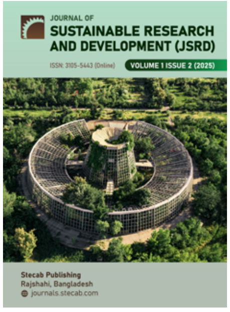

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Research Article

Heavy Metal Contamination and Health Risk Assessment of Smoked-Dried Fish Sold in Eke-Awka Market, Anambra State, Nigeria

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About Article

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ABSTRACT

This study investigated the concentrations of selected heavy metals—zinc (Zn), lead (Pb), cadmium (Cd), copper (Cu), and arsenic (As)—in four smoked-dried fish species widely consumed in southeastern Nigeria: catfish (*Clarias gariepinus*), mackerel (*Scomber scombrus*), bonga fish (*Ethmalosa fimbriata*), and asa fish (*Gymnarchus niloticus*). Samples were obtained from Eke-Awka Market and analyzed using Atomic Absorption Spectrophotometry. Results, expressed in mg/kg dry weight, revealed statistically significant interspecies variations ($p < 0.05$). *G. niloticus* exhibited the highest concentrations of Zn (5.47 ± 0.71), Cd (0.25 ± 0.01), and As (0.04 ± 0.02), while *S. scombrus* contained the highest Pb level (0.16 ± 0.01). Conversely, *C. gariepinus* recorded the highest Cu concentration (0.74 ± 0.05). Although all concentrations were below the permissible limits set by the World Health Organization (WHO) and Federal Ministry of Environment (FME), the health risk assessment revealed that the target hazard quotients (THQs) and the cumulative hazard index (HI = 0.362) were below 1, indicating no significant non-carcinogenic risk. However, the lifetime cancer risk (LCR) for cadmium (1.2×10^{-3}) exceeded the acceptable USEPA threshold, suggesting a potential long-term carcinogenic concern from continuous dietary exposure. These findings indicate that while the smoked-dried fish are generally safe for consumption in the short term, routine monitoring is essential, with particular attention to *G. niloticus*, which demonstrated higher accumulation of several metals. Improved hygienic smoking practices and strengthened regulatory oversight are recommended to safeguard public health.

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1. INTRODUCTION

Fish remains an essential component of human diets worldwide, serving as an important source of high-quality protein, essential fatty acids, vitamins, and minerals. Beyond its nutritional significance, fish also serves as a reliable bioindicator of aquatic ecosystem health due to its ability to bioaccumulate contaminants, particularly heavy metals, from the surrounding environment (Olusola & Festus, 2015).

Heavy metals are of particular concern among environmental pollutants because they are non-biodegradable, highly persistent, and prone to bioaccumulation and biomagnification through food chains (Hassan *et al*., 2012). Their accumulation in fish tissues is influenced by ecological, physiological, and anthropogenic factors, and may result in toxic effects ranging from histopathological alterations to reduced reproductive capacity (Vitek *et al*., 2017). For humans, chronic exposure through consumption of contaminated fish is associated with neurological, renal, hepatic, and hematological disorders (Eslami *et al*., 2011).

In Nigeria, rapid industrialization, agricultural activities, urban expansion, and indiscriminate waste disposal have exacerbated the release of heavy metals into aquatic systems (Uluturhan & Kucuksezgin, 2017). These contaminants eventually accumulate in sediments and aquatic organisms, raising food safety concerns. Smoked-dried fish, a common preservation and marketing practice in southeastern Nigeria, may further contribute to contamination during processing and handling (Okpoji *et al.* 2025).

The aim of this study was to evaluate the concentrations of zinc (Zn), lead (Pb), cadmium (Cd), copper (Cu), and arsenic (As) in smoked-dried fish species sold at Eke-Awka Market, Anambra State, Nigeria, in order to assess their safety for human consumption and to provide baseline data for environmental pollution monitoring.

