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ORIGINAL PAPER

Evaluating the quality of sediments in streams draining contrasting land-use areas in Osogbo metropolis, southwestern Nigeria

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Abstract The attendant effects of urbanization on the environment and human health are evaluable by measuring the potentially harmful element (PHE) concentrations in environmental media such as stream sediments. To evaluate the effect of urbanization in Osogbo Metropolis, the quality of stream sediments from a densely-populated area with commercial/industrial activities was contrasted with sediments from a sparsely-populated area with minimal anthropogenic input.

Forty samples were obtained: 29 from Okoko stream draining a Residential/Commercial Area (RCA, $n = 14$) and an Industrial Area (IA, $n = 15$), and 11 from Omu stream draining a sparsely-populated area (SPA). The samples were air-dried, sieved to < 75 micron fraction, and analysed for PHEs using inductively-coupled plasma atomic emission spectrometry (ICP-AES). Index of geoaccumulation (I_{geo}), pollution index (PI), ecological risk factor (Er) and index (ERI) were used for assessment. Inter-elemental relationships and source identification were done using Pearson's correlation matrix and principal component analysis (PCA).

PHE concentrations in the stream sediments were RCA: Zn > Pb > Cu > Cr > Sr > Ni > Co, IA: Zn > Cr > Ni > Co > Pb > Cu > Sr and SPA: Zn > Co > Cr > Cu > Sr > Ni > Pb. I_{geo} calculations revealed moderate-heavy contamination of Cu, Pb and Zn in parts of RCA, moderate-heavy contamination of Zn in IA while SPA had moderate contamination of Co and Zn. PI values revealed that stream sediments of RCA are extremely polluted, while those of IA and SPA are moderately and slightly polluted, respectively.

The pollution of the stream sediments in RCA and IA is adduced to anthropogenic activities like vehicular traffic, automobile repairs/painting, blacksmithing/welding and metal scraping. In SPA however, the contamination resulted from the application of herbicides/fertilizers for agricultural purposes.

Keywords Osogbo metropolis · Land-use activities · Pb contamination · Vehicular traffic · Agriculture

Introduction

The attendant effects of urbanization include marked increase in population, mining/smelting activities, indiscriminate disposal of domestic and industrial

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waste, manufacturing/production processes, traffic emissions and industrial effluents (Cheng et al., 2014; Pavlović et al. 2017; Kolawole et al., 2018; Fajemila et al., 2022). Metal contamination in the environment has been attributed to these anthropogenic activities, which are ubiquitous especially in densely-populated areas. As the intensity of these activities increases, the by-products from them causes a reduction in the quality of environmental media such as air, soil, stream sediments, as well as surface and ground-water. The concern about the quality of environmental media in urban areas continues to grow, especially from an ecological and health perspective. Although the aforementioned anthropogenic activities are largely responsible for decrease in the quality of the environment, agriculture has also been known to contribute potentially harmful elements (PHEs) to the environment, albeit at minimal to moderate levels.

Research has shown that anthropogenic activities lead to significantly elevated levels of PHEs like Cd, As, Pb, Cu, Zn and Ni in environmental media. As the concentration of these PHEs increase in the environment, they eventually accumulate in the human body and have negative health consequences due to their non-biodegradable nature and long biological half-lives (Akinade & Olisa, 2014; Kirpichtchikova et al., 2006; Kolawole et al., 2022; Olatunji et al., 2022; Sathawara et al., 2004).

Streams are recipients of materials from the catchment areas they drain. Hence, they are natural sinks for debris and metals from upstream areas, and these accumulate over time to form part of the stream beds. There is a direct link between the intensity of anthropogenic activities in upstream areas and the contamination/pollution of stream sediments in an area (Christophoridis et al., 2019; Castro et al., 2021; Phillips and Fajemila 2024). Therefore, the quality of the sediments in a stream can be used as an indicator to evaluate the nature and intensity of human activities taking place within its catchment area. Ultimately, stream sediments can be used to assess the quality of the environment being studied. The general representative nature of stream sediments in downstream sites makes them a useful sampling medium for the detection of PHE anomalies related to mineralisation and for environmental studies related to pollution (Chakrapani, 2002).

An understanding of the dynamic relationship between urbanization and the quality of environmental media is necessary for environmental planning and monitoring. Hence, this study is aimed at evaluating the effect that human activities have on stream sediment quality in Osogbo metropolis. This was done by contrasting the quality of stream sediments in densely-populated and sparsely-populated areas.

Materials and methods

Study area description

Osogbo is a growing metropolitan city, located in southwestern Nigeria. The population of Osogbo has increased steadily since it became a Metropolis in the early 1990s (currently estimated to be 796,000 compared to 200,000 in 1991). With an area of 126 km^2, Osogbo is characterised by dense population, vehicular traffic, indiscriminate waste dumping, welding/blacksmithing and automobile repair activities at the city centre. Northeast of the city centre, there is also a Foundry and scrap metal recycling sites of small to medium scale (Fig. 1). Factories like these are known to contribute high concentrations of Cd, Cr, Ni, Pb and Zn to the environment (Dragović et al. 2014; Owoade et al., 2015; Olatunji et al., 2018). Osogbo has a tropical climate, with annual rainfall of ca. 136 mm. Osogbo lies within the Nigerian Basement Complex, with lithologies such as schist, gneiss and pegmatite being the most dominant. The schists include mica, pelitic and talc-tremlite varieties, while the gneisses are mostly migmatitic. The pegmatite occur commonly as intrusions within the schists (Kolawole et al., 2023; Okunola & Olatunji, 2017).

This study, conducted during the dry season within $7^{\circ}45'00''$–$7^{\circ}48'45''$ N and $4^{\circ}33'00''$–$4^{\circ}37'00''$ E, evaluated the quality of sediments in two streams draining contrasting land-use areas. Okoko stream, which is a tributary of the Osun River, runs through a densely-populated area divided into Residential/Commercial area (RCA) and Industrial area (IA). Okoko stream runs through markets, business districts, auto-repair shops and along/across highways in the city centre. Omu stream, another Osun River tributary, drains a sparsely-populated area (SPA) in the outskirts of Osogbo Metropolis (Fig. 2). RCA covers Ayepe—Tanisin areas, IA covers Testing Ground—Power Line areas while SPA covers Coker Village area.

