

# Influence of heavy metals toxicity on bioaccumulation and histopathological changes in the tissues of *Clarias gariepinus* (Burchell, 1822) at Watari Reservoir of Bagwai in Kano State, Nigeria

Jamila Muhammad Juma'ah<sup>1</sup>, Mustapha Baba Geidam<sup>2\*</sup>, Abubakar Bala Abdullahi<sup>3</sup>, Yakubu Ali Musa<sup>4</sup>, Lawan Alhaji Ahmed<sup>5</sup> and Balarabe Usman Getso<sup>1</sup>

<sup>1</sup>Department of Biological Sciences, Aliko Dangote University Wudil, Kano State, Nigeria.

<sup>2</sup>Department of Fisheries and Aquaculture, Federal University Dutsin-Ma, Katsina State, Nigeria.

<sup>3</sup>Department of Animal Sciences, Federal University Kashere, Gombe State, Nigeria.

<sup>4</sup>Department of Fisheries Technology, Federal College of Freshwater Fisheries Technology, Baga, Borno State, Nigeria.

<sup>5</sup>Department of Biological Sciences, Gombe State University, Gombe State, Nigeria.

\*Corresponding author. Email: mbabageidam@gmail.com

Copyright © 2026 Juma'ah et al. This article remains permanently open access under the terms of the [Creative Commons Attribution License 4.0](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Received 20th September 2025; Accepted 12th December 2025

**ABSTRACT:** This research assessed the impacts of pollution status on the reservoir that revealed insight into the bioaccumulation and histopathological changes in gills and liver tissues of *C. gariepinus* between February and September 2023. The atomic absorption spectrophotometer, Leica DM 750 microscope and Leica ICE 50 HD were used for heavy metals concentrations and photomicrographs. Thus, the data obtained were statistically analysed with IBM-SPSS Version 22. These findings revealed that the tissues were bioaccumulated with different heavy metal concentrations. Evidently, it was discovered that the severity of the tissues damage differed according to the site. This was attributed to a constant influx of different kinds of pollutants into the Watari Reservoir. Also, it was revealed that the level of Cu was significantly higher in gill tissue with 2.90mg/kg as compared with the other heavy metals, and the lowest was found in the liver with 1.04. Notwithstanding, Pb, Cr and Cd also significantly followed the same pattern. Moreover, all the heavy metals obtained were above the safety level of 0.01mg/kg prescribed by FAO/WHO. Thus, it is expected that these affected fishes, when continuously consumed, can bioaccumulate in the end users, and then it affects the health of the consumer. However, the photomicrographs of the *C. gariepinus* tissues from the Up-Stream, Mid-Stream and Down-Stream exposes cellular alterations such as deformed epithelia, inflamed lamellae and disrupted gill filaments. Also, deformed hepatocytes, cellular infiltration and haemorrhage were observed in the liver. Therefore, it is recommended to provide wastewater catchment basins and treatment plants to treat in order to regulate or to stop the direct discharge of effluents into the water bodies. Hence, this may curtail the menace that can disrupt the survival of the aquatic organisms, especially fish species in the reservoir, and directly or indirectly affect human lives.

**Keywords:** Bioaccumulation, health hazards, heavy metals, histopathological changes, pollution of effluents, Watari Reservoir.

## INTRODUCTION

The freshwater bodies in Sub-Saharan Africa, especially the Northern Nigerian regions, are blessed with several rivers, seasonal streams, and artificial and natural lakes.

Watari Reservoir of Bagwai in Kano State is among the man-made lakes which are home to fishery resources, a source of drinking water, irrigation activities, recreation

and conservation of biodiversity.

However, this reservoir is presently threatened by anthropogenic activities. These might cause an influx of contaminants such as fertilisers, herbicides, pesticide residues, etc., due to high irrigation intensity. Also, it is influenced by the deposition of detergent through laundry services surrounding it (Rabiu *et al.*, 2018; Usman and Maitera, 2025). Though, even the natural pollutants, for examples decayed organic matters, minerals from hills, acid rains, etc., are not exempt.

Therefore, aquatic ecosystem toxicity is of greatest concern in the freshwater bodies, although these are continually increasing. The vulnerability to heavy metals had increased rapidly due to exposure to natural sources, industrial and human activities in the 20th century (Orimoloye and Mohammed, 2020; Olayinka-Olagunju, 2022; Abd Elnab *et al.*, 2023; Mora *et al.*, 2023). Notwithstanding, pollution of water bodies by heavy metals is now a global problem that raises an alarm due to its negative influences on fish ecosystems and also affects human consumption (Mamman *et al.*, 2017; Gashua *et al.*, 2018; Abalaka *et al.*, 2020).

In accordance with Bob-Manuel *et al.* (2015), the heavy metals are among the persistent and potentially harmful pollutants. Though, an elevation in the levels of heavy metals exerts a harmful health risk on all aquatic zoic and human beings. Heavy metals might seriously threaten fisherfolk, those that utilises the water and consume the fish of the affected water body.

Therefore, human activities were leading this water body to pollution that causes heavy metal accumulation. The accumulation factor (AF) is the average of the accumulated concentration of the pollutant in any organ and its concentration in water. Heavy metals are dangerous elements that have the capability to bioaccumulate in the tissues of fish and other living organisms. In accordance with Davidson *et al.* (2019), who stated that heavy metals can be ingested and stored more rapidly than to metabolise or as well to excrete. Although these heavy metals bioaccumulate to cause different toxic effects on organs. These metals have variant mechanisms of action discloses that it initiates different pathways which produce reactive oxygen species. Also, the inactive enzymes can cause oxidative stress, which jointly induces toxicity. Thus, this might be acute and or chronic; however, water, air and food are major sources of exposure. The prevalence of lead, Chromium and cadmium is very rampant and can cause toxicity in both fish and human beings.

Moreover, heavy metals are chemical elements that their higher density, relatively equivalent or  $> 5\text{g/cm}^3$  in the medium, which exert toxicity even at lower concentrations (Useh and Dauda, 2018; Davidson *et al.*, 2019). Although the changes occur due to over-dependence on the reservoir for municipal water supply, fisheries activities and other water usage. So, prolonged exposure to heavy metals by human beings and higher vertebrates can cause

