# Bioaccumulation Factors (BAF) for Heavy Metals in Freshwater Fish, Water and Sediment of Some Aquatic Habitats in Sokoto State, Nigeria

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***Abstract:***

*This study was conducted to determine and compare the Bioaccumulation Factors (BAF) for Heavy Metals in Fresh Fish, Water and Sediment of Some water bodies in Sokoto State, heavy metals contents of all the samples were found by atomic absorption spectrometry (AAS), Clarias gariepinus consistently exhibited the highest median BAFs for cadmium (Cd) and zinc (Zn), followed by Oreochromis niloticus. At the same time, Bagrus bayad showed the lowest accumulation for these metals. The elevated BAFs for Cd—particularly in C. gariepinus—are ecologically and toxicologically significant. The baseline assessment of heavy metal contamination across four aquatic systems in Sokoto State—Wurno River, Rima River, Romo Lake, and Shagari Dam—revealed distinct spatial and matrix-specific pollution profiles, with Shagari Dam emerging as a hotspot for Zn (0.387 mg/kg) and Mn (0.336 mg/kg) in sediment. At the same time, Rima River showed elevated levels of Cu (0.198 mg/kg) and Cd (0.070 mg/kg). Temporal analysis of Zn in water revealed pronounced seasonal fluctuations, particularly at Wurno River and Romo Lake, where concentrations peaked during months March, April, and October, potentially linked to agricultural runoff or industrial discharge cycles (Figure 2) and The high Mn concentrations in water, particularly at Wurno River and Romo Lake (exceeding WHO guidelines of 0.05–0.1 mg/L). Therefore, monitoring and managing these potential pollution sources is crucial to protecting the lake's ecosystem and the local population's health. The concentrations observed in the fish, particularly in B. bayad, are a clear indication that the dam's ecosystem is under stress from these pollutants.*

***Key words:*** *Bioaccumulation Factors, Freshwater Fish, Heavy Metals , Sediment, Water.*

## Introduction

Heavy metals are elements with specific gravities greater than 5.0mg and are toxic at low concentrations (Nevel *et al.*, 2014; Van Nevel *et al.*, 2014). Metals are non-biodegradable and are considered major environmental pollutants, causing cytotoxic, mutagenic, and carcinogenic effects in animals (Kamaruzzaman *et al.*, 2010). Heavy metals such as copper (Cu) and Zinc (Zn) are essential for fish metabolism, while others, such as Lead (Pb) and Cadmium, have no known role in biological systems. However, at high concentrations, these metals tend to accumulate in fish bodies and later pose a threat to human health through the food chain.

