Arabian Journal of Geosciences (2022) 15:1549
https://doi.org/10.1007/s12517-022-10833-9

ORIGINAL PAPER

Pollution profile, ecological and health risk assessment of trace metals in soils of auto mechanic workshops at Gombe metropolis, Gombe State, Northeastern Nigeria

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Received: 8 February 2022 / Accepted: 11 September 2022 / Published online: 20 September 2022

Abstract

This study was conducted to assess the pollution profile, ecological and health risks associated with trace metals (Cr, Mn, Cu, Ni, Cd and Pb) in soils in the vicinity of auto mechanic workshops in Gombe metropolis, Nigeria. Soil samples were collected at depths of 0–15 cm and analyzed after acid digestion using an atomic absorption spectrophotometer (AAS). The data collected were analyzed for descriptive and inferential statistics. The mean concentration of trace metals (mg kg^{-1}) ranged Cr (0.14–12.7), Mn (1.46–32.65), Cu (3.22–183.80), Ni (2.47–138.50), Cd (0.23–14.50) and Pb (1.39–135.40). The result showed that metals were highly accumulated in the following trend: Cu > Ni > Pd > Mn > Cd > Cr. Correlation, principal component analysis (PCA) and hierarchical clustering analysis (HCA) revealed that the major source of pollution might be linked to the anthropogenic activities at auto mechanic workshops. Pollution indices studies showed that soil samples were highly contaminated with Cu, Ni, Cd and Pb. The ecological risk assessment is classified under high to serious ecological risk, and cadmium contributes 88–92% of the total potentially ecological risk. The total hazard index (HI) for ingestion was > 1 for children, which indicated a non-carcinogenic health risk effect for children. The cancer risk (CR) values for ingestion and dermal pathways exceeded the threshold value (1×10^{-6} to 1×10^{-4}) for both children and adults, indicating possible cancer development. The study concludes that the activities at the mechanic workshops contaminated the soil and eventually pose threat to humans, suggesting adequate attention should be given to the risk of these trace metals in the study areas.

Keywords Auto mechanics · Distribution · Pollution indices · Soil · Trace metals

Introduction

Soil pollution by trace metals could be through various anthropogenic activities such as mining, fertilizer application, petrochemicals spillage, coal combustion and higher waste disposal due to the increase in population and industries (Sadick et al. 2015; Anegbe et al. 2016; Ibrahim et al. 2019; Nguyen et al. 2020). In most developing nations like Nigeria, automobile repairs/workshop activities are increasing due to the purchase of imported used cars (mostly referred to as Tokunbo) used automobiles (Ololade 2014; Sadick et al. 2015; Nguyen et al. 2020). The importation of these used vehicles into the nation might be the cause of the high rate of vehicle repair actions in the country (Inam et al. 2015). This occurs as a result of the short life expectancy of such automobiles; thus, they are easily deserted by the roadsides in nearly all cities (Inam et al. 2015).

Responsible editor: Amjad Kallel

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In automobile workshops, wastes are usually generated due to artisan activities (Pam et al. 2013; Ibrahim et al. 2019). These workshops are widely found as clusters of open land in the vicinity of urbanized areas offering services that generate various waste products (Nwachukwu et al. 2011; Rabe et al. 2018). Wastes from these automobile mechanic workshops are disposed and dumped indiscriminately into the environment (Aelion et al. 2009; Roland 2016). The improper disposal of these metal scraps, worn-out vehicle parts, used batteries, hydraulic fluids, engine oils, power steering pump oil and lubricants may contain trace metals (Hirsch 2004; Kalpakjian and Schmidt 2006; Ndukaa et al. 2019) and can lead to environmental deterioration.

Several studies reported a considerable amount of trace metals (Pb, Ni, Cd, Cu, Cr, Mn and Zn) around the surrounding soils of automobile mechanic workshops (Sadick et al. 2015; Anegbe et al. 2016; Rabe et al. 2018; Ibrahim et al. 2019; Joyce et al. 2021). Generally, the studies revealed that soils of automobile mechanic workshops are more polluted than the surrounding soils in metals which are contained as additives in gasoline and lubricants, which are non-biodegradable in the soil (Ololade 2014). Some of these trace metals such as Cd, Pb and Cr have been classified as concern pollutants by the United States Environmental Protection Agency (Sharma and Reddy 2004; Ololade 2014).

Trace metals are considered one of the most serious environmental pollutants due to their bioaccumulation, toxicity and persistent nature (Anegbe et al. 2019). The highly toxic and persistent nature of the environment made them priority pollutants (Abechi et al. 2010). These metals can bioaccumulate in plants through soil, and animals feed on them and finally make their way to humans through the food chain (Anegbe et al. 2019). The toxicity of these metals can pose health implications to humans and greatly depends on their concentration (Yang et al. 2016; Joyce et al. 2021). Risk assessment models are used to estimate the health risk of metals to humans including non-carcinogenic and carcinogenic risks (Ghosh et al. 2018; Weerasundara et al. 2018). The non-carcinogenic risk was reported to be associated with systemic toxicity (e.g., kidney and liver), reproductive toxicity (e.g., fertility), neurotoxicity (brain pathology), etc. (EPA 2012; Sulaiman et al. 2021), while the carcinogenic risk is associated with lung cancer, gastric carcinoma, brain cancer, etc. (Angel et al. 2018; Sulaiman et al. 2021).

The occurrence of these metals in various parts of Nigeria has been reported; this includes a relatively high content of Pb, Cd, Ni, Cr, etc. in soil from mining areas, road dust, municipal solid waste, mechanic workshops, etc. (Ihedioha et al. 2016; Taiwo et al. 2017; Rabe et al. 2018; Ndukaa et al. 2019; Taiwo et al. 2020; Henry et al. 2021). Gombe State is one of the hubs of mechanic workshop settings in Northeastern Nigeria, particularly Gombe metropolis. Despite the prospective sources of metals from the auto mechanic workshops in Gombe metropolis, the pollution profile of trace metal at the auto mechanic workshops is not well studied. Thus, there is a need to investigate the concentrations of the trace metal around auto mechanic workshops soils in Gombe metropolis, to understand the status of trace metal pollution profile, ecological and human health risks associated with the sites. This study was conducted to assess the pollution profile, ecological and health risk assessment associated with trace metals (Cr, Mn, Cu, Ni, Cd and Pb) in soils in the vicinity of auto mechanic workshops soils in Gombe metropolis, Nigeria. The work is anticipated to give baseline data for future investigation of activities leading to provisional changes, in pollution profile, ecological and health risk assessment of trace metals in the vicinity of auto mechanic workshops soils in Gombe, Northern Nigeria.

