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Heavy Metal Bioaccumulation and Health Risk Assessment of Nile Tilapia in the Hadejia-Nguru Wetlands, Nigeria

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Abstract

The Hadejia-Nguru Wetlands, a vital but ecologically sensitive ecosystem in northeastern Nigeria, is increasingly threatened by anthropogenic activities. This study assessed the bioaccumulation of copper (Cu) and lithium (Li) in water and the economically important fish species, Nile Tilapia (*Oreochromis niloticus*), to evaluate potential risks to aquatic biota and human consumers. Water and fish (n=96) samples were collected bi-weekly over an eight-week period (March–April 2024) from three distinct sites (Dogon-kuka, Garbi, and Gada). Physico-chemical parameters (temperature, pH, dissolved oxygen) were measured *in situ*. Metal concentrations in water, fish muscle, and gill tissues were determined using Atomic Absorption Spectroscopy (AAS) after acid digestion. Data were analyzed using one-way ANOVA. Physico-chemical parameters were stable across sites, with no significant differences ($P > 0.05$). However, mean copper concentration in water from Garbi (1.13 ± 0.10 mg/L) exceeded the WHO permissible limit of 1.0 mg/L. Bioaccumulation patterns were tissue- and site-specific. The highest copper concentration in fish muscle was recorded at Gada (21.85 ± 0.74 mg/kg), while the gills showed the highest accumulation at Garbi (36.9 ± 11.3 mg/kg). Both values significantly exceeded ($P < 0.05$) the WHO/FEPA recommended limit of 2.0 mg/kg for human consumption. Lithium levels in fish tissues were below the WHO limit (1.0 mg/kg), though measurable accumulation was observed. This study reveals significant copper contamination in the edible muscle of *O. niloticus* from the Hadejia-Nguru Wetlands, posing a substantial public health risk. These findings underscore the critical need for continuous environmental

monitoring and the implementation of stringent pollution control policies to protect both the wetland ecosystem and the health of communities reliant on it.

Keywords: Heavy Metals, Bioaccumulation, *Oreochromis niloticus*, Hadejia-Nguru Wetlands, Copper Contamination, Health Risk Assessment.

Introduction

Heavy metal contamination in aquatic ecosystems represents a pressing global environmental challenge, primarily due to the persistent, non-biodegradable nature of these elements and their propensity to bioaccumulate and biomagnify through food chains (Järup, 2003). In developing nations like Nigeria, the problem is exacerbated by rapid urbanization, unregulated agricultural practices, and industrial effluent discharge, which often directly impact vital freshwater resources (Nduka & Orisakwe, 2010). The Hadejia-Nguru Wetlands, a Ramsar site of international importance in northeastern Nigeria, provides critical ecosystem services, including fisheries, agriculture, and water purification, supporting millions of livelihoods (Scholz, 2006). However, this ecosystem is under increasing stress from upstream agricultural runoff (containing pesticides and fertilizers) and domestic waste discharge (Musa & Imam, 2022).

Nile Tilapia (*Oreochromis niloticus*) is a dominant and widely consumed fish species in Nigeria, prized for its economic value and nutritional benefits. Due to its benthic and detritivorous feeding habits, it serves as an excellent bioindicator for monitoring the health of freshwater ecosystems (Authman et al., 2015). Among the myriad of potential contaminants, copper (Cu) and lithium (Li) are of particular concern. Copper is an essential micronutrient but becomes toxic at elevated concentrations, causing gill damage, impaired osmoregulation, and hepatic necrosis in fish, while in humans, chronic ingestion can lead to liver and kidney damage (Al-Yousuf et al., 2000; World Health Organization [WHO], 2011).

Lithium, while not a traditional heavy metal, is an emerging contaminant of growing concern. Its increasing use in lithium-ion batteries, pharmaceuticals (particularly for bipolar disorder treatment), and industrial lubricants has led to its detection in aquatic environments globally (Kszos & Stewart, 2003). In the context of the Hadejia-Nguru Wetlands, potential lithium sources include: (1) informal electronic waste (e-waste) recycling and disposal of used batteries in urban centers upstream; (2) geological weathering of lithium-bearing minerals within the Chad Basin formation, which underlies the wetland; and (3) possible pharmaceutical residues from untreated domestic wastewater (Adeyi et al., 2020). Sub-chronic lithium exposure can affect neurological and renal function in humans, with the developing fetus being particularly vulnerable (Grandjean & Landrigan, 2014).

