FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 1, No. 2, 2024
Print ISSN: 1595-9686
EISSN: 1595-9708

HEAVY METALS BIOACCUMULATION IN SELECTED FISH SPECIES OF RIVER GONGOLA AT YAMALTU DEBA, GOMBE STATE, NIGERIA

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https://doi.org/10/33003/jees.2024.0102/03

ABSTRACT

This study was aimed to determine the level of heavy metals in water and the bioaccumulation factor of heavy metals in selected fish species (Bagrus bayad macropterus, Oreochromis niloticus and Clarias gariepinus) of River Gongola, Gombe State. Water and fish samples were collected from two locations for 18 months (Dec. 2021- May 2023). Water and fish samples were analysed for heavy metals (Cu, Cd, Cr, As, Ni, Mn, Fe and Zn) concentration using an Atomic Absorption Spectrophotometer (AAS). Bioaccumulation factors of heavy metals were determined in the selected fish species. The Cd, As and Mn concentrations in water exceeded the recommended standards. The levels of heavy metals varied significantly among fish organs. The liver had the highest concentration of most metals, followed by the gills and the muscles. The levels of heavy metals in the fish tissues were below standard limits. However, Zn was reported to have the highest concentration in all the tissues studied. The BAF values calculated were mostly < 1, indicating no probability of bioaccumulation except for Fe in B. bayad macropterus and C. gariepinus and As in C. gariepinus Periodic monitoring of the water and biota of the river is recommended to ensure the safety of these resources for consumer use.

Keywords: Bioaccumulation, Heavy metals, fish species, River Gongola and Ecotoxicology

INTRODUCTION

Aquatic ecotoxicology is the study of the effects of chemical contaminants on living organisms, especially on populations and communities within a specific aquatic ecosystem. It concerns the mode of transfer of those contaminants and their interaction with the marine environment (Butler, 1978).

When these foreign materials, also known as contaminants, enter the environment and are absorbed into the water cycle, water gets contaminated. They contaminate water supplies and can risk public health and the environment. Thus, any alteration in water that is detrimental to living things is considered water pollution (Neighborhood Water Quality, 2000).

Heavy metals are naturally occurring components of the Earth's crust. They are not biodegradable and cannot be destroyed. Some of these metals are highly soluble, making it easier for species to take up and absorb them and pass through the food chain. Once heavy metals enter the food chain, they bioaccumulate in living tissues, which can harm the organism. Because these metals are not biodegradable, these elements have accumulated (Lenntech, 2004; Abbas et al., 2016; He et al., 2020). Heavy metals are considered dangerous because they tend to bioaccumulate- when a chemical’s concentration in a biological organism rises over time relative to its concentration in the environment. When substances are ingested and stored more quickly than they are degraded or eliminated (metabolised), compounds build up within living organisms. In addition to coming from consumer and industrial waste, heavy metals can also find their way into water supplies through acid rain, which breaks down soil and releases heavy metals into lakes, rivers, streams, and groundwater (Lenntech, 2004). The primary anthropogenic sources of heavy metals are the combustion of fossil fuels and gasoline, waste incinerators, mining, foundries, and smelters. The European Monitoring and Evaluation Program (EMEP) considers mercury, cadmium and lead to be the significant heavy metals of concern because they are the most toxic and have been shown to have profound effects on human health, among other things (Ilia et al., 2004).

Fish is a vital source of protein in the human body. It supplies crucial fatty acids, which lower the risk of heart disease and stroke. It also supplies critical vitamins and minerals and helps lower blood cholesterol levels (Al-Busaidi et al., 2011). Fish and other aquatic creatures are seriously threatened by chemical pollutants such as heavy metals that contaminate the marine environment. This could have long-term consequences for the human food chain (Abah et al., 2016). Fish have been utilised extensively as bioindicators of water and in the identification and evaluation of the biological effects of contaminants in the aquatic environment because they are sensitive indicators of heavy metal pollution (Anders et al., 1988; Ampiah-Bonney et al., 2007).

