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ORIGINAL ARTICLE

SEASONAL DYNAMICS OF HEAVY METAL POLLUTION IN WATER, SEDIMENT AND FISH OF OYIVO RIVER IN ABIA STATE NIGERIA

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Abstract

This study investigated the seasonal variation in heavy metal ion concentrations in sediment and fish tissues from Oyivo River, a freshwater body in Umuahia Abia State, Nigeria, affected by various anthropogenic activities. Samples were collected monthly in July, August, and September from four strategic locations: Ohiya Nsukwe, Express Road, Egbeada, and Ehume Bridge, using a stratified random sampling method. Composite sediment and fish tissue samples were analyzed for Zn, Ni, Fe, Cu, Co, Cr, Cd, Pb, Mn, Na, K, Ca, and Mg using atomic absorption spectroscopy. Sediment analysis revealed elevated levels of Pb (2.86–4.73mg/kg), Cd (0.42–1.38mg/kg), and Co (2.24–3.96mg/kg), with the Ohiya Nsukwe location in August recording the highest concentrations. The Express Road location also showed significantly high Ca levels, likely due to runoff from nearby kaolin mining operations. Fish tissue analysis revealed lower levels of metal accumulation, with concentrations such as Zn (4.92mg/kg), Ni (0.21mg/kg), Cu (1.07mg/kg), and Mn (1.23mg/kg), suggesting minimal immediate dietary risk. However, the persistence of heavy metals in sediment poses long-term ecological risks through bioaccumulation and bio-magnification. The study emphasizes the need for continuous environmental monitoring and effective land-use management to reduce contamination in freshwater systems across Abia State.

Keywords: Fishing, ecosystem health, seasonal variability, water quality indices.

Introduction

The Oyivo River, located in Umuahia North Local Government Area of Abia State, Nigeria, serves as a vital resource for surrounding communities, providing water for domestic activities, agriculture, and fishing (Anyanwu *et al.*, 2022). However, increasing anthropogenic pressures including industrial effluents, agricultural runoff, and indiscriminate waste disposal have raised serious issues concerning the river's water quality, particularly with respect to heavy metal pollution. These contaminants are known to accumulate in aquatic environments—water, sediments, and biota posing significant risks to ecosystem health and human populations that rely on aquatic products (Sonone *et al*., 2020).

Previous studies in nearby rivers, such as the Ikwu and Ahi Rivers in Umuahia, have documented elevated concentrations of heavy metals that frequently exceed safe thresholds, rendering the water unfit for human consumption and indicating substantial pollution potential (Anyanwu *et al*., 2023; Anyanwu *et al*., 2024). Seasonal fluctuations further complicate this issue, as variables like rainfall, temperature, and flow rate influence the solubility, mobility, and biological uptake of metals (Agbasi *et al*., 2023). A meta-analysis of Nigerian surface waters underscored the ecological and public health risks posed by current pollution levels, calling for sustained and systematic monitoring (Bawa-Allah, 2023). Similarly, significant ecological degradation linked to heavy metal contamination has been observed in the Hadejia River, stressing the urgency of evaluating pollution in other critical water bodies (Ibe and Okoro, 2023).

Despite the Oyivo River's importance to local livelihoods, there is a marked lack of detailed data on the seasonal dynamics of heavy metal contamination in its aquatic system. This knowledge gap hinders evidence-based management and policy formulation aimed at mitigating pollution and safeguarding public health (Ibe and Okoro, 2023). Given the documented risks and increasing anthropogenic pressures, a detailed monthly assessment of heavy metal concentrations in water, sediments, and fish is urgently needed. Such an investigation will not only illuminate current contamination trends but also guide targeted interventions to preserve the river's ecological function and protect the well-being of dependent communities (Anyanwu *et al*., 2022).

Consequently, a comprehensive assessment of the Oyivo River's water quality was carried out using multi-compartmental monitoring across different seasons, with a focus on metal concentrations in water, sediment, and fish tissues. Pollution levels were further evaluated using indices such as the heavy metal pollution index, contamination factor, and pollution load index, while potential risks to human and ecological health were assessed through hazard quotient analysis and reference dose comparisons.

Materials and Methods

The Study Area

Oyivo is a perennial River that originates from a deep basin in Okpururi village, Afaraukwu Ibeku, situated behind the Modern Ceramics Industry. It flows in a northwestward direction, passing through Afara Technical Secondary School in Umuahia North Local Government Area of Abia State. The stream continues into the Ohiya Autonomous Community in Umuahia South Local Government Area, crossing the Port Harcourt–Enugu Expressway near the Mechanic Village. From there, it flows through the communities of Umuihe, Ogbodi, and Ogbodinaibe before emptying into the Imo River. Near its confluence, Oyivo serves as a natural boundary between the Ehume and Ogbodinibe communities.

Oyivo stream which spans approximately 18.1 kilometers (Figure 1) receives water from various smaller tributaries along its course. The stream's hydrology is influenced by seasonal rainfall patterns, with increased water volume during the rainy season due to surface runoff and reduced flow in the dry season. Several human activities, including farming, washing, and industrial discharges, contribute to variations in the water quality (Ngah and Ekpebegh, 2016).

