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Trace metal distribution in *Tilapia zillii* and *Synodontis schall* from the Siluko River, Edo State, Nigeria

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Metal pollution of aquatic ecosystems has raised concerns about their uptake by aquatic organisms and subsequent biomagnification along the aquatic food chain. This study determined trace metal distribution in *Tilapia zillii* and *Synodontis schall* from the Siluko River in Edo State, Nigeria. Fresh fish samples were harvested monthly from September 2021 to August 2022 with the assistance of artisanal fishermen. Trace metal contents in the gills, liver, and muscles were determined using atomic absorption spectrophotometer. The metal pollution index (MPI) was used to estimate the extent of metal bioaccumulation in the fishes. Results showed species variation in metal accumulation in various organs: *T. zillii* had a higher mean content of Cu, Zn, Mn and Fe in all the organs, while *S. schall* had a higher mean content of Ni, Cr, and Pb in all the organs. The MPI values ranged from 5.28 to 5.94 in the organs of *T. zillii* and *S. schall*. The order of MPI values in *T. zillii* was muscles > liver > gills; in *S. schall*, it was liver > gills > muscles. The results indicate trace metal contamination of fishes due to aquatic pollution. High MPI values is an indication of the degree of metal pollution of the Siluko River and the high susceptibility of these metals to bioaccumulation in the fishes. This predisposes the fishes to metal toxicity and portends health risk to fish consumers. The continuous monitoring of activities within the river watershed to mitigate heavy metal pollution is recommended.

Keywords: aquatic toxicity, bioaccumulation, metal toxicity, metal pollution index (MPI), Siluko River

INTRODUCTION

The increasing exposure of freshwater bodies to the influx of diverse forms of pollutants from various anthropogenic activities within their watershed has resulted in the deterioration of their water quality and raised concerns about the sustainability of the aquatic ecosystem for optimal production (Egun, Oboh, 2022a; Egun, Oboh, 2023; Biose et al., 2024). Trace metals are elements that are present in small amounts in the environment and in living organisms. Such trace metals as iron, zinc,

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copper and manganese are essential elements for nutrition and physiology, as their deficiencies may result in organism malfunctioning; other trace metals, such as nickel, chromium and lead, have no known biological function and cause toxic effects and portend health risk to organisms in the environment even at low concentrations (Rainbow, 2007). The aquatic ecosystem is the final receptor of the released harmful substances, leading to the uptake and accumulation of these contaminants in the aquatic organisms. Trace metal contamination of aquatic ecosystems is an issue of global concern (Islam et al., 2020; Zahoor et al., 2023; Tesfaye et al., 2024), and particularly in the developing countries such as Nigeria (Enuneku et al., 2013; Egun, Ogiesoba-Eguakun, 2018; Egun, Oboh, 2022a; Egun, Oboh, 2023; Biose et al., 2024) as it poses a threat to achieving the United Nations sustainable development goals of life below water (Goal 14), provision of clean water (Goal 6) and good health and wellbeing (Goal 3).

The trophic position of fishes in the aquatic food web and their ability to accumulate metals from various sources, including sediments and water, identify them as bioindicators of trace metal contamination in aquatic ecosystems (Tesfaye et al., 2014; Muhammad, Ahmad, 2020). Also, the accumulation of trace metals in various tissues of fishes gives credence to exposure to polluted aquatic environment and could be used to evaluate the health condition of the environment from which they were collected (Qadir, Malik, 2011). Increasing global demand for fish meat as source of animal protein and the contribution of capture fisheries to household nutritional needs (Egun et al., 2024) emphasize the importance of assessing trace metal levels in fish populations in the wild (Bawuro et al., 2018; Chen et al., 2022; Muneer et al., 2022). The increase or decrease in the levels of certain pollutants in water bodies have been reported to directly or indirectly affect the behavioural and physiology of fishes (Egun, 2021). Reported studies on trace metal pollution of aquatic ecosystems globally (Custer et al., 2000; Juśkiewicz, Gierszewski, 2002; Basooma et al., 2021; Tesfaye et al., 2024), and freshwater bodies in Nigeria (Oboh, Agbala, 2017; Egun, Oboh, 2022a; Egun, Oboh, 2023; Biose et al., 2024) have raised concerns about their uptake by aquatic organisms and subsequent biomagnification along the aquatic food chain (Egun et al., 2023; Uwaifo et al., 2023; Egun et al., 2025).

