Assessment of Heavy Metal Contamination in Water, Sediment, and Fish Tissues from Biu Reservoir, Borno State, Nigeria

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ABSTRACT

Heavy metals are naturally occurring elements with high atomic weights and densities at least five times greater than water. Known for their toxicity, persistence, and bioaccumulation, they pose serious risks to aquatic ecosystems and human health. This study evaluated the contamination levels of six heavy metals; zinc (Zn), lead (Pb), cadmium (Cd), copper (Cu), manganese (Mn), and chromium (Cr); in water, sediment, and two fish species (Oreochromis niloticus and Clarias gariepinus) from Biu Reservoir, an important freshwater source in southern Borno, Nigeria. Using Atomic Absorption Spectrophotometry, results showed Clarias gariepinus accumulated more metals, particularly in gills. Lead in water (0.016 mg/L) and cadmium in O. niloticus gills (0.058 mg/kg) exceeded WHO safety limits. While other metals remained within permissible ranges, the elevated Pb and Cd levels pose potential health risks. Continuous environmental monitoring and pollution control are recommended.

Keywords: *Heavy metal, contamination, fish species, reservoir, pollution*

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INTRODUCTION

Pollution refers to the introduction of harmful substances or contaminants into the natural environment, leading to adverse effects on ecosystems, human health, and biodiversity. These contaminants can be in the form of chemicals, particulate matter, noise, light, or biological agents that degrade air, water, and soil quality. Pollution is primarily caused by human activities such as industrialization, deforestation, urbanization, and agricultural expansion, though natural events like volcanic eruptions and wildfires can also contribute (UNEP, 2021). Water pollution caused by heavy metals is a growing environmental concern due to their toxic, persistent, and bio accumulative nature. Industrialization, agriculture, and urbanization have significantly increased the levels of heavy metals in water bodies, posing severe threats to aquatic life and human health. Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and zinc (Zn) are among the most hazardous contaminants found in aquatic ecosystems (Gunatilake, 2016; Al-Qodah et al., 2017; Li et al., 2019). These pollutants enter water bodies through untreated industrial effluents, agricultural runoff, and domestic waste, leading to long-term ecological consequences (Hasan et al., 2019; Uddin & Jeong, 2021). The bioaccumulation of heavy metals in fish tissues occurs through water absorption and dietary intake. Fish, like terrestrial animals, can accumulate both macro and microelements, which play vital roles in metabolism, growth, and reproduction (Terech-Majewska et al., 2016). However, excessive levels of heavy metals in water disrupt physiological processes in fish, leading to organ damage, reduced growth, and impaired reproduction (Moiseenko & Gashkina, 2020; Ali et al., 2019). The bioavailability of these metals depends on environmental conditions such as water pH, temperature, and dissolved oxygen levels.

Studies indicate that metabolically active tissues like the liver, kidneys, and gills accumulate higher concentrations of heavy metals compared to muscle tissues (Mansouri et al., 2012; El-Moselhy et al., 2014). The impact of heavy metals extends beyond fish health to human food safety. Fish are a crucial source of protein and essential nutrients, especially in developing countries, but the presence of toxic metals in fish tissues raises serious health concerns (Thilsted et al., 2016; Balogun et al., 2023). Chronic exposure to heavy metals through fish consumption can lead to neurological disorders, kidney damage, and cardiovascular diseases in humans (Kim & Lee, 2017). For instance, lead (Pb) and cadmium (Cd) are among the most toxic heavy metals, affecting nervous system functions and increasing cancer risks. This necessitates continuous monitoring of heavy metal concentrations in commercially important fish species to protect human health. The socio-economic impact of heavy metal contamination in fisheries is profound. Many communities depend on fisheries for food, income, and employment, yet pollution threatens the sustainability of aquatic resources (FAO, 2022; World Bank, 2023). The presence of heavy metals in water bodies reduces fish quality, affecting market demand and economic stability in fishing-dependent communities (Ozigbo et al., 2014; Lynch et al., 2016, 2017). Regulatory frameworks and pollution control measures, such as wastewater treatment and controlled agricultural practices, are necessary to mitigate the adverse effects of heavy metal contamination. This study on the Heavy metal of Biu Reservoir in Borno State, Nigeria, aims to assess heavy metal contamination in water, sediments, and fish species; *Oreochromis niloticus* and *Clarias gariepinus*. Understanding the levels of toxic metals will provide essential data for environmental management and policy-making. The findings will contribute to conservation efforts and inform strategies for sustainable fisheries management, ensuring the safety of aquatic resources for both human consumption and ecological balance.

