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Trace Element Accumulation in Fish from a Mining Pond: Implications for Food and Pharmaceutical Safety

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Abstract

Heavy metal contamination in aquatic environments, particularly from mining activities, poses serious ecological and health risks. This study quantified toxic and essential trace elements (Pb, Cd, Mn, Zn, Fe, Cr, Cu, Ni) in gill and muscle tissues of *Tilapia monodi*, *Barbus trispilopleura*, and *Rastrineobola argentea* from the Shen-Dam mining pond, Jos South, Nigeria. Analysis using ICP-OES revealed that Pb (4.61–8.31 mg/kg) and Cd (1.31–4.49 mg/kg) exceeded WHO/FAO limits by up to 27- and 90-fold, respectively, while Mn (3.44–46.00 mg/kg) and Zn (488–2081 mg/kg) also surpassed permissible thresholds. Fe (54.79–2181 mg/kg) and Ni (0.58–1.17 mg/kg) exceeded limits in most samples, whereas Cr (0.74–3.00 mg/kg) and Cu (1.88–6.06 mg/kg) remained within safe levels. Metal concentrations were highest in gills, but muscle tissues relevant for human consumption also contained Pb and Cd above safe limits. These findings indicate substantial food safety risks and highlight that environmental contamination may compromise the quality of fish-derived materials used in pharmaceuticals, underscoring the urgent need for monitoring and mitigation in mining-impacted ecosystems.

Keywords: Heavy metals, Fish, Food safety, Mining pollution, ICP-OES.

Introduction

Heavy metals are persistent environmental pollutants that bioaccumulate in aquatic organisms, particularly fish, which are widely consumed and serve as sensitive bioindicators of aquatic ecosystem health [1,2]. Mining ponds often act as sinks for toxic metals such as Pb, Cd, and Ni, leading to elevated concentrations in fish tissues that may exceed regulatory safety thresholds for human consumption [3,4]. In addition to their dietary importance, fish and fish-derived products are increasingly utilized in pharmaceutical formulations as sources of gelatin, collagen, and oils [6,7]. Contamination with heavy metals in these organisms poses a dual concern, potentially compromising both food safety and pharmaceutical quality [5]. Essential metals such as Zn, Fe, and Mn, although

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necessary for biological functions, can become toxic when present at elevated levels [2].

Fish-derived compounds, such as omega-3 fatty acids, peptides, and marine collagen, are widely employed in supplements, cardiovascular therapies, anti-inflammatory agents, and dermatological formulations [6,7]. Heavy metal contamination in fish tissues can compromise the safety and efficacy of these pharmaceutical products, as metals may induce chemical instability, reduce potency, or pose toxicological risks to consumers [7,12].

This study investigates the bioaccumulation of trace elements (Pb, Cd, Mn, Zn, Fe, Cr, Cu, Ni) in three fish species *Tilapia monodi*, *Barbus trispilopleura*, and *Rastrineobola argentea* from the mining-impacted Shen-Dam in Jos South, a site where fishing constitutes a major source of food and income for local communities. These species were selected because they are the most abundant in the pond and commonly sold in local markets, making them relevant for dietary exposure assessments and potential use in fish-derived products. No study has assessed both food and pharmaceutical risks of fish from Shen-Dam. Gill and muscle tissues were analyzed using inductively coupled plasma–optical emission spectroscopy (ICP-OES), providing insights into metal accumulation patterns and informing both public health interventions and considerations for the safety of fish-derived pharmaceutical materials [8]

Materials and Methods

Sample Collection, Preparation and Digestion

Fish samples were collected from Shen-Dam, a mining-impacted pond in Jos South LGA, Plateau State, Nigeria (Coordinates: 9.740° N, 8.896° E), which serves as a primary fishing site with catch sold at Bukuru Market. Three species—*Tilapia monodi*, *Barbus trispilopleura*, and *Rastrineobola argentea*—were selected due to their abundance in the pond and consumption by local communities. Species identification was confirmed by the Fisheries Department, University of Jos. For each species, **10 individual fish were collected**, from which **7 samples per species** were selected for analysis. Gill and muscle tissues were excised using plastic dissection tools to prevent contamination, and each tissue type was analyzed in duplicate (technical replicates). Tissues were oven-dried at 105 °C for 15 hours and stored in sterile containers until digestion. Gill tissues were chosen to reflect direct environmental exposure, while muscle tissues were analyzed for human dietary relevance.

Approximately 1.0 g of each dried tissue was digested in Teflon crucibles using 6 mL of hydrochloric acid and 2 mL of nitric acid on a sand bath at controlled temperature for 6 hours to ensure complete matrix decomposition. Following initial digestion, 2 mL of HCl and 10 mL of distilled water were added and heated for 5 minutes to complete acid recovery. The digests were filtered through Whatman No. 42

filter paper and quantitatively transferred into 100 mL volumetric flasks with distilled water. All procedures were performed in a fume hood to minimize exposure to corrosive acids. This digestion method is based on Mohammed et al. (2017) [9].

