



## Evaluation of Heavy Metal Accumulation in Fish from Nguru LGA, Yobe State, Nigeria

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### ABSTRACT

This study aimed to determine heavy metal contents in the fish of Nguru Local Government Area (LGA), Yobe State, Nigeria, and assess the potential health risks associated with their consumption. The work seeks to enhance public health awareness and promote environmental sustainability in the region. Heavy metals, including Lead, Cadmium, Chromium, Arsenic, and Copper, pose significant threats to aquatic ecosystems and human health. The study used a descriptive experimental design and collected fish samples from major fishing sites within the Hadejia-Nguru Wetlands. A total of nine samples of common edible fish species, including African arowana, Tilapia, and Catfish, were analyzed for heavy metal concentrations using Atomic Absorption Spectrophotometry (AAS). Significant findings of environmental contamination and the accompanying health risks were highlighted. All three fish species contained varied amounts of heavy metals. Surprisingly, all of the samples contained very high levels of lead, cadmium, and copper, exceeding the World Health Organization (WHO) and Food and Agriculture Organization (FAO) permissible limits. Arsenic and chromium were found to be within permitted limits. The catfish had the highest lead content, followed by the African Arowana and the Tilapia. African Arowana had the greatest levels of cadmium, followed by Tilapia and Catfish. Similarly, Tilapia has a greater copper level than Catfish and African Arowana. The findings raised major concerns regarding neurological and renal health risks for consumers, particularly in that region of the country, which is presently one of the epicenters for chronic kidney disease. The findings highlight the urgent need for regular monitoring of heavy metal levels in aquatic habitats, as well as the implementation of stronger industrial discharge laws and the promotion of ecologically friendly agricultural practices.

**Keywords:** Heavy metals, Fish, Yobe, Aquatic Ecosystem, Hadejia-Nguru Wetlands

### 1.0 INTRODUCTION

Fisheries and public water sources are seriously threatened by heavy metal pollution in rivers, streams, and lakes (Singh *et al.*, 2017). Heavy metals are prevalent in the aquatic environment as a result of heavy metal contamination from industrial, agricultural, and household waste and byproducts (Alalwan *et al.*, 2020). When heavy metals become significantly concentrated in a medium or niche, such as air, water, or soil, the medium becomes toxic and accumulates in the ecosystem due to its inability to decompose. The gradual, persistent, and rising buildup of these heavy, poisonous metals can have disastrous impacts on life and aquatic biomes, fish life, biodiversity, and conservation (Putra *et al.*, 2026). Living things, particularly humans, become contaminated when they come into contact with aquatic environments that are contaminated by both organic and inorganic heavy metals, as well as when they eat contaminated fish and other aquatic foods (Enerijiofi *et al.*, 2026; Hossain *et al.*, 2026). Fish is a fundamental and significant food for human nutrition, offering vital minerals and vitamins, protein, and a low-cholesterol, beneficial fatty acid that can lower the risk of heart disease and stroke (Anitaş *et al.*,

2026). The function of fisheries in the ecosystem as a food source within the food chain is significant; thus, their presence and value cannot be disregarded, as the accumulation of heavy metals in fish adversely affects human health. In recent years, the rising concentration of heavy metals in fish is concerning and has prompted scientists to investigate the hazards associated with heavy metal accumulation and bioaccumulation in living cells (Bharadava *et al.*, 2026; Kefas *et al.*, 2026b; Tirado Torres *et al.*, 2026).

Heavy metals are quickly accumulated in fish due to their absorption through many body sections, including the skin, gills, digestive tract, liver, and muscles. The organs of fish often exhibit the highest concentrations of heavy metals in the gills, followed by the liver, with the muscles displaying the lowest levels. Nonetheless, muscles are the primary source of heavy metal ingestion in the body, as they are the most extensively ingested tissues, hence posing a significant health risk. Due to their greater capacity for bioaccumulation, freshwater fish are more vulnerable to heavy metal pollution (Dar *et al.*, 2026; Kumari *et al.*, 2026; Lohar *et al.*, 2026). Heavy metal pollution of aquatic environments is a developing environmental and public health issue.