The fish species – *Tilapia zillii* and *Synodontis schall* – are commercial freshwater fish species, with high culinary acceptability in Nigeria. Their omnivorous feeding habit and transitional position in the trophic niche between primary producers and piscivores in the aquatic ecosystems has made them valuable bio-indicators of aquatic pollution and biomagnification of contaminants. Therefore, the aim of this study was to evaluate the distribution of trace metal concentrations in the organs of *T. zillii* and *S. schall* from the Siluko River as an indicator of aquatic biota contamination and a potential source of toxic trace metals (TTEs) to consumers.

MATERIALS AND METHODS

Study location

This study was carried out at the Siluko River (latitudes 06°32'22.5" N and 06°31'59.7" N and longitudes 005°09'32.5" E and 005°09'20.8" E), in Edo State, Nigeria (Figure). The Siluko River receives water from the Owena River and drains into the Atlantic via the Benin River (Oboh, Agbala, 2017). The river is flanked by secondary vegetation of rubber trees (*Hevea brasiliensis*), Awolowo weed (*Chrommolaena odorata*), African white mahogany, (*Khaya anthotheca*), Itako (*Stromboisa pustulata*), palm oil (*Elaeis guinensis*), bamboo tree (*Bambusa* spp.), and shrubs. The river is also characterised by floating vegetation such as duck weed (*Lemna* spp.) and water hyacinth (*Eichorrnia crassipes*).

Sample collection

Fresh samples of *T. zillii* (average weight 480 g) and *S. schall* (avg. wt. 430 g) were harvested monthly for a duration of 12 months (September 2021 to August 2022) using fishing nets and local fishing traps with the assistance of artisanal fishermen, and subsequently identified using taxonomic guides of Idodo-Umeh (2003). Fish

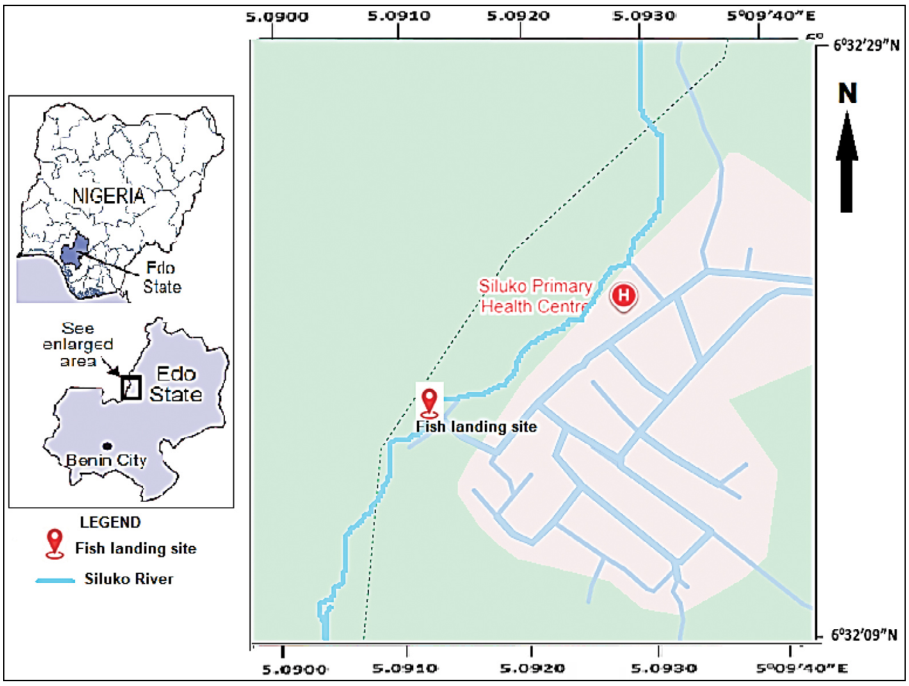

Figure. Map of Siluko River with fish landing site in Siluko Town, Edo State. Insert maps: (A) Nigeria (B) Edo State

samples were collected from fish catches intended for sale in the local fish market to consumers and fish processors. Fish samples were packed in polyethylene bags and preserved in ice boxes. The analysis of heavy metal contents in the fish species was conducted at the national reference laboratory – the Benin Owena River Basin Authority/University of Benin Analytical laboratory.

