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Seasonal Dynamics of Heavy Metals in Water and *Clarias gariepinus* Organs from Lake Geriyo: Implications for Environmental and Human Health

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ABSTRACT

Freshwater ecosystems worldwide are contaminated by heavy metals from industrial, agricultural, and domestic activities, which threaten aquatic biodiversity and human health through bioaccumulation in fish. Lake Geriyo, a key reservoir in northeastern Nigeria, supports local fisheries and irrigation but is exposed to anthropogenic pollutants. This study examined seasonal dynamics of zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn) in lake water and organs (gills and muscle tissue) of the catfish *Clarias gariepinus* from October 2017 to March 2019. Triplicate samples were collected monthly from three sites (lower: Station A; upper: Station B; middle: Station C) during wet (May–October) and dry (November–April) seasons. Water and tissue samples were digested with HNO₃-HClO₄ and analyzed using atomic absorption spectrophotometry. In water, Fe concentrations were highest in the wet season (6.07 ± 1.74 mg/l), exceeding the FAO/WHO (2011) limit of 0.3 mg/l, while Zn (0.11 ± 0.12 mg/l wet; 0.06 ± 0.08 mg/l dry), Cu (0.03 ± 0.02 mg/l wet; 0.11 ± 0.31 mg/l dry), and Mn (0.08 ± 0.03 mg/l wet; 0.02 ± 0.02 mg/l dry) remained compliant. In *C. gariepinus* gills and muscle, all metals were below Codex limits (Zn: 50 mg/kg; Cu: 30 mg/kg; Fe: 100 mg/kg; Mn: 0.5 mg/kg), with dry season levels generally higher than wet season levels (e.g., Zn in gills: 0.76 ± 0.56 mg/kg dry compared to 0.40 ± 0.57 mg/kg wet). No significant spatial variations occurred ($p > 0.05$). These findings indicate low human health risks from fish consumption but highlight seasonal Fe enrichment in aquatic environments, which may cause ecological stress. Recommendations include runoff management and regular monitoring to safeguard environmental and public health, aligning with SDGs 3 and 6.

INTRODUCTION

Water bodies across the globe are increasingly contaminated by industrial effluents, agricultural runoff, and domestic waste, which pose serious risks to aquatic ecosystems and human wellbeing (Bawuro *et al.*, 2018). In developing nations like Nigeria, lakes and reservoirs provide essential resources for irrigation, drinking water, and fisheries. However, these systems often suffer from pollution linked to fertilizer and pesticide applications, as well as inadequate waste disposal (Yamta *et al.*, 2015). Common contaminants include heavy metals such as mercury (Hg), arsenic (As), lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), and manganese (Mn), along with persistent organic pollutants like organochlorine pesticides (OCPs). These substances bind to sediments and accumulate in organisms, resulting in bioaccumulation and biomagnification along food chains (Maitera *et al.*, 2011).

Fish play a central role in aquatic food webs and offer vital protein for communities, especially in regions such as Nigeria. As bioindicators, fish absorb pollutants from water, sediments, and food, reflecting environmental quality (Ikem & Egiebor, 2005). Consumption of contaminated fish can lead to health issues in humans. For instance, prolonged exposure to Pb and Cd may cause kidney damage, neurological problems, reproductive issues, and heart disease (World Health Organization,

2021). OCPs, meanwhile, can interfere with hormones and raise cancer risks (Olayemi *et al.*, 2019).

Lake Geriyo in Yola, Adamawa State, northeastern Nigeria, is a multipurpose lake that supplies fish, irrigation water, and domestic needs for nearby areas (Abubakar *et al.*, 2020). Spanning about 750 ha with a fisheries-usable area of 250 ha, it hosts 34 fish species, including *Clarias gariepinus*, a bottom-dwelling catfish prone to pollutant uptake (Abubakar, 2006; Aliyu & Musa, 2022). Yet, the lake endures pressures from agricultural runoff, sewage discharge, tyre burning, mechanic wastes, and detergent use, introducing heavy metals and organics (Nasir *et al.*, 2015; Shinggu *et al.*, 2015). Prior research has noted elevated Pb, Cd, and Cu in water and fish, sometimes surpassing FAO/WHO limits (Bawuro *et al.*, 2018; Maitera *et al.*, 2011). However, few studies explore seasonal influences on metal dynamics, despite wet-season runoff likely amplifying inputs compared to dry periods. This gap limits understanding of temporal bioaccumulation patterns and risks to fish consumers. The present study addresses this by assessing Zn, Cu, Fe, and Mn in Lake Geriyo water and *C. gariepinus* gills and muscle across seasons. Objectives were to: (1) quantify seasonal and spatial metal concentrations; (2) evaluate compliance with FAO/WHO standards; (3) examine bioaccumulation in fish organs; and (4) discuss environmental and health implications.