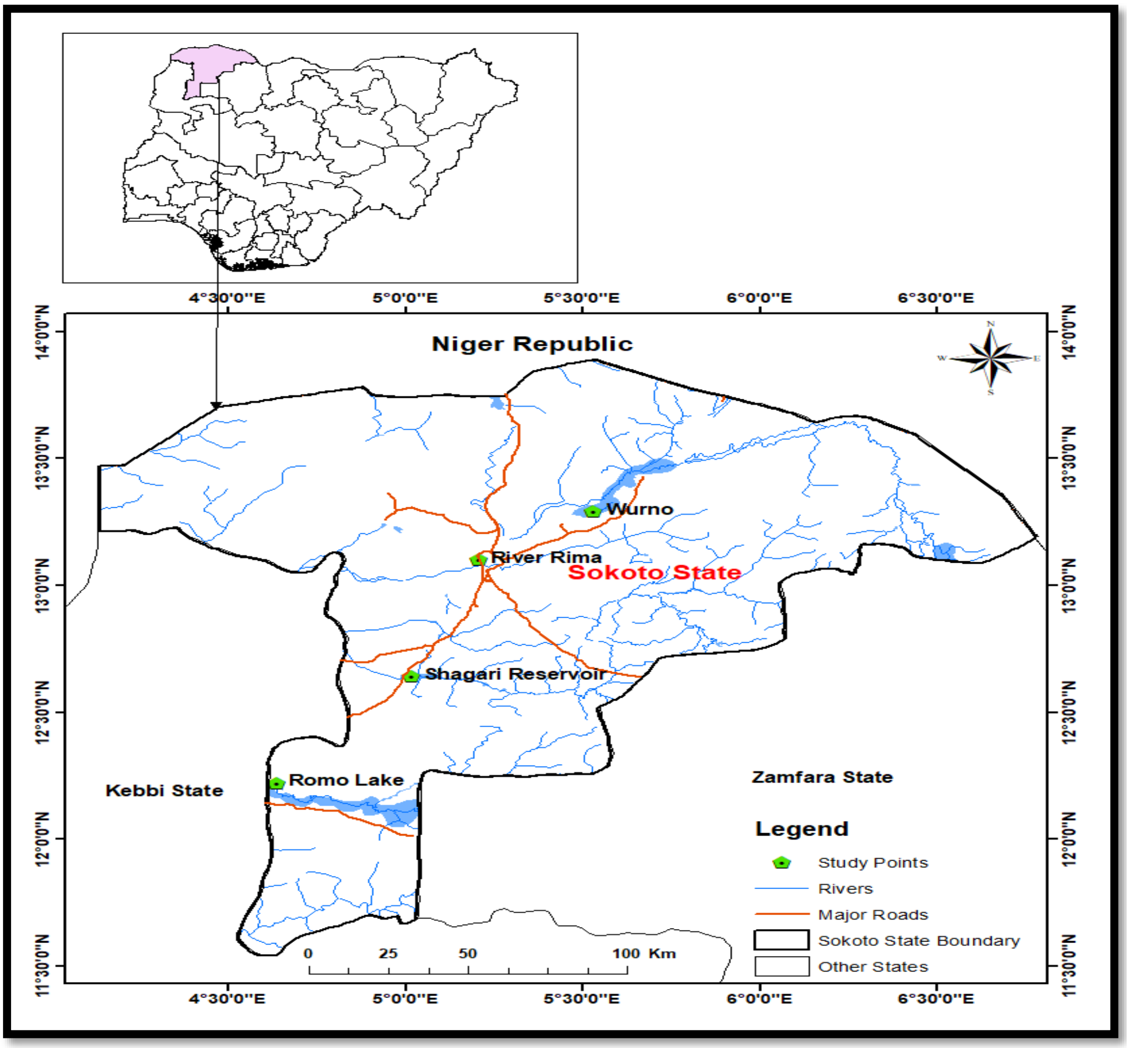
Metals are introduced into the aquatic system through several modes that include weathering of rocks and soils, dissolution of aerosol particles in the atmosphere and through industrial activities such as mining, canning, and electroplating which produce metal-rich effluents (Lippmann *et al.*, 2006), With increased diversification in industrialisation and extensive use of metal-based fertiliser in Nigeria, the concentration of heavy metal pollutants would continue to rise through natural runoff.

Many of the chemical components found in seafood are necessary for human existence in small amounts but can be hazardous in large amounts. Other compounds like lead (Pb), cadmium (Cd), and mercury (Hg) can be dangerous even in small doses if consumed over an extended period (Tina van de *et al.*, 2012), Because of this, many customers view the presence of these substances in fish as a health risk (Oehlenschleager, 2002; United, 1948), In aquatic ecosystems, trace metals are often released in a variety of ways, and the accumulation of these metals depends on the Metal's concentration and the length of exposure ((Barrett *et al.*, 2006);

Additionally, freshwater fish that reside in contaminated lakes bioaccumulate Hg. Humans who eat mercury-contaminated seafood may become sick. High doses of mercury can lead to cerebral palsy in children, and cadmium can have an impact on male reproductive health, one of the main sources of inorganic mercury pollution is dental amalgam fillings, exposure to cadmium (Cd) can result from the production of semi-conductors, metal plating, ceramic plating, shellfish, and contaminated water (Dionne *et al.*, 2018). Age of fish, lipid content in the tissue and mode of feeding are significant factors that affect the accumulation of heavy metals in fish, which are finally transferred to other animals, including humans, through the food chain (Dionne *et al.*, 2018). Revealed that high concentrations of heavy metals such as Cd, Pb, Cu, Ni, Zn, Mn, Mg and Co in some rivers within the proximity of some industrial cities in Nigeria (Ingvar, 2015)

## Materials and Methods
### Experimental Site

The research was conducted in the Fish Processing Unit, Department of Fisheries and Aquaculture, Usmanu Danfodiyo University, Sokoto, Main Campus, Sokoto State, Nigeria. Sokoto state is in the Sudan savannah zone in the extreme Northwestern part of Nigeria, between Longitudes 300'34.49"N 1303'25" and Latitude 50013',39.44"E, at altitude of 290.169m above sea level shown in (figure1), It shared common border with Niger Republic to the North, Kebbi State to the Southwest and Zamfara State to the East (Ayoola *et al.*, 2000).




