

Human risk Assessment of heavy metals in fishes from Dadin-Kowa Dam, Yamaltu, Gombe State, Nigeria

Afusat Ibrahim

University of Maiduguri

Abdulrahman Mohammed

`abdulrahmanm@unimaid.edu.ng`

University of Maiduguri

Dawud Jidda

University of Maiduguri

Adamu Saidu Saleh

University of Maiduguri

Mohammed Sani

University of Maiduguri

Abubakar Sadiq Muhammad

University of Maiduguri

Hassan Ismail

University of Maiduguri

Abubakar Usman

University of Maiduguri

Falmata Ali Mustapha

National Institute for Freshwater Fisheries Research, Maiduguri Zonal Office

Abdulyekeen Olawale Tijjani

University of Maiduguri

Nuhu Bala Adamu

University of Maiduguri

Article

Keywords: Fish, Dadin-Kowa Dam, Heavy metals, Health risk, Maximum Allowable Limits

Posted Date: February 25th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-8338814/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.
[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

This study was designed to detect occurrence and levels of concentration of Arsenic (As), Lead (Pb) and Cadmium (Cd), and their relationship with species, age and sex of fish as well as health risk to man. A total of 201 fishes were sampled using systematic random sampling from Dadin-Kowa Dam, Yamaltu Deba Local Government Area of Gombe State, Nigeria. Heavy metals (HMs) concentrations were determined by Atomic Absorption Spectrophotometer. HMs frequency of occurrence observed was 37% in the muscle of the fish samples analyzed with As recording the highest 36%, followed by Pb 1% and then Cd 0%. Likewise, the percentage proportion for As among all the positive samples was 97% and that of Pb was 3%. The mean concentration for As (0.0216 ± 0.041) and Pb (0.0002 ± 0.002) were significantly ($p < 0.0001$) lower than their respective Maximum Allowable Limits (MAL) values of 1 mg/kg for As and 0.5 mg/kg for Pb. Unlike sex, there was a significant association ($p = 0.002$) between species and As contamination with *L. niloticus* recording the highest frequency of occurrence (57%), followed by 54%, 29% and 25% for *O. niloticus*, *C. gariepinus* and *S. membranaceus* respectively. Young fishes had significantly ($p < 0.05$) higher levels (0.0317 ± 0.052) and frequency of occurrence 35 (49%) compared to adult (0.0160 ± 0.033) and 37 (29%) respectively. The non-carcinogenic and carcinogenic risk values of As and Pb were estimated to be less than one; thus, fish from the dam is safe and harmless for human consumption.

INTRODUCTION

Heavy metals (HMs) are widespread environmental pollutants that affect the physical environment and living organisms within the earth's atmospheric system (Jajere *et al.*, 2023). There are two types of HMs: non-essential metals and essential metals (Adamu *et al.*, 2023). The biological system depends heavily on the essential elements (manganese, copper, and nickel). The non-essential elements, lead, cadmium, and mercury can be hazardous and poisonous to living things, even at low concentrations when consumed over an extended period (Yang *et al.*, 2021; Su *et al.*, 2023; Blankson *et al.*, 2024). Unfortunately, these substances are abundant, occurring naturally as volcanic ash or artificially created from human activities like agriculture, mining, excavations and construction (Goher *et al.*, 2019). Runoff from these sites constitutes the major way through which HMs enter water bodies (Elkady *et al.*, 2015) and damages its quality (Brack *et al.*, 2017). Long-term persistence of HM in soil and water increases their chances of exposure, thus, presenting a serious risk to the health of human and animals (Konduracka, 2019; Aladaileh *et al.*, 2020).

Fish has so many nutritional and medicinal benefits, and its consumption has increased worldwide in recent years because they provide vitamins, minerals, and unsaturated fats to their consumers (Sroy *et al.*, 2021; Luczynska *et al.*, 2022; Kalipci *et al.*, 2023). Moreover, it is globally regarded as the most affordable source of animal-based protein (Obiero *et al.*, 2019; Maulu *et al.*, 2021). In Nigeria, fish is consumed more frequently than other sources of animal protein like beef, mutton and chicken (Jajere *et al.*, 2023). Therefore, in the food industry today ensuring the safety and quality of fish and fish-derived products remains a major public health concern. Once HMs contaminate water they are directly

absorbed by fish through their gills and/or skin, as well as by consuming contaminated feed and particles present in the water (Mziray and Kimirei, 2016). The non-degradable nature of HMs and their tendency to bio-accumulate in living organisms increase their concentration in fishes used as food for humans. Therefore, the presence of HMs in fish can cause serious health issues in people, causing kidney failure, hepatic damage, cardiovascular disorders, and even mortality (Tokath and Varol, 2021; Akila *et al.*, 2022; Biswas *et al.*, 2023). Concerns on these health impacts resulting from exposure of food including seafoods and fish containing high levels of HMs, led to establishment of maximum allowable limits (MAL) to these substances by World Health Organization (WHO) (WHO, 2011). Any HM found in food meant for human consumption with concentration above MAL is considered potentially toxic (Makedonsky *et al.*, 2017).