The accumulation of pollutant concentrations in aquatic species after absorption from the surrounding ambient medium is known as bioaccumulation. It explains how pollutants build up and become more concentrated in organisms than in the environment (Green et al., 2023). Studies concerning heavy metals bioaccumulation and pollution of water bodies have become a major global environmental issue for decades. The capacity of aquatic species to absorb heavy metals from the river, the concentration of heavy metals in the surrounding environment, and the organisms' feeding habits all influence how quickly heavy metals bioaccumulate in aquatic organisms (Ansari et al., 2004). One of the key indicators for keeping an eye on the geochemical cycle of heavy metals in the marine ecosystem is bioaccumulation assessment (Jamil-Emon et al., 2023). This study evaluated the concentrations of some of these metals in water and their bioaccumulation in three commercially abundant fish species from River Gongola to determine their safety for human consumption.

MATERIALS AND METHODS

Study Area

The study area was the Dadinkowa and Kanar axis of the River Gongola at Yamaltu Deba L.G.A. The River lies within latitude 10°21′42.73″N and longitude 11°23′13.56″E of the equator. The river is a major tributary of the Benue River, originating in the Jos plateau area. The region experiences two distinct seasons: the rainy season, which is characterised by heavy rainfall and the potential for flooding, and the dry season, which is characterised by dry weather. The region's climate is classified as a tropical continental type in Nigeria. The area typically experiences a short rainy season followed by a long, variable dry season. The dry season is characterised by calm, dusty, dry winds and intense heat (Santuraki et al., 2022). The area's people are into irrigation farming (including irrigation farming), fishing and livestock grazing along the river course.

Sample Collection

Fresh fish samples of *B. bayad macropterus*, *O. niloticus* and *C. gariepinus* were collected from the river with the help of local fishermen. These fish species were chosen because they are readily available and seen all year round in the river. Both water and Fish samples were collected once monthly between 07:00 and 9:00 hours between December 2021 and May 2023. Water samples

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 1, No. 2, 2024
Print ISSN: 1595-9686
EISSN: 1595-9708

were collected for eighteen (18) months, covering two dry and one rainy season at 0.5 m below the water surface (because the water is deep). The water samples were collected from two sampling locations 2 kilometres apart, then filtered in a pre-cleaned litre bottle acidified by adding 5 ml of concentrated nitric acid (HNO_3) and kept for analysis. The fish species were collected from the two sampling locations, where the water samples were taken using gill nets, put in an ice box and transported to the Biochemistry Laboratory of Gombe State University on each sampling day for preparation.

Sample Preparation and Digestion

The fish samples were put on a dissection board and allowed to thaw at room temperature before dissecting. Dissection of the fish samples was done using a clean stainless-steel knife to separate liver, gill, and muscle tissues. Composite samples of each species' liver, gill, and muscle tissues were drawn—each composite sample comprised three (3) fishes of the same species. The liver, gills and muscles of the three different fish species were placed differently on a foil paper and put in an oven at a temperature of 105^0C for 24 hours to obtain a constant weight (AOAC, 2000). After oven drying, the samples were homogenised differently for the three fish species using a porcelain mortar and pestle and put in a sample bottle before digestion.

Samples were digested in the Biochemistry Department laboratory of Gombe State University. Before the digestion process, all glass wares and sample bottles were carefully cleaned with deionised water, oven-dried, and powdered samples (1g of each sediment and fish sample) were precisely weighed using weighing balance (Ohaus Model- AR 2130) and placed into a round bottom flask. Each sample was mixed with concentrated acids W(10 ml nitric acid (HNO_3) and 5 ml perchloric acid ($HClO_4$) prepared in a measuring cylinder), shaken and placed on a hot plate (Kjabahl litter) to digest until a transparent or clear solution was reached. After letting the mixture cool, it was filtered through Whatman No.1 filter paper, and the filtrate was then filled with deionised water to the mark of 100ml. The mixture was then put into a labelled sample bottle for analysis, and a sample blank was made using the same digestion process. Still, it was put into the sample bottles without the fish samples for analysis (AOAC, 2000).