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MATERIALS AND METHODS

Study Area

Lake Geriyo (9°7'N, 12°25'E) lies on the edge of Jimeta-Yola metropolis in Adamawa State, northeastern Nigeria (Figure 2). Covering ~750 ha with a volume of $7.5 \times 10^6 \text{ m}^3$, it originated as a gully in the 1950s, filled by rainfall and Benue River inflows, and now supports stable aquatic vegetation and diverse fish populations (Abubakar, 2006; Aliyu & Musa, 2022). The lake experiences wet (May–October; heavy rains, flooding) and dry (November–April; 20–40°C, low inflows) seasons (Kefas, 2016). Anthropogenic activities include waste dumping (Plate I), intensive farming with agrochemicals (Plate II), tyre burning (Plate III) (releasing Zn, Cd, Pb, and hydrocarbons), mechanic effluents (petroleum toxics), and phosphorus-rich detergents, all contributing to pollution via runoff and erosion (Nasir *et al.*, 2015; Shinggu *et al.*, 2015).

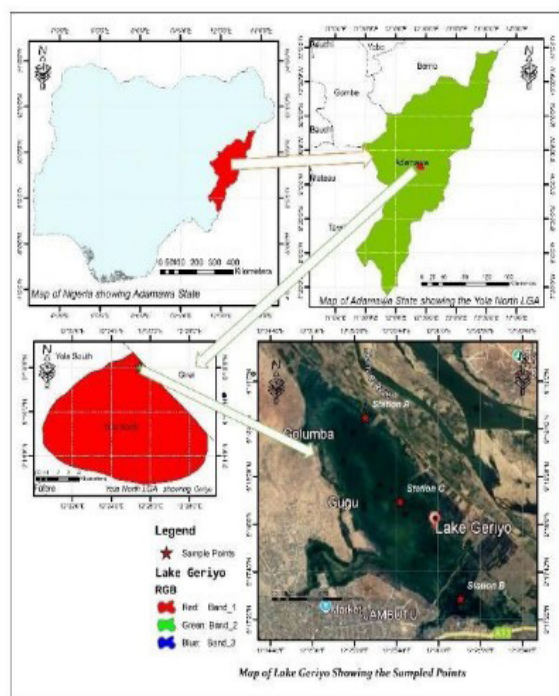


Figure 1: Map of Lake Geriyo



Plate I: Waste Dump at the Lake Site



Plate II: Intense Agricultural Activities



Plate III: Tyre Burning Activities



Plate IV: Waste Dump at the Lake Site

Data Collection / Experimental Design

Triplicate water and fish samples from *C. gariepinus* (Plate IV) were collected monthly over 18 months (October 2017–March 2019) at dawn (6:00 a.m.) from three sites: Station A (lower lake; high discharge), Station B (upper lake; low runoff), and Station C (middle lake; transitional). Water (250 ml) filled pre-rinsed bottles, preserved with MnSO_4 and KI/KOH , and transported to the Biochemistry Laboratory, Modibbo Adama University, Yola (Wakil, 2014). *C. gariepinus* ($n=30/\text{site}$, 1–2 kg) were captured by gillnets, euthanized humanely, dissected for gills and muscle, weighed wet, iced, and frozen at -20°C .

Samples (1 g tissue or water) were digested in $\text{HNO}_3\text{-HClO}_4$ (3:1 v/v) at 200°C , filtered, diluted to 50 mL, and analyzed for Zn (213.9 nm), Cu (324.8 nm), Fe (248.3 nm), and Mn (279.5 nm) using PerkinElmer Analyst 400

AAS. Quality controls included blanks, duplicates (RSD <5%), and NIST SRM 1577c (recovery 95–105%); LOD was 0.001 mg/l (water) or 0.01 mg/kg (tissue).

Data Analysis

Data were grouped by season (wet: n=7 months; dry: n=11 months). Means $\pm$ SD were calculated using SPSS v.25. One-way ANOVA with Tukey post-hoc tested seasonal and spatial differences ($p < 0.05$). Compliance followed FAO/WHO (2011): water (Zn: 5.0 mg/l; Cu: 2.0; Fe: 0.3; Mn: 0.1); fish (Zn: 50 mg/kg; Cu: 30; Fe: 100; Mn: 0.5).