Instrumental Analysis

Trace element concentrations in gill and muscle tissues were determined using an Inductively Coupled Plasma–Optical Emission Spectrometer (ICP-OES, PerkinElmer Optima 2000 DV, USA) operated in dual-view mode with automated wavelength selection. Calibration standards were prepared according to AOAC Official Method 999.10. Blanks and duplicate analyses were included for each batch to ensure precision and accuracy [10]. Instrument calibration was verified before and after each set of measurements.

Limits of Detection and Quantification (LOD and LOQ)

LOD and LOQ were calculated using the standard deviation of the blank (SD_blank) and the slope of the calibration curve as follows: LOD = 3 × SDblank / slope, LOQ = 10 × SDblank / slope

Element	LOD (mg/kg)	LOQ (mg/kg)
Pb	0.02	0.07
Cd	0.005	0.015
Mn	0.01	0.03
Fe	0.05	0.17
Zn	0.02	0.07
Cr	0.01	0.03
Cu	0.005	0.015
Ni	0.01	0.03

The low LOD and LOQ values confirm that the analytical method was sufficiently sensitive to detect trace levels of toxic and essential metals in fish tissues [10].

Results and Discussion

Metal Concentrations in Fish Tissues

Table 2. Toxic and essential trace elements concentrations (mg/kg dry weight) in the fish tissues

Element (mg/kg wet weight)	*Tilapia monodi* (Gills)	*Tilapia monodi* (Muscle)	*Barbus trispilopleura* (Gills)	*Barbus trispilopleura* (Muscle)	*Rastrineobola argentea* (Gills)	*Rastrineobola argentea* (Muscle)	Regulatory Limit (mg/kg)
Pb	8.31 ± 0.61 ***	6.06 ± 0.38 ***	5.01 ± 1.06 ***	5.63 ± 0.29 ***	5.59 ± 0.27 ***	4.61 ± 0.31 ***	0.3 (WHO/FAO, 2021)[3]; 0.5 (EU, 2023)[4]
Cd	1.98 ± 0.01 ***	1.46 ± 0.04 ***	1.31 ± 0.07 ***	1.57 ± 0.03 ***	1.57 ± 0.11 ***	4.49 ± 0.38 ***	0.05 (WHO/FAO, 2021)[3]; 0.1 (EU, 2023)[4]
Mn	46.00 ± 0.00 ***	20.74 ± 0.05 ***	24.03 ± 0.03 ***	21.61 ± 0.22 ***	11.05 ± 0.04 ***	3.44 ± 0.00 ***	0.5–5 (ICH Q3D R2, 2022)[5]
Fe	2181.00 ± 0.005 ***	106.10 ± 0.90 ***	259.00 ± 0.18 ***	189.00 ± 1.25 ***	695.00 ± 4.81 ***	54.79 ± 0.15	50–300 (ICH Q3D R2, 2022)[5]
Zn	778.70 ± 11.27 ***	895.10 ± 3.99 ***	2081.00 ± 27.90 ***	1297.00 ± 29.70 ***	1470.00 ± 7.50 ***	488.20 ± 1.97 **	50–500 (ICH Q3D R2, 2022)[5]
Cr	3.00 ± 0.06	1.56 ± 0.05	2.22 ± 0.03	1.90 ± 0.31	1.65 ± 0.06	0.74 ± 0.01	0.2 (ICH Q3D R2, 2022)[5]
Cu	4.83 ± 0.05	1.88 ± 0.00	6.06 ± 2.42	5.03 ± 0.24	3.13 ± 0.02	3.04 ± 0.03	30 (WHO/FAO, 2021)[3]
Ni	1.17 ± 0.07 ***	0.58 ± 0.01 ***	0.72 ± 0.01 ***	0.72 ± 0.02 ***	0.61 ± 0.01 ***	0.73 ± 0.13 ***	0.2 (ICH Q3D R2, 2022)[5]

Key

Values are presented as mean ± standard deviation (mg/kg dry weight).
*** indicates values exceeding regulatory limit.

