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ASSESSMENT OF POTENTIALLY TOXIC HEAVY METALS AND HUMAN HEALTH RISK IN WATER, SEDIMENTS AND TISSUES OF MOON FISH *Citharinus citharus* FROM THE AXIS OF LOWER RIVER NIGER AT OGURO AJAOKUTA NIGERIA

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ABSTRACT

This study determined bio concentration of heavy metals in water, sediment, and tissues (gill, viscera and muscle) of Citharinus citharus from the axis lower River Niger at Oguro, Ajaokuta, Nigeria, and also assessed potential human health risks from consuming water and fish therein. Water, sediment, and fish samples were collected from three designated sites along the river twice per month for three months June, July and August (rainy season). The samples were analyzed using Atomic Absorption Spectrophotometry (AAS) for heavy metals which includes iron (Fe), lead (Pb), nickel (Ni), chromium (Cr), cadmium (Cd), and zinc (Zn). The findings show that Fe concentrations in water peaked at 11.679 mg/kg in July, exceeding the WHO guideline of 0.300 mg/kg, while Pb and Ni concentrations surpassed WHO limits at all sites across the three months. Sediment analysis revealed that Fe ranged from 168.282 mg/kg to 244.800 mg/kg, with Cd peaking at 0.841 mg/kg in July. In fish tissues, Fe concentrations were highest in gills (51.121 mg/kg), followed by viscera (48.403 mg/kg), and muscle (34.921 mg/kg). The Estimated Daily Intake (EDI) for zinc in gills reached 2.99 × 10^{-2} mg/kg/day, while the Target Hazard Quotient (THQ) for Cr in gills was 0.127, signaling a moderate health risk. The study concludes that heavy metal contamination in the Lower River Niger poses no significant ecological and human health risks, particularly during the study period . It recommends stricter regulation of industrial discharge, public health campaigns on fish consumption, and continuous environmental monitoring to mitigate the long-term impacts of heavy metal pollution

1.0 INTRODUCTION

Water pollution occurs when certain materials enters into the water bodies and change the water quality and becomes harmful to aquatic organism and human health (Arulkuman *et al.,*2020). Water plays an important role in nutrient recycling and is an imperative natural source used for drinking and other purposes. Aquatic eco-systems are usually used for disposal and re-utilizing the sewage and contaminated wastes. Thus, the double pressure wielded on the water bodies is eventually faced by the biological communities dwelling in them. Generally, fish is one of the most important aquatic communities that has connections with human being (Briggs, 2019). The pollution generally denotes any unwanted alteration in the natural quality of any ecosystem brought about by the changes in their physical, chemical, as well as in biological factors (Solima, et al., 2021). Aquatic ecosystems are delicate and at high risk mostly due to the majority of pollutants derived from domestic, urban and industrial sources i.e. various agricultural practices result in the release of pollutants into the riverine system (Byme, *et al.*, 2021). Mainly in aquatic ecosystem, the most frequent contaminants are in the forms of heavy metals and pesticides (Amenyogbe, et al., 2021). The heavy metals are one of the major pollutants, which quickly amass in the body and are leisurely digested in and excreted from aquatic animals. Mainly the pesticides used in agricultural activities are directly released into the open atmosphere by drift spray, volatilization and wind erosion of soil (Xiao *et al*., 2018).

Heavy metals pollution has become a major concern worldwide due to their toxicity, intrinsic persistence, non-biodegradable nature, and accumulative behaviors (Adeaga, *et al.,* 2017). These metals differ from other toxic materials in a way that they are neither created nor destroyed by human. They are inert in the environment and are often considered to be conservative pollutants if left undisturbed (Adefemi,*et al.,* 2018). However, the rapid industrialization, urbanization, population growth, agricultural and other human activities have resulted in severe pollution by heavy metals globally, especially in developing countries (Akan, *et al.,* 2020). Significant quantities of heavy metals from such activities are discharged into rivers, which can be strongly bio-accumulated and biomagnified along water, sediment, and aquatic food chain, resulting in sublethal effects or death in local fish populations (FAO, 2018). As fishes occupy higher trophic level in the food chain, they are considered one of the most common bioindicators for pollutants (FAO, 2020). Again, fishes are consumed by human as a major source of protein for many years. Thus, the human body is largely susceptible to enriched heavy metal concentration in fishes (Nsofor, *et al.,* 2018). Consequently, an analysis of the levels of heavy metals in fish could be used to investigate anthropogenic impacts on ecosystem and human health.

Generally, bioaccumulation and biomagnification occur due to longstanding anthropogenic activities within a coastal ecosystem (Nsofor, *et al.,* 2018). The accumulation of heavy metals in fish organs could also be driven by physiochemical and biological variables such as pH, temperature, hardness, exposure duration, feeding habits of species and habitat complexity (Adefemi, 2018). Heavy metals and metalloids, when occurring at higher concentrations, become severe poisons for all living organisms including human. For example, an excessive amount of Hg, As, Pb, and Cd elements could be detrimental to the living cells, and a prolonged exposure to the body can cause illness or death (Nsofor, *et al.,* 2018). Fish are widely used to evaluate the health of aquatic ecosystem because pollutants build up in the food chain and are responsible for adverse effects and death of animals in the aquatic ecosystems (Bayen *et al*., 2021). Most of the freshwater fishes are confined to specific micro-habitat within inter-connected river/stream ecosystem. If such ecosystem becomes contaminated by heavy metals, fish species either migrate to less polluted segment of river/stream ecosystem or die off which ultimately disturb the food chains (Rashed, 2017). High level of heavy metals have apparent lethal and chronic effects on fish (Akan *et al*., 2020). Thus, the utility of fish for assessing environmental conditions in aquatic ecosystem has gained prominence in recent years (Ikem and Egibor 2019; Zhong, *et al* 2018; Adefemi *et al*., 2018; Ogundiran *et al*., 2019; Akan *et al*., 2020).