Laboratory analysis

In the laboratory, fresh fish samples were dissected and gutted, and tissues of interest (muscles, gills, and liver) were extracted. The extracted sample tissues were wrapped in aluminium foil paper and oven -dried at a temperature of 105°C for 1 h. Sample preparation and digestion using nitric acid (HNO_3) and perchloric acid ($HClO_4$) were carried out following the procedure described by APHA (2012). Trace metal concentrations in the sample filtrates were determined using the flame atomic absorption spectrophotometer (FAAS) (Model 210 VGP, Buck Scientific).

Quality assurance and control

Analysis was done in triplicates for all samples with mean values reported. Trace metal content in sample filtrates for the respective tissues was analysed using the FAAS, which was calibrated using Buck-certified atomic absorption standards for several trace metals to obtain a calibration curve. Details of certified reference materials, detection limits, quantification limits, and percentage material recovery on each metal are presented in Table 1.

To preserve the biological integrity of tissues of interest, collected fish samples were immediately placed in polyethylene bags and kept in an ice box which was used to carry the samples to the laboratory. A national reference laboratory – the Benin Owena River Basin Authority/University of Benin Analytical laboratory, University of Benin, Nigeria was utilized for laboratory analysis.

Metal pollution index (MPI)

The total amount of metals found in the fish samples was compared using the metal pollution index (MPI) as described by USEPA (2011). The MPI was determined for each examined organ using the equation:

$$MPI = (M_1 \times M_2 \times M_3 \times M_4 \times M_5 \times M_6 \times M_7)^{1/n}$$

where M is the concentration of metals measured and expressed (mg/kg), and n is the number of metals measured.

Table 1. **Certified values for elements in SRM 3233 detection limit (DL), quantification limit (QL), % of relative standard deviation (RSD) and recovery**

Metals	Detection limits (DL) (μg mL⁻¹)	Quantification limit (QL) (μg mL⁻¹)	Relative standard deviation (%RSD)	% recovery
Fe	0.1–1.0	0.01–1.0	1–5	99
Zn	0.1–1.0	0.01–1.0	1–5	99
Cu	0.1–1.0	0.01–1.0	1–5	90
Mn	0.1–1.0	0.01–1.0	1–5	90
Ni	0.1–1.0	0.01–1.0	1–5	90
Cr	0.1–1.0	0.01–1.0	1–5	99
Pb	0.1–1.0	0.01–1.0	1–5	99

Source: Standard Reference Material (SRM) 3233 (2020).

Data analysis

All statistical analysis was computed using Microsoft Excel and Statistical Package for Social Sciences (SPSS) v.21. At every sampling visit, five specimens of each species were collected from an artisanal fish landing site in Siluko community. Analytical results are presented as the pooled means ± SD per kg of each fish species, and ANOVA ($p < 0.05$) was used to determine the variation in the trace metal content among the selected organs in fish species.

RESULTS

The mean concentrations of metals (Fe, Zn, Cu, Mn, Ni, Cr, and Pb) in gills, liver and muscles of *T. zillii* and *S. schall* from the Siluko River are presented in Table 2. The analytical results

Table 2. **Summary of the metal content in the organs of *T. zillii* and *S. schall* from the Siluko River**

