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*Full Length Research*

# Accumulation of heavy metals in the muscle tissues of smoked tilapia, catfish, and African lungfish sold by fish vendors along the Komodugu River, Yobe State, Nigeria

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**ABSTRACT:** Heavy metal contamination in aquatic ecosystems poses serious health risks to both aquatic life and humans. The tissue-specific bioaccumulation of these metals in fish from polluted waters can result in life-threatening illnesses or even mortality. In the Komodugu River region, limited research has been conducted to evaluate heavy metal concentrations in fish consumed by residents. This study sought to determine the levels of five heavy metals—Lead (Pb), Cadmium (Cd), Chromium (Cr), Mercury (Hg), and Arsenic (As)—in the muscle tissues of three commonly smoked fish species: Tilapia, African lungfish, and catfish. Ten samples of each species were purchased from local vendors along the Komadugu River in Yobe State, transported under chilled conditions in an ice box to maintain sample integrity, and analysed in the laboratory using atomic absorption spectrophotometry. Findings showed no statistically significant differences ($p>0.05$) in Cr, Cd, and Hg concentrations in African lungfish, whereas Pb levels differed significantly ($p<0.05$). Overall, the concentrations of most heavy metals exceeded the maximum permissible limits, except for mercury (Hg). These results suggest that consumption of these fish species may pose potential health hazards to humans. The study contributes to the growing body of evidence on freshwater ecosystem contamination and highlights the need for stricter regulation of artisanal fish processing and distribution practices.

**Keywords:** Aquatic pollution, contaminant, health risk, heavy metals, sustainable.

## INTRODUCTION

Fish is a major and commonly consumed source of animal protein in Nigeria, playing a vital role in household nutrition and contributing significantly to the country's animal-protein supply (FAO, 2023; Bradley *et al*., 2020; Saba *et al*., 2024). Growing research emphasises the dietary importance of fish, stressing its value as a readily absorbable provider of premium-quality protein, essential amino acids, and long-chain omega-3 polyunsaturated fatty acids such as EPA and DHA, which are recognised for their benefits in maintaining heart health, neurodevelopment, and immune regulation (Kelley-Hedgepeth, 2021). Komodugu River provides a suitable ecosystem for freshwater fishing and farming. This enables the people in the region not only to meet their protein requirements but also to provide women's entrepreneurship opportunities around fish smoking and vending. It is estimated that the demand for fish in Yobe state along is about 1,500 tons, while fish supply was about 800 tons in 2008 (Sogbesan *et al*.,2015). However, recently there has been a decline in fish population, accompanied by complaints from consumers having some food poisoning symptoms after consuming fish sold by vendors within the study area. Research revealed that over time, human and animal activities, such as improper waste disposal and the release of contaminants from factories and mining, significantly contribute to the elevated concentrations of heavy metals in rivers. These heavy metals find their way into the ecosystem either directly or indirectly into the water and food system, which are subsequently consumed by humans.

Studies have demonstrated that fish exposed to polluted water are capable of absorbing and storing trace elements, heavy metals, pesticide remnants, and persistent organic pollutants, such as polychlorinated biphenyls (PCBs), in their tissues. (Jia *et al*., 2018). When the concentration of these toxic metals exceeds safe limits, their consumption can pose significant health risks to humans. Notably, fish tend to accumulate considerable quantities of metals in specific organs, particularly the gills and muscle tissues. The extent of metal accumulation is influenced by multiple factors, including ambient environmental conditions, seasonal variations, species-specific physiology, and the developmental stage and age of the fish (Łuczyńska *et al.*, 2019). Moreover, heavy metals may attach to cell membranes and hinder the body's transportation mechanisms. These toxic metals can cause harm when consumed in large amounts, leading to various health conditions. For instance, high intake of copper, zinc, and lead has been linked to Alzheimer's disease. Zinc and iron are also associated with Parkinson's disease, while cadmium exposure has been connected to a range of health issues, including kidney damage, bone weakening (osteomalacia), and reproductive complications (Han *et al*, 2013). It has been shown that fish absorb heavy metals and dissolved substances from the surrounding water and their diet. Researchers focus on these metals and pollutants because they impact both human and environmental well-being, even in minute concentrations in aquatic environments. According to Seymore (2016), these pollutants accumulate considerably in various fish tissues, leading to toxic effects at critical sites. Yaduma and Humprey (2009) explain that aquatic species can bio-accumulate heavy metals in their tissues at levels far greater than those in the surrounding water, sediments, or associated microorganisms. Consuming such polluted fish can result in the intake of harmful metals, potentially causing severe health risks, such as cancer and damage to vital organs. Given these issues, this study was conducted to evaluate the levels of specific heavy metals, Lead (Pb), Cadmium (Cd), Chromium (Cr), Mercury (Hg), and Arsenic (As) in smoked samples of catfish (*Clarias gariepinus*), Tilapia (*Oreochromis niloticus*), and African lungfish (*Protopterus annectens*) collected from the Komadugu River in Yobe State, Nigeria.

