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Determination of Heavy Metals in Three Fish Species *(Tilapia zilli, Clarias anguillaris* and *Synodontis filamentous)* from Upper River Benue Yola, Adamawa State, Nigeria

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ABSTRACT **Original Research Article**

This study determined the heavy metals in three fish species (Tilapia zilli, Clarias anguillaris and Synodontis filamentous) from Upper River Benue Yola, Adamawa State, Nigeria. The study was aimed at determining the concentration of some selected heavy metals namely; Zinc, Lead, Cadmium and Copper (Zn, Pb, Cd and Cu) in Clarias anguillaris, Synodontis filamentous and Tilapia zilli from Upper River Benue using standard methods. Sample were blended into fine powder and sieved for digestion. The levels of heavy metals were determined using atomic absorption spectrophotometer. The results revealed that Zinc has the highest concentration (12.35±1.79 µg/g) in Tilapia zilli, followed byPb (4.06±2.02 µg/g) in Synodontis filamentous, while Copper has the lowest concentration (0.74±0.71 µg/g) in Synodontis filamentous followed by Cd (1.27±0.55 µg/g) from Clarias anguillaris and it follow the same trend in order of decreasing: Zn > Pb > Cd > Cu. There was a significant difference in the concentrations of heavy metals among the fish species ($P < 0.05$). All the concentrations obtained for these heavy metals analysis was below the permissible limit recommended by international standard organization, hence they are safe for human consumption.

Keywords: Spectrophotometer, Heavy metals, Clarias anguillaris, Synodontis filamentous, Tilapia zilli.

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Introduction

The contamination of water bodies by heavy metals has emerged as a worldwide concern in recent times, as these elements are persistent in the environment and frequently induce harmful effects in living organisms (Mac Farlane and Burchett, 2000). Among various contaminants, heavy metals are particularly alarming because of their toxicity and tendency to accumulate progressively within aquatic systems (Adebesi *et al*., 2022). Human exposure to these metals via food, drinking water, and air, facilitated by their movement up the food web, can lead to a variety of health complications. In freshwater environments, fish are frequently utilized as key bioindicators to evaluate the extent of metal contamination. Considerable research has focused on commercially valuable and commonly consumed fish species to pinpoint those that could endanger human health (Mac Farlane and Burchett, 2000; Adebesi *et al.*, 2022). Furthermore, exposure to heavy metals has been connected to neurological issues, particularly in unborn children, potentially causing behavioral alterations and reduced performance on IQ tests (Adebesi *et al*., 2022).

Fish residing in heavy metal-contaminated waters are prone to accumulating significant quantities of these harmful substances, largely due to their constant interaction with the environment. The process of respiration involves drawing substantial amounts of water across their gills, and they also ingest materials while feeding. These pathways facilitate the bioaccumulation of toxic metals within their systems, endangering the fish themselves and, ultimately, the humans who regularly consume them (Orosum *et al*., 2016). As a fundamental part of aquatic ecosystems, fish are valuable tools for monitoring environmental well-being. The presence of metallic contaminants in fish has been correlated with negative impacts on their survival, reproductive success, and growth rates (Fianko *et al*., 2013; Adharsh *et al*., 2022). The degree to which metals accumulate in fish is influenced by multiple variables, including the specific species, its sex, body fat content, dietary patterns, the time of year, and the water's pH level (Authman *et al*., 2015).

