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# Impact of Sediment and Water Heavy Metal Concentrations on Fish Bioaccumulation in Hadejia River, Nigeria

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**Abstract**

Human-induced pollution in aquatic environments, particularly from metals, poses a significant threat to fish and other aquatic organisms, leading to chronic stress and long-term ecological damage. This study assessed the bioaccumulation levels of heavy metals (chromium, nickel, copper, lead, cadmium, and zinc) in the sediments, water, and liver of catfish (*Clarias anguillaris*) and tilapia fish (*Oreochromis niloticus*) from the Hadejia River. Using atomic absorption spectrophotometry (AAS) and standard analytical methods, heavy metal concentrations data were measured and analyzed using analysis of variance (ANOVA) to determine significant differences. The results revealed that heavy metals, particularly chromium, copper, and nickel, are concentrated at higher levels in the liver of *C. anguillaris* compared to *O. niloticus*. In sediments, the order of heavy metal accumulation was Zn > Cr > Cu > Ni, while in water, it was Cr > Cu > Ni > Cd. The bioaccumulation factor (BAF) showed that *C. anguillaris* absorbed higher levels of heavy metals from both sediments and water compared to *O. niloticus*. The findings highlight the importance of ongoing monitoring of the Hadejia River to address potential health risks, as the buildup of heavy metals in aquatic organism (fish) can pose significant long-term health threats.

**Keywords:** Bioaccumulation; environmental monitoring; heavy metals; sediment analysis; water quality

## 1. Introduction

Pollution of freshwater systems by domestic and industrial waste is a global issue that affects countries of all developmental statuses(Garba *et al.,* 2022; Yehia & Sebaee, 2012). The Hadejia River has recently faced significant anthropogenic disturbances, including defecation, washing, urination, waste disposal, and fertilizer runoff from agriculture (Garba *et al.,* 2022). Population growth from migration has further exacerbated these issues, impacting the riverecological health (Gupta *et al.,* 2009). Studies have reported significant degradation of water quality in the Hadejia River, which has adversely affected the aquatic ecosystem (Umara *et al.,* 2019; Umar *et al.,* 2018).Ahmed *et al.* (2018) noted that the river acquires contaminants from the Kano and Challawa Rivers. Metals are major environmental pollutants that pose serious threats when present in high concentrations in air, water, and soil, originating from both human activities and natural sources (Afzaal *et al.,* 2022; Kanamarlapudi *et al.,* 2018). In aquatic environments, these metals readily integrate into the food chain, presenting significant hazards to ecosystems(Pandiyan *et al.,* 2021; Pandiyan *et al.,* 2020). Heavy metals enter freshwater bodies and sediments through several processes, such as atmospheric deposition, erosion, and the physiological activities of plants (Pandiyan *et al.,* 2021; Islam *et al.,* 2017; Ujah *et al.,* 2017). Additionally, urbanization, industrial discharges, domestic sewage, and agricultural practices exacerbate soil and water contamination with these metals.

Sediments act as long-term reservoirs for micropollutants, making their analysis crucial for assessing pollution levels (Siregar *et al.,* 2020). They are effective indicators for monitoring contaminants, including heavy metals (Ayotunde *et al.,* 2012). Studies have examined the pollution history and metal behavior in sediments (Siregar *et al.,* 2020). Fish, key organisms in the aquatic food chain, often accumulate elements at higher levels than their environment (Bhuyan *et al.,* 2019; Baki *et al.,* 2018). Heavy metals from anthropogenic sources distribute through water, suspended solids, and sediments, affecting fish based on their metal-processing abilities, metal concentrations in water and sediment, and feeding habits (Ishaq *et al.,* 2011). Fish significantly bioaccumulate trace metals through their diet (Pandiyan & Asokan, 2015) and are known to accumulate both organic and inorganic pollutants. As heavy metals are non-degradable, as they persist in water, sediments, and food items, there-by posing risks to aquatic organisms (Botte *et al.,* 2020).

Bioaccumulation of pollutants in a river can significantly harm current and future generations, especially with high exposure levels. Given the river importance for activities like swimming, fishing, domestic use, irrigation, and sand dredging, assessing its health concern is important. This study seeks to assess the river's health by evaluating the levels of bioaccumulated heavy metals (lead, cadmium, zinc, chromium, copper, and nickel) in river water, sediment, and aquatic organism (fish). The results will support river managers and authorities in managing the river sustainably and addressing potential health concerns.