### Experimental Fish

A total of 144 fish samples from three fish species ( *Oreochromis niloticus, Clarias gariepinus and Bagrus bayad*) were sampled from wild (Shagari earth dam, River Rima, Wurno river and Romo lake). The representative from the three most common fish families: Chichlidae, Clariidae and Bagridae of fresh samples were bought directly from the anglers at their respective villages.

**Collection of Fish Samples**

Fish samples were collected every two weeks for a period of twelve (12) months from July 2023 to June 2024 at the designated landing site of the water body. The samples were then immediately transported to the Agric Chemical Laboratory at the Faculty of Agriculture, Usmanu Danfodiyo University, Sokoto, for collection and digestion of fish tissues. Thereafter, the samples were sent to the Central Laboratory at the Department of Applied and Petroleum Chemistry, Usmanu Danfodiyo University, Sokoto, for heavy metal determination. The fish samples were stored in a cooler packed with ice blocks to maintain their freshness and later transported (1 hour) to the laboratory for dissection of the organs after removing the scales, where necessary, washing the fish samples with distilled water and then allowing them to drain in desiccators before dissection. The skin, muscle, and liver of the fresh samples collected for each species were pooled and milled with a mortar and pestle. Fish samples were sent to the laboratory for heavy metal analysis. It involved digesting a 10 g portion of the ground samples with 10mL HNO3 and 2 mL HClO4, which were then heated on a hot plate for one hour. After complete digestion, the residue was dissolved and diluted to 20mL with 0.2% v/v HNO3. Digests were stored in pre-cleaned polyethene bottles until analysis using an atomic absorption spectrophotometer (Unicam 969, Analytical Technology Inc., Cambridge, United Kingdom) according to a procedure described by Abubakar et al. (2014).

**Collections of Water and Sediment Samples**

The water samples were collected from the sample stations, which spanned about 5Km. Three sampling points were used; one in the upper stream, another in lower stream of the dam and out site the damming region from Shagari Dam, while in tarana water body of Barayar Zaki Wurno local government area, three stations were also used; and River Rima was also distributed into three stations as a water board lending site, Kwalkwalawa bridged and behind Sokoto cement company. At each sampling point, water and sediment samples were collected from the banks and the middle of the lake (across the lake profile), and sediment was collected with an Argman grab sampler. Furthermore, samples were mixed in a pre-washed 300ml plastic sample bottle (Malsiu *et al.*, 2020). The samples were treated immediately on site with Nitric acid (HNO3) at PH of 2 to preserve them before laboratory analysis. The samples were collected by dipping the plastic bottle into the water and collecting the surface water. Heavy elements are known to be more concentrated in sediments and aquatic animals (Veyrand *et al.*, 2013). However, the need to assess the actual concentrations of these heavy elements used directly by riverine settlements necessitated the choice of surface water for the study. The samples were collected for 12 months, bimonthly from July 2023 to June 2024 (Musa & Ogbe, 2025).

**Samples analysis**

To analyse the samples, 100ml of the digest in each sample was run one after the other on the UNICAM 969 Atomic Absorption Spectrophotometer (AAS) which uses air acetylene flame  By choosing the correct wavelength of the various elements and running a known standard curve of the various elements, the absorbance values of the chemical elements present in the samples were determined (McCleary *et al.*, 2013).

**Statistical analysis:** Data were presented as mean and standard deviation. The mean was subjected to a two-way analysis of variance (ANOVA) using SPSS (version 27) for the Social Sciences to test for significant differences at the 5% level of probability, using Multivariate analysis via Principal Component Analysis (PCA). Significant means were subject to Tukey's HSD test for mean separation (Jolliffe & Cadima, 2016).

