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Ecological and human risk assessments of heavy metal contamination of surface soils of auto-mechanic shops at Bogoso Junction, Tarkwa, Ghana

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Abstract There is a growing recognition that activities at automobile mechanic shops could contribute to heavy metal contamination of soils. This study seeks to evaluate the ecological and human risk assessments of heavy metal contamination of surface soils of auto-mechanic shops at Bogoso Junction, Tarkwa, Ghana. Herein, 20 composite soil samples were taken, acid-digested, and the concentrations of Cu, Pb, Cd, Mn, Ni, Cr, and Fe were measured using a flame atomic adsorption spectrometer (SHIMADZU, AA 7000). Appraising metal pollution indices, the potential human and ecological risks associated with analyzed metals were carried out. Findings of the present study indicate that the levels of analyzed metals of soils exceeded the control soil sample and the European Union standards for soil quality. The mean metal concentration increased in the order Fe > Mn > Cu > Ni > Pb > Cr > Cd in the soils. Outcomes of enrichment factor, geo-accumulation index, and contamination factor revealed that the soil quality is deteriorated with Cu, Pb, and Cd. The potential ecological risk identified Cd and Pb as the richest elements and offered a high ecological risk in all sampling sites. Furthermore, hazard quotient of analyzed metals depicted that Ni and Mn in urban soils of Bogoso Junction automobile mechanic shops may pose a threat to children (HI > 1). Dermal contact and inhalation of soil particles are the main exposure routes for children susceptibility. Specifically, cancer risk associated with Cd inhalation was 10 times greater than oral ingestion of Pb, showing a relatively high carcinogenic hazard to humans. Altogether, artisanal activities such as engine repair, welding and soldering, vehicle overhauling, and oil exchange at the automobile mechanic shops could deteriorate the soil quality resulting in ecological and human health implications within the vicinity of automobile mechanic shops in Ghana.

Keywords Auto-mechanics · Cancer risk · Ecological risk · Heavy metal · Health risk · Soil quality

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Introduction

Soil is widely considered a significant repository for most environmental insults, such as trace metals, resulting from various lithogenic and human influences (Bauvais et al., 2015). The heavy metal profile of rural and urban topsoil has become more relevant as urbanization and industrialization have progressed (Agyemang et al., 2022). This supposition is because most urban communities are usually characterized by anthropogenic activities including, but not limited to, metals scrapping, sludge dumping, metal smelting, and untreated solid waste disposal (Wu et al., 2018). Due to metals' persistence and non-degradable nature in the milieu, metals in soils bio-accumulate in the biota and biomagnify in the food chain, thereby becoming detrimental to both wildlife and public health (Tóth et al., 2016). Automobile shops have received a lot of attention in developing nations like Ghana as contributors to heavy metal pollution of soils in metropolitan areas. The hypothesis is based on the fact that the wastes (metal scraps, used batteries, worn-out vehicle parts, etc.) generated from auto-mechanic shops are dumped indiscriminately into the environment (Rabe et al., 2018). Also, in the urban vicinities, the sitting of vehicle shops is frequently observed as clusters of open ground (Ihedioha et al., 2017). In Ghana, studies have reported the occurrence of trace metals and some toxic metals such as lead (Pb), arsenic (As), and cadmium (Cd) in urban soils of automobile villages (Gyan & Ofosu, 2016; Appiah-Adjei et al., 2019; Agyemang et al., 2022; Asamoah et al., 2021). Hence, soils within the locale of automobile artisans are significant sinks for heavy metals and could be used to monitor the environment's integrity about its ecological and human health risks (Kormoker et al., 2019).