The enduring presence and prolonged toxic effects of metals like lead (Pb), nickel (Ni), manganese (Mn), zinc (Zn), cadmium (Cd), and chromium (Cr) on people, primarily through eating contaminated aquatic life, have prompted significant scientific and environmental worry (Olowoyo *et al*., 2012). Within these environments, larger organisms such as fish are subjected to heightened metal concentrations through the process of biomagnification (Javed and Usmani, 2011). The potential for harm, even at minimal concentrations detected in fish and water, underscores their importance in ecotoxicological research. Numerous studies have documented their toxic impact across various water bodies (Abdel-Baki *et al*., 2011; Ekwanyanwu *et al*., 2011). The gill tissue is a primary location for metal uptake and is considered a crucial indicator for evaluating waterborne metal contamination (Rshed, 2001; Ekwanyanwu *et al*., 2011). Investigating the transfer factor of heavy metals into fish gills relative to the surrounding water provides insight into the mechanisms of metal movement from the environment into fish tissues (Abdel-Baki *et al*., 2011). Other tissues, including muscle, liver, and kidney, have also been the subject of investigation regarding their capacity to accumulate these metals (Edem *et al*., 2009; Ekwanyanwu *et al*., 2011; Javed and Usmani, 2011).

Given their critical role in human diets, fish require consistent monitoring to confirm that heavy metal concentrations stay within established safety thresholds for consumption. Consequently, the objective of this research was to ascertain the potential contamination levels of specific heavy metals present in three different fish species obtained from the Upper River Benue

Study Area Description

Adamawa State is situated in Nigeria's Northeastern region. Its geographical coordinates place it between latitudes 7° and 11° N and longitudes 11° and 14° E. With an elevation of roughly 185.9 meters above sea level, the state encompasses a total land area of about 38,741 square kilometers. It is bordered by Taraba State to the south and west, Gombe State to the northwest, and Borno State to the north. Additionally, its eastern frontier forms an international boundary with the Republic of Cameroon. The primary waterway in the region is the River Benue, which originates in the Cameroonian highlands and travels southward to merge with the River Niger at Lokoja (Figure 1). Climatically, the state experiences two distinct periods: a wet season from May to October, characterized by rainfall exceeding 60 mm across all areas, and a dry season spanning November to April. The Harmattan period occurs between November and February. The hottest weather is typically in March and April, with maximum temperatures reaching 42.78°C, whereas November and December are the coolest months, with minimum temperatures falling to approximately 11.11°C [10, 11].

The Upper River Benue is the principal water source supporting irrigation, fishing, domestic needs, and industrial operations within the state. Beyond rainwater, the main sources of water provision are surface water and groundwater. The river itself is fed by a network of tributaries. It stretches approximately 1,400 km in length and remains largely navigable during the summer months (Adebayo and Tukur, 1999).

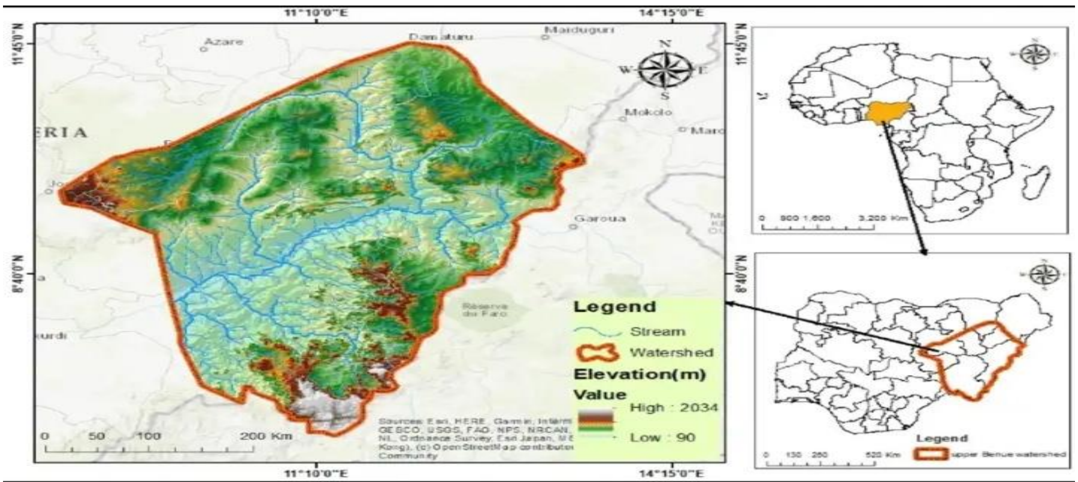

Figure 1. Map of the study area (Upper River Benue, Yola Adamawa state)

Sampling Period

The fieldwork was carried out over a three-month period, specifically from July 2025 to September 2025. Fish specimens were gathered on a monthly basis throughout this time.

