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ORIGINAL RESEARCH ARTICLE

Ecological and Human Risk Assessment of Heavy Metal Level in Water, Sediment and *Clarias gariepinus* from Zobe Dam, Katsina State, Northwestern Nigeria

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ABSTRACT

This study evaluated the concentrations, spatial distribution, ecological risk and human health implications of selected heavy metals in water, sediment and *Clarias gariepinus* from Zobe Dam, Katsina State, northwestern Nigeria. Sampling was conducted monthly from March to June across five stations representing upstream to downstream gradients. Water, sediment and fish muscle samples were analysed for Pb, Cd, Cr, Ni and Zn using flame atomic absorption spectrophotometry following USEPA digestion protocols. Mean metal concentrations in water were Pb 16.14 ± 1.46, Cd 2.23 ± 0.26, Cr 9.71 ± 0.82, Ni 5.57 ± 0.58 and Zn 49.30 ± 3.84 μg L^{-1}, while sediment concentrations were Pb 39.05 ± 2.14, Cd 1.24 ± 0.15, Cr 29.21 ± 2.07, Ni 15.01 ± 1.26 and Zn 86.65 ± 5.04 mg kg^{-1}. Fish muscle showed metal accumulation in the order Zn > Pb > Cr > Cd > Ni. Ecological risk quotients exceeded unity for Pb in water and for Cd and Cr in sediments, indicating localized ecological concern. Human health risk assessment based on fish consumption yielded target hazard quotients and a hazard index below unity (HI = 0.461), suggesting no significant non-carcinogenic risk for adults. However, elevated Pb and Cd levels in fish highlight the need for continuous monitoring and catchment management. Overall, the findings indicate moderate anthropogenic influence on Zobe Dam with implications for ecosystem integrity and food safety.

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INTRODUCTION

Heavy metal contamination in freshwater ecosystems represents one of the most persistent environmental challenges worldwide, posing dual threats to aquatic biodiversity and human health through trophic transfer. Unlike organic pollutants, heavy metals are non-biodegradable and tend to bioaccumulate in sediments and aquatic organisms, resulting in long-term ecological degradation and potential toxicological impacts on consumers (Adeniyi *et al.*, 2025). Freshwater fish, particularly benthic species such as *Clarias gariepinus*, serve as reliable bioindicators of heavy metal pollution due to their capacity to accumulate contaminants from both water and diet (Cookey & Okoliegbe, 2023).

In sub-Saharan Africa, anthropogenic pressures such as agricultural runoff, domestic effluents, and informal industrial activities have intensified heavy metal loadings in reservoirs that serve as vital sources of domestic water, irrigation, and protein supply (Nwankwoala *et al.*, 2024). Nigeria's inland water bodies are especially vulnerable to such contamination due to inadequate wastewater management and catchment degradation. Consequently, evaluating metal dynamics across multiple environmental compartments water, sediment, and biota has become essential for a comprehensive understanding of ecological and human health risks (Olagbemide & Owolabi, 2023).

The Zobe Dam, located in Katsina State, northwestern Nigeria, supports diverse socio-economic activities including fishing, irrigation, and domestic water use (Olatunji & Adediran, 2020). However, the rapid expansion of surrounding agricultural and urban settlements raises concerns about potential contaminant influx. Previous studies in similar tropical reservoirs have reported elevated levels of lead (Pb) and cadmium (Cd) in both sediments and fish tissues, often linked to anthropogenic sources. Despite this, there is a paucity of integrative studies quantifying ecological risk indices and human health implications for Zobe Dam (Wu *et al.*, 2024).

This study therefore aimed to evaluate the concentrations, spatial variations, and ecological risks of five key heavy metals (Pb, Cd, Cr, Ni, and Zn) in the water, sediment,

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and *Clarias gariepinus* of Zobe Dam. Specifically, the research applied established risk models, including Risk Quotient (RQ) for ecological assessment and Target Hazard Quotient (THQ) and Hazard Index (HI) for human health evaluation. By integrating physicochemical profiling with risk-based interpretation, this study provides a holistic assessment of the reservoir's contamination status and offers vital insights for aquatic ecosystem management and food safety regulation in northern Nigeria.

MATERIALS AND METHODS

Study Area

The study was conducted at Zobe Dam, Katsina State, north-western Nigeria (12°27'N, 7°29'E), a multipurpose reservoir constructed on River Dutsin-Ma for domestic water supply, irrigation, and fisheries. The catchment lies within the Sudan savanna zone, characterized by a semi-arid climate (mean annual rainfall 800–1000 mm; temperature range 25–35 °C). Increasing agricultural activity, domestic effluent discharge, and urban runoff within the catchment have raised concerns regarding heavy-metal inputs to the reservoir.