Materials and methods

Study area

The study area is in Gombe metropolis, the capital of Gombe State, situated in Northern Nigeria. It is located between latitude 10°17′05.88″N and 11°10′36.78″E (Fig. 1) with an area coverage of about 52 km^2. The study area has a Sudan savanna climate, characterized by a tropical climate with two distinct seasons: a wet season (May–October) and a dry/harmattan season (November–April), with a temperature range from 18 to 39 °C and rainfall of 850–954 mm (Iloeje 2001). The relative humidity ranged from 70 to 80% in August and decreases to 15 to 20% in December (Sulaiman et al. 2018).

Soil sample collection

Soil samples were collected from topsoil (0–15 cm) using a soil auger; the sampling locations were composed of six major auto mechanic workshop clusters (Tashan Bauchi = A, Tashan Dukku = B, Idi = C, Gidan Zamfara = D, Malam Kawo = E, Dogon Dibino = F and Control sample = CS from a virgin soil) in Gombe metropolis. At each sampling location, four subsamples were randomly collected for a period of 6 months from February to July 2021, to form a composite sample; 18 soil samples were collected from each sampling site making a total of 126 samples. About 50 g of each composite sample was placed into zip-mouthed polyethylene bags and transported to the laboratory, stored at room temperature for 72 h to remove moisture for pretreatment and analyses.

Sample preparation and digestion of soil

The air-dried soil samples were pulverized with an agate mortar and sieved through a 1-mm mesh standard sieve.

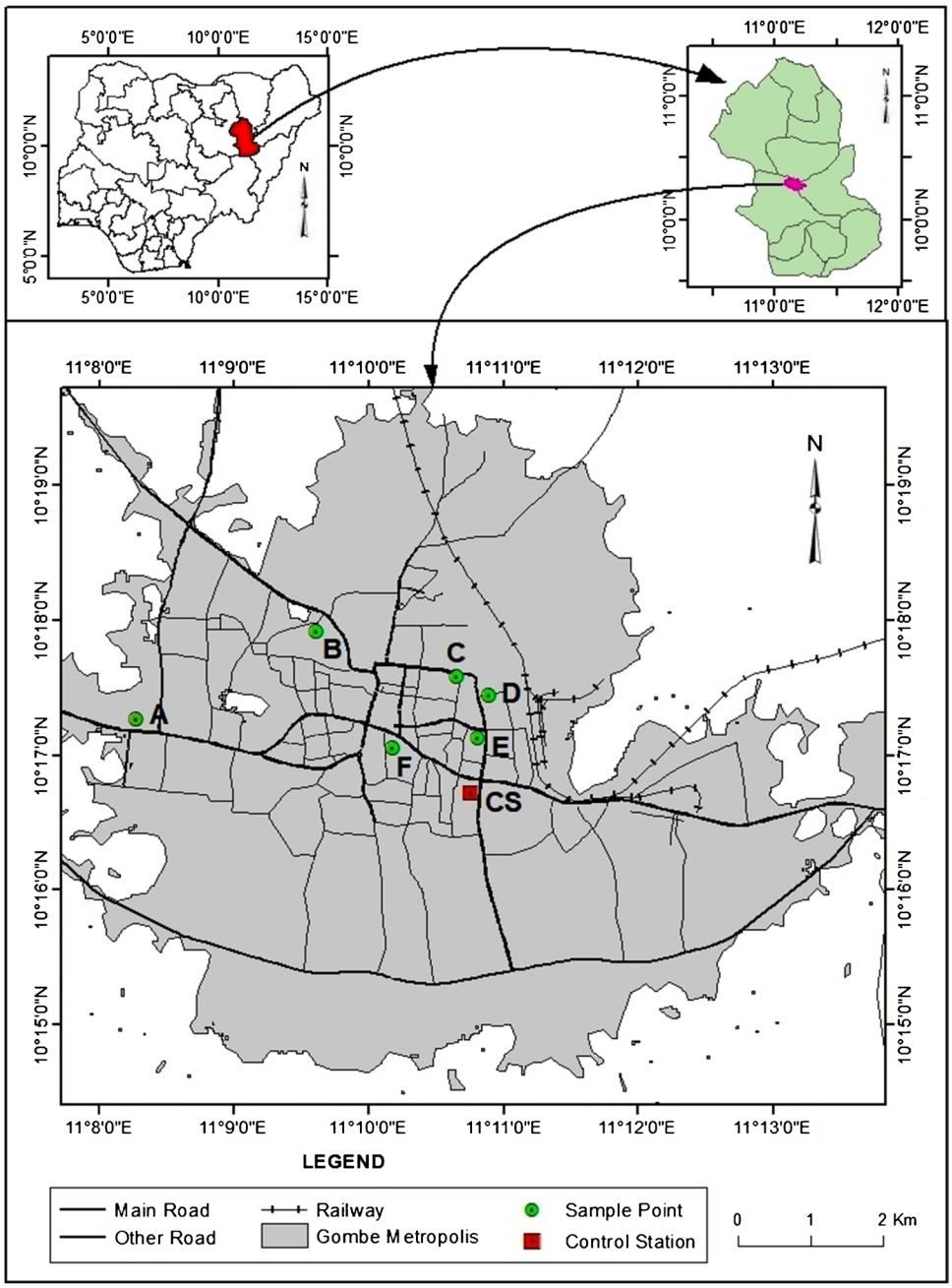

Fig. 1 A map of the study area showing sampling sites

About 0.5 g of each of the samples was transferred to Teflon cups and digested in 20 mL freshly prepared aqua regia (1:3 HNO_3:HCl) on a hot plate for 3 h at 80 °C in a fume cupboard. The digest was allowed to cool filtered (Whatman, 1.0-µm pore size) into a 100-mL standard flask and diluted with distilled water to the mark 50 mL. The concentration of Cr, Mn, Cu, Ni, Cd and Pb was determined using an atomic absorption spectrophotometer (AAS) (AA6300, Shimadzu, Japan).

Quality control and quality assurance

All reagents and standards used were of analytical grade. For quality control, the detection limit was set at 0.001 mg L^{-1}, and blank samples were also analyzed to cancel the background effects. The calibration of the AAS instrument follows the preparation of a series of standards in the concentration range of 0–100 mg L^{-1}, to obtain the calibration curves. Soil samples from the workshops were also analyzed

using the same method. All the sample analysis was done in three replicates, and the recovery study was adapted elsewhere Ihedioha et al. (2016), with mean recovery percentages of the metals ranging from 87 to 106%. The limits of detection for Cr, Mn, Cu, Ni, Cd and Pb were 0.06, 0.04, 0.06, 0.08, 0.02 and 0.04 µg/L, respectively, and were evaluated using the following expression: LOD = 3.3 standard deviation (SD)/*b*.

