

GILL-TISSUE BIOACCUMULATION OF HEAVY METALS IN OREOCHROMIS NILOTICUS AND LABEO COUBIE AND ASSOCIATED DRINKING-WATER HEALTH RISK IN THE LOWER RIVER NIGER, LOKOJA, KOGI STATE, NIGERIA

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Abstract

Bioaccumulation of aquatic pollutants by fish in the lower River Niger at Lokoja can expose those who consume them to elevated risk, yet species specific bioaccumulation and consumption risk data are lacking for these fish communities. Samples of *Oreochromis niloticus* and *Labeo coubie* were collected monthly over six months spanning the dry season from January to March and the onset of the rains from June to August, and concentrations of cadmium, lead, chromium, zinc, mercury and nickel were measured in gill tissue by atomic absorption spectrophotometry. Bioaccumulation factors were computed from paired tissue and water concentrations collected at the same stations on the same occasions, and the estimated daily intake, hazard quotient, hazard index, margin of exposure and cancer risk were computed for the drinking water exposure pathway separately for adults and children. Gill tissue is the site of waterborne uptake rather than the edible portion, so the concentrations reported here are an upper bound on the edible portion burden and any inference drawn from them about consumption exposure is correspondingly conservative. Tissue concentrations of cadmium, lead, zinc and mercury remained below the WHO and FAO limits in every month and in both species, whereas chromium, at 1.04 to 1.28 mg per kg against a limit of 0.15, and nickel, at 1.14 to 1.25 mg per kg against a limit of 0.6, exceeded theirs throughout. Nickel then rose sharply in August, to 3.70 mg per kg in *O. niloticus* and 3.65 in *L. coubie*, approximately six times the permissible limit and the largest tissue exceedance recorded in the study. Bioaccumulation factors were below unity for lead, chromium, zinc and mercury, close to unity for cadmium, and above unity for nickel in both species, reaching 2.952 in *L. coubie*. In the health risk assessment chromium dominated the non carcinogenic profile, with an adult hazard quotient of 0.883 and a child hazard quotient of 1.68 in the dry season, rising to 0.918 and 1.74 in the wet season. Hazard indices exceeded unity for both age groups in both seasons and were approximately twice as high for children as for adults. The study concludes that chromium and nickel, rather than the metals most often monitored, determine risk at this reach, and that children are the population for whom the acceptable exposure threshold is crossed.

Keywords: bioaccumulation; health risk assessment; *Oreochromis niloticus*; *Labeo coubie*; hazard quotient; cancer risk; River Niger

1. Introduction

Fish provide one of the most direct routes by which metal contamination passes from a river into the body of a consumer. Unlike a single sample of ambient water or sediment, which records conditions at one moment, fish tissue integrates exposure over time and therefore registers intermittent discharges that spot sampling would miss.

The capacity to bioaccumulate is not uniform across species or metals. Uptake efficiency is influenced by feeding habit, gill surface area, metabolic rate and the chemical form in which the metal occurs, so that two species sharing a reach may carry markedly different burdens. This is the reason species specific data are required rather than a single figure for the fishery as a whole (Abalaka, Enem and Idoko, 2020; Ajibare, Ogungbile and Ayeku, 2021).

Metal toxicity cannot be evaluated from tissue concentration alone. Measured concentrations have to be translated into an estimated daily intake using an assumed consumption rate and body weight, and then compared against an oral reference dose. Because the framework scales exposure to body weight, it generates systematically different conclusions for adults and for children at the same environmental concentration, and that distinction turns out to be decisive in the present dataset.

This study set out to quantify cadmium, lead, chromium, zinc, mercury and nickel in *Oreochromis niloticus* and *Labeo coubie* tissue across six months spanning both hydrological seasons, to compute bioaccumulation factors against paired water concentrations, and to evaluate the resulting health risk for adults and children separately.

2. Materials and Methods

2.1 Study Area

The study was carried out along the lower River Niger at the Marine Police station in Lokoja, Kogi State, Nigeria (Figure 1). The reach lies downstream of the Niger and Benue confluence and supports an active artisanal fishery.



Figure 1: Map of the study area showing Nigeria, Kogi State and the course of the lower River Niger, with the Marine Police station sampling site at Lokoja marked. Source: Department of Geography, Federal University Lokoja (2023).

2.2 Sampling of Fish Tissues

Forty individuals of each species were obtained from local fisherfolk operating along the Marine Police axis of the lower River Niger at Lokoja, sampled monthly across six months: January, February and March, representing the dry season, and June, July and August, representing the onset of the rains.