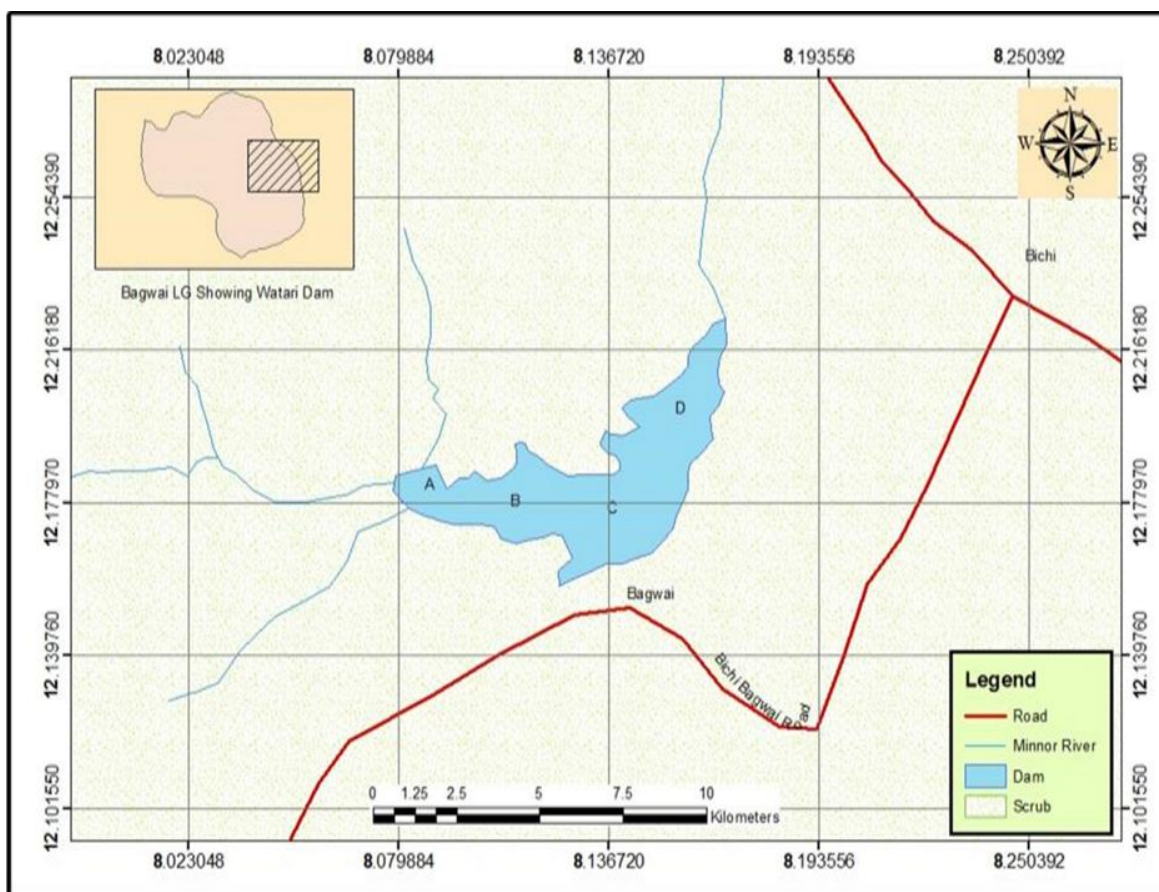
mental disorder, kidney malfunction or failure, disorder of the central nervous system of the brain, lung cancer and bone fractures (Useh and Dauda, 2018; Jasmina *et al.*, 2020). In addition, most of the heavy metals that bioaccumulate in the tissues of aquatic animals are toxic without a beneficial role in the body of a living organism (Edward *et al.*, 2017).

Hence, the presence of pollutants can result in heavy metal contamination in the Watari ecosystem (Usman and Maitera, 2025). They are known for their non-biodegradable nature, when discharged atmospheric deposition and erosion due to rainwater. Fishes are bio-indicators of aquatic ecosystem pollution due to their different sensitivities to contaminants. This can also exert a bioaccumulation and histopathology in the tissues. Fish species are generally among the components of the aquatic food chain and web. These might accumulate the heavy metals into their body and bio-magnify to determine the process and the pathways of contaminants from different tiers of trophism in the fish tissue through metabolism and bio-absorption (Akan *et al.* 2012). Thus, the study on heavy metals' constituents and their concentrations in *Clarias gariepinus* and other fish species can contribute to the knowledge; identify risk and safety levels that are related to haphazard consumption of contaminated freshwater and marine fish species (Geidam *et al.*, 2023). Though the aquatic habitats are exposed to elevated levels of metals due to pollution; then might be filtered or come into contact with the body, invariably accumulated into a various organs' tissues to cause toxicity in the fish. This work aimed to assess the bioaccumulation and histopathological changes in the gills and liver of *C. gariepinus* at Watari Reservoir. In accordance with Geidam *et al.* (2023), who recommended that the safety margin from other sources, species of fish and heavy metals, which predispose humans to cancer and toxins, need to be investigated.

## MATERIALS AND METHODS

### Study area

Watari Reservoir was impounded in 1977. It is situated about 47 km away from Kano city along the old Bichi-Gwarzo road in Bagwai and Bichi Local Governments Area of Kano, 2 km from Bagwai town and 8 km southwest of Bichi, Kano, Nigeria. It has 1,959 hectares of surface area and an active storage capacity of 92.74million litres. The Reservoir is located between latitude  $12^{\circ}9'24''\text{N}$  and  $8^{\circ}8'12''\text{E}$  with two distinct seasons (wet and dry). The rainy season lasts from May to October, and the dry season lasts from November to April. The mean annual temperature is between  $16 - 41^{\circ}\text{C}$  and the mean annual rainfall ranges from 700 – 813 mm (Geography Department Bayero University, Kano, 2022).



**Figure 1.** A map showing the three sampling sites at Watari Reservoir, Bagwai.

### Fish samples collection

The six (6) samples of *C. gariepinus* of different weights and sizes were randomly selected fortnightly for eight months from February to September 2023. A total of 144 fish samples were collected from fisher folks along the sites (Up-Stream, Mid-Stream and Down-Stream) of the Watari Reservoir at Bagwai in Kano State, Nigeria. This was achieved with the method described by Badamasi (2014) and Mamman *et al.* (2017).

### Fish samples Identification

The captured samples of *C. gariepinus* were collected and identified at the spot using Fish Identifier, known as "Picture Fish" Android Version, and preserved in an isolated ice-box. They were compared with the Fish Water Fish Identification field guide. Therefore, immediately transported to the laboratory for further analysis, they were counted and weighed to the nearest 0.1 g using a sensitive weighing balance (M-Metlar Model). The biometric features such as the type of mouth, position of the mouth,

fin count, spine count, barbell counts and position, kind of teeth, dorsal and anal fin rays count, gill raker count, body shape, size, colour and shape of the caudal fin were examined on the fish species using identification keys by Olaosebikan and Raji (2013).

### Samples preparations

The fish samples were dissected using the procedure described by Usman *et al.* (2015) and Geidam *et al.* (2023). Gills and liver were removed and oven-dried at a temperature of 105°C until they reached a constant weight. Each organ was ground into a powdery form and kept in the desiccator prior to digestion. Then 2 g of this powdered tissues were homogenized and subjected to digestion using concentrated nitric acid (HNO<sub>3</sub>) and hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) (1:1) v/v.

### Fish samples digestion

Exactly 2 g of the powdered samples were weighed into a

250 ml round-bottom flask, and 10ml each of HNO<sub>3</sub> and H<sub>2</sub>O<sub>2</sub> was added to the contents of the flask to remove organic materials and then purified, and then allowed to undergo digestion (Jim-Halliday *et al.*, 2024). The content of the flask was heated on a heating mantle to a temperature of 130°C till dissolution inside a fume hood, and the volume was reduced to 4 ml. This was done in accordance with Iromini and Atiola (2021). The digested samples were allowed to cool and filtered into a conical flask. The filtered samples were transferred to a 50 ml volumetric flask, and de-ionised water was used to further dilute the sample to 50 ml in the volumetric flask. The concentration of heavy metals such as Cadmium (Cd), Chromium (Cr), Copper (Cu) and Lead (Pb) was determined using an Atomic Absorption Spectrophotometer (Perkin Elmer PinAAcle 900H Model) at the Central Laboratory of Bayero University Kano.