Statistical analysis

Data collected were subjected to simple descriptive statistics (mean and standard deviation), analysis of variance (ANOVA), correlation analysis, hierarchical clustering analysis (HCA) and principal component analysis (PCA) executed using SPSS version 25, to identify the sources or patterns within a set of data based on similarities and their sources (Wei et al. 2011; Nguyen et al. 2020).

Pollution indices

Pollution indices are useful tools for processing raw environmental information (Ihedioha et al. 2016). The following pollution indices used in this study are geo-accumulation load index (I_{geo}), contamination factor (CF) and pollution load index (PLI) used to evaluate the extent of metal pollution in the soils.

Geo-accumulation index (I_{geo})

The geo-accumulation index (I_{geo}) for evaluation of soil contamination by trace metals was based on using the model proposed by Muller (1969) in Eq. (1):

$$I_{geo} = \mathrm{Log}_2\left[\frac{C_i}{Bn \times 1.5}\right] \quad (1)$$

where C_i = concentration of an element in the weighted soil (mg kg^{-1}), Bn = geochemical background value of the metal, and world average elemental values reported elsewhere were used (Turekian and Wedepohl 1961), and 1.5 = control values for lithogenic variation in the soil. Pollution mode was classified on seven parameters in Table 1, according to Muller (1969).

Contamination factor (CF)

The contamination factor (CF) was calculated based on a model developed by Lacatusu (2000).

$$Cf = \frac{C_n}{C_o} \quad (2)$$

where Cf = contamination factor, C_n = metal content in the weighted soil and C_o = geochemical background concentration or reference value of the metal. The DPR (2002) reference value was used as a reference value for the study. The Cf pollution classification was presented in Table 1, according to Sutherland (2000).

Pollution load index (PLI)

The pollution load index (PLI) obtained was based on a model developed by Thomilson (1980). The PLI was calculated by the *n*-root from the *nCfn* that were obtained for all the metals (Sulaiman et al. 2019a).

$$\mathrm{PLI} = n\sqrt{(Cf1 \times Cf2 \times Cf3 \times Cf4 \times Cfn)} \quad (3)$$

where n = number of metals studied, Cf = contamination factor calculated as described in Eq. (2). The rank of values of PLI < 1 denotes perfection, PLI = 1 presents that only baseline levels of pollutant are present and PLI > 1 indicates deterioration of site quality (Thomilson et al. 1980; Sulaiman et al. 2019b).

Ecological risk assessment

Ecological risk assessment E^i_r and potential ecological risk index (R_i) according to equations proposed by Hakanson (1980).

Table 1 The parameters for evaluation of geo-accumulation, contamination factor, ecological risk and risk index

Geo-accumulation (*I*geo)			Contamination factor (CF)		Ecological risk (*Eir*)		Risk index (RI)	
*I*geo	Class	Pollution level	CF	Pollution degree	*Eir*	*Eir* of each metal	RI	Comprehensive
*I*geo < 0	0	Unpolluted	< 1	Low	< 40	Low	< 150	Low
0 ≤ *I*geo < 1	1	Unpolluted-moderately	1 < CF < 3	Moderate	40–80	Moderate	150–300	Moderate
1 ≤ *I*geo < 2	2	Moderately	3 < CF < 6	Considerable	80–160	Considerable	300–600	High
2 ≤ *I*geo < 3	3	Moderately-strongly	≥ 6	Very high	160–320	High	≥ 600	Serious
3 ≤ *I*geo < 4	4	Strongly			≥ 320	Very high		
4 ≤ *I*geo < 5	5	Strongly-extremely						
*I*geo > 5	6	Extremely						

$$R_i = \sum E_r^i \tag{4}$$

$$E_r^i = T_r \frac{C_n}{C_o} \tag{5}$$

where R_i = sum of potential ecological risk factors, T_r = toxic respond factor, E_r^i = potential ecological risk factor, C_n = metal content in the soil and C_o = background value or reference value of metals. The parameters for evaluation of ecological risk are presented in (Table 1).

Health risk assessment

The exposure of metals determined in soil was assessed for human health effects using the model designed by the United States Environmental Protection Agency (USEPA) and other relative studies (Ihedioha et al. 2016; Fakhri et al. 2018; Henry et al. 2021). The three potential exposure pathways, ingestion, inhalation, and dermal contact, were used in this study.

$$\mathrm{ADD_{ing}} = \frac{\mathrm{C} \times \mathrm{IngR} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}} \tag{6}$$

$$\mathrm{ADD_{inh}} = \frac{\mathrm{C} \times \mathrm{InhR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{PEP} \times \mathrm{BW} \times \mathrm{AT}} \tag{7}$$

$$\mathrm{ADD_{derm}} = \frac{\mathrm{C} \times \mathrm{SL} \times \mathrm{SA} \times \mathrm{ABS} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}} \tag{8}$$

Non-carcinogenic risk assessment

The hazard quotient (HQ) was used to estimate the non-carcinogenic effect of metals in soil and was estimated using the equation below (USEPA 2001).

$$\mathrm{HQ} = \frac{\mathrm{ADD}}{\mathrm{RfD}} \tag{9}$$

Hazard index (HI) is the sum of multiple-route HQ (USEPA 2009). A HI value > 1 implies that non-carcinogenic effects may occur; the higher the value of HI, the higher the likelihood of non-carcinogenic effects (USEPA 2001).

$$\mathrm{HI} = \sum\nolimits_n^i \mathrm{HQ}_i \tag{10}$$

Carcinogenic risk assessment

The carcinogenic risk was also estimated using Eq. (11) as developed by USEPA (2001).

$$\mathrm{CR} = \mathrm{ADD} \times \mathrm{CSF} \tag{11}$$

where ADD = average daily exposure dose of metals in soil (mg/kg/d), RfD = reference dose and CSF = cancer slope factor (mg/kg/d). The parameters and input assumptions for exposure assessment are presented in Table 2.

Results and discussion

Trace metal concentration in the soil samples

Table 3 presents the mean concentrations of trace metals in the soil in the vicinity of the auto mechanic workshops.