MATERIALS AND METHODS

Description of the study area

Biu Reservoir is in Biu Local Government Area of Borno State, located at latitude 10.038'00" N and longitude 12.005'31" E. The Reservoir has an area of 1.77sq km (Goggle Earth Pro, 2025). The Reservoir was originally constructed in 80s to supply portable drinking water to Biu Township and its surrounding areas and to support irrigation of the surrounding fertile agricultural land. However, the project was later abandoned by successive governments. Today, the Reservoir's water is primarily used for irrigation, fishing, and various domestic purposes, such as washing and animal rearing (Shingu et al., 2015). The Biu Plateau, where the Reservoir is located, features a rugged terrain overlain by volcanic rocks, with elevations gradually descending to the north and west. The plateau is typically covered with Sudan Savannah vegetation, consisting mainly of scrub vegetation interspersed with tall trees and woodland (Ikusemoran et al., 2014). The region experiences three distinct seasons: The cold dry season (harmattan) from October to March. The hot dry season from April to June. The rainy season from July to September. The mean annual rainfall is approximately 800 mm, with the rainy season lasting about 150 days (Ikusemoran et al., 2014).

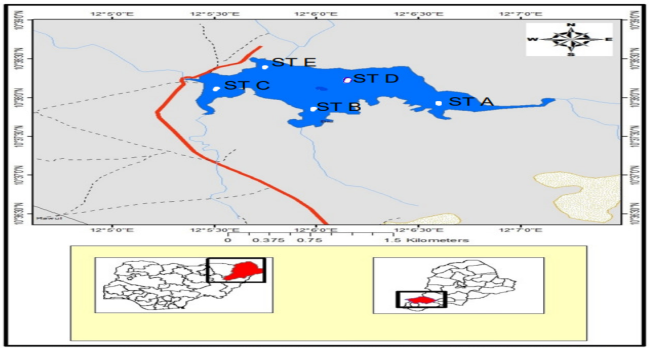
Sampling Stations

The sampling stations and their respective distances from the center of the reservoir are as follows: Station A: Located around the main water inlet, receiving runoff from Biu Township, the Cotton Company, and dry-season farming activities. It measures about 706.37 meters from the center. Station B: 403.21 meters from the center, positioned near the second water inlet in between Station A and Station C, where runoff from Tum Village and the NNPC unit enters the reservoir. Distance Station C: Situated near the water outlet, where most fishing activities take place. This area also serves as a water-fetching point for villagers and is used for household washing, dry-season farming, and fish processing. Additionally, the management office is located here. Distance 996.75 meters from the center of the reservoir. Station D: Found in center opposite Station B, in between Station A and Station E. Distance: 485.20 meter from the center Station E: Located adjacent Station C, connecting Stations A, D, and C. Distance: 664.84 meter from the center (Figure 1).

Determination of Heavy Metals in Water, Sediment and Fish Samples

Collection of samples

The specimen each water, sediment, *Clarias gariepinus*, Oreochromis niloticus of Biu reservoir were collected at five different locations of the dam. Water samples were



ST = Station. Source: Cartography Lab Geography Department, BUK, February, 2025

Figure 1: Map of Biu

collected using plastic bottle below the surface each of the five sampling sites, labelled and stored in a flask. Due to the rocky nature of the floor of the reservoir, the sediment samples were collected by scooping with a plastic spoon from the points where the water samples were taken, air dried and kept awaiting analysis. The sorted fish samples were put into a pre-cleaned polythene bag and then inside icebox and transported to ADSU Animal Science Laboratory for analysis.

Digestion of water samples.

Five 5 cm^3 of concentrated hydrochloric acid were added to 250 cm^3 of water sample and evaporated to 25 cm^3. The concentrate was transferred to a 50 cm^3 standard flask and diluted to the mark with de-ionized water.

