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Concentration of Heavy Metals in Playground Soils Near Schools and Auto Mechanic Sites Along Busy Roads in Kaduna State, Nigeria

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Abstract: *This study assessed the concentrations and interrelationships of heavy metals in soil samples collected from Kaduna North, Central, and South zones to evaluate potential contamination levels and implications for environmental health. A total of nine heavy metals—chromium (Cr), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), tantalum (Ta), and lead (Pb)—were analyzed using standard procedures. Results indicated that Zn had the highest concentration across all zones, with a peak value of 327.50 mg/kg in Kaduna North, while the lowest recorded value was for Ni at 1.95 mg/kg in Kaduna Central. Pearson correlation analyses revealed strong positive correlations among several metals, particularly between Cu and Zn (r = 0.99), As and Zn (r = 1.00), and Pb and Zn (r = 0.99) in Kaduna North. In Kaduna Central, significant positive correlations were observed between Cr and As (r = 0.93), Cu and Pb (r = 0.90), and As and Zn (r = 0.95), while Ni showed a strong negative correlation with Pb (r = -1.00). In Kaduna South, nearly perfect correlations were found between Cr and Cu (r = 0.99), Zn and Cu (r = 0.98), and Fe and As (r = 0.99), indicating possible common anthropogenic sources. These results suggest widespread heavy metal contamination, potentially from industrial, vehicular, and agricultural activities. The presence of toxic metals like Pb, As, and Cr in elevated concentrations raises environmental health concerns and highlights the urgent need for regulatory interventions, continuous monitoring, and remediation strategies to protect both ecological systems and public health.*

Keywords*: Heavy metals, Soil contamination, Pearson correlation, Kaduna, Environmental health*

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1.0 Introduction

The contamination of soil by heavy metals has emerged as a pressing global environmental and public health concern, especially in urban areas where anthropogenic activities are rampant. Heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), mercury (Hg), and nickel (Ni) are naturally occurring elements in the Earth's crust. However, their widespread release into the environment through industrial processes, vehicular emissions, waste disposal, and other human activities has led to elevated concentrations in environmental media, especially in soil. Once introduced, these metals persist in the environment due to their non-biodegradable nature and possess the ability to bioaccumulate through the food chain, thereby posing serious risks to human health and ecosystems.

Urban soils, especially those in proximity to major roads and automobile workshops, are particularly vulnerable to contamination by heavy metals due to constant vehicular traffic, tire wear, brake linings, fuel combustion, oil leaks, and metal corrosion. Studies have consistently shown that soil adjacent to busy roads contains elevated levels of toxic metals compared to background levels (Ogunkolu et al., 2019; Ahmed et al., 2015). This becomes particularly alarming when such contaminated soils are located near schools or children's playgrounds, as children are more susceptible to the toxic effects of heavy metals due to their developing physiological systems, frequent hand-to-mouth behaviors, and increased soil ingestion during play (Durowoju et al., 2018; Biose et al., 2021).

Numerous studies from various parts of the world have documented the extent and sources of heavy metal pollution in urban soils. For instance, Rashid et al. (2021) identified vehicle exhaust and industrial emissions as major contributors to soil metal contamination in urban environments. Chowdhury et al. (2020) also emphasized that heavy metals such as Pb, Cd, Zn, and Ni are consistently present in vehicular emissions and can settle on nearby soils. Jin et al. (2020) further showed that these contaminants not only impact human health but also adversely affect plant growth and microbial activity in soils. In Nigeria, studies conducted by Okereke et al. (2017) and Wirnkor & Ngozi (2018) similarly reported hazardous levels of heavy metals in soils around urban schools, garages, and highways. These findings emphasize the widespread nature of the problem, yet most existing studies have focused on heavily industrialized or highly populated cities, leaving gaps in localized assessments, especially in states such as Kaduna.

Despite the global and national evidence of soil heavy metal pollution, there is a paucity of data on the concentrations and distribution of these metals in playground soils within the vicinity of schools and automobile workshops in Kaduna State, Nigeria**.** This presents a significant knowledge gap, particularly in understanding the potential exposure pathways and risks posed to vulnerable populations such as schoolchildren. Without such data, policymakers, educators, and health professionals lack the necessary evidence to design and implement risk mitigation strategies.

The aim of this study is to assess the concentration and spatial distribution of selected heavy metals (Cr, Fe, Co, Ni, Cu, Zn, As, Cd, Ta, Au, Pb, and Th) in playground soils located within 10 meters of major roads in the vicinity of primary schools and automobile workshops in Kaduna State**.** This assessment is conducted across 13 local government areas spanning the three geo-political zones of the state. The study utilizes Energy Dispersive X-ray Fluorescence (EDXRF) analysis to quantify metal concentrations at different distances from the road and at multiple soil depths.

