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Analysis of potentially toxic elements from selected mechanical workshops using the geo-accumulation index and principal component analysis in Omu-Aran Community, Nigeria

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Abstract Bioaccumulation of potentially toxic elements in soil threatens public health and the ecosystem. This study aims to assess the concentration of potentially toxic elements (chromium (Cr), lead (Pb), iron (Fe), arsenic (As), and cadmium (Cd)) in selected automobile workshop premises in Omu-Aran, Nigeria. Forty-eight samples were collected at a depth (15 cm) in six locations, including a control point. Acid digestion was carried out to prepare the soil samples before assessing their concentration via an atomic absorption spectrophotometer. Geo-accumulation index (Igeo) was used to classify the level of contamination. Statistical analysis, which includes principal component analysis (PCA) and Pearson's correlation, was also determined. The difference in concentration was determined using ANOVA. In the study area, the lowest observed concentration values for Cr, Pb, Fe, As, and Cd, which are 0.246±0.002 mg/kg, 0.178±0.001 mg/kg, 90.715±0.038 mg/kg, 0.012±0.004 mg/kg, and 0.078±0.004 mg/kg, respectively, are relatively higher than observed for the control. The observed potentially toxic elements fall within three Igeo based on Muller's interpretation; heavily to extremely contaminated (Cd), moderately to heavily contaminated (Pb, Cr, and As), and uncontaminated to moderately contaminated (Fe). PCA shows that two principal components (PC) account for up to 91.052% of the original mean dataset variability. PC1 explains 67.723% of the total variance associated with Cd, Cr, Fe, Pb, and As, indicating anthropogenic is the primary source of these potentially toxic elements. The PC2 accounted for 23.329%, with Pb and As significant contributors. Cadmium contamination of soil was the most influential, with an Igeo value ranging from 4 to 5. Residents in the polluted region face considerable health risks from potentially toxic elements.

Keywords Heavy metals · Automobile mechanical workshops · Geo-accumulation index · Principal component analysis

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Introduction

Heavy metal is a generic word that refers to a class of metals and metalloids having atomic densities of more than 5.0 g/cm^3 (Duffus, 2002). Potentially toxic elements (PTEs) contamination of soil is detrimental to man and thus poses a serious challenge to man and the environment (Xiang et al., 2020). Heavy metal contamination is a critical situation resulting from mechanical operations that accidentally release waste into the environment and ecosystem (Soriano et al., 2012). The soil absorbs contaminants (heavy metals) and distributes them to other ecosystems such as groundwater, crops, rivers, and the atmosphere (Cocârţă et al., 2016). These potentially toxic elements contaminate food supplies such as vegetables in polluted water and soil (Chauhan & Chauhan, 2014).

Demand for personal vehicles, especially fairly used cars in Nigeria, increases mechanical workshop operations, contributing to heavy metal pollution (Ololade, 2014). Some potentially toxic elements are present in lubricants, and gasoline is a significant pollutant by the United States Environmental Protection Agency (Sharma & Reddy, 2004). During repair or maintenance operations at the mechanical workshop, operators often discard waste materials such as petroleum products on the ground surface, triggering an increase in pollution levels in the soil, water, and the atmosphere (Nwachukwu et al., 2011). A wide range of mechanical workshops utilizes petroleum products such as motor oil, fuel oil, diesel, and kerosene. These products are toxic and tend to harden or modify the soil's composition, influencing the physicochemical and microbial properties of the contaminated soil (Muhammad et al., 2014). Due to a lack of waste management practices, these wastes are released haphazardly into the mechanical workshop premises. The soil gradually becomes a storehouse for metals deposited by vehicle workshops (Chokor & Ekanem, 2016). Some heavy metals, such as Cr, Co, Cu, Fe, Mn, Mo, Ni, Zn, Ca, Mg, K, and Na, are essential nutrients that are required for the growth and development of living organisms, whereas other elements, such as Cd, Pb, and Hg, do not serve any nutritional or biochemical functions (Chapman & Wang, 2000). Although trace elements are naturally found in soils, however, they become potentially toxic at elevated levels (Ackah, 2019). Pb has the potential to build up in the bones, where it then has the potential to desorb and cause chronic neurotoxic consequences. In addition, the practice of pica and other hand-to-mouth behaviors makes youngsters more susceptible to the harmful effects of lead than adults (Papanikolaou et al., 2005). During precipitation, these toxic substances in the soil may be transmitted by infiltration ground or discharged into underground or surface water (Sasakova et al., 2018).