2.3 Analysis of Metal Concentrations

Gill tissue was excised from each specimen, rinsed with deionised water to remove adhering debris and oven dried at 105 °C to constant weight. Dried tissue was digested and analysed by atomic absorption spectrophotometry for cadmium, lead, chromium, zinc, mercury and nickel. Results are reported as species means per month from three replicate pools.

2.4 Bioaccumulation Factor

The bioaccumulation factor was determined for each metal and species as the ratio of the concentration in fish tissue to that in the surrounding water:

$$BAF = C_{\text{tissue}} / C_{\text{water}} \quad (1)$$

A value above unity indicates true bioaccumulation, in the sense that the organism holds the metal at a concentration exceeding that of the medium from which it is drawn.

2.5 Estimated Daily Intake, Hazard Quotient and Hazard Index

The estimated daily intake, in mg per kg of body weight per day, was calculated for each metal from the measured concentration, an ingestion rate of 19.5×10^{-3} kg per day and a mean adult body weight, with corresponding values applied for children:

$$EDI = (C \times IR) / BW \quad (2)$$

The hazard quotient expresses the intake relative to the oral reference dose, and the hazard index sums the quotients across metals:

$$HQ = EDI / RfD, \quad HI = \sum_i HQ_i \quad (3)$$

A hazard quotient or hazard index above unity indicates exposure in excess of the dose considered acceptable for chronic non carcinogenic effects.

2.6 Margin of Exposure and Cancer Risk

The margin of exposure relates the reference dose to the estimated intake (Watanabe et al., 2003), and is the reciprocal of the hazard quotient:

$$MOE = RfD / EDI = 1 / HQ \quad (4)$$

Incremental lifetime cancer risk was computed for metals with an established oral slope factor:

$$CR = EDI \times CSF \quad (5)$$

A margin of exposure above unity indicates intake below the reference dose, and cancer risk is conventionally regarded as acceptable below 10^{-6} to 10^{-4} .

2.7 Statistical Analyses

Data were subjected to one way analysis of variance comparing species and month means using the PAST software package, with differences considered significant at $p < 0.05$.

3. Results

3.1 Tissue Concentrations

Concentrations of cadmium, lead, zinc and mercury remained below the WHO and FAO permissible limits in every month and in both species (Table 1). Chromium and nickel exceeded theirs throughout the study, chromium by roughly sevenfold to eightfold and nickel by approximately twofold for most of the series.

Table 1: Heavy metal concentrations in fish gill tissue by month and species

Month	Species	Cd	Pb	Cr	Zn	Hg	Ni
January	<i>O. niloticus</i>	0.081	0.062	1.04	4.85	ND	1.16
January	<i>L. coubie</i>	0.088	0.075	1.13	5.10	0.0012	1.20
February	<i>O. niloticus</i>	0.066	0.070	1.20	5.23	ND	1.22
February	<i>L. coubie</i>	0.059	0.066	1.12	5.10	ND	1.14
March	<i>O. niloticus</i>	0.066	0.070	1.18	5.00	ND	1.20
March	<i>L. coubie</i>	0.050	0.068	1.14	4.96	ND	1.25
June	<i>O. niloticus</i>	0.082	0.055	1.14	4.95	0.0011	1.21
June	<i>L. coubie</i>	0.090	0.065	1.20	5.50	0.0016	1.20
July	<i>O. niloticus</i>	0.081	0.051	1.08	4.97	0.0016	1.20
July	<i>L. coubie</i>	0.089	0.068	1.28	5.52	0.0017	1.18
August	<i>O. niloticus</i>	0.068	0.070	1.18	5.10	0.0010	3.70
August	<i>L. coubie</i>	0.070	0.067	1.20	5.00	0.0010	3.65
WHO/FAO limit		2.0	0.2	0.15	75	0.5	0.6

Note. Concentrations in mg kg^{-1} . ND denotes not detected. Values are species means per month from three replicate pools. Permissible limits are those of WHO and FAO (2011). Values exceeding the limit are those for chromium throughout and nickel throughout, with the August nickel values shown in bold.

Nickel produced the most striking pattern in the dataset. Between January and July both species held nickel within a narrow and stable band of 1.14 to 1.25 mg per kg, approximately twice the permissible limit. In August the concentration rose abruptly to 3.70 mg per kg in *O. niloticus* and 3.65 in *L. coubie*, roughly six times the limit and the largest tissue exceedance recorded

for any metal in the study. That the rise occurred simultaneously and to almost the same magnitude in both species argues against a species specific artefact of sampling or analysis (Figure 2).

