BIU Journal of Basic and Applied Sciences 9(2): 198 – 215, 2024.

ISSN: 2563-6424

ARE OUR WATERS SAFE? INVESTIGATING HEAVY METAL RISKS IN THE IKPOBA RIVER ECOSYSTEM

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ABSTRACT
The Ikpoba River, a crucial waterway in the rainforest belt of Edo State, Nigeria, has raised concerns regarding heavy metal contamination and its potential risks to the local population and ecosystem. This study aimed to assess the risk of heavy metal contamination in the water, sediment, and Clarias gariepinus and Tilapia zilli of the Ikpoba River. Water, sediment, and fish samples were collected and analyzed for heavy metals, including lead (Pb), cobalt (Co), chromium (Cr), cadmium (Cd), and nickel (Ni). The results showed significant concentrations of Pb, Co, Cr, and Ni in the water samples, with the Metal Index (MI) increasing from 2.633 in May to 3.523 in June, exceeding the permissible limits. The Potential Ecological Risk Index (PERI) for the sediment samples was highest in May at 435.262, indicating a significant ecological risk. While the Geo-accumulation Index (Igeo) values were negative, suggesting no significant geo-accumulation of metals, the human health risk assessment revealed potential toxicity concerns. The Hazard Quotient (HQ) for Pb in the sediment samples via ingestion exceeded 1 in June and July, and the HQ for Cr ingestion was above 1 across all months, indicating potential chronic toxicity. For fish consumption, the HQ values for Cd were consistently above the toxicity threshold for children, and the Pb levels exceeded the threshold for both adults and children in June. These findings highlight the need for regular monitoring and implementation of appropriate management strategies to mitigate the risks associated with heavy-metal contamination in the Ikpoba River ecosystem.

KEYWORDS: *Heavy Metals, Ikpoba River, Risk Assessment, Environmental Pollution, Water Quality, Sediment Contamination*

INTRODUCTION

The Ikpoba River is a crucial waterway in the rainforest belt of Edo State, Nigeria and serves as a vital resource for the local population and ecosystem (Egun and Oboh, 2022; Okonofua *et al.*, 2019; Ologbosere and Aluyi, 2016; Ufuah *et al.*, 2023). Previous studies have highlighted the concerns regarding the water quality and environmental conditions of this 4th order creek, which joins the larger Ethiope River (Adegbite *et al.*, 2022; Enuneku and Ineh, 2019; Igboanugo *et al.*, 2013; Imiuwa *et al.*, 2014; Obasohan *et al.*, 2008; Ojeah and Oriakhi, 2022; Ologbosere and Aluyi, 2016). One of the primary issues of concern is the presence and potential risk of heavy metal contamination in the river's water, sediment, and fish (Enuneku and Ineh, 2019; Ogbeide and Okoduwa, 2024; Oguzie, 2006; Oguzie and Okhagbuzo, 2010).

Heavy metals, which are characterized by a specific gravity exceeding 5 g cm^{-3}, are prevalent environmental pollutants that have substantial impacts on human and ecological well-being. These contaminants infiltrate aquatic ecosystems via diverse anthropogenic activities such as industrial processes, mining operations, and agricultural practices (Arora *et al.*, 2023; Aziz *et al.*, 2023; Jadaa and Mohammed, 2023). Although certain heavy metals are essential micronutrients for plant and animal life, their bioaccumulation in the food chain can result in detrimental effects, including developmental disorders in children, infertility, cardiovascular diseases, and cancer (Gulati *et al.*, 2022; Jadon, 2022). The persistence and accumulation of heavy metals in ecosystems pose a significant threat to both aquatic species and human health, necessitating effective strategies for their removal from wastewater to mitigate associated risks (Singh *et al.*, 2023; Yunusa *et al.*, 2023).

Studies on health risks associated with metals in the Ikpoba River have yielded relevant findings. Research has shown that river sediments contain various heavy metals, some of which exceed permissible limits, posing risks to both ecological and human health (Adegbite *et al.*, 2022; Igboanugo *et al.*, 2013; Oguzie, 2006; Oguzie and Okhagbuzo, 2010; Ojeah and Oriakhi, 2022; Okonofua *et al.*, 2019; Olele *et al.*, 2013; Osa-Iguehide *et al.*, 2016; Wangboje and Ekundayo, 2013). The accumulation of heavy metals in commercially available fish from rivers also raises health concerns for consumers, as certain metals, such as chromium and lead, exceed acceptable levels (Obasohan *et al.*, 2007; Obasohan *et al.*, 2008; Ogbeide and Okoduwa, 2024; Osa-Iguehide *et al.*, 2016). Despite these risks, human health risk assessments have indicated that non-carcinogenic risks from heavy metal exposure in river sediments and fish samples generally fall below the threshold levels for both adults and children (Enuneku and Ineh, 2019; Enuneku and Ineh, 2020).