In developing countries, lands are leased for different purposes, including farming, commercial, and sometimes mechanical operations. Over the years, it has been retrieved and used for residential areas, which accounts for traces of some metals found in some hand-dug wells. In addition, civilization and the development of communities have brought about an increase in the construction of residential buildings, especially at the outskirt of communities where automobile mechanical workshops are located. Compared to geogenic or natural processes, uncontrolled commercial and municipal operations have considerably given rise to a high concentration of certain metals in the soil profile (Pradesh et al., 2011). Therefore, monitoring heavy metal contamination is of great relevance.

Principal component analysis (PCA) is a statistical technique that reduces parameters from interrelated datasets into principal components (Herojeet et al., 2016). It uses total variance in the real data, but the number of variables is reduced while the maximum variance is retained (Tripathi & Singal, 2019). PCA is used by several studies to assess the levels of heavy metal contamination in soil analysis, which involves data reduction and interpretation (Kardanpour et al., 2014; Park et al., 2006; da Silva et al., 2021; Yang et al., 2020).

Several methods have been used to assess and monitor the concentration of potentially toxic elements in soil media (Mohammadi et al., 2020; Shafie et al., 2014). One of the most effective techniques to assess heavy metal concentration is the geo-accumulation index. According to Zhiyuan et al. (2011), Müller proposed the index of geoaccumulation (Igeo) in 1969 to estimate the contamination levels of bottom sediments (Muller, 1969). Several researchers have applied the technique to assess the contamination levels of potentially toxic elements in soil (Ackah, 2019; Mohammadi et al., 2020; Olatunde et al., 2020). The combined use of PCA and Igeo can determine both the comprehensive and single-factor pollution levels of various elements in soils, making them particularly significant to the process of assessing soil contamination (Shafie et al., 2014).

Past research has reported the use of the geo-accumulation index and other pollution indices to access heavy metal concentration in soil (Bali & Sidhu, 2021);

however, this study aimed at accessing heavy metal concentration using geo-accumulation index (Igeo) and multivariate analysis by principal component analysis (PCA) around mechanical workshops in Omu-Aran community. Furthermore, the study aims to determine whether there is no significant relationship between anthropogenic activities in selected mechanical workshops and the geo-accumulation of potentially toxic elements.

Materials and methods

Study area and sampling points

The study area is situated at Omu-Aran, the administrative headquarters of Irepodun Local Government Area, Kwara State, Nigeria, as shown in Fig. 1. Omu Aran, a section of Kwara, forms part of north-central Nigeria. It has a land size covering an area of 73.7 km^2 and a human population of 148,610 by the 2006 census (National Population Commission, 2013). Five sampling points were selected in automobile workshop premises to collect samples, including control over 5 months. The specific location of sampling points in the field study using GPS location and altitude is shown in Table 1.

The city's population is unevenly distributed; therefore, municipal, commercial, and agricultural districts; recreational and administrative areas; automobile repair workshops; and residential neighborhoods are dispersed across the city. The description of sampling locations in the study area is shown in Table 1.

In total, 48 soil samples were collected at a depth of 0 to 15 cm in the vicinity of the automobile workshop. Soil from each sampling location was mixed thoroughly and kept in an airtight polythene bag. A random selection of soil sampling locations was conducted based on visual examination.