Lead (Pb), cadmium (Cd), mercury (Hg), chromium (Cr), and arsenic (As) are examples of heavy metals that can build up in water bodies as a result of industrial processes, agricultural runoff, household trash, and natural processes (Jimoh *et al.*, 2026). Fish and other aquatic species may absorb these metals once they enter aquatic settings, which could result in bioaccumulation and biomagnification along the food chain (Dar *et al.*, 2026). For many communities, including those in Nguru Local Government Area, fish is a vital source of nourishment. However, there are serious health hazards associated with eating fish tainted with high amounts of heavy metals, including cancer, neurological conditions, and kidney failure (Polak-Juszczak & Barcz, 2026). In order to guarantee food safety and environmental sustainability, it is essential to evaluate the presence and concentration of heavy metals in fish from nearby water bodies. Like many other areas, Nguru Local Government Area is experiencing environmental contamination as a result of human activities like trash disposal, agriculture, and potential industrial emissions. Given that fishing is a significant source of income in the region, it is necessary to look into whether fish from nearby water bodies contain dangerous concentrations of heavy metals. Previous studies have reported the presence of heavy metals in fish from different regions of Nigeria (Akinpelumi *et al.*, 2026; Bello *et al.*, 2026; Ibrahim *et al.*, 2026; Kefas *et al.*, 2026). As for their concentration in fish from Nguru LGA, not much is known. Heavy metal contamination in fish can

seriously endanger the local population's health if it is not properly monitored. Thus, the purpose of this study is to ascertain whether the levels of heavy metals in fish from Nguru LGA are within acceptable bounds established by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO).

## 2.0 EXPERIMENTALS

Prior to and during the experiment, all tools and equipment involved in the investigation were calibrated. All of the glassware was washed with 10% concentrated nitric acid ( $\text{HNO}_3$ ) to eradicate any heavy metals from their surfaces, and then rinsed with deionized water.

### 2.1 Materials And Reagents

Every chemical and reagent used in the lab was of analytical quality. Glassware and sample bottles were cleaned before analysis, and sample and intermediate metal standard solutions were diluted with deionized water.

### 2.2 Sampling Study Area

The research was conducted in Nguru Local Government Area, Yobe State, located in northeastern Nigeria. Nguru lies within the Hadejia-Nguru Wetlands, at  $12.8758^\circ \text{N}$ ,  $10.4535^\circ \text{E}$ . It is a significant ecological zone that supports agriculture, fishing, and livestock rearing. Fishing is a major economic activity, and the wetlands provide diverse fish species consumed locally and traded regionally.