The objective of this study was to assess the risk of heavy metal contamination in water, sediment, and fish in the Ikpoba River. This information is crucial for understanding the potential impacts on the local population, wildlife, and overall ecosystem and can inform the development of appropriate management strategies to mitigate risks. Understanding the distribution and potential risks of heavy metals in this important waterway is crucial for ensuring long-term sustainability and well-being of the local environment and communities.

MATERIALS AND METHODS

Study Area

The Ikpoba River is positioned at latitudes 6°11′ and 6°29′N, and longitudes 5°33′ and 5°47′E, in Benin City, Edo State, Southern Nigeria lies within the western littoral hydrological area (Akintola 1986). Originating northwest of Benin City, it flows south through dense rainforests and receives organic matter from the surface runoff. The vegetation of the river includes secondary rainforest species such as grasses, shrubs, epiphytic ferns, water hyacinth, palm trees, bamboo, and rubber trees (Ibezute *et al.*, 2016; Tawari-Fufeyin and Ekaye, 2007)). Riparian communities engage in farming, fishing, and palm-wine tapping with a sparse population density. Industrial waste and drainage enter the river, notably at Benin City stormwater discharge (Chukwuka and Ogbeide, 2021). Sampling stations were established: Upstream Station 1 (Upper Lawani, N 6° 22'34.39452″, E 5° 38'45.92796″) and downstream station 2 (N 6° 20'3.594112″, E 5° 39'48.906 ″), receiving brewery effluent (Agashua *et al.*, 2023; Benka-Coker and Ojior, 1995).