Digestion of sediment

5g of prepared sediment sample was digested with 15 cm^3 nitric acid, 20 cm^3 Perchloric acid and 15 cm^3 hydrofluoric acid and placed on a hot plate for 3hrs. On cooling, the digest was filtered into a 100 cm^3 volumetric flask and made up to the mark with distilled water

Preparation and digestion of fish samples

The fish samples each of *Clarias gariepinus* and Oreochromis niloticus were washed with distilled water and dried for 24 hours. After drying the fish samples, the muscles and the gills were carefully removed and milled in a mortar. The contents were put in a dry labelled crucible and stored until digestion (Aleksandar, 2016). This followed the digesting of 2g of the grounded samples with 5ml of HNO_3 and 2ml of $HClO_4$ and was pre heated on a hot plate for 30 minutes at 85 °C and then more heated to 105oC until colour and bubbles disappeared. After completing the digestion, the residue was allowed to cool and filtered into a 50ml volumetric flask. Distilled water was then added to it to fill up to the mark. The filtrate was then transferred into a pre-cleaned sample bottle and stored under cool temperature until it was taken for further Atomic Adsorption.

Spectrophotometer (AAS) analysis

Analysis of heavy metals using atomic absorption spectrophotometer A black model 200A flame Atomic Absorption Spectrometer was used in the metal analysis of the sample (Perkin Elmer, 2000). The major underlined principle of AAS is that the ground state atoms are capable of absorbing radiant energy of their own specific resonance wavelength when passed through a solution containing the atoms or parameters in question, then part of the light will be absorbed. The extent of absorption is proportional to the number of ground state atoms present in the flame.

Data Analysis

Data obtain from heavy metal analysis of all the sampling stations were subjected to statistical analysis. One-way analysis of variance (One-way ANOVA), using SPSS 23.While mean values were compared for significant differences at ($p<0.5$).

DISCUSSION

Comparison of levels of some metals in the water, sediment and fish from Biu reservoir, Borno State, Nigeria

Montazer and Ali (2018) suggested that understanding the concentrations of heavy metals in freshwater fishes will help us to deal with the risks of heavy metals contamination on human health. Generally, fluctuations of Zn concentrations in water, sediment and fish tissues examined were minimal and within recommended permissible limits of 5m/L, 3mg/L and 50mg/kg according to WHO and SON however, in comparism to all the parameters measured the level of concentration of Zn in gill and flesh of *Clarias gariepinus* were more than the gill and flesh of Oreochromis niloticus. This may be attributed to their differences in sizes, absorption capabilities between species, duration of exposure and feeding habits; for instance, *Clarias gariepinus* in size is bigger than Oreochromis niloticus, *Clarias gariepinus*, being a demersal fish (bottom feeder) must have a higher concentrations chances of the heavy metals than tilapia fish (pelagic fish) as asserted by Isibor and Imoobe (2017). A very small amount of Zn is essential for all living organisms (Odigie and Adejumo, 2018), as well excessive amounts can result in fatal poisoning of aquatic organism and even humans. Afshan et al. (2014) reported that too much Zn can cause prominent health problems such as skin annoyances, stomach cramps, anaemia, vomiting and nausea and equally its high levels damage the pancreas and disturb the protein metabolism, and cause arteriosclerosis.

Table 1: Metal concentrations in Water, Sediment and two species of Fish from Biu Reservoir compared with standards.

	Metal	**Water (Mg/L)**	**Sediment (Mg/kg)**	**O. niloticus gill (Mg/kg)**	**O. niloticus flesh (Mg/kg)**	**C. gariepinus gill (Mg/kg)**	**C. gariepinus flesh (Mg/kg)**	**WHO/SON (2007/2017) Water**	**RSMERS, (2002) Sediment**	**FAO/SON (2003/2007) Fish**
1	Zinc	1.85 ±0.35	2.29±0.33	9.98±1.12	6.59±1.02	15.11±0.60	7.44±0.21	5.0mg/L	3mk/kg	50.0mg/kg
2	Lead	0.016±0.00	0.054±0.02	0.026±0.00	0.025±0.00	0.028±0.00	0.024±0.00	0.01mg/L	1.3mg/kg	0.2mg/kg
3	Cadmium	0.003±0.00	0.005±0.00	0.058±0.01	0.032±0.00	0.022±0.01	0.040±0.01	0.05mg/L	0.03mg/kg	0.05mg/kg
4	Copper	0.78±0.11	0.046±0.00	9.01±0.36	7.33±1.26	13.32±1.77	10.00±0.85	1.3mg/L	20m/kg	30mg/kg
5	Manganese	0.07±0.01	2.22±0.25	0.045±0.00	0.036±0.01	0.034±0.01	0.220±0.01	0.05mg/L	30mg/kg	1mg/kg
6	Chromium	0.04±0.00	0.11±0.01	0.120±0.01	0.99±0.12	0.11±0.01	1.040±0.15	0.05mg/L	30mg/kg	3mg/kg