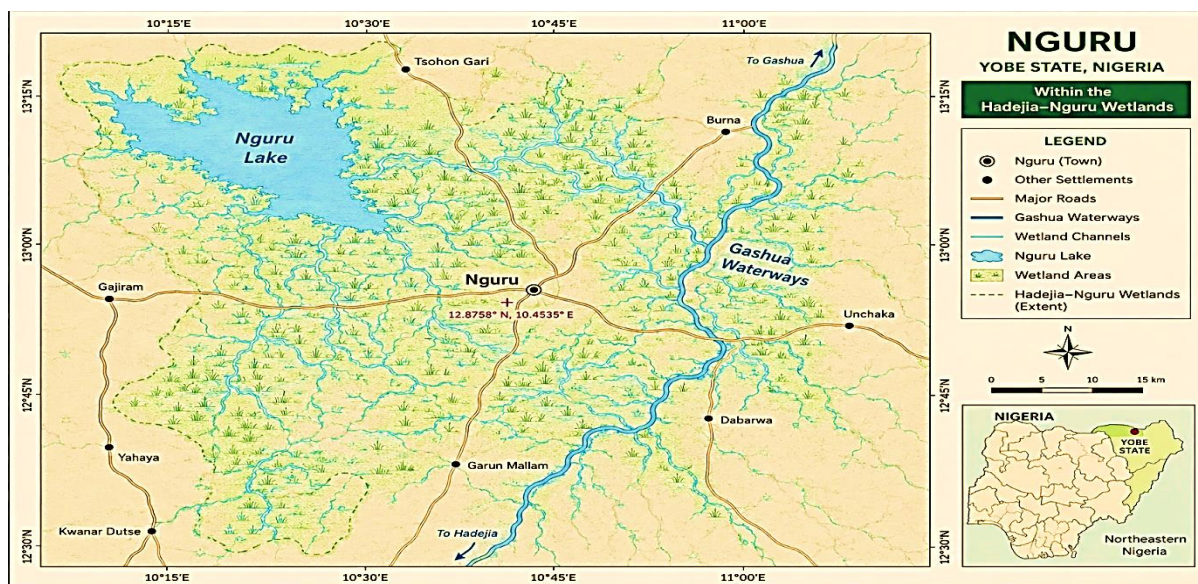


Figure 1: Map of Nguru showing the sampling sites

### 2.3 Sample Collection

The sample collection was done in October 2025, at the end of the rainy season. Fish samples were randomly collected from major fishing sites in Nguru: Nguru Lake (Point A), Gashua Waterways (Point B), and

Wetland channels (Point C). A total of 9 composite samples of common edible fish species (African arowana, Tilapia, and catfish) were collected using gillnets and traps with the assistance of local

fishermen. The fish were preserved in ice and transported to the laboratory for analysis.



Figure 2: (a) African arowana, (b) Tilapia, and (c) Catfish samples collected

#### 2.4 Sample Preparation

Upon arrival at the laboratory, the fish were washed with deionized water to remove surface contaminants. The edible muscle tissues of each fish were dissected using acid-washed stainless-steel knives. The tissues were oven-dried at 105°C until a constant weight was achieved (AOAC, 2000). Dried tissues were then ground to a fine powder using a ceramic mortar and pestle in each case.

#### 2.5 Sample Digestion

About 0.5 g of dried sample was transferred into a Teflon beaker, and 8 mL of concentrated nitric acid was added. The mixture was pre-digested overnight at room temperature and then heated on a hot plate at 80°C until the solution became clear. 2 mL of hydrogen peroxide was added to ensure complete oxidation of organic matter. After cooling, the digest was filtered through Whatman No. 42 filter paper into a 50 mL volumetric flask and diluted to the mark with deionized water. The

digests were then stored in acid-washed bottles for further analysis.

#### 2.6 Determination of Metal Contents Of Each Sample

The concentration of the metal ions contained in the sample was evaluated by reading their absorbance using a Buck Scientific AAS Model 210VGP (Buck Scientific, East Norwalk, CT, USA) and comparing it to the relevant standard calibration curve. The machine is equipped with Hollow Cathode Lamps (HCL) light sources for each element and a Deuterium background corrector. It also has a titanium burner head with an air-acetylene flame type. Three replicate determinations were carried out on each sample. The metals were determined by absorption/concentration mode, and the instrument readout was recorded for each solution manually.

## 2.7 Quality Assurance and Quality Control (QA/QC)

To ensure accuracy and reliability:

- Glassware was acid-washed and rinsed with distilled water.
- Reagent blanks and spiked samples were included to assess contamination and recovery.
- Duplicate samples were analyzed to ensure reproducibility.
- Certified reference materials (CRM) were used where available to validate results (FAO/WHO, 2011).

## 2.8 Data Analysis

The concentration of metals was expressed in milligrams per kilogram (mg/kg) of dry weight. Descriptive statistics such as mean and standard deviation were computed using Microsoft Excel. The results were compared with permissible limits established by WHO/FAO for safe fish consumption.

## 3.0 RESULTS AND DISCUSSION

This section presents the results of the studies conducted to assess the heavy metal contents of the fishes found in Nguru Local Government Area of Yobe State. The findings for the heavy metal content from the three sampled locations (Point A, Point B, and Point C) are discussed in this section.

### 3.1 Concentrations of Heavy Metals in Fish Samples

In Nigeria, the majority of our water bodies serve as reservoirs for drinking and household purposes, making the spread of heavy metals and pesticides in the aqueous phase, suspended particles, and sediments inevitable. Pesticide buildup in our water bodies poses a significant public health hazard (Popoola, 2025). Pesticides enter the aquatic environment by contact with the gills and skin, as well as ingestion or inhalation into the gastrointestinal tract and muscles. Within the fish, the heavy metal is either digested, expelled, stored, or bioaccumulated (Saha & Dutta, 2024). Heavy metals are absorbed by different fishes in different forms and at different speeds, depending on a variety of circumstances. It could be either environmental (water chemistry, salinity, temperature, and contamination levels) or biological (species, size,

gender, sexual maturity, and food supply). These heavy metals are delivered to humans because their tissues have a stronger absorption mechanism for these elements (Yi *et al.*, 2012).