2. LITERATURE REVIEW

2.1. Fish as a nutritional and economic resource

Fish is one of the most widely consumed animal proteins worldwide due to its high nutritional value. It provides not only easily digestible proteins but also essential fatty acids, vitamins, and minerals such as calcium, phosphorus, and iron (Nkpaa *et al*., 2013). Fish accounts for about 30% of human protein intake in Asia, 20% in Africa, and 15% in Latin America and the Caribbean, reflecting its global importance in food security (Bone & Moore, 2008). Compared to terrestrial animals, fish generally possess a higher muscle-to-bone ratio, which enhances their nutritional value. The rapid expansion of aquaculture further underscores the increasing global demand for fish as a healthy and sustainable protein source (Lekang, 2017).

2.2. Heavy metals in aquatic ecosystems

Among environmental pollutants, heavy metals are particularly concerning because they are indestructible, highly persistent, and toxic at relatively low concentrations (MacFarlane & Burchett, 2010). They enter aquatic ecosystems from both natural processes and anthropogenic sources such as industrial effluents, mining, agriculture, and domestic waste disposal (Youn-Joo, 2013). In aquatic systems, heavy metals partition into sediments and biota, often existing in trace concentrations in water but reaching elevated levels in benthic sediments and organisms (Wilhm, 2012). Sediments act as both sinks and potential secondary sources of heavy metals under changing environmental conditions, thereby influencing long-term exposure risks (Özmen *et al*., 2015).

2.3. Bioaccumulation and food chain implications

Fish readily bioaccumulate heavy metals through water, sediments, and food. Accumulated metals can be transferred along trophic levels, resulting in biomagnification that poses risks to higher organisms, including humans (Croteau *et al*., 2015; Okpoji *et al.* 2025). Previous studies have shown that plankton and benthic organisms accumulate metals which are then transferred to fish and ultimately to humans through consumption (Farkas *et al*., 2012; Okpoji *et al.* 2025). The degree of accumulation depends on species physiology, habitat, and feeding ecology (Storelli *et al*., 2015).

2.4. Human health risks of heavy metals

Chronic exposure to toxic metals through fish consumption has been linked to a range of adverse health effects. Lead (Pb) can impair neurological development and inhibit enzymatic processes (Adeyeye, 2015). Cadmium (Cd) is associated with kidney dysfunction, skeletal damage, and carcinogenicity, while arsenic (As) exposure has been linked to skin lesions, cardiovascular diseases, and cancer (Benedict *et al*., 2014). Although essential elements like zinc (Zn) and copper (Cu) are required in trace amounts for metabolic and enzymatic functions, their excessive accumulation can cause oxidative stress and organ damage (Carpen, 2013).

2.5. Relevance to nigeria

In Nigeria, rapid urbanization, artisanal refining, agricultural runoff, and poor waste management have exacerbated heavy metal contamination in aquatic systems (Stephen, 2010). Previous studies in different Nigerian markets have reported varying levels of heavy metals in commonly consumed fish, raising concerns about consumer safety (Nkpaa *et al*., 2013; Olowu *et al*., 2016). Given the popularity of smoked-dried fish as a staple in southeastern Nigeria, assessing its heavy metal content is crucial to understanding potential risks to human health and guiding regulatory monitoring (Okpoji *et al.* 2025).

3. METHODOLOGY

3.1. Study area

The study was conducted in Eke-Awka Market, located in Awka, the capital city of Anambra State, southeastern Nigeria. Awka serves as a major commercial hub, with Eke-Awka Market functioning as one of its busiest food distributions centers. The market is characterized by high volumes of fish trade, including smoked-dried products sourced both locally and from other regions. Its central role in food marketing makes it a suitable location for assessing potential human exposure to heavy metals through smoked fish consumption.

3.2. Sample collection

Four fish species commonly consumed in southeastern Nigeria were selected: catfish (*Clarias gariepinus*), mackerel (*Scomber scombrus*), bonga fish (*Ethmalosa fimbriata*), and asa fish (*Gymnarchus niloticus*). Multiple smoked-dried samples of each species were purchased directly from vendors at Eke-Awka Market. Each sample was wrapped in sterile polyethylene bags to prevent cross-contamination, properly labeled, and transported to the laboratory for analysis.