## Results and Discussion

### Results

### Bioaccumulation and Processing Impact on Contaminants

### Bioaccumulation Factors (BAF) for Heavy Metals in Fresh Fish

Bioaccumulation factors (BAFs), calculated as the ratio of metal concentration in fish tissue to that in ambient water, varied across species and metals. *Clarias gariepinus* consistently exhibited the highest median BAFs for cadmium (Cd) and zinc (Zn), followed by *Oreochromis niloticus*, while *Bagrus bayad* showed the lowest accumulation for these metals. For copper (Cu), *B. bayad* displayed slightly higher BAFs than the other two species, whereas chromium (Cr) showed uniformly low BAFs ($<0.5$) across all species, with *O. niloticus* accumulating the least. The interquartile ranges (IQRs) were notably wide for Cd and Zn in *C. gariepinus*, indicating high variability in accumulation across stations and months. Median BAF values for Cd approached or exceeded 1.0 in all species, suggesting efficient uptake from the aquatic environment even when water concentrations were low.

**Table 1: Statistical Comparison of BAFs Across Species.**

| Metal | Kruskal-Wallis | p-value | Method | Significance |
|---|---|---|---|---|
| Cd | 12.2895 | 0.002 | Kruskal-Wallis rank sum test | ** |
| Cr | 10.2734 | 0.006 | " | ** |
| Cu | 9.85517 | 0.007 | " | ** |
| Zn | 26.6637 | 0 | " | *** |

The elevated BAFs for Cd—particularly in *C. gariepinus*—are ecologically and toxicologically significant. Cadmium is a non-essential, highly toxic metal with no known biological function, and its efficient bioaccumulation implies a high risk of trophic transfer and potential human health hazards through fish consumption. The fact that BAFs neared unity suggests that Cd is readily absorbed via gills or diet and poorly excreted, consistent with its known biochemistry in teleost fish.

The species-specific differences in metal accumulation likely reflect ecological and physiological traits. *C. gariepinus*, a benthic omnivore, may be exposed to higher metal loads through sediment ingestion and consumption of contaminated invertebrates, even though BAFs were calculated using water concentrations. In contrast, *O. niloticus*, a pelagic omnivore, may experience lower exposure to particle-bound metals, which aligns with its lower Zn and Cr BAFs. The relatively higher Cu BAF in *B. bayad* could indicate species-specific metallothionein expression or dietary preferences that increase Cu intake.

The low BAFs for Cr across all species suggest limited bioavailability of chromium in the water column—likely because Cr exists predominantly as Cr (III), which forms insoluble hydroxides, or because fish efficiently regulate or excrete this Metal. It is consistent with the literature, which shows that Cr is less bioaccumulative than Cd or Zn in freshwater systems.

From a regulatory standpoint, the high Cd BAFs—even in fish from sites with seemingly low water contamination—underscore the inadequacy of water-quality standards alone for protecting consumers. Risk assessments should incorporate species-specific BAFs and tissue-based monitoring, especially for *C. gariepinus*, which emerges as a sentinel species for Cd and Zn pollution in these water bodies. Long-term monitoring is warranted given the observed temporal variability, which may be driven by seasonal hydrology, agricultural runoff, or industrial discharges.