### Bio-accumulation factor determination

Bioaccumulation factors (BAF) were calculated using the protocol described by Vaseem and Banerjee (2013):

$$BAF = \frac{M \text{ tissue}}{M \text{ water}}$$

Where: M = Tissue is the metal concentration in fish tissue (mg/kg), and M = water is the metal concentration in Reservoir water (mg/L).

### Histopathological studies of *Clarias gariepinus* liver and gills

The biopsies of gills and liver in *C. gariepinus* were conducted at the Histopathology Laboratory of Aminu Kano Teaching Hospital, Kano, Nigeria, and Bayero University, Kano. The *C. gariepinus*'s tissues were fixed with 10% buffered formalin for 24 hours, dehydrated with ascending grades of alcohol, cleared with xylene and embedded with molten paraffin wax. Microtome sections (5µm) of the tissues were stained with Haematoxylin and Eosin stains, examined under a microscope (LEICA DM 750 model) and photomicrographed with an HD camera (LEICA ICE 50 model), as described by Suwanpraserta (2020).

### Fixation

The tissues were expunged and rinsed with deionised water, then carefully taken while the chemical constituents of the cells, shapes and structures were preserved with 10% neutral buffered formalin for histological study (Bob-Manuel *et al.*, 2015).

### Tissue processing and tissue sectioning

The selected tissues were dehydrated, cleared, impregnated and embedded in paraffin wax and tissues were passed through 70% and 90% as absolute I and absolute II for an hour, respectively. The tissues were passed via two changes of xylene for an hour to de-alcoholise. Also, during impregnation, the clearing agent was eliminated from the tissues with molten paraffin at 54°C.

Finally, the tissues were embedded in paraffin wax, and the processed tissues were rendered stiff enough as described by Bob-Manuel *et al.* (2015). The tissue blocks were sectioned using a microtome (HistoCore 149 Multicut), Leica Biosystems Model. The gauge controlling the thickness of sections was properly set; the thickness of sections was set at 15 µm. Then the microtome was set up, a cutting rhythm was formed of a ribbon of about 1.5 cm long. The sections were spread out in a water bath at 45°C. The sections were successfully attached to the slide using bovine albumen adhesive. Slides were prepared and incubated at 50°C, dried, and the sections were fixed as described by Bob-Manuel *et al.* (2015).

### Staining of sections

The sectioned tissues were stained with Haematoxylin and Eosin (H and E) stains, stained slides were examined for histopathological lesions. These were achieved using a light-camera microscope (LEICA DM 2500 model) at Aminu Kano Teaching Hospital, Kano, Nigeria. The histological alterations were observed in each of the five (5) sectioned fish tissues. Microtome sections (5 µm) were stained with Haematoxylin and Eosin stains that were examined with a Leica DM 750 microscope and finally photomicrographed with LEICA ICE 50 HD camera as adopted by Bob-Manuel *et al.* (2015).

### Statistical analysis

Data was analysed using descriptive statistics to determine means and standard deviations. The data were subjected to one-way analysis of variance (ANOVA) to determine differences between sites, and where differences existed, they were separated with LSD at 0.05%. Seasonal variations were analysed using Student's Independent T-test. All analyses were carried out using SPSS version 22.0 software.

## RESULTS

### Spatial variation in the bioaccumulation of heavy metal levels in tissues of *C. gariepinus*

In this research, the spatial variation of Cr, Cd, Cu, and Pb concentrations in the liver and gills of *C. gariepinus*

**Table 1.** Spatial variation of heavy metals (mg/kg) in fish tissues obtained from Watari Reservoir, Kano State (February- September, 2023).

Sites	Parts	Pb	Cu	Cr	Cd
A	Liver	0.19 ± 0.11 <sup>b</sup>	1.17 ± 0.10 <sup>a</sup>	0.50± 0.01 <sup>b</sup>	0.25 ± 0.04 <sup>b</sup>
	gills	0.61 ± 0.02 <sup>a</sup>	0.61 ± 0.01 <sup>b</sup>	0.82 ± 0.10 <sup>a</sup>	0.42 ± 0.11 <sup>a</sup>
B	Liver	0.41 ± 0.07 <sup>b</sup>	0.45 ± 0.10 <sup>b</sup>	0.43 ± 0.01 <sup>b</sup>	0.11 ± 0.01 <sup>b</sup>
	gills	0.91 ± 0.11 <sup>a</sup>	0.77 ± 0.10 <sup>a</sup>	0.65 ± 0.01 <sup>a</sup>	0.35 ± 0.10 <sup>a</sup>
C	Liver	0.76 ± 0.10 <sup>b</sup>	0.78 ± 0.10 <sup>b</sup>	0.31 ± 0.30 <sup>b</sup>	0.08 ± 0.11 <sup>b</sup>
	gills	0.91 ± 0.06 <sup>a</sup>	0.91 ± 0.29 <sup>a</sup>	0.73 ± 1.05 <sup>a</sup>	0.37 ± 0.02 <sup>a</sup>

Values are means and S.D, values with the different superscript in a column differed significantly ( $p < 0.05$ ).

**Table 2.** Mean monthly values of heavy metals (mg/kg) in fish tissue from Watari Reservoir, Kano State (February- September, 2023).

Concentrations	Parts	Pb	Cu	Cr	Cd
February	Liver	0.80± 0.11 <sup>b</sup>	0.85 ± 0.12 <sup>b</sup>	0.61 ± 0.10 <sup>b</sup>	0.01 ± 0.01 <sup>a</sup>
	Gills	0.89 ± 0.10 <sup>a</sup>	1.32 ± 0.67 <sup>a</sup>	0.90 ± 0.10 <sup>a</sup>	0.01 ± 0.00 <sup>a</sup>
March	Liver	0.60 ± 0.11 <sup>a</sup>	1.10 ± 0.01 <sup>b</sup>	0.29± 1.01 <sup>b</sup>	0.01 ± 0.01 <sup>b</sup>
	Gills	0.45± 0.54 <sup>b</sup>	1.70 ± 0.10 <sup>a</sup>	1.73 ± 0.02 <sup>a</sup>	0.30 ± 0.12 <sup>a</sup>
April	Liver	ND	1.19± 0.10 <sup>a</sup>	0.27± 0.21 <sup>b</sup>	ND
	Gills	1.25 ± 1.01 <sup>a</sup>	0.86 ± 0.04 <sup>b</sup>	0.61 ± 0.10 <sup>a</sup>	0.30 ± 0.01 <sup>a</sup>
May	Liver	0.50± 0.01 <sup>b</sup>	1.69 ± 0.02 <sup>a</sup>	0.88 ± 0.01 <sup>a</sup>	0.09± 0.01 <sup>b</sup>
	Gills	0.89 ± 0.01 <sup>a</sup>	1.39 ± 0.67 <sup>b</sup>	0.23± 0.14 <sup>b</sup>	0.42± 0.10 <sup>a</sup>
June	Liver	0.60 ± 0.01 <sup>b</sup>	1.03 ± 0.01 <sup>b</sup>	0.28± 0.11 <sup>b</sup>	0.65± 0.10 <sup>a</sup>
	Gills	0.81 ± 0.00 <sup>a</sup>	1.70 ± 0.10 <sup>a</sup>	0.30 ± 0.02 <sup>a</sup>	0.55± 0.00 <sup>b</sup>
July	Liver	0.28 ± 0.11 <sup>b</sup>	0.19± 0.12 <sup>b</sup>	0.21± 0.21 <sup>b</sup>	0.76± 0.02 <sup>a</sup>
	Gills	0.65 ± 0.01 <sup>a</sup>	1.42 ± 0.10 <sup>a</sup>	0.34 ± 0.04 <sup>a</sup>	0.65± 0.00 <sup>b</sup>
August	Liver	ND	1.19± 0.10 <sup>a</sup>	0.27± 0.21 <sup>b</sup>	ND
	Gills	1.25 ± 1.01 <sup>a</sup>	0.86 ± 0.04 <sup>b</sup>	0.61 ± 0.10 <sup>a</sup>	0.30 ± 0.01 <sup>a</sup>
September	Liver	ND	1.19± 0.10 <sup>a</sup>	0.27± 0.21 <sup>b</sup>	ND
	Gills	1.25 ± 1.01 <sup>a</sup>	0.86 ± 0.04 <sup>b</sup>	0.61 ± 0.10 <sup>a</sup>	0.65 ± 0.01 <sup>a</sup>