Oguro community in Ajaokuta is an important and industrial area in Kogi state Nigeria as it habours three ceremic companies and their effluents discharge into river Niger. Iron and steel company is equally located few meters upper stream away. The flood plain of the river is engaged with agricultural activities which meet with heavy use of agrochemical. Anthropogenic activities such as mechanic workshops, filling stations and other artisan activities also dominate this community. The products from these activities is likely to introduce heavy metals into the river. The resident of Oguro community are actively engaged in farming, fishing, water transport and artisan works. The river Niger water is used by this community for domestic purposes making the river ecologically and economically important. The ecosystems support diverse aquatic life, including various commercially important fish species that contribute substantially to the livelihoods of local communities and the nation's food security. However, the health and sustainability of these ecosystems are under constant threat due to human activities, industrialization, and urbanization, which have led to the release of heavy metals into the aquatic environment.

2.0 MATERIALS AND METHODS

2.1 Study Location

The study was conducted at Oguro, a village situated along the banks of the River Niger in Ajaokuta Local Government Area, Kogi State, Nigeria. The community lies within latitude 7^{o} 25’’N and longitude 6^{o} 42’’E. The vegetation of the area is guinea savannah and the climate is tropical in nature with two seasons (rainy and dry). Dry season running from November to March while rainy season run from April to October. Annual temperature ranges from 23^{o}C to 35^{o}C, while annual humidity ranges from 67 to 94%. The occupation of the people includes commerce, fishing, farming, mining, artisan industries and transportation (road and water transport). The community also host three ceramics companies whose effluents discharges into the river Niger at different points. Sampling (water, sediment and fish) were done at three designated sites 1, 2 and 3.

Site 1 was located at the railway bridge crossing River Niger at the upper part of the study area and 1km from Ajaokuta iron and steel company,150m before the effluent of AB and Royal Ceramic Company into River Niger and lie between latitude 7^{o} 27’’N and longitude 6^{o} 41’’E.

Site 2 was located at the vehicle bridge crossing river Niger, a kilometer from site 1 downstream, 150m before the effluent of West African Ceramics into River Niger, lies within latitude 7^{o} 25’’N and longitude 6^{o} 41’’E.

Site 3 was located one kilometer from site 2 down the River and 700m down the West African Ceramic effluent into River Niger, lies within latitude 7^{o} 25’’N and longitude 6^{o} 41’’E.

2.2 Sample Collection

Sampling was carried out in three months (June, July, August) from the three designated sites along the river and was done twice per month.

2.2.1 Water Sample

Water samples were collected at the three sites at a depth of about 50 cm below the surface to avoid water surface and air contaminants using two litre clean, acid-washed plastic bottles five meters away from river bank in a canoe. (Adeyemi *et al* 2020). The water samples collected were placed in an ice bath container and carried to the multipurpose laboratory Chemistry Department ABU for heavy metal analysis.

2.2.2 Sediment Sample

Sediment samples were collected from the riverbed using ¾ inches diameter PVC pipe and one meter in length. One length of the pipe for each site at every sampling period. Sediment samples were collected by inserting the PVC pipe into the sediment to the pre-marked point of 10cm.The pipe was then turned to the angle of 45^0 to the water surface and brought out over turned to removed water collected, then hit gently on the clean surface to separate the sediment and collected at the depth of 1-4 cm, 4-7cm and7-10cm. The sediment samples were collected in 50 ml sample bottle, kept at temperature of 4^0C using ice block container, then taken to the laboratory for analysis.

2.2.3 Fish Sample

Citharinus citharus, a commercially important fish species commonly caught around the sampling area was selected for this study. The fish samples were collected using cast nets and fishing traps, with the special arrangement with local fishermen. The fish caught were identified using monograph and keys (Olasebikan and Raji, 2013), weighed, dissected to remove three tissues (gills, viscera and muscle) using dissecting kits. The tissues removed were placed in separate sample bottles stored on ice container kept at -5^{o}C, taken to the laboratory for analysis.

2.3 Sample Analysis

2.3.1Water Sample Analysis

Water samples were filtered using Whatman No. 42 filter paper to remove particulate matter and the filtrate were digested by adding concentrated nitric acid and heating the solution in a water bath. This digestion process breaks down organic material and ensures that the metals are in a dissolved state and not adhere to the wall of the bottle (Oguzie and Izevhigie, 2009), making them easier to detect and quantify. The filtrate was then subjected to heavy metal analysis using Atomic Absorption Spectrophotometer (AAS) Agilent technology (AAS-4200) The AAS is an analytical technique used to measure the concentration of metals in a solution. It works by passing a beam of light through the sample, where specific wavelengths corresponding to the metals being tested are absorbed. The amount of light absorbed is directly proportional to the concentration of the metal in the sample.

2.3.2 Sediment Sample Analysis

Sediment samples were first air-dried and oven dried, then ground into fine particles using a mortar and pestle. The dried and ground samples were sieved through a 63-micron mesh sieve to ensure uniformity. After sieving, a portion of the sample was digested with a mixture of concentrated nitric acid (HNO_3) and hydrochloric acid (HCl) in a ratio of 3:1, known as aqua regia. This strong acid mixture is capable of dissolving most heavy metals bound to sediment particles after which the sample solutions were filtered and analyzed using AAS (Galyean, 2010).

2.3.3 Fish sample Analysis

The fish tissues were washed with distilled water, weighed, and dried in an oven at 105°C until a constant weight was achieved. The dried tissues were ground into a fine powder, and a known weight of the powdered tissue was digested using nitric acid and perchloric acid ($HClO_4$) in a controlled heating process. After digestion, the resulting solutions were filtered, and the filtrates were analyzed for heavy metals using AAS (Galyean, 2010).

