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Lead (Pb) Accumulation in Water, Sediment and Distribution of Macro-Invertebrates in Delimi River, Jos, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Background: This study assessed the concentrations of lead (Pb) in the water column and sediment as well as macro-invertebrates in River Delimi with a view to determining its ability to support aquatic life.
Methodology: Water and sediment samples were collected simultaneously between August and November 2019 at designated stations: A (Abattoir), B (British America bridge), and C (Farin Gada bridge). Composite method was employed to collect water samples from different points in each station in 250 ml capacity plastic bottles with screw caps. The plastic bottles had previously

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washed with detergent and finally rinsed using distilled water. The water samples were filtered using 0.4 mm Whatman filter paper. Samples were then digested with few drops of concentrated nitric acid (HNO_3). Sediment samples were collected in decontaminated airtight polythene bags measuring 500_g each. Sub-samples of the material were sun-dried for three (3) days and homogenized by grinding in laboratory mortar and pestle and sieved (aperture 125 µm). Sediment samples were digested with 20 cm^3 aqua regia (3HCl:1HNO_3), filtrate were stored in glass bottles and transported to the laboratory for chemical analyses. Macroinvertebrates were collected using a D-frame kick-net (30) at each site over a three-minute period. The collected specimens were preserved in 70% formalin and transported to the laboratory for sorting, identification, and enumeration.

Result: Showed that the concentration of lead (Pb) in all the water samples were found to be less than the permissible limit set by WHO/FAO except site WA3 (0.0874ppm) and WC3 (0.0678 ppm) which were higher than the permissible limit. The concentration of lead (Pb) in sediment was higher than the WHO/FAO permissible limit in all sampling stations which is most likely to pose serious health risks to macrobenthos. Also, 7 Micro-invertebrate taxa were identified in the sampling stations. Chironomidae, Eristalis Larva (Syrphidae), Tabanidae and Whirligig beetle (Gyrinidae) comprised more than 79% of the total abundance while stone fly Larva, hydrophilidae and beetle larva constituted the remaining.

Conclusion: water samples suggest potential environmental contamination of lead in some locations while sediment samples indicate a significant contamination with lead, posing potential health risks to organisms living in the sediment, including macrobenthos.

Keywords: Sediment; heavy metals; urbanization; macro-invertebrates.

1. INTRODUCTION

The industrial boom, urban migration, and increasing human and vehicular activity have all increased in Nigeria's modern cities over the past 20 years (Orisakwe 2017). These activities have led to various pollutants in agricultural soils and enhance environmental pollution by releasing hazardous compounds into the atmosphere (Orisakwe 2017). Industrial water consumption, intentional or unintentional discharge of effluents from industry, agriculture, and residential practices, and poor wastewater treatment all have a significant impact on aquatic environments (Bashir et al. 2020). Heavy metals have been identified as the most critical pollutants and priority chemicals to be monitored in order to protect the quality of aquatic habitats and human health (Ali et al. 2019).

Most rivers in Nigeria, especially those in metropolitan and semi-urban areas, are increasingly used to dispose of both solid and liquid trash. These high-polluting activities are now jeopardising the viability and operation of Nigeria's freshwater ecosystems (Arimoro 2009, Arimoro and Oganah 2010).