The presence of these heavy metals in the aquatic environment renders the water hazardous. The level of toxicity varies according to the type of metal, its biological purpose, and the species exposed to it. Surprisingly, freshwater fish are more harmed than saltwater fish when it comes to heavy metal accumulation. It was noticed that freshwater fish accumulate heavy metals in their organs more than marine fish (Jia *et al.*, 2017). The explanation for this difference is that freshwater fish tend to lose salts and gain water, whereas marine fish prefer to gain salts and lose water. As a result, freshwater fish are more exposed and susceptible to heavy metal pollution. The concentrations of the selected heavy metals: Lead (Pb), Arsenic (As), Chromium (Cr), Cadmium (Cd), and Copper (Cu) in fish muscle tissues are presented in Table 1.

### 3.2 Pb

Pb concentrations exceeded the WHO/FAO limit (0.3 mg/kg) in all the samples. This suggests environmental contamination, possibly from agricultural runoff, discarded batteries, or motor oil residues, which are common around Nguru wetlands. Pb is a cumulative toxin that induces both chronic and acute poisoning. Ingesting fish with elevated lead levels might result in lead poisoning. Due to the accumulation of Pb in the body and the absence of a safe exposure threshold, prolonged consumption results in significant brain damage, cardiovascular complications, anemia, and reproductive abnormalities, with children being particularly susceptible to irreversible developmental and cognitive deficits. Pb bioaccumulates in bones and soft tissues over time, impairing several organ systems, like the nervous, cardiovascular, renal, hematological, and reproductive systems (Generalova *et al.*, 2025; Mazumder *et al.*, 2026; Salim *et al.*, 2003). Nguru and its environs nowadays have become a hotspot for chronic kidney diseases (CKD); this calls for serious attention, as the problem may not be unconnected with elevated amounts of such heavy metals in foods, soil, and water.

**Table 1: Mean Concentrations of Heavy Metals in Fish (mg/kg dry weight)**

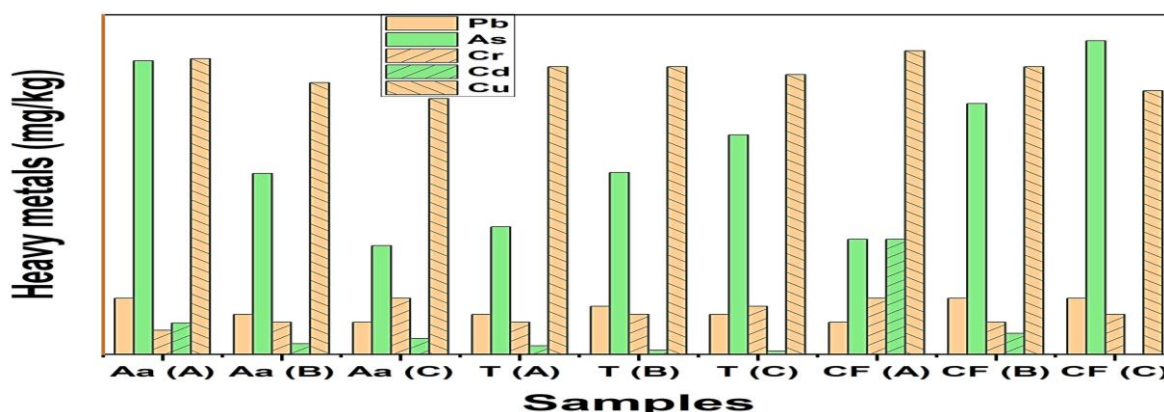
| Samples/Heavy Metals (mg/kg) | Pb  | As    | Cr  | Cd   | Cu  |
|------------------------------|-----|-------|-----|------|-----|
| African arowana (Aa) A       | 0.7 | 0.281 | 0.3 | 0.63 | 3.7 |
| African arowana (Aa) B       | 0.5 | 0.173 | 0.4 | 0.10 | 3.4 |
| African arowana (Aa) C       | 0.4 | 0.104 | 0.7 | 0.15 | 3.2 |
| Tilapia (T) A                | 0.5 | 0.122 | 0.4 | 0.28 | 3.6 |
| Tilapia (T) B                | 0.6 | 0.174 | 0.5 | 0.24 | 3.6 |
| Tilapia (T) C                | 0.5 | 0.21  | 0.6 | 0.31 | 3.5 |
| Catfish (CF) A               | 0.4 | 0.11  | 0.7 | 0.11 | 3.8 |
| Catfish (CF) B               | 0.7 | 0.24  | 0.4 | 0.20 | 3.6 |
| Catfish (CF) C               | 0.7 | 0.30  | 0.5 | 0.21 | 3.3 |
| WHO/FAO Limits (mg/kg)       | 0.3 | 2.0   | 1.0 | 0.1  | 3.0 |