Despite several studies reporting the occurrence of HMs in fish in many regions in Nigeria (Santuraki *et al.*, 2021; Adamu *et al.*, 2023; Jajere *et al.*, 2023), there are recommendations of regular monitoring to update and expand the scope of knowledge on HMs at various intervals and locations. Against this background, the present study was undertaken to quantify the concentrations of arsenic (As), lead (Pb) and cadmium (Cd), and their relationship with species, age and sex of fish harvested from Dadin-Kowa Dam, Yamaltu Deba Local Government Area of Gombe State and compared the observed levels with established MALs. Furthermore, the study evaluated the potential public health implications of consuming fish from the dam.

MATERIALS AND METHODS

Study area

The study was conducted at the Dadin-Kowa Dam located in Yamaltu Deba Local Government Area (LGA) of Gombe State between latitude 10°18'N and longitudes 11°30'E and 11°32'E of the equator. The Dam can hold 800 million m³ of water and has a surface area of 300 km². In addition to serving as a possible fish source, the Dam was put into service in 1984 with the intention of supplying irrigation and energy for the upcoming sugar plantation project. The six-month dry season and the subsequent six-month rainy season are the two main features of the Dam's climate. The dam is a multifunctional project with the following intended uses: flood control, irrigation, industrial and residential supplies.

Study Design and Sample Collection

A cross-sectional study design was employed. Fish samples consisted of freshly dead specimens purchased directly from local fishermen's early morning catches at Dadin Kowa Dam immediately after capture. Only fish without visible signs of spoilage were selected. The samples were transported on ice to the laboratory, where muscle tissues were dissected and analysed for heavy metal concentrations. The laboratory is in the Fishery Department at College of Horticulture, Dadin-Kowa, Yamaltu Deba (LGA), Gombe State where sorting and classification of samples into four different species namely: *Clarias gariepinus*, *Oreochromis niloticus*, *Synodontis membranaceus* and *Lates niloticus* were undertaken. A total of 201 fishes were collected using systematic random sampling among the sorted fish type collected for

the study. Samples were collected weekly for a period of 20 weeks, spanning four months. The collected fish samples were then weighed, and their sex determined by examination of their fins size and eye coloration and thereafter appropriately labeled. The samples were then stored at 4°C before further procedure.

Sample Preparation, Processing and Digestion

After being removed from the fridge and allowed to defrost to room temperature, the fish samples were rinsed in distilled water. Each fish's muscle was then removed using a stainless-steel instrument, and 2g of the muscle was digested using a 3:1 ratio of nitric acid and hydrogen peroxide. The mixture was then heated until it solidified. After the sample was fully digested, it was cooled to an ambient temperature, and its contents were filtered, labeled, and kept in a refrigerator at -4°C until heavy metals analysis was done. The As, Pb and Cd content of the digested fish muscle was detected and quantified as absorbance by Atomic Absorption Spectrophotometer (AAS Buck Scientific Model 210vvp, USA) and is measured against standards.

Sex determination and Gonadal analysis

Sex identification was based on secondary sexual characteristics unique to each species. In *Oreochromis niloticus*, males were identified by pointed genital papillae and brighter breeding coloration, while females exhibited rounded papillae and duller coloration. For *Clarias gariepinus* and *Synodontis membranaceus*, males had narrow, elongated papillae located posterior to the anus, whereas females had broader papillae with visible oviduct openings. Due to weak external dimorphism in *Lates niloticus*, morphometric parameters such as body depth and head length were used cautiously, but definitive sex determination was conducted through gonadal inspection. Fish were dissected along the ventral midline, and gonads were examined macroscopically to determine sex and maturity stage based on shape, colour, size, and vascularization, following the maturity scales of West (1990) and Brown-Peterson *et al.* (2011).

Age determination

Age estimation was conducted using species-specific calcified structures: sagittal otoliths for *Lates niloticus* and *Oreochromis niloticus*, and pectoral fin spines for *Clarias gariepinus* and *Synodontis membranaceus*, following established protocols (Campana, 2001; Panfili *et al.*, 2002). Otoliths were extracted via a transverse cranial incision, cleaned, air-dried, and stored in labelled vials. Fin spines were excised, cleaned of tissue, and stored dry for sectioning.

Health Risk Assessment

Human health risks associated with dietary exposure to As, Pb and Cd through fish consumption were evaluated using the following indices: Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI) and Target Cancer Risk in accordance with United States Environmental Protection Agency (USEPA, 2021) guidelines.