Metal (mg/kg) of wet weight		Gills	Liver	Muscles	*p* value
		Mean ± SD	Mean ± SD	Mean ± SD	
Iron (Fe)	*T. zillii*	74.56 ± 1.08[a]	84.84 ± 1.38[b]	74.51 ± 0.35[a]	$p < 0.05$
	S. chall	68.50 ± 6.16[a]	62.5 ± 3.04[a]	61.40 ± 7.23[a]	$p > 0.05$
Zinc (Zn)	*T. zillii*	15.02 ±0.05[a]	21.90 ± 0.25[b]	17.60 ± 0.42[b]	$p < 0.05$
	S. schall	13.67 ± 1.26[a]	17.96 ± 0.70[b]	11.66 ± 1.52[a]	$p < 0.05$
Copper (Cu)	*T. zillii*	12.25 ± 0.39[a]	10.89 ± 0.54[a]	17.43 ± 0.70[b]	$p < 0.05$
	S. schall	9.65 ± 0.51[a]	9.25 ± 2.02[a]	16.01 ± 1.25[b]	$p < 0.05$
Manganese (Mn)	*T. zillii*	6.55 ± 0.39[a]	8.32 ± 0.89[a]	6.73 ± 0.30[a]	$p > 0.05$
	S. schall	5.87 ± 0.61[a]	6.02 ± 0.10[a]	5.41 ± 0.48[a]	$p > 0.05$
Nickel (Ni)	*T. zillii*	4.85 ± 0.19[a]	4.20 ± 0.34[a]	4.91 ± 0.06[a]	$p > 0.05$
	S. schall	5.56 ± 0.07[a]	5.25 ± 0.97[a]	5.74 ± 0.86[a]	$p > 0.05$
Chromium (Cr)	*T. zillii*	6.99 ± 0.21[a]	4.91 ± 0.57[a]	6.91 ± 0.08[a]	$p > 0.05$
	S. schall	7.85 ± 0.38[a]	7.89 ± 0.34[a]	8.04 ± 0.72[a]	$p > 0.05$
Lead (Pb)	*T. zillii*	0.04 ± 0.002[a]	0.06 ± 0.004[a]	0.05 ± 0.006[a]	$p > 0.05$
	S. schall	0.05 ± 0.005[a]	0.05 ± 0.008[a]	0.04 ± 0.006[a]	$p > 0.05$

Note: values are presented as pooled means ± standard deviations (SD) of the metal content in the organs of fish species throughout the duration of the study. Across each row, similar superscripts indicate no significant difference ($p > 0.05$), while dissimilar superscripts indicate significant difference ($p < 0.05$).

showed that *T. zillii* had a higher mean content of Fe, Zn, Cu and Mn, while *S. schall* had a higher mean content of Ni, Cr, and Pb in all the organs. In both fish species, the content of Fe was the highest and that of Pb the lowest across the organs. The order of heavy metal contents in the gills of *T. zillii* and *S. schall* was Fe > Zn > Cu > Cr > Mn > Ni > Pb. For liver, the order was Fe > Zn > Cu > Mn > Cr > Ni > Pb in *T. zillii* and Fe > Zn > Cu > Cr > Mn > Ni > Pb in *S. schall*. In the muscles, the order was Fe > Zn > Cu > Cr > Mn > Ni > Pb in *T. zillii* and Fe > Cu > Zn > Cr > Ni > Mn > Pb in *S. schall*.

Metal pollution index (MPI)

The MPI values for the examined organs in *T. zillii* and *S. schall* varied from 5.28 to 5.94 (Table 3). The order of MPI values in *T. zillii* was muscles > liver > gills; in *S. schall*, it was liver > gills > muscles. *T. zillii* recorded higher non-significant MPI values in all the organs examined of both fish species.

Table 3. **Metal pollution index (MPI) of organs of *T. zillii* and *S. schall* from the Siluko River**

Organs	MPI (mg/kg)		*p* value
	T. zillii	*S. schall*	
Gills	5.33[a]	5.29[a]	$p > 0.05$
Liver	5.75[a]	5.37[a]	$p > 0.05$
Muscles	5.94[a]	5.28[a]	$p > 0.05$
P value	$p > 0.05$	$p > 0.05$	

Note: across each row and down each column, similar superscripts indicate no significant difference ($p > 0.05$), while dissimilar superscripts indicate significant difference ($p < 0.05$).