Industrial and anthropogenic activities, fishing, quarrying, sprawling urbanization, and water pollution are common issues among rivers that have threatened the quality of fresh water (Arimoro et al. 2018a, Keke et al. 2020b). Urbanisation and industrialisation are identified as important stresses contributing to the deterioration of riverine systems (Keke et al. 2021). Storm water return flow, sewage disposal, agricultural runoff, and effluent discharge are all consequences of urbanisation and industrialisation. This phenomenon causes water quality deterioration and biodiversity reduction in freshwater ecosystems, posing severe management challenges for water quality managers and policymakers (Blessing et al. 2022). If not addressed immediately, it could have serious consequences for the riverine system's community structure and functionality (Luo et al. 2012). The presence of some metals in the environment, such as lead (Pb), cadmium (Cd), and mercury (Hg), is a public health concern when their concentrations exceed the limits defined by WHO/FAO, USEPA, and EU in various matrices (Fakhri et al. 2015, Ahmad et al. 2009). Exposure to lead (Pb) occurs mainly via inhalation and ingestion from contaminated foods, which may pose a threat to human health especially children who may suffer a high health risk (elevated Blood Lead Level) due to the bio accumulative potential (Paul et al. 2013, Hu et al. 2014). Lead (Pb) makes up 0.002% of the Earth's crust and is considered the second most hazardous environmental element (Kumar et al. 2020). Because of its availability, quick and high bioaccumulation, and long biological half-life, it has received more attention than other heavy metals (such as cadmium, chromium, and nickel) and is a major concern in food safety disputes (FSS) globally (Cheema et al. 2020). Pb enters aquatic habitats via natural (e.g., erosion and atmospheric deposition) or anthropogenic inputs such as agricultural, urban, or industrial wastewater (Kumar et al. 2020) resulting in widespread contamination of many water bodies, with an estimated concentration in surface water ranging from 0.05 to 566.2 mg/L worldwide (Li et al. 2019). Unlike in developed countries, the majority of the population in Nigeria are unaware of the toxic effects of Lead (Pb) exposure hence the population is at high risk. It has been discovered that the majority of solid trash created in the city is thrown in waterways (Farooq and Umar 2008). The rivers Delimi and Jenta are the primary sources of irrigation water in and around Jos (Abdullahi et al. 2009). These rivers contain a significant amount of useful nutrients as well as poisonous heavy metals, which presents both potential and challenges for agricultural productivity.

The aquatic environment is severely degraded as a result of various anthropogenic activities that result in domestic and industrial effluents. Specifically, rivers, lakes, and reservoirs (aquatic ecosystems) near industrial and urban areas are potential targets for the disposal of environmentally harmful elements such as organic and inorganic contaminants (Kamaludeen et al. 2003).

Thus, a comprehensive health risk assessment of agricultural soils in this region is urgently needed, to assess the level of soil pollution by Lead (Pb) due to mining activities.

Heavy metals are of particular concern due to their non-biodegradable nature and their detrimental effect on human health. These heavy metals have a high ability to bio-accumulate in various organs and muscle tissue of fish (DeForest et al. 2007). Trace elements are spread throughout the aquatic environment in dissolved, colloidal, suspended, and sedimentary phases. In the hydrological cycle, less than 0.1% of metals are dissolved in water, whereas more than 99.9% are deposited in sediments and soils (Pradit et al. 2010). Human activities such as mining, manufacturing and fossil fuel burning have resulted in the accumulation of Lead and its compounds in the environment, including air, water and soil (Jaishankar 2014). Lead is used in the manufacture of batteries, cosmetics, metal items such as ammunition, solder, and pipes, among others (Martin and Griswold 2009). Lead is exceedingly dangerous, thus its use in a variety of items, including paints and petrol, has been significantly reduced in recent years. The most common causes of lead exposure include lead-based paints, petrol, cosmetics, toys, home dust, polluted soil, and industrial pollutants (Gerhardsson et al. 2002).

Acute exposure occurs primarily in the workplace and in some manufacturing industries that utilise lead (Jaishankar 2014). Chronic exposure to lead can induce mental retardation, birth defects, psychosis, autism, allergies, dyslexia, weight loss, hyperactivity, muscular weakness, brain damage, kidney damage, and even death (Jaishankar 2014). Lead (Pb) is a common environmental pollutant, and the negative health effects of lead (Pb) exposure in children and adults are well known; yet, no safe blood lead threshold in children has been identified (Brown and Margoli 2012). Human activities have the potential to impact the spatiotemporal functional and structural compositions of macroinvertebrate assemblages in any stream system (Arimoro et al. 2012). Benthic macroinvertebrate assemblages contain species with varying sensitivity to pollutants and are commonly used to assess the ecological effects of metal contamination in streams (Maret et al. 2003). Metal contamination has been shown to affect benthic macroinvertebrate species diversity, density, growth, and production (Gray and Delaney 2008). The effects of heavy metals on macroinvertebrates vary greatly between species and may have an impact on ecosystem function. (Clements 1999) observed a shift in the functional feeding groups (FFG) of benthic macroinvertebrates, with reduced abundances of scrapers, shredders, collectors, and predators in sites with medium and high heavy metal concentrations compared to reference stations. At higher elevations, benthic macroinvertebrates were found to be more vulnerable to heavy metals (Clements 1999).