2.4 Ecological Risk Assessment

2.4.1Bio-Concentration Factor (BCF) or Bio-Accumulation Quotient

Bio-concentration factor for fish muscle was determined according to the methods of Lau *et al*. (1998,USEPA 2020) using the formula;

i $BCF_{fish} = \frac{C_{fish}(mg/kg)}{C_{water}(mg/l)}$

Where; C_{fish} is the mean concentration of the heavy metal in fish; C_{water} = is the overall mean concentration of heavy metals in the river water and BCF_{fish} is the bio-concentration factor of the metal in the fish. Note that: a BCF_{fish} value >1 indicates bioaccumulation of a heavy metal by fish.

ii $BCF_{fish} = \frac{C_{fish}(mg/kg)}{C_{sediment}(mg/kg)}$ Where; C_{fish} is the mean concentration of the heavy metal in fish; $C_{sediment}$ is the mean concentration of heavy metals in the sediment, BCF_{fish} is the bioconcentration factor of the metal in the fish. Note that: a BCF_{fish} value >1 indicates bioaccumulation of a heavy metal by fish. (OECD 2020)

2.5 Human/Health Risk Assessment

2.5.1 Margin of Exposure (MOE) was employed to access the specific risk from consumption of contaminated fish with heavy metals as given by Watanbe *et al*. (2003), IPCS (2020).

$$MOE = \frac{MCR \times CR}{BW \times RFD}$$

Where; MCR = Species Specific Mean Chemical Concentration
CR = consumption rate [assumed to be 0.03kg/day]
BW = human body weight (assumed to be 70kg for adult Nigerian (USEPA, 2005)
RFD = Reference dose for the specific constituent in established USEPA (2017) AND USEPA (2012) to assess the health risk from fish consumption.

If MOE is greater than one (MOE>1), it indicate the expose of a dose higher than the safe daily dose value as adopted by USEPA (2017).

The value of heavy metal accumulation in different species was used to calculate the following.

2.5.2 Estimated Daily Intake of Metals (EDI)

$$EDI = \frac{MC+FIR\times10^{-3}}{BW}$$

Where; MC = average heavy metal concentration (wet weight) in fish muscle (mg/kg). Because the concentrations of heavy metals in the fish muscles in this study was presented in dry weight, a conversion factors of 4.8 was used to convert dry weight (dw) to wet weight (ww) according to the procedure of Rhaman *et al*. (2012).

FIR = food ingestion rate, which is the daily fresh water fish consumption (gday^{-1}) per capita as recorded by statistic division of FAO. On average, the daily consumption rate of fresh water fish is 8.26g person^{-1} day^{-1} in Nigeria (FAOSTAT, 2013).

BW = the average body weight (kg) based on USEPA (2005) statistics, an average weight of 70kg was assumed for an adult in Nigeria.

2.5.3 Toxicity/Hazard Quotient (TQ)

TQ is comparison of the measure of the chemical element of the concentration of site related element ecological matrices with specific health base criteria (Islam *et al.*, 2015).

Therefore TQ = measured concentration of chemical element in ecological matrix/ health base criteria.

Where; TQ> toxicity/hazard indicate.

2.5.4 Target Hazard Quotient (THQ)

The TQ is an estimate non-carcinogenic risk level because of pollutant exposure (Islam *et al*., 2015) and was calculated according to USEPA (2011) guideline using the equation;

$$THQ= \frac{EFr\times ED\times FIR\times C\times10^{-3}}{RFD\times BW\times ATn}$$

Where;

EFr = the exposure frequency 365days/year

ED = the exposure duration (54.5years) (Life-expectancy of male is 53years and for females the two will be taken according to WHO (2017)

RFD = Reference dose as established by USEPA (2011) and USEPA (2012) to assess the health risk from fish consumption

AT_n = the average exposure time for non-carcinogens (365days ×no of exposure years; i.e. 54.5yrs)

C = mean heavy metal concentration in fish muscle

FIR = Food ingestion rate. 8.26g/person (FAOSTAT, 2013)

BW = the average body weight 70kg (USEPA, 2005)

2.5.5 Hazard Index (HI)

HI = overall potential health risk posed by one or more heavy metals

HI the2refore is the sum of THQ of every heavy metals in the study. HI can be calculated by the sum of the target hazard quotient of each metal under study (USEPA, 2011). For example if Cd, Cr, Zn, Ni, Pb and Fe are metals under study, Hazard index (HI) = THQCd +THQCr +THQZn +THQNi +THQPb +THQFe

2.6 Data Analysis

The analysis of variance (ANOVA one way) was used to evaluate the difference between sites. Differences were considered significant at p values <0.05. Statistical analyses (mean value, minimum, maximum) were carried out with Statistical 7.1 software.

3.0 RESULTS AND DISCUSSION

3.1 Monthly Heavy Metal Concentration in Water in lower River Niger at Oguro.

The concentrations of heavy metals in water samples collected from three sites across the months of study is shown in the table below. In June, Fe concentrations ranged from 3.012 to 3.990 mg/kg in July in site 1. Pb showed variability, with values ranging from 0.104 mg/kg site 2 in July to 0.355 mg/kg at Site 3 in June.. Ni concentrations increased steadily from June to August, with Site 1 in August recording 0.159 mg/kg. Zn concentrations were highest in July at 3.465 mg/kg at Site 1.

Table 4.1: Monthly Heavy Metals Concentration in Water in lower River Niger at Oguro

Month	Site	Fe (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Cr (mg/kg)	Cd (mg/kg)	Zn (mg/kg)
June	1	3.990 ± 0.123 [a]	0.287 ± 0.012 [a]	0.027 ± 0.005 [a]	0.000 ± 0.000 [a]	0.014 ± 0.002 [a]	0.132 ± 0.054 [b]
	2	3.821 ± 0.145 [a]	0.187 ± 0.021 [a]	0.016 ± 0.003 [a]	0.001 ± 0.000 [a]	0.009 ± 0.001 [a]	1.211 ± 0.098 [a]
	3	3.012 ± 0.178 [a]	0.212 ± 0.015 [a]	0.022 ± 0.004 [a]	0.002 ± 0.001 [a]	0.015 ± 0.002 [a]	0.142 ± 0.078 [b]
July	1	4.826 ± 0.234 [b]	0.211 ± 0.015 [b]	0.056 ± 0.008 [b]	0.002 ± 0.001 [a]	0.014 ± 0.003 [a]	0.822 ± 0.120 [b]
	2	5.214 ± 0.321 [b]	0.302 ± 0.019 [b]	0.082 ± 0.012 [b]	0.001 ± 0.000 [a]	0.032 ± 0.005 [a]	1.212 ± 0.143 [a]
	3	7.822 ± 0.432 [c]	0.355 ± 0.021 [b]	0.103 ± 0.014 [b]	0.001 ± 0.000 [a]	0.041 ± 0.007 [b]	2.332 ± 0.178 [a]
August	1	11.679 ± 0.543 [d]	0.203 ± 0.017 [b]	0.159 ± 0.023 [c]	0.001 ± 0.000 [a]	0.042 ± 0.006 [b]	3.465 ± 0.234 [a]
	2	8.552 ± 0.412 [c]	0.104 ± 0.012 [c]	0.168 ± 0.024 [c]	0.002 ± 0.001 [a]	0.020 ± 0.004 [a]	2.112 ± 0.187 [a]
	3	9.660 ± 0.376 [c]	0.293 ± 0.021 [b]	0.102 ± 0.015 [b]	0.001 ± 0.000 [a]	0.016 ± 0.003 [a]	1.332 ± 0.154 [b]
WHO(PL) (2017)		0.300	0.010	0.070	0.050	0.003	3.000
SEM		**0.123**	**0.015**	**0.006**	**0.000**	**0.002**	**0.098**