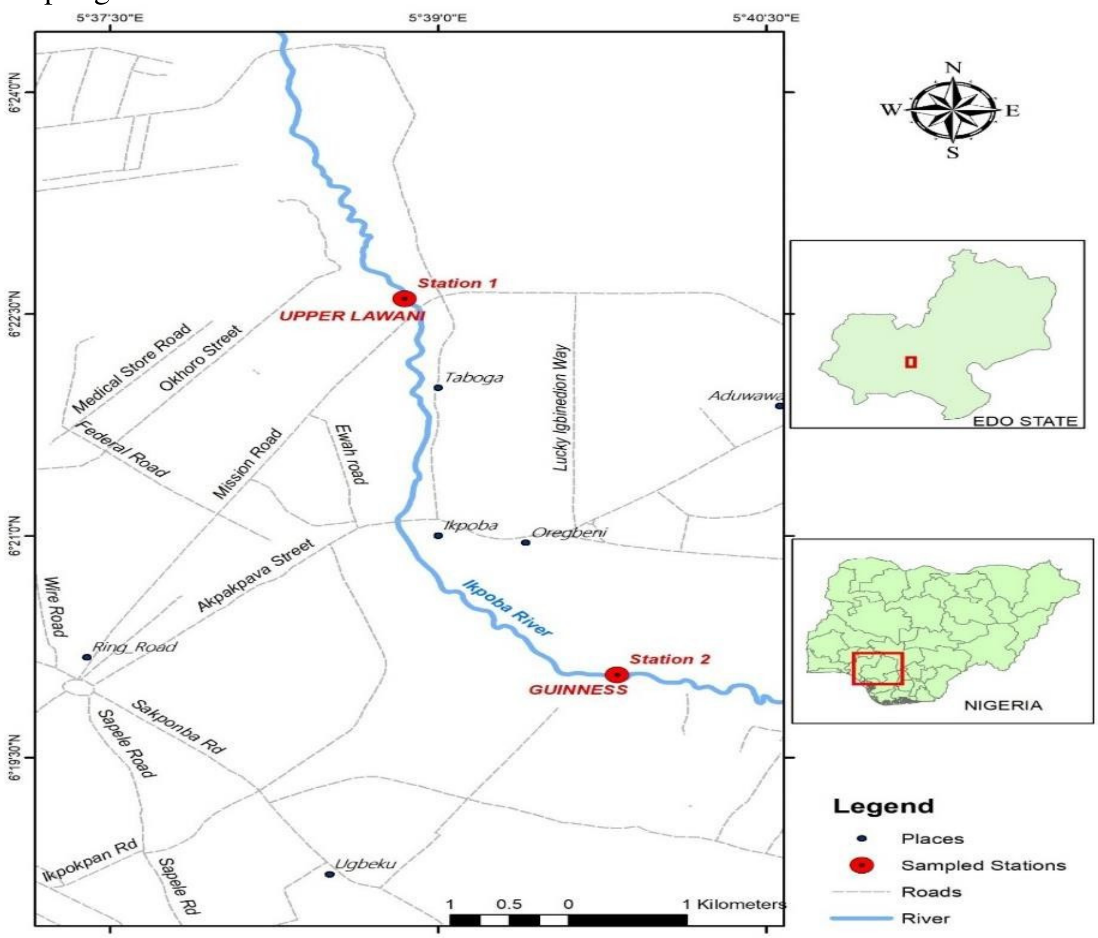

Fig. 1: Map of Study area

Collection of Water, Sediment and Fish Samples

During monthly sampling from June to August 2023, water, sediment, and fish samples were collected as follows: Water samples were collected for heavy metal analysis using a 75 ml plastic bottle. The bottles were selected, washed, dried, and labeled. The collection process involved submerging the bottle into the river, filling it with water, covering it, and setting it aside before transferring it to the laboratory. (Wang *et al.,* 2011). Sediment samples from the benthic area of the water body were collected using an Eckman grab. The samples were wrapped in foil and set aside before transportation to the laboratory for examination. Before digestion, the sediment samples were pulverized into fine, uniform particles, air-dried in the laboratory, and sieved through a 2 mm mesh sieve. (Davies and Ekperusi, 2021). Fish samples were obtained using a fishing net, according to the technique detailed in (Chukwuka. *et al.*, 2019), each of mature tilapia fish (*T. zilli)* and catfish (*C gariepinus*) were collected randomly from each sampling point in the river and transferred immediately into an icebox.

Heavy Metal Analysis

The methodologies were outlined by Davies and Ekperusi (2021) and Osioma and Iniaghe (2019). Water samples (25 ml) were treated with 1 ml HNO3 and 3 ml HCl, heated for 30 min, cooled, diluted to 50 ml, and stored. Sediment samples (10 g) were mixed with 25 ml distilled water, 1 ml HNO3, and 3 ml HCl, heated for an hour, cooled, filtered, diluted to 50 ml, and stored. Fish samples were dried, ground, treated with aqua regia, heated for 2 h at 80°C, periodically treated with 1% HNO3, filtered, and diluted. Heavy metals in all samples were analyzed using the AAS 969 Unicam Series for Cr, Co, Cd, Ni, and Pb. Each sample was analyzed three times using the standard calibration plot method (Wangboje and Ekundayo, 2013; Olele *et al*., 2013)

Quality Control

Throughout the experiments, the laboratory was maintained in a clean environment. The glassware was cleaned with detergent and water and then dried in an oven. The reagents were high-purity, and the sample blanks were analyzed for metals. Spike recovery analysis verified the procedure and instruments, and heavy metal concentrations were determined in triplicate for the spiked and unspiked water, sediment, and fish samples. (Bashir *et al.*, 2021; Egorova. *et al.*, 2021).

Data Analysis

Results were reported as mean ± SD. One-way ANOVA, conducted at a 95% confidence level, evaluated differences in metal concentrations across sites, with significance set at $P < 0.05$. Pearson's correlation analysis, using SPSS version 23 for Windows, assessed relationships between metal content in fish and their environment.

Ecological Risk Assessment

Metal Index (MI)

The Metal Index (MI) evaluates water quality based on the heavy metal content by summing the ratios of metal concentrations to their permissible limits (Ojekunle *et al.*, 2016). $MI = \sum\{Ci/(MAC)i\}$

The MI was calculated by comparing the concentration of each metal (Ci) to its maximum allowable concentration (MAC). An MI value greater than one indicates poor water quality. This method, supported by Raikwar *et al.* (2008) and Prasad and Sangita (2008), assesses the drinking water quality.