Note: ND = Not detected, ± Plus or Minus, Values are means and S.D, values with the different superscript in a column differed significantly ( $P < 0.05$ ) F crit. Value= 5.23.

sampled from Watari Reservoir is illustrated in Table 1. The Pb had the highest concentration in gills at sites B and C compared with the liver at sampling site A. Pb concentrations differed significantly between sites ( $p < 0.05$ ). Cu had the highest mean value in gills at sampling site C, followed by site B (in gills) and the lowest concentration recorded in liver at sampling site A. Spatially, a significant difference in Cu was recorded between the sites ( $p < 0.05$ ). Chromium concentrations had the gills at sampling sites C compared to sites B and A, respectively. The Cr concentrations did not differ significantly between the sites ( $p > 0.05$ ). Mean Cd concentration spatially was highest in the gills at site C than in the liver from sites B and A, respectively. Mean Cd concentration revealed a significant difference between the sampling sites ( $p < 0.05$ ).

### Temporal variation in the bioaccumulation of heavy metal levels in tissues of *C. gariepinus*

The monthly variation of heavy metal concentrations in fish tissues recorded from Watari Reservoir is presented in Table 2 of this study. However, the mean monthly values revealed that Pb had the highest concentrations of 1.25±1.01 mg/kg in September from gill tissue, while the lowest value of 0.28±0.11mg/kg was obtained in December from liver tissues.

The concentrations of Pb revealed a significant difference monthly-wise ( $p < 0.05$ ). Monthly variation revealed a significant difference ( $p < 0.05$ ) for Cu in gill tissues during the study period. Mean monthly values for Cr in gills ranged from 0.34±0.04mg/kg to 1.73±0.02 mg/kg. The Cr concentration in the liver ranged between

**Table 3.** Seasonal variation of mean heavy metals concentrations in fish tissue of Watari Reservoir.

Parts	Season (s)	Heavy metals (mg/kg)			
		Cr	Cd	Cu	Pb
Liver	Dry	0.224 <sup>b</sup>	0.010 <sup>a</sup>	0.43 <sup>b</sup>	0.011 <sup>a</sup>
	Wet	0.574 <sup>a</sup>	0.021 <sup>a</sup>	0.64 <sup>a</sup>	0.031 <sup>a</sup>
Gills	Dry	0.850 <sup>a</sup>	0.018 <sup>b</sup>	0.834 <sup>b</sup>	0.320 <sup>b</sup>
	Wet	0.780 <sup>b</sup>	0.394 <sup>a</sup>	0.990 <sup>a</sup>	0.705 <sup>a</sup>

Note: Means followed by superscript with different letters across the column are significant at  $P < 0.05$  using T-test.

**Table 4.** Bioaccumulation factor of heavy metals in fish tissues from Watari Reservoir

Conc. (mg/L)	Water	Gills	Liver	BAF	FAO/WHO (2017); FAO/IWMI (2023) Maximum Limit(s)
Cu	1.67	2.90	1.04	1.01	0.2
Pb	1.81	2.16	1.33	2.52	0.3
Cr	2.15	1.64	1.50	2.26	0.5
Cd	0.94	1.74	0.89	2.68	0.01-0.03

**Foot note:** BAF = Bioaccumulation Factor, NA= Not available.

0.21±0.21 mg/kg and 0.88±0.01mg/kg. Mean monthly concentrations of Cr differed significantly ( $p < 0.05$ ).

#### Seasonal variation in bioaccumulation of heavy metals levels in tissues of *C. gariepinus*

In this work, the mean concentration of Cu was found to be highest during the wet season in the gills, 0.99 mg/kg, compared with the liver with 0.43 mg/kg had shown in Table 3. Cu concentration differed between seasons and indicated no significant difference ( $p > 0.05$ ). Seasonally, the highest mean Cr concentration in gills was obtained during the wet season, while the lowest value was recorded in the dry season. Seasonal variation of Cr varied significantly between seasons ( $p < 0.05$ ) in all the fish organs. The seasonal variations in the mean Cd concentrations indicated that the dry season had recorded lower with 0.018 mg/kg, while the wet season recorded the highest value of 0.394 mg/kg in gills. But a statistically shown significant difference in Cd concentration between the seasons ( $p < 0.05$ ). The mean seasonal variation of Pb showed that the wet season had 0.705mg/kg in gills, while 0.320 mg/kg was recorded during the dry season, and 0.031mg/kg in the wet season and 0.011 in the dry season in the liver. Statistically, Pb revealed a significant difference between the two seasons ( $p < 0.05$ ).

#### Bioaccumulation Factor (BAF)

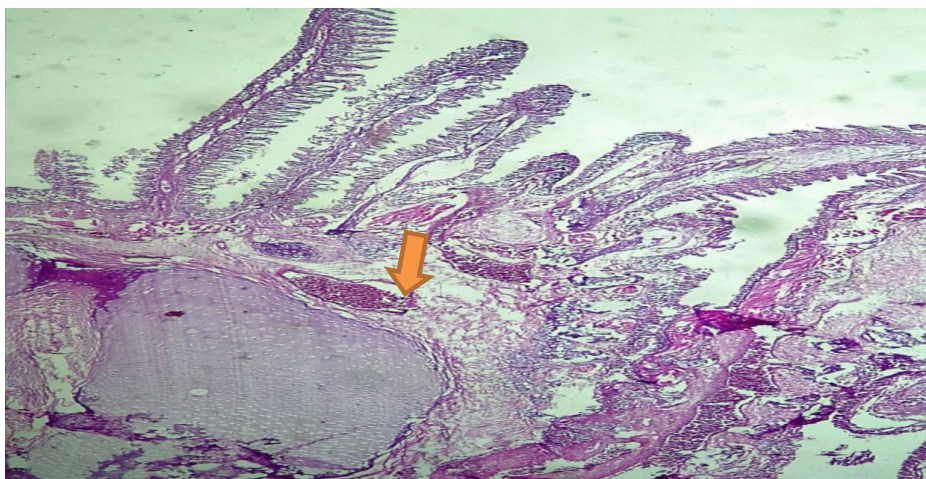
Bioaccumulation Factor (BAF) of heavy metal concentrations in samples decreased in the order of  $Cr >$

$Pb > Cu > Cd$ . BAF for Cu was highest in the gills' tissues with 2.90 mg/kg, while the lowest was obtained in the liver with 1.04 mg/kg. Pb had its highest in gills with 2.16, and the lowest value of 1.33 was obtained in the liver. BAF in the liver revealed higher concentrations of Cr, followed by Pb, Cu and Cd recorded the least. BAF in gills' tissues decreased in the order of  $Cu > Pb > Cr > Cd$  as depicted in Table 4.