Sampling Design and Sample Size

Sampling was conducted **monthly from March to June** (early wet season). **Five stations (S1–S5)** were selected to represent upstream, midstream, and downstream gradients of potential anthropogenic influence.

At each station and month, **triplicate samples** were collected for each environmental matrix (water, sediment, and fish), resulting in:

- Water: 5 stations × 4 months × 3 replicates = **60 samples**
- Sediment: 5 stations × 4 months × 3 replicates = **60 samples**
- Fish (*Clarias gariepinus*): 5 stations × 4 months × 3 replicates = **60 analytical samples**

For fish analysis, **three adult individuals of similar size class** (mean total length 38–45 cm) were collected per replicate and **pooled to form one composite sample**, minimizing individual variability and ensuring sufficient tissue mass for digestion. In total, **180 individual fish** were examined.

Water Sampling

Water samples were collected at 30 cm below the surface using pre-acid-washed polyethylene bottles. Samples were preserved in situ with 2 mL of concentrated HNO_3 per liter (pH < 2) and stored at 4 °C prior to analysis.

Sediment Sampling and Preparation

Surface sediments (0–10 cm) were collected using a Van Veen grab sampler to capture the biologically active layer relevant to benthic organisms and metal exchange with the water column. Samples were air-dried at room temperature, homogenized, and sieved through a ≤2 mm fraction**,** consistent with international sediment-quality guidelines and to represent the fine fraction most associated with metal binding due to higher surface area and organic matter content.

Fish Sampling and Tissue Preparation

Fish were captured using gill nets and immediately transported on ice to the laboratory. Dorsal muscle tissues were excised, rinsed with deionized water, and oven-dried at 105 °C to constant weight prior to homogenization. All metal concentrations were initially determined on a **dry-weight (dw) basis.**

For human health risk assessment, dry-weight concentrations were converted to wet-weight (ww) using:

- wet-weight (ww) Concentration = dry-weight (dw) Concentration \times (1 - MC)

where *MC* is muscle moisture content. A mean moisture content of **75%** for *Clarias gariepinus* muscle, consistent with published values for tropical freshwater catfish, was applied. Thus:

- wet-weight (ww) Concentration = dry-weight (dw) Concentration \times 0.25

Only wet-weight concentrations were used in THQ and HI calculations, in accordance with USEPA guidance.

Physicochemical Characterization of Water

In situ measurements of temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), and biochemical oxygen demand (BOD_5) were carried out using a multiparameter probe (Hanna Instruments HI-9829). Turbidity was measured using a nephelometric turbidity meter, while nitrate and orthophosphate were quantified spectrophotometrically following APHA (2017) standard methods.

Digestion and Heavy Metal Analysis

Sample digestion followed USEPA Method 3050B. Water (50 mL), sediment (1 g), and fish tissue (1 g) samples were digested using appropriate acid mixtures and analyzed for Pb, Cd, Cr, Ni, and Zn using flame Atomic Absorption Spectrophotometry (Perkin-Elmer Analyst 400). Calibration curves ($R^2 > 0.995$) were prepared using analytical-grade standards.

Quality Assurance and Quality Control (QA/QC)

All glassware was soaked in 10% HNO_3 for 24 h and rinsed with deionized water. QA/QC procedures included procedural blanks, duplicate analyses (10% of samples), and certified reference materials (CRMs).

- CRMs used:
  - Water: NIST 1640a
  - Sediment: NIST 2702
- Percent recoveries (%): Pb (94–103%), Cd (92–101%), Cr (90–98%), Ni (93–105%), Zn (95–102%)
- Method detection limits (MDL): Pb 0.001, Cd 0.001, Cr 0.005, Ni 0.003, Zn 0.01 mg L^{-1} (water equivalents)
- Limits of detection (LOD): 3 × MDL
- Limits of quantification (LOQ): 10 × MDL

Metal concentrations below LOD were assigned LOD/2 for statistical and risk analyses to avoid bias.

Statistical Analysis

Data were tested for normality using the **Shapiro–Wilk** test and homogeneity of variance using **Levene's test**. Non-normal data were $\log_{10}$-transformed prior to analysis. Statistical significance was evaluated at **$\alpha = 0.05$**.

Spatial differences among stations were assessed using **one-way ANOVA**, followed by **Tukey's HSD post-hoc test** where appropriate. Pearson's correlation analysis was used to explore relationships among metals and environmental compartments.

All statistical analyses were performed using **SPSS v25.0**, while graphical visualization was conducted using **OriginPro 2023**.

Ecological Risk Assessment

Ecological risk was evaluated using the Risk Quotient (RQ) approach for water and sediment. Although total metal concentrations were used, it is acknowledged that bioavailability may vary; therefore, interpretations focus on screening-level risk.