All values are the average of three replicates on each treatment ±SD.

The concentration of Lead obtained in Biu reservoir was above the maximum permissible limits (0.01mg/l) for water only and within maximum permissible limit (1.5mg/kg) for sediment, 0.2mg/kg for gills and fleshes of two species of fish as set by FEPA/WHO (2004). The study further showed that gills of Oreochromis niloticus accumulated same levels of Lead as the gills of *Clarias gariepinus* but more than the fleshes of the two fishes alike. The variations between two examined fish species may be due to the fact that levels of heavy metals in fish vary in various species and different aquatic environment. Despite its low concentration, Lead is reported to severely damage liver, kidneys, brain, nerves and other organs. Lead is reported to be non-essential element that constitutes body burden and a great threat to life if present in substantial quantity. Moses (2018) suggested that Lead can be toxic even at minimal concentrations and has no known function in biochemical processes. Exposure to Pb may also lead to reproductive disorders osteoporosis (brittle bone disease), memory problems, anaemia and an increase in heart disease, high blood pressure, especially in men (Afshan et al., 2014). Cadmium is regarded as one of the most harmful trace elements in the environment. The increased burning resulting from waste disposal combined with its persistence in the environment, and its comparatively rapid uptake and accumulation through the food chain add to its potential environmental hazards. The highest cadmium (Cd) concentration was observed in the gill of *Oreochromis niloticus* backed by flesh of *Clarias gariepinus (*Table 1*).* Physical observation during this study also suggested that frequent burning of used scraped tires and polyethylene materials by the fisher folks within the reservoir together with airborne cadmium particulate matters, especially in the work environment may also be contributing factors. Concentrations of Cadmium obtained apart from gill of *Oreochromis niloticus* were relative lower but within the recommended limits 0.05mg/L, 0.03-1mg/kg and 1.00 mg/kg by WHO (2004; 2016) and El-Moselhy et al. (2014). According to Mehdi et al. (2019), Cadmium is toxic even at low concentrations (0.1 mg/l) and has the capacity to accumulate in sediments and animal tissues. Therefore, its low concentration should not be recommended even for the irrigation of plants. High concentrations of Cd have been found to lead to chronic kidney dysfunction (Moses, 2018). In fish, it can cause anaemia and vertebral fractures, osmo-regulatory problems, decreased digestive efficiency, hematological and biochemical effects, growth deficits (Hosnia et al., 2015). More Cu concentration was obtained the gill and flesh of *Clarias gariepinus* than in the gill and flesh of *Oreochromis niloticus,* water and sediment. *Clarias gariepinus* is omnivorous and preys on small fish of other species this could have led to high Cu levels in them compared to tilapia which feeds on phytoplankton. Lower value has been reported by Daniel and Bassey, (2022) in Esuk Ekpo Eyo Beach, Akpabuyo, and South-East Nigeria, significantly very low was reported by Akan et al. (2012) in liver of fish sampled from a river in Vinikilang of Adamawa state. According to Olsson et al. (2013), copper toxicity is taken up directly from the water via gills, this accounted for the differences in their concentrations in the gills of Oreochromis niloticus and *Clarias gariepinus* to their fleshes. Generally, the metal concentration in the sediment increases with decreasing particle size and increasing organic content. The current finding supports the assertions made above and showed similar concentration of copper in the gills of Oreochromis niloticus and *Clarias gariepinus* as previously reported by (Sani, 2011). Copper being micronutrient is needed in trace amount for proper body functions; however, its high concentration can affect the brain, liver, or kidneys resulting in mental illness nausea, vomiting, stomach cramps or diarrhoea (Ukachukwu, 2012; Afshan et al., 2014) and (Moses, 2018). The recommended concentration of copper in fish established by WHO/FAO was 30 mg/kg, that of water was 2mg/L by WHO (2004) and for sediment 20mg/kg by RSMENR (2002). The samples analyzed in this research were all found to be below the standard limit. The Manganese level in water of Biu reservoir was very high as recommended by WHO and within the limit as recommended by FMEv. This may be due to runoff which contains manganese contaminants from agricultural activities. The maximum permissible limit of manganese set by WHO, (2003)/FMEv, (2016) is 0.05 – 0.5mg/l in water, 30mg/kg, (USEPA, 1993) and 0.5 – 1.0mg/kg (WHO, 2003/FEPA, 2007; El-Moselhy et al., 2014). Apart from the value obtained in water, all other parameters were found to be within the acceptable limit. Lower values 0.14 - 0.74μg/g were reported in a liver of a sampled fish from Vinikilang of Adamawa state by Akan et al. (2012). In a similar study by Emurotu et al. (2014), the value of manganese in the liver of dried catfish showed 3.70 mg/kg while it was not detected in the fresh sample. Afshan et al. (2014) and Amirah et al. (2013) reported that high levels of Manganese (Mn), can cause lung, liver and vascular disturbances, decline in blood pressure and possible failure in development of Animal foetus and Brain. Chromium is also essential for organisms as a micro nutrient in form of fat and carbohydrate metabolism Afshan et al. (2014). Its presence in the environment can be through geogenic or anthropogenic inputs and can accumulates in fish either from the water or by ingestion of food.