Estimated Daily Intake (EDI)

EDI was calculated using the equation:

$$EDI = [C \times QFC] / BW$$

Where C = mean concentration of As or Pb or Cd (mg/kg), QFC = daily fish consumption rate (0.0345 kg/person/day), BW = body weight (30 kg for children aged 0-17 years; 60 kg for adults $\geq$ 18 years). Results were compared with FAO/WHO provisional tolerable daily intakes (PTDI) values of 0.003 mg/kg/day for As, 0.002 mg/kg/day for Pb and 0.001 mg/kg/day for Cd (FAO/WHO, 2011).

Target Hazard Quotient (THQ)

THQ was estimated using:

$$THQ = [(Ef \times Ed \times QFC \times C) / (RfD \times BW \times Et)] \times 10^{-3}$$

where, Ef = exposure frequency (365 days/year), Ed = exposure duration (55 years; Nigerian life expectancy), RfD = oral reference dose (0.003 mg/kg/day for As, 0.004 mg/kg/day for Pb, and 0.001 mg/kg/day for Cd), Et = exposure time (Ef $\times$ Ed). A THQ value < 1 indicates negligible risk, while THQ $\geq$ 1 suggests potential non-carcinogenic health effects.

Hazard Index (HI)

The combined non-carcinogenic risk was assessed as the sum of the individual THQs:

$$HI = THQ_{As} + THQ_{Pb} + THQ_{Cd}$$

An HI < 1 indicates minimal risk, while HI $\geq$ 1 indicates possible adverse health effects.

Target Cancer Risk (TCR)

Carcinogenic risk was evaluated using:

$$TCR = CSF \times EDI$$

Where CSF (cancer slope factor) values were 1.5 mg/kg/day for As, 0.008 mg/kg/day for Pb, and 0.38 mg/kg/day for Cd (USEPA, 2021). A TCR > 1 denotes potential carcinogenic risk.

Data Analysis

Data was analyzed using the IBM[®] SPSS Statistics version 20 (IBM Corp., Armonk, NY). Results were summarized in tables and percentages. Association between the HM levels and fish characteristics (species, sex and age) were evaluated using Chi-square tests. Differences in mean concentrations were

assessed using independent t-test and one-way ANOVA. A p-value < 0.05 was considered statistically significant.

RESULTS

Detection and levels of HMs in the Muscle tissues of fish

Approximately 37% of the 201 fish samples analyzed were found to be contaminated with at least one of the following two different HMs: As or Pb. However, none of the fish sampled were found to have Cd in their muscles. The values of As concentration in the muscle tissues ranged from 0.0000 to 0.2200 mg/kg with a mean concentration of 0.0216 ± 0.041 , while that of Pb ranged from 0.0000 to 0.0200 mg/kg with a mean concentration of 0.0002 ± 0.002 as was shown in Table 1. In comparison with WHO MAL, the mean concentration for As obtained (0.0216 ± 0.041) was significantly ($t_{(200)} = -337.347, p < 0.0001$) lower than the MAL value for As of 1 mg/kg. Similarly, the mean for Pb obtained (0.0002 ± 0.002) was significantly ($t_{(200)} = -3560.710, p < 0.0001$) lower than the MAL value for Pb of 0.5 mg/kg. In terms of frequency of occurrence ($\approx$ percentage positive), As recorded the highest 72 (36%), followed by Pb 2 (1%) and none for Cd 0 (0%). Likewise, the percentage proportion for As among all the positive samples was 97% and that of Pb was 3% (Table 1).

Table 1: HMs (mg/kg) in the fish muscle tissues (n=201) from Dadin-Kowa Damx

HMs	WHO MAL	Mean $\pm$ SD	Range	Positives (%) samples	Percentage contribution
As	1*	0.0216 ± 0.041	ND – 0.2200	72 (35.8)	97.3
Pb	0.5*	0.0002 ± 0.002	ND – 0.0200	2 (0.99)	2.7
Cd	0.05	-	ND	ND	ND

As, Arsenic; Pb, lead; Cd, Cadmium; MAL, Maximum allowable limits set by WHO; * p – value < 0.0001; SD, Standard deviation; ND, Not determined = 0.0000; %, percent

Mean concentration levels and Standard deviation (mg/kg) of HMs in the Muscle tissues in relation to different parameters (species, sex and age)