2. MATERIALS AND METHODS

2.1 Study Area

This study was conducted at River Delimi of Jos-North local government area, Plateau State. Water from this River is used for domestic purposes and irrigation. Jos North local government area is located at the extreme north of Plateau State on latitude 09^0 53' and 09^0 059'

North, and Longitude 08^0 51' and 09^0 02' East. It shares a boundary to the North with Toro local government area of Bauchi State; to the South with Jos South local government area; to the North-East with Jos- East local government area, and to the West with Bassa local government area. Jos North local government area enjoys a temperate climate with an average temperature of between 11 ^{0}C minimum and 28 ^{0}C maximum. It covers the total land area of 291km^2. Jos-North local government area is characterized by a mean annual rainfall of between 1317.5mm (131.75cm) and 1460.00mm (146cm), mostly from May to August.

2.2 Collection and Preparation of Samples

Water and sediment samples were collected simultaneously from August to November 2019 from predetermined sampling points which were designated station A (Abattoir), B (British America bridge) and C (Farin Gada bridge) with a sampling distance of at least 2km from each station. A total of thirty-six (36) water samples were collected using composite methods at different points from each station in 250 ml capacity plastic bottles with screw caps. The plastic bottles had previously washed with detergent and finally rinsed using distilled water. The water samples were filtered using 0.4 mm Whatman filter paper in order to remove impurities. Samples were digested with concentrated nitric acid (HNO_3) then transferred back to the plastic bottles. Physicochemical parameters of the water were monitored for each sampling station using the methods described by (APHA 2005).

A total of thirty-six (36) sediment samples were collected. The sample mass was collected in decontaminated airtight polythene bags measuring 500_g each. Sub-samples of the material were sun-dried for three (3) days and homogenized by grinding in laboratory mortar and pestle and sieved (aperture 125 µm). Sediment samples were digested with 20 cm^3 aqua regia (3Hcl:1HNO_3), filtrate were stored in glass bottles and transported to the laboratory for chemical analyses.