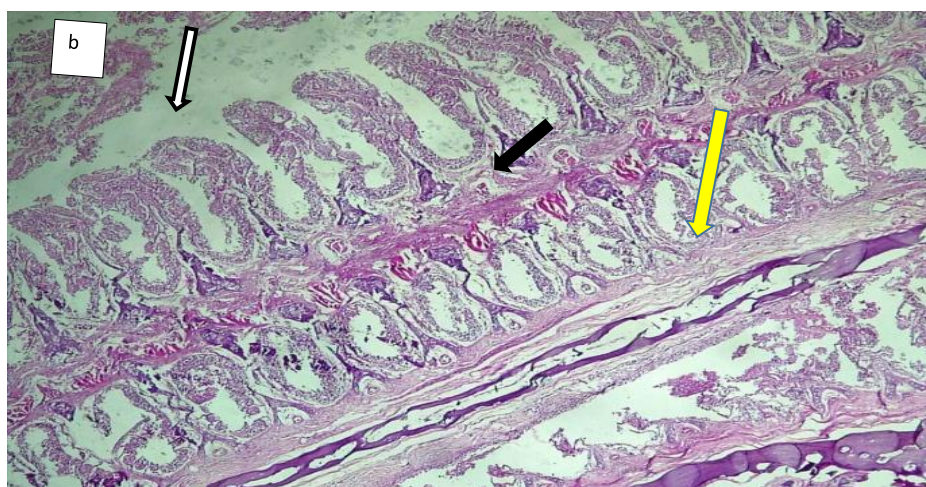
#### Histopathological changes in the tissues of *C. gariepinus* from Watari reservoir

In this study, the histological investigation of gills from Site-A indicated that the fusion of secondary lamellae and disruption of the filament arrangement were observed in the tissues of *C. gariepinus* had presented in Plate 1a. Conversely, samples collected at Site B revealed epithelial lifting, swollen and shortened lamellae, as shown in Plate 1b, whereas hyperplasia of the gill filament, epithelial reveals the lifting and swollen lamellae that were recorded in sampled *C. gariepinus* as shown in Plate 1c.

Furthermore, the liver tissues indicating areas of hepatocytes, hypertrophy, sinusoidal dilatation and cytoplasmic vacuolation were observed in *C. gariepinus* collected from Site A had shown in Plate 2a. Although blood congestion in hepatic parenchyma and hepatocyte infiltration were recorded from fish at Site-B had depicted in Plate 2b. In addition, the epithelial degeneration, distorted central vein and necrosis were observed in the sampled *C. gariepinus* from Site C had presented in Plate 2c.



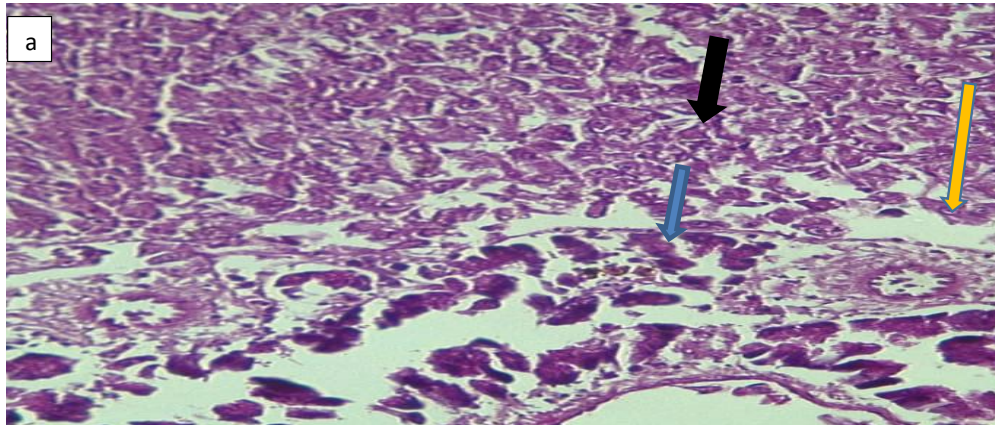
**Plate 1a.** Photomicrograph of gills tissues in indicating fusion of secondary lamellae (Blue arrow) and disruption of the filament arrangement (yellow arrow) (H & E mag x 100).



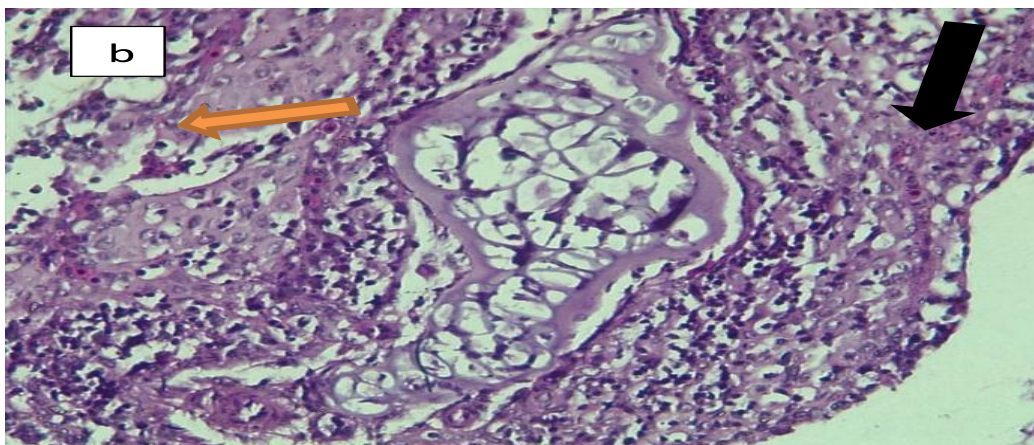
**Plate 1b.** Photomicrograph of the gill tissues indicating epithelial lifting (white arrow), swollen and shortened lamellae (yellow arrow) (H & E mag x 100).



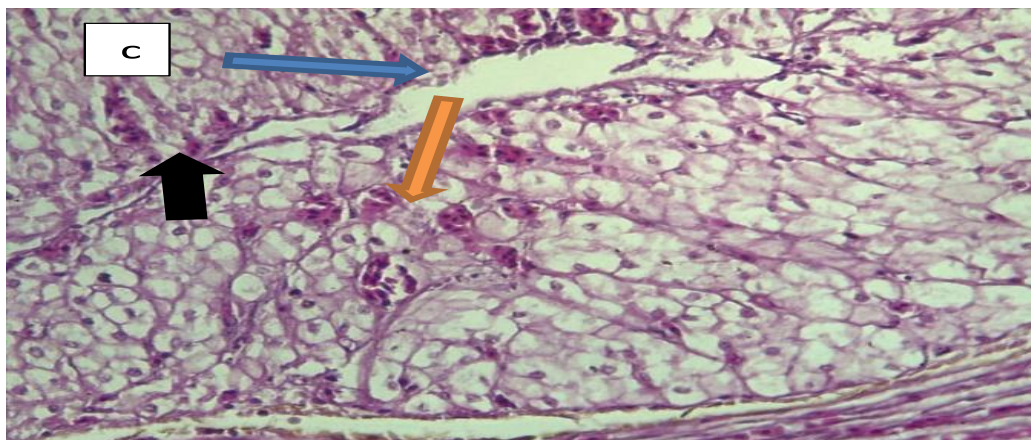
**Plate 1c.** Photomicrograph of the gill tissues indicating hyperplasia of the gill filament (red arrow), epithelial lifting and swollen lamellae (green arrow) (H & E mag x4100).