3.3. Sample preparation and digestion

In the laboratory, fish samples were homogenized, and 2 g of muscle tissue was weighed into a digestion flask. An acid mixture (aqua regia: 6.5 mL concentrated HNO_3, 0.8 mL $HClO_4$, and 0.2 mL concentrated H_2SO_4) was added, and the samples were heated gently on a hot plate until a clear digest was obtained. The digests were diluted to 100 mL with distilled water, filtered through Whatman No. 45 filter paper, and the filtrates were collected in acid-washed polyethylene bottles for analysis.

3.4. Heavy metal analysis

Heavy metal concentrations (Zn, Pb, Cd, Cu, and As) were determined using a Buck Scientific 200A Atomic Absorption Spectrophotometer (AAS). Results were expressed in milligrams per kilogram (mg/kg) dry weight. Instrument calibration was performed with certified standard solutions, and blanks were analyzed to ensure the absence of contamination. To validate the accuracy of the method, certified reference materials (CRMs) for fish tissue were analyzed in parallel. Instrument detection limits (IDL) and method detection limits (MDL) were established for each metal based on three times the standard deviation of replicate blanks. Spike recovery tests were performed, with percentage recoveries ranging between 85% and 105%, indicating acceptable accuracy and precision of the analytical procedure.

3.5. Health risk assessment

To evaluate potential human health risks from consumption of the smoked-dried fish, both non-carcinogenic and carcinogenic risk indices were estimated. The Estimated Daily Intake (EDI) of each metal was calculated using the equation:

$$EDI = \frac{(Cmetal \times IR)}{BW}$$

where C is the concentration of the metal (mg/kg), IR is the ingestion rate of fish (g/person/day), and BW is the average body weight (70 kg for adults).

Non-carcinogenic risk was assessed using the Target Hazard Quotient (THQ), defined as: the

$$THQ = \frac{EDI}{RfD}$$

where RfD is the oral reference dose for each element (mg/kg/day). The reference doses applied were: Zn (0.3), Cu (0.04), Pb (0.004), Cd (0.001), and As (0.0003). The cumulative risk from simultaneous exposure to multiple metals was expressed as the Hazard Index HI = ΣTHQ

A THQ or HI greater than 1 indicates a potential non-carcinogenic health concern.

Carcinogenic risk for cadmium, lead, and arsenic was estimated using the Lifetime Cancer Risk (LCR) equation: LCR=EDI×CSF where CSF is the cancer slope factor, with values of 6.1 (Cd), 1.5 (As), and 0.0085 (Pb) $(mg/kg/day)^{-1}$. Acceptable risk levels range from 10^{-6} to 10^{-4}, with values above this threshold indicating an elevated potential cancer risk.

3.6. Statistical analysis

Data were expressed as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was employed to test for significant differences ($p < 0.05$) among fish species. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, version 22.0).