Selection of Sampling Points for the Study

A reconnaissance survey was conducted before water, sediments and fish sample collection to identify potential effluent sources, rainwater runoff pathways, and human-ecological interactions along the stream. This preliminary assessment informed the selection of upstream, midstream, and downstream sampling stations. Four sampling locations were established for the study;

- Sampling Point 1 (Express Road/Bridge Crossing), located just after the express road at 5.50972°N, 7.44583°E and an elevation of 89 m, where the stream forms a large plunge pool upon crossing the bridge. This point captures runoff from the Mechanic Village and nearby kaolin mining activities.

- Sampling Point 2 (Egbeada Village), situated at 5.51694°N, 7.43972°E and an elevation of 75 m, where residents use the stream for domestic activities such as fetching water, swimming, and washing clothes.

- Sampling Point 3 (Umuihe Bridge), located at 5.52222°N, 7.42833°E and an elevation of 65 m, represents the lower course of the stream for this study. Similar to Egbeada, it is used by locals for various domestic activities.

- Sampling Point 4 (Ohiya Nsukwe Village), positioned at 5.50123°N, 7.47060°E and an elevation of 91 m, served as the control site, as it was presumed to experience minimal anthropogenic influence.

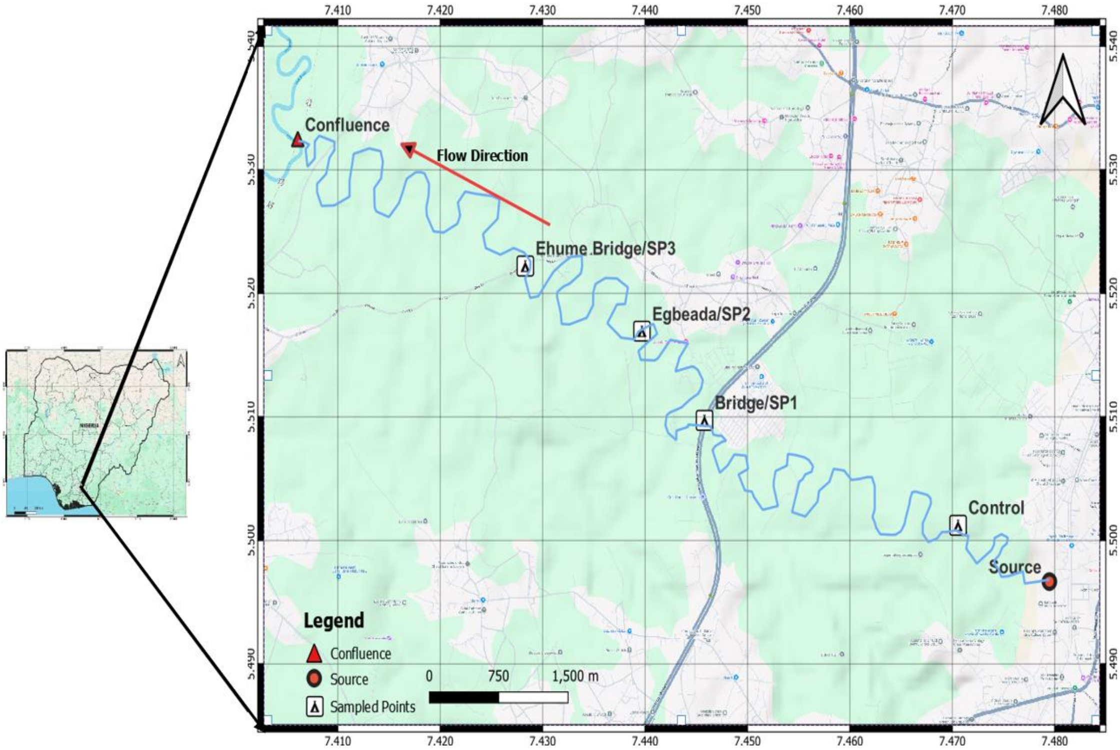

Figure 1: Map of the study area and sampled points

Sample Collection Methods

Fish, sediment, and surface water samples were collected from each of the four designated sampling stations along the Oyivo River during the rainy season, specifically in the months of July, August, and September. For fish collection, three basket traps were set up at each location to catch specimens of similar size and weight. A total of six *Oreochromis niloticus* (Nile tilapia), each weighing between 0.4 and 0.5kg, were harvested per site. The fish were placed in small coolers containing river water collected from the same location where the fish were captured. These coolers were clearly labelled and placed within larger coolers to prevent contamination from external sources. Using the same species across all sites helped ensure that any variations observed in tissue metal concentrations were attributable to environmental exposure rather than biological differences.

Sediment samples were collected to evaluate heavy metal deposition at the bottom of the stream. Twelve sediment samples were randomly obtained at each sampling station using a grab sampler. The samples were placed in clean, labelled containers and promptly transported to the laboratory for analysis. Surface water samples were collected at a depth of 1 meter below the water surface. Prior to sampling, each pre-cleaned bottle was rinsed three times with river water from the sampling location. The bottles were then filled to the brim, acidified with 10% nitric acid (HNO_3), tightly sealed, and labelled. All water samples were stored in ice chest containers and transported to the laboratory for pre-treatment and subsequent analysis.