Sample Analysis

Samples were analysed using an atomic absorption spectrophotometer (Bulk Scientific, model 205). The instrument was calibrated by first analysing two standard solutions for each metal, followed by the blank analysis before the sample analysis. The metals analysed were Cu, Cr, Cd, As, Ni, Fe, Mn, and Zn.

Bioaccumulation Factor (BAF) Determination

According to USEPA (2014) guidelines, the BAF is the ratio of the chemical concentration of metals in the organism to that in the surrounding water. The bioaccumulation Factor (BAF) for heavy metals in fish was calculated as described by Oboh and Okpara (2019).

$$\textbf{BAF} = \frac{\text{Heavy metal concentration in fish } (mg/kg)}{\text{Heavy metal concentration in water } (mg/l)}$$

RESULTS AND DISCUSSION

Heavy Metals in Water

The summary of the results for heavy metals in water for the two sampled stations is shown in Table 1. Cd, As and Mn were above the WHO/NSDWQ standard for heavy metals in water. The values for Cd were both 0.006mg/l, which is greater than the 0.003mg/l limit for WHO/NSDWQ.

Cd is a very toxic metal that can replace Zn in the body and can be an accumulative toxicant that can harm living organisms (Uba et al., 2019). Majorly, Cd is released into the environment by human activities such as manufacturing, gasoline, waste incineration, etc. (Lenntech, 2004; Ilia et al., 2004). Cd can cause kidney disease and is considered a cancer-causing agent. The high concentration of Cd recorded in this study might result from the dumpsite and municipal sewage in the river; water from other villages and towns upstream, even the Gombe metropolis, finds its way into the river. High Cd levels documented in this study agree with the findings of Talal et al. (2023), Omoigberale et al. (2014) and Emeka and Solomon (2020).

Table 1: Summary of Heavy Metals Concentration in Water of River Gongola (Dec. 2021- May 2023)

Heavy Metals	Station 1 Mean±SD	Station 2 Mean±SD	P-Value	WHO	NSDWQ
Cu	0.035	0.039	P>0.05	2	1
Cr	0.045	0.021	P>0.05	0.05	0.05
Cd	0.006	0.006	P>0.05	0.003	0.003
As	0.018	0.024	P>0.05	0.01	0.01
Ni	0.056	0.091	P>0.05	0.7	0.2
Fe	0.017	0.027	P>0.05	0.3	0.3
Mn	0.289	0.259	P>0.05	0.4	0.2
Zn	0.878	0.333	P<0.05	5	3

The values were 0.018 and 0.024mg/l for stations 1 and 2, respectively. Even at low concentrations, it is not an essential element, so it may be detrimental to the body. The high As values recorded in the study might be due to anthropogenic activities, especially of agricultural origin. The stations studied are close to agricultural lands that engage in rainy and dry season farming, and runoffs from these farmlands might end up in the water channel. These runoffs might contain heavy metals because farmers use pesticides and herbicides. Some of these heavy metals might be from fertilisers applied on the farmlands to boost productivity. Other causes can be municipal waste discharges from towns and cities nearby. Mn had 0.289 and 0.259 mg/l for stations 1 and 2, respectively. The trend for heavy metals concentration in station 1 was Zn >Mn>Ni>Cr>Cu>As>Fe>Cd, and for station 2 was Zn> Mn>Ni>Cu>Fe>As>Cr>Cd. Cr, Mn and Zn were higher in station 1 while Cu, As, Ni and Fe were higher in station 2. Both stations had the same value for Cd.

Heavy Metals in Fish

The variation of the concentrations of the different heavy metals studied in the liver of the three fish species is shown in Figure 1. Zn had the highest value in the liver of all the three fish species. However, the liver of *Clarias gariepinus* recorded the highest value of 0.508mg/kg, followed by *Bagrus bayad macropterus* with 0.478mg/kg. *Oreochromis niloticus* had the lowest value of Zn (0.195mg/kg). Zn, Cu, Cr, As, Ni, Fe and Mn were reported to be higher in the liver of *C. gariepinus* than the other two fish species. *O. niloticus* recorded the lowest concentration for most heavy metals studied (Figure 1).