## MATERIALS AND METHODS

### Study area

The Komodugu Yobe-River is one of the most significant rivers in Yobe State, located in (longitud12º52´N and latitude 10º58´E) Gashua area of Bade LGA. The Hadejia and Jama' are rivers which converge near the Hadejia Nguru Wetlands, giving rise to the river, which then passes through Gashua and empties into Lake Chad (KYBP, 2006). With a population of roughly 139,804 people, the river is investigated at its full length of roughly 10 km in Gashua, covering an area of 772 sq km (NPC, 2006). The town experiences 38º to 40º Celsius on average per year, with mean maximum temperatures of 39.8º Celsius in March and April and mean lowest temperatures of 28.1º Celsius in June through September. Gashua is located in the Sudan Savannah vegetation zone, which is primarily made up of shrubs and short trees. The area receives 500–1000 mm of rain in a year, which falls over 120 days.

### Sample collection of the fishes

Three species of fish, catfish (*Clarias gariepinus)*, Tilapia (*Oreochromis niloticus*), and African lungfish (*Protopterus annectans*) were sampled from fish vendors along the Komodugu River, Yobe State. The samples of each species were collected in triplicate from the Gashua traders of smoked fish. The smoked fish were purchased and then aseptically packaged in sterile containers, which were then moved to the lab and stored at a temperature of 4±1°C. Fresh fish samples were initially procured and handed over to local fishermen for smoking according to specified requirements. The smoked specimens collected from designated sampling locations were subsequently oven-dried at 105°C for 10 hours. Once dried, the samples were finely ground and stored in airtight containers before extraction procedures (Olabemiwo *et al*., 2011). The targeted heavy metals for analysis included Cadmium, Chromium, Mercury, Lead, and Arsenic. Quantification of these metals was performed following acid digestion using an atomic absorption spectrophotometer (Buck Scientific Model 210 VGP). For digestion, 2 grams of the homogenised fish powder were weighed into digestion tubes, followed by the addition of concentrated nitric acid (65%) and hydrogen peroxide (30%) in a 2:1 volume ratio, as described by Abarshi *et al.* (2017). The mixture was allowed to react and then placed in a digestion chamber for 2 to 3 hours until the volume was reduced to approximately 4–5 mL. Once cooled, the digested solution was filtered, diluted with deionised water, and prepared for heavy metal analysis.

Final quantification of Pb, Hg, As, Cd, and Cr was conducted using atomic absorption spectrophotometry at the Chemistry Department of Yobe State University.