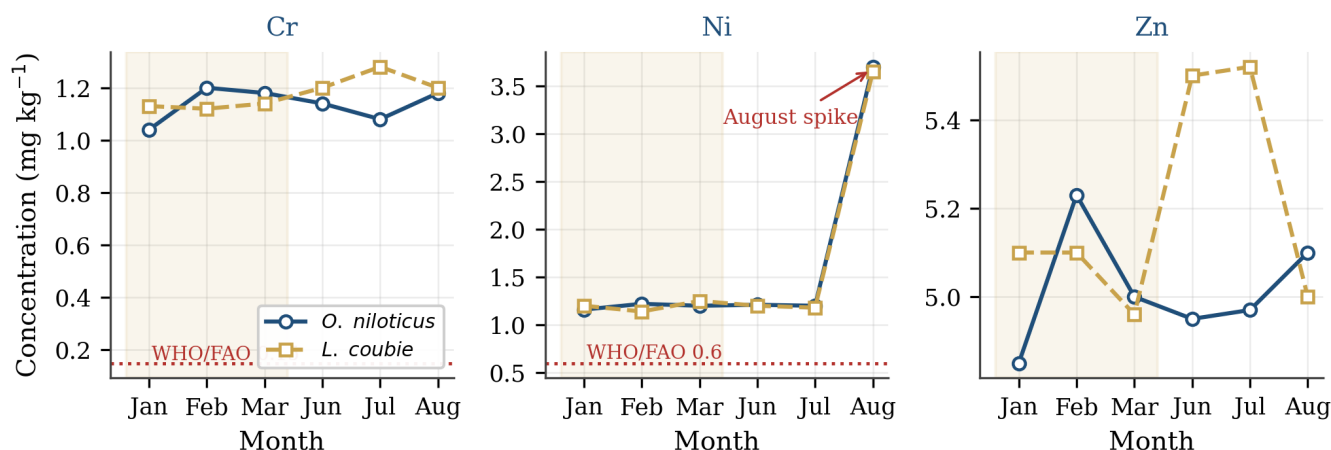


Figure 2: Monthly gill tissue concentrations of chromium, nickel and zinc in the two species. Shading marks the dry season months. Dotted red lines mark the WHO and FAO permissible limits where these fall within the plotted range. The simultaneous August nickel rise in both species is arrowed.

3.2 Bioaccumulation Factors

Bioaccumulation factors were below unity for lead, chromium, zinc and mercury in both species, and close to unity for cadmium, at 0.963 in *O. niloticus* and 1.038 in *L. coubie*. Nickel was the exception, exceeding unity in both species and reaching 2.952 in *L. coubie* (Table 2, Figure 3). Factors were consistently higher in *L. coubie* than in *O. niloticus* for every metal examined.

Table 2: Bioaccumulation factors by species and metal

Species	Cd	Pb	Cr	Zn	Hg	Ni
<i>O. niloticus</i>	0.963	0.024	0.813	0.491	0.032	1.637
<i>L. coubie</i>	1.038	0.027	0.885	0.523	0.037	2.952

Note. The factor is the ratio of tissue concentration to water concentration. Values above unity, shown in bold, indicate true bioaccumulation.

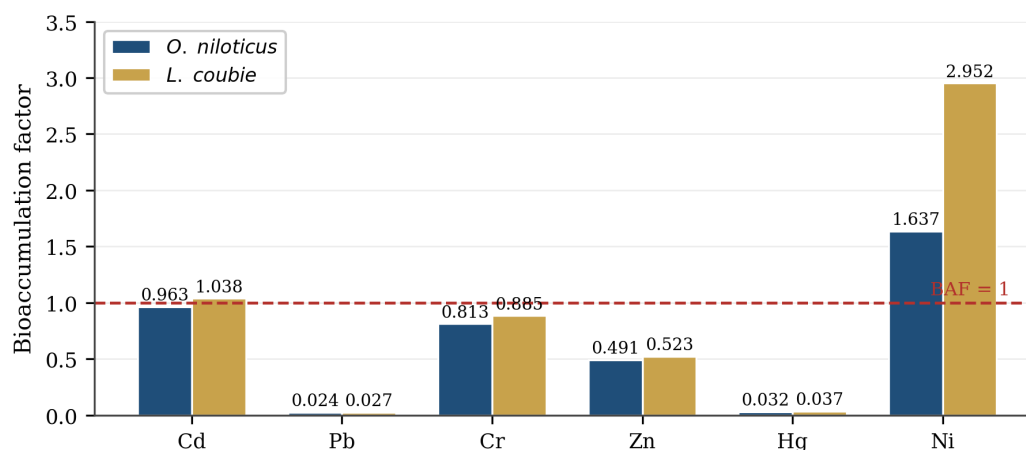


Figure 3: Bioaccumulation factors by metal and species. The broken line marks unity, above which tissue concentration exceeds that of the ambient water. Only nickel in both species and cadmium in *L. coubie* cross that line.