In this study the mean concentration of chromium obtained in water, sediment and, gills and fleshes of two species of fish were below the maximum acceptable limit 0.05mg/L, 26 mg/kg and 3mg/kg as set by WHO, (2003) and SON, (2007). Higher levels of trace elements such as chromium and zinc in liver relative to other tissues may be attributed to the affinity or strong coordination of metallothionein protein with these elements (Ikem and Nyavor, 2003). Apart from water and sediment which their scale of acceptable levels are different, the gill of *Oreochromis niloticus* accumulated comparatively high concentration of Chromium more than the gill of *Clarias gariepinus* and so also the flesh of *Clarias gariepinus* more than the flesh of Oreochromis niloticus as recorded throughout the study period. Different factors such as physical and chemical properties of water as well as seasonal changes are the reason of significant augmentation of metals in different fish tissues, according to Afshan et al. (2014). Also the difference in the concentration in the gills and fleshes of the two fish species may be in tune to Pramita et al. (2021) who also reported that accumulation of chromium in aquatic organisms dependent upon various biotic factors like age, developmental phase and type of species; and abiotic factors like pH, temperature and alkalinity of water. This corroborated the works of Olsson et al. (2013), El-Moselhy et al. (2014), Dang et al. (2016), Soltani et al. (2019) and who all reported that flesh of freshwater fishes are not always active tissue for accumulating heavy metals. Initial exposure of fish to chromium showed different behavioural changes thus; uneven swimming, mucous discharge, and change in body colour, loss of appetite. Higher concentration 126 of chromium may lead to cancer as reported by Malami et al. (2014) and DNA damage according to Ibrahim et al. (2018). The importance of monitoring heavy metals in freshwater fish to safeguard human health cannot be overemphasized (Montazer and Ali, 2018). The study found variations in Zn, Cu, Pb, Cd, Mn, and Cr concentrations between *Clarias gariepinus* and *Oreochromis niloticus*, influenced by species behavior and habitat (Isibor and Imoobe, 2017; Odigie and Adejumo, 2018). While most levels were within permissible limits, elevated Lead in water (FEPA/WHO, 2004) and Cadmium in fish tissues raised toxicity concerns (Mehdi et al., 2019; Moses, 2018), with bioaccumulation patterns affected by both environmental and species-specific factors (Afshan et al., 2014; Ikem and Nyavor, 2003; Pramita et al., 2021).

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