DISCUSSION

Freshwater fish species have been described as wholesome foodstuffs, and its consumption is highly recommended by various nutritional health authorities (Egun, Oboh, 2022b; Egun et al., 2022; Egun et al., 2024). However, the ability of fishes to bioaccumulate toxic and non-biodegradable trace metals in various body parts from the aquatic environment, has been raising serious concerns about the sustainable productivity of fishery resources and safety of fish food to consumers (Serviere-Zaragoza et al., 2021; Egun et al., 2023; Zaghloul et al., 2024). In this study, species variation in the accumulation of metals in the organs of *T. zillii* and *S. schall* was observed: the highest content of Fe, Zn, Mn and Pb was recorded in the liver and the highest content of Cu, Ni and Cr was found in the muscles of both fish species. The observed variations in the levels of accumulation of these metals in different organs of the fish species can be attributed to the differences in the physiological role of each organ and fish species. In similar studies, trace metal accumulation order of Fe > Zn > Cu > Pb > Cd was recorded in the gills, liver and muscles of *Clarias gariepinus* and *T. zillii* from the Owan River (Egun et al., 2025), while Fe > Zn > Mg > Cu > Pb > Cd (gills and muscles) and Fe > Zn > Cu > Mg > Pb > Cd (liver) in *C. gariepinus* and *T. zillii* from Ikpoba reservoir (Egun et al., 2023). That the observed similarity in the order of bioaccumulation of metals in this study compares with reported similar studies is indicative of the predisposition of these fish organs to readily take up iron, zinc, and copper from their environment. The unique structure of the gills for the direct absorption of trace metals from the environment and the role of the liver in the biotransformation and detoxification makes these organs prominent sites for accumulation of metals. These factors including sex, fish habitat, and level of water pollution have been reported to influence the accumulation of metals in fish tissues (Nussey et al., 2000; Zaghloul et al., 2024).

Essential micronutrients – Fe, Zn, Cu, and Mn were present in good quantities in the fishes, which are attributed to their various functions as co-factors for the activation of a number of enzymes needed to regulate and maintain homeostatic status in fish (Kumar et al., 2020). The content of Fe, Zn, and Cu in the muscles of *T. zillii* and *S. schall* did not exceed their respective permissible concentrations of 100 mg/kg for Fe and 30 mg/kg for Zn and Cu each in fish food (FAO/WHO, 2014). The content of Mn in the muscles of *T. zillii* (6.73 mg/kg) and *S. schall* (5.41 mg/kg) was very high and exceeded the WHO limit of 2.50 mg/kg in fish and fish products, although the high content of Fe, Zn, Cu, and Mn recorded in the muscles *T. zillii* and *S. schall* makes them good sources of mineral elements to consumers. Several toxicological studies reported negative effects of the bioaccumulation of these metals on the physiology of fishes exposed to elevated levels of these metals in their habitats (Akan et al., 2012; Simionov et al., 2019; Zeeshan et al., 2021; Zaghloul et al., 2024). Similar studies have reported high Fe and Zn contents in the muscles of *T. zillii* from Ikpoba reservoir (Egun, Oboh, 2022) and the Owan River (Egun et al., 2022b); lower Cu (0.25–0.52 mg/kg) and Mn (0.52 mg/kg) contents in *T. zillii* from the Ogbese River (Olayinka-Olagunju, 2021), and *a* higher content of Mn was recorded in the muscles of *T. zillii* from Ogbainbiri (22.67 mg/Kg) and Samabiri (14.64 mg/Kg) along the Nun River in Bayelsa State (Aigberua, Tarawou, 2017).

The presence of non-essential toxic trace elements – Ni, Cr, and Pb – in the organs of the fish species, especially in fish muscles, is an indication of fish meat contamination. The content of Ni and Cr in the muscles of *T. zillii* and *S. schall* exceeded the maximum permissible limit of 0.4 mg/kg for Ni in fish meat (EU Commission Regulation, 2006), and WHO/FEPA maximum allowable limit for Cr (0.05–0.15 mg/kg) in fish food (FEPA, 2003; Bakshi, Panigrahi, 2018). For Pb, its content in the muscles of *T. zillii* and *S. schall* was very low and below the maximum permissible limit of 0.3 mg/kg for lead in fish meat (FAO/WHO, 2010). These non-essential toxic trace elements have been reported to cause several disruptive effects on the growth and development of fishes even at very low concentrations (Burger et al., 2002; Krishna et al., 2014). Also, the carcinogenic potentials of Ni, Cr, and Pb portends a concern for consumers and public health, as human exposure to these metals has been linked to several ailments in adults and children (Umar et al., 2021)