Sample Digestion and Heavy Metal Determination

Fish samples were digested following the procedures outlined by the Association of Official Analytical Chemists (AOAC, 2000), while sediment digestion followed the method of Defew *et al*. (2005). Water samples were digested using a wet acid extraction method (Matusiewicz, 2003). Specifically, 20mL of each sample was placed into a 150mL Pyrex beaker, followed by the addition of 10mL concentrated nitric acid. The mixture was heated on a mantle at 200°C until it evaporated to near dryness. After cooling for approximately 20 minutes, 5mL of 75% perchloric acid was added, and the samples were reheated until white perchloric acid fumes were emitted, indicating complete digestion. Once cooled, the digests were diluted to 50mL with deionized water in a volumetric flask.

The concentrations of heavy metals in water, fish, and sediment samples were determined using an Atomic Absorption Spectrophotometer, Model 210 VGP (Buck Scientific) with appropriate cathode lamps for each target metal.

Quality Assurance and Control

To ensure data integrity and minimize contamination, all glassware and polyethylene containers were pre-cleaned with 5% nitric acid and rinsed thoroughly with distilled, deionized water. Water samples for pH and dissolved oxygen measurements were collected in 1-litre dark brown glass bottles, while those for other chemical analyses were stored in high-density polyethylene bottles, in line with established protocols (APHA, 2017). Only analytical-grade reagents were used throughout the experimental procedures.

Statistical Analysis

Data obtained from laboratory analyses were subjected to multivariate analysis of variance (MANOVA) to assess the effects of sampling month, sampling location, and their interaction (Month × Location) on the concentrations of heavy metal ions in water and sediment samples. Following MANOVA, univariate analysis of variance (ANOVA) was conducted to determine significant differences in heavy metal concentrations across sampling months and locations for water, sediment, and fish tissue samples. Where significant differences were detected, Tukey's post hoc test was employed to identify specific months and locations that differed significantly from each other. All statistical analyses were performed using IBM SPSS Statistics software, version 25, with significance considered at $p < 0.05$.

Results

Table 1 shows the multivariate analysis of variance. It was indicated that the sampling months (temporal), locations (spatial) variations, and their interaction (Month×Location) have statistically significantly affected the concentration of heavy metals in water and sediments from Oyivo River. The effect of Month was significant (p = 0.016 for Pillai's Trace, p=0.025 for Wilks' Lambda), indicating that heavy metals varied across the months of July, August and, September. Similarly.

Table 1: Multivariate Tests of Month, Location, and Interaction Effects on Water and Sediment Heavy Metal Level

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	1.000	67887.162[b]	18.000	1.000	.003	1.000
	Wilks' Lambda	.000	67887.162[b]	18.000	1.000	.003	1.000
	Hotelling's Trace	1221968.913	67887.162[b]	18.000	1.000	.003	1.000
	Roy's Largest Root	1221968.913	67887.162[b]	18.000	1.000	.003	1.000
Month	Pillai's Trace	1.980	10.851	36.000	4.000	.016	.990
	Wilks' Lambda	.000	38.770[b]	36.000	2.000	.025	.999
	Hotelling's Trace	9899.347	.000	36.000	.000	.	1.000
	Roy's Largest Root	9850.771	1094.530[c]	18.000	2.000	.001	1.000
Location	Pillai's Trace	2.974	18.720	54.000	9.000	.000	.991
	Wilks' Lambda	.000	56.433	54.000	3.796	.001	.999
	Hotelling's Trace	.	.	54.000	.	.	.
	Roy's Largest Root	21888.642	3648.107[c]	18.000	3.000	.000	1.000
Month * Location	Pillai's Trace	3.677	2.529	72.000	16.000	.020	.919
	Wilks' Lambda	.000	13.717	72.000	6.289	.001	.993
	Hotelling's Trace	.	.	72.000	.	.	.
	Roy's Largest Root	9079.513	2017.670[c]	18.000	4.000	.000	1.000

a. Design: Intercept + Month + Location + Month * Location
b. Exact statistic
c. The statistic is an upper bound on F that yields a lower bound on the significance level.

The effect of Location was also highly significant ($p \leq 0.001$ across all tests), meaning that different locations exhibited distinct patterns of heavy metal contamination of water and sediments. Additionally, the Month×Location interaction is significant ($p=0.020$ for Pillai's Trace, $p=0.001$ for Wilks' Lambda), suggesting that the impact of month varies across different locations. This implies that temporal variations heavy metals were not uniform across locations. The high Partial Eta Squared values (ranging from 0.919 to 1.000) indicated that these factors explained a large proportion of the variance in the dataset on heavy metal concentrations in sediment and water samples collected across different months (July, August, September) and locations (Ohiya Nsukwe, Express Road, Egbeada, and Ehume Bridge).

Heavy metals in water samples from Oyivo River

Table 2 shows the concentration of heavy metals in Oyivo River across the locations and months (July–September). Higher levels of heavy metals were generally observed at the Express Road crossing (upstream) and lowest at the control site, Ohiya Nsukwe. Zinc ranged from 0.00±0.00 to 0.07±0.07mg/L, well below the FME (2011) limit of 5mg/L. Nickel exceeded the 0.02mg/L limit at all sites, peaking at 0.58±0.02mg/L in July (Express Road). Mercury, though low (0.00±0.00 to 0.02±0.01mg/L), surpassed the 0.001mg/L threshold at all stations.