HMs levels and frequencies were studied in relation to the species, sex and age of the fish sampled to find out correlation of these parameters with contamination levels in fish muscle (Table 2). The study of HMs with respect to species shows that the mean concentration of As among the different fish species sampled were 0.0192 ± 0.037 , 0.0254 ± 0.044 , 0.0182 ± 0.043 and 0.0351 ± 0.047 for *C. gariepinus*, *O. niloticus*, *S. membranaceus* and *L. niloticus* respectively. Pb was detected only in *S. membranaceus* with a mean concentration of 0.0007 ± 0.004 , however, none of the sampled fish species were found to have Cd

in their muscles. Analysis of variance (ANOVA) didn't show any significant difference in As ($f=0.872$, $p=0.456$) and Pb ($f=1.588$, $p=0.193$) concentration among four fish species. In terms of presence or absence of HMs, there was a significant association ($\chi^2 = 14.772$, $df = 3$, $p = 0.002$) between species and As contamination with *L. niloticus* recording the highest frequency of occurrence ($\approx$ percentage positive) 8 (57%), followed by 27 (54%), 22 (29%) and 15 (25%) for *O. niloticus*, *C. gariepinus* and *S. membranaceus* respectively. As far as sex is concerned, the mean concentration levels of As was higher in female (0.0229 ± 0.048) compared to that of male (0.0205 ± 0.034), but this difference was not statistically significant ($t_{(199)} = 0.414$, $p = 0.679$). Likewise, there was no significant difference ($\chi^2 = 2.402$, $df = 1$, $p = 0.121$) between occurrence of As in female 27 (31%) and male 40 (41%) ($\chi^2 = 2.402$, $df = 1$, $p = 0.121$). Pb was detected only in male with 2 (1.8%) frequency of occurrence and a mean concentration of 0.0004 ± 0.003 , however, none of the sexes were found to have Cd in their muscles. Young fishes had a significantly higher ($t_{(101.707)} = 2.318$, $p = 0.022$) Mean concentration levels of 0.0317 ± 0.052 compared to adult with 0.0160 ± 0.033 . Similarly, there was a significant difference ($\chi^2 = 8.670$, $df = 1$, $p = 0.003$) between occurrence of As in young 35 (49%) and adult 37 (29%). Here Pb was detected only in adult with 2 (1%) frequency of occurrence and a mean concentration of 0.0003 ± 0.002 , however, none of the ages were found to have Cd in their muscles.

Table 2: Mean concentration levels and Standard deviation (mg/kg) of HMs in fish muscle in relation to different parameters (species, sex and age).

Parameters	Mean Concentrations $\pm$ SD (mg/kg)		
	As	Pb	Cd
Species			
<i>C. gariepinus</i> (n=77)	0.0192 $\pm$ 0.037	ND	ND
<i>F</i> (%)	22 (28.6)	-	-
<i>O. niloticus</i> (n=50)	0.0254 $\pm$ 0.044	ND	ND
<i>F</i> (%)	27 (54.0)	-	-
<i>S. membranaceus</i> (n=60)	0.0182 $\pm$ 0.043	0.0007 $\pm$ 0.004	ND
<i>F</i> (%)	15 (25.0)	2 (3.3)	-
<i>L. niloticus</i> (n=14)	0.0351 $\pm$ 0.047	ND	ND
<i>F</i> (%)	8 (57.1)	-	-
Sex			
Female (n=90)	0.0229 $\pm$ 0.048	ND	ND
<i>F</i> (%)	27 (30.0)	-	-
Male (n=111)	0.0205 $\pm$ 0.034	0.0004 $\pm$ 0.003	ND
<i>F</i> (%)	45 (40.5)	2 (1.8)	-
Age			
Young (n=71)	0.0317* $\pm$ 0.052	ND	ND
<i>F</i> (%)	35* (49.3)	-	-
Adult (n=130)	0.0160 $\pm$ 0.033	0.0003 $\pm$ 0.002	ND
<i>F</i> (%)	37 (28.5)	2 (1.0)	-

n, sample size; * p – value < 0.05

Health risk assessment of HMs (As, Pb and Cd) specific to children and adult consumers of fish

The Health Risk Assessment of AS, Pb and Cd specific to children and adult consumers of fish caught from Dadin-Kowa Dam is shown in Table 3 and 4. In children the calculated EDI values of As (2.5E-05) and Pb (2.3E-07) were higher compared to their respective adult values of 1.2E-05 and 1.2E-07, however, these values were lower than the WHO-recommended PTDI (Table 3). Similarly, the TCR values of 3.7E-05 for As and 1.8E-09 for Pb in children were higher compared to their 1.9E-05 and 9.2E-10 in adult respectively and were lower than the TCR $\geq$ 1= carcinogenic risk (Table 3).

Table 3: Estimated daily intake (EDI) and target cancer risk (TCR) of HMs specific to children and adult consumers of fish caught (n=201) from Dadin-Kowa Dam, Gombe State, Nigeria.