Means in the same column with different superscript letter are significantly different ($p<0.05$). Fe (Iron), Pb (Lead), Ni (Nickel), Cr (Chromium), Cd (Cadmium), Zn (Zinc) PL(Permissible Limit), SEM(Standard Error of Mean)

3.2 Heavy Metal Concentration of Sediment in the lower River Niger at Oguro in the month of June

The concentration of heavy metals in sediments at different depths (1–4 cm, 4–7 cm, and 7–10 cm) across three sites (1,2and 3) in the month of June showed substantial variation in the levels in iron (Fe), lead (Pb), nickel (Ni), chromium (Cr), cadmium (Cd), and zinc (Zn). Fe concentrations was the highest across the site and the depth ranged from 168.282 mg/kg at Site 2 (1–4 cm depth) to 244.800 mg/kg at Site 1 (7–10 cm depth), followed by Zn and the least concentration was recorded with Cd. This is shown in the table below

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Table 2: Heavy Metals Concentration in Sediments in lower River Niger at Oguro in the month of June

Month/Site	Site	Depth	Fe (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Cr (mg/kg)	Cd (mg/kg)	Zn (mg/kg)
June	1	1-4cm	174.269 ± 11.432 [a]	1.432 ± 0.065 [a]	1.024 ± 0.065 [b]	1.696 ± 0.087 [b]	0.473 ± 0.012 [a]	30.911 ± 0.823 [a]
		4-7cm	201.310 ± 15.231 [a]	0.856 ± 0.056 [a]	0.654 ± 0.043 [b]	1.148 ± 0.043 [b]	0.431 ± 0.012 [a]	28.672 ± 0.743 [a]
		7-10cm	244.800 ± 16.876 [a]	0.790 ± 0.043 [b]	0.791 ± 0.043 [b]	1.147 ± 0.054 [b]	0.831 ± 0.054 [a]	33.900 ± 0.876 [a]
June	2	1-4cm	168.282 ± 10.654 [a]	0.823 ± 0.045 [a]	0.946 ± 0.065 [b]	1.644 ± 0.065 [b]	0.445 ± 0.012 [a]	31.432 ± 0.854 [a]
		4-7cm	207.310 ± 14.324 [a]	0.634 ± 0.034 [b]	1.231 ± 0.065 [b]	1.236 ± 0.043 [b]	0.672 ± 0.043 [a]	29.470 ± 0.743 [a]
		7-10cm	240.408 ± 15.876 [a]	0.620 ± 0.043 [b]	0.767 ± 0.043 [b]	1.142 ± 0.043 [b]	0.841 ± 0.043 [a]	32.142 ± 0.876 [a]
June	3	1-4cm	172.188 ± 12.432 [a]	0.767 ± 0.034 [b]	0.982 ± 0.054 [b]	1.816 ± 0.087 [b]	0.512 ± 0.013 [a]	30.667 ± 0.832 [a]
		4-7cm	198.987 ± 14.567 [a]	0.743 ± 0.045 [b]	0.766 ± 0.045 [b]	1.446 ± 0.065 [b]	0.761 ± 0.054 [a]	31.402 ± 0.854 [a]
		7-10cm	208.642 ± 15.786 [a]	0.782 ± 0.043 [b]	0.737 ± 0.054 [b]	1.321 ± 0.054 [b]	0.813 ± 0.054 [a]	33.110 ± 0.876 [a]
SEM			**21.654**	**0.232**	**0.008**	**0.004**	**0.001**	**0.000**

Means in the same column with different superscript letter are significantly different ($p<0.05$). Fe (Iron), Pb (Lead), Ni (Nickel), Cr (Chromium), Cd (Cadmium), Zn (Zinc)

4.3 Heavy Metal Concentration of Sediment in lower River Niger at Oguro, Ajaokuta in July

In July, the heavy metal concentrations followed similar patterns, with the month of June showing elevated Fe levels, ranging from 176.442 mg/kg in the surface (1-4cm) sediment to 202.113 mg/kg in deeper layers (7-10cm). Lead (Pb) concentrations were lower in July compared to June, with values at Site 1 ranging from 0.719 mg/kg at the deepest layer to 0.923 mg/kg near the surface. Nickel (Ni) levels were consistent but varied slightly between sites and depths, with Site C showing a significant increase at 1.812 mg/kg in the 7–10 cm range, while chromium (Cr) levels peaked at 1.914 mg/kg at Site 2 in deeper sediments. Cadmium (Cd) concentrations remained within similar ranges as June, with no drastic changes observed. Zinc (Zn) levels, however, Fe remained elevated across the sites, particularly at Site 3, where it reached 80.117 mg/kg at the 1–4 cm depth range, which marked the highest observed concentration in the study. These elevated Zn levels at Site 3 may indicate localized pollution or contamination, potentially from industrial or agricultural runoff. Overall, the heavy metal concentration trends in July indicate a moderate increase in some metal levels compared to June, particularly in deeper sediments at certain sites.