Manganese reached 0.58±0.02mg/L in July upstream, apparently well above the 0.1mg/L limit, while Lead spiked at 0.10 ± 0.10 mg/L in August at the control site, exceeding the 0.01mg/L standard. Iron mostly stayed within safe limits (0.00±0.00 to 0.31±0.01mg/L), except in July upstream. Copper rose to 0.41±0.42mg/L at the same location. Cadmium was consistently above the 0.003 mg/L limit, peaking at 0.36 ± 0.46 mg/L upstream in July. At Ohiya Nsukwe (control), none of the measured heavy metals showed statistically significant monthly variations ($p > 0.05$) for Zn, Ni, Mn, Co, Cr, and Cd, suggesting that their concentrations remained stable over time. In contrast, at Express Road/Bridge Crossing (upstream) the water exhibited more dynamic behavior—while Zn and Cd remain stable, Mn, Co, and especially Cr showed significant monthly differences. Egbeada's (midstream) data reveal significant temporal variability in Ni and Cr ($p < 0.05$), whereas Zn, Mn, Co, and Cd remain comparatively stable ($p>0.05$). Finally, at Ehume (downstream), Zn, Ni, and Cr show marked monthly variation, ($p<0.05$), while Mn, Co, and Cd do not vary significantly across the sampled months ($p<0.05$).

Heavy metals in sediment samples from Oyivo River

Table 3 shows the concentration of heavy metal in sediment samples from the Oyivo River. Similar to the trend observed for heavy metals in water, higher values were recorded at Express Road (upstream) compared to Ohiya Nsukwe (control). Zinc levels ranged from 0.12 ± 0.04mg/kg at Ohiya Nsukwe in August to 1.76±0.11mg/kg upstream in August. Nickel (Ni^{2+}) was highest at the upstream site (12.66±0.40mg/kg in July), exceeding acceptable thresholds, while remaining lowest at the control (0.47±0.46mg/kg in July). Mercury was largely undetectable across sites, except for trace levels upstream (0.02±0.01mg/kg in August).

Manganese values peaked upstream at 8.57±0.43mg/kg in July, significantly surpassing those at the control (0.36±0.38mg/kg). Lead ranged from 0.00 ± 0.00mg/kg at Ohiya Nsukwe to 0.81±0.67mg/kg upstream in September. Iron was consistently highest upstream (4.92±0.07mg/kg in July) and lowest at the control (1.58±0.50mg/kg in September). Copper followed a similar trend, with maximum values of 4.85±0.41mg/kg upstream in August and a minimum of 0.42 ± 0.47mg/kg at the control. Cobalt remained relatively low but was highest upstream (0.32±0.02mg/kg) and lowest at the control (0.14±0.02mg/kg). Chromium was notably elevated upstream (0.47±0.20mg/kg in September) compared to downstream values. Cadmium concentrations were highest upstream (0.50±0.13mg/kg in August), while it was undetectable at the control site throughout.

At Ohiya Nsukwe (control), the heavy metals in sediments remained largely stable over the sampling months with no statistically significant difference ($p>0.05$) observed. In contrast, Express Road/Bridge Crossing (upstream) sediments exhibited slightly higher variability for Zn and Mn.

Table 2: Heavy metal contents in water samples (mg/L)