## 2. Materials and Methods

### 2.1 Study area

The Hadejia River, a tributary of the Yobe River in Jigawa State, Northwestern Nigeria, has a catchment area of about 3,500 km² at an elevation between 152 and 305 meters above sea level (BirdLife International, 2016). It is located at latitude 12°27'12.49"N and longitude 10°02'28.14"E, it flows through settlement like Hadejia and Nguru, with diverse land uses along its banks (Abubakar, 2009). The semi-arid region experiences annual rainfall between 600 mm and 762 mm, humidity from 25% to 41% (Edegbene, 2020), and its temperatures ranging from 12°C in December and January to 40°C in March and April (Garba *et al.,* 2022). The geology features of the study area is Chad formation rocks with younger sediments, while the vegetation is typical Sudan Savannah with open grasslands and scattered trees (Abubakar, 2009).

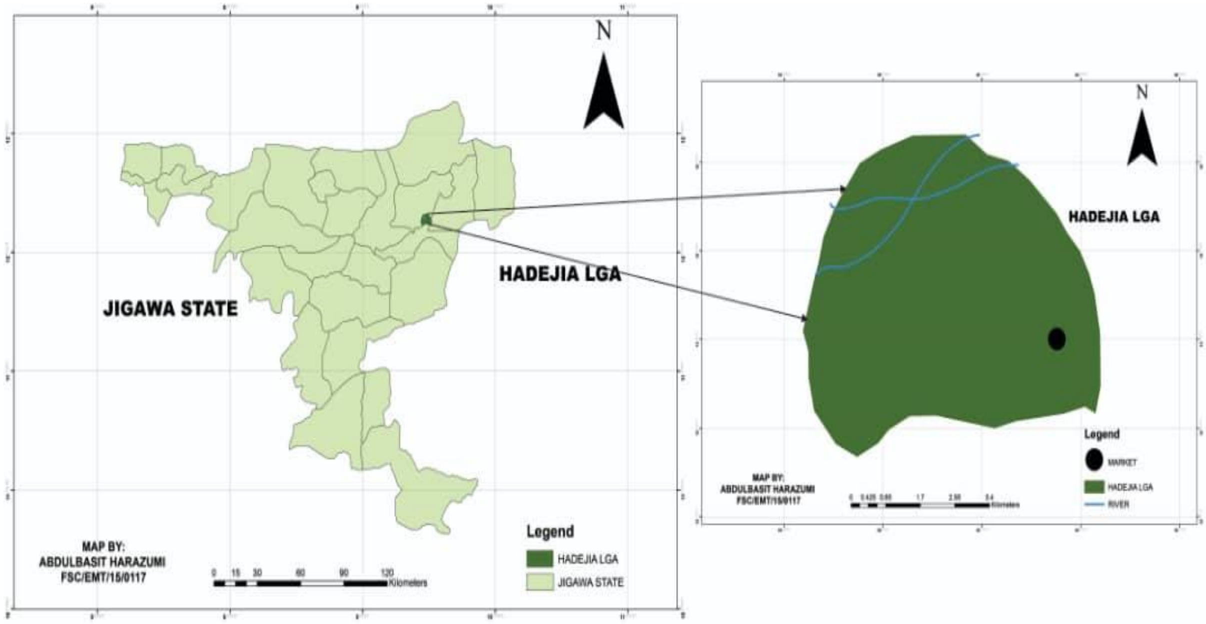


**Figure 1.** Map of the study area

## 2.2 Sample Collection

### *2.2.1 Preparation of sampled river water for heavy metal analysis*

River water samples were collected from September to November 2023 using sterilized 2-liter bottles at three different locations at the flow of the river in Hadejia. Each sample bottle is preserved in coolers with granular ice as described by Adeleye *et al.* (2021); AWWA, (2017). The samples were filtered using Whatman No. 1 filter paper (0.45 µm) upon arrival at the laboratory. Each 100 mL sample was mixed with 5 mL of concentrated $H_2SO_4$, heated at 105°C until reduced to 25 mL, then diluted to 100 mL with deionized water (Adebayo, 2017). The solution was stored in labeled containers until heavy metal analysis (AWWA, 2017).

### *2.2.2 Heavy metals determination in Sediment*

Sediment samples were collected from the same locations as the water samples using grab sampling as described by Adeleye *et al.* (2021). After drying, the sediments were placed in pre-cleaned polythene bags for heavy metal analysis. In the laboratory, they were air-dried, and heavy metals were extracted using mixed acid digestion with a 20 mL mixture of concentrated HClO4 and HNO3 (2:1 v/v) heated until nearly dry. Then, 20 mL of 0.5 M $HNO_3$ was added, and the mixture was filtered through Whatman No. 42 filter paper into a 50 mL volumetric flask(Olawale *et al.* (2016). The filtrate was diluted to 50 mL with distilled water and analyzed using a Buck Scientific 210VGP atomic absorption spectrophotometer as documented by Islam *et al.* (2015).