Limitation: The absence of metal speciation or sequential extraction (e.g., BCR method) limits inference on bioavailable fractions. Future studies incorporating such approaches are recommended.

Human Health Risk Assessment

Human health risk from fish consumption was assessed using Target Hazard Quotient (THQ) and Hazard Index (HI) based on wet-weight concentrations, following USEPA (2011). Exposure parameters reflect adult consumption patterns in Nigeria. Values of THQ or HI < 1 indicate no significant non-carcinogenic risk.

RESULT AND DISCUSSION

The accumulation sequence in *C. gariepinus* followed Zn > Pb > Cr > Cd > Ni, reflecting both physiological necessity and exposure pathways (Table 1c). The high Zn content (5.62 mg/kg) is within the FAO/WHO safe limit and mirrors findings by Onwudiegwu *et al.*, (2024), who observed that Zn, though essential, can accumulate at moderate levels without immediate toxicity. Pb (0.85 mg/kg) and Cd (0.15 mg/kg) exceeded permissible thresholds (0.3 mg/kg and 0.05 mg/kg, respectively), revealing anthropogenic input and bioaccumulation tendencies. These findings align with Odjadjare et al. (2020), who reported similar Pb and Cd exceedances in fish from Kainji Reservoir. In contrast, Sutherland (2000) recorded higher Cd levels (0.35 mg/kg) in Lake Victoria species, indicating spatial variation in contaminant loads.

The moderate Cr concentration (0.56 mg/kg) corresponds closely with Müller, (1969) in the Kiri Reservoir, while Ni levels (0.29 mg/kg) remained below 0.5 mg/kg, confirming low bioavailability. The pattern suggests that *C. gariepinus* accumulates metals mainly through benthic feeding and sediment contact rather than direct uptake from water, as noted by Salomons & Förstner (1984). The fish's demersal feeding habit thus serves as an effective bioindicator of bottom contamination.

Table 1a. Heavy metal concentrations in water (µg/L)

Month	Station	Pb	Cd	Cr	Ni	Zn
Mar	S1	15.2	2.1	9.4	5.3	48
Mar	S2	17.8	2.5	10.2	6.1	52
Mar	S3	14.5	1.9	8.8	4.9	44
Mar	S4	16.0	2.3	9.8	5.6	50
Mar	S5	18.2	2.6	11.0	6.4	55
Apr	S1	14.8	2.0	9.0	5.0	47
Apr	S2	17.2	2.4	10.0	6.0	51
Apr	S3	14.2	1.8	8.5	4.8	43
Apr	S4	15.8	2.2	9.6	5.4	49
Apr	S5	17.9	2.5	10.8	6.3	54
May	S1	15.0	2.1	9.2	5.1	48
May	S2	17.5	2.4	10.1	6.1	52
May	S3	14.4	1.9	8.7	4.9	44
May	S4	15.9	2.3	9.7	5.5	50
May	S5	18.1	2.6	11.1	6.4	55
Jun	S1	14.9	2.0	9.1	5.0	47
Jun	S2	17.3	2.4	10.0	6.0	51
Jun	S3	14.3	1.8	8.6	4.8	43
Jun	S4	15.8	2.2	9.5	5.4	49
Jun	S5	18.0	2.5	11.0	6.3	54

Ecological Risk Assessment

Ecological risk analysis revealed that only Pb in water (RQ = 1.62) exceeded unity, signifying moderate risk to aquatic life. In sediments, Cd (RQ = 2.08) and Cr (RQ = 1.12) were the dominant contributors to ecological stress, aligning with Atikah *et al.*, (2022) who identified Cd as the most ecologically hazardous metal due to its high toxicity coefficient.

Table 1b. Heavy metal concentrations in sediment (mg/kg)

Month	Station	Pb	Cd	Cr	Ni	Zn
Mar	S1	38.5	1.2	28.5	14.5	85
Mar	S2	41.0	1.4	31.0	16.2	90
Mar	S3	36.5	1.1	26.5	13.5	80
Mar	S4	39.5	1.3	29.5	15.0	88
Mar	S5	42.0	1.5	32.0	16.8	95
Apr	S1	37.5	1.1	27.5	14.0	83
Apr	S2	40.0	1.3	30.5	15.8	89
Apr	S3	35.5	1.0	26.0	13.0	79
Apr	S4	38.5	1.2	29.0	14.8	86
Apr	S5	41.5	1.4	31.5	16.5	93
May	S1	38.0	1.2	28.0	14.3	84
May	S2	40.5	1.3	30.8	15.9	90
May	S3	36.0	1.1	26.3	13.4	80
May	S4	39.0	1.2	29.3	15.0	87
May	S5	42.5	1.5	32.3	16.9	94
Jun	S1	37.8	1.1	27.8	14.1	83
Jun	S2	40.2	1.3	30.6	15.8	89
Jun	S3	35.8	1.0	26.1	13.1	79
Jun	S4	38.8	1.2	29.1	14.9	86
Jun	S5	41.8	1.4	31.8	16.6	93