Table 2 The parameters and input assumptions for exposure assessment of metals via ingestion, inhalation and dermal routes

Parameters	Meaning	Units	Value			References
			Non cancer		Cancer	
			Adults	Children		
C	Concentration of metals in the soil	mg/kg				
AT	Average time for carcinogens	days	ED × 365 days	ED × 365 days	70 × 365 days	USEPA (2001)
CF	Conversion factor	kg/mg	10−6	10−6		USEPA. (2004)
EF	Exposure frequency	days/year	365	365		USEPA (2004)
ED	Exposure duration	years	25	6	70	USEPA (2001)
BW	Body weight	kg	60	15		USEPA (2001)
IRing	Ingestion rate	mg/day	100	200		USEPA (2001)
IRinh	Inhalation rate	m^3/day	20	10		Van den Berg (1995)
SA	Skin surface area	cm^2	2800	3300		USEPA (2001)
SL	Skin adherence factor	mg/(cm^2/h)	0.2	0.2		USEPA (2001)
PEF	Particulate emission factor	m^3/kg	1.36 × 109	1.36 × 109		USEPA (2001)
ABS	Dermal absorption factor	-	0.001	0.001	0.03	USEPA (2002)

Table 3 Descriptive statistics of trace metals concentration (mg kg^{-1}) in the soil samples

Locations	Bearing	Cr	Mn	Cu	Ni	Cd	Pb
A ($n = 30$)	10°17′54.7″N, 11°08′17.0″E	6.12 ± 0.010	22.33 ± 0.030	153.70 ± 0.005	138.50 ± 0.040	15.00 ± 0.040	123.00 ± 0.020
B ($n = 30$)	10°17′35.1″N, 11°10′39.3″E	5.21 ± 0.010	25.80 ± 0.040	154.00 ± 0.005	126.58 ± 0.030	10.55 ± 0.020	121.23 ± 0.020
C ($n = 30$)	10°17′35.1″N, 11°10′39.3″E	10.01 ± 0.010	32.65 ± 0.040	171.01 ± 0.010	131.03 ± 0.020	10.42 ± 0.020	135.40 ± 0.040
D ($n = 30$)	10°17′26.5″N, 11°10′53.9″E	12.70 ± 0.020	30.10 ± 0.050	168.03 ± 0.010	128.10 ± 0.050	11.01 ± 0.010	131.31 ± 0.010
E ($n = 30$)	10°17′07.8″N, 11°10′39.7″E	5.32 ± 0.010	30.83 ± 0.030	183.08 ± 0.020	126.55 ± 0.050	12.00 ± 0.040	128.10 ± 0.020
F ($n = 30$)	10°03′35.2″N, 11°10′10.8″E	6.54 ± 0.025	21.52 ± 0.020	174.10 ± 0.020	127.80 ± 0.030	13.30 ± 0.025	126.50 ± 0.070
CS (n=30)	10°17′43.2″N, 11°10′44.8″E	0.14 ± 0.042	1.46 ± 0.011	3.22 ± 0.030	2.47 ± 0.051	0.23 ± 0.025	1.39 ± 0.044
DPR target values		100.00	476.00	36.00	35.00	0.80	85.00

CS control sample, *DPR* Department of Petroleum Resources of Nigeria

The mean concentrations of Cr in the sampled soils ranged (0.14–12.7 mg kg^{-1}) and Mn (1.46–32.65 mg kg^{-1}). The concentrations of Cu ranged (3.22–183.08 mg kg^{-1}), while Ni (2.47–138.50 mg kg^{-1}). The concentrations of Cd ranged (0.23–15.00 mg kg^{-1}), while that of Pb ranged (1.39–135.40 mg kg^{-1}). The abundance of the trace metals declined in order of Cu > Ni > Pb > Mn > Cd > Cr. The lowest concentration of all the studied metals was obtained in the control sample. The highest concentration of Cr (12.70 mg kg^{-1}) was obtained at D workshop, followed by C (10.01 mg kg^{-1}), F (6.54 mg kg^{-1}), while A, E and B were (6.12 mg kg^{-1}), (5.32 mg kg^{-1}) and (5.21 mg kg^{-1}) respectively. Although Cr is a vital element, it could be toxic at an elevated level by reducing blood glucose, cardiovascular disorders and alimentary, etc. (USEPA 1997; WHO 2007; Ghani et al. 2012). The highest concentration of Mn (32.65 mg kg^{-1}), (30.83 mg kg^{-1}), (30.10 mg kg^{-1}) and (25.80 mg kg^{-1}) in C, E, D and B, respectively, were higher than those of workshops C (22.33 mg kg^{-1}) and F (21.52 mg kg^{-1}). The concentration of Cu in workshops E (183.08 mg kg^{-1}), F (174.10 mg kg^{-1}), C (171.01 mg kg^{-1}), D (168.03 mg kg^{-1}) was higher than those of workshops B (154.00 mg kg^{-1}) and A (153.70 mg kg^{-1}). The high levels of Cu and Cr could be a result of spraying of car bodies, overhauling of vehicle engines and other activities which take place at automobile workshops (Joyce et al. 2021). The highest Ni concentration of (138.50 mg kg^{-1}) and (131.03 mg kg^{-1}) was obtained in workshops A and F, followed by D (128.10 mg kg^{-1}), which were higher than those of workshops F (127.80 mg kg^{-1}), B (126.58 mg kg^{-1}) and E (126.55 mg kg^{-1}). The highest Cd concentration of (15.00 mg kg^{-1}) and (13.30 mg kg^{-1}) was obtained in workshops A and F were higher than those of workshops D (11.01 mg kg^{-1}), B (10.55 mg kg^{-1}) and C (10.42 mg kg^{-1}). The high level of cadmium obtained could be a result of the dumping of nickel–cadmium batteries, disposal sludge, motor oil and PVC plastics at auto mechanic workshops (Ebong et al. 2008; Anegbe et al. 2019). The high level of cadmium in automobile soils was also reported in similar studies by Sadick et al. (2015) and Jolaoso et al. (2019). The concentration of Pb in workshops C (135.40 mg kg^{-1}), D (131.31 mg kg^{-1}), E (128.10 mg kg^{-1}), F (126.50 mg kg^{-1}) was higher than those of workshops A (123.00 mg kg^{-1}) and B (121.23 mg kg^{-1}). Lead is highly toxic to humans with typical symptoms of headache, convulsions, hypertension, muscular, skeletal, colic, chronic nephritis, anemia and central nervous system disorders (Khan et al. 2008; Edebi and Alade, 2011). The mean concentration of Pb was higher than 15.1 mg kg^{-1}, 14.13 mg kg^{-1} and 76.92 mg kg^{-1} reported by Adelekan and Abegunde (2011), Babatunde et al. (2014) and Okunola et al. (2007) respectively. However, values obtained in the study were lower than the value of 197.94 mg kg^{-1} reported in automobile soil from Kumasi, Ghana (Sadick et al. 2015) and 307.50 mg kg^{-1} reported in automobile soil from Lagos, Nigeria (Jolaoso et al. 2019). Elevated levels of lead could be a result of the use of automobile batteries which are a ready source of the lead (Anegbe et al. 2019).