*2.2.3 Extraction of metals from Fish Organ*

With help from a local fisherman, fresh catfish (*Clarias anguillaris*) and fresh tilapia fish (*Oreochromis niloticus*) samples were collected from sampled river bodies, cleaned with distilled water, drained, wrapped in aluminum foil, and frozen. The fish organ (liver)disected were dried at 105°C for 24 hours, grind, and stored in labeled plastic containers. A 10 g portion of the grind liver was digested with 10 mL $HNO_3$ and 2 mL $HClO_4$, heated, and then diluted to 20 mL with 0.2% $HNO_3$(Olawale *et al.* (2016). The solution was stored in clean containers until analyzed using a Buck Scientific 210VGP atomic absorption spectrophotometer (Islam *et al.* 2015).

*2.2.4 Bioaccumlation Factor (BAF)*

The bioaccumulation factor measures the ratio of a pollutants concentration in an organism to its concentration in the environment at equilibrium, either from direct uptake or through the food chain (U.S. Environmental Protection Agency, 2010). It is calculated using the formula provided by Klavins *et al.* (1998):

$$\textbf{BAF} = \frac{M_{Liver}}{M_{Sediment}}\ Or\ \frac{M_{Liver}}{M_{Water}} \qquad \text{eqn. 1}$$

Where; $M_{sediment}\ or\ M_{water}$ indicates the concentration of the metal within the sediment or water $M_{liver}$ indicates the concentration of the metal in liver of fish.

**2.3 Statistical Analysis**

One-way ANOVA was used to compare heavy metal concentrations across water, sediment, and fish samples after data validation. Pearson correlation tested the relationships between these sources, while simple linear regression examined how sediment metal concentrations affect fish. Statistical analyses were performed with SPSS version 25.0.

## 3. Results and Discussion

### 3.1 Heavy metals concentration in river water

The concentrations of heavy metals collected from river water samples are depicted in Table 1. The average concentrations of heavy metals in the Hadejia River water were 0.27 mg/L for cadmium (Cd), 0.053 mg/L for chromium (Cr), 0.045 mg/L for copper (Cu), and 0.029 mg/L for nickel (Ni). Cadmium had the highest concentration, significantly exceeding the WHO limit of 0.01 mg/L and the USEPA standard of 0.005 mg/L, indicating severe contamination risks, which is in-concord from the research of Zhang *et al.* (2020), thereby posing serious risks to both aquatic life and human health due to its toxicity.

**Table 1:** Mean concentration of heavy metals (mg/L) in river water (Sep - Nov, 2023)

| Parameter | Lead (mg/L) | Cadmium (mg/L) | Zinc (mg/L) | Chromium (mg/L) | Copper (mg/L) | Nickel (mg/L) |
|---|---|---|---|---|---|---|
| Mean | ND | 0.27 | ND | 0.053 | 0.045 | 0.029 |
| USEPA (2007) | 0.05 | 0.005 | - | 0.10 | 2.0 | - |
| WHO (2004) | 0.01 | 0.01 | 3.0 | 0.05 | 2.0 | - |

The study found no lead or zinc in the samples; the absence of lead is reassuring given its neurotoxic effects, while the lack of zinc could suggest less industrial impact but warrants further investigation. Chromium levels slightly exceeded the WHO limit, necessitating ongoing monitoring due to its carcinogenic risks. Copper and nickel concentrations were below WHO limits but still require monitoring due to potential toxicity at higher levels. These findings align with recent studies, such as Adedeji *et al.* (2023) and Ibrahimi *et al.* (2023), which also reported elevated cadmium levels in study conducted in River Ogun and neighbouring countries river within West African. Chromium and copper level contaminant varied across studies, the need for targeted pollution control and regular monitoring is evident, which is line with the submission of Oduor *et al.*(2022); Prasad & Kumari, (2021) with high amount in their various studies. The order of metal concentration in the river water was as follow Cd > Cr > Cu > Ni.

### 3.2 Heavy metals in sediment

The sediment analysis from the Hadejia River showed mean concentrations of 0.23 mg/L for cadmium (Cd), 10.29 mg/L for zinc (Zn), 4.20 mg/L for chromium (Cr), 3.85 mg/L for copper (Cu), and 1.30 mg/L for nickel (Ni), with lead (Pb) not detected as presented in Figure 2. Cadmium exceeded the WHO limit of 0.01 mg/L, indicating serious contamination risks due to its potential for bioaccumulation and adverse effects on aquatic life and humans. Chromium levels (4.20 mg/L) were also notably high, far surpassing the WHO water standard of 0.05 mg/L, suggesting significant industrial or mining pollution and highlighting the need for immediate remediation. Zinc, at 10.29 mg/L, exceeded the WHO limit of 3.0 mg/L, pointing to potential issues from agricultural runoff or industrial discharge.