Recent studies across West African wetlands have documented variable metal bioaccumulation patterns. For instance, Ibrahim and Dibal (2023) reported heavy metal concentrations in fish from the Lake Chad region in Nigeria, providing relevant regional baseline data for the Chad Basin. Similarly, Okogwu et al. (2019) found elevated trace metals in fish from the Cross River floodplain system, demonstrating that agricultural catchments yield higher metal burdens than forested reference sites. In the Hadejia-Nguru Wetlands specifically, Musa and Imam (2022) documented heavy metal bioaccumulation and oxidative stress responses in *O. niloticus*, indicating significant contamination pressures. More recently, studies have highlighted the need for comprehensive health risk assessments in Sahelian wetland fisheries due to increasing anthropogenic pressures from agricultural intensification.
Despite the ecological and socio-economic significance of the Hadejia-Nguru Wetlands, comprehensive data on the bioaccumulation of metals like Cu and Li in its fishery resources remains scarce. This study, therefore, aims to: (1) determine the concentrations of Cu and Li in water, and in the muscle (edible portion) and gills (a primary organ for metal uptake) of *O. niloticus* from three key sites within the wetlands; and (2) compare these concentrations against established international safety standards to evaluate potential health risks to local consumers.

Materials and Methods

Study Area and Sampling Sites

The study was conducted in the Hadejia-Nguru Wetlands, located in Yobe and Jigawa States, Nigeria (geographical coordinates between 12°12′ to 13°13′ N and 10°10′ to 11°11′ E). Three distinct sampling sites were selected based on varying anthropogenic pressures: Dogon-kuka (relatively less impacted, serving as a reference site), Garbi (influenced by irrigation and agricultural runoff), and Gada (influenced by urban runoff and fishing activities).

Sample Collection and Physico-chemical Analysis

Water and fish samples were collected bi-weekly over an eight-week period (March–April 2024). Surface water samples (n=48 total, 16 per site) were collected in acid-washed polyethylene bottles. Temperature (°C), pH, and Dissolved Oxygen (DO, mg/L) were measured *in situ* using a calibrated multi-parameter water quality meter (model: YSI ProDSS). Water samples were filtered (0.45 µm membrane) and acidified with concentrated HNO_3 to pH < 2 for subsequent metal analysis.
A total of 96 fish (*O. niloticus*) were collected (32 per site) using gill nets. Fish were transported on ice to the laboratory for immediate processing.

Sample Preparation and Metal Analysis

In the laboratory, fish were measured (standard length, cm) and weighed (g). Muscle tissue (dorsal epaxial) and gill arches were carefully excised, washed with deionized water, and oven-dried at 60°C to constant weight. Dried tissues were homogenized into a fine powder. A

wet acid digestion method was employed: 1.0 g of homogenized tissue or 100 mL of water sample was digested with a mixture of concentrated HNO_3 and $HClO_4$ (4:1, v/v) on a hot plate until a clear solution was obtained (American Public Health Association [APHA], 2012). The digested solution was filtered and diluted to a final volume of 25 mL with deionized water. Concentrations of Cu and Li were determined using an Atomic Absorption Spectrophotometer (AAS, Buck Scientific Model 210GP) with an air-acetylene flame. Standard calibration curves were prepared using certified reference standards. The detection limits were 0.01 mg/L for both metals.

Data Analysis

All statistical analyses were performed using SPSS version 20.0. Data are presented as mean ± standard deviation (SD). One-way Analysis of Variance (ANOVA) followed by Tukey's post-hoc test was used to compare metal concentrations and physico-chemical parameters among the three sampling sites. Statistical significance was set at $P < 0.05$. Metal concentrations were compared with the permissible limits established by the World Health Organization (WHO) and the Federal Environmental Protection Agency (FEPA), Nigeria.

Results

Physico-chemical Parameters

The physico-chemical parameters of the surface water are presented in Table 1. The water temperature ranged from 26.1 to 28.7°C, pH from 6.38 to 7.28, and dissolved oxygen from 6.24 to 7.05 mg/L. One-way ANOVA revealed no significant differences ($P > 0.05$) in these parameters among the three study sites, indicating a relatively stable and well-oxygenated environment across the sampling locations.