3.3 Human Health Risk Assessment

For the dry season (Table 3) chromium dominated the non carcinogenic risk profile, with an adult hazard quotient of 0.883 and a child hazard quotient of 1.68, the latter above the threshold of concern. The hazard index reached 1.05 for adults and 2.00 for children, both exceeding unity.

Table 3: Human health risk assessment for the drinking water pathway, dry season (January to March)

Metal	EDI adult	HQ adult	MOE adult	CR adult	EDI child	HQ child	MOE child	CR child
Cd	4.81×10^{-5}	0.0962	10.4	–	9.62×10^{-5}	0.192	5.20	–
Pb	4.80×10^{-5}	0.0137	73.0	4.08×10^{-7}	9.59×10^{-5}	0.0274	36.5	7.76×10^{-7}
Cr	7.95×10^{-4}	0.883	1.13	2.15×10^{-4}	1.51×10^{-3}	1.68	0.596	4.09×10^{-4}

Metal	EDI adult	HQ adult	MOE adult	CR adult	EDI child	HQ child	MOE child	CR child
Zn	3.53×10^{-3}	0.0118	85.1	–	6.72×10^{-3}	0.0224	44.6	–
Hg	0	0	–	–	0	0	–	–
Ni	8.37×10^{-4}	0.0418	23.9	7.03×10^{-4}	1.59×10^{-3}	0.0797	12.6	1.34×10^{-3}
HI	–	1.05	–	–	–	2.00	–	–

Note. EDI, estimated daily intake in $\text{mg kg}^{-1} \text{ day}^{-1}$; HQ, hazard quotient; HI, hazard index; MOE, margin of exposure; CR, cancer risk. A dash indicates no established carcinogenic slope factor. Margins of exposure are the reciprocals of the corresponding hazard quotients.

Table 4: Human health risk assessment for the drinking water pathway, wet season (June to August)

Metal	EDI adult	HQ adult	MOE adult	CR adult	EDI child	HQ child	MOE child	CR child
Cd	5.60×10^{-5}	0.112	8.93	–	1.07×10^{-4}	0.214	4.67	–
Pb	4.39×10^{-5}	0.0125	79.8	3.73×10^{-7}	8.36×10^{-5}	0.0239	41.9	7.10×10^{-7}
Cr	8.26×10^{-4}	0.918	1.09	2.23×10^{-4}	1.57×10^{-3}	1.74	0.573	4.25×10^{-4}
Zn	3.62×10^{-3}	0.0121	82.8	–	6.90×10^{-3}	0.0230	43.5	–
Hg	9.30×10^{-7}	0.0093	108	–	2.22×10^{-6}	0.0222	45.0	–
Ni	1.42×10^{-3}	0.0708	14.1	1.19×10^{-3}	2.70×10^{-3}	0.135	7.41	2.27×10^{-3}
HI	–	1.13	–	–	–	2.16	–	–

Note. Abbreviations and conventions as in Table 3.

The wet season followed a closely similar pattern with two differences worth noting. Mercury, undetectable in dry season water at the stations and months feeding that calculation, became quantifiable and contributed a small hazard quotient. Nickel intake and risk rose, the adult hazard quotient increasing from 0.0418 to 0.0708 and the child value from 0.0797 to 0.135, consistent with the August tissue rise. Hazard indices rose correspondingly to 1.13 for adults and 2.16 for children (Figure 4).