Preparation for Digestion

Each fish specimen was initially rinsed with distilled water and subsequently oven-dried at 105°C for 24 hours until a consistent mass was attained. Following the drying process, the bones, head, and scales were removed. The remaining muscle tissue was then pulverized using a mortar and pestle. This powdered material was transferred into a clean, dry, pre-labeled crucible and kept in storage until the digestion phase commenced (Adebayo, 2017; Buhari *et al.*, 2025).

Sample Digestion Procedure

For the digestion process, 2 g of the ground sample was precisely weighed and combined with 5 mL of HNO3 and 2 mL of $HClO_4$. This procedure was performed in triplicate. The resulting mixture was heated on a hot plate maintained at 85°C for 30 minutes. After digestion, the solution was left to cool and then filtered into a 50 mL volumetric flask. Distilled water was then added to bring the volume up to the calibration mark. The resulting filtrate was placed into a pre-cleaned sample bottle and kept under cool conditions until analysis via Atomic Absorption Spectrophotometry (AAS) was performed (Adebayo, 2017).

Heavy Metal Determination

The quantification of heavy metals in the samples was conducted using a black model 200A flame AAS (Perkin Elmer 2000). The operational principle of this instrument is that atoms in their ground state will absorb radiant energy at their specific characteristic wavelength when light passes through a solution containing those atoms. This absorption causes a reduction in the light's intensity. The amount of light absorbed correlates directly with the concentration of ground state atoms present within the flame (Adebayo, 2017). Four specific heavy metals—Lead (Pb), Cadmium (Cd), Copper (Cu), and Zinc (Zn)—were analyzed in the collected specimens. (Note: Corrected "Cadmium, Cadmium" to "Cadmium (Cd), Copper (Cu)" based on context and the results section).

Data Analysis

To assess variations in heavy metal concentrations among the three fish species, a two-way analysis of variance (ANOVA) was employed, with significance set at the 5% probability level. In instances where the ANOVA indicated statistically significant differences, Fisher's Least Significant Difference (LSD) test was utilized to differentiate between the means.

Results

The analysis for Cd, Cu, Pb, and Zn was performed on *Clarias anguillaris*, *Synodontis filamentous*, and *Tilapia zilli*. The concentrations detected for each metal in each species are presented in Table 1. For Zinc, the maximum concentration (12.35±1.79 µg/g) was observed in *Tilapia zilli* during July 2025, followed by *Synodontis filamentous* with 7.24±0.74 µg/g. The minimum Zn value (2.00 ± 2.24 µg/g) was recorded for *Clarias anguillaris* in both September and July. The lowest Lead level (1.65±0.42 µg/g) was found in *Clarias anguillaris* in August, followed by *Tilapia zilli* in July (2.74±0.43 µg/g). Conversely, the peak Pb concentration (4.06±2.02 µg/g) was measured in *Synodontis filamentous* in September. Regarding Cadmium, the highest level (2.34±0.65 µg/g) was detected in *Tilapia zilli* in September, while *Synodontis filamentous* also showed a high value (1.94±1.30 µg/g) in the same month. The lowest Cd concentration (1.27±0.55 µg/g) was recorded for *Clarias anguillaris* in September. For Copper, the maximum concentration (1.48±0.26 µg/g) was found in *Clarias anguillaris* in September, with *Tilapia zilli* showing a value of 1.22±0.63 µg/g. The lowest Cu level (0.74 ± 0.71 µg/g) was measured in *Synodontis filamentous* during September and July. The statistical analysis revealed a significant difference ($P < 0.05$) in heavy metal concentrations among the three fish species examined.