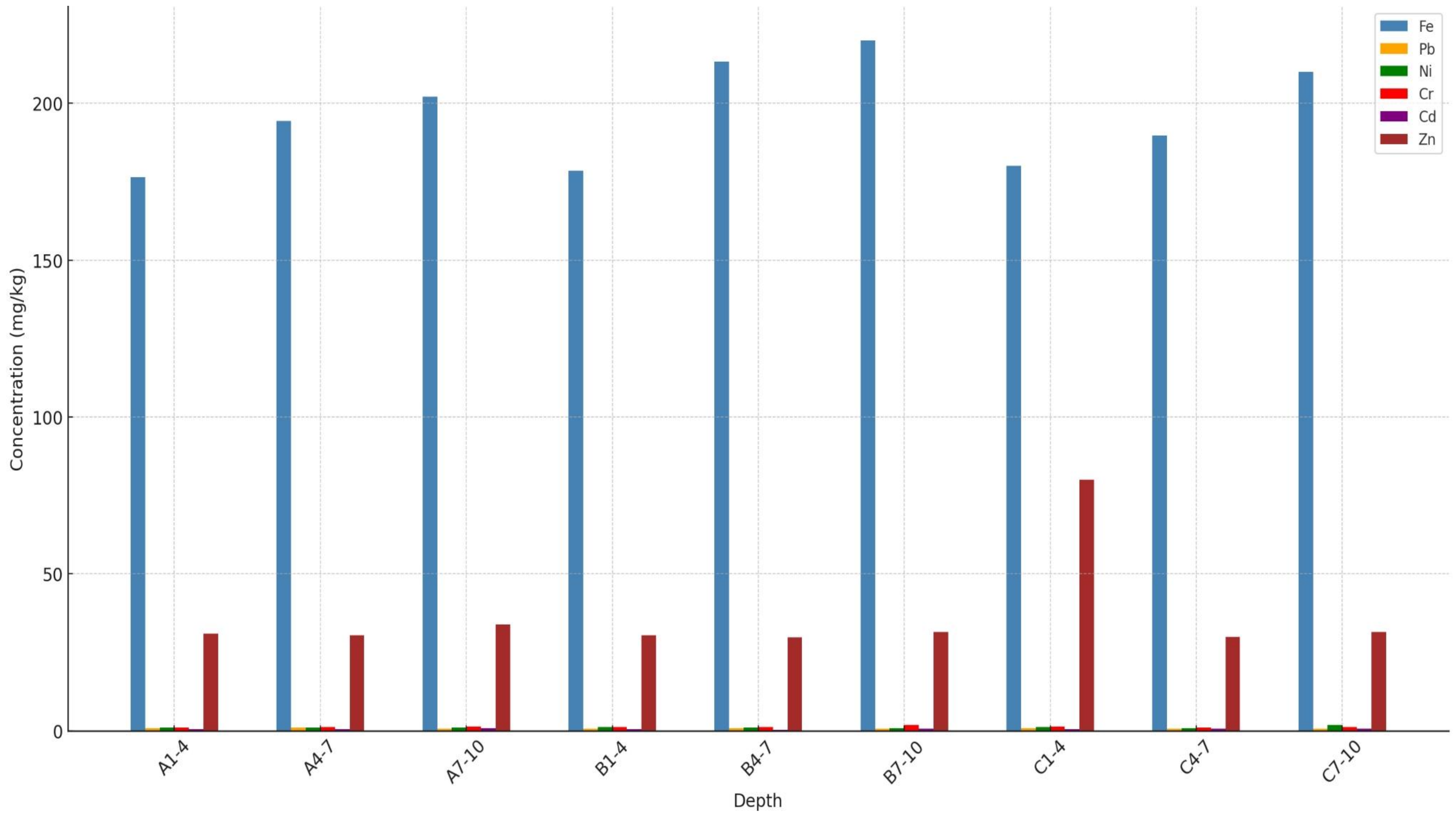

Figure 1: Heavy metal concentration in sediment in the month of July

4.4 Heavy Metal Concentration in Sediment in lower River Niger at Oguro, Ajaokuta in August.

In August, the concentrations of heavy metals in sediment samples showed a more pronounced variation compared to the previous months. Iron (Fe) levels ranged from 184.197 mg/kg to 199.813 mg/kg across the different sites and depths, remaining relatively stable. However, lead (Pb) concentrations saw a sharp increase at certain depths, particularly at Site 1, where the concentration at 7–10 cm dropped significantly to 0.167 mg/kg, contrasting with higher values recorded at other depths and sites. Nickel (Ni) concentrations experienced a marked increase, particularly at Site 1 and 2, where values rose to 3.984 mg/kg and 3.934 mg/kg, respectively, in the 7–10 cm range. Chromium (Cr) concentrations also spiked, reaching 5.372 mg/kg at Site 1 in the deeper sediment layers, indicating potential contamination sources. Cadmium (Cd) concentrations, while fluctuating, remained within similar ranges as the previous months, with slight increases at certain depths. Zinc (Zn) concentrations were slightly lower than in July, but still elevated, especially at Site 1 in the 7–10 cm depth, where it reached 32.114 mg/kg. The consistent presence of high heavy metal concentrations in August, particularly for Ni, Cr, and Zn, suggests that sediment pollution is persistent and possibly increasing due to ongoing anthropogenic activities in the region, such as mining, industrial discharge, or agricultural runoff. These findings highlight the need for continued monitoring and potential remediation efforts to reduce heavy metal accumulation in the river sediments.

Table 4.2: Heavy Metals Concentration in Sediments at Three Sites (1,2,3) for August