Principal component, cluster and correlation analyses

The results of the principal component analysis (PCA) are presented in Table 4. Three components illustrating 92.91% of the total variance are presented in Fig. 2. According to the results, component 1 elucidated 44.555% of the total variance and positive loadings on Ni (0.944) and Cd (0.771),

Table 4 Principal component analysis of trace metals in the soil samples

Trace metals	Component		
	1	2	3
Cr	0.100	**0.918**	0.129
Mn	−0.469	**0.738**	0.229
Cu	−0.447	0.064	**0.891**
Ni	**0.944**	0.011	−0.116
Cd	**0.771**	−0.581	0.228
Pb	−0.468	−0.249	−0.847
Eigenvalues	2.673	1.780	1.121
% of variance	44.555	29.665	18.688
Cumulative %	44.555	74.220	92.908

Strong correlation is shown in bold font

while Cr (0.918) and Mn (0.738) were associated with component 2, which accounted for 29.665% of the total variance, and component 3 Cu (0.944), accounting for 18.688% of the total variance. This conformed to the correlation analysis results in Table 5. Table 5 shows positive correlations between the Ni and Cd in auto mechanic workshop soil. This reveals that Ni and Cd have an almost similar distribution, or they were likely attributable to the same anthropogenic sources, as a result of discharging components of nickel–cadmium batteries (Sulaiman et al. 2019b).

In addition, cluster analysis was used to recognize the relationships among the analyzed metals and group their likely sources. The results indicated that the points were categorized into three groups and were illustrated in a

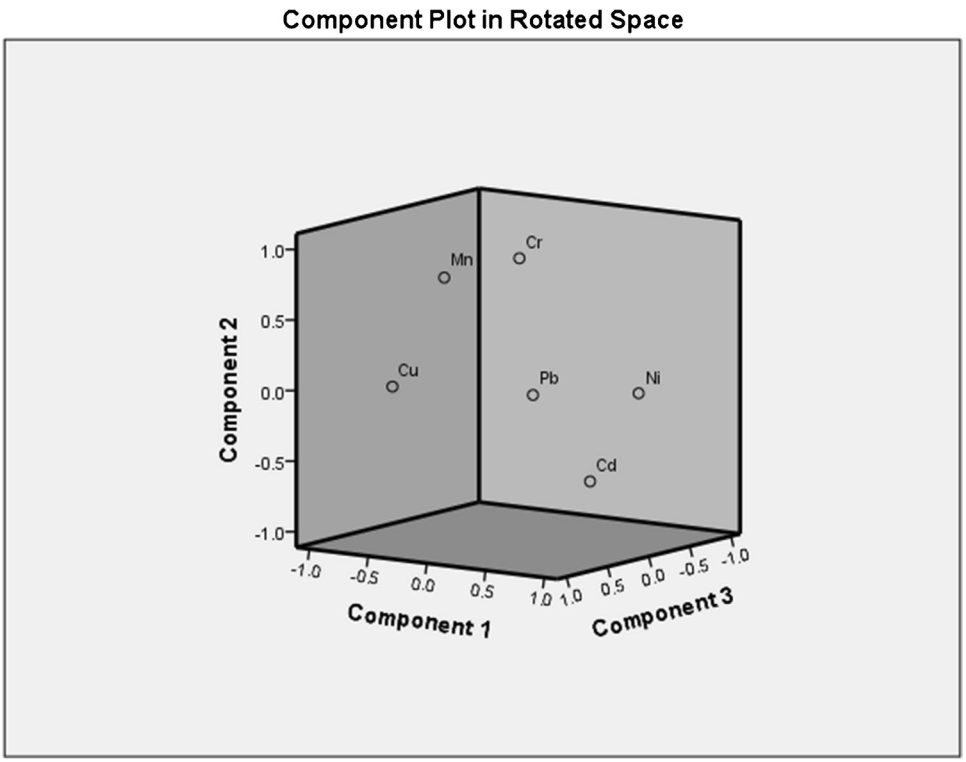

Fig. 2 Rotated component loading plot of component analysis of trace metals of soil samples

Table 5 Correlation analysis for the trace metals in the soil samples

Metals	Fe	Cr	Mn	Cu	Ni	Cd	Pb
Fe	1						
Cr	0.238	1					
Mn	−0.154	0.511	1				
Cu	**−0.748****	0.122	0.465	1			
Ni	−0.080	−0.019	−0.341	−0.516	1		
Cd	−0.406	−0.407	−0.741**	−0.183	0.671*	1	
Pb	−0.266	**0.751****	**0.755****	**0.590***	−0.130	−0.461	1

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

* Correlation is significant at the 0.05 level (2-tailed)

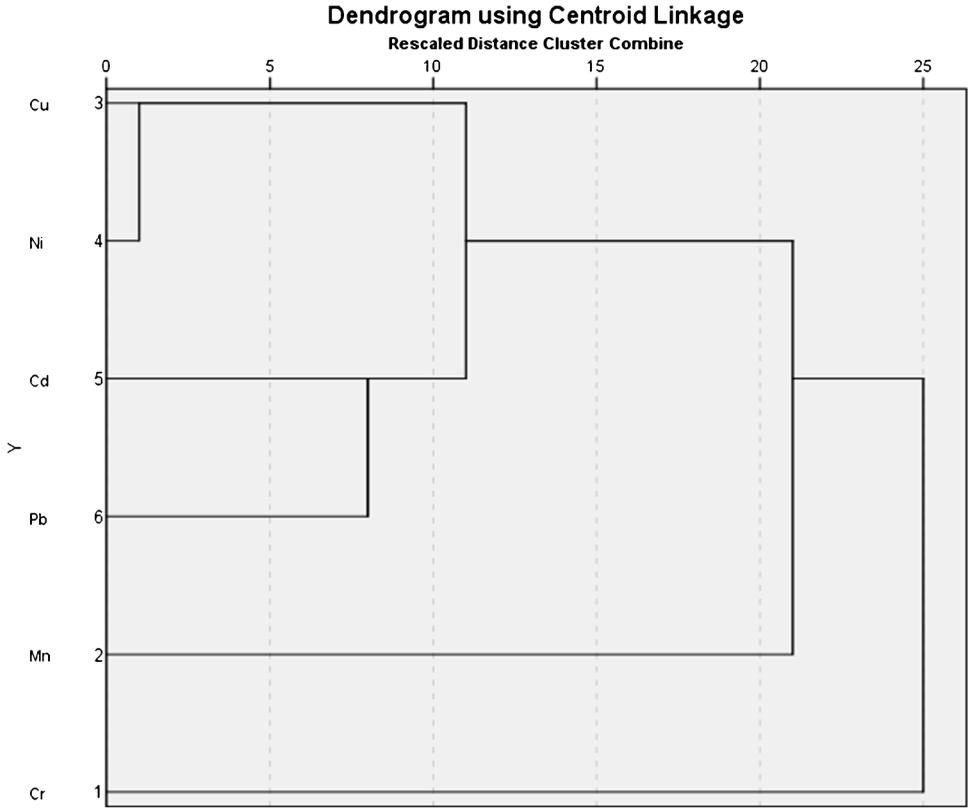

Fig. 3 Dendrograms produced by hierarchical clustering for trace metals of soil samples

dendrogram of the six trace metals in clusters (Fig. 3). The first cluster in HCA comprised Cu, Ni, Cd and Pb forming one group, the second cluster is related to Cu, Cd and Mn and the third cluster was only Cr. The trace metals in groups one and two of the cluster analyses were likely from anthropogenic and geogenic or natural sources respectively.