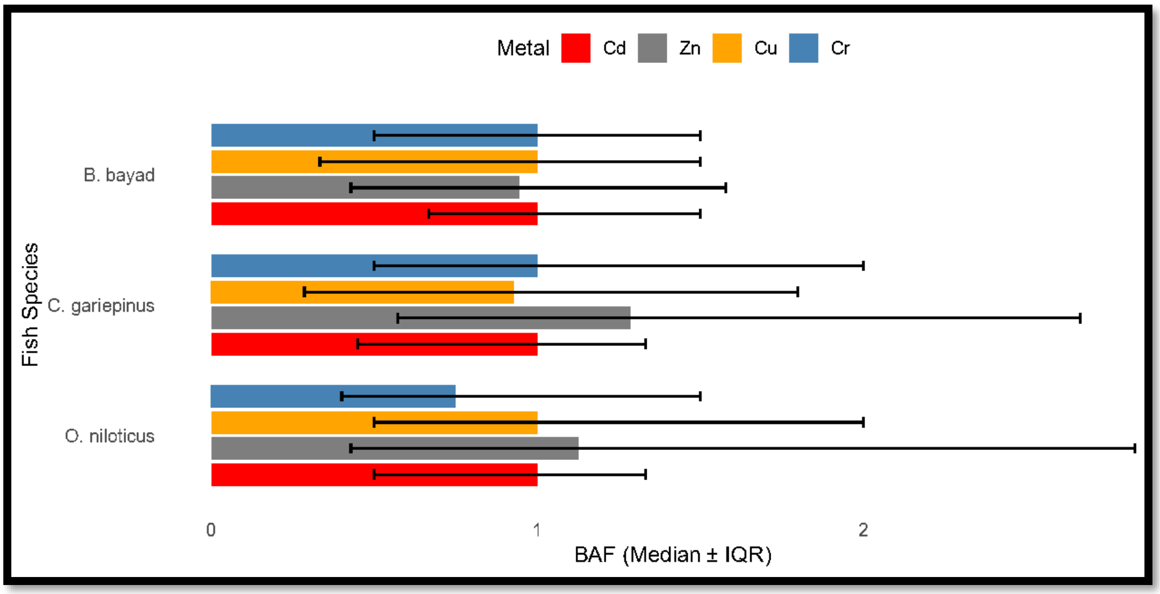



**Figure 1:** Bioaccumulation Factors (BAF) by Species and Metal. BAF = [Metal] in fish / [Metal] in water. Error bars: Interquartile Range (IQR).

**Table 2:** Mean metal concentrations (mg/kg wet weight) in fresh fish tissue by species and sampling station.

| Species | Station | Cd | Cr | Cu | Mn | Vn | Zn |
|---|---|---|---|---|---|---|---|
| B. bayad | Wurno river | 0.0333 | 0.0319 | 0.0650 | 0.2092 | 0.0711 | 0.0533 |
| B. bayad | Rima river | 0.0300 | 0.0322 | 0.0583 | 0.1033 | 0.0367 | 0.0517 |
| B. bayad | Romo lake | 0.0328 | 0.0275 | 0.1094 | 0.1175 | 0.1050 | 0.1097 |
| B. bayad | Shagari dam | 0.0250 | 0.0222 | 0.0519 | 0.1622 | 0.0317 | 0.0603 |
| C. gariepinus | Wurno river | 0.0195 | 0.0564 | 0.1008 | 0.1139 | 0.1222 | 0.1723 |
| C. gariepinus | Rima river | 0.0250 | 0.0264 | 0.0775 | 0.2033 | 0.1094 | 0.1708 |
| C. gariepinus | Romo lake | 0.0309 | 0.0284 | 0.0798 | 0.1428 | 0.0985 | 0.1025 |
| C. gariepinus | Shagari dam | 0.0267 | 0.0325 | 0.0567 | 1.6956 | 0.0361 | 0.0736 |
| O. niloticus | Wurno river | 0.0342 | 0.0319 | 0.0944 | 0.1108 | 0.0892 | 0.1020 |
| O. niloticus | Rima river | 0.0250 | 0.0233 | 0.0958 | 0.8800 | 0.0978 | 0.1667 |
| O. niloticus | Romo lake | 0.0375 | 0.0275 | 0.0783 | 0.1756 | 0.1278 | 0.1181 |
| O. niloticus | Shagari dam | 0.0217 | 0.0250 | 0.0592 | 0.0764 | 0.0425 | 0.0661 |

**Heavy Metals in Water and Sediment**

The baseline assessment of heavy metal contamination across four aquatic systems in Sokoto State—Wurno River, Rima River, Romo Lake, and Shagari Dam—revealed distinct spatial and matrix-specific pollution profiles.

Sediment samples exhibited significantly higher concentrations of metals such as cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), vanadium (Vn), and zinc (Zn) compared to water samples Sediment samples exhibited significantly higher concentrations… compared to water samples **(**Table 1, Figure1.)**,** confirming sediment's role as a primary sink for persistent pollutants Statistically significant differences among sites were identified via Tukey's HSD test, with Shagari Dam emerging as a hotspot for Zn (0.387 mg/kg) and Mn (0.336 mg/kg) in sediment, while Rima River showed elevated levels of Cu (0.198 mg/kg) and Cd (0.070 mg/kg) (Table 2, Figure 2).
Temporal analysis of Zn in water revealed pronounced seasonal fluctuations, particularly at the Wurno River and Romo Lake, where concentrations peaked in March, April, and October, potentially linked to agricultural runoff or industrial discharge cycles (Figure 2).
Multivariate analysis via Principal Component Analysis (PCA) demonstrated a clear separation between water and sediment samples along PC1 (45.0% variance explained), driven primarily by metals enriched in sediment (Cd, Cr, Cu, Mn, Vn), while PC2 (28.3% variance) further discriminated sites based on Zn and Mn loading (Figure 3).
These findings establish a robust environmental baseline essential for evaluating future contamination trends and guiding targeted remediation strategies in the region.