The Potential Ecological Risk Index (PERI)

The Potential Ecological Risk Index (PERI) assesses hazards to ecosystems from elements (Hakanson, 1980), focusing on the toxicological impact of heavy metals. It includes a contamination coefficient, toxic response factor, comprehensive contamination measure, and the PERI formula.

$$PERI = \sum_{i=1}^{n} E^i{}_r$$

Where E_r^i is the Ecological Risk Factor which is estimated using the fomular below

$E_r^i = C_f^i \text{ x } T_r^i$

Where T_r^i is the toxic-response factor of the *i-th* metal which is Pb 5, Co: 5, Cr 2, Cd: 30, Ni: 5 (Hakanson, 1980). While C_f^i. is the contamination factor which is calculated using the fomular below,

$$C_j^i = \frac{C_b^i}{C_n^i}$$

Where C_b^i is the background value of the *i-th* metal, C_n^i is the measured concentration of the *i-th* metal in sediment.

Igeo (Geo-accumulation Index)

The geoaccumulation index (Igeo) was used to evaluate the contamination levels of the heavy metals in the sediments. It compares the current concentrations with pre-industrial levels (background values).

$$(Igeo) = Log_2\left(\frac{C_s}{1.5\ x\ C_b}\right)$$

where the factor 1.5 is used to account for possible variations in the background values due to lithogenic effects.

Human Health Risk Assessment

Risk Assessment of Heavy Metals in the Water and Sediment

To estimate the heavy metal risks in water from the Ikpoba River, the following formula was used:

$$\text{ADDing} = \frac{C * IR * EF * ED}{BWX\ AT}$$

$$\text{ADDdermal} = \frac{C\ x\ SA\ x\ kp\ x\ ET\ x\ EF x\ ED}{BWX\ AT}$$

$$\text{ADDinh} = \frac{C\ x\ IR\ (inh)\ x\ EFx\ ED}{PEF\ X\ BWX\ AT}$$

Hazard quotient (HQ) = ADD/*RfD*

For the sediment samples, the Chronic Daily Intake (CDI) was estimated as follows:

$$\text{CDIing} = \frac{C * IR * EF * ED}{BWX\ AT}$$

$$\text{CDIdermal} = \frac{C\ x\ SA\ x\ ABS\ x\ ET\ x\ EF x\ ED}{BWX\ AT}$$

$$\text{CDIinh} = \frac{C\ x\ IR\ (inh)\ x\ EFx\ EDxPET}{BWX\ AT}$$

Hazard quotient (HQ) = CDI/*RfD*

The EPA guidelines specify the ingestion rate (IR) as 100 mg/day, exposure frequency (EF) at 350 days/year, and exposure duration (ED) of 30 years. The body weight (BW) was 70 kg. The average time (AT) for non-carcinogens was 30 years × 365 days/year, totaling 10,950 days. For dermal exposure, the surface area (SA) was 5,700 cm^2, the adherence factor (AF) 0.07 mg/cm^2, and the absorption factor (ABS) 0.001. The inhalation rate (IR) was 20 m^3/day, with a particle emission factor (PEF) of 1.36×10^9 m^3/kg.

Risk Assessment of Heavy Metal Consumption in Fish

The human health risk assessment of heavy metals in fish samples was performed using the formula described by the USEPA (USEPA, 1989, 2001 and 2011).

The Estimated Daily Intake (EDI = $\frac{C * FIR * EF * ED}{ABW * AT}$

Hazard quotient (HQ) = *EDI/RfD*

Carcinogenic risk (CR) = *EDI X CSF*

The parameters included exposure frequency (EF) of 365 days/year, exposure duration (ED) of 55 years, and average exposure time (AT) of 20,075 days. The fish ingestion rate (FIR) is 55.8 g/day for children and 52.8 g/day for adults, with an average body weight (ABW) of 60 kg for adults and 30 kg for children (WHO, 1994). The reference dose (RfD) values for Ni, 0.001 mg/kg/day for Cd, 0.043 mg/kg/day for Co, 1.5 mg/kg/day for Cr, and Pb were 0.02, 0.001, 0.043, 1.5, and 0.004 mg/kg/day, respectively. The Cancer Slope Factor (CSF) values are 0.042 mg/kg/day for Pb, 15 mg/kg/day for

Cd, and 0.5 mg/kg/day for Cr (Ahmed *et al.*, 2015; Yin *et al.*, 2024). The toxicity thresholds indicated that HQ and HI values above 1 were considered toxic, and for CR, values above 1 × 10^6 (for a single heavy metal) and 1 × 10^4 (for multiple heavy metals) were considered toxic.