4. RESULTS AND DISCUSSION

4.1. Heavy metal concentrations in smoked-dried fish

The concentrations of zinc, lead, cadmium, arsenic, and copper in the smoked-dried fish species obtained from Eke-Awka Market revealed clear interspecies variations, though all values remained below the permissible limits set by the World Health Organization and the Federal Ministry of Environment. Zinc was most abundant in *Gymnarchus niloticus* (5.47 ± 0.71 mg/kg), closely followed by *Ethmalosa fimbriata* (4.87 ± 0.22 mg/kg), while *Scomber scombrus* and *Clarias gariepinus* had much lower concentrations. Lead levels were generally low across the species, with the highest value found in *S. scombrus* (0.16 ± 0.01 mg/kg) and the lowest in *C. gariepinus* (0.02 ± 0.04 mg/kg), although the relatively large standard deviation for the latter suggests variability that may be linked to values near the detection limit of the instrument. Cadmium concentrations were highest in *G. niloticus* (0.25 ± 0.01 mg/kg) and lowest in *C. gariepinus* (0.04 ± 0.01 mg/kg), with intermediate values in the other species, indicating differences in the tendency of these fish to bioaccumulate the metal. Arsenic was consistently detected at very low levels, again highest in *G. niloticus* (0.04 ± 0.02 mg/kg) and lowest in *C. gariepinus* (0.01 ± 0.03 mg/kg), where the higher variability relative to the mean also reflected proximity to the detection threshold. Copper showed a different pattern, with *C. gariepinus* recording the highest concentration (0.74 ± 0.05 mg/kg) and *G. niloticus* the lowest (0.15 ± 0.05 mg/kg) as shown in Table 1.

Table 1. Heavy metal concentrations (mg/kg, mean ± SD) in smoked-dried fish species from Eke-Awka Market compared with permissible limits (WHO/FME)

Metals	*G. niloticus* **(Asa fish)**	**E. fimbriata (Bonga fish)**	*S. scombrus* **(Mackerel fish)**	*C. gariepinus* **(Catfish)**	**WHO/FME Limit**
Zinc (Zn)	5.47 ± 0.71	4.87 ± 0.22	1.10 ± 0.28	1.13 ± 0.36	99.40
Lead (Pb)	0.03 ± 0.06	0.05 ± 0.10	0.16 ± 0.01	0.02 ± 0.04	0.50
Cadmium (Cd)	0.25 ± 0.01	0.15 ± 0.03	0.06 ± 0.02	0.04 ± 0.01	0.50
Arsenic (As)	0.04 ± 0.02	0.03 ± 0.01	0.02 ± 0.00	0.01 ± 0.03	0.05
Copper (Cu)	0.15 ± 0.05	0.26 ± 0.05	0.55 ± 0.01	0.74 ± 0.05	3.00

There was significant difference (p<0.05) in the concentration of heavy metals between fish species