### 3.3 As

The contents in all the samples were found to be within the acceptable limit. This is understandable owing to the fact that fish and seafood contain significant quantities of total As, often ranging from 1 to 10 mg per kg. However, more than 90% of this is stored as arsenobetaine, an organic, non-toxic form commonly known as "fish arsenic". The most harmful form, inorganic arsenic, is usually found at low or very safe levels in finfish (Mania *et al.*, 2015; Singhato *et al.*, 2025). It is important to note that organic arsenic is non-toxic and harmless to humans; the body excretes this type of arsenic through urine within 48 hours, without causing any damage. However, inorganic arsenic is toxic, and long-term exposure to it is strongly linked to an increased incidence of skin, bladder, lung, liver, and kidney cancers (Fatoki & Badmus, 2022).

### 3.4 Cr

Cr was found below the safe limit in almost all the samples. Obtaining excessive amounts of chromium from natural foods is nearly impossible. Because Cr from food is poorly absorbed and eliminated spontaneously, there are no set maximum intake limits for entire meals. However, excessive ingestion of supplementary or industrially polluted chromium might have negative side effects (Kośla *et al.*, 2019). Likewise, consuming food with a high content of Cr often leads to hypoglycemia, stomach pain, nausea, vomiting, skin rashes, dermatitis, and other ailments. Similarly, Individuals with pre-existing kidney or liver disease are highly susceptible to organ damage and dysfunction from elevated Cr levels (Pathak *et al.*, 2023).


**Figure 3: Heavy Metals Concentration Profile for the fish samples**

### 3.5 Cd

Cd levels in all the samples have also exceeded the minimum permissible limit of the WHO/FAO (0.1 mg/kg). Cd is often associated with phosphate fertilizers and sewage discharge. Ingesting elevated amounts of Cd in food induces acute gastrointestinal issues, including nausea, vomiting, and diarrhea.

Prolonged dietary exposure results in toxic bioaccumulation in the kidneys and bones, potentially leading to chronic kidney disease, significant bone demineralization (osteoporosis), and an elevated risk of many malignancies (Mazumder *et al.*, 2026). Cd is removed very slowly by the human body, with a biological half-life of 10 to 30 years in the kidneys. As

a result, even tiny quantities in everyday foods such as cereals, root vegetables, and seafood can add up dramatically over a lifetime (Chunhabundit, 2016; Rasin *et al.*, 2025). This elevated amount of Cd and the earlier discussed high content of Pb revealed that we are literally consuming poisons unknowingly; such drastic and urgent attention needs to be given in order to ascertain the mode of exposure and devise the means of solving the problem.

### 3.6 Cu

Similarly, Cu levels in all the samples have exceeded the minimum permissible limits of the WHO/FAO limit (3.0 mg/kg). This is consistent with what was usually obtained for fishes of Komadugu River, Gashua, and other neighbouring water bodies (Lami Jafiya *et al.*, 2022). Consuming fish with abnormally high copper concentration provides distinct health hazards to both the fish and the human consumer, resulting in toxicity and organ damage. While fish require tiny amounts of copper for development, excess dietary copper produces significant bioaccumulation and physiological discomfort. High daily copper ingestion can cause nausea, vomiting, diarrhea, and abdominal pain. Chronic, long-term exposure can cause severe anemia, impaired brain function, and liver and kidney damage (Kong *et al.*, 2013).