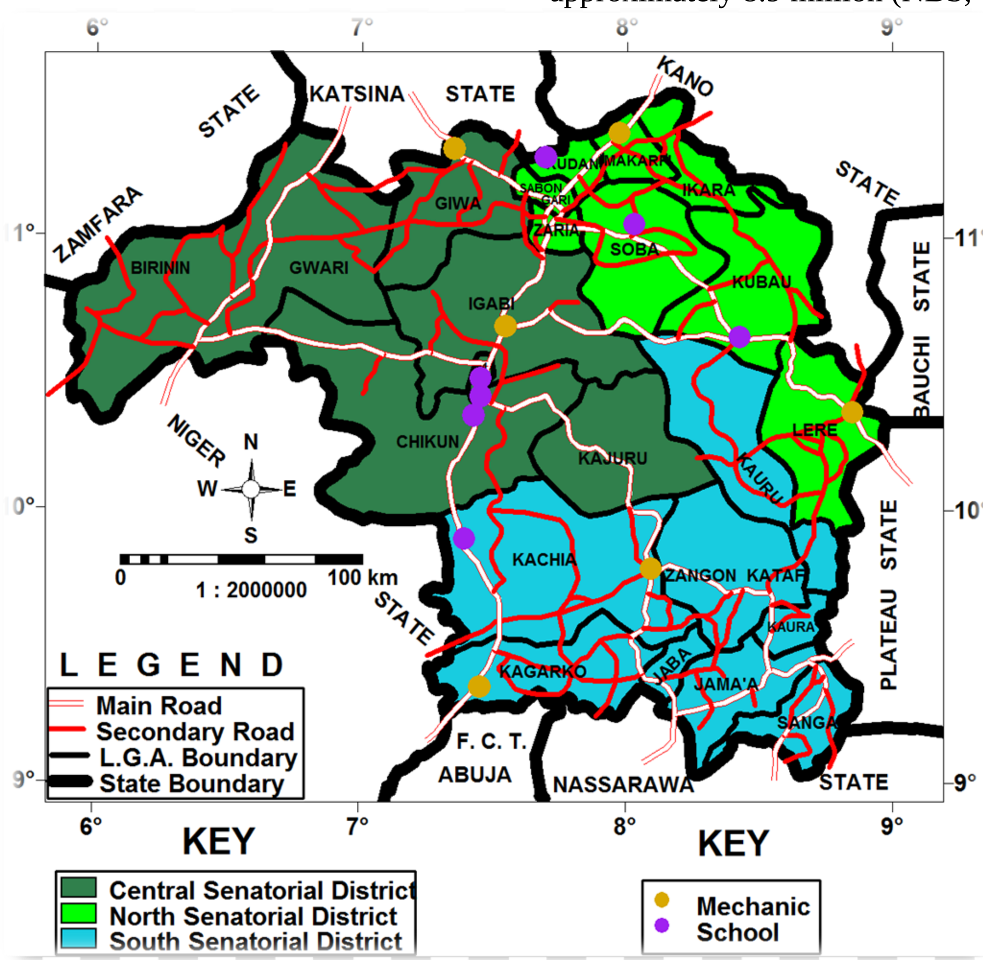
This research is significant for several reasons**.** First, it provides the first comprehensive dataset on heavy metal pollution in school and mechanic workshop soils in Kaduna State, filling a critical regional data gap. Second, the findings will inform risk assessments and environmental health interventions aimed at protecting schoolchildren and residents in affected areas. Third, it contributes to the growing body of literature on urban soil contamination in Nigeria, offering a basis for comparative studies in other states and regions. Finally, the study supports evidence-based policymaking by recommending actionable steps for environmental regulation, soil remediation, and public health protection.

In conclusion, the increasing urbanization and vehicular density in Nigerian cities such as Kaduna necessitate regular monitoring of environmental pollutants such as heavy metals. By focusing on areas of high human activity, particularly those frequented by children, this study highlights the urgent need for targeted environmental health policies and public awareness to mitigate the potential long-term effects of heavy metal exposure.

2.0 Materials and Methods

2.1 Study Area

Kaduna State is located in northwestern Nigeria, lying between latitudes 8°N and 12°N, and longitudes 6°E and 9°E (Fig. 1). The state covers an area of approximately 45,000 square kilometers and is bordered by nine other Nigerian states: Kano, Katsina, Niger, Zamfara, Kebbi, Bauchi, Plateau, Nasarawa, and the Federal Capital Territory (FCT). As of 2021, the National Bureau of Statistics (NBS) estimated the state's population at approximately 8.9 million (NBS,



2022).

Fig. 1: Map **shows the sampling locations within the Kaduna North, Central, and South zones.**

Kaduna is ethnically diverse, with more than 50 ethnic groups including the Hausa, Fulani, Gbagyi, Adara, and Kagoro peoples (World Bank, 2018). The state experiences two main climatic seasons—rainy (April–October) and dry (November–March)—which significantly influence soil characteristics and anthropogenic activities.

2.2 Sample Collection and Preparation

Sampling was conducted during both the wet season (June–July 2018) and the dry season (December 2018–January 2019). A total of fourteen Local Government Areas (LGAs) were selected from the three geopolitical zones of Kaduna State. These include Zaria, Kaduna South, Kaduna North, Giwa, Soba, Lere, Egabi, Kubau, Ikara, Makarfi, Sabon Gari, Kajuru, Chikun, and Kachia. Nine LGAs—Zangon-Kataf, Kaura, Sanga, Jama'a, Jaba, Kagarko, Birnin Gwari, and Kauru—were excluded due to security concerns.

Primary schools and mechanic workshops located within 10 meters of major roads were identified within each selected LGA. Using simple random sampling by balloting in accordance with the United States Environmental Protection Agency (EPA, 2001) guidelines, one sampling location (either a school or a workshop) was chosen per LGA. In total, 8 primary schools and 5 mechanic workshops were sampled.

At each selected site, ten sampling spots were demarcated at 1.0-meter intervals starting from the road edge. Surface soil (0–1 cm depth) was collected after scraping off surface debris. In addition, deeper samples were collected using a calibrated auger drill at distances of 2 m, 4 m, and 6 m from the road at depths of 20 cm, 40 cm, and 60 cm. The auger was thoroughly cleaned between sampling points to avoid cross-contamination. Soil samples were collected using clean plastic scoops and stored in individually labeled double polythene bags.

The geographic coordinates of each site were recorded using a GPS-enabled Android mobile phone. Samples were air-dried at room temperature and sieved through a 0.05 mm mesh to remove stones and large particles. For analysis, 3–5 g of the sieved soil were weighed and loaded into circular cups (7–8 mm in height). Each sample was sealed with prolene thin film and compressed using a rod to ensure compaction and air-tightness for consistent analytical conditions.

2.3 Sample Analysis

Elemental analysis of the soil samples was conducted using a benchtop Energy Dispersive X-ray Fluorescence (EDXRF) spectrometer—Model NEX CG with RIGAKU branding. The instrument features a Pd X-ray tube, silicon drift detector, 14-sample spinner tray, and operates with secondary targets (Mo, Cu, Rx9, and Si) arranged in Cartesian geometry to enhance sensitivity and reduce background noise.

Analyses were performed using the standard-less Fundamental Parameters (FP) method (Omote et al., 1995; Kataoka et al., 2006). A vacuum chamber was used during analysis to improve sensitivity to light elements (Singh and Agrawal, 2012; Maruyama et al., 2008). The instrument is equipped with alpha correction capabilities and allows for the creation of custom matching libraries to adjust FP-derived values.