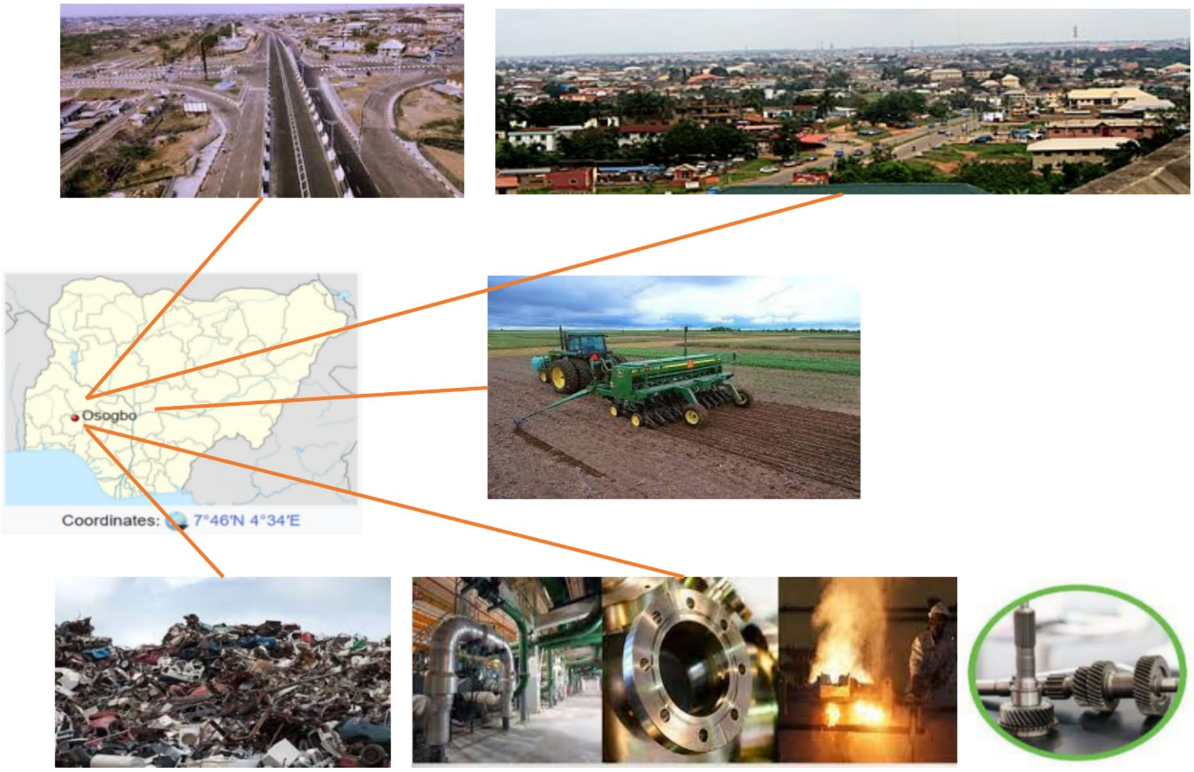


Fig. 1 Different land-use activities in Osogbo Metropolis (Image sources: en.wikipedia.org, nigeriamachinetools.com)

Peri-urban areas, such as RCA in this study, are usually a mixture of residential and commercial activities. This combined land use is particularly a feature of low-income areas where most individuals conduct commercial activities at or near their residences (Kolawole et al., 2023). These activities include indiscriminate dumping and incineration of waste, blacksmithing/metal welding, automobile repair and painting, etc. IA is characterised by the presence of Nigerian Machine Tools, a Foundry where industrial and agricultural machines and machine parts were manufactured until 2007. The area is also characterised by low-scale metal scrapping and sorting activities. SPA, on the other hand, has agricultural activities such as farming and animal husbandry as the major land use.

Sample collection

A total of forty (40) stream sediment samples were obtained from 0–20 cm depth at the beds of active streams using a stainless-steel shovel and transported in labeled polyethylene bags to the laboratory. While sampling stations were predetermined during desk study using satellite imagery of the study area, sampling on the field was modified and done based on accessibility to the streams. At points where tributary confluences occurred, samples were collected just before and after the confluence. A total of twenty-nine samples were collected from Okoko stream while eleven samples were collected from Omu stream (Fig. 2), based on accessibility and stream lengths.

Sample preparation and analysis

The stream sediments were air-dried, disaggregated and sieved to obtain the < 75 micron fraction in the Geochemistry laboratory of the Department of Geological Sciences, Osun State University, Osogbo. Physico-chemical properties such as pH, total carbon (TC) and total organic matter (OM) content were also done. To determine the pH of the stream sediments, the pH meter was calibrated with buffer solutions 4, 7 and 9. 1 g of sample was weighed into a 50 ml glass