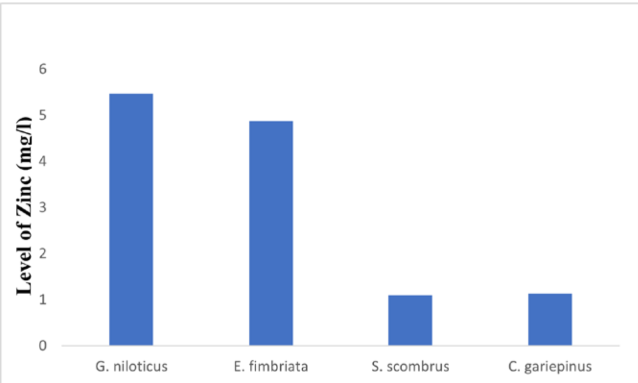

Figure 1. Level of Zinc in the selected fish species

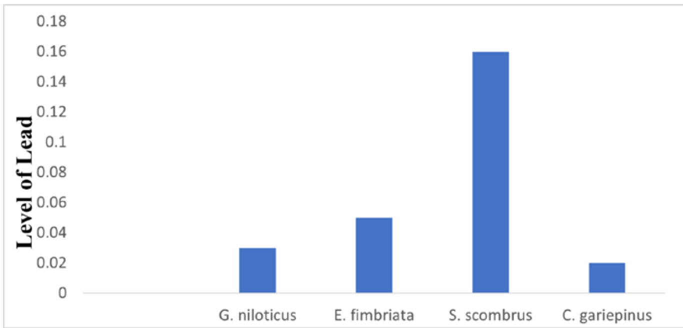

Figure 2. Level of Lead in the selected fish species

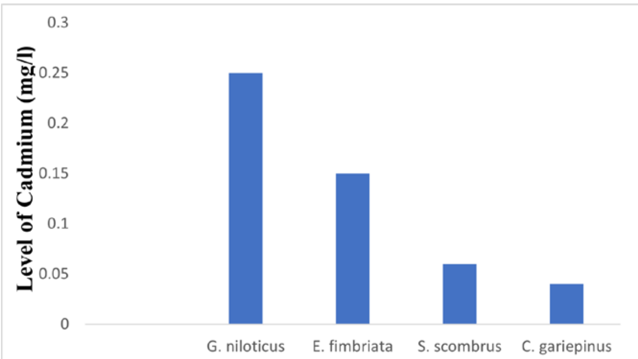

Figure 3. Level of Cadmium in the selected fish species

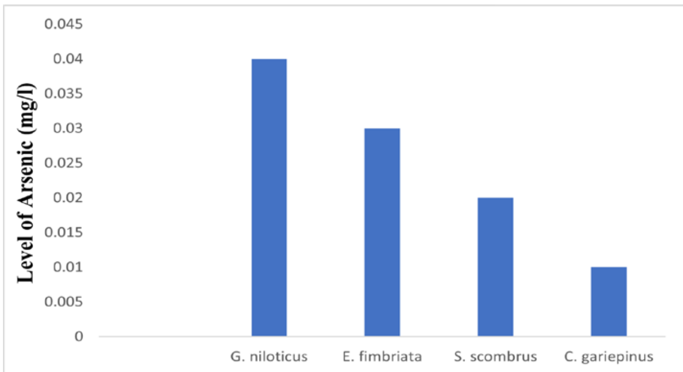

Figure 4. Level of Arsenic in the selected fish species

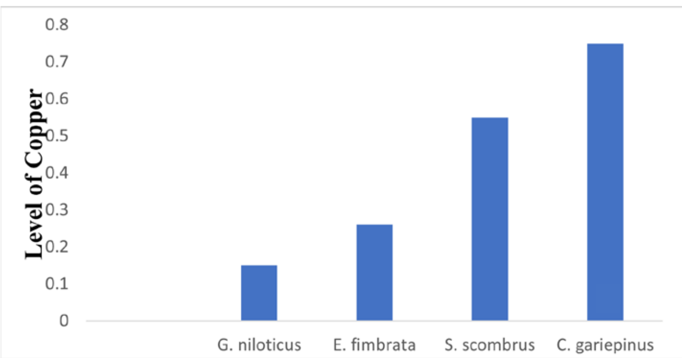

Figure 5. Level of copper in the selected fish species

Figure 1 to 5 showed the concentration of heavy metals in *C. gariepinus*, *S. scombrus*, E. fimbriata, and *G. niloticus* sample. The result revealed that the *G. niloticus* has highest concentration of Zinc, Cadmium and Arsenic. The concentration of lead was much higher in *S. scombrus*, while *C. gariepinus* has the highest concentration of copper.

4.2. Estimated Daily Intake (EDI)

The estimated daily intake of heavy metals from smoked-dried fish consumption. Zinc had the highest EDI value (0.0043 mg/kg/day), while arsenic had the lowest (0.000031 mg/kg/day). All calculated EDIs were lower than their respective reference doses (RfDs), indicating that consumption of these fish does not exceed the recommended safe intake levels for any of the metals studied as shown below.

Table 2. Estimated Daily Intake (EDI) of heavy metals from smoked-dried fish consumption

Metal	Highest Concentration (mg/kg)	EDI (mg/kg/day)	Reference Dose (RfD, mg/kg/day)
Zinc (Zn)	5.47	0.0043	0.3
Copper (Cu)	0.74	0.00058	0.04
Lead (Pb)	0.16	0.00013	0.004
Cadmium (Cd)	0.25	0.00020	0.001
Arsenic (As)	0.04	0.000031	0.0003

4.3. Target Hazard Quotient (THQ) and Hazard Index (HI)

Table 3 shows the target hazard quotient for individual metals and the cumulative hazard index. The THQ values were 0.014 for zinc, 0.015 for copper, 0.033 for lead, 0.200 for cadmium, and 0.100 for arsenic. The hazard index (HI), which sums these values, was 0.362. Since all THQs and the overall HI were below the threshold of 1, the results suggest that there is no significant non-carcinogenic health risk associated with consuming the smoked-dried fish species examined as shown below.