Copper concentrations (3.85 mg/L) also exceeded the WHO water standard of 2.0 mg/L, indicating possible pollution sources impacting aquatic organisms. Nickel levels (1.30 mg/L) were moderate but still relevant for assessing environmental stress and bioaccumulation, the outcome is in agreement with the study from Bianchi *et al.* (2020) from their study area. These findings also align with recent research indicating widespread heavy metal contamination across rivers in Nigeria, such as those reported by Perez *et al.* (2022); Oduro *et al*. (2022); Khan *et al.* (2021); Adedeji *et al.* (2023) in their various study, who observed similar contamination patterns linked to anthropogenic activities. The absence of lead is a is a positive outcome, as lead severe neurotoxic effects on both aquatic life and humans (López *et al.,* 2020) are well-documented. The order of heavy metal concentrations in the sediment was Zn > Cr > Cu > Ni > Cd.

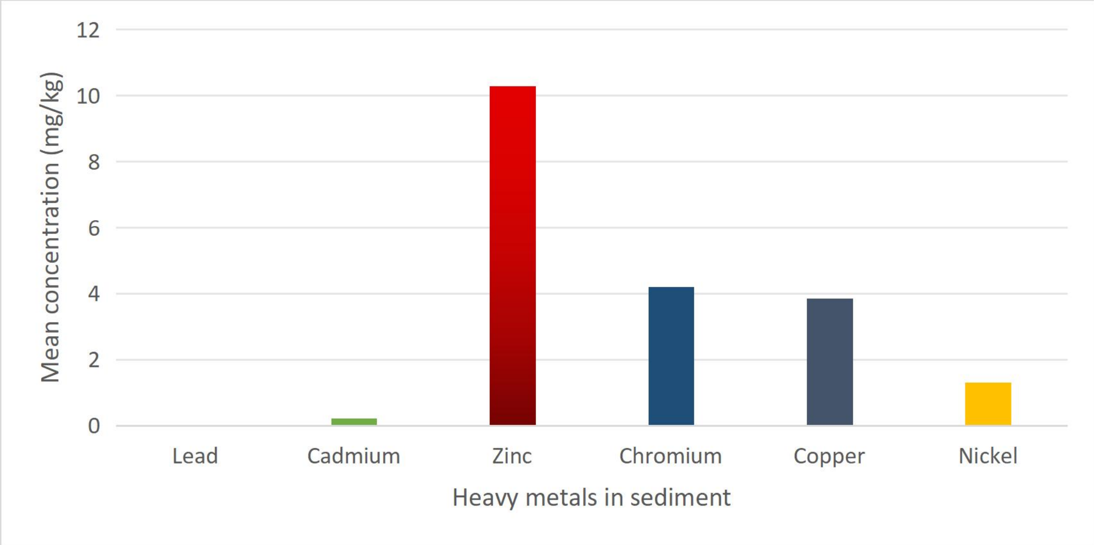


**Figure 2:** Heavy metals profile (mg/kg) of river sediment (Sep - Nov, 2023)

### 3.3 Heavy metal profiles in Fishorgan: concentration trends

The analysis of heavy metals in the liver of catfish (*Clarias anguillaris*) and tilapia fish (*Oreochromis niloticus*) from the Hadejia River revealed significant bioaccumulation, particularly of chromium, zinc, and copper as depicted in Table 2. Catfish exhibited average concentrations of 200.35 mg/L for chromium, 13.50 mg/L for zinc, 12.75 mg/L for copper, and 9.0 mg/L for nickel, while tilapia fish absorption showed lower levels of 3.80 mg/L for chromium, 0.99 mg/L for zinc, 2.95 mg/L for copper, and 0.50 mg/L for nickel. Lead and cadmium were not detected in either species. The chromium levels in catfish significantly exceed the permissible limits set by the USEPA and WHO, raising ecological and health concerns.This variation in metal content can be attributed to factors such as fish species habitat, size, sex, reproductive system, and feeding behavior (Kumar *et al.,* 2020). Additionally, the data revealed that metal accumulation was high in fish stomachs, moderate in gills, and low in muscles. Aquatic species primarily ingest heavy metals through their diet, sediment particles, or water, either via gills or the skin (Gheorghe *et al.,* 2017). Consequently, heavy metals often accumulate in the gills, stomach, and digestive glands (Lipy *et al.,* 2020). The authors also noted that while fish stomachs are rarely consumed by locals, they could serve as effective indicators of heavy metal contamination in the environment.