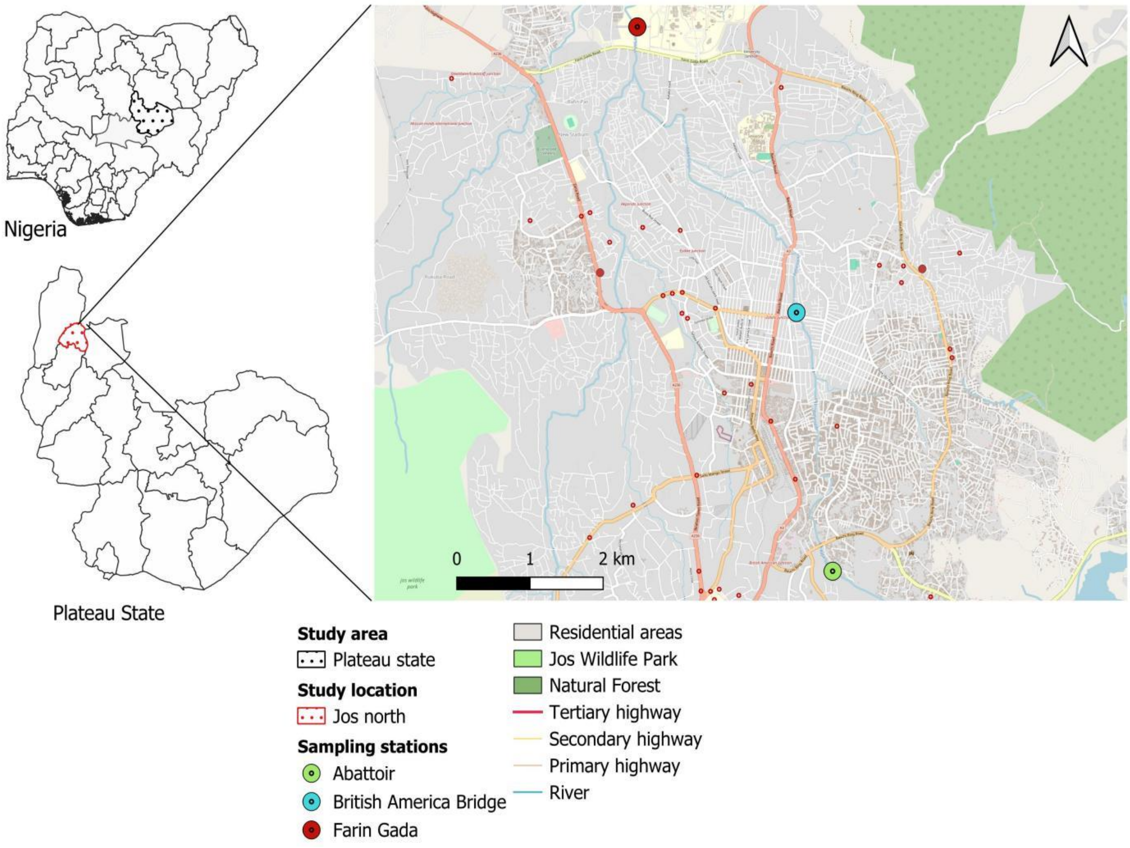

Fig. 1. Map of Nigeria showing location of sample collection (Generated using QGIS version 3.38.3)

Macroinvertebrates were collected using a D-frame kick-net (30) at each site for three minutes. The samples collected were preserved in 70% formalin and taken to the laboratory for sorting, identification and enumeration following (Pennak 1978, Merritt and Cummins 1996, Gerber and Gabriel 2002, Huxley 2003). Macroinvertebrates were identified to family level using light microscope at x10 magnification and other available keys.

2.3 Determination of Lead (Pb) Concentration in Samples

Total concentrations of lead (Pb) in water and sediment samples were determined using an atomic absorption spectrophotometer (Varian Spectr AA 20), equipped with single elements hollow-cathode lamps at the wavelengths of 324.7, 213.9, 283.3, 228.8, 232.0 and 357.9 nm, respectively. Water samples were digested with few drops of concentrated nitric acid (HNO_3). For the determination of total heavy metal concentration in sediment, exactly 1.00g of powdered sediment sample was digested with aqua regia (HNO_3 HCl = 1: 3). Before use, all glass and plastic wares were soaked in 14% HNO_3 for 24 hrs. The washing was completed with a distilled water rinse.

2.4 Data Analyses

Statistical analysis was done on SPSS using the one-way ANOVA to determine if there is any significant difference between the means of the samples collected from the three locations. Values were considered statistically significant at P=.05.

3. RESULTS AND DISCUSSION

3.1 Water Quality Parameters

The water quality characteristics revealed that temperature ranged between 22.00-23.00℃ with the value of station C higher than station A and B, pH ranged 5.40-7.90g/L with station C having lowest value than station A and B. The low pH (below 7) in water collected at station B and C indicated that it is slightly acidic. Dissolved oxygen ranged from 4.20-11.20mg/L indicating higher dissolved oxygen in station A and B than station C, free carbon dioxide ranged from 90.00-120.00mg/L with station C having higher value than station A and B while alkalinity ranged 50.00-136.00mg/L with station A having lower value (50.00 mg/L) than station B (66.00 mg/L) and C (136.00 mg/L) respectively. Earlier studies (Absalom et al. 2005) recorded similar values while studying the Coliform, Planktonic and Macro-invertebrates of river Delimi.