To ensure precision and accuracy, the following quality control procedures were adopted:

- Calibration was verified using pure elemental standards to detect and correct for instrumental drift.
- Drift monitor samples, including Cu, Sn, and SiO_2, along with a Multi-Channel Analyzer (MCA), were employed for instrument performance verification.
- Certified Reference Materials (CRMs) were analyzed alongside each batch of samples.
- The Limit of Detection (LOD) for each element was determined using the equation:

$$LOD = \frac{3}{S}\sqrt{\frac{I_b}{T}} \quad (1)$$

where s = sensitivity in counts per ppm; I_b = background intensity; and T = counting time in seconds

This ensured reliable quantification of both major and trace elements in the soil matrix.

2.4 Statistical Analysis

Descriptive statistics such as means and standard deviations of elemental concentrations were computed using SPSS version 23.0. Microsoft Excel 2016 was used for data processing, computation of single and integrated pollution indices, and for graph generation. These indices included metrics to assess contamination levels, spatial trends, and seasonal variations across the different sampling zones.

2.0 Results and Discussion

Table 1 presents the concentrations of heavy metals in soil samples collected from five different sites within the Kaduna North Zone, including Kudan School (KUDAN SCH), Soba School (SOBA SCH), Makarfi Mechanic Workshop (MKRF MECH), Lere Mechanic Workshop (LERE MECH), and a background location (BGRD). The data include mean values and standard deviations. The concentration of Chromium (Cr) ranged from 18.7 ± 5.2 ppm in the background sample to 104.0 ± 38.2 ppm at Makarfi Mechanic Workshop. Iron (Fe) showed an extremely high concentration of 367,638.8 ± 232.4 ppm at Kudan School, whereas background levels were significantly lower at 440.5 ± 32.8 ppm. Cobalt (Co) was only detected in Kudan School (250.6 ± 63.0 ppm) and was below detection limits (BDL) at all other sites. Nickel (Ni) was detected at Kudan School (185.0 ± 17.0 ppm), Makarfi (13.7 ± 23.7 ppm), and at trace levels (0.0 ppm) in the background.

Copper (Cu) concentrations were highest at Makarfi and Lere Mechanic Workshops with values of 105.4 ± 49.1 ppm and 100.4 ± 23.0 ppm, respectively, while levels were very low in the school vicinities and background. Zinc (Zn) levels were elevated at all sites, especially Lere (563.0 ± 184.6 ppm) and Makarfi (307.2 ± 124.3 ppm), compared to the background (80.1 ± 8.2 ppm). Arsenic (As) was present in significant amounts at Makarfi (90.0 ± 60.0 ppm), Kudan (26.4 ± 1.8 ppm), and the background (9.5 ± 1.8 ppm), but was BDL in the remaining sites.

Tantalum (Ta) was detected in Soba School (36.4 ± 3.0 ppm), Makarfi (78.5 ± 47.0 ppm), and Lere (36.0 ± 5.9 ppm), but was BDL or zero in Kudan and the background. Gold (Au) was only detected at Kudan (8.3 ± 7.3 ppm). Lead (Pb) showed extreme variability, with Makarfi recording the highest value of 1,641.9 ± 2,363.7 ppm, followed by Soba School (124.8 ± 22.4 ppm), and the lowest in the background (20.4 ± 2.7 ppm). Thorium (Th) was detected in Kudan (35.8 ± 11.3 ppm) and Soba School (2.0 ± 3.5 ppm), while Uranium (U) was detected only in Kudan at 15.2 ± 5.2 ppm.

These results suggest that mechanic workshops, particularly Makarfi and Lere, significantly contribute to elevated levels of Cr, Fe, Cu, Zn, As, Ta, and Pb, indicating contamination due to anthropogenic activities. Schools in this zone also show elevated metal levels compared to background, although to a lesser extent. Kudan School notably had high Fe and Co levels, possibly linked to nearby industrial or vehicular activities.

Table 2 presents data for heavy metal concentrations from school vicinities in Kaduna North (K/NORTH SCH), Chikun (CHIKUN SCH), and Kaduna South (K/SOUTH SCH), as well as mechanic workshops in Giwa (GIWA MECH) and Igabi (IGABI MECH), with the background level (BGRD) included for comparison.

Chromium (Cr) ranged from 3.5 ± 4.8 ppm in Igabi to 88.5 ± 9.8 ppm in Giwa, with all other locations ranging between 63.6 ± 6.1 and 70.1 ± 26.8 ppm. Iron (Fe) concentrations showed wide variability, with the highest level found in Chikun (60,178.8 ± 202,184 ppm) and the lowest in Kaduna North (8,718.8 ± 6,205.2 ppm), while background levels were 8,645.5 ± 212 ppm.

Cobalt (Co) was present in school vicinities (K/North, Chikun, K/South) with values between 101.8 ± 7.6 and 177.2 ± 34.3 ppm, while it was BDL at the mechanic workshops and background. Nickel (Ni) was found in Chikun (41.0 ± 15.6 ppm) and minimally in K/North and K/South (0.2 ± 0.0 ppm), but was BDL in Giwa. Copper (Cu) levels were highest in Igabi (42.9 ± 14.9 ppm) and Giwa (32.4 ± 10.9 ppm), showing clear contamination from mechanical activities, while lower values were found in schools and background (4.1 ± 2.3 ppm).