Noteworthily, the type of metal pollutant and the extent of pollution are greatly influenced by the nature of the human activities within the vicinity (Chen et al., 2021). However, a plethora of studies have indicated that metal-contaminated soils contribute to heavy metal exposure to humans, and the etiology of myriad disease outcomes in human populations has been associated (Cai et al., 2019). For example, prolonged exposures to metal-contaminated soils resulted in damaging effects on the mammalian central nervous system (Chen et al., 2016). Furthermore, the US Environmental Protection Agency (USEPA) has designated Cr, Pb, Cu, Zn, and Ni as priority control pollutants (Chen et al., 2016). In practice, ecological risk assessments of heavy metals in soils are centered on indices such as enrichment factor, geo-accumulation index, and comprehensive pollution index, all of which take into consideration the relative measure of the metal level of the soil to a reference value (Sun et al., 2010). Furthermore, heavy metal–contaminated soils in metropolitan areas may enter the human body directly or indirectly through oral intake, skin contact, and inhalation of soil particles, resulting in carcinogenic and non-carcinogenic consequences (Wu et al., 2015). Therefore, the probable health risk implications to humans via the possible routes of exposure to metals in urban soils warrant significant attention.

Tarkwa (05° 18′ 00″ N; 01° 59′ 00″ W) is located in the southwestern part of Ghana. Tarkwa is the largest city in the Tarkwa-Nsuaem municipality, with an estimated population of 90,477 (Ghana Statistical Service, 2014). Mining activities and other commercial activities primarily mark Tarkwa city. As an emerging industrial city, Tarkwa is prone to soil contaminants including heavy metal. Although a few studies have reported the levels of heavy metal contamination in agricultural soils (Bortey-Sam et al., 2015a, 2015b), the metal pollution profile and its eco-environmental risk susceptibilities, especially at artisanal sittings, remain vague. For the past two decades, the Bogoso Junction auto-mechanic village has served as a hub for several mechanic garages in Tarkwa. Numerous artisanal activities such as metal welding, vehicle maintenance and fabrication, and engine servicing are predominant. Despite this menace, there is a dearth of information on the pollution profile, ecological risk, and the health implication of heavy metals to biota. Herein, the present study seeks (1) to determine the concentrations of Cu, Pb, Cd, Mn, Ni, Cr, and Fe in the soil; (2) to estimate the pollution profile of the analyzed metals in surface soil and the potential ecological risk at the Bogoso Junction; and (3) to evaluate the plausible health risks associated with analyzed metals through the three possible exposure routes.

Materials and methods

Description of the study area

Bogoso Junction is located in the northern part of Tarkwa, stretching on latitude 5° 19′ N and longitude 1° 58′ E, joining the Tarkwa Agyempoma (also known as the Tarkwa-Abosso road). The area is approximately 545,120.24 square meters (m^2) and about 4.6 km (km) from the University of Mines and Technology (UMaT), Tarkwa, as depicted in Fig. 1. Bogoso Junction has a population of about 1000 people engaged in different trades in the area. As several hundreds of vehicles