Pearson correlation analysis was performed for trace metal in all the sites at levels of significance ($p < 0.05$ and $p < 0.01$). The ($r > 0.5$) values obtained indicated positive correlations and a significant linear relationship between pairs of metals Ni–Cd, Cr–Pb, Mn–Pb and Cu–Pb. This strong association reflects their simultaneous release and the same source from the auto mechanic workshop. This confirmed the existing associations between the metals as presented by the factor analysis. There were positive loadings between Ni and Cd, which was the elements of group one, which likely came from anthropogenic sources, as a result of discharged component of nickel–cadmium batteries, and the linear relationship between pairs of Cr–Pb, Mn–Pb and Cu–Pb could be as a result of spraying of car bodies, overhauling of vehicle engines and other activities which take place at automobile workshops (Table 5).

Table 6 Geo-accumulation index (I_{geo}), contamination factor (CF) and pollution load index (PLI) of trace metals in the soil samples from of auto mechanic workshops in Gombe, Nigeria

Locations	Igeo						CF						
	Cr	Mn	Cu	Ni	Cd	Pb	Cr	Mn	Cu	Ni	Cd	Pb	PLI
A	0.014	5.27E-03	0.685	0.409	9.699	1.234	0.061	0.047	4.27	3.96	18.75	1.45	28.54
B	0.012	6.09E-03	0.687	0.374	7.057	1.216	0.052	0.054	4.27	3.62	13.19	1.43	22.62
C	0.022	7.71E-03	0.763	0.387	6.971	1.359	0.100	0.069	4.75	3.74	13.03	1.59	23.28
D	0.028	7.10E-03	0.749	0.378	7.365	1.318	0.127	0.063	4.67	3.66	13.76	1.54	23.82
E	0.012	7.28E-03	0.820	0.373	8.027	1.269	0.053	0.064	5.11	3.61	15.00	1.49	25.33
F	0.015	5.08E-03	0.776	0.377	8.904	1.270	0.065	0.045	4.84	3.65	16.63	1.49	26.72
CS	0.003	3.00E-04	0.014	0.007	0.154	0.014	0.001	0.002	0.09	0.07	0.288	0.02	0.020

Pollution indices

The results of the geo-accumulation index (I_{geo}) of the soil samples from the various sites are presented in Table 6. I_{geo} revealed that all the sites studied in respect of all the metals were unpolluted to extremely polluted. The I_{geo} value of Cd ranged from (6.971 to 9.699) extremely polluted, while that of Pb (1.216 to 1.359) was moderately polluted. The I_{geo} of other metals (Cr, Mn, Cu and Ni) were unpolluted to moderately polluted, while the I_{geo} of all studied metals in the control sample were unpolluted. The I_{geo} values in this study were above the values reported in a related study (Roland 2016; Orji et al. 2018; Yerima et al. 2020), but similar to values of Pb reported in auto mechanic workshop clusters soils from Edwenase Kwadaso, Ghana (Sadick et al. 2016).

The results of the contamination factor (Table 6) indicated low contamination (< 1) for Cr and Mn, moderate contamination (1 < Cf < 3) for Pb and considerable (3 < Cf < 6) for Ni and Cu. Very high contamination (Cf > 6) was obtained for Cd in all sites. The pollution load index (Table 6) revealed that values of each of the sites were greater than 1; this is an indication that the studied sites have been severely contaminated.

Ecological risk assessment

The ecological risk assessment results are presented in Table 7. It was observed that the value of E_r^i for Cr, Mn, Cu and Pb were below 40, consequently signifying low potential ecological risk. However, the E_r^i values observed for Cd (390.90–562.50) were within the very high potential ecological risk, indicating Cd poses a potential risk to the environment. The potential ecological risk value of Cd observed in this study is greater than values reported by Sadick et al. (2016) and Orji et al. (2018), but lower than the value of Pd (122.20) reported by Sadick et al. (2016). Overall, E_r^i of the trace metals were sorted in declining order of Cd > Cu > Ni > Pb > Cr > Mn. The calculated ecological risk index (R_i) values for soil are classified under the high to serious ecological risk. The contribution to the overall potential ecological risk shows that cadmium contributed 88–92% of the total potential ecological risk in the premeditated sites.

Health risk assessment

Tables S1 and S2 present the values of ADDs for non-carcinogenic and carcinogenic respectively. The estimated values of hazard quotient (HQ), hazard index (HI) and cancer risk (CR) of the trace metals for both children and adults via (ingestion, inhalation and dermal contact) are presented in Tables 8 and 9 for non-carcinogenic and carcinogenic respectively. The exposure pathways for the ADDs of the trace metals are in the order of ingestion > dermal > inhalation in Table S1. The higher ADD values of metal dosage via ingestion are in line with similar studies earlier reported (Ihedioha et al. 2016; Adewale et al. 2019; Taiwo et al. 2020; Henry et al. 2021).

The HQ_{ing} values for both children and adults are in the following order Pb > Cd > Ni > Mn > Cu > Cr. HQ_{inh} for both children and adult was Pb > Mn > Cd > Cr > Ni > Cu, while HQ_{derm} followed the order of Cd > Pb > Cu > Cr > Ni > Mn. The estimated HQ declined in the order of ingestion > dermal contact > inhalation. This indicated that the ingestion pathway might pose a considerable risk compared with dermal and inhalation pathways. It has been reported that the ingestion pathway resulted in higher levels of risk exposure to soil compared with dermal contact with inhalation being the least (Van den Berg 1995).