### 4.0 CONCLUSION

The study was conducted to ascertain heavy metal concentrations in African arowana, Tilapia, and catfish from Nguru Local Government Area, as they are commonly found and consumed fishes in the region. The study aims to contribute to public health awareness and environmental sustainability in the region. Significant findings regarding environmental contamination and associated health risks were discussed. All three fish species exhibited varying levels of heavy metals. Surprisingly, very high lead, cadmium, and copper contents were observed in all the samples, while arsenic and chromium were found to be within the permissible limit. The catfish showed the highest concentrations of lead, followed by African Arowana and Tilapia. African Arowana showed the highest contents of cadmium, followed by Tilapia and Catfish. Likewise, copper content was higher in Tilapia, followed by Catfish and African Arowana. The results raised serious concerns about neurological and renal health risks for consumers, especially in that part of the country, as it is currently one of the hotspots for chronic kidney diseases. The findings underscore the urgent need for regular monitoring of heavy metal levels in aquatic environments and recommend implementing stricter regulations on industrial discharges and promoting environmentally friendly agricultural practices.

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### REFERENCES

- Akinpelumi, V. K., Onyena, A. P., Abdulai, P. M., Ossai, C. M., & Orisakwe, O. E. (2026). Evaluation of Some Selected Heavy Metal Concentrations in Five Fish Species, Water, and Sediment Samples Obtained in Argungu River and Two. *Saudijournals.Com*, 23(4). <https://doi.org/10.1007/S13762-026-07115-2>
- Alalwan, H. A., Kadhom, M. A., & Alminshid, A. H. (2020). Removal of heavy metals from wastewater using agricultural byproducts. *Journal of Water Supply: Research and Technology-Aqua*, 69(2), 99–112. <https://doi.org/10.2166/AQUA.2020.133>
- Anitaş, Ö., Göncü, S., Hepsağ, F., Koluman, N., & Ozogul, Y. (2026). Macronutrient and micronutrient profiles of meat types: insights into human health and diet. *Journal of the Science of Food and Agriculture*. <https://doi.org/10.1002/JSFA.70709;CTYPE:STRING:JOURNAL>
- Bello, A., Olawumi, O., & Abdulwasiiu, A. (2026). Heavy Metals in Smoked Fish: A Comprehensive Review of Nutritional Implications, Health Impacts, and Public Health Challenges in Nigeria. <https://doi.org/10.1016/J.TOXREP>
- Bharadava, K., Makarani, N., & Kaushal, R. S. (2026). Co-selection of antimicrobial and heavy metal resistance in aquatic microbial communities at the water interface. *Environmental Geochemistry and Health* 2026 48:8, 48(8), 362-. <https://doi.org/10.1007/S10653-026-03254-0>
- Chunhabundit, R. (2016). Cadmium Exposure and Potential Health Risk from Foods in Contaminated Area, Thailand. *Toxicological Research*, 32(1), 65. <https://doi.org/10.5487/TR.2016.32.1.065>
- Dar, R. A., Qadiri, S. S. N., Shah, F. A., Dar, S. A., & Amin, A. (2026). Bioaccumulation of Plastics in Fish Raises Health Concerns and Regulatory Gaps. *Plastic Tides: Tackling Plastic Pollution for Global Food Security*, 163–174. [https://doi.org/10.1007/978-3-032-17411-6\\_6](https://doi.org/10.1007/978-3-032-17411-6_6)
- Enerijiofi, K. E., Musa, S. I., Bhowmik, D., & Nath, S. (2026). Detrimental Influence of Diverse Pollutants on Water Environment and Human Life Public Health Implications. *Coresource* 4, 89–110. <https://doi.org/10.1201/9781003500452-5/Detrimental-Influence-Diverse-Pollutants>