Table 1: Heavy Metals Concentrations (ppm) in Samples from Kaduna North Zone

	KUDAN SCH	**SOBA SCH**	**MKRF MECH**	**LERE MECH**	**BGRD**
HM	**Aver± S.D**	**Aver± S.D**	**Aver± S.D**	**Aver± S.D**	**Aver± S.D**
Cr	77.3±18.4	56.5±1.7	104.0±38.2	67.0±11.2	18.7±5.2
Fe	367638.8±232.4	25433.6±132.7	51317.5±287.2	156.3±108.6	440.5±32.8
Co	250.6±63.0	BDL	BDL	BDL	BDL
Ni	185.0±17.0	BDL	13.7±23.7	BDL	0.0
Cu	0.2±0.0	13.1±2.9	105.4±49.1	100.4±23.0	0.4±0.1
Zn	99.3±11.9	205.5±13.7	307.2±124.3	563.0±184.6	80.1±8.2
As	26.4±1.8	BDL	90.0±60.0	BDL	9.5±1.8
Ta	BDL	36.4±3.0	78.5±47.0	36.0±5.9	0.0±0.0
Au	8.3±7.3	BDL	BDL	BDL	BDL
Pb	47.9±27.0	124.8±22.4	1641.9±2363.7	BDL	20.4±2.7
Th	35.8±11.3	2.0±3.5	BDL	BDL	0.0
U	15.2±5.2	BDL	BDL	BDL	BDL

Key: HM-heavy metal, BDL-Blow detection Limit, Sch-school vicinity, Mkrf- Makarfi L.G, Mech-Mechanic workshop and BGRD-background.

Zinc (Zn) levels were elevated across all sites, especially in mechanic workshops like Igabi (234.8 ± 62.8 ppm) and Giwa (224.2 ± 24.9 ppm), compared to the background (56.3 ± 4.8 ppm). Arsenic (As) was detected in Chikun (5.1 ± 4.2 ppm), K/South (2.5 ± 3.3 ppm), and Giwa (10.6 ± 16.6 ppm), but was BDL in K/North and the background.

Tantalum (Ta) levels were very high in Giwa (147.9 ± 195.6 ppm), moderate in Igabi (25.3 ± 16.3 ppm), and low in the schools. Gold (Au) was detected only in schools, with values ranging from 5.5 ± 7.5 to 8.0 ± 1.5 ppm. Lead (Pb) showed high variability, with the highest values in Igabi (577.8 ± 352.7 ppm) and Giwa (133.4 ± 53.3 ppm), compared to lower levels in the schools and background.

Thorium (Th) was present in the school vicinities only, ranging from 14.3 ± 2.6 to 31.3 ± 8.1 ppm. Uranium (U) followed a similar trend, detected only in the schools, with average values between 10.1 ± 2.2 and 10.7 ± 2.5 ppm.

The data for Kaduna Central Zone show that both mechanic workshops and school environments have elevated levels of heavy metals, particularly Fe, Pb, Zn, Ta, and Cu, with mechanic workshops posing a higher contamination risk. The consistent detection of Th and U in schools, but not workshops, suggests possible geological contributions in those areas.

Table 3 summarizes the concentrations of heavy metals in soil samples from Kachia Mechanic Workshop (KACHIA MECH), Kachia School (KACHIA SCH), Kauro School (KAURO SCH), Kagarko School (KGARKO SCH), and a background site (BGRD).

Chromium (Cr) concentrations ranged from 42.4 ± 13.0 ppm in Kagarko to 94.1 ± 19.8 ppm in Kachia School, with the background level at 23.0 ± 8.6 ppm. Iron (Fe) concentrations were particularly high at Kauro School (671,798.8 ± 273,511.9 ppm), indicating potential industrial or vehicular influence, while the background level was 7,373.0 ± 122 ppm.

Table 2: Heavy Metals Concentrations (ppm) in Samples from Kaduna Central Zone

	K/NORTH SCH	**CHIKUN SCH**	**K/SOUTH SCH**	**GIWA MECH**	**IGABI MECH**	
HM	**Aver± S.D**	**Aver± S.D**	**Aver± S.D**	**Aver± S.D**	**Aver ±S.D**	**BGRD**
Cr	63.6±6.1	68.6±2.0	70.1±26.8	88.5±9.8	3.5±4.8	12.3±4.2
Fe	8718.8±6205.2	60178.8±202184	30478.8±7950.5	29978.8±2714.8	34353.4±4889.3	8645.5±212
Co	113.6±16.0	177.2±34.3	101.8±7.6	BDL	0.2±0.0	BDL
Ni	0.2±0.0	41.0±15.6	0.2±0.0	BDL	0.1±0.1	12.3±3.6
Cu	10.5±5.0	23.8±1.6	17.5±14.6	32.4±10.9	42.9±14.9	4.1±2.3
Zn	168.2±74.5	84.1±57.1	148.2±41.4	224.2±24.9	234.8±62.8	56.3±4.8
As	ND	5.1±4.2	2.5±3.3	10.6±16.6	0.1±0.1	0.0±0.0
Ta	0.2±0.0	7.9±10.8	0.2±0.0	147.9±195.6	25.3±16.3	23.7±2.2
Au	5.5±7.5	8.0±1.5	6.1±5.2	BDL	BDL	BDL
Pb	67.1±2.9	42.9±7.7	67.5±6.1	133.4±53.3	577.8±352.7	73.5±8.8
Th	20.8±5.7	31.3±8.1	14.3±2.6	BDL	0.0±0.0	0.0±0.0
U	10.7±2.5	10.1±2.2	10.7±1.5	BDL	BDL	BDL

Key: HM-heavy metal, BDL-Blow detection Limit, sch-school vicinity, K/North- Kaduna north L.G, K/south- Kaduna south L.G, mech-mechanic workshop and BGRD-background.

Cobalt (Co) was detected in Kachia Mechanic (181.9 ± 78.1 ppm), Kauro (191.0 ± 37.4 ppm), and Kagarko (115.7 ± 22.2 ppm), but was BDL in Kachia School and the background. Nickel (Ni) levels were highest at Kauro (18.6 ± 4.1 ppm), moderate at Kachia sites, and lowest at Kagarko (0.2 ± 0.0 ppm), while the background recorded 15.2 ± 3.2 ppm.

Copper (Cu) concentrations ranged from 12.9 ± 2.3 ppm in Kagarko to 39.1 ± 5.9 ppm in Kachia School, with a background value of 1.9 ± 0.6 ppm. Zinc (Zn) levels were elevated across all sites, especially in Kauro (247.0 ± 49.1 ppm) and Kachia Mechanic (204.9 ± 49.8 ppm), compared to the background level of 33.1 ± 2.8 ppm.