**Table 2:** Heavy metals concentrations (mg/kg) in liver of Tilapia fish (*Oreochiromis niloticus*) and Cat fish (*Clarias anguillaris*)

| Parameter | Lead (mg/L) | Cadmium (mg/L) | Zinc (mg/L) | Chromium (mg/L) | Copper (mg/L) | Nickel (mg/L) |
|---|---|---|---|---|---|---|
| *Cat fish* | | | | | | |
| Mean | ND | ND | 13.50 | 200.35 | 12.75 | 9.0 |
| *Tilapia fish* | | | | | | |
| *Mean* | ND | ND | 0.30 | 1.70 | 0.70 | 0.30 |
| USEPA (2007) | 0.05 | 0.2 | 150 | - | - | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| WHO (2004) | 1.5 | - | 5.0 | - | 1.0 | - |

These findings align with recent studies indicating widespread of heavy metals contamination in their study area as reported by Adedeji *et al.* (2023) in the Ogun River and Oduor *et al.* (2022) in the River Nyando, where similar bioaccumulation patterns were attributed to industrial and agricultural activities. The elevated levels of chromium, particularly in catfish(*Clarias anguillaris*), reflect broader regional issues of heavy metal pollution, underscoring the urgent need for enhanced monitoring and pollution management efforts across affected ecosystems.The order of metal accumulation in *Clarias anguillaris* was Cr > Zn > Cu > Ni. In *Oreochromis niloticus*, chromium also had the highest concentration, and the order of metal accumulation in *Oreochromis niloticus* was Cr > Cu > Zn > Ni.

### 3.4 Comparisons and implications of BAFof heavy metals in sampled fish

The comparisons of bioaccumulation factor (BAF) analysis for heavy metals in the liver of catfish (*Clarias anguillaris*) and tilapia fish (*Oreochromis niloticus*) from the Hadejia River revealed significant differences between the species and metals. *C. anguillaris*exhibited the highest BAF for chromium (3780.19), nickel (310.34), and copper (283.33) from water, while *O. niloticus*had lowest BAF for these metals: chromium (71.70), copper (65.56), and nickel 17.24) as presented in Table 3.

**Table 3:** BAF of fishes sampled in relation with River water and sediment

| HM | **Cat Fish** | | **Tilapia Fish** | |
|---|---|---|---|---|
| | Sediment | Water | Sediment | Water |
| Zn (mg/L | 1.31 | 0 | 0.10 | 0 |
| Cr (mg/L) | 47.70 | 3780.19 | 0.90 | 71.70 |
| Pb (mg/L) | ND | ND | ND | ND |
| Cu (mg/L) | 3.31 | 283.33 | 0.77 | 65.56 |
| Cd (mg/L) | ND | ND | ND | ND |
| Ni (mg/L) | 6.92 | 310.34 | 0.38 | 17.24 |

In sediment, catfish (*Clarias anguillaris*)showed higher BAF for chromium (47.70) and zinc (1.31) compared to tilapia fish (*Oreochromis niloticus*). Both species had zero BAF for zinc in water, indicating low bioavailability. The high BAF for chromium in catfish, in particular, point to severe contamination risks. These findings align with recent research from Adedeji *et al.* (2023), which reported high BAF for metals like cadmium and chromium in fish from the Ogun River, Nigeria, linking these to industrial and agricultural pollution.

**Table 4:** Comparison of BAF for HMs in sediment, water of Catfish and Tilapia fish

| **Fish type** | **Source** | **Mean** | **SD** | **Minimum** | **Maximum** |
|---|---|---|---|---|---|
| CF | Sediment | 14.31 | 21.43 | 1.31 | 47.70 |
| CF | Water | 1093.96 | 1777.79 | 0 | 3780.9 |
| TF | Sediment | 0.5395 | 0.304 | 0.10 | 0.90 |

| | | | | | |
|---|---|---|---|---|---|
| TF | Water | 38.63 | 34.37 | 0 | 71.70 |

The bioaccumulation factor (BAF) analysis in the Hadejia River reveals that catfish (*Clarias anguillaris*) exhibit significantly higher BAF values for nickel (310.34) and copper (283.33) from water compared to tilapia (*Oreochromis niloticus*), indicating that catfish are more affected by nickel and copper contamination (Table 4). Catfish also show high BAF values for chromium from both water (1093.965 mg/L) and sediment (14.31 mg/L), reflecting severe contamination and bioaccumulation, while tilapia fish have low BAF values for these metals. This pattern is consistent with recent studies by Oduor *et al.* (2022) and Ibrahimi *et al.* (2023), who reported similar high BAF for chromium and copper in fish from their study area.Despite cadmium not being detected in the Hadejia River samples, the high chromium and copper levels observed emphasize significant pollution issues, necessitating stringent observance and rectification to protect aquatic system and human health.