Table 1. Monthly Variation of some Heavy Metals Concentrations (μg/g) in *Clarias anguillaris*, *Synodontis filamentous* and *Tilapia zilli* of Upper River Benue from July, 2025 –September, 2025

Metals/Months	*Clarias anguillaris*	*Synodontis filamentous*	*Tilapia zilli*
Zinc	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
July	$2.00{\pm}2.24^{c}$	$6.96{\pm}1.30^{b}$	$11.58{\pm}2.20^{a}$
August	$2.11{\pm}0.71^{b}$	$7.22{\pm}1.20^{a}$	$10.75{\pm}1.14^{a}$
September	$2.96{\pm}0.94^{c}$	$7.24{\pm}0.74^{b}$	$12.35{\pm}1.79^{a}$
Lead			
July	$1.95{\pm}1.68^{c}$	$3.09{\pm}1.44^{a}$	$2.74{\pm}0.43^{b}$
August	$1.65{\pm}0.42^{b}$	$3.13{\pm}0.87^{a}$	$3.37{\pm}0.69^{a}$
September	$1.99{\pm}0.92^{c}$	$4.06{\pm}2.02^{a}$	$3.18{\pm}0.70^{b}$
Cadmium			
July	$1.33{\pm}1.26^{a}$	$1.47{\pm}1.32^{a}$	$1.46{\pm}1.20^{a}$
August	$1.55{\pm}0.53^{a}$	$1.36{\pm}0.62^{a}$	$1.68{\pm}0.72^{a}$
September	$1.27{\pm}0.55^{a}$	$1.94{\pm}1.30^{a}$	$2.34{\pm}0.65^{a}$
Copper			
July	$1.37{\pm}0.45^{a}$	$0.74{\pm}0.71^{a}$	$0.94{\pm}0.88^{a}$
August	$1.19{\pm}0.30^{a}$	$1.01{\pm}0.12^{a}$	$0.91{\pm}0.17^{a}$
September	$1.48{\pm}0.26^{a}$	$0.78{\pm}0.48^{a}$	$1.22{\pm}0.63^{a}$

Mean with different superscript letters across the rows are significantly different ($p < 0.005$)

Discussion

Among all the metals analyzed across the different fish species and sampling months, Zinc was found at the highest concentrations. As an essential trace element, Zn plays a critical role in various enzymatic functions and physiological processes in fish. The notably elevated levels observed in *Tilapia zilli* (likely Oreochromis niloticus) can be explained by its omnivorous feeding behavior. Consuming algae, plankton, and detritus exposes this species to Zn that has already undergone bioaccumulation at lower trophic levels (Egungwu *et al*., 2021). This observation is consistent with the research conducted by Yohannes *et al*. (2023), who similarly documented significantly greater Zn concentrations in *Tilapia zilli* compared to catfish in Lake Hawassa, Ethiopia, which they ascribed to the tilapia's planktivorous diet. Additionally, the widespread use of Zn in agricultural inputs such as fertilizers and pesticides contributes to its presence in runoff, potentially affecting its availability in the reservoir. The comparatively reduced levels found in the benthic *Clarias anguillaris* point to a distinct exposure route, likely through sediment where other metallic contaminants may dominate. Crucially, all measured Zn concentrations remained beneath the established safe threshold of 30-100 μg/g, suggesting no immediate health risk from Zn contamination (FAO/WHO, 2019; EC, 2021). These mean values were also below the 100 mg/kg maximum permissible limit set by NAFDAC. As noted by Yohannes *et al*. (2023), the varying accumulation rates among different fish species may stem from the provision and/or synthesis of non-exchangeable binding sites within different tissues, leading to disparate metal concentrations.