- Water-Environment-Human-Life-Kingsley-Erhons-Enerijiofi-Saheed-Ibrahim-Musa-Deepshikha-Bhowmik-Soumitra-Nath
- Fatoki, J. O., & Badmus, J. A. (2022). Arsenic as an environmental and human health antagonist: A review of its toxicity and disease initiation. *Journal of Hazardous Materials Advances*, 5, 100052. <https://doi.org/10.1016/J.HAZADV.2022.100052>
- Generalova, A., Davidova, S., & Satchanska, G. (2025). The Mechanisms of Lead Toxicity in Living Organisms. *Journal of Xenobiotics* 2025, Vol. 15, Page 146, 15(5), 146. <https://doi.org/10.3390/JOX15050146>
- Hossain, M. S., Lima, M. A., Jamee, M. F., Jahan, T., Dithakit, P., Rahman, M. S., Chanda, S., Omit, M. S., Bordin, C., & Hridoy, M. A. A. M. (2026). Assessing the Genotoxic Effects of Emerging Organic Contaminants in Water Systems: Current Trends and Future Directions. *Scientifica*, 2026(1), 5677364. <https://doi.org/10.1155/SCI5/5677364>
- Ibrahim, A., Mohammed, A., Jidda, D., Saleh, A., & Sani, M. (2026). Human risk Assessment of heavy metals in fishes from Dadin-Kowa Dam, Yamaltu, Gombe State, Nigeria. <https://www.researchsquare.com/article/rs-8338814/latest>
- Jia, Y., Wang, L., Qu, Z., Wang, C., & Yang, Z. (2017). Effects on heavy metal accumulation in freshwater fishes: species, tissues, and sizes. *Environmental Science and Pollution Research* 2017 24:10, 24(10), 9379–9386. <https://doi.org/10.1007/S11356-017-8606-4>
- Jimoh, A. A., Azeez, S. O., & Jamiu, W. (2026). Recent developments in heavy metal remediation from polluted water: sources, environmental impacts, and sustainable hybrid treatment strategies. *Discover Chemistry* 2026 3:1, 3(1), 279-. <https://doi.org/10.1007/S44371-026-00721-6>
- Kefas, M., Michael, K. G., Labaran, N. D., & Godfrey, J. (2026). Determination of Heavy Metals in Three Fish Species (*Tilapia zilli*, *Clarias anguillaris* and *Synodontis filamentous*) from Upper River Benue Yola, Adamawa. [Ikrpublishers.Com. https://doi.org/10.5281/zenodo.19071631](https://doi.org/10.5281/zenodo.19071631)
- Kong, X., Jiang, H., Wang, S., Wu, X., Fei, W., Li, L., Nie, G., & Li, X. (2013). Effects of copper exposure on the hatching status and antioxidant defense at different developmental stages of embryos and larvae of goldfish *Carassius auratus*. *Chemosphere*, 92(11), 1458–1464. <https://doi.org/10.1016/J.CHEMOSPHERE.2013.04.004>
- Kośla, T., Lasocka, I., & Kołnierzak, M. (2019). Chromium, Cr. Mammals and Birds as Bioindicators of Trace Element Contaminations in Terrestrial Environments: An Ecotoxicological Assessment of the Northern Hemisphere, 57–124. [https://doi.org/10.1007/978-3-030-00121-6\\_3/SAVE-RESEARCH](https://doi.org/10.1007/978-3-030-00121-6_3/SAVE-RESEARCH)
- Kumari, P., Gupta, U., & Basak, S. (2026). Minimizing Metal(loid) Risks Through Safe Fish Cooking Techniques: Insights into Toxicity Mechanisms. *Biological Trace Element Research* 2026 204:6, 204(6), 4561–4581. <https://doi.org/10.1007/S12011-026-04981-2>
- Lami Jafiya, Simeon Adole Akogwu, Jibrin Sabo Suleimana, & Osunlaja AA. (2022). Assessment of heavy metals in some edible fish species of the Komadugu-Yobe River, Gashua, Yobe State, North-East Nigeria: Threat to public health. *International Journal of Biological and Pharmaceutical Sciences Archive*, 4(1), 001–011. <https://doi.org/10.53771/IJBPSA.2022.4.1.0068>
- Lohar, S., Mavry, B., Sharma, V., Sharma, A., Kumar, R., & Singh Sankhla, M. (2026). Impact of Pathotoxicity and Bioaccumulation of Lead on Fish Health and Ecosystem Dynamics. *Anim. Sci*, 26, 15–25. <https://doi.org/10.2478/aoas-2025-0020>
- Mania, M., Rebeniak, M., Szynal, T., Wojciechowska-Mazurek, M., Starska, K., Ledzion, E., & Postupolski, J. (2015). Total and inorganic arsenic in fish, seafood and seaweeds - exposure assessment. *Roczniki Państwowego Zakładu Higieny*, 66(3).
- Mazumder, S., Bhattacharya, D., Lahiri, D., Nag, M., Maity, S., Raja, V., Sharma, S., Dwivedi, S. P., Rajeev, M., & Kadirov, I. (2026). Lead and Cadmium Induced Toxicity Under Prolonged Low-Dose Exposure: Food Chain Driven Source, Molecular Mechanisms, Signaling Cascade, and Health Implications. *Journal of Applied Toxicology*. <https://doi.org/10.1002/JAT.70136;CSUBTYP E:STRING:AHEAD>
- Pathak, A., Asediya, V., Anjaria, P., & Singh, S. P. (2023). Health Risk Linked to Cr Toxicity in Food and Environment. *Environmental Science and Engineering, Part F1975*, 217–252. [https://doi.org/10.1007/978-3-031-44029-8\\_10/SAVE-RESEARCH](https://doi.org/10.1007/978-3-031-44029-8_10/SAVE-RESEARCH)
- Polak-Juszczak, L., & Barcz, L. (2026). Toxic metals in fish from polish market, health risk assessment. *Food and Chemical Toxicology*, 211, 115974. <https://doi.org/10.1016/J.FCT.2026.115974>