Metabolically active organs like the gut, gills, liver, and kidneys tend to accumulate more heavy metals compared to other organs such as skin and muscles (Lipy *et al.,* 2020; Islam *et al.,* 2015). Among the two fish species studied, catfish (*C. anguillaris)* showed the highest accumulation of heavy metals, likely due to its greater ability to absorb metals from the water environment, which is in agreement from the study from Sun *et al.*(2020). The bioaccumulation factor (BAF) for each metal followed the sequence: Cr > Cu > Ni > Cd. Chromium, an essential element for life, is actively absorbed by organisms, resulting in a higher enrichment capability compared to other non-essential elements.

## 4. Conclusion

The bioaccumulation of heavy metals in catfish (*Clarias anguillaris*) and tilapia fish (*Oreochromis niloticus*)from the Hadejia River underscores severe environmental contamination, with particularly high levels of chromium and copper. This issue is consistent with recent studies on heavy metal accumulation in other river systems, highlighting the urgent need for enhanced pollution control measures and continuous environmental monitoring. The elevated concentrations of zinc, chromium, copper, and nickel in the liver tissues of these fish species indicate significant risks to aquatic life and potential health hazards for humans through contaminated fish consumption. These findings reflect similar issues observed in other regional studies, underscoring the necessity for targeted pollution control and ongoing monitoring to protect both aquatic ecosystems and public health. Additionally, sediment analysis reveals troubling levels of cadmium, zinc, and chromium that exceed international permissible limits, posing substantial risks due to bioaccumulation in aquatic organisms. This scenario aligns with recent research from other river systems, further emphasizing the need for effective management and remediation strategies. To address these risks and safeguard the river ecological integrity and the health of local communities, it is essential to implement continuous monitoring, public awareness programs, and stricter regulations on industrial discharges.

**Declaration of competent interest**

The authors declare that they have no known competing interest or personal relationships that could have appeared to influence the work reported in this paper.

## References

Abubakar, B. H. (2009). *Weather focus in Hadejia*. Liberty printing press, Hadeja, Jigawa State Nigeria.

Adebayo, I.A. (2017). Determination of Heavy Metals in Water, Fish and Sediment from Ureje Water Reservoir. *J Environ Anal Toxicol* 7, 486. https://doi.org/10.4172/2161-0525.1000486.

Adedeji, O. A., Akintunde, J. M., & Ajayi, O. F. (2023). Assessment of heavy metal contamination in water and sediment of Ogun River, Nigeria. *Environmental Monitoring and Assessment*, 195(2), 1-12.

Adeleye, A.O., Amoo, A.O., Bate, G.B., Sadiq, I.S. and Ugba, S. (2021). Physicochemical and bacteriological assessment of ricemill wastewater discharged into river Benue, Nigeria. *Biological Environment and Pollution* 1(1): 1 – 10.https://doi.org/10.31763/bioenvipo.v1i1.381

Afzaal, M., Hameed, S., Liaqat, I., Ali Khan, A.A., Manan, H.A., Shahid, R. & Altaf, M. (2022). Heavy metals contamination in water, sediments and fish of freshwater ecosystems in Pakistan. *Water Practice & Technology.* 17(5): 1253.
doi: 10.2166/wpt.2022.039

Ahmed, S. D., Agodzo, S. K., Adjei, K. A., Deinmodei, M. & Ameso, V. C. (2018). Preliminary investigation of flooding problems and the occurrence of kidney disease around Hadejia-Nguru wetlands, Nigeria and the need for an ecohydrology solution. *Ecohydrology and Hydrobiology*, *18*(2), 212–224. doi:10.1016/j.ecohyd.2017.11.005

American Water Works Association. (2017). *Standard methods for the examination of water and wastewater*. (American Public Health Association, American Water Works Association, Water Environment Federation, 2017).

Ayotunde, E.O., Offem, B.O. & Fidelis, B.A. (2012). Heavy metal profile of water, sediment and freshwater cat fish, *Chrysichthys nigrodigitatus* (Siluriformes:Bagridae), of Cross River, Nigeria. *Int. J. Trop. Biol.* Vol. 60 (3): 1289-1301.