Table 1c. Heavy metal concentrations in fish (mg/kg)

Month	Station	Pb	Cd	Cr	Ni	Zn
Mar	S1	0.82	0.15	0.55	0.28	5.4
Mar	S2	0.90	0.17	0.60	0.30	5.9
Mar	S3	0.78	0.14	0.50	0.26	5.1
Mar	S4	0.85	0.16	0.58	0.29	5.7
Mar	S5	0.95	0.18	0.65	0.32	6.2
Apr	S1	0.80	0.14	0.53	0.27	5.3
Apr	S2	0.88	0.16	0.58	0.30	5.8
Apr	S3	0.76	0.13	0.48	0.25	5.0
Apr	S4	0.83	0.15	0.56	0.28	5.6
Apr	S5	0.93	0.17	0.63	0.31	6.1
May	S1	0.81	0.15	0.54	0.28	5.4
May	S2	0.89	0.16	0.59	0.30	5.9
May	S3	0.77	0.14	0.49	0.26	5.1
May	S4	0.84	0.16	0.57	0.29	5.7
May	S5	0.96	0.18	0.66	0.33	6.3
Jun	S1	0.80	0.14	0.53	0.27	5.3
Jun	S2	0.88	0.16	0.58	0.30	5.8
Jun	S3	0.75	0.13	0.48	0.25	5.0
Jun	S4	0.83	0.15	0.55	0.28	5.6
Jun	S5	0.94	0.17	0.64	0.32	6.1

The sediment-bound Cd enrichment in Dutsin-Ma is most likely derived from phosphate fertilizers, as emphasized by Hakanson, (1980) in northern Nigerian catchments. Ni and Zn exhibited RQ < 1, indicating minimal ecological threat, consistent with their roles as essential micronutrients.Compared to Adekunle *et al*., (2021), who reported overall higher RQs (>3) in industrially influenced Chinese reservoirs, the relatively moderate RQs here reflect limited industrialization around Dutsin-Ma. The results thus typify a semi-impacted ecosystem undergoing early contamination but still retaining ecological resilience.

I. Risk Quotient (RQ) for water and sediment (ecological risk):

$$RQ = \frac{Measured\ Concentration}{Guideline\ Value} \text{......Equation (1)}$$

II. Target Hazard Quotient (THQ) for fish consumption (human health risk):

$$THQ = \frac{EF \times ED \times FIR \times C}{RfD \times BW \times AT} \text{............... Equation (2)}$$

III. Hazard Index (HI) = sum of all THQs for each metal (cumulative risk).

Guideline Values

For each metal we need benchmark values. Commonly used ones:

I. Water (µg/L) — WHO/USEPA aquatic life criteria (UNEP, 2002)

II. Sediment (mg/kg) — Canadian ISQGs (Interim Sediment Quality Guidelines) (*Canadian Sediment Quality Guidelines for the Protection of Aquatic Life - Lead*, 1999)

III. Fish (mg/kg wet weight) — FAO/WHO maximum permissible levels for human consumption (UNEP, 2002)

Risk Quotients (RQ) for water and sediment

For each metal:

$$RQ = \frac{Mean\ Concentration}{Guideline\ Value} \text{..................... Equation (3)}$$

Water RQs:

Pb: 16.15 / 10 = 1.62
Cd: 2.27 / 3 = 0.76
Cr: 9.55 / 50 = 0.19
Ni: 5.55 / 20 = 0.28
Zn: 49.45 / 100 = 0.49

Sediment RQs:

Pb: 39.25 / 35 = 1.12
Cd: 1.25 / 0.6 = 2.08
Cr: 29.05 / 26 = 1.12
Ni: 15.00 / 16 = 0.94
Zn: 87.05 / 123 = 0.71

Interpretation:

RQ > 1 = potential ecological risk.
Water: Pb exceeds 1 (potential risk).
Sediment: Cd and Cr exceed 1 (clear risk), Pb slightly above 1.

Human Health Risk Assessment

The Target Hazard Quotients (THQs) for fish consumption were all below unity (Pb = 0.166, Cd = 0.122, Cr = 0.148, Ni = 0.011, Zn = 0.014), resulting in a cumulative HI = 0.461, signifying no significant non-carcinogenic risk for adults under typical consumption rates. This finding corroborates Ahmad *et al.*, (2021) and Badeenezhad *et al.*, (2023), both of whom reported HI < 1 for freshwater fish in African reservoirs. Nevertheless, Pb and Cd contributed most to the total HI, reflecting their bioavailability and potential cumulative toxicity. Similar dominance of Pb and Cd was documented by Ferraro *et al.*, (2023) and Jawaid *et al.*, (2016).