Month/Site	Site	Depth	Fe (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Cr (mg/kg)	Cd (mg/kg)	Zn (mg/kg)
August	1	1-4cm	184.197 ± 10.123 [a]	1.346 ± 0.023 [a]	3.880 ± 0.154 [a]	4.224 ± 0.212 [a]	0.393 ± 0.012 [a]	29.220 ± 0.540 [a]
		4-7cm	192.894 ± 12.345 [a]	1.563 ± 0.087 [a]	2.772 ± 0.098 [b]	2.113 ± 0.210 [b]	0.422 ± 0.015 [a]	30.432 ± 0.672 [a]
		7-10cm	199.813 ± 14.567 [a]	0.167 ± 0.045 [b]	3.984 ± 0.231 [a]	5.372 ± 0.231 [a]	0.457 ± 0.021 [a]	32.114 ± 0.789 [a]
August	2	1-4cm	192.567 ± 11.987 [a]	1.346 ± 0.023 [a]	3.880 ± 0.154 [a]	4.224 ± 0.212 [a]	0.393 ± 0.012 [a]	29.220 ± 0.540 [a]
		4-7cm	192.894 ± 12.345 [a]	1.563 ± 0.087 [a]	2.772 ± 0.098 [b]	2.113 ± 0.210 [b]	0.422 ± 0.015 [a]	30.432 ± 0.672 [a]
		7-10cm	199.813 ± 14.567 [a]	1.667 ± 0.112 [a]	3.934 ± 0.187 [a]	5.342 ± 0.211 [a]	0.452 ± 0.018 [a]	32.114 ± 0.789 [a]
August	3	1-4cm	11.679 ± 2.876 [b]	1.346 ± 0.023 [a]	3.889 ± 0.098 [a]	4.224 ± 0.212 [a]	0.393 ± 0.012 [a]	29.220 ± 0.540 [a]
		4-7cm	192.894 ± 12.345 [a]	0.563 ± 0.076 [b]	2.772 ± 0.098 [b]	2.113 ± 0.210 [b]	0.422 ± 0.015 [a]	30.432 ± 0.672 [a]
		7-10cm	199.813 ± 14.567 [a]	0.667 ± 0.098 [b]	3.934 ± 0.187 [a]	5.342 ± 0.211 [a]	0.452 ± 0.018 [a]	32.114 ± 0.789 [a]
SEM			**19.650**	**0.258**	**0.007**	**0.003**	**0.001**	**0.000**

Means in the same column with different superscript letter are significantly different ($p<0.05$). Fe (Iron), Pb (Lead), Ni (Nickel), Cr (Chromium), Cd (Cadmium), Zn (Zinc)

4.5 Heavy Metal Concentration of *Citharinus citharus* Tissues in June , Julyand August

The result of the concentration of heavy metals in the tissues of ***Citharinus citharus*** assessed across the months of study is shown in the table below. In June, Fe concentration was higher in the gills (49.512 mg/kg), followed by the viscera (41.332 mg/kg), and lowest in the muscle (32.114 mg/kg). Pb and Ni concentrations were also significantly higher in the gills compared to other tissues, with the gills recording 0.971 mg/kg of Pb and 1.712 mg/kg of Ni. Zn concentrations showed a similar pattern, with the gills having the highest levels at 6.891 mg/kg. In July, heavy metal concentrations generally increased, particularly in the viscera, where Fe reached 47.812 mg/kg and Ni peaked at 1.846 mg/kg. August saw slight increases in Fe levels in the gills (51.121 mg/kg) but a notable decrease in Zn,

Table 4.3: Heavy Metals Mean Concentration in *Citharinus citharus* Tissues (June, July and August)

Month	Tissue	Fe (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Cr (mg/kg)	Cd (mg/kg)	Zn (mg/kg)
June	Gill	49.512 ± 1.234 [a]	0.971 ± 0.056 [a]	1.712 ± 0.112 [a]	0.251 ± 0.045 [a]	0.003 ± 0.001 [a]	6.891 ± 0.542 [a]
	Viscera	41.332 ± 1.054 [b]	0.783 ± 0.043 [a]	0.981 ± 0.098 [b]	0.108 ± 0.034 [a]	0.004 ± 0.002 [a]	5.118 ± 0.412 [b]
	Muscle	32.114 ± 0.876 [c]	0.417 ± 0.032 [b]	0.401 ± 0.054 [c]	0.065 ± 0.012 [a]	0.000 ± 0.000 [a]	2.671 ± 0.321 [c]
July	Gill	50.672 ± 1.567 [a]	0.815 ± 0.054 [a]	1.792 ± 0.123 [a]	0.095 ± 0.021 [b]	0.004 ± 0.001 [a]	5.218 ± 0.423 [a]
	Viscera	47.812 ± 1.654 [b]	0.728 ± 0.034 [a]	1.846 ± 0.156 [a]	0.438 ± 0.065 [a]	0.003 ± 0.001 [a]	6.314 ± 0.512 [a]
	Muscle	35.667 ± 1.012 [c]	0.701 ± 0.043 [b]	0.643 ± 0.087 [b]	0.422 ± 0.054 [a]	0.002 ± 0.001 [a]	2.111 ± 0.354 [b]
August	Gill	51.121 ± 1.654 [a]	0.910 ± 0.067 [a]	1.682 ± 0.143 [a]	0.418 ± 0.065 [a]	0.004 ± 0.001 [a]	4.932 ± 0.512 [b]
	Viscera	48.403 ± 1.789 [b]	0.642 ± 0.045 [b]	1.912 ± 0.165 [a]	0.392 ± 0.054 [a]	0.002 ± 0.001 [a]	4.142 ± 0.432 [c]
	Muscle	34.921 ± 1.124 [c]	0.682 ± 0.032 [b]	0.945 ± 0.076 [b]	0.174 ± 0.034 [b]	0.000 ± 0.000 [a]	2.412 ± 0.234 [b]
WHO (PL) (WHO2017)		0.300	0.010	0.070	0.050	0.003	3.000
SEM		**0.234**	**0.045**	**0.065**	**0.021**	**0.001**	**0.112**

Means in the same column with different superscript letter are significantly different ($p<0.05$). Fe (Iron), Pb (Lead), Ni (Nickel), Cr (Chromium), Cd (Cadmium), Zn (Zinc)

4.6 Bio-Accumulation Quotient of *Citharinus citharus* Tissues in June, July and August

The result of BAQ showed that gills among the tissues examined has higher bioaccumulation quotients for most metals, with Fe at 50.67 mg/kg, Pb at 0.910 mg/kg, and Ni at 1.682 mg/kg, while Viscera also had bioaccumulation quotients, with Ni, having 1.912 mg/kg, and Cr at 0.392 mg/kg. Muscle tissues recorded the lowest bioaccumulation quotients with Fe having 34.92 mg/kg and Zn at 2.412 mg/kg. The result is shown in the table below.