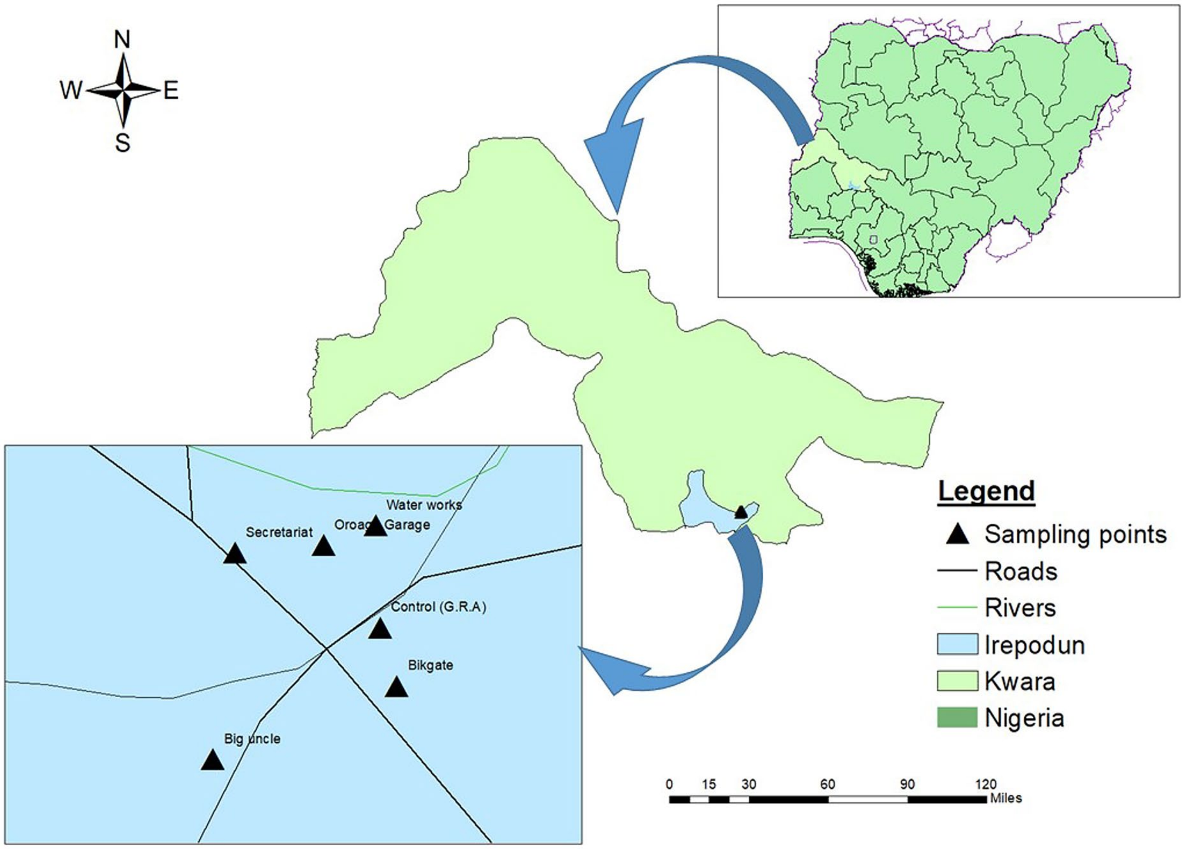

Fig. 1 Study map of Omu-Aran, Kwara State, Nigeria

Table 1 Characteristics and coordinates of sampling sites

S/N	Location	Latitude	Longitude	Altitude	Land use	Site description
1	Bikgate	8.133507	5.111817	528	Residential	Opposite Bikgate hotel and suite
2	Waterworks	8.146333	5.110095	525	Residential	Adjacent to the waterworks office
3	Oroago garage	8.144758	5.105858	540	Commercial	Situated at the center of Oroago garage
4	Secretariat	8.144158	5.098618	543	Residential	Adjacent to the Irepodun secretariat office
5	Big uncle	8.127655	5.09683	538	Commercial	Opposite big uncle filling station
6	Control (G.R.A)	8.138170	5.110450	530	Residential	Close to government residential area

Sample preparation and analysis

Digestion of soil sample for heavy metal determination

The soil samples were collected using a soil auger from five different locations where the hand-dug wells are situated. Samples were collected using a soil auger that lasted 4 months (October to January). Afterwards, the USEPA Method 3005A acid digestion procedure was adopted to prepare the soil samples for analysis. A total of 1 g of each soil sample was digested in 10 mL of concentrated HCl and mixed thoroughly. Finally, the mixture was filtered, and analytical procedures were carried out on each sample, including investigating heavy metal parameters. The level of heavy metals was determined by using atomic absorption spectrophotometer (AAS BULK SCIENTIFIC MODEL 211 VGP). Strict preservation guidelines were followed to ensure no further reaction occurred after collecting samples.

Geo-accumulation index

The geo-accumulation index (Igeo) was adopted to determine to what extent the heavy metal has contaminated the soils within the premises of the five automobile repair workshops and control points. The Igeo values were obtained using Muller's expression:

$$I_{geo} = \log_2 \frac{Cn}{1.5Bn}$$

where,

Cn = measured total concentration of metals in soils ($\mu g \cdot g^{-1}$).

Bn = geochemical background values of metals ($\mu g \cdot g^{-1}$).