Arsenic (As) was extremely high in Kauro School (301.8 ± 129.4 ppm), significantly higher than the background (2.5 ± 0.6 ppm) and other locations. Tantalum (Ta) was highest in Kauro (369.9 ± 1.8 ppm), followed by Kachia School (57.3 ± 24.6 ppm) and Kachia Mechanic (30.8 ± 2.6 ppm). Gold (Au) was present in Kachia Mechanic (8.7 ± 8.7 ppm), Kagarko (7.9 ± 1.5 ppm), and minimally in Kauro (0.2 ± 0.0 ppm).

Lead (Pb) concentrations were elevated in all sites, with Kachia School having the highest (102.8 ± 47.4 ppm), and background levels being slightly lower (62.2 ± 10.3 ppm). Thorium (Th) reached an extreme value of 952.2 ± 651.4 ppm at Kauro School, while being relatively low or undetected elsewhere. Uranium (U) was also elevated in Kachia Mechanic (27.6 ± 6.6 ppm), with minor detection in Kauro and Kagarko.

Table 3: Heavy Metals Concentrations (ppm) in Samples from Kaduna South Zone

	KACHIA	KACHIA	KAURO SCH	KGARKO	
H	**Aver± S.D**	**Aver± S.D**	**Aver± S.D**	**Aver± S.D**	**BGRD**
Cr	80.0±22.4	94.1±19.8	85.9±44.5	42.4±13.0	23.0±8.6
Fe	58059.9±214	35058.9±86	671798.8±273	31178.8±75	7373.0±
C	181.9±78.1	BDL	191.0±37.4	115.7±22.2	BDL
Ni	13.3±16.9	8.4±14.5	18.6±4.1	0.2±0.0	15.2±3.2
C	28.9±14.1	39.1±5.9	14.9±6.7	12.9±2.3	1.9±0.6
Zn	204.9±49.8	169.8±87.3	247.0±49.1	162.0±21.6	33.1±2.8
As	11.2±1.9	BDL	301.8±129.4	3.6±4.8	2.5±0.6
Ta	30.8±2.6	57.3±24.6	369.9±1.8	0.2±0.0	3.4±0.8
A	8.7±8.7	BDL	0.2±0.0	7.9±1.5	BDL
Pb	65.8±47.9	102.8±47.4	41.2±1.2	60.9±8.2	62.2±10.
Th	23.3±13.9	8.8±12.4	952.2±651.4	15.5±1.3	BDL
U	27.6±6..6	BDL	7.5±6.4	6.3±1.9	BDL

Key: HM-heavy metal, BDL-Blow detection Limit, sch-school vicinity, mech-mechanic workshop and BGRD-background

.The results from Kaduna South Zone indicate significant contamination in both school and mechanic sites, particularly in Kauro, which recorded extremely high levels of Fe, As, Ta, and Th. This may reflect environmental pollution from industrial activities, agricultural runoff, or natural geological deposits.

Fig 3.1a, b and c depicts the number of times by which the average concentration of some heavy metals in schools replicates that of auto mechanic workshops and the other way round for Kaduna north, Kaduna central and Kaduna south zones respectively.

It is clear from the fig. 3.1 that heavy metals such as Cr, Cu, Zn, As, Pb, Fe, and Ta were (2 - 33) several higher in the schools and auto mechanic workshops than in the background area concentration. Fe was found to have exceptionally high concentrations in all samples analyzed. This is attributed to its presence as a ubiquitous element and macro nutrient, as well as anthropogenic factors such as automobile crankshaft wear and vehicle body damage, waste generated in automobile workshops, and metal construction works.