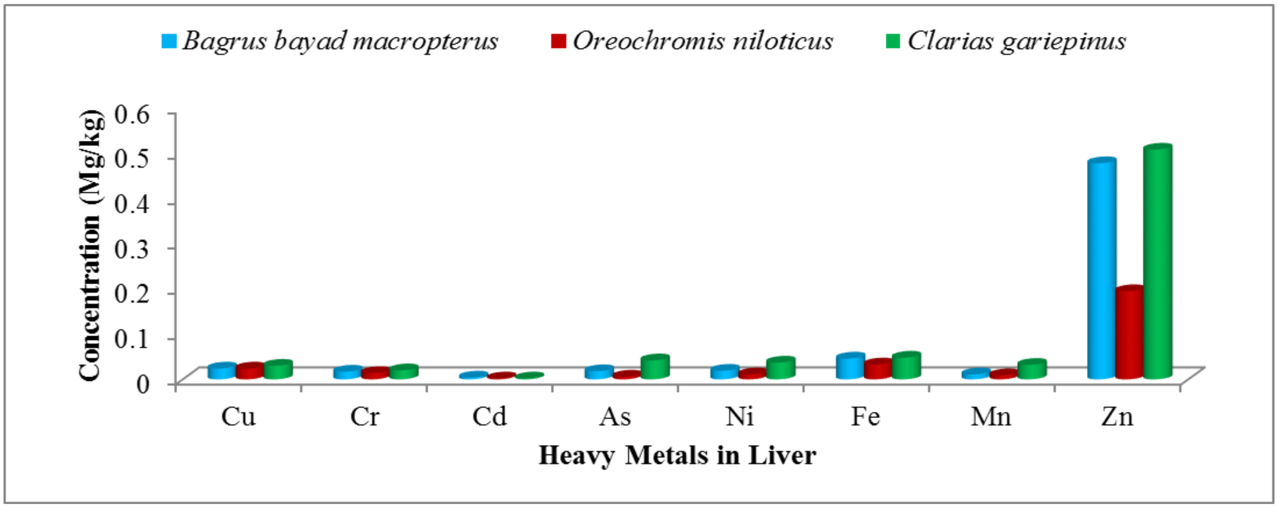

Figure 1: **Variation of Heavy metals in the liver of the three fish species**

In the muscle, Cd, Fe and Zn were the metals that recorded higher values in the muscle of *B. bayad macropterus*. Cu, Cr, As, Ni and Mn recorded higher values in the muscle of *C. gariepinus*. O. niloticus recorded the lowest muscle values for all the heavy metals studied. Zn was the highest in the muscles of the three fish species (figure 2) with the following values: 0.184, 0.170 and 0.177mg/kg, respectively, for *B. bayad macropterus, O.niloticus* and *C. gariepinus*. However, all the values of the heavy metals in the muscles were below the recommended limits for heavy metals in fish.