1.5 = the background matrix correction factor due to lithogenic effects.

The I_{geo} scale consists of seven grades (0–6), as shown in Table 2.

Statistical analysis

Statistical analysis was carried out using the raw data. Descriptive analyses were used to interpret the data and determine the mean and standard deviation for each input parameter to establish a relationship between soil parameters at sampling points. The relationship between concentrations of potentially toxic elements across the locations was established using variance analysis (ANOVA) at $P < 0.05$. SPSS software (version 13.0) tool was used to carry out all analyses.

Results and discussion

Assessment of heavy metal

Many researchers have indicated that urban soils accumulate toxins attributed to the high tempo of human

Table 2 Classification of the geo-accumulation index (I_{geo}) after (Muller, 1969)

Class	Igeo value	Designation of soil quality
0 class	Igeo > 0	Practically uncontaminated
1 class	0 < Igeo < 1	Uncontaminated to moderately contaminated
2 class	1 < Igeo < 2	Moderately contaminated
3 class	2 < Igeo < 3	Moderately to heavily contaminated
4 class	3 < Igeo < 4	Heavily contaminated
5 class	4 < Igeo < 5	Heavily to extremely contaminated
6 class	5 < Igeo	Extremely contaminated

Table 3 Descriptive statistics for soil potentially toxic elements properties

Parameters	Unit	Bikgate (HW1)	Waterworks (HW$_2$)	Oroago garage (HW3)	Secretariat (HW4)	Big uncle (HW$_5$)	Control
Pb	mg/kg	0.276 ± 0.004^{b}	0.178 ± 0.001^{b}	0.212 ± 0.001^{b}	0.279 ± 0.004^{b}	0.313 ± 0.004^{b}	0.025 ± 0.021^{a}
Fe	mg/kg	120.375 ± 0.081^{c}	90.715 ± 0.038^{b}	115.278 ± 0.040^{c}	131.838 ± 0.050^{c}	178.582 ± 0.089c	50.23 ± 0.421^{a}
Cd	mg/kg	0.106 ± 0.002^{c}	0.078 ± 0.004b	0.115 ± 0.007^{c}	0.084 ± 0.003^{b}	0.154 ± 0.004^{c}	0.003 ± 0.001^{a}
Cr	mg/kg	0.337 ± 0.004^{c}	0.279 ± 0.005^{b}	0.305 ± 0.003^{c}	0.246 ± 0.002^{b}	0.429 ± 0.002^{c}	0.051 ± 0.015^{a}
As	mg/kg	0.111 ± 0.004^{b}	0.091 ± 0.002^{b}	0.102 ± 0.004^{b}	0.087 ± 0.002^{b}	0.012 ± 0.004^{a}	0.01 ± 0.023^{a}

Results are expressed as the mean of duplicates ± SD and as compared on the same row followed by different superscripts (a–d) showing a significant difference ($P < 0.05$) using Duncan's test (ANOVA).

activities in urban populations (Adelekan & Alawode, 2011). The heavy metal parameters include lead (Pb), cadmium (Cd), iron (Fe), chromium (Cr), and arsenic (As). The summary of heavy metal levels across the locations is presented in Table 3.

Lead (Pb)

A high concentration of lead was found in all samples from the sampling points in the mechanical workshops. The lead values ranged from 0.178 ± 0.001 to 0.313 ± 0.004 mg/kg. In the control soil, the mean concentration of Pb was 0.025 ± 0.021 mg/kg. Levels of Pb in the soil samples were significantly higher than that of the control soil, at $p < 0.05$. Lead (Pb) is associated with battery, welding, and painting operations (Baloch et al., 2020). This explains its presence in the mechanical workshop.

Iron (Fe)

Iron has the highest concentration among the identified heavy metals, and it was discovered at all mechanical workshop sites. The concentration of iron ranged from 90.688 ± 0.03 to 178.358 ± 0.08 mg/kg. The mean concentration was 127.36 ± 30.48 mg/kg. The mean concentration of Fe in the sample and control (50.23 ± 0.421 mg/kg) soil samples was significantly different at $p < 0.05$, indicating the influence of motor oil on automobile workshop soil. The mean Fe concentration is quite high compared to other heavy metal concentrations in a similar study (Sadick et al., 2015).