**Plate 2a.** Photomicrograph of *C. gariepinus* liver tissue from Site-A indicating areas of hepatocytes hypertrophy (black arrow), sinusoidal dilatation (yellow arrow) and cytoplasmic vacuolation (blue arrow) (H&E mag x 400).



**Plate 2b.** Photomicrograph of *C. gariepinus* liver tissue from site B, revealed blood congestion in hepatic parenchyma (black arrow), hepatocyte infiltration (green arrow) H&E mag x 400).



**Plate 2c.** Site-C liver tissues indicating epithelial degeneration (green arrow), distorted central vein (blue arrow) and necrosis (black arrow) under H&E mag x 400.

## DISCUSSION

In this study, the *Clarias gariepinus* from the Clariidae family were sampled because they are highly acceptable freshwater fish of commercial importance. However, the consumption of this species, which is sourced from the polluted water bodies, might cause heavy metal toxicity to human beings. This adversely influences the greater percentage of the populace in the near future, exerting deleterious effects on their health status. This was corroborated by the findings of Bob-Manuel *et al.* (2015), who showed that an increase in the consumption of this species could lead to health problems. This is in agreement with studies of Useh and Dauda (2018); Jasmina *et al.* (2020) reported that heavy metals can cause mental disorder, kidney malfunction or failure, disorder of the central nervous system of the brain, lung cancer and bone fractures.

### Bioaccumulation of heavy metals in the gills and liver of *C. gariepinus*

The heavy metals assessed in this present work were significantly bioaccumulated more in the gills of *C. gariepinus* than in the liver, even though both of them were unfit for consumption. However, the higher concentrations were discovered in the gills during the wet season than the dry season in this study. This could be due to the burning of tyres in the waterways carried away by run-off into the reservoir. The bioaccumulation and histopathological changes due to Cu, Cd, Cr and Pb were presented in Table 1 and Plates 1 (a- c) and 2 (a- c) of this work.

These sampled fish declared in accordance with WHO/FAO are not suitably fit for human consumption. Conversely, the bioaccumulation of Pb and Cu reported by Iromini and Atiola (2021) was similar to the findings of Ibrahim *et al.* (2018), who reported the lowest level in the same species was below the maximum level of FAO/WHO (2017). Definitely, Cu, Cd and Pb were studied in marine species (*Clupea herringus* and *Scomber scombrus*) by Useh *et al.* (2022) and Geidam *et al.* (2023) in the comparative study. Also, Mona *et al.* (2023) reported in the tissues of crayfish (*Procambarus clarkii*). This is in variance with the work of Hagrais *et al.* (2018), which reported in the ovary and testes tissues of the same species. This might be attributed to the pollution discharges into the reservoir through run-off. These findings were in agreement with the work of Adeosun *et al.* (2015), which revealed the elevated levels of Cd and Pb in the liver and gills of *C. gariepinus* that exceeded the permissible limits of 0.03 and 0.3mg/kg or L as prescribed by FAO/WHO (2017). Though, these bio-concentrated heavy metals in this work were possibly ichthyo-absorbed from the polluted reservoir. Therefore, the concentrations of Cd, Cu, Pb and Cr in the gills and liver discovered in this

study exceeded the maximum acceptable limit prescribed by FAO/WHO (2017). Thus, all the heavy metal levels in *C. gariepinus* were above the consumable level permitted by WHO/FAO for their influence on the trophic levels. Unlike in the study of Abalaka (2015) and Musa (2021), which stated that the gills are safe for consumption.

Furthermore, the incidence and occurrence of this bioaccumulation of heavy metals at elevated levels were attributed to the influx of pollutants into the reservoir. These include agricultural, domestic and industrial chemicals into the aquatic ecosystem. They were aggravated due to several human activities such as crop production, tanneries, block industries, laundry, automobiles, domestic sewage, etc. These factors could be a possible source of these toxic metals. This is in line with the study done by Bob-Manuel *et al.* (2015) and Abalaka *et al.* (2020). This was similar to the findings of Abd Elnab *et al.* (2023). Notwithstanding, the toxicity of Cu can be mitigated by the availability and occurrence of complex natural organic substances (Osioma and Iniaqhe, 2019). The natural organic substances include plants and animals' decomposed matter that discharges into the water body. The greater levels of heavy metals bioaccumulated in the gills might be attributed to the ichthyo-absorption processes in the polluted medium. Pb accumulation is unhealthy to both fish and human beings (Osioma and Iniaqhe, 2019); it was reported to have no useful physiological roles in the living body. More so, the bioaccumulation levels of Pb and Cu contents in the gills of the *C. gariepinus* exceeded the FAO/WHO (2017) permissible limits of 0.3 and 0.2 mg/kg in the sampled fish tissues for human consumption in this study. This was agreed with the findings of Oyeleke *et al.* (2018). This could be a result of pollution from mechanics, fuels/oils, ferry boats and water pump engines. Whereas, Edward *et al.* (2017) revealed that the Cu did not exceed limits in the gills, but Pb exceeded the limit of 0.3 mg/kg. This was juxtaposed with the study of Iromini and Atiola (2021), who reported the lowest concentration of Cu and Pb in *C. gariepinus* below the allowable limit for consumption. In this work, the fish gills and liver tissues revealed Cd levels that exceeded the desirable limits of 0.01 to a maximum of 0.03mg/L as prescribed by the regulators had shown in Table 4. This was aligned with findings of Davidson *et al.* (2019), Suwanpraserta *et al.* (2020), and Olayinka-Olagunju (2022). Cd was reported above the safety limits of 0.03 mg/kg set by FAO/WHO (2017). This is in conformity with Drechsel *et al.* (2023) and Jim-Halliday *et al.* (2024). Hence, these findings are useful for biomarkers of Cd, Cr, Cu and Pb pollution in the aquatic environment.

### Histopathological changes in the tissues of *Clarias gariepinus*

In this study, the photomicrograph of *C. gariepinus* tissues

after subjected to hematoxylin and eosin under (x100 and x400) magnification in the Watari Reservoir. Thus, the gills' tissues were observed for the histopathological alterations. This is in accordance with Abalaka *et al.* (2020). Therefore, these fish are more vulnerable to the heavy metals due to the filtration process during intake and expulsion of water through their gills. This could probably decrease osmoregulatory roles. This was aligned with the findings of Suwanpraserta *et al.* (2020).

However, the blue arrow indicates the fusion of secondary lamellae, whereas the yellow arrow signifies the disruption of the filament arrangement in Up-Stream (Site A), as presented in Plate 1a. This might be associated with the over-accumulation level beyond the maximum permissible for normal physiological functions and human consumption. This was agreed with the research of Abalaka *et al.* (2020). Also, it had been discovered in Mid-Stream (Site-A), white arrow denotes the epithelial lifting, while the yellow arrow points to the inflamed and shortened lamella that had presented in Plate 1b. This might be due to irritants that lead to frequent scratches on substrates. This was agreed with the findings of Olayinka-Olagunju (2022). Thus, the red arrow was showing the hyperplasia of the gill filament, coupled with detached epithelia, and the distended and shortened lamella were indicated by the green arrow at the Down-Stream (Site-C) had depicted in Plate 1c of this study. This was contracted with the study of Olayinka-Olagunju (2022). Detected epithelia could be due contacts with the metallic chemical elements.