RESULTS

Heavy Metal Concentrations in Water, Sediment, and Fish

The Ikpoba River water and sediment samples contained varying heavy metal concentrations. Water samples had significant Pb and Co levels in specific months, with consistent Cr and Ni presence (Table 1). Sediment samples showed consistent heavy metal levels, with Pb and Co increasing from May to July and minor Cr and Ca fluctuations (Table 2). Fish samples exhibited species- and month-dependent variations; *C. gariepinus* had higher Ni in May, while *T. zilli* had higher Pb. In July, *C. gariepinus* showed reduced metal concentrations, but *T. zilli* Pb and Cr levels increased compared to June (Table 3).

Table 1: Heavy metal concentration in water samples from Ikpoba River

Water	May	June	July
Pb	0	0.038*	0.033*
Co	0.018*	0	0
Cr	0.038*	0.036*	0.045
Cd	0	0	0
Ni	0.043*	0.027*	0.036*

Statistical significance ($P < 0.05$) is indicated by an asterisk

Table 2: Heavy metal concentration in sediment samples from Ikpoba River

Sediment	May	June	July	Bv	TRf
Pb	0.418*	3.316*	5.517*	24.1	5
Co	1.892*	0.314*	0.501*	12.4	5
Cr	2.362*	1.962*	1.843*	82.5	2
Cd	0.197*	0.144*	0.209*	0.07	30
Ni	7.007*	1.312*	1.516*	0.1	5

Statistical significance ($P < 0.05$) is indicated by an asterisk

Table 3: Heavy metal concentration in fish samples from Ikpoba River

Month	Species	Pb	Co	Cr	Cd	Ni
May	*C. gariepinus*	0.06	0.06*	0.50*	0.05	0.94*
	T. zilli	0.18	0.06*	0.35*	0.04	0.76*
June	*C. gariepinus*	0.70*	0.06*	0.48*	0.02	0.07
	T. zilli	0.11	0.01	0.01	0.01	0.01
July	*C. gariepinus*	0.02	0	0.17	0	0
	T. zilli	0.58*	0.04	0.18	0.02	0.07

Statistical significance ($P < 0.05$) is indicated by an asterisk

Risk Assessment of Metals in Ikpoba River Watershed

As shown in Table 4, the Metal Index (MI) increased for heavy metals in the water samples from May (2.633) to July (3.523), with the highest value in June. Table 5 shows that the Potential Ecological Risk Index (PERI) for heavy metals in the sediment samples was highest in May (435.262), indicating a significant ecological risk. Table 6 shows the negative Geo-accumulation Index (Igeo) values in sediment samples across all months, indicating no significant geo-accumulation of metals.

Table 4: Metal Index (MI) for Heavy Metals in Water Samples

Month	Pb	Co	Cr	Ca	Ni	MI Value
May	0.000	0.360	0.760	0.000	0.430	**1.550**
June	2.533	0.000	0.720	0.000	0.270	**3.523**
July	2.200	0.000	0.900	0.000	0.360	**3.460**

Table 5: Potential Ecological Risk Index (PERI) for Heavy Metals in Sediment Samples

Month	Pb	Co	Cr	Cd	Ni	PERI Value
May	0.087	0.076	0.057	84.429	350.613	**435.262**
June	0.688	0.013	0.048	61.714	65.713	**128.176**
July	1.144	0.020	0.045	89.571	75.982	**166.762**

Table 6: Geo-accumulation Index (Igeo) for Heavy Metals in Sediment Samples

Month	Pb	Co	Cr	Cd	Ni
May	-6.434	-3.297	-5.711	-5,711	-5,711
June	-3,446	-5,888	-5,979	-5,979	-5,979
July	-2,712	-5,214	-6,069	-6,069	-6,069