Cadmium (Cd)

The cadmium concentration ranged from 0.075 ± 0.003 to 0.115 ± 0.002 mg/kg while the mean concentration of cadmium in the soil samples was 0.107 ± 0.03 mg/kg. The cadmium levels of the sample (0.107 ± 0.03 mg/kg) and the control soil concentration (0.003 ± 0.001 mg/kg) were significantly different. The cadmium concentration in this study was considerably lower than in similar studies carried out by (Goyer, 1997). Cadmium compounds can be found in batteries, car stereo equipment, brake light, and power supply boxes (Nduka et al., 2019).

Chromium (Cr)

The chromium levels ranging from 0.244 ± 0.002 to 0.43 ± 0.001 mg/kg were detected in all the soil samples examined. The mean concentration of chromium in the soil was 0.319 ± 0.07 mg/kg. The chromium levels in the contaminated soil (0.319 ± 0.07 mg/kg) and control soil (0.23 ± 0.01 mg/kg) were not significantly different. The chromium concentration (Sadick et al., 2015) is lower than the observed value in this study. Chromium is present in automobile components such as mechanical, polymeric, and sundry components, including electronic and electrical devices that may contain toxic substances (Kalpakjian et al., 2011).

Arsenic (As)

The concentration of arsenic in the sample soil ranges between 0.012 ± 0.004 and 0.111 ± 0.004 mg/kg, with a mean value of 0.102 ± 0.031 mg/kg. There is a significant difference between arsenic concentration in the sample soil and that of the control soil, 0.01 ± 0.023 mg/kg at $p < 0.05$, except at the big uncle location. The arsenic level in the sample area is lower than a similar study carried out within the vicinity of the mechanical workshop by Oloye et al. (2014).

Geo-accumulation index

The results of the Igeo value of heavy metals concentration recorded for the samples are shown in Fig. 2. The Igeo values of each vary with respect to its sampling class location. In all the soils, the five metals fall within three Igeo based on Muller's interpretation; heavily to extremely contaminated (Cd), moderately to heavily contaminated (Pb, Cr, and As), and uncontaminated to moderately contaminated (Fe). This pollution may only be attributed to human activities, especially mechanical operations.

Igeo values of elements such as lead, iron, cadmium, and chromium show a high degree of contamination in the Bikgate and Waterwork areas. However, all sampling locations show the presence of high As concentration in the soil. Only Bikgate and the waterworks area are classified as extremely and moderately contaminated for lead compounds.

Observed Igeo values in sampling locations reflect the heavy metal concentration from possible contamination sources in the study area. The Bikgate area is classified under heavily contaminated for all heavy metal accessed as shown in Table 4. These may result from mechanical operations such as battery charging, welding, and painting operations carried out in the vicinity. In the Oroago garage area, the Igeo value classification for Cr is moderately contaminated due to the use in chrome plating of some motor vehicle parts, mechanical, polymeric, and sundry components, including electronic and electrical devices.

The big uncle area is classified as moderately contaminated for As. Arsenic is emitted from the burning of diesel and gasoline fuel.

Principal component analysis (P.C.A)

PCA examines heavy metal parameters present in all samples, such as lead, iron, cadmium, chromium, and arsenic. Varimax rotation with Kaiser normalization was used to determine the concentration before multivariate analysis such as PCA could be carried out. In addition, the conditions of Kaiser–Meyer–Olkin (KMO) and Bartlett's sphericity must be fulfilled. KMO value between 0.5 and 1.0 is the acceptable range (Elemile et al., 2021). The KMO and Bartlett coefficients were 0.620 and 89.05, respectively (with the degrees of freedom $df = 10$ as shown in Table 5).

Heavy metals exhibit different degrees of pollution, from mild to extreme. The Igeo reveals that the study area is significantly polluted by Cd, Cr, Fe, Pb, and As. The quantification of anthropogenic metal data shows