HMs	Range	Mean	EDI ^a			TCR	
			Children	Adult	PTDI	Children	Adult
As	ND – 0.2200	0.0216	2.5E-05	1.2E-05	3.0E-03	3.7E-05	1.9E-05
Pb	ND – 0.0200	0.0002	2.3E-07	1.2E-07	2.0E-03	1.8E-09	9.2E-10
Cd	ND	-	-	-	1.0E-03	-	-

^a EDI Unit, mg/kg bw/day, bw, body weight; PTDI, provisional tolerable daily intakes

The THQ values of As (8.3E-06) and Pb (5.8E-08) in children were two times more compared to 4.1E-06 and 2.9E-08 of their respective adult values and were < 1 signaling little or no non-carcinogenic health risk (Table 4). The combined effect of As and Pb (HI) is more than two times in children (8.4E-06) compared to that in adult (4.1E-06), although is < 1 indicating no non-carcinogenic adverse health effects (Table 4).

Table 4: Target hazard quotient (THQ) and hazard index (HI) of HMs specific to children and adult consumers of fish caught (n=201) from Dadin-Kowa Dam, Gombe State, Nigeria.

THQ						HI	
As		Pb		Cd			
Children	Adult	Children	Adult	Children	Adult	Children	Adult
8.3E-06	4.1E-06	5.8E-08	2.9E-08	-	-	8.4E-06	4.1E-06

DISCUSSION

In this study, more than one-third of the analysed fish samples were contaminated with non-essential HMs, primarily As and Pb. The presence of these elements indicated contamination of the source - Dadin-Kowa Dam, likely originating from human activities such as agriculture, cement production, construction, and mining. This is consistent with Yedjou *et al.* (2016), who attributed HM contamination largely to anthropogenic activities. Runoff from environments where such activities were carried out often contaminates aquatic ecosystems, where pollutants are subsequently bioaccumulated in fish tissues (Awad *et al.*, 2024). Consequently, human populations consuming contaminated fish are at elevated risk of HM toxicity and its associated adverse health outcomes (Suryapratap and Rahul, 2024). In this study, As accounted for more than 97% of all HM contamination, whereas Pb contributed less than 3%, and cadmium (Cd) was undetected. The predominance of As observed may be linked to agrochemical runoff—particularly from fertilizers, herbicides, and pesticides—or flooding from

contaminated agricultural fields surrounding the dam (Njoga *et al.*, 2021; Suryapratap and Rahul, 2024). Additionally, several reports have shown that As occurs naturally in groundwater in many countries and is highly toxic in its inorganic form (Ganie *et al.*, 2023; Kuivenhoven and Mason, 2023). Although the mean concentrations of As and Pb in fish muscle were significantly lower than their respective MALs of 1 mg/kg for As and 0.5 mg/kg for Pb, As levels were consistently higher than Pb. The average As concentration reported here were lower than those observed in Canada and Nigeria by Tanamal *et al.* (2021) and Adamu *et al.* (2023). Similarly, Pb levels in the present study were lower than those previously documented in Damaturu (0.09–0.40 mg/kg) and Maiduguri (0.27–0.39 mg/kg) (Jajere *et al.*, 2023). These variations likely reflect differences in environmental pollution status and the variability of As and Pb content in fish prey across aquatic ecosystems (Adamu *et al.*, 2023). Despite relatively low concentrations, chronic dietary exposure to As and Pb has been associated with severe health effects, including skin lesions, renal dysfunction, hepatic damage, cardiovascular disease, diabetes, cancer, and mortality (Mazumder, 2015).

Although no statistically significant differences were observed in HM concentrations among the four species studied, *L. niloticus* recorded the highest mean concentration for As, followed by *O. niloticus*, *C. gariepinus* and *S. membranaceus*. Interestingly, Pb was detected only in *S. membranaceus*, which may reflect its close association with sediments, as previously noted by Biotech-Asia (2016). However, there was a significant association between the occurrence of AS and species. All species have the same chances of exposure to these HMs, where they explore and scavenge freely in the dam thereby predisposing themselves to accessing stagnant feed and particles from where contamination with As and Pb may likely occur. Although the chances of exposure to contaminations are similar, it also depends on the variability of As and Pb in the prey available for the fish in the dam.

Regarding sex, the highest mean concentration of As was observed in female fish, though its frequency of occurrence was higher in males. These differences, while not statistically significant, may be explained by feeding behavior, as few female fish ingest particles with higher As content, while males, being more active foragers, may have greater exposure to environmental contaminants. This finding aligns with Varol *et al.* (2025), who reported higher As concentrations in females, although Pb was detected exclusively in males. Overall, sex-related differences in HM accumulation appear negligible, consistent with earlier reports (Adeogun *et al.*, 2020; Outa *et al.*, 2020; Hasanein *et al.*, 2022; Awad *et al.*, 2024).