RESULTS AND DISCUSSION

Heavy Metals in Water

Seasonal means revealed higher Zn, Fe, and Mn in the wet season compared to the dry season, while Cu showed the opposite trend (Figure 1). Fe reached 6.07 ± 1.74 mg/l in wet months, exceeding the 0.3 mg/l limit, likely from erosion-enhanced runoff carrying lithogenic sources (Maitera *et al.*, 2011). Zn (0.11 ± 0.12 mg/l wet) and Mn (0.08 ± 0.03 mg/l wet) also rose with precipitation, but stayed compliant. Cu's dry-season peak (0.11 ± 0.31 mg/l) may stem from reduced dilution and evapoconcentration. No spatial differences emerged ($p > 0.05$), suggesting uniform dispersion. These patterns align with Nigerian reservoirs, where wet-season Fe spikes impair gill function and primary productivity (Bawuro *et al.*, 2018).

The bar chart below visualizes seasonal variations in water heavy metal concentrations, with error bars indicating standard deviations and a reference line for the FAO/WHO (2011) Fe limit (0.3 mg/l). Colors differentiate seasons: blue for wet, orange for dry. Detailed key: X-axis shows metals (Zn, Cu, Fe, Mn); Y-axis is concentration (mg/l); bars grouped by season.

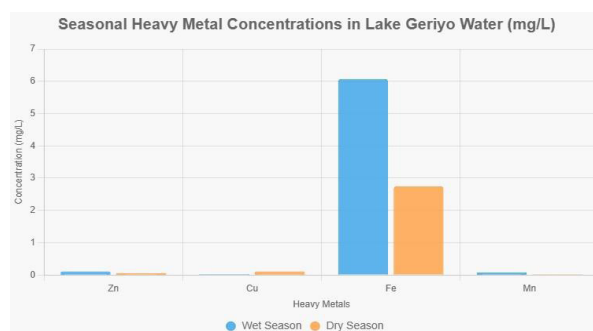


Figure 2: Mean Monthly Variation of Heavy Metals in Water from Lake Geriyo (October 2017–May 2019)

Notes: Wet season higher than dry season except for Cu. All values below FAO/WHO (2011) limits except Fe (<0.3 mg/l); low risk with seasonal monitoring advised.

Heavy Metals in *Clarias gariepinus* Organs

Metal levels in gills and muscle were compliant across seasons and sites ($p > 0.05$ for spatial effects), with dry-season concentrations generally exceeding wet-season values for Zn, Cu, and Fe (Figure 2–5). For Zn, gills averaged 0.76 ± 0.56 mg/kg dry compared to 0.40

± 0.57 mg/kg wet (Figure 2). Cu showed pronounced dry enrichment (e.g., gills at Station A: 3.12 ± 4.27 mg/kg dry compared to 0.13 ± 0.07 mg/kg wet; Figure 3). Fe followed suit (gills at Station C: 3.48 ± 2.21 mg/kg dry compared to 2.67 ± 4.10 mg/kg wet; Figure 4). Mn bucked the trend, with wet gills higher (e.g., Station A: 0.37 ± 0.33 mg/kg wet compared to 0.25 ± 0.15 mg/kg dry; Figure 5). Gills accumulated more than muscle for Cu and Fe, reflecting respiratory exposure in this benthic species (Ikem and Egiebor, 2005). Levels were lower than in regional studies (Bawuro *et al.*, 2018), indicating dilution or detoxification, but dry-season rises suggest evapoconcentration risks. Ecologically, elevated water Fe may induce oxidative stress; for humans, low tissue burdens imply minimal consumption hazards, though vulnerable groups warrant attention (Olayemi *et al.*, 2019). The following bar charts illustrate seasonal variations for each metal in *C. gariepinus* gills and muscle across stations. Each chart uses grouped bars: blue for wet season, orange for dry season. Detailed key: X-axis lists stations (A, B, C) for gills and tissue; Y-axis shows concentration (mg/kg); error bars for SD; legend distinguishes seasons and organs (gills solid, tissue striped pattern via border).