Table 7: Average Daily Dose (ADD (mg/kg-day)) and HQ for Heavy Metals in water

Exposure Route	Metal	May ADD	May HQ	June ADD	June HQ	July ADD	July HQ
Ingestion	Pb	0	0	0.0034	0.85	0.0034	0.85
	Co	0.0008	0.027	0	0	0	0
	Cr	0.0039	1.3	0.0047	1.57	0.0047	1.57
	Ni	0.0045	0.225	0.0038	0.19	0.0038	0.19
Dermal	Pb	0	0	0.0009	0.225	0.0009	0.225
	Co	0.0005	0.017	0	0	0	0
	Cr	0.001	0.33	0.0012	0.4	0.0012	0.4
	Ni	0.0012	0.06	0.001	0.05	0.001	0.05
Inhalation	Pb	0	0	9.86×10^{-10}	2.46×10^{-7}	9.86×10^{-10}	2.46×10^{-7}
	Co	5.36×10^{-10}	1.79×10^{-8}	0	0	0	0
	Cr	1.13×10^{-9}	3.77×10^{-7}	1.34×10^{-9}	4.47×10^{-7}	1.34×10^{-9}	4.47×10^{-7}
	Ni	1.34×10^{-9}	6.7×10^{-8}	1.07×10^{-9}	5.35×10^{-8}	1.07×10^{-9}	5.35×10^{-8}

Table 8: Chronic Daily Dose (CDI (mg/kg-day)) and HQ for Heavy Metals in sediment

Exposure Pathway	Metal	Parameter	May	June	July
Ingestion	Pb	CDI	0.0000213	0.000379	0.000669
		HQ	0.1014	0.8036	1.337
	Co	CDI	7.68E-06	0.0000147	0.0000869
		HQ	0.7633	0.1267	0.202
	Cr	CDI	0.0000259	0.0000241	0.0000203
		HQ	0.0953	0.0789	0.074
	Cd	CDI	2.55E-06	2.27E-06	4.55E-06
		HQ	0.2382	0.0447	0.0606
	Ni	CDI	1.46E-06	9.32E-07	1.25E-06
		HQ	0.0137	0.00257	0.00293
Dermal	Pb	CDI	1.21E-08	2.2E-07	3.84E-07
		HQ	5.78 x E-5	4.59 E--4	7.62 E-4
	Co	CDI	4.33E-09	7.72E-09	1.52E-08
		HQ	4.36 E-4	7.27 E-5	1.16 E-4
	Cr	CDI	1.46E-08	1.34E-08	1.12E-08
		HQ	5.47 E-5	4.53 E-5	4.27 E-5
	Cd	CDI	1.44E-09	1.28E-09	2.56E-09
		HQ	1.37 E-4	1.00 E-8	3.47 *E*-8
	Ni	CDI	8.27E-10	5.75E-10	7.75E-10
		HQ	7.87 *E*-6	5.75 *E*-7	6.52 *E*-7
Inhalation	Pb	CDI	3.9E-11	1.57E-09	2.68E-09
		HQ	2.34 *E*-8	1.86 *E*-7	3.09 *E*-7
	Co	CDI	1.5E-11	3.6E-11	5.3E-11
		HQ	1.78 *E*-7	2.95 *E*-8	4.69 *E*-^-8
	Cr	CDI	5E-11	4.6E-11	3.9E-11
		HQ	2.22 *E*-8	1.85 *E*-8	1.74 *E*-8

Table 9: EDI, HQ, and CR for Adults and Children for heavy metals in fish species

