (2018). Metal accumulation in two contiguous eutrophic peri-urban lakes, Chivero and Manyame, Zimbabwe. *Environmental Monitoring and Assessment*, 190(2), 109.
15. Hu, W., Li, J., & Wang, X. (2017). Assessment of heavy metal contamination and bioaccumulation in freshwater fish from industrial regions of China. *Chemosphere*, 186, 229–239.
16. USEPA. (1996). Method 1669: Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels. Washington, DC: USEPA.
17. Nteziyaremye, P., & Omara, T. (2020). Bioaccumulation of priority trace metals in edible muscles of West African lungfish (*Protopterus annectens*) from Nyabarongo River, Rwanda. *Cogent Environmental Science*, 6(1), 1779557.
18. Li, X., Zhang, Q., & Zhao, Y. (2020). Optimization of acid digestion protocols for atomic absorption spectrometry of aquatic samples. *Analytical Methods*, 12(18), 2250–2258.
19. Niederberger, S., & Spranger, T. (2020). Quality assurance in trace metal analysis of environmental samples. *Talanta*, 219, 121203.

20. Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*, 6(9), e04691.
21. Edogbo, B., Akinola, O., & Adeyemi, R. (2020). Comparative analysis of digestion methods for trace metal determination in fish tissues. *Journal of Environmental Chemical Engineering*, 8(4), 103872.
22. Chowdhury, S. (2020). Quality assurance assessment of heavy metal contamination and bioaccumulation in freshwater fish from industrial regions of Pakistan. *Science of the Total Environment*, 28(2), 215–231.
23. Simukoko, S., Phiri, C., & Banda, P. (2022). Seasonal variation of heavy metal concentrations in Lake Kariba fish species, Zambia–Zimbabwe. *Environmental Monitoring and Assessment*, 194(3), 195.
24. Sodhi, V., Mwangi, S., & Okoth, J. (2022). Influence of environmental factors on heavy metal bioaccumulation in African freshwater fish. *Ecological Indicators*, 143, 109382.
25. Liu, Y., Chen, Z., & Wang, J. (2018). Risk assessment of heavy metal exposure from freshwater fish consumption in developing countries. *Environmental Pollution*, 242, 109–118.
26. Ramos-Miras, J. J., Sánchez-Muros, M. J., Morote, E., Torrijos, M., Gil, C., Zamani-Ahmadmahmoodi, R., & Rodríguez-Martín, J. A. (2019). Potentially toxic elements in commonly consumed fish species from the western Mediterranean Sea. *Science of the Total Environment*, 671, 280–292.
27. Zamani-Ahmadmahmoodi, R., Gil, C., Ramos-Miras, J. J., Sánchez-Muros, M. J., & Rodríguez-Martín, J. A. (2019). Heavy metal exposure in Mediterranean fish and potential human health risks. *Marine Pollution Bulletin*, 149, 110512.