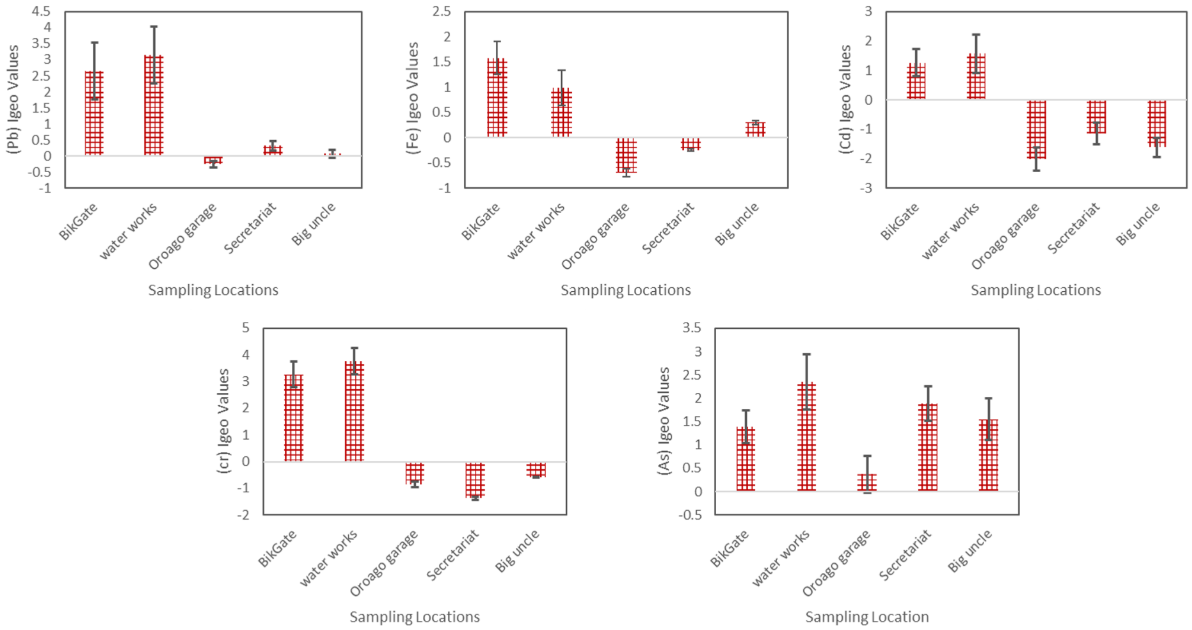

Fig. 2 Mean Pb, Fe, Cd, Cr, and As Igeo values of the measured heavy metals were studied with respect to the natural background

Table 4 Possible contamination sources responsible for Igeo classification in sampling locations

Heavy metals	Igeo classification according to locations	Possible source of contamination
Pb	Heavily contaminated—waterworks Moderately to heavily contaminated—null Moderately contaminated—Bikgate Uncontaminated to moderately contaminated—Secretariat, big uncle Practically uncontaminated—Oroago garage	Battery specialists, "battery chargers", are called across Nigeria and are a significant source of Pb. Welding and painting operations can also contribute to Pb concentration (Lawal et al., 2015)
Fe	Heavily contaminated—null Moderately to heavily contaminated—null Moderately contaminated—BikGate Uncontaminated to moderately contaminated—null Practically uncontaminated—waterworks, Oroago garage, Secretariat, big uncle	Fe, Pb, and As (metalloids and metallic elements) are present in gasoline used as fuel in vehicles (Leite et al., 2018). Previous research on tire wear dust by various researchers establish heavy metals like Fe, Cr, and Pb as constituents (Han et al., 2014)
Cd	Heavily contaminated—null Moderately to heavily contaminated—null Moderately contaminated—BikGate, waterworks Uncontaminated to moderately contaminated—null Practically uncontaminated—Oroago garage, Secretariat, big uncle	Cadmium content is present in the pigments in paints for the car bodywork, glass, welding electrodes utilised by the so-called "panel beaters" (body works specialists), combustion of petroleum products, etc. (Sayadi & Sayyed, 2011, Streitberger & Dossel, 2008). Including some lubricating oils and in some brands tires of motor vehicles (Naser et al., 2012)
Cr	Heavily contaminated—BikGate, waterworks Moderately to heavily contaminated—null Moderately contaminated—null Uncontaminated to moderately contaminated—null Practically uncontaminated—Oroago garage, Secretariat, big uncle	Cr is often associated with the use in chrome plating of some motor vehicle parts, mechanical, polymeric, and sundry components, including electronic and electrical devices. (Baptista et al., 2021)
As	Heavily contaminated—null Moderately to heavily contaminated—null Moderately contaminated—BikGate, waterworks, Oroago garage, Secretariat, Big uncle Uncontaminated to moderately contaminated—null Practically uncontaminated—Null	Heavy metals such as arsenic, cadmium, and chromium are generated from diesel and gasoline fuel burning (Gran-Scheuch e. al., 2020; Gupta, 2020)

that a larger percentage of Cd, Cr, As, Fe, and Pb in the samples are of anthropogenic origin. This supports our earlier hypothesis that the mechanic workshop is experiencing geo accumulation of potentially toxic elements caused mainly by anthropogenic sources.