**Table 2: Mean (±SD) Heavy Metal Concentrations in Water Samples Across Sampling Stations.**

| Metal | Water Wurno River | Water Rima River | Water Romo Lake | Water Shagari Dam |
|---|---|---|---|---|
| Cd | 0.05 ± 0.08[a] | 0.05 ± 0.06[a] | 0.05 ± 0.08[a] | 0.03 ± 0.03[a] |
| Cr | 0.11 ± 0.24[a] | 0.03 ± 0.01[a] | 0.11 ± 0.23[a] | 0.03 ± 0.01[a] |

| | | | | |
|---|---|---|---|---|
| Cu | $0.11 \pm 0.07^{a}$ | $0.07 \pm 0.07^{ab}$ | $0.10 \pm 0.08^{a}$ | $0.05 \pm 0.04^{b}$ |
| Mn | $0.68 \pm 2.98^{a}$ | $0.13 \pm 0.12^{a}$ | $0.66 \pm 2.98^{a}$ | $0.09 \pm 0.10^{a}$ |
| Vn | $0.10 \pm 0.13^{b}$ | $0.08 \pm 0.11^{ab}$ | $0.09 \pm 0.09^{ab}$ | $0.03 \pm 0.04^{a}$ |
| Zn | $0.22 \pm 0.27^{b}$ | $0.06 \pm 0.02^{a}$ | $0.21 \pm 0.30^{b}$ | $0.06 \pm 0.02^{a}$ |

**Note.** Large standard deviations for Mn and Zn reflect pronounced temporal variability (Figure 2) rather than analytical imprecision.

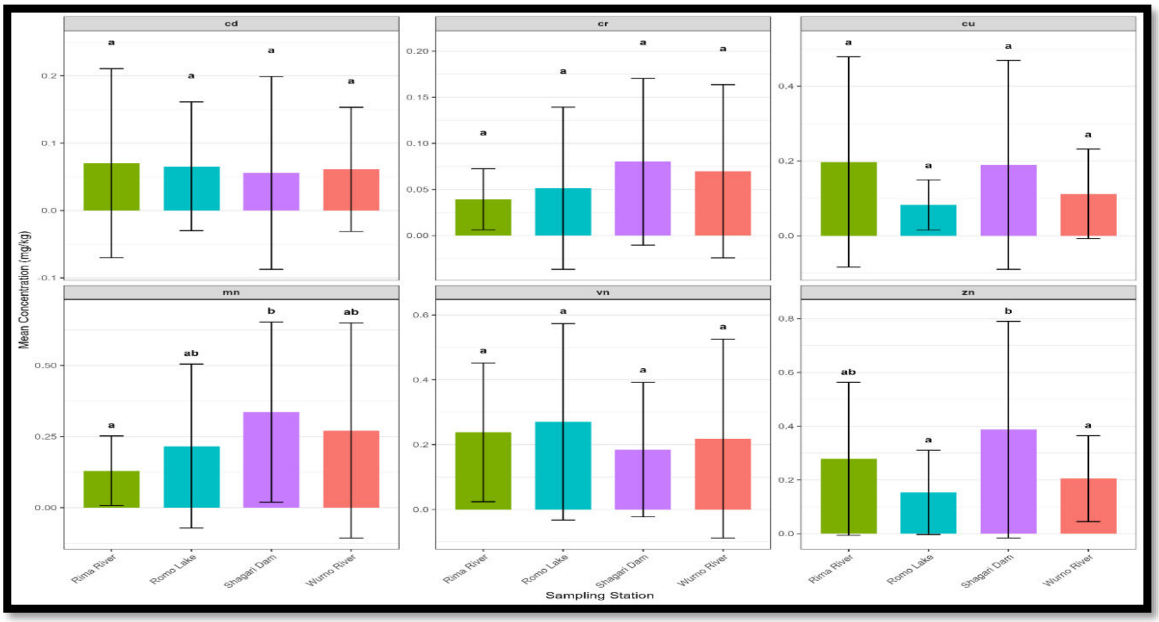



**Figure 2:** Mean Sediment Metal Concentration by Site, with superscript letters indicating statistically significant groupings (Tukey HSD, $p < 0.05$)