In respect to age of fish sampled, the mean concentration and frequency of occurrence of As were significantly higher in young than adult fishes. Moreover, within the age groups preference of occurrence (62.9% for young and 62.2% for adult) was in male. The greater susceptibility of younger fish may be attributed to their rapid growth rates and increased nutritional demands, which may predispose them to higher ingestion of arsenic-laden particles or sediments. Pb, by contrast, was detected only in adult males, in line with previous findings that Pb concentrations tend to increase with age and body size (Biotech-Asia, 2016). Nonetheless, As occurrence was variable across age classes, often lower in adults

The health risk assessment revealed that EDI, THQ, HI, and TCR values for both As and Pb were below their respective threshold limits, indicating minimal risk of adverse health effects from consuming fish harvested from Dadin-Kowa Dam. Comparable findings were reported by Adamu *et al.* (2023) and Jajere *et al.* (2023).

Conclusion

Non-essential HMs, As and Pb were detected in fish at a concentration below their MALs. Age was significantly associated with As contamination, while sex and species exhibited no consistent influence. Health risk assessments indicated that fish consumption from this dam currently poses no significant health hazard. Nevertheless, given the bioaccumulative nature of HMs and the potential for chronic exposure, continuous monitoring of HM contamination in fish is strongly recommended. Public awareness campaigns should also be intensified to educate consumers on the potential risks associated with HM exposure and the need for periodic health screening to detect early signs of metal toxicity. Limitations of this work include non-consideration of possible seasonal variation in exposure to heavy metals.

Declarations

Acknowledgements

The authors of this article wish to acknowledge the technical and administrative support received from Fishery Department at College of Horticulture, Dadin-Kowa, Yamaltu Deba (LGA), Gombe State as well as Dadin-Kowa Dam management and fish catchers.

Conflict of Interest

The authors have no conflict of interest to declare.

Animal Ethics declaration

Not applicable'.

Funding

There was no funding available for this research. It was out-of-pocket spending with institutional support of equipment and reagents.

Authors' Contribution

AM, DJ and AI contributed to the study concept and design. Material preparation, data collection and analysis were performed by AM, DJ, AI, ASS, AU, FAM, HI, and SM. The draft manuscript was prepared by

AM, DJ, AOT, and AI. AM, DJ, ASS, NBA and SM read, corrected and approved the manuscript for publication. All authors have read and approved the final manuscript.

Statements and Declaration

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors

Data Availability Statement

All data generated or analysed during this study are included in this manuscript and its supplementary information file.

References

1. Adamu, S. G., Saidu, A. S., Adamu, A. I., Sadiq, M. A., Jajere, S. M., Mohammed, S., Tijjani, A. O., Musa, H. I., Usman, U. B. and Thaddeus, A. L. (2023). Detection, distribution, and health risk assessment of heavy metals in wild catfish sold in Maiduguri Metropolis of Borno State, Northeastern Nigeria. *Nigerian Veterinary Journal*, 44(2): 48-58.
2. Adeogun, A. O., Ibor, O. R., Omiwole, R., Chukwuka, A. V., Adewale, A. H., Kumuyi, O. and Arkwe, A. (2020). Sex-differences in physiological and oxidative stress responses and heavy metals burden in the black jaw tilapia, *Sarotherodon melanotheron* from a tropical freshwater dam (Nigeria). *Comparative Biochemistry and Physiology part C Toxicology & Pharmacology*, 229(3): 108676. Doi:10.1016/j.cbpc.2019.108676
3. Akila, M., Anbalagan, S., Lakshmisri, N. M., Janaki, V., Ramesh, T., Jancy-Merlin, R. and Kamala-Kannan, S. (2022). Heavy metal accumulation in selected fish species from Pulicat Lake, India, and health risk assessment. *Environmental Technology Innovation*, 27: 102744.
4. Aladaileh, S. H., Khafaga, A. F., Abd El-Hack, M. A., Al-Gabri, N. A., Abukhalil, M. H., Alfwuaires, M. A., Bin-Juma, M., Alkahtani, S., Abdel-Diam, M. M., Aleya, L. and Abdednour, S. (2020). Spirulina platensis ameliorates the sub chronic toxicities of lead in rabbits via anti-oxidative, anti-inflammatory and immune stimulatory properties. *Science of the Total Environment*, 701: 134879. Doi: 10.1016/j.scitotenv.2019.134879
5. Awad, S. T., Hemada, S. A., El Nahas, A. F., Abbas, E. M., Abdel-Razek, M. A. S., Ismail, M., Mamoon, A. and Ali, F. S. (2024). Gender-specific response in gene expression of Nile tilapia (*Oreochromis niloticus*) to heavy metal pollution in different aquatic habitats. *Scientific reports*, 14(1): 14671. <https://doi.org/10.1038/s41598-024-64300-4>
6. Biotech-Asia (2016). Heavy metals in water and *Synodontis membranaceus* near a cement factory (Nkalagu, Nigeria). *Journal of Applied & Natural Science* (Biotech-Asia online article). biotech-asia.org
7. Biswas, A., Kanon, K. F., Rahman, M. A., Alam, M. S., Ghosh, S. and Farid, M. A. (2023). Assessment of human health hazard associated with heavy metal accumulation in popular freshwater, coastal