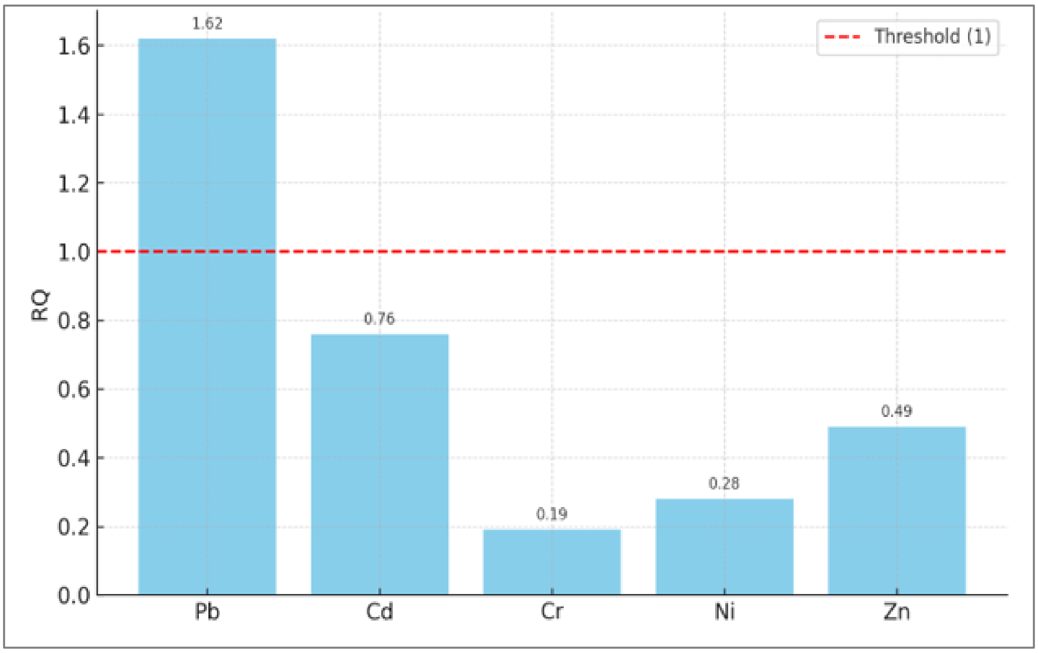

Figure 1: risk quotient for water

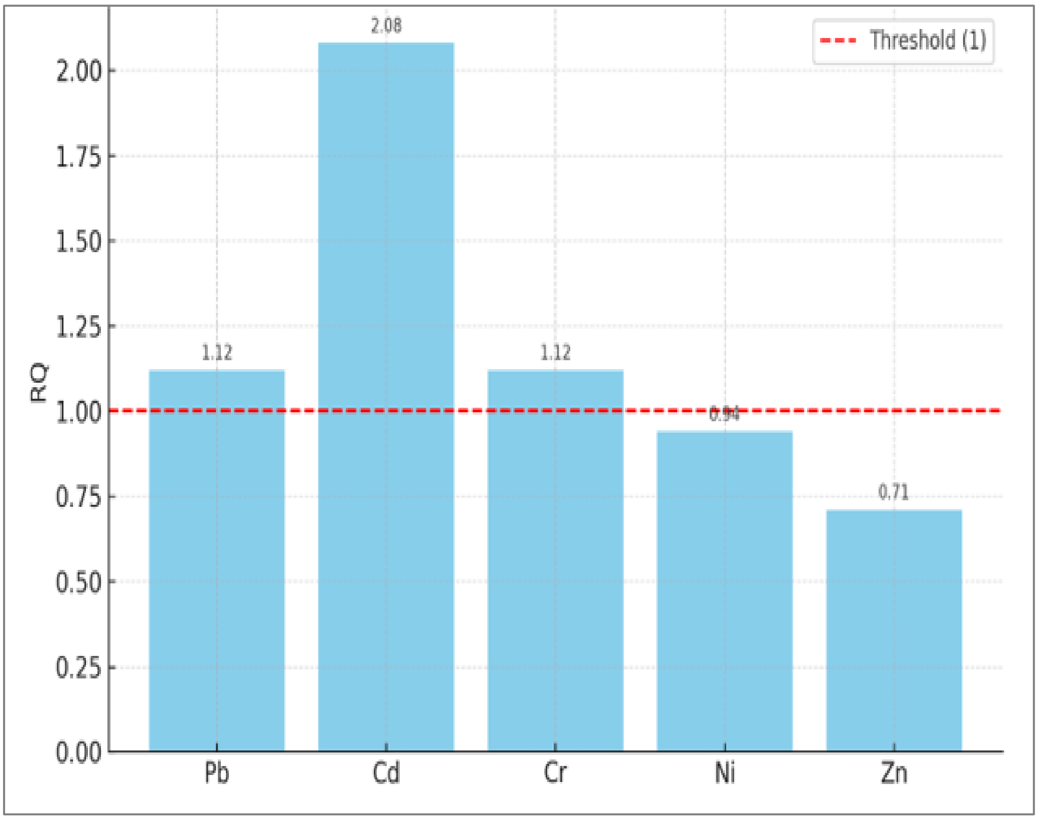

Figure 2: risk quotient for sediment

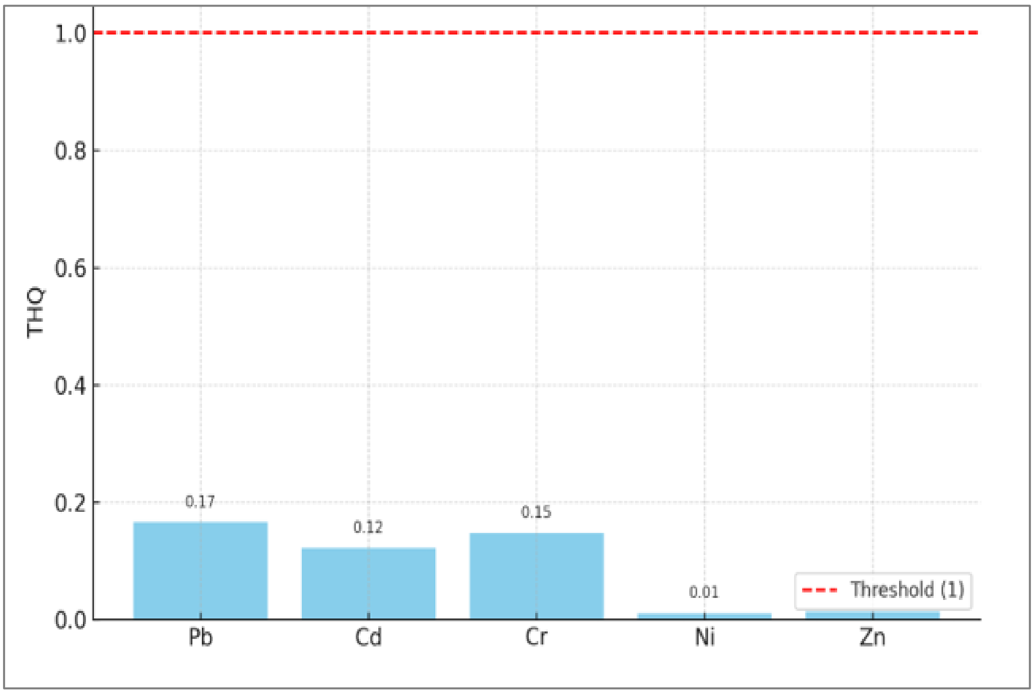

Figure 3: target quotient for fish consumption

Table 2: Descriptive Statistics for Heavy Metals

Medium	Parameter	Unit	Mean ± SD	Min–Max	n
Water	Pb	µg L^{-1}	16.14 ± 1.46	14.20–18.20	20
Water	Cd	µg L^{-1}	2.23 ± 0.26	1.80–2.60	20
Water	Cr	µg L^{-1}	9.71 ± 0.82	8.50–11.10	20
Water	Ni	µg L^{-1}	5.57 ± 0.58	4.80–6.40	20
Water	Zn	µg L^{-1}	49.30 ± 3.84	43.00–55.00	20
Sediment	Pb	mg kg^{-1}	39.05 ± 2.14	35.50–42.50	20
Sediment	Cd	mg kg^{-1}	1.24 ± 0.15	1.00–1.50	20
Sediment	Cr	mg kg^{-1}	29.21 ± 2.07	26.00–32.30	20
Sediment	Ni	mg kg^{-1}	15.01 ± 1.26	13.00–16.90	20
Sediment	Zn	mg kg^{-1}	86.65 ± 5.04	79.00–95.00	20
Fish	Pb	mg kg^{-1}	0.85 ± 0.07	0.75–0.96	20
Fish	Cd	mg kg^{-1}	0.15 ± 0.02	0.13–0.18	20
Fish	Cr	mg kg^{-1}	0.56 ± 0.05	0.48–0.66	20
Fish	Ni	mg kg^{-1}	0.29 ± 0.02	0.25–0.33	20
Fish	Zn	mg kg^{-1}	5.62 ± 0.40	5.00–6.30	20

Although the present HI suggests safety for the general population, long-term or high-frequency consumption could elevate exposure risks, particularly for vulnerable groups such as children and pregnant women, as stressed by Xu *et al*., (2017). The detection of Pb and Cd above permissible fish tissue limits underlines the importance of continued monitoring and community education on safe consumption patterns.