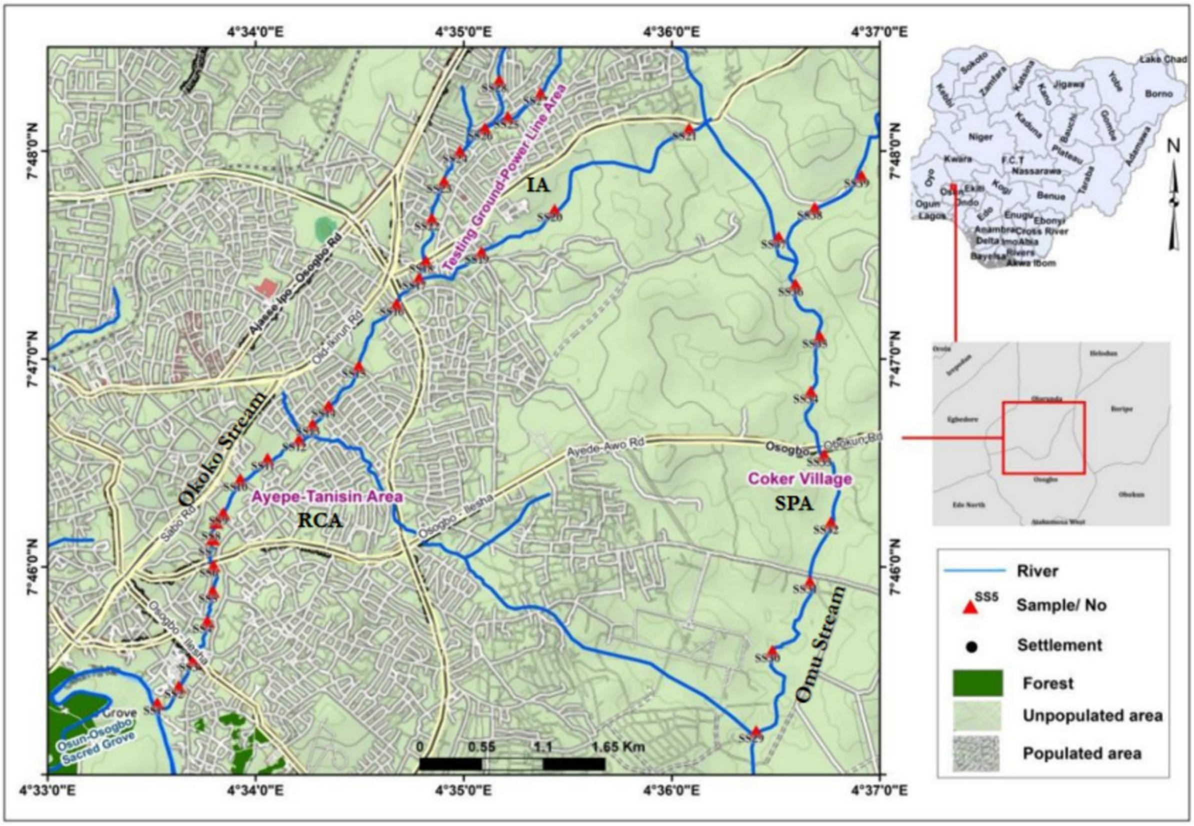


Fig. 2 Sediments sampled from streams draining densely-populated (RCA and IA) and sparsely-populated (SPA) areas

beaker, 10 ml of distilled water was added, and the solution agitated for few minutes. The supernatant was decanted into a 20 ml tube. The pH meter probe was inserted into the decanted solution, and the pH value read.

For organic carbon (OC) content determination, 0.5 g of air-dried sample was weighed into a conical refluxing flask and 10 ml of standard $K_2Cr_2O_7$ solution was added. 15 ml of concentrated H_2SO_4 was added and the refluxing flask was connected to a condenser. This was refluxed for 60 min, cooled and rinsed with distilled water. After, this was titrated against standard $Fe(NH_4)_2(SO_4)_2.6H_2O$ (FAS) in the presence of ferroin indicator from blue-green to violet-red. A blank was also analysed in the same way.

OC was calculated using the formula:

$$OC = \frac{18*C*V}{W}*(1 - V1/V2) \quad (1)$$

where:

C = Conc. of $K_2Cr_2O_7$.

V = Volume of $K_2Cr_2O_7$ used (10 ml).

W = Weight of Sample (g).

V1 = Volume of FAS used to titrate sample.

V2 = Volume of FAS used to titrate blank.

The organic matter (OM) content was calculated using the relation:

$$OM\ (\%) = 1.72 \text{ x } OC\ (\%) \quad (2)$$

The sieved samples were analysed using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES), to determine the concentration of Fe, Co, Cu, Cr, Ni, Pb, Sr and Zn, at ALS Canada Laboratory Ltd., Vancouver. 0.50 g of stream sediment was digested with aqua regia for 45 min in a graphite heating block. After cooling, the resulting solution was diluted to 12.5 ml with deionized water, mixed and analyzed by ICP-AES.

Quality assurance/quality control (QA/QC)

Standard reference materials such as EMOG17, MRGeo08, OREAS 906 and OREAS 45 h were used for quality assurance and quality control measures. Blanks and pulp duplicates were also analysed, while the intensities of the measured pulses were compared with the standards and the analytical results were corrected for inter-element spectral interference. The lower detection limits for Fe, Co, Cu, Cr, Ni, Pb, Sr and Zn were 0.01 (%), 1, 1, 1, 1, 2, 1 and 2 mg/kg, respectively.

Data analysis

Statistical evaluation using the Pearson's Correlation and Principal Component Analysis (PCA) were done on the geochemical data obtained using the Statistical Package for the Social Sciences (SPSS) software (Čakmak et al., 2020). The Pearson's Correlation analysis tests the strength of the association between two random variables and it is used to describe observed geochemical distribution and associations (Olatunji & Abimbola, 2010). PCA groups relate variables into principal associations known as components on the basis of their mutual correlation coefficients (Asaah et al., 2006). The components obtained are related to actual processes influencing the geochemistry of the stream sediments.

Indices for the assessment of stream sediment quality

Calculation of geochemical and ecological indices can be applied to most chemical elements and to several geomaterials. The quality of the stream sediments was assessed with parameters such as Index of geoaccumulation (I_{geo}), Pollution Index (PI) and Ecological Risk Factor (Er) and Index (ERI). These were calculated to evaluate the degree of possible contamination and pollution in the stream sediments. Sediment quality indices have been widely used to determine significant impact of metals on the environment (Fakayode & Olu-Owolabi, 2003; Loska et al., 2004; Gbadebo and Bankole 2007; Odewande & Abimbola, 2008; Akinade & Olisa, 2014; Odukoya, 2015; and Olatunji & Ajayi, 2016). The background value used for calculation is the Average Shale Content (ASC) prescribed by Turekian and Wedepohl (1961).