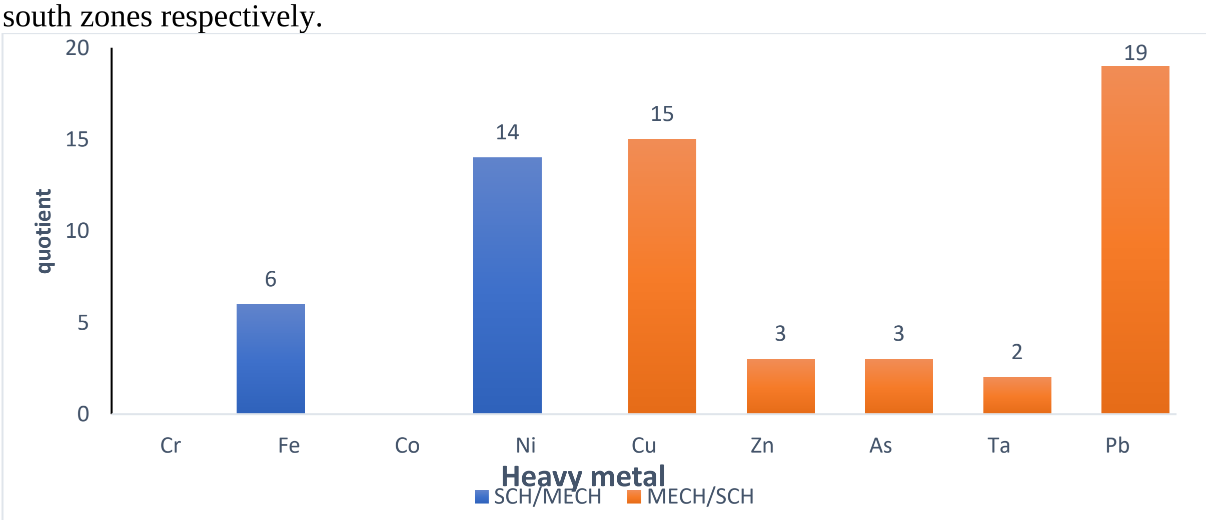


Fig 3.1a: Comparison of HM concentrations within Kaduna north zone

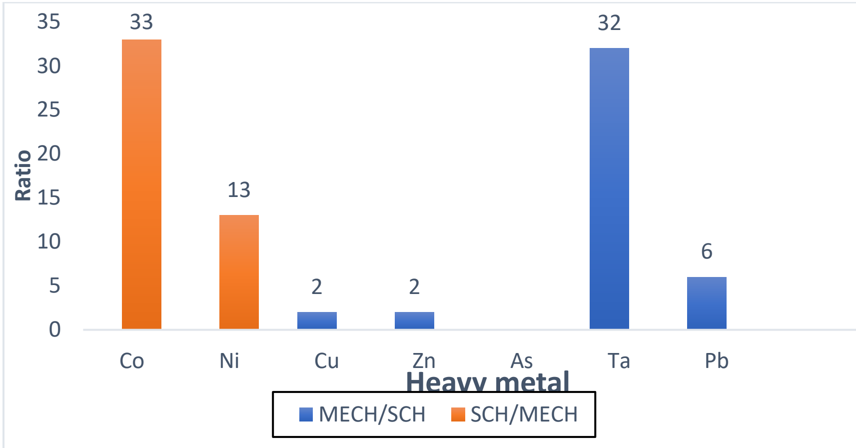


Fig 3.1b: Comparison of HM concentrations within Kaduna central zone

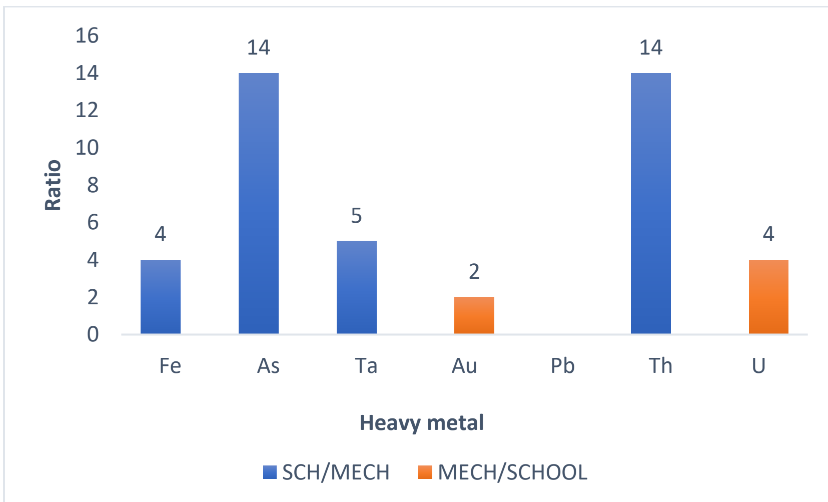


Fig 3.1c: Comparison of HM concentrations within Kaduna south zone

The concentration of copper in the samples can be attributed to factors such as metal-bearing wear, copper cables used as electrical light source, and used oils that contain high proportions of copper as well as lead and antimony. The concentration of Zn may be due to several factors, including the age of the mechanic workshops, volume of work done on each site, types of automobile service or repairs, type of lubricant commonly used, mode of waste disposal, and type of soil. Other possible sources may include wearing of brake, cooling liquid of vehicles, and wearing of road paved surface. Cu, Zn, Mn, and Fe are present in regular gasoline and petroleum products sold in Nigeria, which could also contribute to their higher concentration levels. Furthermore, vehicular exhaust emissions can end up in soils or be inhaled by humans.

The world health organization (WHO) and the food and agriculture organization (FAO) have stipulated the thresholds limits of heavy metals concentration in soil thus: As-20 ppm, Pb-100 ppm, Cd-3 ppm, Cr-100 ppm, Cu-100 ppm, Zn-300 ppm, Co-50 ppm and Ni-50 ppm. The average concentrations obtained in this work for each heavy metal in both the schools and the auto mechanic workshops were compared in the form of ratio (quotient) with the threshold limits recommended by WHO/FAO.