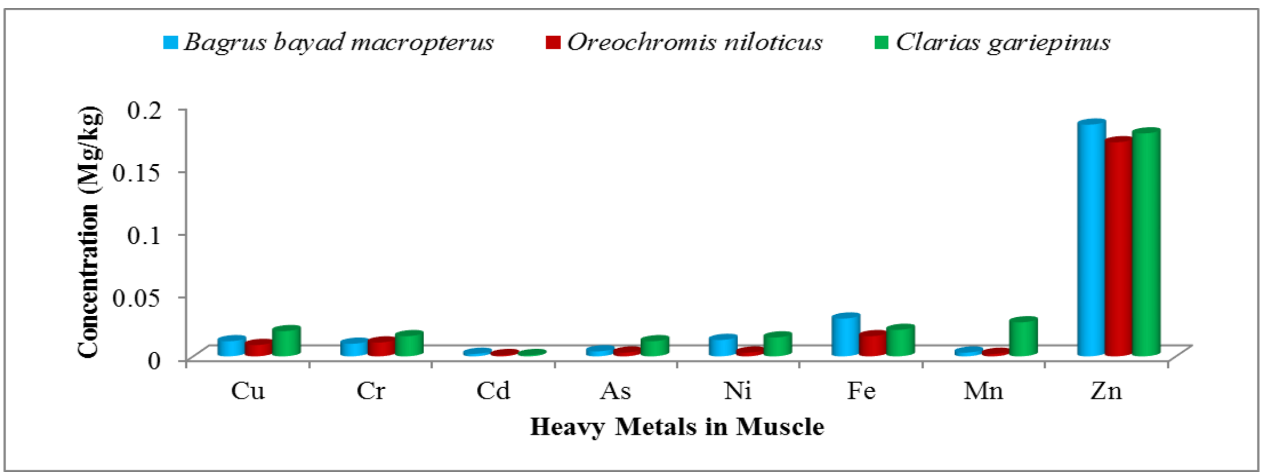

Figure 2: Variation of Heavy metals in the Muscles of the three fish species

Like the muscle and liver, Zn also recorded the highest concentration in the gills of the three fish species. However, *C. gariepinus* had the highest value (0.317mg/kg), followed by B. bayad macropterus (0.238mg/kg), then O. niloticus (0.202mg/kg), as seen in Figure 3 below. Cu, Cr, Ni and Zn were higher in *C. gariepinus* gills. Cd and Fe were higher in *B. bayad macropterus* gills and as was higher in the gills of *O. niloticus.* In all the heavy metals studied, Cd recorded the lowest values. However, the concentrations of these metals in the muscles were below the standard limit of WHO for heavy metals in fish.

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 1, No. 2, 2024
Print ISSN: 1595-9686
EISSN: 1595-9708