- and marine fishes from south-west region Bangladesh. *Heliyon*, 9: e20514
8. Blankson, E. R., Ohene-Obeng, N. K., Awuah, B. A., Oduro, D., Ewool, J., and Gbogbo, F. (2024). Heavy metal bioaccumulation in highly consumed pelagic and benthic fish and associated health risk. *Biological Trace Element Research*, 202: 3781-3788.
 9. Brack, W., Dulio, V., Agerstrand, M., Allan, I., Altenburger, R., Brinkmann, M., Bunke, D., Burgess, M. R., Cousins, I., Escher, B. I., Hernandez, P. J. et al. (2017). Towards the review of the European Union Water Framework Directive: Recommendations for more efficient assessment and management of chemical contamination in European surface water resources. *Science of Total Environment*, 576: 720-737.
 10. Brown-Peterson, N. J., Wyanski, D. M., Saborido-Rey, F., Macewicz, B. J., & Lowerre-Barbieri, S. K. (2011). A standardized terminology for describing reproductive development in fishes. *Marine and Coastal Fisheries*, 3(1), 52–70.
 11. Campana, S. E. (2001). Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology*, 59(2), 197–242.
 12. Elkady, A. A., Sweet, S. T., Wade, T. L. and Klein, A. G. (2015). Distribution and assessment of heavy metals in the aquatic environment of Lake Manzala, Egypt. *Ecological Indicators*, 58: 445-457.
 13. Food and Agriculture Organization; World Health Organization (FAO/WHO) (2011). Evaluation of certain food additives and contaminants (seventy-third report of the joint FAO/WHO expert committee on food additives); WHO technical report series 960 held in Geneva, Switzerland in 2011; World Health Organization: Geneva Switzerland.
 14. Ganie, S. Y., Javaid, D., Hajam, Y. A. and Reshi, M. S. (2023). Arsenic toxicity: Sources, pathophysiology and mechanism. *Toxicology Research*, 13(1):tfat111. Doi:10.1093/toxres/tfad111. PMID:38178998: PMCID: PMC10762673.
 15. Goher, M. E., Ali, M. H. H. and El-Sayed, S. M. (2019). Heavy metals contents in Nasser Lake and the Nile River, Egypt: An overview. *Egyptian Journal of Aquatic Research*, 45: 301-312.
 16. Hasanein, S. S., Mourad, M. H. and Haredi, A. M. M. (2022). Health-risk assessment of heavy metals to human health through the consumption of tilapia spp and catfish caught from Lake Mariut, Egypt. *Heliyon*, 8(10): e09807. ScienceDirect
 17. Jajere, S. M., Jidda, D., Goni, M. D., Sadiq, M. A., Adamu, S. G., Mohammed, S., Saidu, A. S., Malah, M., Musa, H. I. and Tijjani, A. O. (2023). Health risk assessment of heavy metals in imported frozen fish sold in Damaturu and Maiduguri fish markets, Nigeria. *Sahel Journal of Veterinary Sciences*, 20(3): 38-45.
 18. Kalipci, E., Cüce, H., Ustaoglu, F., Dereli, M. A. and Türkmen, M. (2023). Toxicological health risk analysis of hazardous trace elements accumulation in the edible fish species of the Black Sea in Türkiye using multivariate statistical and spatial assessment. *Environmental Toxicology and Pharmacology*, 97: 104028.
 19. Konduracka, E. (2021). A link between environmental pollution and civilization disorder: a mini review. *Reviews on Environmental Health*, 34(3): 227-233.