3.2 Concentration of Lead (Pb) In Water Column

Anthropogenic activities like mining, farming and indiscriminate refuse dumping alter the clean water and soil composition and are considered one of the most significant sources of Lead(Pb) pollution in rivers. Lead (Pb), due to its high toxicity and bioaccumulation tendency, is one of the top three pollutants of concern for both humans and wildlife and occupies second place in the priority list of hazardous substances (Vittoria etb al. 2022). The local residents living around Abattoir, British America and Farin Gada communities mainly engage in farming and artisanal mining as part of their occupation. The three (3) communities showed diverse concentrations of lead (Pb) in water of river Delimi. as shown in Table 2, the mean lead concentrations in water collected from the three Sites ranged from 0.0085 – 0.0874 ppm with the highest concentrations in WA3 (Abattoir) and WC3 (Farin Gada) with values higher than the permissible limit of 0.01 ppm provided by WHO/FAO which is in agreement with (Farooq and Umar 2008). Concentrations were lower in WA1 (Abattoir) as well as WB1 (British America).

3.3 Concentration of Lead (Pb) In Sediment

A study carried out by (Loska et al. 2004) suggested that dumping of different waste materials such as plastics, electrical and electronic materials, metal scraps, old batteries, spent lubricating oil from nearby mechanic workshops along the Delimi River bank may be responsible for the high level of heavy metals in the river water. Although sediment have heavy metal immobilizing capability, the ability of metals to bio-accumulate over a period of time will result in uptake by benthic organisms in the contaminated soils. Since Lead (Pb) is not very mobile in soil, concentrations of lead in soil which are representative of the degree of pollution/contamination may not directly be linked to an adverse health effect without conducting a health risk assessment of the organisms, because only a fraction is taken up by the organisms (ATSDR 2010). The bioavailable metal content in water and soil exerts a significant impact on water quality and this might affect food safety and biodiversity of macro invertebrates. Hence, the assessment of heavy metal contamination is of public health importance in agricultural soils (Sabo et al. 2013). The disparity in concentration observed in this study could be as a result of the different contamination source. The increase in Blood Lead Level (BLL) among Nigerians may not be unconnected to environmental Lead (Pb) emission from industries, mines and leaded gasoline due to limited regulatory restrictions from the relevant government agencies to check pollution. Lead (Pb) accumulates in sediment and can pose a hazard to sediment dwelling organisms at concentration above 30.2ppm according to Canadian interim marine sediment quality guideline (Mariantika and Retnaningdyah 2014).

3.4 Macro-invertebrates Distribution

A total of 7 macro-invertebrates taxa were identified in the three (3) sampling stations of River Delimi. Chironomidae, *Eristalis* Larva (Syrphidae), Tabanidae and Whirligig beetle (*Gyrinidae*) comprised more than 79% of the total abundance, while stonefly Larva, Hydrophilid beetle and beetle larva (*Coleoptera*) constitute 21% of the total abundance, respectively. As seen in Table 4, it will be observed that only two (2) taxa (hydrophilid beetle and whirling beetle) were found in station A implying moderate water quality of the station. While the presence of *Eristalis* larva and *Chironomus* larva though in low index suggest that station B is slightly polluted. The high dominance index of *Chironomus* larva and *Eristalis* larva indicates that station C were unstable using imbalance of ecosystem. Usually certain organism like *Chironomus* sp. can thrive in an environment with high organic contamination. Most Chironomidae larvae are efficient indicators of mesotrophic waters, and these are usually found at location having high decomposed organic matter. Thus, presence of the Chironomidae family by higher percentage reflected that station C was highly polluted. According to (Absalom et al. 2005, Sabo et al. 2013), *Chironomus* species are indicator of waters contaminated by high load of organic waste. According to (Setiawan 2009). Studying macro-invertebrate diversity is one of the most effective and inexpensive ways to estimate the ecological quality of the waters. For example,