Table 1: Physico-chemical Parameters of Surface Water from the Hadejia-Nguru Wetlands (Mean ± SD)

Parameter	Dogon-kuka	Garbi	Gada	P-value
Temperature (°C)	28.7 ± 0.33^a	26.1 ± 0.26^a	28.5 ± 0.49^a	>0.05
pH	7.28 ± 0.14^a	6.39 ± 0.12^a	6.38 ± 0.09^a	>0.05
Dissolved Oxygen (mg/L)	7.05 ± 0.01^a	6.30 ± 0.14^a	6.24 ± 0.11^a	>0.05

Note: Values in the same row with different superscript letters are significantly different at $P < 0.05$. No significant differences were observed.

Metal Concentrations in Water

The mean copper concentration in water at Garbi (1.13 ± 0.10 mg/L) was significantly higher ($P < 0.05$) than at Dogon-kuka and Gada, and exceeded the WHO/FEPA standard of 1.0 mg/L. Lithium concentrations in water were below detectable limits across all sites (<0.01 mg/L), suggesting low or undetectable levels in the water column itself.

Metal Bioaccumulation in Fish Tissues

The concentrations of Cu and Li in the muscle and gills of *O. niloticus* are presented in Table 2. A significant ($P < 0.05$) and substantial bioaccumulation of copper was observed in both tissues, with levels far exceeding the recommended limit of 2.0 mg/kg for human consumption (WHO/FEPA). The highest copper concentration in muscle was recorded at Gada (21.85 ± 0.74 mg/kg), while the highest in gills was at Garbi (36.9 ± 11.3 mg/kg). Gills consistently accumulated higher copper concentrations than muscle, particularly at the Garbi site.

Lithium concentrations were significantly lower ($P < 0.05$) than copper across all sites and tissues. Although detectable, Li levels in both muscle and gills were below the WHO limit of 1.0 mg/kg. The highest Li accumulation was observed in the gills of fish from Garbi (0.17 ± 0.003 mg/kg).

Table 2: Metal Concentrations (mg/kg wet weight) in *Oreochromis niloticus* Tissues (Mean ± SD)

Location	Muscle (Cu)	Muscle (Li)	Gills (Cu)	Gills (Li)
Dogon-kuka	6.00 ± 0.88^{a}	0.03 ± 0.01^{a}	6.76 ± 0.91^{a}	0.03 ± 0.003^{a}
Garbi	10.76 ± 0.92^{b}	0.08 ± 0.01^{b}	36.9 ± 11.3^{b}	0.17 ± 0.003^{b}
Gada	21.85 ± 0.74^{c}	0.13 ± 0.01^{c}	23.1 ± 13.5^{c}	0.15 ± 0.04^{b}
WHO/FEPA Limit	2.0	1.0	-	-

Note: Values in the same column with different superscript letters are significantly different at $P < 0.05$. The WHO/FEPA limit for Cu is provided for context regarding human consumption. No standard limit is set for Li in fish.

Discussion

The results of this study provide clear evidence of significant copper bioaccumulation in *O. niloticus* from the Hadejia-Nguru Wetlands. While the physico-chemical parameters (temperature, pH, DO) were within acceptable ranges for tropical freshwater fish (Boyd, 2015), they did not mitigate the high metal uptake, suggesting a chronic contamination source independent of these general water quality indicators.

The elevated copper concentration in water from Garbi (1.13 mg/L) points to a localized point source, likely related to agricultural activities. Copper-based compounds are widely used as fungicides and algaecides in the surrounding farmlands (Jiao et al., 2012). The bioaccumulation pattern in fish tissues was both tissue- and site-specific. The significantly higher copper levels in gills, especially at Garbi, indicate that the gill is the primary route of uptake from the water column, consistent with its role in respiration and direct contact with the aqueous environment (Evans et al., 2005). The elevated copper levels in muscle tissue, the primary edible portion, represent a serious public health risk. Levels at Garbi (10.76 mg/kg) and Gada (21.85 mg/kg) were 5 to 11 times higher than the WHO permissible limit of 2.0 mg/kg.