Metal Pollution Index (MPI)

The Metal Pollution Index (MPI) indicates the degree of bioaccumulation of metals within a biota and has garnered interest as a valuable tool for estimating metal contamination (USEPA, 2011). In this study, high values of the MPI, particularly in fish muscles, is a cause of concern for food safety and public health, as it is an indication of the degree of metal pollution of the Siluko River and high susceptibility of these metals to bioaccumulate in the fishes. Variations in metal accumulation and distribution in fish organs have been attributed to the route of organ exposure to the metal source such as through diet or by direct contact with polluted water (Zaghloul et al., 2024).

CONCLUSIONS

This study assessed the concentrations of trace metals in *T. zillii* and *S. schall* from the Siluko River. The identified metals – Fe, Zn, Cu, Mn, Ni, Cr, and Pb – were detected in substantial amounts. The high content of essential trace elements – Fe, Zn, Cu, and Mn – recorded in the muscles *T. zillii* and *S. schall* makes them good sources of the mineral elements to consumers. However, the elevated levels of these essential trace elements and the non-essential toxic elements – Ni, Cr and Pb – in the fishes as indicated by the MPI values predisposes the physiology of the fishes to metal toxicity and portends health risk to consumers. There is a need for (1) the identification of the sources of these heavy metal pollutants with the Siluko River catchment area, (2) commencement of a management strategy that will ensure a decline in the inflow of pollutants into the river, and (3) continuous monitoring of heavy metal pollution levels in water and fish to guarantee public health.

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DECLARATIONS

The authors have no relevant financial or non-financial interests to disclose.

The authors have no competing interests to declare that are relevant to the contents of this article.

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MIKROELEMENTŲ PASISKIRSTYMO SILUKO UPĖS (EDO VALSTIJA, NIGERIJA) *TILAPIA ZILLII* IR *SYNODONTIS SCHALL* ŽUVYSE TYRIMAS

Santrauka

Sunkiųjų metalų tarša vandens ekosistemose kelia susirūpinimą dėl jų kaupimosi vandens organizmuose ir tolesnio biomagnifikacijos poveikio vandens mitybos grandinėje. Šiuo tyrimu buvo nustatytas mikroelementų pasiskirstymas Siluko upės *Tilapia zillii* ir *Synodontis schall* žuvyse Edo valstijoje, Nigerijoje. Švieži žuvų mėginiai buvo renkami kas mėnesį nuo 2021 m. rugsėjo iki 2022 m. rugpjūčio mėnesio kartu su vietiniais žvejais. Mikroelementų kiekiai žiaunose, kepenyse ir raumenyse buvo nustatyti atomų absorbcinės spektroskopijos metodu. Metalų taršos indeksu (MPI) buvo įvertintas žuvų metalų bioakumuliacijos lygis. Rezultatai atskleidė tarprūšinius metalų kaupimosi įvairiuose organuose skirtumus: *T. zillii* turėjo didesnį vidutinį vario (Cu), cinko (Zn), mangano (Mn) ir geležies (Fe) kiekį visuose tirtuose organuose, o *S. schall* – didesnį nikelio (Ni), chromo (Cr) ir švino (Pb) kiekį. MPI reikšmės svyravo nuo 5,28 iki 5,94 *T. zillii* ir *S. schall* organuose. *T. zillii* atveju MPI reikšmės mažėjo tokia tvarka: raumenys > kepenys > žiaunos, o *S. schall* – kepenys > žiaunos > raumenys. Gauti rezultatai patvirtina su vandens tarša susijusį žuvų užterštumą mikroelementais. Didelės MPI reikšmės rodo Siluko upės taršos metalais lygį ir ryškią jų bioakumuliacijos žuvų audiniuose tendenciją, ir tai kelia pavojų žmonių sveikatai vartojant žuvis maistui. Rekomenduojama nuolatinė veiklos stebėsena Siluko upės baseine siekiant sumažinti sunkiųjų metalų taršą.

Reikšminiai žodžiai: toksiškumas vandens organizmams, bioakumuliacija, metalų toksiškumas, metalų taršos indeksas (MPI), Siluko upė