Month	Species	Metal	EDI (Adults) (mg/kg/day)	HQ (Adults)	CR (Adults)	EDI (Children) (mg/kg/day)	HQ (Children)	CR (Children)
May	*C. gariepinus*	Pb	8.80E-07	2.20E-04	3.70E-08	3.72E-06	9.30E-04	1.56E-07
		Co	8.80E-07	2.05E-05	N/A	3.72E-06	8.65E-05	N/A
		Cr	7.33E-06	4.89E-06	3.67E-06	3.10E-05	2.07E-05	1.55E-05
		Cd	7.30E-07	7.30E-01	1.10E-05	3.10E-06	3.10E+00	4.65E-05
		Ni	1.38E-05	6.90E-04	N/A	6.20E-05	3.10E-03	N/A
	T. zilli	Pb	2.64E-06	6.60E-04	1.11E-07	1.12E-05	2.80E-03	4.71E-07
		Co	8.80E-07	2.05E-05	N/A	3.72E-06	8.65E-05	N/A
		Cr	5.13E-06	3.42E-06	2.57E-06	2.17E-05	1.45E-05	1.09E-05
		Cd	5.90E-07	5.90E-01	8.90E-06	2.48E-06	2.48E+00	3.72E-05
		Ni	1.14E-05	5.70E-04	N/A	4.72E-05	2.36E-03	N/A
June	*C. gariepinus*	Pb	1.02E-05	2.55E+00	4.30E-07	4.34E-05	1.09E+01	1.82E-06
		Co	8.80E-07	2.05E-05	N/A	3.72E-06	8.65E-05	N/A
		Cr	7.04E-06	4.70E-06	3.52E-06	3.09E-05	2.06E-05	1.55E-05
		Cd	2.90E-07	2.90E-01	4.35E-06	1.29E-06	1.29E+00	1.94E-05
		Ni	1.01E-06	5.05E-05	N/A	4.13E-06	2.07E-04	N/A
	T. zilli	Pb	1.61E-06	4.00E-04	6.75E-08	6.50E-06	1.63E-03	2.73E-07
		Co	1.50E-07	3.40E-06	N/A	5.80E-07	1.35E-05	N/A
		Cr	1.50E-07	1.00E-07	7.50E-08	5.80E-07	3.90E-07	2.90E-07
		Cd	1.50E-07	1.50E-01	2.25E-06	5.80E-07	5.80E-01	8.70E-06
		Ni	1.50E-07	7.50E-06	N/A	5.80E-07	2.90E-05	N/A
July	*C. gariepinus*	Pb	2.90E-07	7.25E-05	1.22E-08	1.24E-06	3.10E-04	5.20E-08
		Co	0.00E+00	0.00E+00	N/A	0.00E+00	0.00E+00	N/A
		Cr	2.49E-06	1.66E-06	1.25E-06	1.04E-05	6.93E-06	5.20E-06
		Cd	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Ni	0.00E+00	0.00E+00	N/A	0.00E+00	0.00E+00	N/A
	T. zilli	Pb	8.48E-06	2.12E-03	3.56E-07	3.59E-05	8.97E-03	1.51E-06
		Co	5.80E-07	1.35E-05	N/A	2.48E-06	5.77E-05	N/A
		Cr	2.64E-06	1.76E-06	1.32E-06	1.12E-05	7.47E-06	5.60E-06
		Cd	2.90E-07	2.90E-01	4.35E-06	1.24E-06	1.24E+00	1.86E-05
		Ni	1.01E-06	5.05E-05	N/A	4.13E-06	2.07E-04	N/A

Discussion

Heavy Metals in Water, Sediment and Fish from Ikpoba River

The significant concentrations of Pb, Co, Cr, and Ni in Ikpoba River water samples likely result from industrial discharge, agricultural runoff, and improper waste disposal, while the absence of significant Cd levels may indicate lower anthropogenic input or effective dilution (Adeleke *et al*., 2023; Adeniyi *et al*., 2024). Sediments accumulate heavy metals from geological, land cover, and anthropogenic influences, which can be released back into water, affecting ecosystems and human health, harming aquatic organisms, disrupting food webs, and posing carcinogenic risks via bioaccumulation (Adeleke *et al*., 2023; Lotz and Opp, 2022; Bhuyan *et al*., 2023; Wojtkowska, 2023; Chris *et al*., 2023; Panda *et al*., 2023; Saini and Dhania, 2022). Global studies, including those on the Xiaoqing River and in Poland, echo these concerns (Fang *et al*., 2023; Sojka and Jaskuła, 2022). Heavy metals in fish can cause ailments, affect hatching rates, and lead to deformities, while human consumption of contaminated fish results in health issues due to bioaccumulation (Ajala *et al*., 2022; Sojka and Jaskuła, 2022). Studies on the Meghna River Estuary, fish cultured using biofloc technology, and comprehensive assessments of freshwater fish confirm these patterns (Habib *et al*., 2023; Surya and Malsoor, 2023; Aarabi *et al*., 2023).