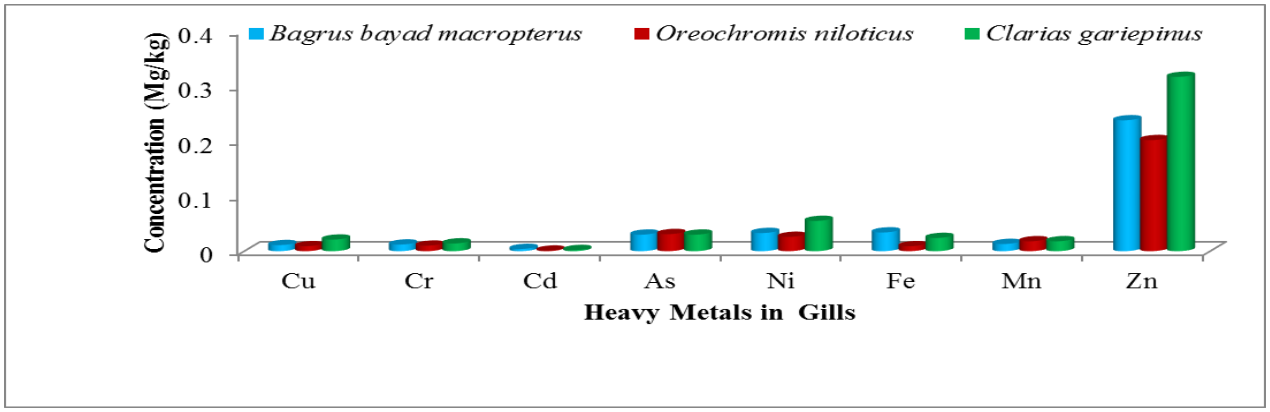

Figure 3: **Variation of Heavy metals in the Gills of the three fish species**

The mean values of the heavy metals studied in the different tissues of the three fish species were all below the WHO's recommended standard. This agrees with the findings of Ezekiel *et al*. (2019) and Rajesh-Kumar and Li (2018). The result of this study reported elevated values of the metals in the liver followed by the gills and then the muscles (Liver > gills > muscles) for all three fish species. Higher values in the liver agree with the reports of Green et al. (2023), who attributed the reason being that the liver is an active organ for physiological processes in metabolism and storage of essential metals. The gill is next in terms of high concentration. Due to their large surface area, the gills are pathways for metal ion exchange from water. This could be one of the reasons for high metal uptake (Dhaneesh et al., 2012). The muscles reported the lowest concentration of the metals in all three fish species. This could be because the muscle is not an active organ. Zn recorded the highest in all tissues (liver, muscles and gills) regarding individual metal concentration levels. However, all the values were below the recommended standard. Zn is an essential metal with high bioavailability in soil and water (Akbulut & Akbulut, 2010). According to Al-weather (2008), most Zn uptake was through the skin, not the gills. He attributed the high levels of zinc in the tissues due to the uptake of the metals through the skin. Higher concentrations of Zn in this study agree with the reports of Ayodele et al. (2019). Analysis of variance showed that the cumulative heavy metal concentrations were higher in C.gariepinus, followed by B. bayad macropterus than in *O. niloticus* (figure 4).

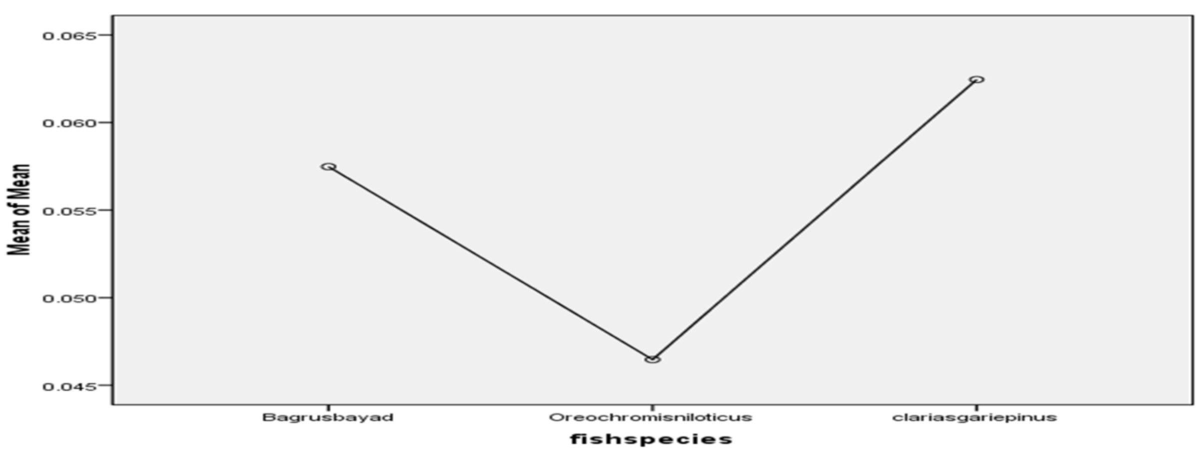

Figure 4: ANOVA Graph showing variation in heavy metals concentrations between fish species

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 1, No. 2, 2024
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The following factors may have contributed to *C. gariepinus'* higher metal concentration than the other fish species: 1. Feeding behaviour: *C. gariepinus* are omnivores, meaning they will consume a wide range of foods, such as dead animals, birds, reptiles, microscopic zooplankton, fish that are half their length or 10% of their body weight, and other fish (Moussa *et al.,* 2022; Mwebaza-Ndawula, 1984). When a fish engages in this type of feeding behaviour, it may be exposed to a wider variety of heavy metals than when it feeds on detritus and other aquatic foods like *B. bayad macropterus*, which is also omnivorous and *O. niloticus*, which is primarily herbivorous (Zita *et al.*, 2021; Usman *et al*., 2021). Even though both *C. gariepinus* and *B. bayad macropterus* are benthic and omnivorous fish species, *C. gariepinus* has a more varied diet than *B. bayad macropterus,* encompassing a greater variety of food items. 2. Habitat: compared to *O. niloticus*, a pelagic fish, *C. gariepinus*, a bottom-dwelling fish that spends most of its time feeding, may be more exposed to heavy metals in the sediment in this habitat (Moussa *et al.,* 2022; Zita *et al*., 2021). 3. Metabolism: *C. gariepinus* may metabolise metals differently than other species, impacting how it bioaccumulates metals (Heba *et al.,* 2022; Ezeonyejiaku *et al*., 2014). 4. Size and Exposure duration: compared to other fish species, *C. gariepinus* most have been exposed to heavy metals for a longer duration. They are also larger fish than *O. niloticus* and *B. bayad macropterus,* which may cause a higher accumulation because of their large bodies (Moussa *et al*., 2022; Kosgei *et al*., 2019).