**Fish dissection and sample preparation**

The smoked tilapia samples were transported to the laboratory in clean polyethylene bags and stored under hygienic conditions prior to analysis. Each fish sample was properly labelled, and the external surface was cleaned to remove adhering particles. Using a clean stainless-steel dissecting knife and forceps, the fish was dissected on a clean dissection board. The edible muscle tissue was carefully separated from the skin, bones, head, viscera, and gills to avoid cross-contamination from non-edible organs. Similar fish heavy-metal studies commonly use the edible muscle or fillet portion for metal analysis because it represents the part consumed by humans. The collected muscle tissues were cut into small pieces, oven-dried until constant weight, and ground into a fine homogeneous powder using a clean mortar and pestle or laboratory grinder. The powdered samples were stored in labelled airtight containers or desiccators until digestion and metal analysis. This preparation approach is consistent with previous tilapia heavy-metal studies, where edible tissues were oven-dried, powdered, and preserved before chemical analysis.

**Sample digestion**

Approximately 0.5–1.0 g of the homogenised dried fish muscle sample was weighed into a clean digestion tube or microwave digestion vessel. A mixture of concentrated nitric acid and hydrogen peroxide was added to digest the organic matrix and release metals into solution. Nitric acid and hydrogen peroxide are widely used for the digestion of fish tissue before heavy-metal determination. In a Nile tilapia study, dried fish muscle powder was digested using concentrated nitric acid and hydrogen peroxide before analysis. The samples were allowed to pre-digest at room temperature and then heated carefully on a hot plate or digested using a microwave digestion system until a clear solution was obtained. Microwave-assisted acid digestion is also supported by USEPA Method 3052, which applies to organic matrices and biological tissues and is suitable for elements such as Cd, Pb, As, Cr, Cu, Hg, Fe, Ni, and Zn. After cooling, the digested samples were filtered and diluted to a known final volume with deionised water. Reagent blanks containing the same acids but no fish tissue were prepared and digested using the same procedure.

**Instrumentation and metal determination**

The concentrations of selected heavy metals, including Pb, Cd, Cr, Cu, Zn, Fe, Hg, and As, were determined using Atomic Absorption Spectrophotometry (AAS). The instrument was operated according to the manufacturer's instructions using element-specific wavelengths for AAS or mass-to-charge ratios for ICP-MS. Metal concentrations were calculated from calibration curves and expressed as mg/kg dry weight of fish muscle tissue.

**Calibration and quality control**

Calibration standards for each metal were prepared from certified stock standard solutions by serial dilution using deionised water or dilute nitric acid. A calibration curve was prepared for each metal before sample analysis, and linearity was checked using the correlation coefficient. To ensure analytical reliability, all glassware and digestion vessels were washed, acid-rinsed, and thoroughly rinsed with deionised water before use.

**Statistical analysis**

Heavy metal concentrations were analysed using standard procedures. Data were organised in Microsoft Excel 2023 and analysed using SPSS version 20.0. ANOVA was performed, and significant means were separated using DMRT at $p<0.05$. Pearson correlation analysis was used to assess relationships among variables

## RESULTS AND DISCUSSION

Table 1 shows the values of heavy metal concentrations in three (3) species of fish in the study area. The value recorded in this study ranged between 0.82 - 1.40 mg/kg, 0.49 - 0.70 mg/Kg, 0.65 - 0.80 mg/Kg and 0.69 - 0.95 mg/Kg for Pb, Cd, Cr and As, respectively, while the value of Hg was below the detectable value. The range value recorded in this study was lower than 0.14 – 0.48 mg/Kg, 0.001 - 0.062 mg/Kg, 0.001- 0.004 mg/Kg, 0.001- 0.008 mg/Kg, 0.001 - 0.006 mg/Kg and 0.092-0.278mg/Kg in fish muscle found in Komodugu River, Yobe. European lake Spain, Atlantic Bluefin tuna steak Portugal, Atlantic blue tuna canned Thailand, Patagonian squid Spain and Blue mussel Spain (Jafiya *et al*., 2022; Djedjibegovic *et al*., 2020).