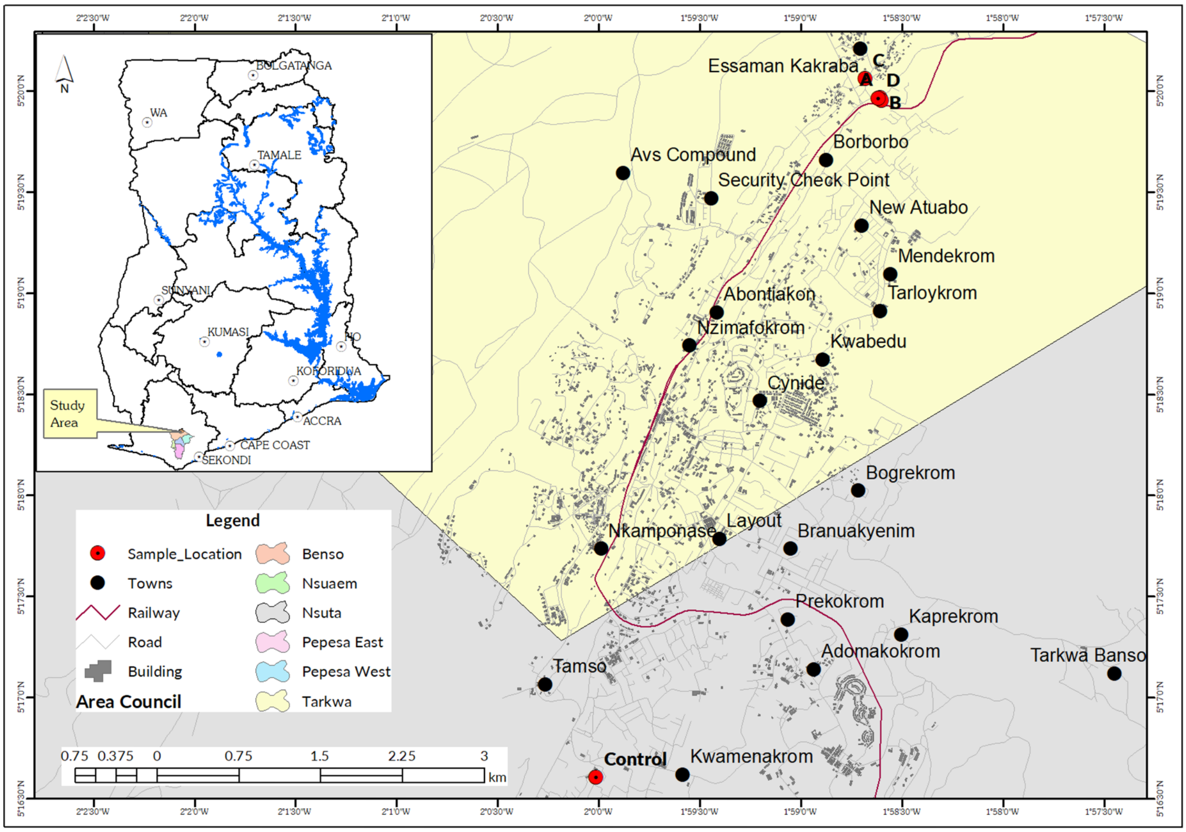

Fig. 1 Map of the study area showing the sampling points

plough the Bogoso-Tarkwa and Tarkwa Agyempoma roads, at least a hundred vehicles are serviced in a day in these garages. Activities including, but not limited to, metal welding, vehicle maintenance and fabrication, and disposal of used batteries as well as metal waste at the study site could contribute to metal levels of surface soils. Generally, in the Tarkwaian system, intrusive rocks contribute to about 20% of the total thickness. These rocks range from hypabyssal felsic to basic igneous rocks (Kuma, 2004).

Sampling

The study location was divided into four (4) zones (zones A–D), each of which was divided into five grids. Twenty (20) composite samples of surface soils were collected from the four sampling zones ($n=5$, from each zone), at depths of 0–10 cm, in June 2021, using a soil depth–calibrated auger. It is worth stating that the rationale for the zones is to have a representative sample of the entire area, with no attribute to specific activities. The sitting of shops is scattered, and similar artisanal activities go on in the various sampling zones. Within the study area, soil samples were taken from garages, fuel-filling stations, petty trading shops, scrap yards, areas of residence, and restaurants. Soil samples within a zone were then mixed, from which a representative sample was obtained for a zone. The composite soil samples were kept in separate zip-mouthed polythene bags, labeled, and sent to the University of Mines and Technology (UMaT) Tarkwa laboratory for further analyses. Because of the dearth of data on the background concentrations of metals in soils at auto-mechanic shops in Tarkwa, the same sampling procedure was employed to obtain soil samples from the UMaT campus to serve as a reference value on which the metal pollution at the study site could be assessed, because the activities that take place in the study area are not present on the UMaT campus. Five sampling ($n=5$) were taken from the control site. All soil samples collected were stored at room temperature at the Environmental and Safety Laboratory of the UMaT, following standard protocols to keep samples' integrity.