Index of geoaccumulation (I_{geo})

The degree of metal contamination in the stream sediments was determined using the six classes of geoaccumulation index proposed by Muller (1981) ranging from practically uncontaminated to extremely contaminated, using the equation:

$$I_{geo} = \log_2\left(\frac{Cn}{1.5 * Bn}\right) \quad (3)$$

where;

I_{geo} is the index of geoaccumulation,

Cn is the measured concentration of metal in the stream sediments,

Bn is the background value of the metal (i.e. ASC),

1.5 is a constant used as a correcting factor for the variation in lithogenic effects.

Pollution index (PI)

The Pollution Index was used to determine the level of pollution of the areas studied by the PHEs, using the relation proposed by Nemerow, 1991:

$$PI = \sqrt{\frac{\left(CF_{Average}\right)^2 + \left(CF_{Max.}\right)^2}{2}} \quad (4)$$

where PI is Pollution Index.

$CF_{Average}$ is average value of contamination factors.

$CF_{Max.}$ is maximum contamination factor value.

The various thresholds for contamination and pollution are highlighted in Supplementary Material A1, while calculated CF values are presented in Supplementary Material A2.

Ecological indices

Ecological risk factor (Er) (Hakanson, 1980) refers to the risk posed to living organisms by the presence of anthropogenically-introduced metals in the sediments of the streams. The sum of the individual risk factors is termed the potential ecological risk index (ERI). Er and ERI are calculated using the equations:

$$Er = Tr.CF \quad (5)$$

$$\mathrm{ERI} = \sum_{i=1}^{7} \mathrm{Er} \tag{6}$$

where, Er is the ecological risk factor,

Tr is the toxicity response of individual metals: Co (5), Cr (2), Cu (5), Ni (6), Pb (5), Sr (2), Zn (1) (Hakanson, 1980; Xie et al., 2016).

ERI is the risk index, and.

$\sum_{i=1}^{7}$ Er is the sum of calculated risk factors.

The levels of Ecological Risk are presented in Supplementary Material A3.

Results and discussion

Physico-chemical properties

The pH values for stream sediments from RCA revealed they are slightly acidic; with TC and OM content averaging 3.9% and 6.7%, respectively. Stream sediments from IA were acidic to slightly acidic and had average TC and OM values of 3.4% and 5.9%, respectively. Though SPA stream sediments were also acidic to slightly acidic, they had higher TC and OM concentrations of 6.2% and 10.6%, respectively (Table 1). Acidity of environmental media facilitates element mobility and bioavailability (Kolawole et al., 2023; Pavlović et al., 2021); implying that the PHEs in the sediments from the streams will be readily mobile and bioavailable. Using the average pH values of the sediments from the streams in the three zones, PHE mobility and bioavailability is expected to be in the order RCA < IA < SPA. The dominance of Agricultural activities in SPA explains the higher average OM content. This is as a result of the extensive use of fertilizers to achieve improved crop yield. Animal dung, which is rich in OM, is also a contributing factor as some cattle grazing is done in the zone (Bakayoko et al., 2009; Guo et al., 2016).

PHEs concentration in the stream sediments

Sediments from streams are representative of the quality of the environment from which they are derived. Therefore, PHE contamination in the sediments can serve as a valuable indicator of contamination in the source-areas of the sediments. The summary of concentrations of the PHEs in the sediments is presented in Table 2 and Fig. 3. As and Hg concentrations were below detection limit (BDL) of the analytical instrument used, while that of Cd

Table 1 Physico-chemical properties of stream sediments from Osogbo Metropolis

	pH		Total carbon (%)		Organic matter (%)	
	Min.–Max.	Mean	Min.–Max.	Mean	Min.–Max.	Mean
RCA	6.0–6.5	6.4	2.3–8.1	3.9	3.9–14.0	6.7
IA	4.7–6.5	5.9	0.4–8.4	3.4	0.6–14.5	5.9
SPA	4.6–6.5	5.4	1.0–11.1	6.2	1.8–19.1	10.6

Table 2 Summary of concentration (mg/kg) of PHEs and Fe in the stream sediments from the three land-use areas

PHE	RCA (n = 14)		IA (n = 15)		SPA (n = 11)		ASC[1]
	Min.–Max.	Mean ± Std. Dev	Min.–Max.	Mean ± Std. Dev	Min.–Max.	Mean ± Std. Dev	
Co	6.0–19.0	10.1 ± 3.3	6–37	14.7 ± 10.1	4–82	32.0 ± 25.0	19
Cr	40.0–69.0	52.1 ± 8.3	37–101	52.9 ± 15.3	30–77	51.0 ± 15.3	90
Cu	16.0–151.0	54.4 ± 35.8	12–24	16.6 ± 3.2	6–39	19.2 ± 9.9	45
Ni	8.0–27.0	13.4 ± 4.8	5–58	16.3 ± 12.4	4–31	17.1 ± 8.3	68
Pb	29.0–223.0	94.6 ± 69.3	17–36	21.6 ± 5.1	11–26	19.0 ± 4.1	20
Sr	11.0–38.0	27.6 ± 15.2	8–23	13.8 ± 5.0	6–38	18.7 ± 10.6	300
Zn	95.0–865.0	309.6 ± 192.3	60–782	172.1 ± 191.6	29–417	106.3 ± 108.9	95
Fe	17,500–48100	27,721 ± 7431.2	17,100–41700	25,160 ± 8555.8	10,200–99600	35,681 ± 23,624	47,000

[1] *ASC* Average Shale Content (Turekian & Wedepohl, 1961)