The HI values were observed for all the metals in children (1.92×10^{-1} to 5.41×10^{0}) and adults (2.41×10^{-2} to 7.69×10^{-1}) for ingestion, children (5.80×10^{-5} to 1.27×10^{-3}) and adult (2.90×10^{-5} to 6.24×10^{-4}) for inhalation, and children (1.37×10^{-2} to 4.34×10^{-1}) and adult (2.97×10^{-3} to 9.20×10^{-2}) for dermal contact. Generally, values obtained for children were higher than those of adults. The HI values for inhalation and dermal pathways were < 1, which implies little or no probable adverse non-carcinogen effect observed, while the ingestion pathway was > 1 for children, but > 1 for adults, indicating non-carcinogenic effects for children. Among the metals, Cd contributed 32 to 33% and Pb 48 to 51% of the

Table 7 Potential ecological risk factor (E_r^i) and risk index (R_i) values of soil samples

Locations	Potential ecological risk factor *Eir*						Ri	Risk grade
	Cr	Mn	Cu	Ni	Cd	Pb		
A	0.22	0.047	21.35	19.80	562.50	7.25	611.10	Serious ecological risk
B	0.10	0.054	21.35	18.10	395.70	7.15	442.45	High ecological risk
C	0.20	0.069	23.75	18.70	390.90	7.95	441.57	High ecological risk
D	0.55	0.063	23.35	18.30	412.80	7.70	462.18	High ecological risk
E	0.11	0.064	25.50	18.05	450..00	7.45	501.17	High ecological risk
F	0.13	0.045	24.20	18.25	498.90	7.45	548.98	High ecological risk
CS	0.002	0.002	0.45	0.36	8.64	0.08	9.53	Low ecological risk

Table 8 Non-carcinogenic hazard quotient and hazard index values of trace metals in soil via ingestion inhalation and dermal contact

Locations	Pathways	Children							Adults						
		Cr	Mn	Cu	Ni	Cd	Pb	HI	Cr	Mn	Cu	Ni	Cd	Pb	HI
A	HQing	1.34E-01	3.20E-02	2.53E-01	4.56E-01	1.97E+00	2.31E+00	5.15E+00	1.68E-01	4.00E-03	3.15E-02	5.70E-02	2.46E-01	2.89E-01	7.69E-01
	HQinh	5.17E-05	3.86E-04	9.28–07	1.63E-06	7.24E-05	4.95E-04	1.00E-03	2.59E-05	1.93E-04	4.65E-07	8.11E-07	3.62E-05	2.48E-04	5.04E-04
	HQderm	2.22E-02	2.03E-03	2.78E-02	5.57E-03	3.25E-01	5.12E-02	4.34E-01	4.70E-03	4.31E-04	5.89E-03	1.18E-03	6.90E-02	1.18E-04	9.20E-02
B	HQing	1.14E-01	3.57E-02	2.53E-01	4.16E-01	1.39E+00	2.03E+00	4.24E+00	1.14E-02	4.61E-03	3.18E-02	5.20E-02	1.73E-01	2.85E-01	5.58E-01
	HQinh	4.41E-05	4.45E-04	9.30E-07	1.49E-06	5.10E-05	4.44E-04	1.03E-03	2.20E-05	2.23E-04	4.65E-07	7.43E-07	2.56E-05	2.45E-04	5.17E-04
	HQderm	1.88E-02	2.34E-03	2,82E-02	5.09E-03	2.29E-01	5.01E-02	3.03E-01	4.00E-03	4.98E-04	5.90E-03	1.08E-03	4.86E-02	9.00E-05	7.08E-02
C	HQing	2.19E-01	4.67E-02	2.80E-01	4.31E-01	1.37E+00	2.57E+00	4.92E+00	2.74E-02	5.83E-03	3.53E-02	5.15E-02	1.71E-01	3.17E-01	6.08E-01
	HQinh	8.46E-05	5.64E-04	1.03E-06	1.54E-06	5.04E-05	5.45E-04	1.25E-03	4.23E-05	2.82E-04	5.18E-07	7.67E-07	2.52E-05	2.73E-04	6.24E-04
	HQderm	3.62E-02	2.96E-03	3.09E-02	5.26E-03	2.26E-01	5.60E-02	3.55E-01	7.68E-03	6.28E-04	6.56E-03	1.12E-03	4.80E-02	1.19E-02	2.79E-02
D	HQing	2.78E-01	4.30E-02	2.75E-01	4.21E-01	1.47E+00	2.47E+00	4.96E+00	3.47E-02	5.37E-03	3.45E-02	5.25E-02	1.81E-01	3.14E-01	5.60E-01
	HQinh	1.07E-04	5.19E-04	1.02E-06	1.50E-06	5.32E-05	5.28E-04	1.27E-03	5.38E-05	2.60E-04	5.08E-07	7.52E-07	2.66E-05	2.65E-04	6.07E-04
	HQderm	4.60E-02	2.78E-03	3.04E-02	5.15E-05	2.39E-01	5.43E-02	3.78E-01	9.75E-03	5.82E-04	6.44E-03	1.09E-03	5.10E-02	1.15E-02	8.04E-02
E	HQing	1.17E-01	4.41E-02	3.00E-02	4.20E-01	1.58E+00	2.42E+00	4.60E+00	1.46E-02	5.50E-03	3.75E-02	5.2-E-02	1.92E-01	3.00E-01	6.02E-01
	HQinh	4.51E-05	5.32E-04	1.11E-06	1.48E-06	5.80E-05	5.15E-04	1.16E-03	2.25E-05	2.66E-04	5.53E-07	7.43E-07	2.90E-05	2.58E-04	6.02E-04
	HQderm	1.92E-02	2.80E-03	3.31E-02	5.09E-03	2.00E-01	5.30E-02	3.73E-01	4.08E-03	5.94E-04	7.03E-03	1.08E-03	5.52E-02	1.12E-02	7.92E-02
F	HQing	1.43E-01	3.09E-02	2.85E-01	4.18E-01	1.75E+00	2.78E+00	5.41E+00	1.74E-02	3.85E-03	3.58E-02	5.25E-02	2.20E-01	2.97E-01	6.27E-01
	HQinh	5.52E-05	3.71E-04	1.05E-06	1.50E-06	6.42E-05	5.10E-04	1.00E-03	2.76E-05	1.86E-04	5.25E-07	7.48E-07	3.22E-05	2.55E-04	5.02E-04
	HQderm	2.37E-02	1.97E-03	3.15E-02	5.13E-03	2.89E-01	5.22E-02	4.04E-01	5.17E-03	4.14E-04	6.68E-03	1.09E-03	6.12E-02	1.11E-02	8.57E-02
CS	HQing	6.17E-03	4.24E-03	1.07E-02	1.65E-02	1.02E-01	5.28E-02	1.92E-01	7.77E-04	5.28E-04	1.34E-03	2.06E-03	1.28E-02	6.63E-03	2.41E-02
	HQinh	2.45E-06	5.29E-05	4.08E-08	6.07E-08	2.34E-06	2.00E-07	5.80E-05	1.24E-06	2.64E-05	2.04E-04	3.04E-08	1.17E-06	1.00E-07	2.90E-05
	HQderm	1.03E-03	2.69E-04	9.33E-04	2.02E-04	1.01E-02	1.17E-03	1.37E-02	2.18E-04	5.69E-05	2.51E-04	4.28E-05	2.15E-03	2.48E-04	2.97E-03