Table 3. Target Hazard Quotient (THQ) and Hazard Index (HI) for heavy metals.

Metal	EDI (mg/kg/day)	RfD (mg/kg/day)	THQ
Zinc (Zn)	0.0043	0.3	0.014
Copper (Cu)	0.00058	0.04	0.015
Lead (Pb)	0.00013	0.004	0.033
Cadmium (Cd)	0.00020	0.001	0.200
Arsenic (As)	0.000031	0.0003	0.100
Hazard Index (HI)			0.362

4.4. Lifetime Cancer Risk (LCR)

Table 4 provides the lifetime cancer risk values for lead, cadmium, and arsenic. The calculated risks were 1.1×10^{-6} for lead, 4.7×10^{-5} for arsenic, and 1.2×10^{-3} for cadmium. Both lead and arsenic fell within the USEPA's acceptable risk range of 10^{-6} to 10^{-4}, suggesting minimal cancer risk from long-term exposure. However, cadmium exceeded the upper acceptable limit, with an LCR of 1.2×10^{-3}, indicating a potential carcinogenic concern from prolonged dietary intake of cadmium-contaminated fish as shown below.

Table 4. Lifetime Cancer Risk (LCR) from heavy metal exposure.

Metal	EDI (mg/kg/day)	Cancer Slope Factor (CSF, $(mg/kg/day)^{-1}$)	LCR = EDI × CSF	Risk Range (USEPA)
Lead (Pb)	0.00013	0.0085	1.1×10^{-6}	Acceptable (10^{-6} – 10^{-4})
Cadmium (Cd)	0.00020	6.1	1.2×10^{-3}	Above safe limit
Arsenic (As)	0.000031	1.5	4.7×10^{-5}	Acceptable (10^{-6} – 10^{-4})

4.5. Discussion

The present study revealed notable variations in the concentrations of zinc, copper, lead, cadmium, and arsenic among the smoked-dried fish species analyzed from Eke-Awka Market, Anambra State. Although all the detected levels fell below the maximum permissible limits set by WHO (2015) and FEPA (2013), the interspecies differences observed emphasize the combined influence of ecological, physiological, and anthropogenic factors on metal bioaccumulation. Such findings are consistent with earlier studies reporting spatial and species-specific variations in heavy metal uptake in fish across Nigeria and other aquatic ecosystems (Olowu *et al.*, 2016; Barletta *et al.*, 2014; Okpoji *et al.*, 2025a).

Zinc concentrations were highest in *Gymnarchus niloticus* and *Ethmalosa fimbriata*, while *Scomber scombrus* and *Clarias gariepinus* recorded lower levels. Zinc is an essential trace element for growth and reproduction in fish and humans (Carpen, 2013), and elevated levels in some species may be attributed to contamination from fishing gear and galvanized metallic coatings that leach zinc into aquatic environments (Lalshman *et al.*, 2019). Copper concentrations were highest in *C. gariepinus* and lowest in *G. niloticus*. Similar results have been reported in earlier Nigerian studies (Rejomon *et al.*, 2010; Olowu *et al.*, 2016), and the levels in the present study remained well within WHO safety limits (3.0 mg/kg), suggesting minimal risk of copper toxicity to consumers.

Lead concentrations varied among species, with *S. scombrus* exhibiting the highest levels and *C. gariepinus* the lowest.