Location	Month	Zn	Ni	Hg	Mn	Pb	Fe	Cu	Co	Cr	Cd
Ohiya Nsukwe (Control)	July	$0.03^{ab}\pm0.04$	$0.27^{b}\pm0.18$	$0.00^{a}\pm0.00$	$0.19^{bc}\pm0.15$	$0.00^{b}\pm0.00$	$0.00^{c}\pm0.00$	$0.00^{a}\pm0.00$	$0.06^{a}\pm0.01$	$0.02^{d}\pm0.01$	$0.02^{a}\pm0.00$
	August	$0.02^{b}\pm0.02$	$0.06^{b}\pm0.02$	$0.01^{a}\pm0.01$	$0.02^{c}\pm0.01$	$0.10^{a}\pm0.10$	$0.06^{b}\pm0.01$	$0.03^{a}\pm0.03$	$0.05^{a}\pm0.03$	$0.02^{cd}\pm0.00$	$0.02^{a}\pm0.00$
	September	$0.03^{ab}\pm0.01$	$0.31^{b}\pm0.41$	$0.02^{a}\pm0.01$	$0.02^{c}\pm0.01$	$0.06^{ab}\pm0.03$	$0.00^{c}\pm0.01$	$0.00^{a}\pm0.01$	$0.00^{a}\pm0.01$	$0.01^{d}\pm0.01$	$0.02^{a}\pm0.00$
Express Road crossing (Upstream)	July	$0.06^{a}\pm0.02$	$0.58^{a}\pm0.02$	$0.01^{a}\pm0.00$	$0.58^{a}\pm0.02$	$0.01^{b}\pm0.00$	$0.31^{a}\pm0.01$	$0.41^{a}\pm0.42$	$0.06^{a}\pm0.00$	$0.06^{a}\pm0.00$	$0.36^{a}\pm0.46$
	August	$0.07^{a}\pm0.07$	$0.43^{ab}\pm0.19$	$0.01^{a}\pm0.01$	$0.42^{ab}\pm0.29$	$0.01^{b}\pm0.00$	$0.05^{b}\pm0.00$	$0.36^{a}\pm0.48$	$0.06^{a}\pm0.00$	$0.03^{b}\pm0.00$	$0.09^{a}\pm0.00$
	September	$0.03^{ab}\pm0.03$	$0.30^{ab}\pm0.02$	$0.00^{a}\pm0.00$	$0.12^{c}\pm0.00$	$0.01^{b}\pm0.00$	$0.04^{bc}\pm0.00$	$0.01^{a}\pm0.01$	$0.02^{a}\pm0.02$	$0.03^{bc}\pm0.00$	$0.09^{a}\pm0.01$
Egbeada (Midstream)	July	$0.01^{b}\pm0.01$	$0.24^{ab}\pm0.01$	$0.00^{a}\pm0.00$	$0.07^{c}\pm0.12$	$0.00^{b}\pm0.00$	$0.03^{bc}\pm0.03$	$0.01^{a}\pm0.01$	$0.32^{a}\pm0.53$	$0.03^{bc}\pm0.00$	$0.03^{a}\pm0.02$
	August	$0.01^{b}\pm0.01$	$0.06^{b}\pm0.03$	$0.00^{a}\pm0.00$	$0.03^{c}\pm0.03$	$0.00^{b}\pm0.00$	$0.00^{c}\pm0.00$	$0.05^{a}\pm0.00$	$0.00^{a}\pm0.00$	$0.02^{cd}\pm0.00$	$0.03^{a}\pm0.00$
	September	$0.01^{b}\pm0.01$	$0.04^{b}\pm0.00$	$0.00^{a}\pm0.00$	$0.00^{c}\pm0.00$	$0.00^{b}\pm0.00$	$0.00^{c}\pm0.00$	$0.02^{a}\pm0.00$	$0.01^{a}\pm0.00$	$0.02^{cd}\pm0.00$	$0.03^{a}\pm0.00$
Ehume Bridge (Downstream)	July	$0.01^{a}\pm0.00$	$0.08^{b}\pm0.0$	$0.01^{a}\pm0.00$	$0.00^{c}\pm0.00$	$0.00^{b}\pm0.00$	$0.02^{bc}\pm0.04$	$0.01^{a}\pm0.01$	$0.00^{a}\pm0.00$	$0.02^{cd}\pm0.00$	$0.08^{a}\pm0.01$
	August	$0.00^{b}\pm0.00$	$0.03^{b}\pm0.00$	$0.00^{a}\pm0.00$	$0.00^{c}\pm0.00$	$0.00^{b}\pm0.00$	$0.00^{c}\pm0.00$	$0.00^{a}\pm0.00$	$0.00^{a}\pm0.00$	$0.02^{bc}\pm0.00$	$0.06^{a}\pm0.01$
	September	$0.01^{ab}\pm0.00$	$0.03^{b}\pm0.00$	$0.01^{a}\pm0.01$	$0.00^{c}\pm0.00$	$0.00^{b}\pm0.00$	$0.00^{c}\pm0.00$	$0.00^{a}\pm0.00$	$0.00^{a}\pm0.00$	$0.01^{d}\pm0.00$	$0.08^{a}\pm0.0$
FME 2011 Standard limit		5	0.02*	0.001	0.1	0.01	0.3	1	0.05	0.05	0.003

^{a,b,c,d}: Means with similar superscript in the same column are not significantly different (P>0.05).

Egbeada (representing the midstream) sediments showed moderate fluctuations for some metals, likely reflecting a combination of agricultural runoff and natural weathering processes influencing metal mobility. Finally, Ehume (downstream) sediments were the most stable among the locations—with heavy metal concentrations (including Zn, Ni, Mn, Fe, Cu, Co, and Cr) displaying minimal variation over time, which suggests a relatively undisturbed environment and effective buffering in the sediment matrix. The level of Zn, Ni, Mn, Pb, Cu and Cr values of sediment samples obtained throughout the study period were above the acceptable limit set by WHO (2004) and FEPA (1991).

Table 3: Heavy Metal Contents in Sediment Samples (mg/kg)