Table 9 Cancer risk values of trace metals in soil through ingestion, inhalation and dermal contact

Locations	Pathways	Children				Adults			
		Cr	Ni	Cd	Pb	Cr	Ni	Cd	Pb
A	CRing	2.02E−04	1.55E−02	1.48E−02	6.88E−05	2.52E−05	1.94E−03	1.85E−02	8.59E−06
	CRinh	6.22E−08	2.81E−08	2.29E−08	8.27E−10	3.11E−08	1.40E−08	1.14E−08	6.26E−10
	CRderm	9.96E−05	3.83E−02	-	3.36E−05	1.69E−05	8.12E−03	-	7.14E−06
B	CRing	1.72E−04	1.41E−02	1.04E−02	6.77E−05	2.10E−05	1.77E−03	1.30E−03	8.21E−06
	CRinh	5.29E−08	2.57E−08	1.61E−08	1.23E−09	2.65E−08	1.28E−08	8.06E−09	6.17E−10
	CRderm	6.78E−05	3.50E−02	-	3.31E−05	1.44E−05	7.44E−03	-	7.01E−06
C	CRing	3.29E−04	1.47E−02	1.03E−02	7.57E−05	4.12E−05	1.84E−03	1.28E−03	9.44E−06
	CRinh	1.02E−07	2.66E−08	1.59E−08	1.37E−09	5.08E−08	1.33E−08	7.94E−09	6.89E−10
	CRderm	1.30E−04	3.62E−02	-	3.70E−05	2.76E−05	7.69E−03	-	7.85E−06
D	CRing	4.18E−04	1.43E−02	1.10E−02	7.74E−05	5.20E−05	1.79E−03	1.36E−03	9.18E−06
	CRinh	1.29E−07	2.60E−08	1.68E−08	1.33E−09	6.47E−08	1.30E−08	8.38E−09	6.68E−10
	CRderm	1.65E−04	3.54E−02	-	3.59E−05	3.50E−05	7.52E−03	-	7.60E−06
E	CRing	1.75E−04	1.41E−02	1.18E−02	7.16E−05	2.19E−05	1.77E−03	1.48E−03	8.93E−06
	CRinh	5.42E−08	2.57E−08	1.83E−08	1.30E−09	2.70E−08	1.29E−08	9.14E−09	6.51E−10
	CRderm	6.92E−05	3.50E−02	-	3.50E−05	1.47E−05	7.44E−03	-	7.43E−06
F	CRing	2.15E−04	1.43E−02	1.31E−02	7.07E−05	2.69E−05	1.76E−03	164E−03	8.84E−06
	CRinh	6.64E−08	2.60E−08	2.03E−08	1.29E−09	3.32E−08	1.29E−08	1.01E−08	6.43E−10
	CRderm	8.52E−05	3.54E−02	-	3.46E−05	1.81E−05	7.48E−03	-	7.35E−06
CS	CRing	5.35E−05	1.40E−04	1.15E−04	3.94E−07	2.69E−05	7.00E−05	5.75E−05	1.97E−07
	CRinh	1.71E−08	2.63E−10	1.83E−10	7.39E−12	5.26E−08	5.26E−10	3.67E−05	1.48E−11
	CRderm	2.12E−05	3.46E−04	-	1.93E−07	1.80E−05	2.93E−04	-	1.63E−07

HI ingestion in children. Cadmium causes both persistent poisoning and acute, adverse health effect on the liver, kidney, immune and vascular system (Heyes 1997; Jurowski and Krósniak 2022), and lead exposures in early childhood and prenatally can cause low cognitive advancement, learning deficits and numerous other sound effects (Maobe et al. 2012). The high content of Cd obtained could be a result of the dumping of nickel–cadmium batteries at auto mechanic workshops (Ebong et al. 2008; Anegbe et al. 2019). The ingestion of tiny particles in greater doses could pose more impacts on children due to their body weight which is smaller than adults (Kormoker et al. 2019). The HI obtained in this study was higher than the values reported for adults (1.44×10^{-4} to 2.77×10^{-2}) in Asafo auto-mechanic workshop in Kumasi, Ghana (Joyce et al. 2021).

The estimated cancer risk (CR) for both children and adults as presented in Table 9 are (1.97×10^{-7} to 1.85×10^{-2}), ($1.48\times10^{-}11$ to 6.64×10^{-8}) and (1.63×10^{-7} to 3.85×10^{-2}) for ingestion, inhalation and dermal pathways respectively. The CR for ingestion and dermal pathways exceeded the threshold value (1×10^{-6} to 1×10^{-4}) suggesting possible cancer development. The higher CR value of the ingestion pathway obtained in the present study is similar to trends reported in the previous studies (Taiwo et al. 2017; Praveena and Aris 2018; Adewale et al. 2019). The order of the metal contribution to CRs was Ni > Cd > Cr > Pb for children and Cd > Ni > Cr > Pb for adults.

Conclusion

Assessment of pollution profile of trace metals in soils of auto mechanic workshops in Gombe, Nigeria was evaluated using pollution indices (geo-accumulation index, contamination factor, pollution load index), ecological and health risk assessment. The mean concentrations of Cu, Ni, Cd, and Pb in the soil were above the DPR target values for metals in Nigerian soils. The relative abundance decreased in the order of Cu > Ni > Pd > Mn > Cd > Cr. The pollution index outcome reveals the extremely polluted levels of metal pollution in soil, and the result of the ecological risk assessment implies that the sediments were within the high to serious ecological risk class, and Cd contributed 88–92% of the total potentially ecological risk. The health risk of ADD and HQ followed a similar sequence of ingestion > dermal contact > inhalation for adults and children. The HI values for inhalation and dermal pathways were < 1, which implies little or no probable adverse non-carcinogen effect observed, while the ingestion pathway was > 1 for children, but > 1 for adults, indicating non-carcinogenic effects for children. The CR for ingestion and dermal pathways exceeded the

threshold value (1×10^{-6} to 1×10^{-4}) indicating possible cancer development. The study also revealed that Cd and Pb were the main contributors to carcinogenic effects.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12517-022-10833-9.

Declarations

Conflict of interest The authors declare no competing interests.

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