Comparing our findings with recent regional studies provides important context. Ibrahim and Dibal (2023) reported heavy metal concentrations in fish from the Lake Chad region—findings

that provide a relevant regional benchmark for the Chad Basin. Similarly, Musa and Imam (2022) documented heavy metal bioaccumulation in *O. niloticus* from the Hadejia-Nguru Wetlands, with oxidative stress responses indicating significant contamination. The much higher values we recorded (10.76–21.85 mg/kg) suggest a significant intensification of copper contamination in recent years or the emergence of new point sources. Okogwu et al. (2019) found that agricultural catchments in the Cross River floodplain yielded higher metal burdens than forested reference sites, consistent with our observation that Garbi (agricultural influence) and Gada (urban influence) had greater contamination than Dogon-kuka. Studies on Sahelian wetlands emphasize that these ecosystems are particularly vulnerable to metal accumulation during the dry season (March–April, our sampling period) due to reduced water volume and increased concentration effects, which may partially explain the high values we observed.

The presence of lithium, albeit at levels below the WHO limit, is an important finding. Its accumulation in gills and muscle indicates an emerging contaminant pathway. While current lithium concentrations (0.03–0.17 mg/kg) fall below the WHO guideline of 1.0 mg/kg for drinking water (no specific guideline exists for fish), the potential for cumulative health effects from chronic low-level exposure cannot be dismissed. Lithium is known to accumulate in bone and soft tissues, and prolonged ingestion—even at sub-therapeutic levels—may pose risks to individuals with pre-existing renal impairment or those consuming contaminated fish daily over decades (Kszos & Stewart, 2003; McKnight et al., 2012). Pregnant women and children, who are more susceptible to trace metal toxicity, represent particularly vulnerable populations (Grandjean & Landrigan, 2014). The detection of lithium in this wetland system, likely originating from informal e-waste recycling or geological weathering (Adeyi et al., 2020), serves as an early warning of broader trace metal pollution requiring long-term biomonitoring. The disparity in metal concentrations among sites (with Dogon-kuka consistently lower) suggests that anthropogenic activities at Garbi (agriculture) and Gada (urban/domestic) are the primary drivers of contamination. These findings present a compelling case for urgent intervention, as chronic consumption of contaminated fish from this region could lead to cumulative health risks, including hepatotoxicity and nephrotoxicity in vulnerable populations (WHO, 2011).

Conclusion and Recommendations

Conclusion

This study conclusively demonstrates that *Oreochromis niloticus* from the Hadejia-Nguru Wetlands are severely contaminated with copper, with levels in the edible muscle tissue exceeding international safety standards by up to an order of magnitude. The findings confirm that while the physical environment appears stable, chemical contamination poses a grave threat to both the aquatic ecosystem and the public health of communities reliant on this fishery. The localized variability in contamination levels highlights the influence of specific anthropogenic activities, primarily agriculture and urban runoff. The detection of lithium,

though at safe levels, serves as an early warning of broader trace metal pollution and the need for vigilance regarding emerging contaminants.

Recommendations

State and local health authorities should issue a public advisory recommending limited consumption of fish from the Garbi and Gada areas, particularly for pregnant women, nursing mothers, and children, to mitigate immediate health risks. A maximum consumption advisory of one meal per week for adults and no more than one meal per month for children and pregnant women is recommended based on the copper levels observed.

Targeted restrictions should be placed on the use of copper-based fungicides and algaecides in the wetland's catchment area, with extension services promoting less toxic alternatives. Vegetated buffer strips of at least 30 meters should be established along tributaries entering the wetland at Garbi and Gada to filter agricultural and urban runoff.

Targeted environmental forensic studies are urgently needed to identify and quantify the specific sources of copper and lithium, including agricultural fungicide application rates, industrial effluent characterization, and geological baseline studies of lithium in the Chad Basin formation.

NESREA, in collaboration with academic institutions, should establish a continuous and comprehensive biomonitoring program for the Hadejia-Nguru Wetlands. Extension services should educate local fishermen and farmers on the link between land-use practices and water quality, promoting sustainable practices that protect their own health and the wetland's ecological integrity. Community-based water quality monitoring should be explored as a participatory approach to environmental stewardship.