Baki, M.A., Hossain, M.M., Akter, J., Quraishi, S.B., Shojib, M.F.H., Ullah, A.K.M.A. & Khan, M.F. (2018). Concentration of heavy metals in seafood (fishes, shrimp, lobster and crabs) and human health assessment in Saint Martin Island, Bangladesh. *Ecotoxicol Environ Saf.* 159:153–163. https://doi.org/10.1016/J.ECOENV.2018.04.035

Bhuyan, M.S., Bakar, M.A., Rashed-Un-Nabi, Md., Senapathi, V., Chung, S.Y., Islam, M.S. (2019). Monitoring and assessment of heavy metal contamination in surface water and sediment of the Old Brahmaputra River, Bangladesh. *Appl Water Sci* 9. https://doi.org/10.1007/s13201-019-1004-y

Bianchi, T. S. & Canali, M. (2020). Nickel contamination in aquatic systems: Source, transport, and impact. *Science of The Total Environment*, 725, 138338.

BirdLife International. (2016). Important Bird and Biodiversity Area factsheet: Hadejia- Nguru wetlands. http://www.birdlife.orgon. 17/04/2018.

Botté, S.E., Freije, R.H. & Marcovecchio, J.E. (2010). Distribution of Several Heavy Metals in Tidal Flats Sediments within Bahía Blanca Estuary (Argentina). *Water Air Soil Pollut.* (210), 371–388.

DOI: 10.4172/2161-0525.1000507

Edegbene, A. O. (2020). Potential menace posed by invasive grass and water quality deterioration on macroinvertebrates structural distribution in a dam in North-Western Nigeria. *Water Science*, *34*(1), 75–84. doi:10.1080/11104929.2020.1751918

Garba, F., Ogidiaka, E., Akamagwuna, F.C., Nwaka, K.H. & Edegbene, A.O. (2022). Deteriorating water quality state on the structural assemblage of aquatic insects in a North-Western NigerianRiver, *Water Science,* 36:1, 22-31, DOI:10.1080/23570008.2022.2034396

Gheorghe, S., Stoica, C., Vasile, G.G., Nita-Lazar, M., Stanescu, E., Lucaciu, I.E. (2017). Metals toxic effects in aquatic ecosystems: modulators of water quality, in: *water quality. InTech.*https://doi.org/10.5772/65744

Gupta, A., Rai, D.K,, Pandey, R.S. & Sharma, B. (2009). Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad. *Environ. Monit. Assess.* 157: 449-458.

Ibrahimi, A., et al. (2023). Assessment of Heavy Metal Contamination in West African Rivers: A Comparative Study. *Journal of Environmental Management*, 292, 112354.

Ishaq,S. E, Rufus, S.A. & Annune,P.A.(2011). Bioaccumulation of Heavy Metals in Fish (*Tilapia Zilli* and *Clarias Gariepinus*) Organs from River Benue, NorthCentral Nigeria. *Pak. J. Anal. Environ. Chem.* 12(1&2): 25-31.

Islam M.S., Ahmed, M.K., Habibullah-Al-Mamun, M. & Masunaga, S. (2015). Assessment of trace metals in fish species of urban rivers in Bangladesh and health implications. *Environ Toxicol Pharmacol* 39:347–357. https://doi.org/10.1016/j.etap.2014.12.009

Islam, M.S., Ahmed, M.K., Raknuzzaman, M., Habibullah-Al-Mamun, M., Islam, M.K. (2017). Heavy metal pollution in surface water and sediment: A preliminary assessment of an urban river in a developing country. *Ecol Indic* 48:282–291. https://doi.org/10.1016/j. ecolind.2014.08.016

Kanamarlapudi, S. L. R. K., Chintalpudi, V. K. & Muddada, S. (2018). Application of biosorption for removal of heavy metals from wastewater. *Biosorption*18, 69. http://dx.doi.org/10.5772/intechopen.77315.

Khan, S., Shahid, M. & Ullah, N. (2021). Heavy metal contamination in river sediments: Case studies from Pakistan. *Environmental Science and Pollution Research*, 28, 33410-33424.

Kumar, A., Centre, P.G., Kumar, A. &Jha, S.K. (2020). Seasonal pollution of heavy metals in water, sediment and tissues of catfish (Heteropneustes fossilis) from Gogabil lake of north Bihar, India, *Int J Fish Aquat Stud.* 8 163–175. http://www. fisheriesjournal.com

Lipy, E.P., Hakim, M., Mohanta, L.C., Islam, D.I., Lyzu, C., Roy, D.C., Jahan, I., Akhter, S.,Raknuzzaman, M. &Sa, M.A. (2020). Assessment of Heavy Metal Concentration in Water, Sediment and Common Fish Species of Dhaleshwari River in Bangladesh and their Health Implications. *Biological Trace Element Research.*https://doi.org/10.1007/s12011-020-02552-7

López, M. P., Montiel, A. R., & Valdés, J. M. (2020). The impact of lead exposure on human health: A review. *Environmental Science and Pollution Research*, 27(10), 10490-10501.