Likewise, the histopathological damages reported on the liver of *C. gariepinus* were observed in this work. However, revealed hepatocytes and hypertrophy were pointed with a black arrow. This was in line with Abalaka (2015), who revealed that hypertrophy can lead to releases of mucous. The sinusoidal dilation was shown with a yellow arrow. Cytoplasmic vacuolation in the Up-Stream is illustrated in Plate 2a. This was agreed with the findings of Abalaka (2015), who declared that lipids and glycogen storage may result in this condition. This could be associated with the influence of Cr ichthyo-accumulation. This was corroborated by the findings of Ibrahim *et al.* (2013). These damages observed in the liver could be due to its function in the process of detoxification of metals. This is also aligned with the idea of Abalaka (2015). In the Mid-Stream of this research, it was discovered that the blood was congested with the hepatic parenchyma, as pointed with a black arrow. This is due to the ichthyo-accumulation of heavy metals. This was similarly reported by Abalaka (2015) and Suwanpraserta *et al.* (2020). This was contrary to the findings of Olayinka-Olagunju (2022), who reported congestion in the central vein of the gills. Also, hepatocyte infiltration was shown with a green arrow in Plate 2a. This was attributed to the injury as a result of heavy metal contamination. This agreed with the views of Abalaka (2015), who stated that this could be due to inflammatory

responses. Controversially, apart from the heavy metals and the monogeneans, fishing methods also might cause histopathological alterations: for instance, the use of entangling nets and hooks might affect fish gills; also, cast and surrounding nets can cause traumatic injuries during jam-packing and also haemorrhagic septicemia.

Subsequently, it had been revealed that there is epithelial degeneration indicated by the green arrow. Whereas the distorted central vein was pointed with a blue arrow, the necrosis was denoted by a black arrow were viewed at the Down-Stream. The necrosis of the liver tissues occurred due to the mutation of cells. This devastating effect was confirmed in the work of Suwanpraserta *et al.* (2020) and Olayinka-Olagunju (2022), who also, in addition relates the necrosis with monogeneans parasite. In accordance with Abalaka *et al.* (2020) tissues degeneration can depress the immune system. Histopathological alteration could be due to the bioaccumulation of heavy metals. This is in line with Abalaka *et al.* (2020).

## Conclusion and Recommendations

The pollution from the terrestrial environment due to both natural and anthropogenic sources discharges an effluent that contains heavy metals into the reservoir. Though attention should be geared towards the surface water pollution due to its alarming rate in the agricultural, domestics and industrial effluents. Therefore, these elements directly influence the aqueous environment to accumulate over a certain period. Though the wild *C. gariepinus*, which is among the readily available, affordable and accepted freshwater fish species, is a good candidate for a protein source and livelihood. In this study, the heavy metals assessed bioaccumulated in the tissues of sampled *C. gariepinus* and also exerted histopathological changes. However, their levels were higher that discovered in sampled gills and liver tissues was beyond the maximum acceptable limits for both aquatic lives and consumption agreed by FAO/WHO of the United Nations. These undesirable levels obtained may pose a serious threat to the fish and subsequently to the consumers. Fish species are bio-indicator of toxigenic and carcinogenic substances that predisposes end users to health risks. Hence, it is very difficult to prevent their bioaccumulation due to poor policy, by-laws and inadequate implementations. It is suggested that the point of control is the water body and its immediate market, but the authorities involved are after levy collections this can hinder the reduction of health hazards. Therefore, adequate promulgation of legislation that jointly and efficiently implements and regulates by the natives, government fisheries and environmental health authorities.

Strategically, it is recommended that all wastewater

undergo purification processes before discharges into reservoirs, rivers and oceans. These measures, when appropriately embraced, can help in controlling the municipal and industrial effluent discharges into the aquatic ecosystem in order to curtail the menace of heavy metals' pollution. Further study should be recommended to assess the bioaccumulation of heavy metals and histopathology changes. It also suggested investigating damage associated with parasites, tissue changes due to microbial loads, comparative study between large and small-sized species, between juveniles and adult fishes and fish caught with different fishing methods.

## ACKNOWLEDGMENTS

We acknowledged the cooperation and efforts of the Traditional Fisheries Authority leader (Sarkin Ruwa), the entire fisherfolk and fishmongers of Watari Reservoir at Bagwai during the sampling. Also, the Histopathology laboratory's staff of Aminu Kano Teaching Hospital and Chemistry laboratory of Bayero University Kano (BUK), Kano State, Nigeria, for the heavy metals detection and histopathological analysis of this research. Finally, it is declared that this research was zero donor agency funded and was exclusively self supports financing for its success.

## CONFLICT OF INTEREST

I leading author on behalf of the corresponding author and all the co-authors, hereby declare that there is no conflict of interest in all parts of the manuscript submitted. It is originally proven as a product of our research work.