Distribution of the Metals in the Samples

Mean values and standard deviations were calculated to show variation in trace elements across species and tissues, and a bar chart with error bars was produced using the Matplotlib library in Python. The chart Figure 1 also includes regulatory safety limits as reference thresholds. This visualization clearly indicates that Pb, Cd, Mn, Zn, Fe, and Ni concentrations exceeded safe levels, particularly in gill tissues **[3,5].**

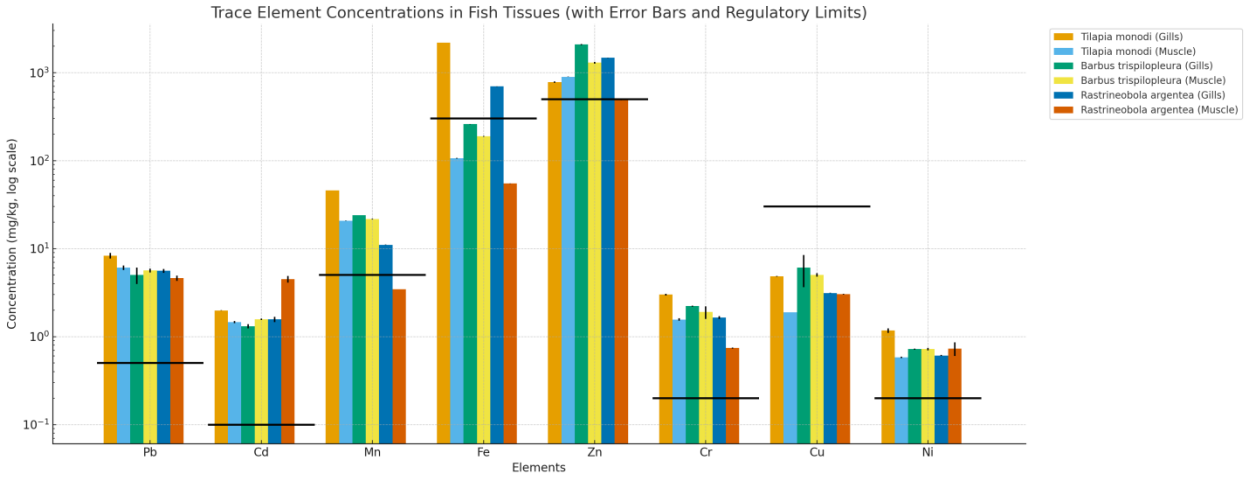


Figure 1: Distribution of Heavy and essential metals(mg/kg dry weight) in the fish tissues (error bars representing standard deviations). The black dash line across the bar graph is the regulatory limits from the table above

Discussion

The gill tissues generally exhibited higher concentrations of heavy metals than the muscle tissues. This observation aligns with previous research showing that gills, as the primary interface with the aquatic environment, readily accumulate metals through passive diffusion and active transport **[11,12].** Muscle tissues, however, also demonstrated contamination, with Cd, Pb, and Mn exceeding limits in all species [11,12]. The combined evidence suggests that mine tailings, sediment-associated metals, and runoff from abandoned mining operations are the dominant sources of heavy metal contamination in Shen-Dam. These pathways explain the disproportionately high levels of Pb, Cd, Mn, Zn, Fe, and Ni observed in the fish, especially in gill tissues. Understanding these sources is critical for designing effective remediation strategies such as sediment stabilization, tailings containment, phytoremediation, and improved watershed management.

Fish are increasingly valued not only for their nutritional importance but also for their biopharmaceutical potential. Compounds derived from fish such as omega-3 fatty acids, peptides, marine collagen, and gelatin are now widely used in pharmaceutical formulations, nutraceuticals, and cosmeceuticals. These fish-derived substances serve as excipients, drug delivery carriers, emulsifiers, and active ingredients in therapeutic products targeting cardiovascular, dermatological, metabolic, and inflammatory conditions. Muscle tissues, however, also demonstrated contamination, with Cd, Pb, and Mn exceeding limits in all species [11,12]. The pharmaceutical relevance of fish-derived products increases concern, as toxic metals can

induce instability or toxicity in drug formulations [6,7].

Pb and Cd detected in the fish samples from Shen-Dam were 6.06 mg/kg and 4.49 mg/kg, respectively, exceeding WHO/FAO maximum limits for edible fish [3]. At these levels, chronic exposure increases the risk of oxidative stress, DNA damage, and kidney toxicity [13,14].

The calculated LOD and LOQ values (Table 1) demonstrate that the ICP-OES method employed in this study possessed adequate sensitivity for detecting trace-level metals in fish tissues. For all elements, the measured concentrations were substantially above their respective LOQ values, confirming that the reported levels represent true quantifiable contamination rather than instrumental noise. The extremely low LOD values (e.g., Pb: 0.02 mg/kg; Cd: 0.005 mg/kg) further validate the ability of the method to detect even minute concentrations, allowing a reliable assessment of metal bioaccumulation in the mining pond ecosystem. Therefore, the high concentrations of Pb, Cd, Mn, Fe, Zn, and Ni observed in the gills and muscles reflect genuine environmental contamination and underscore the potential food safety and pharmaceutical risks associated with fish harvested from the site.

5. Conclusion

Fish from the Shen-Dam mining pond exhibit significant bioaccumulation of toxic elements, particularly Pb and Cd, exceeding both food safety and pharmaceutical safety limits **[3,5]**. These results emphasize the need for regular monitoring and mitigation strategies to reduce contamination in mining-impacted ecosystems.

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