**Determination of lead**

The results significantly ($p<0.05$) revealed higher concentration of Pb in African lungfish and tilapia fish with

**Table 1.** Heavy metal concentrations in three (3) species of fish in the study area.

| Sample | Catfish | African L Fish | Tilapia | SEM |
|---|---|---|---|---|
| Lead (Pb) | $0.82^{b}$ | $1.40^{a}$ | $1.33^{a}$ | 0.94 |
| Cadmium (Cd) | $0.69^{ab}$ | $0.49^{b}$ | $0.70^{a}$ | 0.63 |
| Chromium (Cr) | 0.65 | 0.80 | 0.73 | 0.16 |
| Mercury (Hg) | ND | ND | ND | 0.00 |
| Arsenic (As) | 0.69 | 0.95 | 0.71 | 0.28 |

ND = Not detected.

1.40 mg/kg and 1.33 mg/Kg, respectively, when compared to the values recorded in catfish (0.82 mg/Kg). This value was higher than 0.38, 0.45 and 0.41mg/Kg recorded in *O. niloticus*, *C. gariepinus* and *S. schall* muscle, respectively, in the same river (Jafiya *et al*., 2022) but lower than 3.0, 3.8, and 10.00mg/Kg for C (Table 1). *nigrodigitatus*, E, *fimbriata* and *P*. *elongatus* in the Cross-river system (Asuquo *et al*., 2004). The values were above the maximum limit stated by international bodies, 1.0, 0.5, 0.3, 0.5, and 0.3 mg/Kg (NAFDAC, 2004; FSANZ, 2013; European Commission, 2006; MHPRC, 2013), but lower than 2.0 mg/Kg (WHO, 2020). The presence of lead (Pb) in these species poses a potential risk of toxicity upon consumption. Lead (Pb) exposure is known to impair haemoglobin synthesis and disrupt the normal functioning of the kidneys, reproductive organs, joints, and cardiovascular system, while also causing persistent damage to both the central and peripheral nervous systems (Nolan, 2003). Similarly, ingestion of Pb-contaminated processed (smoked) fish may adversely affect neurological health, with heightened vulnerability observed in infants and young children. Dietary exposure to Pb has been associated with impaired growth and developmental delays, accompanied by symptoms such as gastrointestinal distress, anorexia, headaches, sleep disturbances, anaemia, renal dysfunction, auditory deficits, memory impairment, severe abdominal pain, and motor coordination issues (Jan *et al*., 2015).

## Determination of cadmium

In the current study, the Cd contents in the three samples were range from 0.49 - 0.70 mg/Kg which were above the range of 0.002- 0.060 mg/Kg, 0.049-0.073 mg/Kg, 0.013-0.017 and 0.015-0.027 mg/Kg found in the muscle of fish in Kumadugu river Yobe, Blue mussel Spain, Black tiger shrimp China and Indian white prawn India respectively (Jafiya *et al*., 2022; Djedjibegovic *et al*., 2020). The value recorded in African lungfish (0.049 mg/Kg) was signify-cantly ($p<0.05$) lower than 0.69 mg/Kg and 0.70 mg/Kg recorded in catfish and tilapia fish respectively, all the values were higher than 0.1,0.05 and 0.1mg/Kg set as the maximum limit (NAFDAC, 2004; European Commission, 2006; MHPRC, 2013, respectively) and also 0.05 mg/Kg, 0.19, 0.03 mg/Kg, 0.03 mg/Kg, 0.42 mg/Kg and 0.024 mg/Kg in fish muscle found in Kumadugu Yobe Nigeria, Warri river Nigeria, Okumeshi river Nigeria, Fresh water Lake India and Red Volter river Ghana respectively (Jafiya *et al.,* 2022; Ezemonye and Egbroge, 1992; Ekeanyanwu *et al*., 2010; Mokhtar *et al*., 2010; Asante *et al*., 2014). The elevated concentration of cadmium (Cd) observed in smoked fish suggests that the smoking process may contribute to increased heavy metal accumulation. This observation aligns with findings by Igwegbe *et al*. (2015), who reported that smoking can enhance the concentration of heavy metals in fish products. The implications of these results are concerning, given that Cd has no known function in the human body. Once absorbed, Cd is transported via the bloodstream and tends to accumulate in the liver and kidneys. It exerts significant toxic effects on renal function, as well as on the respiratory and skeletal systems. Cadmium (Cd) is further acknowledged for its cancer-inducing properties and is officially designated as a human carcinogen (Oloruntoba *et al*., 2017).