20. Kuivenhoven, M. and Mason, K. (2023). Arsenic toxicity. Accessible In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing: 2025 Jan-. PMID: 31082169.
21. Luczynska, J., Pietrzak-Fiecko, R., Purkiewicz, A. and Luczynski, M. J. (2022). Assessment of fish quality based on the content of heavy metals. *International journal of environmental Research and Public Health*, 19: 2307
22. Makedonsky, L., Peycheva, K. and Stancheva, M. (2017). Determination of heavy metals in selected black sea fish species. *Food Control*, 72: 313-318.
23. Maulu, S., Nawanzi, K., Abdel-Tawwab, M. and Khalil, H. S. (2021). Fish nutrition value as an approach to children's nutrition. *Frontiers in Nutrition*, 8: 780844 PMID 34977125 doi: 10.3389/fnut.2021.780844
24. Mazumder, D. N. G. (2015). Health effects of chronic arsenic toxicity. In S.J.S Flora, Toxicology. Elsevier Inc. USA. Doi: 137. Doi.org/10.1016/B978-0-12-418688-0.00006-X.
25. Mziray, P. and Kimirei, I. A. (2016). Bioaccumulation of heavy metals in marine fishes (*Siganus sutor*, *Lethrinus harak*, and *Rastrelliger kanagurta*) from Dar es Salaam Tanzania. *Regional Studies in Marine Science*, 7: 72-80.
26. Njoga, E. O., Ezenduka, E. V., Ogbodo, C. G., Ogbonna, C. U., Jaja, I. F., Ofomatah, A. C. and Okpala, C. O. (2021). Detection, distribution and health risk assessment of toxic heavy metals/metalloids, Arsenic, Cadmium and Lead in Goat carcasses processed for human consumption in South-Eastern Nigeria. *Foods*, 10: 798.
27. Obiero, K., Meulenbroek, P., Drexler, S., Dagne, A., Akoll, P., Odong, R., Kaunda-Arara, B. And Waidbacher, H. (2019). The contribution of fish to food and nutrition security in Eastern Africa: Emerging trends and future outlooks. *Sustainability*, 11(6): 1636. <https://doi.org/10.3390/su11061636>
28. Outa, J. O., Kowenje, C. O., Avenan-Oldewage, A. And Jirsa, F. (2020). Trace elements in Crustaceans, Mollusks and fish in the Kenyan part of Lake Victoria: Bioaccumulation, bioindication and health risk analysis. *Archives of Environmental Contamination and Toxicology*, 78: 589-603
29. Panfili, J., de Pontual, H., Troadec, H., & Wright, P. J. (Eds.). (2002). Manual of fish sclerochronology. Ifremer–IRD Co-edition.
30. Santuraki, A. H., Babayo, A. U., Abdu Zakari and Abdulkadir, A. G. (2021). Levels Of Heavy Metals In Some Selected Fish Of River Gongola Basin, Its Dam and Dadinkowa Dam, Gombe State Nigeria. *FUDMA Journal of Sciences*, 5(2): 498–510. DOI: <https://doi.org/10.33003/fjs-2021-0502-644>
31. Sroy, S., Arnaud, E., Servent, A., In, S. and Avallone, S. (2021). Nutritional benefits and heavy metal contents of freshwater fish species from Tonle Sap Lake with SAIN and LIM nutritional score. *Journal of food composition and analysis*, 96: 103731.
32. Su, Q., Wang, C., Huang, L., Shahab, A., He, J., Cheng, Y., Xu, H., Yan, Y. and Kang, B. (2023). Levels and health risk assessment of potential toxic elements in three dominant fish species from the Beibu Gulf South China Sea. *Marine Pollution Bulletin*, 196: 115566.

33. Suryapratap, R. and Rahul, V. (2024). From water to plate: Reviewing the bioaccumulation of heavy metals in fish and unraveling human health risks in the food chain. *Emerging Contaminants*, 10: 100358. <https://doi.org/10.1016/j.emcon.2024.100358>
34. Tanamal, C., Jules, M. B., Emmanuel, Y. and Hing, M. C. (2021). Health risk assessment of inorganic arsenic exposure through fish consumption in Yellowknife, Northwest Territories, Canada: Human and Ecological Risk Assessment. *An international Journal*, 27(4): 1072-1093.
35. Tokath, C. and Varol, M. (2021). Variations, health risks, pollution status and possible sources of dissolved toxic metal(loid)s in stagnant water bodies located in an intensive agricultural region of Turkey. *Environmental Research*, 201: 111571.
36. United State Environmental Protection Agency (USEPA) (2021). Risk-based concentration table. Available online: https://epa-prgs.ornl.gov/cgi-bin/chemicals/csl_search
37. Varol, M., Kaçar, E. and Polat, Y. (2025). Metal(loid)s and minerals in fish tissues: health risk-benefit assessment and variations by gender and size. *Environmental Geochemistry and Health*, 47: 290. <https://doi.org/10.1007/s10653-025-02608-4>
38. West, G. (1990). Methods of assessing ovarian development in fishes: A review. *Australian Journal of Marine and Freshwater Research*, 41(2), 199–222.
39. Yang, C. P., Zhang, Z. W., Liu, Y., Shan, B., Yu, W., Li, H. and Sun, D. (2021). Heavy metal pollution and stable isotope ratios ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) in marine organisms from the Northern Beibu Gulf South China Sea. *Marine Pollution Bulletin*, 166: 112230.
40. Yedjou, C. G., Tchounwou, H. M. and Tchounwou, P. B. (2016). DNA damage, cell cycle arrest, and apoptosis induction caused by lead in human leukemia cells. *International journal of environmental research and public health*, 13(1): 56 PMID: 26703663 DOI: 10.3390/ijerph13010056

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Dataheavymetals.xlsx](#)