Table 1. Mean water quality parameters monitored during the experimental period

Parameter	Station A	Station B	Station C
Temperature (°C)	22.50±0.1	22.00 ±0.3	23.00±0.1
Ph	7.90±0.2	6.50±0.1	5.40 ±0.1
Dissolved oxygen (mg/L)	11.20±0.1	9.50 ±0.2	4.20±0.1
Free carbon dioxide (mg/L)	90.00±0.2	100.00±0.2	120.80±0.4
Alkalinity(mg/L)	50.00 ±0.1	66.00±0.3	136.00±0.5

Table 2. Concentration (mg/l) of Lead (Pb) in water column of River Delimi

Sampling Period	Sampling Stations								
	Station A			Station B			Station C		
	WA1	WA2	WA3	WB1	WB2	WB3	WC1	WC2	WC3
August	0.0455	0.0315	0.0874	0.0105	0.0245	0.0315	0.0245	0.0245	0.0455
September	0.0085	0.0339	0.0424	0.0169	0.0339	0.0085	0.0508	0.0085	0.0678
October	0.0433	0.0234	0.0385	0.0265	0.0532	0.0428	0.0365	0.0423	0.0371
November	0.0588	0.0588	0.0392	0.0000	0.0339	0.0294	0.0392	0.0490	0.0392

Table 3. Concentration (mg/l) of Lead (pb) in Sediment of River Delimi in Four (4) months

Sampling Period	Sampling Stations								
	Station A			Station B			Station C		
	A1	A2	A3	B1	B2	B3	C1	C2	C3
August	25.85	19.07	7.63	12.29	15.25	17.37	31.36	29.66	34.32
September	91.53	43.22	60.17	32.20	40.68	54.24	38.14	39.83	123.20
October	128.32	201.77	240.26	84.07	125.66	80.53	58.41	570.80	120.35
November	43.14	47.06	143.14	33.33	49.02	154.90	418.63	665.69	88.24

Table 4. Species composition, abundance and distribution of macro-invertebrates in River Delimi

Order	Family	Taxa	Stations			Pollution Status
			A	B	C	
Coleoptera	Dysticidae	*Phylodyte Sp*	0	0	10	Very tolerant
	Hydrophilidae	*Crenis Sp*	5	6	0	Sensitive
	Tabanidae	*Tabanus Sp*	0	0	4	Tolerant
Diptera	Chironomidae	*Chironomus Sp*	0	2	18	Very tolerant
	Syrphidae	*Unknown Sp*	0	4	14	Very tolerant
Ephemeroptera	Gyrinidae	*Orectochilus Sp*	4	6	0	Sensitive
Plecoptera	Unidentified	Unidentified	0	0	12	Very tolerant

measurements of the physical and chemical properties of water can also be used to estimate its quality but such measurements cannot exactly represent its actual state. Therefore, it is necessary to combine physical, chemical, and biological evaluation along with other monitoring methods to provide a comprehensive picture of environmental water quality (United States 2018). Biological monitoring using macro-invertebrates has been found accurate and advantageous compared with using other organisms because macro-invertebrates are extremely sensitive to organic pollutants, widely distributed, and easy and economical to sample (Setiawan 2009).

4. CONCLUSION

In conclusion, Delimi River received certain pollutants and can be categorized as a polluted river. (Hu et al. 2014) described numerous sources of Lead (Pb) as sewage sludge, leaded gasoline from vehicular traffic and industrial emission, but recent studies have shown that mining could be a major source point of Lead (Pb) pollution in agricultural soils. The high level of Lead in sediment suggests that sediment dwelling organisms are likely to bio accumulate Lead over time. This study also provides insights on the impacts of environmental variables on the diversity of macro-invertebrate assemblage in River Delimi. Given the negative effects of Lead (Pb) consumption on human lives and macro-invertebrates, the study recommended that: government should enforce the ever-existing law that bans dumping of refuse, sewage and industrial waste into rivers. Restriction of human, industrial and agricultural discharges to this River is required with continuous monitoring to ensure that the concentrations of Lead remain within the prescribed worldwide limits to protect it from further deterioration.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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