Water source	Month	Zn	Ni	Hg	Mn	Pb	Fe	Cu	Co	Cr	Cd
Ohiya Nsukwe	July	$0.14^{e}\pm0.04$	$0.47^{d}\pm0.46$	$0.00^{b}\pm0.00$	$0.36^{e}\pm0.38$	$0.00^{b}\pm0.00$	$1.69^{d}\pm0.36$	$0.50^{c}\pm0.44$	$0.15^{d}\pm0.02$	$0.18^{a}\pm0.07$	$0.00^{c}\pm0.00$
	August	$0.12^{e}\pm0.04$	$0.54^{d}\pm0.51$	$0.00^{b}\pm0.00$	$0.36^{e}\pm0.39$	$0.00^{b}\pm0.00$	$1.76^{d}\pm0.21$	$0.42^{c}\pm0.47$	$0.14^{d}\pm0.02$	$0.11^{a}\pm0.09$	$0.00^{c}\pm0.00$
	September	$0.14^{e}\pm0.05$	$0.56^{d}\pm0.57$	$0.00^{b}\pm0.00$	$0.23^{e}\pm0.14$	$0.00^{b}\pm0.00$	$1.58^{d}\pm0.50$	$0.44^{c}\pm0.46$	$0.15^{d}\pm0.02$	$0.11^{a}\pm0.09$	$0.00^{c}\pm0.00$
Express Rd.	July	$1.50^{ab}\pm0.48$	$12.66^{a}\pm0.40$	$0.01^{a}\pm0.00$	$8.57^{a}\pm0.43$	$0.31^{ab}\pm0.32$	$4.92^{a}\pm0.07$	$4.74^{a}\pm0.24$	$0.32^{a}\pm0.02$	$0.43^{a}\pm0.34$	$0.42^{a}\pm0.03$
(Upstream)	August	$1.76^{a}\pm0.11$	$12.62^{ab}\pm0.25$	$0.02^{a}\pm0.01$	$8.37^{a}\pm0.28$	$0.61^{a}\pm0.38$	$4.89^{a}\pm0.10$	$4.85^{a}\pm0.41$	$0.32^{a}\pm0.01$	$0.46^{a}\pm0.20$	$0.50^{a}\pm0.13$
	September	$1.67^{ab}\pm0.20$	$12.49^{ab}\pm0.33$	$0.02^{a}\pm0.00$	$8.50^{a}\pm0.39$	$0.81^{a}\pm0.67$	$4.89^{a}\pm0.10$	$4.54^{a}\pm0.41$	$0.32^{a}\pm0.01$	$0.47^{a}\pm0.20$	$0.45^{a}\pm0.04$
Egbeada	July	$1.12^{abcd}\pm0.04$	$11.02^{c}\pm0.25$	$0.00^{b}\pm0.00$	$8.30^{ab}\pm0.38$	$0.35^{ab}\pm0.30$	$3.88^{b}\pm0.10$	$3.75^{ab}\pm3.5$	$0.31^{ab}\pm0.01$	$0.19^{a}\pm0.07$	$0.23^{b}\pm0.06$
(Midstream)	August	$1.21^{abc}\pm0.28$	$11.31^{abc}\pm0.72$	$0.00^{b}\pm0.00$	$6.87^{bcd}\pm0.51$	$0.40^{ab}\pm0.25$	$3.89^{b}\pm0.05$	$3.89^{ab}\pm0.10$	$0.32^{a}\pm0.02$	$0.31^{a}\pm0.27$	$0.24^{b}\pm0.06$
	September	$1.16^{abcd}\pm0.11$	$11.25^{bc}\pm0.60$	$0.00^{b}\pm0.00$	$6.68^{cd}\pm0.71$	$0.48^{ab}\pm0.19$	$3.89^{b}\pm0.05$	$3.89^{ab}\pm0.10$	$0.31^{a}\pm0.01$	$0.31^{a}\pm0.27$	$0.24^{b}\pm0.04$
Ehume Bridge	July	$0.42^{de}\pm0.53$	$11.34^{abc}\pm0.51$	$0.00^{b}\pm0.00$	$7.97^{abc}\pm0.05$	$0.45^{ab}\pm0.05$	$2.68^{c}\pm0.10$	$2.86^{b}\pm0.50$	$0.23^{c}\pm0.01$	$0.17^{a}\pm0.03$	$0.05^{c}\pm0.02$
(Downstream)	August	$0.55^{cde}\pm0.43$	$11.32^{abc}\pm0.53$	$0.00^{b}\pm0.00$	$6.27^{d}\pm0.60$	$0.60^{ab}\pm0.23$	$2.89^{c}\pm0.70$	$3.04^{b}\pm0.50$	$0.23^{c}\pm0.01$	$0.13^{a}\pm0.01$	$0.05^{c}\pm0.01$
	September	$0.95^{bcd}\pm0.09$	$11.41^{abc}\pm0.16$	$0.00^{b}\pm0.00$	$6.47^{d}\pm1.00$	$0.50^{ab}\pm0.06$	$2.68^{c}\pm0.11$	$2.83^{b}\pm0.31$	$0.26^{bc}\pm0.03$	$0.13^{a}\pm0.01$	$0.05^{c}\pm0.02$
WHO (2004)/FEPA (1991)		0.3	2		2	0.04/0.5	500	0.025		0.1	0.006

^{a,b,c,d}: Means with similar superscripts in the same column are not significantly different ($p>0.05$)

Heavy metals in fish samples from Oyivo stream

The level of heavy metals in fish is presented in Table 4. The concentration of Zn in fish samples varied from 0.34±0.41mg/kg in September at Ohiya Nsukwe (control point) to 2.25±0.01mg/kg in July at the Express Road crossing point (upstream); but was not significantly different on monthly basis. The range for Nickel (Ni) concentration was between 0.80±0.02mg/kg in July at the control point and 5.09±0.02mg/kg in July at Egbeada (midstream location). Monthly concentration of the above two elements were not significantly different on monthly basis. Mercury concentrations were low at the various months in control a point studied and varied from 0.00±0.00 to 0.68±0.35mg/kg in July at the Express crossing (upstream) and was not significantly different on monthly basis. Manganese concentrations in fish samples were between 0.55±0.24mg/kg in July at the control point to 17.97±0.09mg/kg in July at Ehume Bridge (downstream), which was significant in July at this point/location. Mean values for Lead (Pb) lay between 0.00±0.00mg/kg in July at the control point and 0.61±0.01mg/kg in August at the Express Road crossing but was not significantly different along all the sampling stations studied. Mean values for iron (Fe) ranged between 0.53±0.01mg/kg in July at the control station to 10.12±0.03mg/kg in July at the Express Road crossing point, but was not significantly different on monthly basis. Mean values for copper (Cu) were between 0.00±0.00mg/kg at the control point in July and 0.05±0.06mg/kg in September at the Express Road crossing and was not significantly different at all the other months and sampling points studied. With Cobalt, mean values were between 0.05±0.04mg/kg in August at Egbeada (midstream) and 0.09±0.01 in July at the Express Road crossing position (upstream), which was found to be insignificant ($p>0.05$). Chromium had mean values that ranged from 0.00±0.00 in September at the control point and 0.71±0.01 in July at Egbeada (midstream position). No significant difference ($p>0.05$) was seen in the concentration of chromium from July to September along the sampling points studied. Mean values for Cadmium was between 0.03±0.01mg/kg in July and August at the control point and 0.41±0.01mg/kg in July at the Express Road crossing point/station. No significant difference ($p>0.05$) was observed between July and September along all the sampling positions studied. Minerals like Zn, Ni, Fe, Cu, Cr and Mn values in fish samples obtained throughout the study period were below the acceptable limit, while Pb, Co and Cd value were above the acceptable limit set by WHO (2004) and FEPA (1991).