Sample pretreatment and analysis

At room temperature, soil samples were air-dried for 2 weeks and passed through a 2-mm mesh sieve to remove relatively larger pebbles from the dried samples. Clumps dried soils were subjected to mortar and pestle pulverization, sieved and kept in clean Ziploc bags, and identified accordingly. For soil characterization, soil pH and electrical conductivity (EC) were measured after preparing a soil–water suspension (1:2.5 (w/v)), which was allowed for an equilibrium time of about 30 min. The soil pH was determined using a calibrated Hanna 909 pH meter (buffer solution of pH 4.2 and 7). The EC of the soil samples was also evaluated using the prepared soil/water ratio and a calibrated PHWE EC meter which was calibrated with 1413 µS/cm KCl solution. For heavy metal analysis of soil, 1.0 g of soil samples was acid-digested using aqua regia (1:3 HNO_3:HCl) in a mixture of 10 mL nitric acid (HNO_3; 65%) and 30 mL hydrochloric acid (HCl; 65%). After cooling, the resulting solution was filtered using ashless filter paper 5B (Advantec, Tokyo, Japan). The filtered solution was standardized to 50 mL using distilled water. Reagent blank was prepared accordingly and every experiment was set in replicates of three, and kept at 4 ℃ until needed for analysis. Cu, Pb, Cd, Mn, Ni, Cr, and Fe contents of soils were measured using a flame atomic adsorption spectrometer (SHIMADZU AA 7000). The concentrations of the various heavy metals were expressed in mg/kg dry weight (dw).

Analytical performance

Reagents of analytical grade were purchased from Sigma-Aldrich, St. Louis. After every ten sample analyses, blanks were tested for quality control. For technique validation, SRM 1944 (New York Waterway sediment) was employed as a reference sample. The accuracy of replicate analyses of reference material was good (relative standard deviation (RSD) ≤ 4%), with recovery rates ranging from 85 to 115% (Table S1).

Classifications of heavy metal pollution indices

After measuring the heavy metal levels of soils in each zone, A–D, the mean concentrations of each metal were used to appraise the metal pollution levels as well as the degree of contamination at the Bogoso Junction automobile mechanic workshops. In principle, the extent to which surface soils are contaminated could be evaluated by a direct comparison of site-specific data to the existing background values, or pollution indices (Asamoah et al., 2019). The measured concentrations of heavy metals of soils were also compared with the European Union standard as reported by Hong et al. (2014). The degree of contamination of soils was assessed by using indices such as enrichment factor (EF), contamination factor (CF), pollution load index (PLI), and geo-accumulation index (I_{geo}), using Eqs. (1) to (5) and their respective classifications.

Enrichment factor

$$EF = \frac{C(\text{sample}) \times \text{Fe(background)}}{C(\text{background}) \times \text{Fe(sample)}} \tag{1}$$

where C represents the mean metal concentration, and Fe is the shale element. Iron was selected as a stationary reference element because Fe is naturally abundant in soil (Schropp et al., 1990). EF grouping by Birch (2003) is presented in Table 1.

Contamination factor and degree of contamination (C_d)

$$CF = \frac{C(\text{sample})}{C(\text{background})} \tag{2}$$

where C_{sample} is the concentration of metal in soils from the study site and $C_{\text{background}}$ is the background concentration in the soil sample of UMaT. The classification was based on Muller (1969), depicted in Table 1. $C_d = \sum_{i=1}^{n} CF_i$ where, CF is the contamination factor. According to Hakanson (1980): $C_d < 8$ (low degree of contamination); $8 \leq C_d < 16$ (moderate degree of contamination); $16 \leq C_d < 32$ (considerable degree of contamination); $C_d > 32$ (high degree of contamination).

Geo-accumulation index (I_{geo})

$$I_{\text{geo}} = \log_2 C_n / 1.5B_n \tag{3}$$

Table 1 Classifications of heavy metal pollution indices and ecological risk of soils