Bioaccumulation Factors (BAF) for Heavy Metals in Fish

The BAF values of heavy metals for the three fish species studied are presented in Table 2. The BAF values were attained by dividing the concentration of heavy metals in fish by the concentration of heavy metals in water. According to Davies and Ekperusi (2021), an effective absorption of pollutants is indicated by a BAF value > 1. For *B. bayad macropterus*, all the heavy metals studied had BAF values < 1 except for Fe (1.36±0.01). All the BAF values for *O.niloticus* for all heavy metals studied were <1. Fe had BAF values >1, Zn had BAF = 1 for C. gariepinus, while the other heavy metals were <1. The BAF values were 1.16±0.01, 1.15±0.01 and 1.00±0.017 for As, Fe and Zn, respectively.

Table 2: Bioaccumulation factors of Metals in *B. bayad macropterous,* *O. niloticus* and *C. gariepinus*

Heavy Metals	*B. bayad macropterus*	*O. niloticus*	*C. gariepinus*
Cu	0.40±0.01	0.36±0.01	0.61±0.01
Cr	0.62±0.00	0.56±0.00	0.79±0.00
Cd	0.56±0.00	0.22±0.00	0.28±0.00
As	0.72±0.01	0.56±0.01	1.16±0.01
Ni	0.24±0.01	0.15±0.01	0.39±0.02
Fe	1.36±0.01	0.72±0.01	1.15±0.01
Mn	0.03±0.01	0.04±0.01	0.10±0.01
Zn	0.90±0.16	0.57±0.02	1.00±0.17

Most of the BAF values for this study were < 1 except for Fe in *B. bayad macropterus* and *C. gariepinus* and As and Zn in *C. gariepinus*, which were ≥ 1, indicating possible bioaccumulation by these metals. The BAF values show that *C. gariepinus* had BAF values ≥ 1 in As, Fe and Zn, showing that it has the highest potential for bioaccumulation among the three fish species. This could be due to the high concentration of heavy metals in the tissues of the fish compared to other species. A benthic fish with a diverse diet can concentrate higher values than *O. niloticus*. The *B.*

bayad macropterus was the next, having a BAF > 1 for Fe. For *O. niloticus*, all the heavy metals had BAF < 1, showing no probability of bioaccumulation. This could be due to lower levels of heavy metals in its tissues compared to the other two species, which are also pelagic. Another reason could be that the fish had a short exposure period/residence time in the river.

CONCLUSION AND RECOMMENDATIONS

The study's findings showed that River Gongola's water at this location is contaminated due to higher Cd, As and Mn values. Heavy metal accumulation varied depending on the fish tissue and species. *C. gariepinus* had the highest cumulative heavy metals concentration, followed by B. bayad macropterus and *O. niloticus*. The liver had the highest concentration, followed by the gills and the muscles. Most BAF values showed no probability of bioaccumulation except for Fe in *B. bayad macropterus*, *C. gariepinus,* and As in *C.gariepinus*. From the study, it can be concluded that the water of River Gongola at this location is contaminated with Cd, As, and Mn. Therefore, environmental laws should be reinforced and strictly adhered to to protect the aquatic ecosystem and humans that depend on them. Watershed management should be focused on agricultural activities by encouraging organic farming practices to minimise the use of inorganic substances that currently serve as contaminants in the river

Acknowledgements

The authors wish to acknowledge the assistance of the local fishermen at the study locations who collected samples and all the laboratory technicians of the Department of Biochemistry, Gombe State University, for their support during the laboratory work.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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