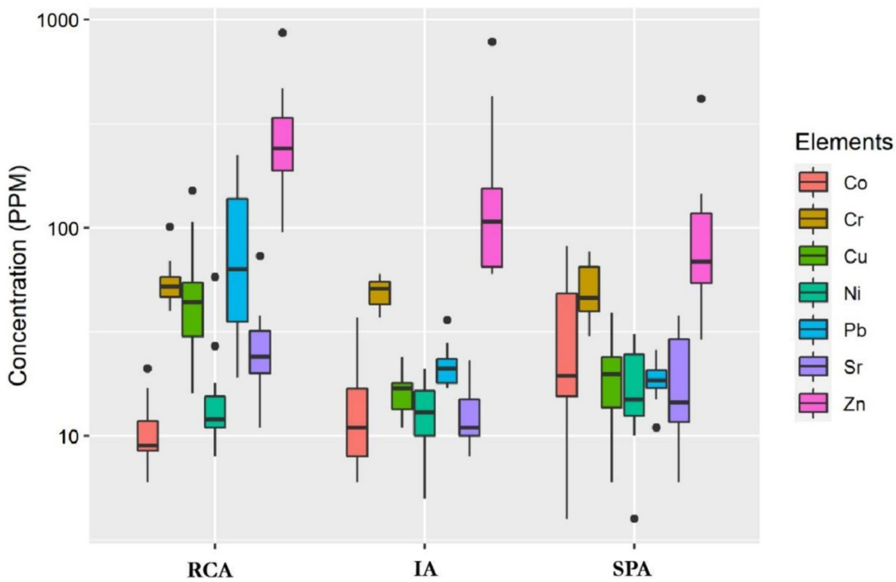


Fig. 3 PHE concentration (mg/kg) in the stream sediments from Osogbo Metropolis

was preponderantly BDL. Mean Zn concentration exceeded the ASC value in the three land use areas, mean Pb concentration exceeded ASC values in RCA and IA, while mean Cu concentration was above ASC value in RCA. The mean value of Co surpassed the ASC value in SPA (Table 2) while the concentrations of Cr, Ni and Sr were below ASC value in all locations sampled.

The mean PHE concentrations of the studied stream sediments were compared with other studies from southwestern Nigeria. The concentration of the PHEs in stream sediments of Ikorodu (Odukoya & Akande, 2015) were lower that of the study while the stream sediments in Ile-Ife (Asowata & Akinwumiju, 2020) had higher concentrations of the PHEs compared to the study, except Pb. Compared with stream sediments of Osogbo, the Ijebu-Ode stream sediments (Akinade & Olisa, 2014) had lower concentrations of all the PHEs except Cr. When compared with stream sediments in Ibadan (Kolawole et al., 2022), the stream sediments studied had lower concentrations of all the PHEs except Cr. The studied stream sediments

Table 3 Comparison of mean PHE concentrations (mg/kg) in sediments of Osogbo streams with other areas

Location	Co	Cr	Cu	Ni	Pb	Sr	Zn	Fe	Study
Osogbo, Nigeria	10.1	54.4	52.1	13.4	94.6	27.6	309.6	27,721	Present Study
Ibadan, Nigeria	12.9	37.2	154.7	25.3	536.7	-	433.5	44,700	Kolawole et al., 2022
Ijebu-Ode, Nigeria	4.8	111.4	27.8	9.2	69.0	15.0	264.4	–	Akinade & Olisa, 2014
Ikorodu, Nigeria	2.9	12.6	9.9	3.3	9.7	11.9	95.2	7500	Odukoya & Akande, 2015
Ile-Ife, Nigeria	29.3	132.8	70.3	24.9	67.3	53.4	357.8	–	Asowata & Akinwumiju, 2020
Orle, Nigeria	4.6	25.3	7.9	8.0	7.7	-	17.4	10,564	Adepoju & Adekoya, 2013
Kienke watershed, Cameroon	–	–	24.2	34.8	5.9	–	46.7	–	Mandeng et al., 2019
Sfax Solar Soltern, Tunisia	–	–	34.3	50.4	68.6	–	101.1	8828	Bahloul et al., 2018
Al-Khowkhah, Yemen	–	–	17.8	19.3	8.8	–	41.2	–	Al-Edresy et al., 2019
Tianjin, China	–	–	19.4	–	4.3	–	88.4	–	Guo et al., 2010
Xiangjiang, China	17.0	59.7	71.3	36.3	102.5	–	257.2	–	Huang et al., 2020
Vembanad wetland system, India	–	2.1	36.1	57.0	33.4	–	165.6	–	Harikumar et al., 2009
Bhatiari, Bangladesh	–	86.7	39.9	35.1	122.0	–	102.1	35,216	Siddiquee et al., 2012
Salimpur, Bangladesh	–	68.4	21.1	23.1	36.8	–	83.8	11,932	

had higher concentrations of all the PHEs when compared with stream sediments of Orle, Niger-Delta area of Nigeria (Adepoju & Adekoya, 2013) (Table 3).

The mean concentrations of Co, Cr, Cu, Ni, Pb, and Zn in the studied stream sediments were less than sediments in Xiangjiang, China (Huang et al., 2020). While the concentrations of Cu, Pb and Zn in sediments of Osogbo streams were higher than those of Cameroon and Tunisia, they both had Ni values higher than those of the sediments of Osogbo (Table 3).

Index of geoaccumulation (I_{geo})

A summary of the calculated I_{geo} for the stream sediments studied is presented in Table 4 and Fig. 4. There was no Co, Cr, Ni and Sr contamination in the stream sediments from RCA. However, moderate contamination of Cu were detected in SS7 and SS8A, moderate to heavy Pb contamination in SS3 and SS5–SS8, and moderate to heavy Zn contamination in SS4, SS5 and SS7. Activities which characterise the locations with moderate Cu include waste dumping and incineration, along with household wastewater discharge into stream channels. Locations where moderate to heavy Pb and Zn contamination were detected were characterised by intense vehicular traffic, automobile repair, blacksmithing, and waste dumping/incineration. These activities are established contributors of these PHEs to the environment (Kolawole et al., 2022, 2023).