Table 4.4: Bio-Accumulation Quotient (BQ) Table for Heavy Metals in *Citharinus citharus* Tissues

Tissue	Fe (mg/kg) (Mean ± SD)	Pb (mg/kg) (Mean ± SD)	Ni (mg/kg) (Mean ± SD)	Cr (mg/kg) (Mean ± SD)	Cd (mg/kg) (Mean ± SD)	Zn (mg/kg) (Mean ± SD)
Gill	50.67 ± 1.57 [a]	0.910 ± 0.067 [a]	1.682 ± 0.143 [a]	0.418 ± 0.065 [a]	0.004 ± 0.001 [a]	4.932 ± 0.512 [a]
Viscera	48.40 ± 1.79 [b]	0.642 ± 0.045 [b]	1.912 ± 0.165 [a]	0.392 ± 0.054 [a]	0.002 ± 0.001 [a]	4.142 ± 0.432 [b]
Muscle	34.92 ± 1.12 [c]	0.682 ± 0.032 [b]	0.945 ± 0.076 [b]	0.174 ± 0.034 [b]	0.000 ± 0.000 [a]	2.412 ± 0.234 [b]
SEM	0.234	0.045	0.065	0.021	0.001	0.112
LOS	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$

Means in the same column with different superscript letter are significantly different ($p<0.05$). Fe (Iron), Pb (Lead), Ni (Nickel), Cr (Chromium), Cd (Cadmium), Zn (Zinc)

4.7 Human Health Risk Assessment (RfD, THQ) of Heavy Metals in *Citharinus citharius* Tissues

Reference Dose (RfD) for each metal, which indicates the safe daily exposure level and the Target Hazard Quotient (THQ) for each tissue is presented in the table below If THQ value >1 suggests a potential health risk. Fe has a high RfD of 0.7 mg/kg/day. The THQ values are below 1 across all tissues: 0.0611 for the gill, 0.059 for the viscera, and 0.0459 for the muscle, indicating low health risk from Iron exposure. Pb) has a low RfD of 0.004 mg/kg/day. The THQ values are also below 1, with 0.0243 for the gill, 0.0196 for the viscera, and 0.0104 for the muscle, suggesting minimal risk of Lead exposure across tissue. Ni has an RfD of 0.02 mg/kg/day. The highest THQ value for Nickel is in the gill tissue (0.0856), while the viscera (0.0593) and muscle (0.0286) show lower THQ values. All values are below 1, indicating low risk.

Table 4.5: Human Health Risk Assessment (RfD,THQ) of Heavy Metals in *Citharinus citharius* tissues

Metal	Fe	Pb	Ni	Cr	Cd	Zn
RfD (mg/kg/day)	0.7	0.004	0.02	0.003	0.001	0.3
THQ (Gill)	6.11×10^{-2}	2.43×10^{-2}	8.56×10^{-2}	1.27×10^{-1}	1.33×10^{-3}	2.30×10^{-2}
THQ (Viscera)	5.90×10^{-2}	1.96×10^{-2}	5.93×10^{-2}	5.47×10^{-2}	1.77×10^{-3}	1.70×10^{-2}
THQ (Muscle)	4.59×10^{-2}	1.04×10^{-2}	2.86×10^{-2}	3.47×10^{-2}	4.90×10^{-4}	9.44×10^{-3}

Means in the same column with the same superscript letter are not significantly different ($p<0.05$). Fe (Iron), Pb (Lead), Ni (Nickel), Cr (Chromium), Cd (Cadmium), Zn (Zinc)

4.8 Estimated Daily Intake (EDI) of Heavy Metals in *Citharinus citharius* Tissues

EDI of the heavy metals in the tissues of *Citharinus citharius* showed that Fe intake was 1.78×10^{-2} mg/kg, which was the highest and Pb intake is 3.45×10^{-3} mg/kg .Ni intake was 2.14×10^{-3} mg/kg. Cr was 3.13×10^{-4} mg/kg .Cd was relatively low at 3.47×10^{-5} mg/kg. However, Zn has the highest intake 2.99×10^{-2} mg/kg. For the viscera tissue, Fe intake is 1.48×10^{-2} mg/kg, slightly lower in the gill tissue. Pb intake is 2.47×10^{-3} mg/kg. Ni intake is 1.23×10^{-3} mg/kg. Cr intake is 1.13×10^{-4} mg/kg .Cd intake is higher than in the gills at 3.81×10^{-5} mg/kg .Zn intake is 1.76×10^{-2} mg/kg. .Muscle tissue: Iron Fe intake is 1.25×10^{-2} mg/kg, the lowest among the tissues was .Pb intake is 1.56×10^{-3} mg/kg .Ni intake is 8.59×10^{-4} mg/kg. Cr intake is 1.15×10^{-4} mg/kg .Cd intake is the lowest overall at 2.35×10^{-6} mg/kg. Zn intake is 1.26×10^{-2} mg/kg, the lowest for this metal. From the result, the gill tissue recorded the highest intake levels for most metals, particularly for Iron and Zinc. The muscle tissue has the lowest intake levels across metals, with the lowest intake in Cadmium. The result is presented in the table below.

Table 4.6: Estimated Daily Intake (EDI) of Heavy Metals in *Citharinus citharius* Tissues

Tissues	Fe(mg/kg bw/day)	Pb (mg/kg bw/day)	Ni(mg/kg bw/day)	Cr(mg/kg bw/day)	Cd(mg/kg bw/day)	Zn(mg/kg bw/day)
Gill	1.78×10^{-2}	3.45×10^{-3}	2.14×10^{-3}	3.13×10^{-4}	3.47×10^{-5}	2.99×10^{-2}
Viscera	1.48×10^{-2}	2.47×10^{-3}	1.23×10^{-3}	1.13×10^{-4}	3.81×10^{-5}	1.76×10^{-2}
Muscle	1.25×10^{-2}	1.56×10^{-3}	8.59×10^{-4}	1.15×10^{-4}	2.35×10^{-6}	1.26×10^{-2}

4.9 Toxicity/Hazard Quotient (THQ) of Heavy Metals in *Citharinus citharius* tissues

The THQ result of heavy metal for the tissues of *Citharinus citharius* is presented in the table below. Fe, (0.087 mg/kg), recorded the highest concentration. Pb was 1.21×10^{-2} mg/kg. and Ni was 1.07×10^{-2} mg/kg. Cr concentration was 4.17×10^{-2} mg/kg, while that of Cd was 4.20×10^{-3} mg/kg. Zn concentration was 2.34×10^{-2} mg/kg, In the muscle Fe has the lowest concentration (0.062 mg/kg). Pb concentration was 7.91×10^{-3} mg/kg. The records of heavy metals concentrations were generally higher in the gill tissue, while the muscle tissue consistently shows the lowest concentration of metals.