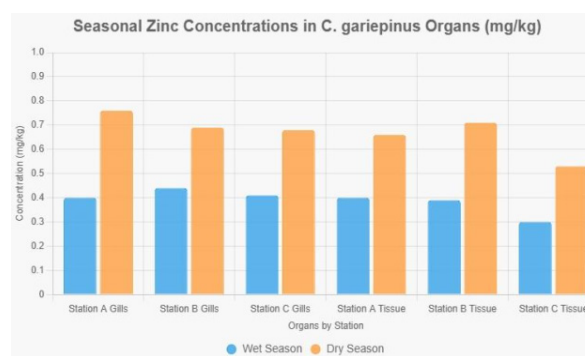


Figure 3: Mean Seasonal Variation of Zinc (mg/kg) in Gills and Tissue of *Clarias gariepinus* from Lake Geriyo (October 2017–March 2019).

Notes: Dry season higher than wet season. All values below FAO/WHO (2011) limits (50 mg/kg); low risk, seasonal monitoring advised.

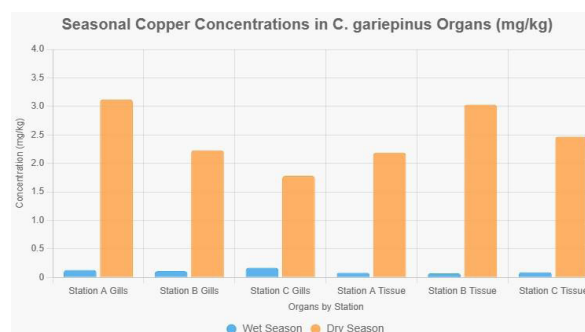


Figure 4: Mean Seasonal Variation of Copper (mg/kg) in Gills and Tissue of *Clarias gariepinus* from Lake Geriyo (October 2017–March 2019).

Notes: Dry season higher than wet season. All values below FAO/WHO (2011) limits (30 mg/kg); low risk, seasonal monitoring advised.

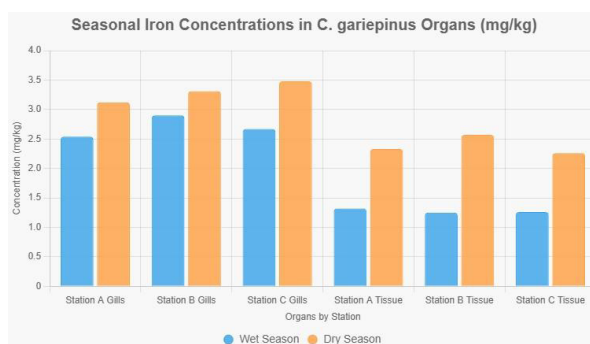


Figure 5: Mean Seasonal Variation of Iron (mg/kg) in Gills and Tissue of *Clarias gariepinus* from Lake Geriyo (October 2017–March 2019).

Notes: Dry season higher than wet season. All values below FAO/WHO (2011) limits (100 mg/kg); low risk, seasonal monitoring advised.

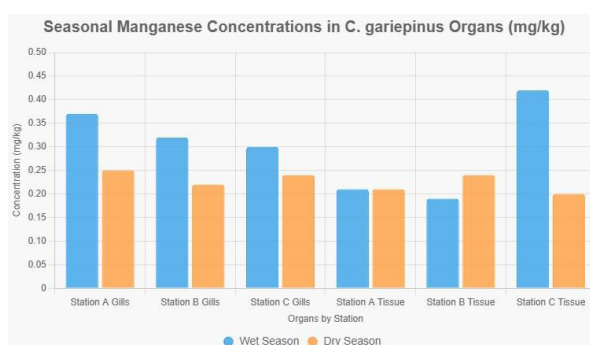


Figure 6: Mean Seasonal Variation of Manganese (mg/kg) in Gills and Tissue of *Clarias gariepinus* from Lake Geriyo (October 2017–March 2019).

Notes: Wet season higher than dry season in gills; comparable in tissues with exceptions. All values below FAO/WHO (2011) limits (0.5 mg/kg); low risk, seasonal monitoring advised.

CONCLUSION

This study highlights seasonal heavy metal dynamics in Lake Geriyo, with wet-season iron in water exceeding FAO/WHO (2011) guidelines due to runoff, while other metals remain compliant. Bioaccumulation in *Clarias gariepinus* organs adheres to Codex Alimentarius maximum levels across seasons, indicating low human health risks from consumption but potential ecological stress from iron overload. Recommendations include erosion controls, waste management, and seasonal monitoring. Future efforts should integrate human biomonitoring for comprehensive risk evaluation, advancing SDGs 3 and 6.

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