Stream sediments from IA had no Cr, Cu, Ni and Sr contamination, none to moderate Co and Pb contamination, while moderate to heavy contamination of Zn was detected in some samples. SS17 and SS28 where moderate to heavy Zn contamination was detected were taken from locations characterised by intense vehicular traffic, household waste dumping and incineration, and welding activities. Wear and tear of vehicle parts, vehicular exhaust and non-exhaust

Table 4 I_{geo} summary for the stream sediments evaluated

PTE	RCA		IA		SPA	
	Range	Contamination	Range	Contamination	Range	Contamination
Co	−2.2–−0.7	None	−2.2–0.4	None—None/Mod.	−2.8–1.5	None—Mod.
Cr	−1.8–−1.0	None	−1.9–−0.4	None	−2.2–−0.8	None
Cu	−2.1–1.2	None—Mod.	−2.5–−1.5	None	−3.5–−0.8	None
Ni	−3.7–−1.9	None	−4.4–−0.8	None	−4.7–−1.7	None
Pb	0.0–2.9	None/Mod.—Mod./Heavy	−0.8–0.3	None—None/Mod.	−1.4–−0.2	None
Sr	−5.4–−2.6	None	−5.8–−4.3	None	−6.2–−3.6	None
Zn	−0.6–2.6	None—Mod./Heavy	−1.1–2.5	None—Mod./Heavy	−2.3–1.5	None—Mod.

Mod. Moderate

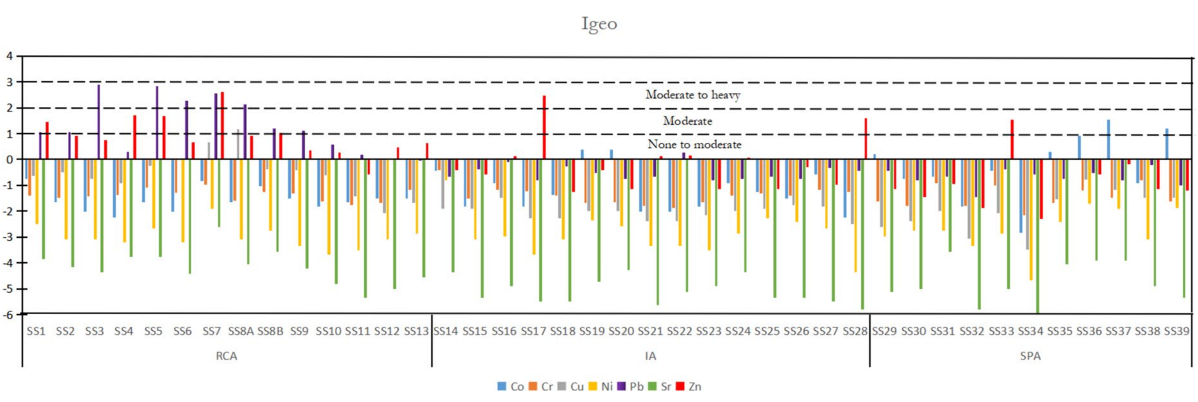


Fig. 4 Index of geoaccumulation for the stream sediments analysed

emissions, and welding activities are sources of PHEs in the environment (Aslam et al., 2013; Kolawole et al., 2022, 2023; Nawrot et al., 2020). While there was no contamination of Cr, Cu, Ni, Pb and Sr in the stream sediments of SPA, moderate contamination of Co and Zn were detected in some locations. SS33 had moderate Zn contamination while moderate Co contamination was detected in SS36, SS37 and SS39. All the SPA samples were taken from locations with intense agricultural activities and occasional cattle grazing. Co and Zn are key ingredients in the manufacture of pesticides, herbicides and fertilizers (Mortvedt & Gilkes, 1993; Defarge et al., 2018; Liu et al. 2020; Alengebawy et al. 2021).

Pollution index (PI)

Results of calculated PI for the studied areas showed that stream sediments of RCA are extremely polluted (PI value = 3.49), those of IA are moderately polluted (PI value = 1.37) while the sediments in SPA are slightly polluted (PI value = 0.94) (Fig. 5).

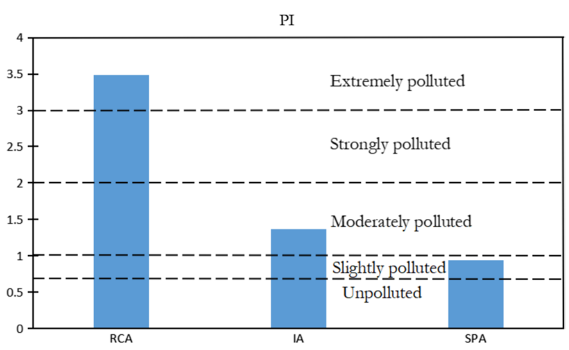


Fig. 5 Pollution Index for the three land-use areas

The moderate to heavy contamination of Cu, Pb and Zn in the stream sediments of RCA is thought to be responsible for the overall classification of the stream sediments as extremely polluted. The moderate pollution of stream sediments in IA is also believed to be caused by moderate Pb and Zn contamination. However, only moderate Zn contamination was detected in stream sediments of SPA (Table 4).

Ecological risk

The calculated Er values for the sediments of the streams reveal that all the PHEs had values less than 30 across the land-use areas. This indicated that each PHE evaluated poses low potential ecological risk. The PHE which had the highest Er value across the land-use areas was Pb, with 23.5, 5.5 and 5.0 for RCA, IA and SPA, respectively. This would have arisen from the relatively high toxicity response value of Pb (i.e. 5). The overall ecological risk across the three land-use areas for all the PHEs (i.e. ERI) also revealed a low-risk index (Table 5, Fig. 6).

Evaluation of sources of PHEs in the stream sediments

To identify the possible sources of the PHEs, Principal Component Analysis (PCA) was used (Bořůvka et al., 2005; Pavlović et al., 2017). Four Principal Components (PC) having a cumulative variance of ca. 88% were calculated for the PHEs. PC 1 accounted for ca. 27% of total variance and contained Cu (0.92), Pb (0.88) and Sr (0.64). PC 2 which was heavily loaded with Fe (0.90) and Co (0.93) accounted for ca. 26% of total variance, while PC 3 accounted for ca. 20% variance and contained Cr (0.93) and Ni (0.78).