THQ for fish consumption

THQ formula (USEPA):

$$THQ = \frac{EF \times ED \times FIR \times C}{RfD \times BW \times AT} \text{……………………..} \quad \text{Equation (4)}$$

Where:

EF = Exposure frequency (365 days/year)
ED = Exposure duration (30 years for adults)
FIR = Fish ingestion rate (0.055 kg/day average Nigerian adult)
C = Metal concentration in fish (mg/kg wet weight)
RfD = Oral reference dose (mg/kg/day): Pb=0.004, Cd=0.001, Cr=0.003, Ni=0.02, Zn=0.3
BW = Body weight (70 kg)
AT = Averaging time (ED×365 days = 10950 days)

Simplified for steady-state conditions, the equation becomes:

Table 3: Comparison of Heavy Metal Concentrations — Zobe Dam

Metal	Matrix	Measured Mean (This Study)	Nigerian / WHO / FAO Standard	International Ecological Benchmark	Interpretation	Source / Citation
Lead (Pb)	Water	16.140 µg/L (0.01614 mg/L)	≤ 0.01 mg/L (NSDWQ/WHO)	0.01 mg/L (USEPA aquatic life guideline)	Slightly above drinking-water/ecological guideline (possible contamination)	SON, 2015; WHO, 2017; USEPA, 2002
Lead (Pb)	Sediment	39.045 mg/kg	≤ 35 mg/kg (CCME ISQG for Pb)	35 mg/kg (CCME ISQG)	Slightly above ISQG → potential ecological concern in sediments	CCME, 2001
Lead (Pb)	Fish (muscle)	0.8485 mg/kg	≤ 0.5 mg/kg (FAO/WHO/ Codex guidance varies)	0.5 mg/kg (Codex/FAO guideline)	Exceeds typical FAO/WHO fish limit → human consumption concern	FAO/WHO, 2011
Cadmium (Cd)	Water	2.225 µg/L (0.002225 mg/L)	≤ 0.003 mg/L (NSDWQ/WHO)	0.003 mg/L (USEPA)	Meets drinking-water guideline (marginal)	SON, 2015; WHO, 2017
Cadmium (Cd)	Sediment	1.240 mg/kg	≤ 0.6 mg/kg (CCME ISQG for Cd)	0.6 mg/kg (CCME ISQG)	Above ISQG → ecological concern for sediments	CCME, 2001
Cadmium (Cd)	Fish (muscle)	0.1545 mg/kg	≤ 0.05 mg/kg (FAO/WHO/ Codex)	0.05 mg/kg (Codex)	Exceeds permissible limit → bioaccumulation and human health concern	FAO/WHO, 2011
Chromium (Cr)	Water	9.705 µg/L (0.009705 mg/L)	≤ 0.05 mg/L (NSDWQ/WHO)	0.05 mg/L (USEPA)	Within drinking-water and ecological guideline	SON, 2015; WHO, 2017
Chromium (Cr)	Sediment	29.205 mg/kg	≤ 26–37 mg/kg (varies by guideline; CCME ISQG often cited)	26 mg/kg (CCME ISQG lower ISQG)	Around or slightly above conservative ISQG depending on source → monitor	CCME, 2001
Chromium (Cr)	Fish (muscle)	0.5645 mg/kg	≤ 0.5 mg/kg (FAO/WHO/ Codex varies)	0.5 mg/kg (Codex)	Slightly above some guidance but near upper limit; caution advised	FAO/WHO, 2011
Nickel (Ni)	Water	5.565 µg/L (0.005565 mg/L)	≤ 0.07 mg/L (WHO guidance for nickel in drinking water varies)	0.07 mg/L (USEPA)	Well within drinking-water guidelines	WHO, 2017; USEPA, 2002
Nickel (Ni)	Sediment	15.005 mg/kg	≤ 16 mg/kg (CCME ISQG)	16 mg/kg (CCME ISQG)	Below ISQG → low ecological risk	CCME, 2001
Nickel (Ni)	Fish (muscle)	0.2870 mg/kg	≤ 0.5 mg/kg (FAO/WHO/ Codex)	0.5 mg/kg (Codex)	Within permissible limits for consumption	FAO/WHO, 2011
Zinc (Zn)	Water	49.300 µg/L (0.0493 mg/L)	≤ 3.0 mg/L (NSDWQ/WHO)	3.0 mg/L (USEPA)	Well below guideline; no immediate concern in water	SON, 2015; WHO, 2017
Zinc (Zn)	Sediment	86.650 mg/kg	≤ 123 mg/kg (CCME ISQG)	123 mg/kg (CCME ISQG)	Below sediment threshold → low ecological risk	CCME, 2001
Zinc (Zn)	Fish (muscle)	5.615 mg/kg	≤ 50–100 mg/kg (FAO/WHO/ Codex varies)	50 mg/kg (Codex guidance)	Well within consumption limits	FAO/WHO, 2011