Table 4: Heavy metals in fish samples

Water source	Month	Zn	Ni	Hg	Mn	Pb	Fe	Cu	Co	Cr	Cd
Ohiya Nsukwe	July	$0.92^{de}\pm0.06$	$0.80^{e}\pm0.02$	$0.00^{c}\pm0.00$	$0.55^{e}\pm0.24$	$0.00^{c}\pm0.00$	$0.53^{c}\pm0.01$	$0.00^{a}\pm0.00$	$0.09^{b}\pm0.01$	$0.04^{a}\pm0.01$	$0.03^{c}\pm0.01$
	August	$0.95^{de}\pm0.04$	$0.85^{de}\pm1.00$	$0.00^{c}\pm0.00$	$0.65^{de}\pm0.11$	$0.02^{c}\pm0.02$	$0.63^{c}\pm0.04$	$0.00^{a}\pm0.00$	$0.09^{b}\pm0.00$	$0.00^{a}\pm0.00$	$0.03^{c}\pm0.01$
	September	$0.34^{e}\pm0.41$	$0.83^{be}\pm0.09$	$0.00^{c}\pm0.00$	$0.82^{de}\pm0.06$	0.00c±0.00	$0.70^{c}\pm0.03$	$0.00^{a}\pm0.00$	$0.09^{b}\pm0.00$	$0.01^{a}\pm0.01$	$0.08^{c}\pm0.01$
Express Rd. Crossing	July	$2.\ 5^{a}\pm0.01$	$5.09^{b}\pm0.02$	$0.68^{a}\pm0.35$	$4.82^{b}\pm0.08$	$0.60^{a}\pm0.01$	$10.12^{a}\pm0.03$	$0.00^{a}\pm0.00$	$0.56^{a}\pm0.02$	$1.02^{a}\pm1.31$	$0.41^{ab}\pm0.01$
	August	$1.99^{abc}\pm0.04$	$2.20^{cde}\pm0.03$	$0.05^{bc}\pm0.01$	$3.68^{bcd}\pm0.31$	$0.61^{a}\pm0.01$	$1.80^{c}\pm0.42$	$0.01^{a}\pm0.00$	$0.56^{a}\pm0.02$	$0.21^{a}\pm0.01$	$0.20^{bc}\pm0.00$
	September	$1.71^{abcd}\pm0.35$	$3.73^{b}\pm0.13$	$0.47^{ab}\pm0.05$	$4.27^{bc}\pm0.09$	$0.21^{b}\pm0.00$	$2.49^{bc}\pm0.01$	$0.05^{a}\pm0.06$	$0.57^{a}\pm0.01$	$0.10^{a}\pm0.00$	$0.48^{a}\pm0.14$
Egbeada	July	$2.14^{ab}\pm0.04$	$4.72^{b}\pm0.02$	$0.29^{abc}\pm0.01$	$2.06^{bcde}\pm2.40$	$0.56^{a}\pm0.06$	$9.76^{ab}\pm0.60$	$0.00^{a}\pm0.00$	$0.55^{a}\pm0.05$	$0.71^{a}\pm0.01$	$0.19^{bc}\pm0.00$
	August	$1.22^{bcde}\pm0.14$	$2.16^{cde}\pm0.01$	$0.10^{bc}\pm0.01$	$1.84^{bcde}\pm1.0$	$0.21^{b}\pm0.00$	$1.30^{c}\pm0.37$	$0.04^{a}\pm0.04$	$0.55^{a}\pm0.04$	$0.15^{a}\pm0.07$	$0.18^{bc}\pm0.02$
	September	$1.14^{cde}\pm0.37$	$3.13^{bcd}\pm0.01$	$0.23^{bc}\pm0.13$	$1.14^{de}\pm0.01$	$0.05^{c}\pm0.02$	$1.15^{c}\pm0.16$	$0.00^{a}\pm0.00$	$0.57^{a}\pm0.00$	$0.43^{a}\pm0.46$	$0.26^{abc}\pm0.06$
Ehume Bridge	July	$2.02^{abc}\pm0.01$	$4.45b^{c}\pm0.92$	$0.08b^{c}\pm1.00$	$17.97^{a}\pm0.09$	$0.50^{a}\pm0.11$	$5.40^{abc}\pm6.31$	$0.00^{a}\pm0.00$	$0.53^{a}\pm0.3$	$0.60^{a}\pm0.01$	$0.15^{c}\pm0.01$
	August	$1.55^{abc}d\pm0.46$	$1.13^{de}\pm0.02$	$0.00^{c}\pm0.00$	$1.56^{cde}\pm0.58$	$0.06^{c}\pm0.01$	$1.21^{c}\pm0.08$	$0.00^{a}\pm0.00$	$0.53^{a}\pm0.01$	$0.08^{a}\pm0.01$	$0.13^{c}\pm0.04$
	September	$0.87^{de}\pm0.0.5$	$11.63^{a}\pm1.80$	$0.21^{bc}\pm0.01$	$0.84^{de}\pm0.18$	$0.00^{c}\pm0.00$	$1.21^{c}\pm0.08$	$0.00^{a}\pm0.00$	$0.55^{a}\pm0.03$	$0.01^{a}\pm0.01$	$0.19^{bc}\pm0.13$