A scree-plot (Fig. 3) for the PCA indicates the top two variables (components) account for up to 91.052% of the original mean dataset variability. The first two PCs were selected with eigenvalues greater than one (Fig. 3). They accounted for up to 67.723% and 91.052% of the overall variance in the heavy metal datasets for sample location, as shown in Table 4. According to Gradilla-Hernández et al. (2020), PC's within 70–90% of the overall variance are acceptable. The Kaiser–Meyer–Olkin (KMO) and

Table 5 Result of KMO and Bartlett's test

KMO and Bartlett's test		
Kaiser–Meyer–Olkin measure of sampling adequacy		.620
Bartlett's test of sphericity	Approx. chi-square	89.051
	df	10
	Sig.	.000

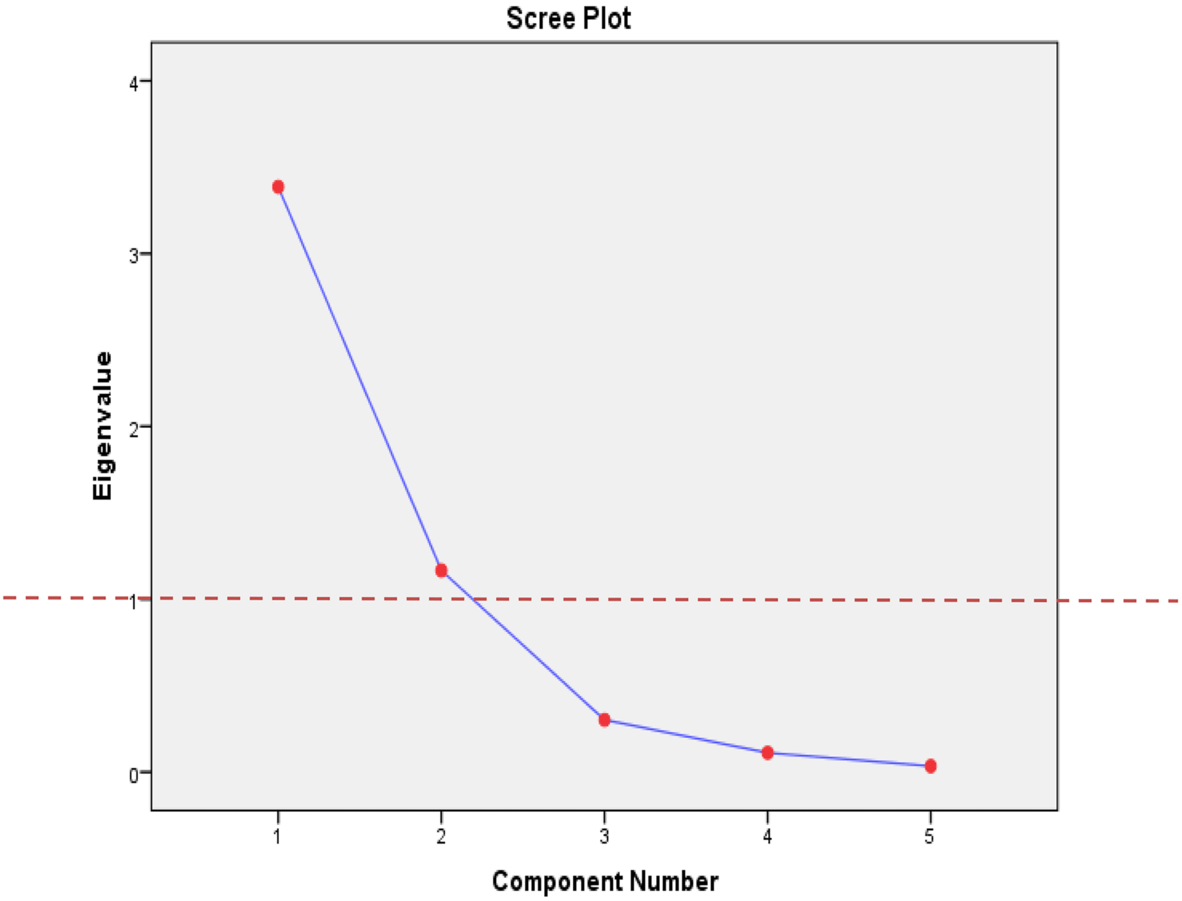

Fig. 3 Scree plots used to identify the number of principal components from eigenvalues (> 1)

Barlett tests were used to test the suitability of PCA, as shown in Table 5. KMO = 0.620 (> 0.5) and Barlett test value = 0.00 (< 0.05) indicating suitability. They represent the independence of variables and the adequacy of samples (Sun et al., 2013).