## Determination of chromium

The chromium values recorded in this study were range from 0.65 - 0.80 mg/Kg found to be similar ($p<0.05$) with each other though slightly higher values were recorded in African lungfish and lower values were recorded in catfish and remained under the regulatory limits of 3.0 mg/kg and 2.0 mg/kg (FAO/WHO, 2011; NAFDAC 2004) respectively but higher than maximum tolerance range of 0.1 - 1.0 mg/Kg set by FAO (1983). This observation might be due to farmers' activities, such as fertiliser, pesticide, insecticide and herbicide application, which could increase environmental levels of heavy metals (ATSDR, 2012). The results are consistent with the findings of BORMLS (2008). The excessive level of chromium can hamper the function of DNA and can cause genotoxicity (Cohen *et al*., 1993). Chromium is internationally recognised as one of the most carcinogenic metals. In the same vein, the mean concentrations were below the permissible limit set by NAFDAC (2004). This observation aligns with the findings of Etim *et al*. (2013), who reported that exposure to chromium (Cr)-containing substances may compromise immune function and contribute to the development of conditions such as lung cancer, gastric ulcers, and hepatic injury. Prolonged exposure to Cr has been associated with detrimental effects on renal, hepatic, and neural tissues. Moreover, several chromium compounds have been identified as carcinogens due to their established cancer-causing potential.

### Determination of arsenic

The results recorded in this study were range from 0.69 - 0.95 mg/Kg though insignificant ($p<0.05$) different were observed among all species slightly higher value was found in African lungfish and lower value was found in catfish and all values were higher than 0.03 - 0.24 mg/Kg in fish gills and 0.20 - 0.38 mg/Kg in fish muscle (Jafiya *et al*., 2022) as well as 0.10 mg/Kg, 0.2 mg/Kg and 0.50 mg/Kg set as upper limits by MHPRIC (2013), FAO/WHO (2011) and NAFDAC (2004), respectively, but lower than 2.0 mg/Kg set as upper limit by FSANZ (2019), and also lower than 3.15 mg/Kg and 4.27 mg/Kg recorded in fishes found in Cika-Koshi reservoir Nigeria and Bangshi river Dhaka Bangladesh respectively (Rahman *et al.,* 2012). Consumption of arsenic (As)-contaminated food has been linked to a range of adverse health effects, including hematuria, alopecia, gastrointestinal disturbances, seizures, emesis, and diarrhoea. Additionally, arsenic exposure is known to impair the function of vital organs such as the skin, liver, lungs, and kidneys, with severe cases potentially resulting in coma or fatality (Jan *et al*., 2015).

### Determination of mercury

Mercury (Hg) was not detected in all three fish samples, which agreed with the work of Shamshad *et al* (2009), who reported that the average Hg content in fish species in Bangladesh was lower than the quantification limit for the analytical methods (0.03 mg/Kg), and also Ozuni *et al*. (2011) did not detect Hg in *S. aurata* and O*. mykiss* species. But contrary to the work of Djedjibegovic *et al.* (2020), who recorded a range of 0.114 - 0.309 mg/Kg in Atlantic bluefin tuna steak species and a range of 0.12 - 0.16 mg/Kg in D. labrax species (Ozuni *et al*., 2011). Mercury (Hg) is a highly harmful substance that originates from both natural and human-induced actions in aquatic settings. Consumption of food tainted with Hg can result in symptoms such as stomach discomfort, shivering, fatigue, cough, difficulty breathing, kidney failure, loss of appetite, and may resemble viral infections (Jan *et al.*, 2015).

### Conclusion

The results show that heavy metals were detected in all fish species except mercury, with African lungfish and tilapia showing higher lead levels, while cadmium was highest in tilapia, indicating possible heavy metal contamination in the study area and the need for regular monitoring to protect consumer health.

## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

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