^{a,b,c,d}: Means with similar superscripts in the same column are not significantly different ($p>0.05$).

Discussion

The study confirmed that Oyivo River is impacted by varying degrees of heavy metal contamination, particularly in sediment and fish tissue samples. Elevated concentrations of heavy metals such as Pb, Co, and Cd in sediments exceeded permissible limits set by WHO (2004) and FEPA (1999), suggesting considerable anthropogenic input into the aquatic system. Sediments, due to their strong adsorption capacity, often act as long-term sinks for heavy metals. However, under changing physicochemical conditions, these metals may remobilize into the water column, posing long-term ecological risks (Olowu *et al*., 2010).

The spatial distribution of metal concentrations suggests multiple point and non-point sources of pollution. For instance, elevated calcium levels at the Express Road/Bridge Crossing likely stem from kaolin mining operations nearby, where runoff discharges into the stream. Likewise, the presence of sodium, potassium, and magnesium at various points may be linked to the automobile repair activities and use of agrochemicals along the banks. These observations are consistent with findings by Obasohan *et al*. (2006) and Adeniyi *et al*. (2008), who reported similar patterns in urban-influenced freshwater ecosystems in Nigeria.

In line with Adeyemo (2003), this study reinforces the view that Nigeria's freshwater systems are increasingly threatened by unregulated industrial activities, urban sprawl, and poor waste management. Non-ferrous metal industries, in particular, are known to release significant quantities of lead, cadmium, and zinc into nearby water bodies through effluents, contributing to persistent pollution loads in aquatic sediments.

The accumulation of heavy metals in sediments poses potential hazards to aquatic organisms, as heavy metals can persist in sediment for long periods, leading to bioaccumulation and bio-magnification within the aquatic food chain. In this study, fish tissue analysis revealed the presence of trace metals, including Zn, Ni, Mn, Pb, Cu, and Cr. While these were below the maximum permissible limits set by the Food and Agriculture Organization (FAO, 2010), the detection of toxic metals such as Pb and Cr is cause for concern. The FAO/WHO (2010) safety thresholds for fish tissues include: Pb (0.2mg/kg), Cd (0.05mg/kg), Zn (30mg/kg), Cu (20mg/kg), Cr (0.5mg/kg), Mn (10mg/kg), and Fe (100mg/kg). Although current concentrations pose no immediate risk, the potential for bioaccumulation and bio-magnification through the food web remains a significant long-term concern, especially among populations with high fish consumption.

The relatively low levels in fish compared to sediments could reflect bioavailability constraints, species-specific uptake patterns, or short-term exposure. However, chronic exposure to even low concentrations of heavy metals can have adverse effects on both aquatic organisms and humans. Studies by Saha and Zaman (2013) and Ali and Khan (2018) have shown that fish species from contaminated waters tend to accumulate metals in edible tissues, increasing health risks for consumers.

Studies by Yousafzai and Shakoori (2008), and Saha and Zaman (2013), support the use of fish as effective bio-indicators of metal pollution due to their capacity to reflect environmental concentrations in their tissues. Bioaccumulation is influenced by several factors including species, environmental pH, temperature, and dietary habits (Ali and Khan, 2018). Notably, chronic exposure to trace metals such as Cr, Ni, and Cu has been linked to oxidative stress and carcinogenicity (Ekeanyanwu *et al*., 2011; Akan *et al*., 2012).

This study highlights the need for continuous monitoring of metal concentrations in both abiotic and biotic components of freshwater ecosystems. Given that sediments can act as secondary sources of pollution and fish serve as vectors for human exposure, coordinated pollution control, community awareness, and environmental regulation enforcement are urgently needed to protect public health and aquatic biodiversity.

Conclusion

This study provides clear evidence of heavy metal contamination in the sediments and fish tissues of Oyivo River, with several metals—particularly Pb, Co, and Cd—exceeding regulatory thresholds in sediment samples. While metal concentrations in fish tissues remained within FAO/WHO permissible limits, their presence underscores the potential for long-term bioaccumulation and food chain transfer. The spatial variation in contamination levels points to multiple anthropogenic sources, including kaolin mining, automobile repairs, and agricultural runoff. These findings reinforce the critical role of sediments as reservoirs of pollution and highlight the need for proactive monitoring, pollution source control, and enforcement of environmental regulations to safeguard aquatic life and public health.

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