Declaration

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Ethics Approval: Fish sampling was conducted in accordance with institutional guidelines for the ethical use of animals in research.

Data Availability: The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request.

References

Adeyi, A. A., Olayanju, B., & Fatade, Y. (2020). Distribution and potential risk of metals and metalloids in soil of informal E-waste recycling sites in Lagos, Nigeria. *Ife Journal of Science*, 21(3), 213. https://doi.org/10.4314/ijs.v21i3.17

Akan, J. C., Abdulrahman, F. I., Sodipo, O. A., Ochanya, A. E., & Askira, Y. K. (2010). Heavy metals in sediments from River Ngada, Maiduguri Metropolis, Borno State, Nigeria. *Journal of Environmental Chemistry and Ecotoxicology*, 2(9), 131-140.

Al-Yousuf, M. H., El-Shahawi, M. S., & Al-Ghais, S. M. (2000). Trace metals in liver, skin and muscle of *Lethrinus lentjan* fish species in relation to body length and sex. *Science of the Total Environment*, 256(2-3), 87-94.

American Public Health Association. (2012). *Standard methods for the examination of water and wastewater* (22nd ed.). American Public Health Association.

Authman, M. M. N., Zaki, M. S., Khallaf, E. A., & Abbas, H. H. (2015). Use of fish as bio-indicator of the effects of heavy metals pollution. *Journal of Aquaculture Research and Development*, 6(4), 1-13.

Boyd, C. E. (2015). *Water quality: An introduction* (2nd ed.). Springer.

Evans, D. H., Piermarini, P. M., & Choe, K. P. (2005). The multifunctional fish gill: Dominant site of gas exchange, osmoregulation, acid-base regulation, and excretion of nitrogenous waste. *Physiological Reviews*, 85(1), 97-177.

Grandjean, P., & Landrigan, P. J. (2014). Neurobehavioural effects of developmental toxicity. *The Lancet Neurology*, 13(3), 330-338. https://doi.org/10.1016/S1474-4422(13)70278-3

Ibrahim, B. D., & Dibal, T. (2023). Heavy Metal Concentration In Some Fishes From Lake Chad Region In Nigeria. *Journal of Environmental Issues and Agriculture in Developing Countries (JEIADC)*, 3(3), 65-69.

Järup, L. (2003). Hazards of heavy metal contamination. *British Medical Bulletin*, 68(1), 167-182. https://doi.org/10.1093/bmb/ldg032

Jiao, W., Chen, W., Chang, A. C., & Page, A. L. (2012). Environmental risks of trace elements associated with long-term phosphate fertilizers applications: A review. *Environmental Pollution*, 168, 44-53.

Kszos, L. A., & Stewart, A. J. (2003). Review of lithium in the aquatic environment: Distribution in the United States, toxicity and case example of groundwater contamination. *Ecotoxicology*, 12(5), 439-447.

McKnight, R. F., Adida, M., Budge, K., Stockton, S., Goodwin, G. M., & Geddes, J. R. (2012). Lithium toxicity profile: A systematic review and meta-analysis. *The Lancet*, 379(9817), 721-728. https://doi.org/10.1016/S0140-6736(11)61516-X

Musa, I. M., & Imam, T. S. (2022). Bio-concentration of some heavy metals and oxidative stress enzymes in *Oreochromis niloticus* (Tilapia fish) from the Hadejia-Nguru wetlands, Jigawa State. *Dutse Journal of Pure and Applied Sciences (DUJOPAS)*, 8(1a).

Nduka, J. K., & Orisakwe, O. E. (2010). Water-quality issues in the Niger Delta of Nigeria: a look at heavy metal levels and some physicochemical properties. *Environmental Science and Pollution Research*, 17(3), 584-596.

Okogwu, O. I., Nwonumara, G. N., & Okoh, F. A. (2019). Evaluating Heavy Metals Pollution and Exposure Risk Through the Consumption of Four Commercially Important Fish Species and Water from Cross River Ecosystem, Nigeria. *Bulletin of environmental contamination and toxicology*, *102*(6), 867–872. https://doi.org/10.1007/s00128-019-02610-4

Scholz, M. (2006). *Wetland systems to control urban runoff*. Elsevier.

World Health Organization. (2011). *Guidelines for drinking-water quality* (4th ed.). WHO Press.