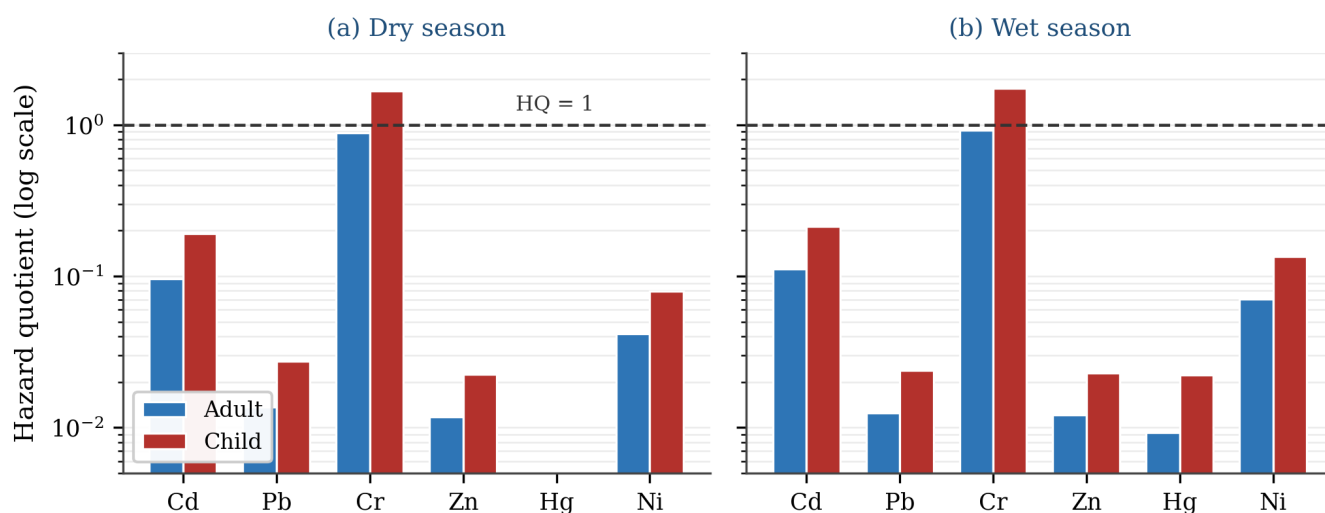


Figure 4: Hazard quotients by metal, season and age group, plotted on a logarithmic scale. The broken line marks a hazard quotient of unity. Chromium is the only metal approaching or crossing that line, and it crosses it for children in both seasons.

4. Discussion

4.1 Two Findings That Appear to Conflict

Two results in this dataset appear to point in different directions, and resolving how they coexist is the main interpretive task. Cadmium, lead, zinc and mercury remained comfortably below the permissible limits for fish consumption in every month and both species, which taken alone would suggest an unremarkable reach. Yet the hazard index exceeded unity for both adults and children in both seasons.

The resolution lies in recognising that the two statements answer different questions. Compliance with a tissue limit asks whether any single metal exceeds a threshold set for that metal in isolation. The hazard index asks whether the combined exposure from all metals exceeds the dose considered acceptable, and it is driven overwhelmingly by chromium, which contributes roughly five sixths of the adult total. A fishery can therefore pass every individual compliance test while the aggregate exposure remains of concern, and reporting only the compliance table would conceal that.

4.2 Nickel as the Anomalous Metal

Nickel warrants separate comment because it is the one metal for which both the tissue concentration and the bioaccumulation factor carry a warning, rather than the concentration alone. A factor approaching three in *L. coubie* indicates that this species concentrates nickel roughly threefold beyond ambient water levels, which is the signature of genuine biological accumulation rather than passive equilibration.

The August rise to 3.65 and 3.70 mg per kg, approximately six times the permissible limit, was the largest tissue exceedance recorded in the study. Its simultaneity across both species argues against an artefact of sampling or analysis and points instead to an event in the river: a discharge, a runoff pulse at the height of the rains, or remobilisation of sediment bound nickel under high flow. The practical implication is that a monitoring programme sampling only in the dry season, which is the more convenient period for fieldwork, would have recorded nickel at a stable twofold exceedance and missed the sixfold event entirely.

4.3 Species Differences and Their Practical Consequence

Bioaccumulation factors were consistently higher in *L. coubie* than in *O. niloticus* for every metal examined, and the gap was widest for nickel, at 2.952 against 1.637. Since the two species share the reach and were sampled on the same occasions, the difference reflects biology rather than exposure, plausibly through differences in feeding habit, gill surface area relative to body mass, and metabolic rate.

The consequence for risk communication is concrete. Advice framed in terms of fish from this reach treats the two species as equivalent, whereas the data indicate that a household consuming predominantly *L. coubie* faces a systematically higher burden than one consuming predominantly *O. niloticus*. Species specific advice is therefore better founded than generic advice.