Enrichment factor (EF)[a]		Contamination factor (CF)[b]		Geo-accumulation index (I_{geo})[b]		Ecological risk (E^i_r) [c]		Risk index (RI)[c]	
EF < 1	No enrichment	CF < 1	Low degree contamination	$I_{geo} < 0$	Uncontaminated	$E^i_r < 40$	Low risk	RI ≤ 150	Low
EF < 3	Minor enrichment	1 ≤ CF < 3	Moderate degree contamination	$0 \leq I_{geo} < 1$	Uncontaminated to moderately contaminated	$40 \leq E^i_r < 80$	Moderate risk	150 < RI ≤ 300	Moderate
3 ≤ EF < 5	moderate Enrichment	3 ≤ CF < 6	Considerable degree contamination	$1 \leq I_{geo} < 2$	Moderately contaminated	$80 \leq E^i_r < 160$	Considerable risk	300 < RI ≤ 600	Considerable
5 ≤ EF < 10	Moderately severe enrichment	CF ≥ 6	Very high degree contamination	$2 \leq I_{geo} < 3$	Moderately to heavily contaminated	$160 \leq E^i_r < 320$	High risk	RI > 600	Very high
10 ≤ EF < 25	Severe enrichment			$3 \leq I_{geo} < 4$	Heavily contaminated	$E^i_r \geq 320$	Extremely high risk		
25 ≤ EF < 50	Very severe enrichment			$4 \leq I_{geo} < 5$	Heavily to extremely contaminated				
EF ≥ 50	extremely severe Enrichment			$I_{geo} \geq 5$	Extremely contaminated				

[a]Classification is according to Birch (2003)
[b]Classification is according to Muller (1969)
[c]Classification is according to Hakanson (1980)

where C_n and B_n depict the concentration of a metal of the soil sample and its geochemical background concentration, respectively. For variations in background concentrations of metals due to lithogenic effect, 1.5 is used as a compensatory factor (Asare et al., 2019). The seven (7) classification scale for I_{geo} (Muller, 1969) is presented in Table 1.

Pollution load index

$$PLI = (CF1 \times CF2 \times CF3 \dots \dots \dots .. \times CFn)^{1/n} \quad (4)$$

where n is the number of metals under study and CF is the contamination factor of the measured metals. Polluted site as perfection (PLI = 0); pollution present for only baseline levels (PLI = 1); and progressive deterioration site (PLI > 1) (Islam et al., 2015).

Potential ecological risk

The potential ecological risk index (RI) is widely used as an indicator to ascertain the ecological risk a metal could pose in the lithosphere (Asamoah et al., 2021; Bortey-Sam et al., 2015a). Therefore, the following equations (Eq. (5) and Eq. (6)) were used to evaluate the RI of the measured metal levels of soils at the Bogoso Junction auto-mechanic shops.

$$E_r^i = T_r^i X C_f^i \quad (5)$$

$$RI = \sum_{i=1}^{n} E_r^i \quad (6)$$

where E_r^i is the potential risk of the individual metals; T_r^i is the toxic response factors for the metals (Cu = 5, Cd = 30, Cr = 2, Ni = 2, Pb = 5) (Hakanson, 1980); C_f^i is the contamination factor; and RI is the risk index for combined metals in the soil. The $E^i{}_r$ and RI classifications are shown in Table 1.

Risks assessments of metal levels of soils

The study adopted health risk indices to evaluate the probable adverse effects of analyzed metals in the soils on humans upon exposure.

Health risk assessment

The indices for measuring the intensity and duration of human exposure to an environmental pollutant, such as heavy metals in soils, include hazard discrimination, exposure evaluation, and risk characterization (Kamunda et al., 2016; Wang et al., 2011). The possible exposure risks of metal levels to human at the Bogoso Junction auto-mechanic shops were evaluated according to the US Department of Energy model (USDoE) (USDoE, 2011). About the probabilistic effects to metal levels, carcinogenicity and non-carcinogenicity risks were estimated for children and adults following three exposure routes: oral ingestion (CDI_{ing}); dermal absorption of metals in soil adhered to the exposed skin (CDI_{dermal}); and inhalation of resuspended soil particles via nose or mouth (CDI_{inh}). According to the USDoE model, exposure dose for non-carcinogenic effects was estimated for children only, whereas carcinogenic risk was considered a lifetime exposure, thus estimated for children and adults' exposure. The exposure dose (chronic daily dose, CDI) was estimated using Eq. (7) to Eq. (12). Of note, for each heavy metal, the concentration used for the health risk assessments is the mean value of the four sampled zones (A–D). Table 2 presents the standard values and definitions of parameters.