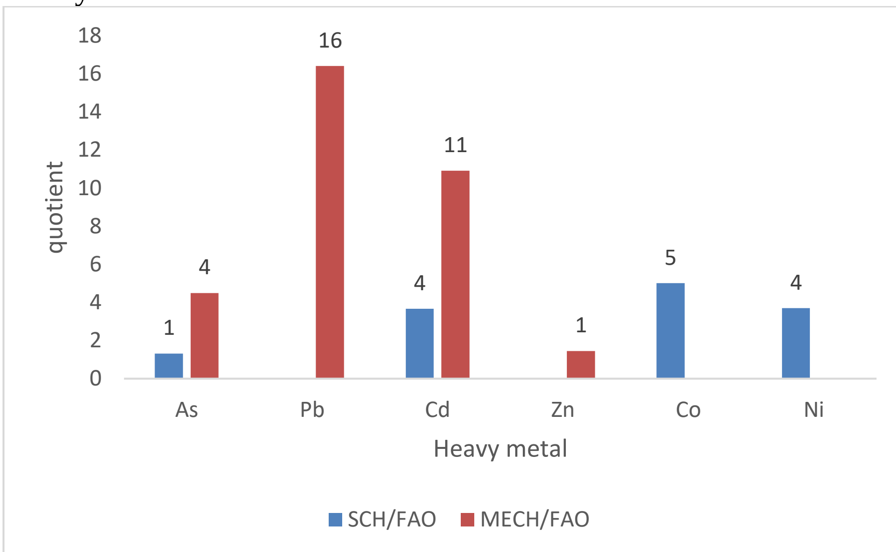


Fig 1.1: Comparison of HM concentrations with WHO/FAO for Kaduna north zone

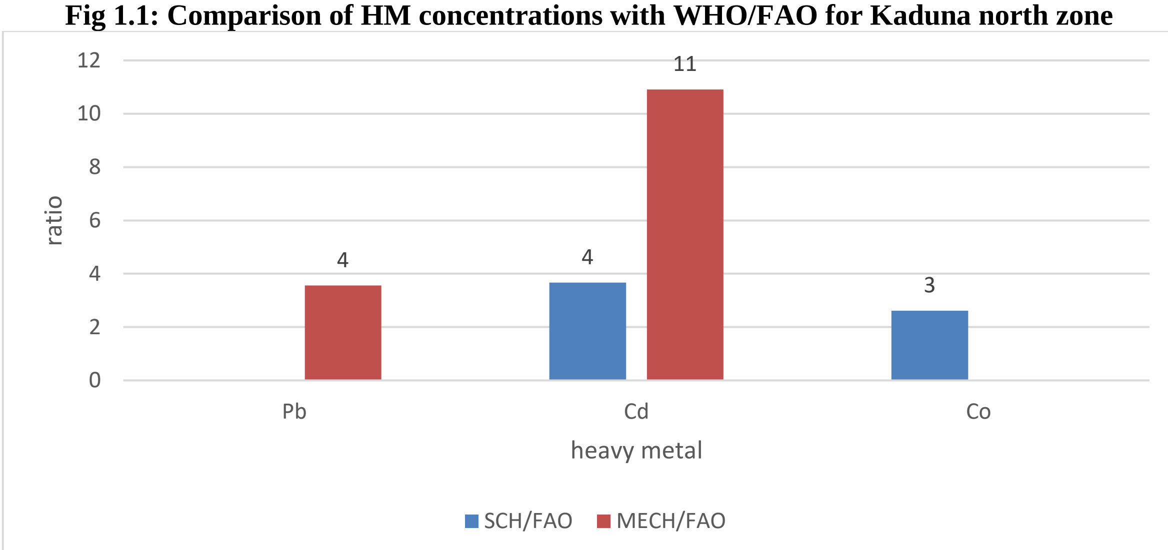


Fig 1.2: Comparison of HM concentrations with WHO/FAO for Kaduna central zone

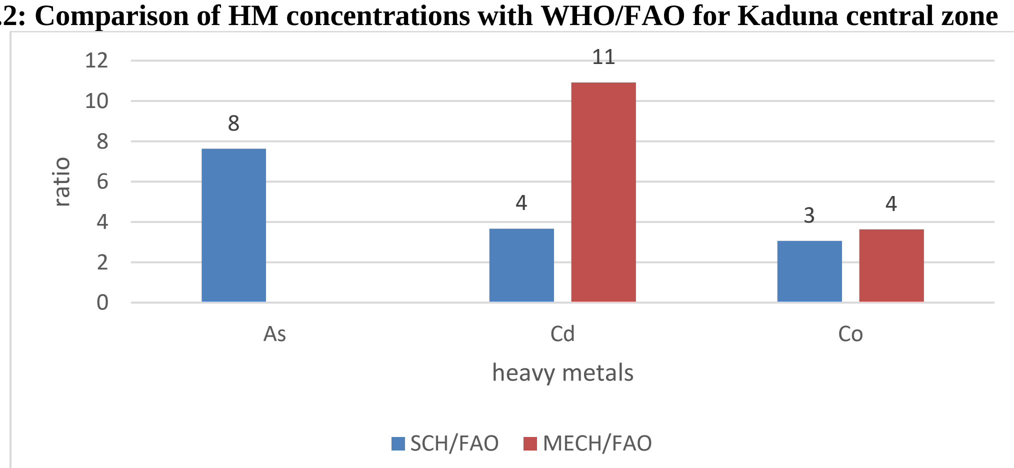


Fig 1.3: Comparison of HM concentrations with WHO/FAO for Kaduna south zone

It was observed that As, Pb, Cd, Co, Ni were found to be of serious health concern as their average concentrations in almost all the zones in Kaduna State were (4 - 16) greater than the threshold provided by WHO/FAO.

The high concentration of Pb could easily be attributed largely to the activities in these areas, how long the workshop was established in that particular location and amount of waste oil, presence of automobile emissions, and expired motor batteries indiscriminately dumped by battery chargers and auto mechanics in the surrounding areas. Concern for Pb concentrations in schools and auto-mechanic workshop soils may therefore arise principally due to the fact that the studied auto-mechanic workshop could also be identified as playground or near residential areas where children play about freely, and for children, ingestion of contaminated soil is the most significant pathway. Heavy metals such as Cr, Cu, Zn, As, Pb, Mn, Fe, and Ta were also higher in the schools and auto mechanic workshops than in the background area.

The findings from the Pearson correlation matrices across the Kaduna North, Central, and South zones reveal important insights for environmental health and pollution control policies. The strong positive correlations observed among certain heavy metals such as copper, zinc, arsenic, and lead, as well as between chromium and tantalum, suggest that these elements may originate from common anthropogenic sources. These could include industrial activities, vehicular emissions, mining, and agricultural practices. As such, regulating these pollution sources could help to simultaneously control multiple contaminants in the environment.

The co-occurrence of highly toxic elements such as lead, arsenic, and chromium across the zones also points to areas that may pose significant environmental health risks. These metals are known to cause various chronic health conditions, and their presence in the environment warrants prioritization in environmental monitoring and risk assessment programs. Moreover, the differences in correlation patterns among the three zones indicate that the sources and behaviors of these pollutants vary across locations. This variation underscores the need for zone-specific pollution control strategies, as a uniform policy approach may not effectively address the unique pollution challenges in each zone.

The observed strong correlations among metals also provide a basis for tracing pollution to specific industrial or agricultural sources. For example, a strong correlation between copper, zinc, lead, and arsenic often points to smelting activities or battery manufacturing. This relationship can support the identification of polluters and enhance the enforcement of environmental regulations. Furthermore, the presence of highly correlated toxic metals in soils raises concerns about potential uptake by crops, leading to contamination of the food chain. This situation highlights the need to establish soil quality standards, conduct regular soil testing, and implement agricultural practices that minimize heavy metal accumulation in crops.

In addition to environmental measures, there is also a need for public health interventions in areas where correlation patterns suggest increased exposure risks. Such interventions may include community education on the dangers of heavy metal exposure, provision of clean alternative water sources, and regular health screenings to detect early signs of contamination-related illnesses. Overall, the findings underscore the importance of integrated policies that combine pollution source regulation, environmental surveillance, public health monitoring, and tailored mitigation strategies to protect both the ecosystem and human health.

The results of the Pearson correlation analysis for heavy metals in soil samples from Kaduna State were presented in Tables 4, 5, and 6, corresponding to Kaduna North, Central, and South zones respectively. These tables show the correlation coefficients among various heavy metals detected, including Chromium (Cr), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Tantalum (Ta), and Lead (Pb). The correlation coefficient values range from -1 to +1, where +1 indicates a perfect positive correlation, -1 a perfect negative correlation, and 0 no correlation. The correlations help identify potential common sources, similar geochemical behavior, or anthropogenic influences on the metal distribution in the studied zones.