Oduor, S. O., Okwiri, M. E., & Aloo, P. A. (2022). Heavy metal contamination in River Nyando, Kenya: Implications for human health and environmental sustainability. *African Journal of Environmental Science and Technology*, 16(3), 88-101.

Olawale, S.A., Emmanuel, A. &Abdulkareem, A. (2016). Concentrations of heavy metals in water, sediment and fish parts from Asa River, Ilorin, Kwara state. *Imperial Journal of Interdisciplinary Research (IJIR)* 2(4): 142-150

Pandiyan, J. & Asokan, S. (2015). Habitat use pattern of tidal mud and sand flats by shorebirds (Charadriiformes) wintering in southern India. *J. Coast. Cons.* 20, 1– 11.

Pandiyan, J., Mahboob, S., Govindarajan, M., Al-Ghanim, K.A., Ahmed, Z., Al- Mulhm, N., Jagadheesan, R. & Krishnappa, K.(2021). An assessment of level of heavy metals pollution in the water, sediment and aquatic organisms: A perspective of tackling environmental threats for food security. *Saudi Journal of Biological Sciences* 28: 1218–1225.

Pandiyan, J., Mahboob, S., Jagadheesan, R., Elumalai, K., Krishnappa, K., Al-Misned, F., Kaimkhani, Z.A. & Govindarajan, M. (2020). A novel approach to assess the heavy metal content in the feathers ofshorebirds: A perspective of environmental research. *J of King Saud University, Science.* 32, 3065–3307.

Pérez, D. M., Cruz, C. A., & Reyes, M. A. (2022). Copper toxicity and environmental implications: A review. *Science of The Total Environment*, 821, 153343.

Prasad, A., & Kumari, S. (2021). Chromium pollution: Human health effects and preventive strategies. *International Journal of Environmental Health Research*, 31(2), 234-246.

Siregar A.S., Sulistyo I. & Prayogo N.A. (2020). Heavy metal contamination in water, sediments and *Planiliza subviridis* tissue in the Donan River, Indonesia. *Journal of Water and Land Development.* No. 45 (IV–VI) p. 157–164. DOI: 10.24425/jwld.2020.133057.

Sun, X., Li, B.S., Liu, X.L., Li, C.X. (2020). Spatial variations and potential risks of heavy metals in seawater, sediments, and living organisms in Jiuzhen Bay, China. *J Chem.*https://doi.org/10.1155/2020/7971294

Ujah, I., Okeke, D.O. & Okpashi, V.E. (2017). Determination of Heavy Metals in Fish Tissues, Water and Sediment from the Onitsha Segment of the River Niger Anambra State Nigeria.*J Environ Anal Toxicol.* 7(5): 1-3.

Umar, D. A., Ramli, M. F., Aris, A. Z., Jamil, N. R. & Abdulkareem, J. H. (2018). Runoff irregularities, trends, and variations in tropical semi-arid river catchment. *Journal of Hydrology: Regional Studies*, *19*, 335–348. doi:10.1016/j.ejrh.2018.10.008

Umara, D. A., Ramlib, M. F., Arisc, A. Z., Jamilb, N. R. & Tukur, A. I. (2019). Surface water resources management along Hadejia River basin, northwestern Nigeria. *H2Open Journal*, *2*(1), 184–199. doi:10.2166/H2OJ.2019.010

USEPA, U.S. Environmental Protection Agency (2010). Methods for Measuring the Toxicity and Bioaccumulation of sediment Associated Contaminants with Freshwater Invertebrates. 2nd Edn., EPA boo/R-9910064, Office of Research and Development Washington, DC. 2007.

WHO, (2004). Health Criteria and Other Supporting Information in Guideline for Drinking Water Quality (3rd Eds), World Health Organization, Geneva. 2: 31 – 388.

Yehia, H.M. & Sebaee, E.S. (2012). Bioaccumulation of heavy metals in water, sediment and fish (*Oreochromis niloticus* and *Clarias anguillaris),* in Rosetta branch of the River Nile, Egypt.*African Journal of Biotechnology* Vol. 11(77): 14204-14216. DOI: 10.5897/AJB11.3745

Zhang, X., Li, S., & Liu, J. (2020). Effects of cadmium on human health: A review. *Environmental Pollution*, 263, 114596.