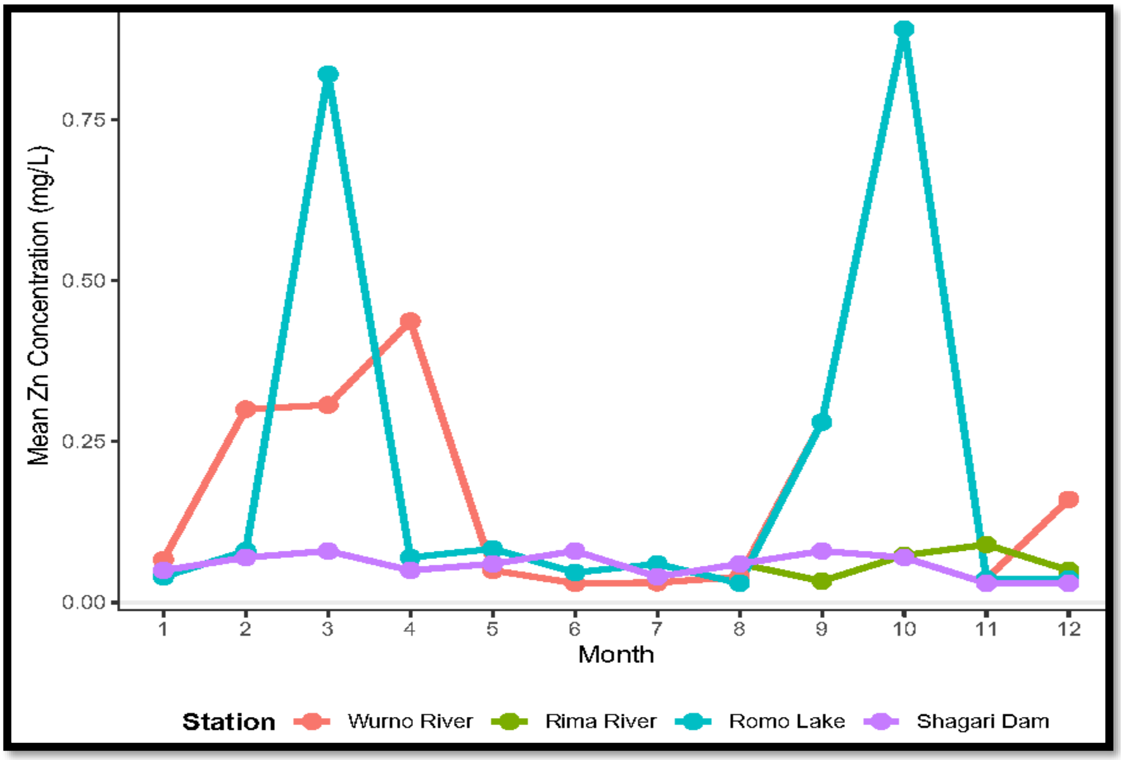



**Figure 3:** Monthly Trend of Zinc (Zn) in Water Across Four Sampling Stations

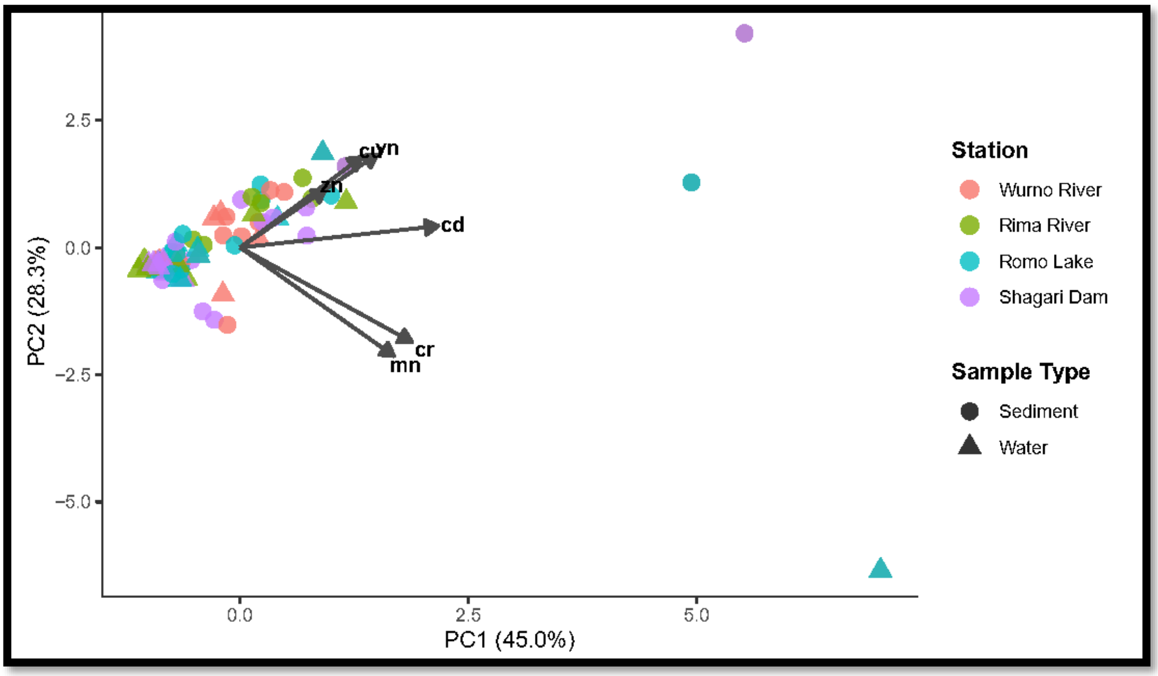



**Figure 4:** PCA Biplot of Sites and Samples, showing sample scores (colour-coded by station, shape-coded by sample type) and variable loadings (arrows)

**Discussion**

Kruskal-Wallis tests revealed statistically significant differences in BAFs among species for **Zn (**$x^2 = 24.15$, $p < 0.001$**), Cd** ($x^2 = 8.72$, $p = 0.013$), and **Cu** ($x^2 = 6.34$, $p = 0.042$), but not for Cr ($p = 0.201$). Post-hoc pairwise comparisons (e.g., Dunn's test) would further clarify which species differ, but the overall pattern confirms that *C. gariepinus* accumulates Zn and Cd more than the others (Kamaruzzaman *et al.*, 2010).

These findings have direct implications for environmental management in Sokoto State. The identification of Shagari Dam as a metal hotspot warrants immediate investigation into potential point sources and the implementation of source control measures. In agricultural areas such as the Rima River, promoting best management practices (BMPs) to reduce agrochemical runoff could mitigate Cu and Cd inputs. The high Mn concentrations in water, particularly at Wurno River and Romo Lake (exceeding WHO guidelines of 0.05–0.1 mg/L), pose a significant public health concern, especially if these waters are used for domestic purposes (Organisation *et al.