The component matrix shows that the 2 PCs contribute 91.13%, as shown in Table 6. With conditions of eigenvalues greater than one, two main components were identified. PC1 explaining 67.72% of the total variance, showed strong loadings for Cd, Cr, Fe, Pb, and As, indicating anthropogenic origin. These potentially toxic elements are associated with mechanical workshop operations such as the battery, welding, painting operations, car stereo equipment, and brake light (Baloch et al., 2020; Nduka et al., 2019). Iron, cadmium, and chromium show strong positive loadings with PC1, while lead and arsenic have moderate positive loadings with PC1.

The PC2 accounts for 23.329% of the total variance, with Pb and As as significant contributors. Pb can be attributed to the geologic sources (rocks) (Al-Badaii, 2014).

Table 6 Extraction method: principal component analysis

Variables	Component	
	PC1	PC2
Lead	0.635	0.720
Iron	0.892	0.413
Cadmium	0.927	−0.182
Chromium	0.924	−0.250
Arsenic	0.688	−0.618
Eigenvalue (> 1.0)	3.386	1.166
Proportion	67.723	23.329
Cumulative	67.723	91.052

Table 7 Correlation matrix of heavy metal parameters

Variable	Lead	Iron	Cadmium	Chromium	Arsenic
Lead	1	0.826**	0.386	0.390	0.086
Iron		1	0.777**	0.707**	0.336
Cadmium			1	0.889**	0.659**
Chromium				1	0.732**
Arsenic					1
KMO (Kaiser–Meyer–Olkin) 0.620 Bartlett's test of Sphericity 0.000					

**Correlation is significant at the 0.01 level (2-tailed)

Lead shows strong positive loadings with PC2, while arsenic shows moderate negative loadings with PC2.

The correlation between lead and iron was highly positive and statistically significant ($r = .826$, $p < .001$), as shown in Table 7. This indicates that an increase in lead concentration would lead to higher levels of iron. Cadmium has a significantly high positive correlation to chromium ($r = 0.889$, $p < 0.001$). There is also a significantly high positive correlation between iron and cadmium. The correlation between iron and chromium is positively significant ($r = 0.707$, $p < 0.001$). Chromium has a significantly high positive correlation to arsenic ($r = 0.732$, $p < 0.001$). This shows that an increase in chromium concentration would lead to higher levels of arsenic.

Conclusion

The five heavy metal concentrations within the mechanic workshop premises were significantly higher than the background values, which shows that mechanical operations have significantly impacted the soil in the polluted region. The most important critical was Cd contamination of soil, with an Igeo value ranging from 4 to 5. The mean concentrations of Pb, Cr, and As in contaminated soils were significantly higher than reference values, but the Fe concentrations are the lowest under the unpolluted Igeo group. PCA also confirms that the significant component PC1 includes Cd, Cr, Fe, Pb, and As. Therefore, the mechanic workshop is experiencing geo accumulation of heavy metal, and the pollution is more anthropogenic. A strong positive correlation exists between cadmium and chromium. Heavy metal concentrations in soil are mostly influenced by the soil's ability to accumulate heavy metals. The people who live in the control area appear to be safe. However, those who reside in the polluted region face considerable health risks from Cd and other potentially toxic elements.

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Author contribution All authors contributed to this study design. Material preparation and data collection analysis were performed by Ejigboye praise oladapo. Analysis was carried out by Mr. Praise Ejigboye, Mr. Enoch Ibitogbe, and Dr. Olugbenga Elemile. Dr. Abu Gana worked on the review. The first draft of the manuscript was written by Ejigboye, praise Oladapo, and all authors commented on previous versions of the manuscript. Mr. Opeyemi Olajide and Olanrewaju Ibitoye review the manuscript and made corrections. All authors read and approved the final manuscript.

Data availability statement All relevant data are available via Data bris repository of Landmark University.

Declarations

Competing interests The authors declare no competing interests.

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