Regarding Lead, *Synodontis filamentous* exhibited elevated concentrations, whereas *Clarias anguillaris* showed the lowest levels during September and August, respectively. The heightened Pb values in *Synodontis filamentous* are consistent with its benthic feeding ecology. This species commonly ingests invertebrates and detritus from bottom sediments, which serve as a major repository for Pb originating from anthropogenic sources like industrial discharge and historical use of leaded fuels. These results corroborate the work of Addo *et al*. (2024), who documented increased Pb concentrations in benthic-foraging fish from Ghana's Volta Lake, attributing this to sediment contamination from urban runoff. The elevated Pb level in *Tilapia zilli* during August may be linked to seasonal influxes of polluted runoff or shifts in dietary composition. The reduced accumulation in *Clarias anguillaris* could reflect species-specific variations in metabolic processes governing metal uptake, storage, or elimination. Importantly, the observed Pb values surpassed the 0.3 μg/g safe limit established by FAO/WHO (2019) and the EU (2021) for fish muscle, reflecting the high toxicity of this metal. Similarly, Adewumi *et al*. (2022) reported elevated Pb concentrations (mean of 2.8 μg/g) exceeding WHO standards in fish species from a Nigerian reservoir impacted by urban runoff. These elevated levels point to substantial anthropogenic contamination within the Upper River Benue, potentially stemming from agricultural chemicals, mining operations, or atmospheric deposition.

For Cadmium, peak concentrations were measured in *Tilapia zilli* during September, while *Clarias anguillaris* exhibited the minimum values. The substantial Cd accumulation in benthic and demersal species like *Tilapia zilli* supports the notion that sediment represents the primary source of this metal. Cadmium readily associates with organic matter within sediments, becoming accessible to organisms foraging on the bottom. This pattern aligns with research by Rahman *et al*. (2020) in the Bay of Bengal, who documented maximum Cd accumulation in benthic fish species attributed to their continuous interaction with contaminated sediments. The marked increase in *Tilapia zilli* during September may result from seasonal sediment disturbance or altered foraging behavior. The comparatively diminished concentration in *Clarias anguillaris*, an air-breathing catfish adapted to low-oxygen, sediment-rich environments, might reflect distinct physiological characteristics or enhanced capacity for Cd metabolism and excretion. All Cd concentrations recorded in this investigation exceeded the 0.1 µg/g threshold established by FAO/WHO (2019).

Regarding Copper, *Clarias anguillaris* demonstrated the highest concentration, whereas *Synodontis filamentous* showed the lowest values. The enhanced Cu accumulation in *Clarias anguillaris* likely results from this species' frequent burrowing activity and sediment ingestion, exposing it to Cu complexes formed under anaerobic sediment conditions. This observation is supported by findings from Nnaji *et al*. (2023), who reported analogous trends of elevated Cu accumulation in *Clarias anguillaris* relative to other species within the Niger Delta, connecting this pattern to their detritivorous feeding habits and persistent sediment contact. Additionally, variations in enzymatic composition and metabolic Cu requirements compared to the other species may explain this distinctive bioaccumulation pattern (Yap *et al*., 2020). All measured Cu values remained within the 1.5 µg/g safe limit established by FAO/WHO and EU standards, presenting no toxicological concerns related to Cu consumption. This finding aligns with the global assessment conducted by Li *et al*. (2024), which determined that Cu concentrations in freshwater fish rarely exceed safety guidelines, unlike non-essential metals such as Cd and Pb.

Conclusion

This investigation was undertaken to assess the concentrations of selected heavy metals (Zn, Pb, Cd, and Cu) in fish specimens (*Clarias anguillaris*, *Synodontis filamentous*, and *Tilapia zilli*) collected from the Upper River Benue. The findings revealed that the various heavy metals analyzed fell within permissible limits established by the World Health Organization, Food and Agricultural Organization, and NAFDAC. Consequently, the fish species examined in this study are considered safe for human consumption.

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