Ecological Risk Assessment of Metals in Ikpoba River Watershed

The results from the Ikpoba River watershed indicate potential water quality issues and significant ecological risks due to heavy metals. The increasing Metal Index (MI) values from May to July, with the highest value of 3.523 in June, suggest that water quality exceeds USEPA permissible limits, posing threats to aquatic life and human health if used for drinking or irrigation without proper treatment (Widyastuti *et al*., 2020). The Potential Ecological Risk Index (PERI) values, particularly in May (435.262), indicate considerable ecological risks, potentially reducing biodiversity and disrupting aquatic food chains, which can affect larger animals and humans relying on these ecosystems for food or recreation (Ajani *et al*., 2021; Enuneku and Ineh, 2020). Negative Geo-accumulation Index (Igeo) values across all months indicate no significant sediment contamination compared to pre-industrial levels, though localized effects or bioaccumulation over time could still pose risks (Kamel *et al*., 2023; Rzetala *et al*., 2023).

Human Risk Assessment of Metals in Ikpoba River Watershed

Tables 7, 8, and 9 present the analysis of toxicity and exposure levels of heavy metals through various environmental pathways, focusing on the Average Daily Dose (ADD), Chronic Daily Intake (CDI), Hazard Quotients (HQ), and Cancer Risks (CR). Table 7 shows the ADD and HQ values for heavy metals in water via ingestion, dermal contact, and inhalation from May to July. Pb ingestion HQs are generally low, except in June and July when Cr ingestion exceeds the threshold (>1), indicating potential toxicity. Dermal and inhalation exposures remain below toxicity levels. Similar studies have shown that ingestion often has higher HQ values than dermal and inhalation exposures (Alidadi *et al*., 2019; Mohammed *et al*., 2023). These findings are consistent with previous regional studies (Alidadi *et al*., 2023; Alidadi *et al*., 2019; Lan *et al*., 2023; Zanon *et al*., 2023; Xu *et al*., 2023).

Table 8 presents the CDI and HQ values for heavy metals in sediment via ingestion, dermal contact, and inhalation. The HQ value of Pb exceeds 1 in July, indicating potential chronic toxicity. Co and Cr exhibit fluctuating HQs, generally below 1, with Cd and Cr near the threshold. Dermal contact and inhalation pose minimal risks, with HQs well below toxicity levels. Studies have highlighted health risks posed by heavy metals in sediments, particularly through ingestion. Research in Nigeria has found significant risks from ingestion, similar to the high HQ values for Pb and Cr in this study (Adesiyan *et al*., 2018; Ololade *et al*., 2024). Heavy metals in sediments can enter the biological chain, threatening water supply and health (Miletić *et al*., 2023). Carcinogenic risks, especially from industrial and coal sources, often exceed safe levels for children, with Cr being a major contributor (Liu *et al*., 2023). Additionally, non-carcinogenic risks in bed sediments can surpass safe levels, particularly for children (Panqing *et al*., 2023). Monitoring and mitigating these risks are crucial for protecting health and the environment.

Table 9 provides the EDI, HQ, and CR values for heavy metals in fish, revealing significant risks from Cd in children, with HQ values consistently above the toxicity threshold. Pb levels also exceed the threshold for both adults and children in June. Cr and Ni have moderate HQ values, generally below the threshold, whereas CR values for Cr are low, indicating minimal carcinogenic risk. Similar studies have reported comparable risks for heavy metals in fish. Research in Nigeria has reported significant HQ values for Pb and Cr, indicating health risks from ingestion (Chima *et al*., 2022). Studies from the Gulf of Catania have reported HQ values for various metals that pose health risks, especially through ingestion (Copat *et al*., 2013). Other studies in locations such as India and Nigeria have also highlighted elevated levels of toxic metals in fish, posing health hazards (Aarabi *et al*., 2023; Hossain *et al*., 2022; Köker *et al*., 2021; Pinzón-Bedoya *et al*., 2020; Yaradua *et al*., 2022). These findings underscore the need for regular monitoring and regulatory measures to ensure the safe consumption of fish

Conclusion

This study's findings reveal significant concerns about heavy metal contamination and related ecological and human health risks. Increasing Metal Index (MI) values, high Potential Ecological Risk Index (PERI), and elevated heavy metal levels in water, sediment, and fish samples necessitate urgent intervention and management strategies. The human health risk assessment indicated potential chronic toxicity from ingesting water and sediment and elevated cancer risks from fish consumption, especially in children. These results emphasize the need for regular monitoring, pollution control measures, and public awareness campaigns to protect the Ikpoba River ecosystem and local population health. Comprehensive and sustained efforts are crucial to mitigate these risks and ensure the long-term sustainability of this vital water resource.

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