## REFERENCES

- Abalaka, S. E. (2015). Heavy metals bioaccumulation and histopathological changes in *Auchenoglanis occidentalis* fish from Tiga dam, Nigeria. *Journal of Environmental Health Science and Engineering*, 13, 67.
- Abalaka, S. E., Enem, S. I., Idoko, I. S., Sani, N. A., Tenuche, O. Z., Ejeh, S. A., & Sambo, W. K. (2020). Heavy metals bioaccumulation and health risks with associated histopathological changes in *Clarias gariepinus* from the Kado fish market, Abuja, Nigeria. *Journal of Health & Pollution*, 10(26), 200602.
- Abd Elnabi, M. K., Elkaliny, N. E., Elyazied, M. M., Azab, S. H., Elkhalfifa, S. A., Elmasry, S., Mouhamed, M. S., Shalamesh, E. M., Alhorienny, N. A., Abd Elaty, A. E., & Mahmoud, Y. A. G. (2023). Toxicity of heavy metals and recent advances in their removal: a review. *Toxics*, 11(7), 580.
- Adeosun, F. I., Akinyemi, A. A., Idowu, A. A., Taiwo, I. O., Omoike, A., & Ayorinde, B. J. O. (2015). The effects of heavy metals concentration on some commercial fish in Ogun River, Opeji, Ogun State, Nigeria. *African Journal of Environmental Science and Technology*, 9(4), 365-370.
- Akan, J.C., Mohmoud, S., Yikala, B.S., & Ogugbuaja, V.O. (2012). Bioaccumulation of Some Heavy Metals in Fish Samples from River Benue in Vinikilang, Adamawa State, Nigeria. *American Journal of Analytical Chemistry*, 3, 727-736.
- Badamasi, I. (2014). Distribution of Stomach food content of fish species collected from industrial waste water effluents. A case study of Jakara Dam. *International Journal of Innovation and Technology*, 5(2), 124-129.
- Bob-Manuel, F.G., Wokoma, O.A.F., & Friday, U. (2015). Heavy metal concentration in some organs of *Clarias gariepinus* (African Catfish) from Okilo Creek, Rivers State, Nigeria. *Annals of Biological Research*, 6(11), 68-71.
- Davidson Jnr, A., Ogo, O.A., Bawa, I., & Onyekwere, O. (2019). Heavy metal bioaccumulation in liver & blood tissues of *C. gariepinus* (African Sharp Tooth Catfish) found in River Benue, Benue State, Nigeria. *International Journal of Life Science Research*, 7(3), 177-184.
- Drechsel, P., Marjani Z. S., & Pedrero, F. (eds.). (2023). Water quality in agriculture: Risks and risk mitigation. (Eds). FAO & IWMI, Rome. Retrieved from <https://doi.org/10.4060/cc7340en>.
- Edward, A., Abubakar, K. A., Ladu, B. M. B., Elihu, A., & Umar, I. (2017). Bioaccumulation of heavy metals in *Auchenoglanis occidentalis*, *Clarias gariepinus* and *Oreochromis niloticus* Tissues in Upper Benue River, Adamawa State, Nigeria. *Journal of Environmental Science, Toxicology and Food Technology*, 11(1), 13-17.
- FAO/IWMI (2023). Water quality in agriculture: Risks and risk mitigations. Food and Agriculture Organisation of the United Nation in Collaboration with International Water Management Institute. Drechsel, P., Marjani Z.S., & Pedrero F. (eds.). Pp. 192.
- FAO/WHO (2017). Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda. Report of a joint FAO/WHO Expert group, FAO, © World Health Organization Library Cataloguing in Publication Data. Pp. 631.
- Gashua, M.M., Kabir, J., Suleiman, M.M., & Jajere, S.M. (2018). Assessment of some heavy metals in the liver of freshwater Catfish (*Clarias gariepinus*) in Northeastern Nigeria. *Research Journal of Animal, Veterinary and Fisheries*, 6(3), 1-6.
- Geidam, M. B., Sadauki, M. A., Dauda, A. B., Idris, B. M. Garba, Yagana, A., Ali, J., & Bichi, A.H. (2023). Analysis of Heavy Metals in Some Fresh and Marine Water Fish Species Sold in Damaturu Metropolis. *Life Science: An International Journal*, 1(1), 29-37.
- Hagras, A.E., Elbaghdady, H.A.M., & Gouda, A.M.R. (2018). Assessment of Water Quality and Heavy Metals in Water, Sediments, and Some Organs of African Catfish (*Clarias gariepinus*) in El-Serwdrain, Nile Delta, Egypt. *International Journal of Environment*, 7(4), 124-141.
- Ibrahim, D., Ibrahim, A., Paule, A., Umar, M., & Zannah, U. A. (2018). determination of some heavy metal content in tilapia and cat fish species in Lake Njuwa, Adamawa State, Nigeria. *Journal of Applied Science and Environmental Management*, 22(8), 1159-1165.
- Iromini, A., & Atilola, O. (2021). Comparative assessment of some heavy metals bioaccumulation in Juvenile African catfish (*Clarias gariepinus*) exposed to detergent and spent oil pollutants. *Journal of pollution*, 4(6), 1-6.
- Jasmina, D. A., Marjanovic, D., Tahirovic, K., Caklovica, A., Turalic, A., Lugusic, E., Omeragic, M., & Caklovica, F. (2020). Heavy metals in commercial fish and seafood products and risk

- assessment in adult population in Bosnia and Herzegovina. *Scientific Report*, 10, Article number 13238.
- Jim-Halliday, T. T., Osu, C. I., & Iwuoha, G.N. (2024). Evaluation of Heavy Metals in Water, Sediments and African Catfish (*Clarias gariepinus*) Obtained from Earthen and Concrete Fish Ponds in Port Harcourt, Nigeria. *International Journal of Chemistry and Material Sciences*, 7(11), 168-177.
- Mamman, K. I., Abubakar, K. A., & Thagriki, D. (2017). Comparative Analysis of Heavy Metals Detected in *O. niloticus* found in Lake Geriyo, Yola, Adamawa State. *International Journal of Research in Pharmacy and Biosciences*, 4(12), 11-18.
- Mona, M.M., Younis, M.L., & Atlam, Al. (2023). Evaluation of freshwater heavy metals accumulation effect on oxidative stress, Metallothionein in biosynthesis and histopathology of *Procambarus clarkia* (Girard,1985) collected from three locations in the Delta Region, Egypt. *BMC Zoology*, 8, 21.
- Musa, M.S. (2021). Determination of Selected Heavy Metals in Gills and Livers of Some Catfish (*Clarias gariepinus*) from Two Dam Reservoirs in Katsina State, Nigeria. *Dutse Journal of Pure and Applied Sciences* 7(1), 339-346.
- Olaosebikan, B., & Raji, A. (2013). Field guide to Nigerian freshwater fishes. National Institute for Freshwater Fisheries Research, New-Bussa, Nigeria. Remi Thomas Press New-Bussa (3rd Edition) Pp.144
- Olayinka-Olagunju, J.O. (2022). Heavy Metal Bioaccumulation and Histopathological Studies of Fish Tissues from Ose River, Ondo State, Nigeria. *European Journal of Environment and Earth Sciences*, 3(4), 70-78.
- Orimoloye, M. A., & Mohammed, A. (2020). Bioaccumulation of heavy metals exposed to untreated paint effluent. *International Journal of Trend in Science Research and Development*, 4(2), 279-284.
- Osioma, E., & Iniaghe, P.O. (2019). Concentration of heavy metals in water, sediments and tissues of *Clarias gariepinus* from earthen ponds in Kolo Creek Communities in Bayelsa State, Niger Delta, Nigeria. *Asian Journal of Water, Environment & Pollution*, 16(4), 97-106.
- Oyeleke, P. O., Okparaocha, F. J., & Abiodun, O. A. (2018). Human health risk assessment of heavy metals (lead, cadmium and copper) in fresh water tilapia fish (*Oreochromis niloticus*) from Eleyele River, Ibadan, Southwestern Nigeria. *Chemistry Research Journal*, 3(4), 134-142.
- Rabiu, H. D., Umar, L. M., Sulaiman, I., Madina, M., & Abubakar, A. I. (2018). Assessment of the Water Quality of Watari Dam, Kano State Using Selected Physicochemical Parameters. *International Journal of Advanced Academic Research in Sciences, Technology & Engineering*, 4(5), 62-77.
- Suwanpraserta, S., Saenphetb, S., Buncharoenb, W., Kullasootc, S., Sareeinc, N., & Phalarakshb, C. (2020). Effects of cadmium on acetylcholinesterase activities and histopathology of African catfish (*Clarias gariepinus*) from contaminated fish farm in Mae Sot District, Tak Province, Thailand. *ScienceAsia* 46, 611-618.
- Useh, M. U., & Dauda, M. S. (2018). Heavy metals contamination and their potential toxicity in petroleum sludge Impacted Soils from Itsekiri Communities, Delta State, Nigeria. *Chemical Science International Journal*, 24(1), 1-15.
- Useh, M. U., Etuk-Udoh, G., & Uzama, D. (2022). Heavy metals determination and microbial assessment of some species of frozen fish sold at Utako Market, Abuja, Nigeria. *Bayero Journal of Pure and Applied Sciences*, 15(1), 87-94.
- Usman, I. B., & Maitera, O.N. (2025). Assessment of pollution status of Wataridam using selected physicochemical parameters in Kano State, Nigeria. *International Journal of Advances in Engineering and Management*, 7(4), 440-453.