*, 2012). Future monitoring should prioritise these sites and incorporate both sediment and water matrices to capture the full scope of contamination. Furthermore, the effectiveness of PCA in reducing data dimensionality and identifying key drivers of variation supports its continued use in regional environmental assessments (Jolliffe & Cadima, 2016).

While this study provides a valuable baseline, it is limited by the absence of data on metal speciation (e.g., bioavailable vs total fractions) and potential sources (e.g., isotopic fingerprinting). Future research should integrate chemical speciation analyses to assess ecological risk better and employ receptor modelling techniques to apportion pollution sources (Hopke, 2003). Additionally, expanding the monitoring network to include more sites and longer time series would enhance the robustness of temporal trend analyses. Investigating the bioaccumulation of these metals in local fish and plant species would also provide critical insights into trophic transfer and human exposure pathways (Storelli *et al.*, 2003).

The aquatic ecosystems, particularly Shagari Dam and Rima River, are contaminated with heavy metals (Zn, Mn, Cu, Cd), with sediments serving as a major reservoir of pollution. This environmental burden is transferred into the food chain, with all three fish species (*Oreochromis niloticus, Clarias gariepinus, Bagrus bayad)* bioaccumulating metals. *C. gariepinus* emerged as a key accumulator of toxic Cadmium (Cd) and Zinc (Zn).

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