Although these values were below the FAO permissible limit of 0.5 mg/kg, lead is a cumulative toxicant that interferes with enzymatic processes, protein synthesis, and neurological function (Adeyeye, 2015; Stephen, 2010). Chronic exposure through frequent consumption, therefore, remains a concern. Cadmium, which is of particular toxicological importance due to its persistence, was most elevated in *G. niloticus* and lowest in *C. gariepinus.* While concentrations were below the 0.5 mg/kg guideline, cadmium exposure has been associated with renal impairment, skeletal disorders, and carcinogenic outcomes (Benedict *et al.*, 2014; Okpoji *et al.*, 2025b). Arsenic, although detected in trace amounts, was also highest in *G. niloticus.* Even at low levels, arsenic is hazardous due to its carcinogenic potential (Al-Bader, 2018; Anarado *et al.*, 2023).

The interspecies differences observed reflect ecological and physiological factors, including feeding habits and habitat use. Benthic feeders, such as *G. niloticus*, may accumulate higher metal loads from sediment, whereas pelagic species reflect contamination from water and plankton (Farkas *et al.*, 2012; Okpoji *et al.*, 2025c). In addition, contamination can arise from post-harvest handling and processing. Smoked fish, particularly those processed under unhygienic conditions, may incorporate metals from fuel sources and handling surfaces (Duffys, 2012).

The health risk assessment provides deeper insight into the implications of these findings. The Estimated Daily Intake (EDI) values for all metals were below their respective reference doses, indicating that consumption of the smoked-dried fish at the estimated rate does not exceed safe daily intake levels. Similarly, the Target Hazard Quotient (THQ) values for individual metals were below 1, and the cumulative Hazard Index (HI) was 0.362, demonstrating no immediate non-carcinogenic risk. These findings align with previous assessments in Nigerian aquatic systems where HI values for metals were found to be <1 (Nkpaa *et al.*, 2013; Okpoji *et al.*, 2025d).

However, the carcinogenic risk assessment revealed important long-term concerns. Lifetime cancer risk (LCR) values for lead (1.1×10^{-6}) and arsenic (4.7×10^{-5}) were within the USEPA's acceptable risk range of 10^{-6} to 10^{-4}, but cadmium (1.2×10^{-3}) exceeded this range, suggesting a potential carcinogenic hazard from chronic dietary exposure. This corroborates earlier studies from polluted Nigerian rivers and estuaries, where cadmium bioaccumulation in aquatic organisms exceeded cancer risk thresholds (Okpoji *et al.*, 2025e; Anarado *et al.*, 2023). Such findings underscore the need for dietary diversification and strict monitoring of cadmium contamination in fish consumed across southeastern Nigeria.

5. CONCLUSION

This study evaluated the concentrations of zinc, lead, cadmium, arsenic, and copper in four smoked-dried fish species obtained from Eke-Awka Market, Anambra State. The results demonstrated significant interspecies variations, with *Gymnarchus niloticus* consistently recording the highest levels of zinc, cadmium, and arsenic, *Scomber scombrus* showing the highest lead concentration, and *Clarias gariepinus* exhibiting the highest copper levels. Although all measured concentrations were below the permissible limits set by the World Health Organization (WHO) and the Federal Ministry of Environment (FME), the detection of cadmium and lead, even at sub-threshold levels, raises concerns about chronic dietary exposure.

The health risk assessment further confirmed that the overall non-carcinogenic risk from fish consumption was low, as both individual target hazard quotients (THQs) and the cumulative hazard index (HI = 0.362) remained below the threshold of 1. However, the lifetime cancer risk (LCR) values revealed that cadmium (1.2×10^{-3}) exceeded the USEPA's acceptable range, indicating a potential carcinogenic risk from long-term consumption, particularly in species such as *G. niloticus.* In light of these findings, it is recommended that continuous monitoring of heavy metals in smoked-dried fish be prioritized, with particular attention to *G. niloticus*, which demonstrated the highest accumulation tendency. Improved hygienic smoking and handling practices should be enforced to minimize contamination during processing. Public health authorities should also promote dietary diversification to reduce the risk of chronic exposure to cadmium and lead. Strengthening regulatory frameworks for food safety surveillance will be critical to safeguard consumers and ensure the long-term sustainability of fish as a vital protein source in southeastern Nigeria.

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