Table 5 Calculated Er and ERI values for stream sediments in the land-use areas

PHE	RCA		IA		SPA	
	Er	Classification	Er	Classification	Er	Classification
Co	2.5	Low risk	4.0	Low risk	8.5	Low risk
Cr	1.2	Low risk	1.2	Low risk	1.2	Low risk
Cu	6.0	Low risk	2.0	Low risk	2.0	Low risk
Ni	1.2	Low risk	1.2	Low risk	1.8	Low risk
Pb	23.5	Low risk	5.5	Low risk	5.0	Low risk
Sr	0.2	Low risk	0.1	Low risk	0.1	Low risk
Zn	3.3	Low risk	1.8	Low risk	1.1	Low risk
ERI	37.88	Low	15.8	Low	19.72	Low

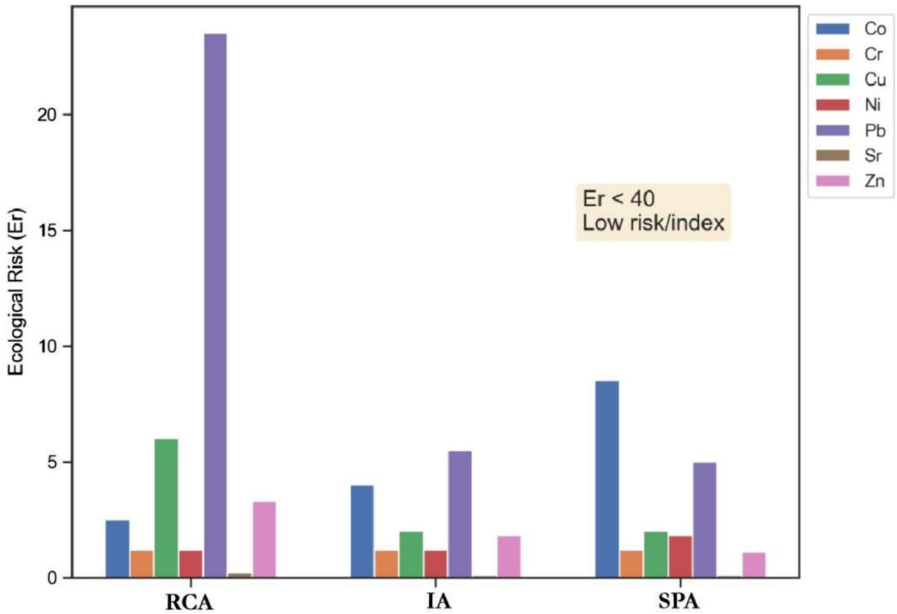


Fig. 6 Ecological risk of PHEs in stream sediments of the different zones

PC 4 contained only Zn (0.90) and accounted for ca. 15% of total variance (Table 6).

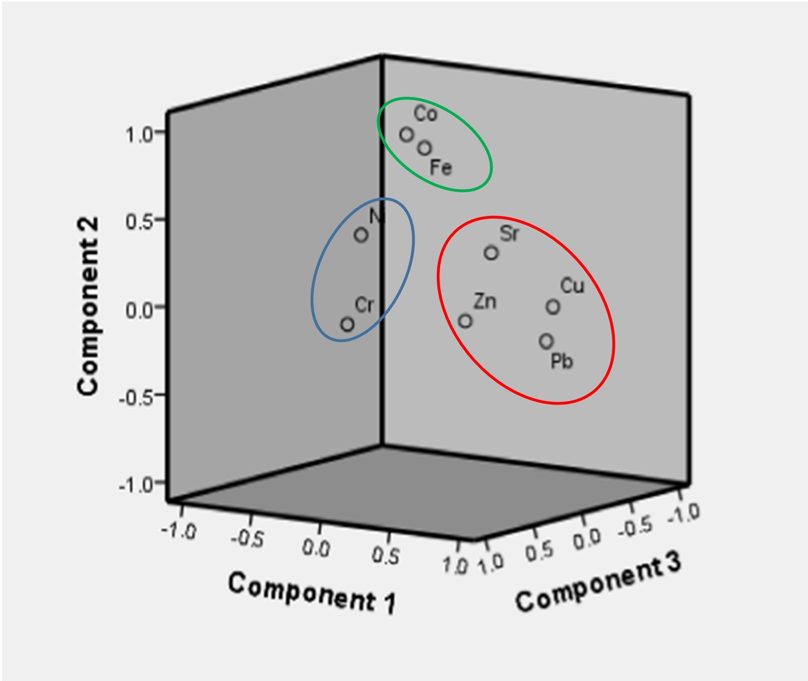
An anthropogenic origin is adduced for the occurrence of Cu, Pb and Sr in PC1. These metals are common components of automobile parts/paints, blacksmithing/welding activities, waste dumping (especially e-waste) and incineration. These activities are common in RCA and IA. Cu and Pb are common by-products of vehicular emissions, while Sr is used as a flux in welding/blacksmithing (Kozyrev et al., 2018; Kryukov et al., 2017). Fe, which is believed to be sourced from the Foundry activities and minor metal scrapping/sorting in IA, often serves as an adsorbing site for other metals like Cr, Ni, Co, etc. (Kolawole et al., 2022). This explains its relationship with Co, which could result from waste combustion and vehicular traffic. Co is also a component of agrochemicals used in agriculture (Defarge et al., 2018; Agency for Toxic Substances and Disease Registry [ATSDR], 2019; Mahey et al., 2020). Some farming activities were observed in parts of IA. SPA in the study area is characterised by intensive agricultural activities. Cr and Ni, having close geochemical affinity, are from geogenic contributions. They are trace components associated with mafic rocks, and enclaves of amphibolite have been reported in the area. Zn is very commonly used in the automotive industry, as components of car parts. Therefore the wear and tear, and corrosion of car parts will yield Zn (Fomba et al., 2018; Kolawole et al., 2023). Zn is also a component of agrochemicals (Alengebawy et al. 2021).