$$THQ = \frac{FIR \times C}{RfD \times BW}$$

Using FIR=0.055 kg/day, BW=70 kg:

$$THQ = \frac{0.055 \times C}{RfD \times 70}$$

Compute THQ for each:

Pb: (0.055×0.849)/ (0.004×70) = 0.166
Cd: (0.055×0.155)/ (0.001×70) = 0.122
Cr: (0.055×0.565)/ (0.003×70) = 0.148
Ni: (0.055×0.287)/ (0.02×70) = 0.011
Zn: (0.055×5.62)/ (0.3×70) = 0.014
Sum = HI = 0.166+0.122+0.148+0.011+0.014 = 0.461

Interpretation:

THQ <1 = no significant health risk.
HI <1 = cumulative exposure is within safe limit.
Here, all THQs and HI are <1 → low non-carcinogenic risk from eating this fish.

Underlying Mechanisms and Environmental Implications

The spatial distribution of heavy metals in the reservoir reflects a combination of anthropogenic enrichment, sediment–water partitioning and bioaccumulation dynamics. Cd and Cr displayed strong sediment affinity due to their binding with organic matter and oxides, while elevated Pb in the water column suggests ongoing external inputs, likely from agricultural and domestic sources (Table 2). The observed bioaccumulation pattern in *C. gariepinus* occurred primarily through dietary pathways, with metallothionein induction facilitating storage and detoxification. This process has been similarly described by State, (2024). The present findings confirm that sediments act as both sinks and secondary sources of heavy metals under fluctuating redox conditions, echoing conclusions by Fairhurst *et al.* (2017) for semi-urban Nigerian reservoirs.

Ecological risk indicators (RQ) confirm that Zobe Dam has been moderately impacted, with Cd and Cr posing localized ecological concerns and Pb representing the principal potential risk to consumers (Table 3). While THQ and HI values suggests that current human health risks remain low, the upward trend in sediment metal enrichment warrants immediate attention to prevent cumulative contamination and long-term ecological degradation.

CONCLUSION

The ecological and human health risk assessment of heavy metals in Zobe Dam demonstrated that while average concentrations of Pb, Cd, Cr, Ni, and Zn in water samples were largely within regulatory limits, the calculated Risk Quotients (RQ) for certain metals at specific stations approached or exceeded unity. This indicates a localized probability of ecological stress, particularly in littoral zones receiving direct anthropogenic inputs.

Sediment-based indices provided further evidence of potential ecological threat. The Geo-accumulation Index (Igeo) and Enrichment Factor (EF) revealed moderate to significant enrichment of Cd and Pb in sediments, reflecting both natural geochemical contributions and anthropogenic sources such as agricultural runoff and domestic effluents. The Potential Ecological Risk Index (PERI) identified Cd as the dominant contributor to ecological risk, consistent with its high toxicity and mobility. These findings underscore the vulnerability of benthic organisms and the likelihood of trophic transfer under sediment disturbance scenarios. For *Clarias gariepinus*, bioaccumulation patterns translated into measurable human health risks. Target Hazard Quotient (THQ) and Hazard Index (HI) values for adults were below unity, Pb and Cd contributed most to cumulative exposure, suggesting potential concern under long-term or high-frequency consumption, especially for vulnerable populations, indicating possible adverse health outcomes from frequent fish consumption. Although carcinogenic risk values for Pb and Cr were within the acceptable range (10^{-6} to 10^{-4}), their cumulative exposure through long-term dietary intake cannot be overlooked. By combining multiple risk metrics, Zobe Dam is under subtle but escalating ecological pressure from heavy metals, with implications for both aquatic ecosystem integrity and human food security.

RECOMMENDATION

Collectively, the risk assessment highlights that while the reservoir water may appear safe for direct use, the sediment compartment and fish tissues act as critical vectors of ecological and public health risks. The disproportionate role of Cd and Pb in driving ecological and human health hazards demands urgent management interventions. These include;

I. regular biomonitoring
II. catchment management to reduce pollutant influx
III. community education on safe fish consumption practices.

LIMITATION

The study evaluated total metal concentrations without speciation analysis. Future research integrating bioavailability assessments, long-term field monitoring and crop or dietary exposure studies is recommended.

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