Table 4.7: Toxicity/Hazard Quotient (THQ) of Heavy Metals in Citharinus citharius tissues

Tissues	Fe	Pb	Ni	Cr	Cd	Zn
Gill	0.087	1.21×10^{-2}	1.07×10^{-2}	4.17×10^{-2}	4.20×10^{-3}	2.34×10^{-2}
Viscera	0.074	1.12×10^{-2}	8.94×10^{-3}	1.51×10^{-2}	4.62×10^{-3}	1.77×10^{-2}
Muscle	0.062	7.91×10^{-3}	6.22×10^{-3}	1.23×10^{-2}	2.85×10^{-4}	1.21×10^{-2}

Means in the same column with the same superscript letter are not significantly different ($p<0.05$) :**RfD** = Reference Dose,**THQ** = Target Hazard Quotient,
EDI = Estimated Daily Intake

4.0 DISCUSSION

4.1 Heavy Metal in Water

The concentration of heavy metals in water showed a progressive increase in June, July and August with iron (Fe), lead (Pb), and zinc (Zn) consistently exceeding World Health Organization (WHO) permissible limit. This trend aligns with research by Arulkumar *et al*. (2020) on the accumulation of toxic metals in aquatic systems, which similarly reported higher heavy metal concentrations during the rainy season, likely due to runoff from industrial activities and soil erosion. In the present study, the rise in iron and lead levels during August may be attributable to increased agricultural runoff and industrial discharges, particularly from the Ajaokuta Steel Company and local mining operations. These results are consistent with findings of Adefemi *et al*., (2018) who reported that industrial activities are significant sources of heavy metal pollution in aquatic ecosystems in Nigeria

4.2 Heavy Metal in Sediment

In the sediment, the concentration of heavy metals such as nickel (Ni), chromium (Cr), and cadmium (Cd) were higher deeper layers (7–10 cm), particularly in August, suggesting that these metals have been accumulating over time. This pattern of metal deposition in sediments is consistent with the work of Soliman *et al*. (2021), who observed similar sediment-bound heavy metal concentrations in riverine systems exposed to industrial waste. Sediments act as long-term sinks for heavy metals, releasing them slowly back into the water, thus posing persistent ecological risks.

4.3 **Heavy Metal in Fish**

The bio concentration of heavy metals in the tissues (gills, viscera, and muscles) of Moon fish *Citharinus citharus* revealed from the result that iron and nickel concentrations were significantly higher in the gills, while cadmium accumulated predominantly in the viscera. These findings agreed with the findings of Bosch *et al*. (2020), who reported that gills are primary sites for heavy metal absorption in fish due to direct contact with contaminated water during respiration. The lower concentrations of heavy metals in muscle tissue, compared to gills and viscera, suggest that muscle accumulation may not pose immediate risks to human consumers, though prolonged exposure could still be hazardous. A study by Ahmed *et al*. (2021) in Bangladesh highlighted similar bioaccumulation patterns, indicating that muscle tissues, while safer for consumption than gills or viscera, still present risks if contamination persists.

4.4 **Human Health Risk Assessment**

The health risk assessment which focused on the estimated daily intake (EDI) and target hazard quotient (THQ) of heavy metals from the consumption of *Citharinus citharus*. The EDI values for most heavy metals studied were higher in the gill tissues, but are lower in the viscera and lowest in the muscle. These variations in the values across the tissues indicate that gills are always in direct contact with the water, are more prone to heavy metal bio accumulation, a trend similar to the findings of Ahmed *et al*., (2021), who reported similar patterns in fish from polluted rivers in Bangladesh.

The THQ values were also showed a potential health risks posed through fish consumption. A THQ above 1 suggests a potential health risk, yet in this study, all values were below 1. For instance, the THQ for Fe in gills was 0.0611, indicating minimal risk from iron exposure. However, the THQ for chromium in gill tissues (0.127) was notably higher than other metals, signaling a possible long-term risk. These results are consistent with findings by Bosch *et al*. (2020) in South Africa, where heavy metal contamination in fish was also linked to localized industrial activities.

Overall, the heavy metal concentrations in the river, sediments, and fish tissues underscore the significant environmental impacts of industrial and agricultural activities in the region. The progressive accumulation of metals like iron, lead, and zinc, particularly in water and sediment, suggests ongoing pollution, which is exacerbated by seasonal factors such as rainfall and runoff. The findings from this study agreed with the work of Akan *et al*., (2020), who emphasized the increasing threat of heavy metal contamination in Nigerian water bodies due to rapid industrialization and inadequate waste management practices.

Conclusion

This study provides insights into the extent of heavy metal pollution in the Lower River Niger, highlighting the risks posed to aquatic life and human health. The concentrations of iron, lead, nickel, and zinc in water samples regularly exceeded WHO permissible limits, indicating that the river is significantly polluted, especially during the rainy season. Sediment analysis further confirmed the presence of long-term heavy metal contamination, with deep sediment layers showing higher concentrations of iron, nickel, chromium, and zinc. The bioaccumulation of these metals in the tissues of *Citharinus citharus* underscores the health risks to fish consumers, particularly in communities that rely on the river for their primary protein source.

It can then be concluded from the findings of this study that there is heavy metal pollution in Lower River Niger, at Oguro which poses a serious threat to both biodiversity and public health. Immediate measures are needed to mitigate these risks and protect the ecological integrity of the river.

Recommendations

Study revealed elevated levels of heavy metals in the water, exceeding WHO guidelines. To address this, local and regional authorities should enforce stricter regulations on industrial discharges, particularly from the Ajaokuta Steel Company and other nearby facilities. Monitoring systems should be enhanced to ensure compliance with environmental standards. The accumulation of heavy metals in sediments indicates long-term pollution. Future research should be conducted to know the specific sources of contamination in detail and develop targeted strategies for mitigating the impact of industrial and agricultural activities on the river ecosystem.

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