4.4 Children as the Threshold Population

Children carried disproportionately higher risk than adults throughout, and for chromium the difference is not merely one of degree. The child hazard quotient exceeds unity in both seasons while the adult value does not, and the child margin of exposure falls below unity while the adult margin remains above it. The threshold separating acceptable from unacceptable non carcinogenic exposure at this site therefore falls between the two populations.

This is not because children are exposed to more contaminated water in absolute terms but because the risk assessment framework scales exposure to body weight, so that a smaller body receives a larger dose per kilogram from the same intake. The inference is that any threshold based management decision taken on adult figures alone would be set at the wrong level, and that the child values are the operative ones for this reach.

Mercury deserves brief mention in the same connection. Its hazard quotients remained far below unity, rising only from 0.0093 in adults to 0.0222 in children, yet methylmercury is repeatedly identified in the fish consumption literature as the metal of greatest neurodevelopmental concern for children even at exposures that would not trigger a numerical breach. The toxicity operates partly through oxidative stress, disruption of neuronal signalling and interference with selenium dependent enzyme systems, pathways to which the developing nervous system is particularly sensitive. A hazard quotient below unity should therefore not be read as establishing the absence of concern for this metal.

4.5 Limitations

Five limitations should be stated plainly. First, gill tissue was selected because it is the primary site of direct metal uptake from water, not because it is eaten; gill concentrations typically exceed those of muscle, so the burdens reported here are an upper bound on the edible portion and the risk estimates derived from them are conservative in that direction. Second, the water concentrations from which bioaccumulation factors and the drinking water exposure estimates were derived are not tabulated in this article, which limits independent verification of those quantities; they should be reported in full in any subsequent presentation of this dataset. Third, sampling covered six months within a single year, so interannual variation is unobserved and the August nickel event cannot be placed in a longer context. Fourth, chromium was not speciated, and since the trivalent and hexavalent forms differ by orders of magnitude in toxicity and reference dose, the metal that dominates the hazard index is also the one whose risk estimate carries the greatest uncertainty. Fifth, the assessment addresses the drinking water pathway and does not model the fish consumption pathway separately, so the two routes of exposure are not summed.

5. Conclusion and Recommendations

Gill tissue concentrations in both *Oreochromis niloticus* and *Labeo coubie* from the Marine Police axis of the lower River Niger remained within the WHO and FAO limits for cadmium, lead, zinc and mercury throughout the study, while chromium and nickel exceeded theirs in every month. Bioaccumulation factors exceeded unity only for nickel, in both species, and for cadmium in *L. coubie*. Hazard indices exceeded unity for both adults and children in both seasons, driven principally by chromium, and were approximately twice as high for children.

The study concludes that the metals determining risk at this reach are chromium and nickel rather than the cadmium, lead and mercury that attract the greater share of monitoring attention, and that children are the population for whom the acceptable exposure threshold is actually crossed. The following recommendations follow.

1. **Speciate chromium in subsequent work.** Chromium contributes the greater part of the hazard index, and its reference dose differs by orders of magnitude between the trivalent and hexavalent forms, so speciation would materially change the confidence attaching to the headline result.
2. **Sample across the full year rather than in the dry season alone.** The August nickel event, six times the permissible limit, would have been missed entirely by a dry season programme.
3. **Investigate the source of the August nickel rise.** Its simultaneity across species points to a river scale event, and identifying whether the cause is discharge or runoff determines which control is appropriate.
4. **Frame consumption advice by species.** *Labeo coubie* carried higher bioaccumulation factors for every metal examined, so advice that treats the catch as homogeneous understates the burden for households favouring that species.
5. **Set management thresholds on child rather than adult exposure.** The acceptable threshold is crossed for children while adults remain below it, so decisions taken on adult figures would be pitched at the wrong level.
6. **Report water concentrations and extend the assessment to the consumption pathway.** Publishing the paired water data would permit independent verification, and modelling fish consumption alongside drinking water would give the combined exposure that households actually experience.

Ethical Statement

Fish specimens were obtained commercially from local fishermen. No experiment was performed on any living organism and no human participants were involved in sample collection, so ethical approval and informed consent were not required.

Conflict of Interest

The authors disclose no competing interests.

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This study did not receive external financing.

Data Availability

The datasets generated and analysed during this study are available from the corresponding author on reasonable request.

Authors Contributions

I. E. Nweke conceived the study and conducted the fieldwork and the tissue analysis. **M. A. Adelanwa** and **P. O. Somdare** supervised the research, contributed to the study design and methodology, and reviewed and edited the manuscript. All authors read and approved the final version.

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