- Popoola, O. J. (2025). Heavy Metals in Water and Implications for the Food Chain in Nigeria. *Handbook of Public Health Nutrition*, 1–30. [https://doi.org/10.1007/978-3-031-32047-7\\_103-1](https://doi.org/10.1007/978-3-031-32047-7_103-1)
- Putra, N. R., Suryadi, Y., Affandi, A., Wartono, W., Susilowati, D. N., Yuniarti, E., Ikhwan, I., & Airlangga, B. (2026). Green solutions to soil pollution: a review on natural extracts for heavy metal remediation, current challenges, and future directions. *International Journal of Phytoremediation*. <https://doi.org/10.1080/15226514.2026.2660155>
- Rasin, P., V. A. A., Basheer, S. M., Haribabu, J., Santibanez, J. F., Garrote, C. A., Arulraj, A., & Mangalaraja, R. V. (2025). Exposure to cadmium and its impacts on human health: A short review. *Journal of Hazardous Materials Advances*, 17, 100608. <https://doi.org/10.1016/J.HAZADV.2025.100608>
- Saha, R., & Dutta, S. M. (2024). Pesticides' mode of action on aquatic life. *Toxicology Reports*, 13, 101780. <https://doi.org/10.1016/J.TOXREP.2024.101780>
- Salim, A., Hassanin, M. A., & Zohair, A. (2003). A simple procedure for reducing lead content in fish. *Food and Chemical Toxicology*, 41(4), 595–597. [https://doi.org/10.1016/S0278-6915\(02\)00259-4](https://doi.org/10.1016/S0278-6915(02)00259-4)
- Singh, R., Singh, A., Bhadouria, R., & Kumar Yadav, H. (2017). Impact and Assessment of Heavy Metal Toxicity on Water Quality, Edible Fishes and Sediments in Lakes: A Review. In *Trends in Biosciences* (Vol. 10, Number 8).
- Singhato, A., Rueangsri, N., Thanaratsotornkun, P., Boonyingsathit, K., Sridonpai, P., Laitip, N., Ornthai, N., & Judprasong, K. (2025). Risk Assessment of Toxic Heavy Metal Exposure in Selected Seafood Species from Thailand. *Foods*, 14(21), 3725. <https://doi.org/10.3390/FOODS14213725/S1>
- Tirado Torres, D., Vázquez Rodríguez, G., Rodríguez Núñez, J. R., Carreño Aguilera, G., Bravo Cobarrubias, A., & Costilla Salazar, R. (2026). Bioadsorbents for Heavy Metal Removal: A Critical Review of Advances, Limitations, and Prospects. *World Sustainability Series, Part F1753*, 371–411. [https://doi.org/10.1007/978-3-032-10314-7\\_19/SAVE-RESEARCH](https://doi.org/10.1007/978-3-032-10314-7_19/SAVE-RESEARCH)
- Yi, Y., Research, S. Z.-E. S. and P., & 2012, undefined. (2012). Heavy metal (Cd, Cr, Cu, Hg, Pb, Zn) concentrations in seven fish species in relation to fish size and location along the Yangtze River. *Springer*, 19(9), 3989–3996. <https://doi.org/10.1007/S11356-012-0840-1>