A further representation of the relationship and linkage between the PHEs is illustrated by the loading plot (Fig. 7a) and dendogram (Fig. 7b), respectively. The loading plot shows a clustering of PHEs into: Cr and Ni, Fe and Co, and Cu, Pb, Sr and Zn. The Cr–Ni cluster corresponds to the PHE association in PC3, the Fe–Co cluster tallies with the association in PC2, while Cu–Pb–Sr are associations in PC1. The inclusion of Zn in this cluster, especially its link with Sr in

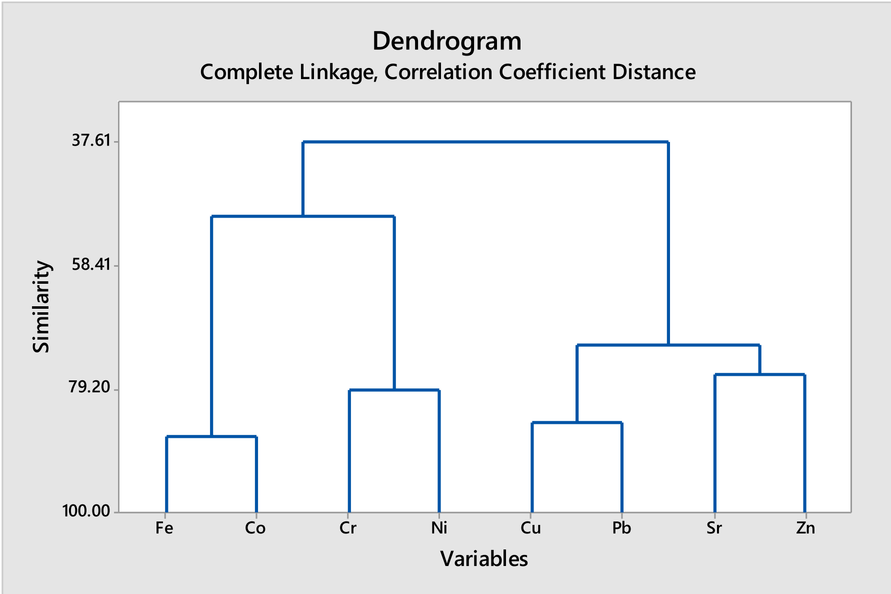
Table 6 Results of Varimax normalized PCA for the PHEs

Element	PC 1	PC 2	PC 3	PC4
Fe	0.10	0.90	0.19	0.13
Co	−0.12	0.93	0.05	−0.17
Cr	0.06	−0.01	0.93	0.24
Cu	0.92	0.05	0.02	0.14
Ni	0.06	0.48	0.78	−0.18
Pb	0.88	−0.15	0.03	0.18
Sr	0.64	0.36	0.26	0.45
Zn	0.32	−0.09	0.08	0.90
Eigen Value	2.15	2.07	1.58	1.21
%Variance	26.88	25.85	19.76	15.14
Cumulative %	26.88	52.73	72.48	87.62

Fig. 7 **a** Component plot of PHEs in Rotated Space. **b** Dendogram showing linkage between the PHEs



a: Component plot of PHEs in Rotated Space



b: Dendogram showing linkage between the PHEs

the dendogram, could result from the fact that Sr–Zn alloys are used for anti-corrosion protection in welding processes (Gad et al., 2022).

Co, Cu, Pb and Zn, which are the contaminants in the stream sediments, are harmful to humans when they enter the body and accumulate to toxic levels.

Health effects such as kidney necrosis, liver cirrhosis and gastrointestinal problems are caused by Cu toxicity (Fraga, 2005; Uriu-Adams & Keen, 2005). Apart from being a known carcinogen, Pb toxicity has effects such as damage to the nervous system, and cognitive decline, learning and behavioural problems in children. Pb toxicity also causes hypertension and kidney dysfunction (Onianwa and Fakayode 2000; Mason et al., 2014; Olajide-Kayode et al., 2023). More than necessary Zn concentrations in the human body causes diarrhoea, lethargy, and elevated risk of prostate cancer (Chasapis et al., 2020). Health effects of Co toxicity include lung fibrosis, asthma attacks and thyroid problems (Leyssens et al., 2017).

Conclusion

The stream sediments of RCA were slightly acidic, while those of IA and SPA were acidic—sightly acidic. The OM content of stream sediments in the zones were relatively high, and in the order: RCA < IA < SPA.

All sediment quality indices used revealed moderate Cu, Pb and Zn contamination in stream sediments of RCA, while Pb and Zn contamination were detected in IA stream sediments. In SPA however, the stream sediments were mostly contaminated with Co and Zn. The dense population and associated anthropogenic activities in RCA and IA is responsible for the Cu, Pb and Zn contamination. This has led to the extreme and moderate pollution of RCA and IA stream sediments, respectively. Though Agriculture is believed to be a low contributor to environmental contamination, it was observed that the use of agrochemicals and cattle grazing led to increased Co and Zn concentrations in the stream sediments of SPA. This led to the classification of the sediments as slightly polluted even though the zone is very sparsely populated. The use of inorganic fertilizers, herbicides and pesticides with potential uptake of those metals by field crops, poses major threat to animals and humans through the food chain (Costa, 2000; Zeng et al., 2011). The dung of animals has also been proven to contain certain PHEs such as Co, Cu, Se and Zn (Gupta et al., 2016; Sheppard & Sanipelli, 2012). Animal dung, either as animal waste or as manure, can also contribute these elements to environmental media, albeit in minimal to moderate concentrations.

Though the ecological risk of the stream sediments posed by the PHEs is currently low, activities that would increase the PHE concentration in them must be avoided, in order to mitigate risk. Periodic environmental monitoring is also recommended, to evaluate the status of stream sediments and other media in the areas investigated.

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Data availability All inquiries on data to be sent to jolugbn@gmail.com or jerry.olajide-kayode@uniosun.edu.ng.

Declarations

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