Table 4: Pearson correlation matrix for Kaduna North zone

	Cr	Fe	Ni	Cu	Zn	As	Ta	Pb
Cr	1.00							
Fe	0.19	1.00						
Co	0.25	**1.00**						
Ni	0.31	**0.99**	1.00					
Cu	**0.75**	-0.51	-0.39	1.00				
Zn	**0.84**	-0.38	-0.26	**0.99**	1.00			
As	**0.84**	-0.37	-0.25	**0.99**	**1.00**	1.00		
Ta	**1.00**	0.09	0.22	**0.81**	**0.88**	**0.89**	1.00	
Pb	0.74	-0.52	-0.41	**1.00**	**0.99**	**0.99**	0.80	1.00

Table 5: Pearson correlation matrix for Kaduna Central zone

	Cr	Fe	Co	Ni	Cu	Zn	As	Ta	Pb
Cr	1.00								
Fe	**0.98**	1.00							
Co	0.59	**0.75**	1.00						
Ni	-0.31	-0.11	0.58	1.00					
Cu	**0.73**	0.57	-0.12	**-0.88**	1.00				
Zn	**0.77**	0.62	-0.06	**-0.85**	**1.00**	1.00			
As	**0.93**	**0.83**	0.24	-0.65	**0.93**	**0.95**	1.00		
Ta	0.17	-0.03	-0.69	**-0.99**	**0.80**	**0.76**	0.53	1.00	
Pb	0.37	0.16	-0.54	**-1.00**	**0.90**	**0.88**	0.69	**0.98**	1.00

Table 6: Pearson correlation matrix for Kaduna South zone

	Cr	Fe	Co	Ni	Cu	Zn	As	Ta	Pb
Cr	1.00								
Fe	0.59	1.00							
Co	**1.00**	0.55	1.00						
Ni	-0.67	-1.00	-0.63	1.00					
Cu	**0.99**	0.47	**1.00**	-0.55	1.00				
Zn	**1.00**	0.62	**1.00**	-0.69	**0.98**	1.00			
As	0.46	**0.99**	0.42	**-0.97**	0.33	0.49	1.00		
Ta	0.58	**1.00**	0.53	**-0.99**	0.46	0.60	**0.99**	1.00	

Pb	**0.87**	**0.91**	**0.84**	**-0.95**	**0.79**	**0.89**	**0.84**	**0.91**	1.00

Table 4 reveals several strong positive correlations among the heavy metals, suggesting common sources or mutual geochemical behavior. Notably, Cr correlates perfectly with Ta (r = 1.00), indicating a strong likelihood of co-occurrence and possibly a shared origin. Cu shows a very strong positive correlation with Zn (r = 0.99), As (r = 0.99), and Pb (r = 1.00), suggesting these metals may originate from similar anthropogenic sources such as industrial or vehicular emissions. Additionally, Zn is highly correlated with As (r = 1.00) and Pb (r = 0.99), reinforcing this inference. Conversely, Fe shows weak or negative correlations with Cu, Zn, As, and Pb, indicating different sources or behavior in the soil. Ni has a strong positive correlation with Fe (r = 0.99), suggesting they might be of natural lithogenic origin.

In the central zone, Cr and Fe show a strong positive correlation (r = 0.98), indicating a shared geochemical pathway or source. As and Cr also correlate strongly (r = 0.93), as do As with Zn (r = 0.95) and Cu (r = 0.93), suggesting that these metals may be associated with agricultural or industrial activities. The most striking negative correlations are observed between Ni and Ta (r = -0.99), and Ni and Pb (r = -1.00), implying that where Ni concentrations are high, those of Ta and Pb are low. This inverse relationship may indicate different geochemical behaviors or distinct contamination sources. The strong positive correlations between Pb and Ta (r = 0.98), and between Pb and Cu (r = 0.90), further support the possibility of anthropogenic origin for these metals.

In the southern zone, several very strong correlations were observed. Cr is perfectly correlated with Zn (r = 1.00) and Co (r = 1.00), while Zn also shows strong positive correlations with Cu (r = 0.98) and Pb (r = 0.89), suggesting these elements likely stem from similar sources, possibly related to industrial activities or vehicular emissions. The strongest negative correlations are found between Ni and Ta (r = -0.99) and between Ni and As (r = -0.97), indicating contrasting behavior or origins. The strong positive correlations between Fe and As (r = 0.99), and Fe and Ta (r = 1.00), suggest a possible linkage between natural geogenic sources or metal mobilization processes in the zone. Overall, the correlations in the south zone reinforce pattern

3.0 Conclusion

The analysis of soil samples from Kaduna North, Central, and South zones revealed the presence of multiple heavy metals, including chromium, iron, cobalt, nickel, copper, zinc, arsenic, tantalum, and lead. The Pearson correlation matrices demonstrated strong positive correlations among several of these metals, suggesting common sources of contamination such as industrial discharge, agricultural runoff, mining activities, and vehicular emissions. Notably, the strong associations between copper, zinc, arsenic, and lead across all zones point to possible joint release from anthropogenic activities. Additionally, certain metals like chromium and tantalum showed consistent positive correlations, indicating similar environmental behavior or shared sources. Variations in correlation patterns across the zones suggest that pollution sources and environmental dynamics differ by location, requiring tailored control strategies.

The study concludes that soils across the three zones are contaminated with multiple heavy metals, some of which are highly toxic and pose significant environmental and public health risks. The consistent presence and co-occurrence of these metals indicate ongoing anthropogenic activities contributing to environmental degradation. The findings underscore the need for urgent environmental interventions and continuous monitoring to mitigate the spread and impact of these contaminants.

Based on these findings, it is recommended that comprehensive pollution control policies be developed and enforced at both local and regional levels. These policies should target key sources of contamination, including industrial operations, improper waste disposal, and unregulated agricultural practices. Regular environmental monitoring and assessment should be implemented to track changes in soil quality and pollutant levels. Public health initiatives should be introduced in affected communities to raise awareness about the dangers of heavy metal exposure and promote safe agricultural practices. Furthermore, remediation programs such as phytoremediation and soil amendment techniques should be considered to restore the quality of contaminated soils and reduce the risks associated with heavy metal accumulation in the food chain.

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