Exposure assessment for non-carcinogenicity

$$\mathrm{CDI}_{\mathrm{ingestion-nc}} = \frac{C_m \times \mathrm{OSIR_c} \times \mathrm{ED_c} \times \mathrm{EF_C} \times \mathrm{ABS}}{\mathrm{BW_c} \times \mathrm{AT_{nc}}} \times 10^{-6} \quad (7)$$

$$\mathrm{CDI}_{\mathrm{dermal-nc}} = \frac{C_m \times \mathrm{SAE_c} \times \mathrm{SSAR_c} \times \mathrm{ED_c} \times \mathrm{EF_c} \times \mathrm{E_v} \times \mathrm{ABS}}{\mathrm{BW_c} \times \mathrm{AT_{nc}}} \times 10^{-6} \quad (8)$$

$$\mathrm{CDI}_{\mathrm{inhalation-nc}} = \frac{C_m \times \mathrm{PM10} \times \mathrm{DAIR_C} \times \mathrm{PIAF} \times (\mathrm{fspo} \times \mathrm{EFO_c} \times \mathrm{fspi} \times \mathrm{EFI}_c)}{\mathrm{BW_c} \times \mathrm{AT_{nc}}} \times 10^{-6} \quad (9)$$

Table 2 Definition of terms and reference values of parameters used for exposure assessment of metals in soils

Symbol (units)	Definition	Reference value	
		Child	Adult
OSIR (mg/day)	Oral ingestion rate of soil	200 [a]	100 [a]
ED (year)	Exposure duration	6 [a]	24 [b]
EF (day/year)	Exposure frequency	350 [a]	350 [a]
ABS (−); for non-carcinogenic	Absorption efficiency factor of heavy metal by human via oral ingestion and dermal contact of soil particles	0.001 [c]	0.001 [c]
ABS (−); for carcinogenic	Absorption efficiency factor of heavy metal by human via oral ingestion and dermal contact	0.03 [c]	0.03 [c]
BW (kg)	Average body weight	15.90 [a]	56.80 [b]
AT (day); for non-carcinogenic	Averaging time	2190 [a]	2190 [b]
AT (day); for carcinogenic	Averaging time	26,280 [a]	26,280 [b]
SAE (cm^2)	Surface area of exposed skin	2800 [b]	5800 [b]
SSAR (mg/cm^2)	Skin surface adhesion rate of soil on the body	0.200 [a]	0.07 [a]
Ev (day^{-1})	Frequency of daily event for skin contact with soil	1.00 [a]	1.00 [a]
PM10 (mg/m^3)	Concentration of inhalable particulate matter in air	0.15 [a]	0.15 [a]
DAIR (m^3/d)	Daily air inhalation rate	7.50 [a]	15.0 [a]
PIAF (−)	Retention ratio of soil particles in human body through inhalation	0.75 [a]	0.75 [a]
fspo (−)	Fraction of soil particles in indoor	0.50 [a]	0.50 [a]
fspi (−)	Fraction of soil particles in outdoor	0.80 [b]	0.80 [b]
EFO (day/year)	Outdoor exposure frequency	87.50 [a]	87.50 [a]
EFI (day/year)	Indoor exposure frequency	262.50 [a]	262.50 [a]
SAF (−)	Soil allocation factor of reference dose for heavy metals	0.20 [a]	0.20 [a]

[a]Values according to USDoE (2011)
[b]Values according to MEP (2014)
[c]Values according to USEPA (2012)

Carcinogenic effect (lifetime)

$$CDI_{ingestion-ca} = \left(\frac{OSIR_c \times ED_c \times EF_C}{BW_c} + \frac{OSIR_a \times ED_a \times EF_a}{BW_a}\right) \times \frac{C_m \times ABS_o}{AT_{ca}} \times 10^{-6} \quad (10)$$

$$CDI_{dermal-ca} = \left(\frac{SAE_c \times SSAR_c \times ED_c \times EF_c}{BW_c} + \frac{SAE_a \times SSAR_a \times ED_a \times EF_a}{BW_a}\right) \times \frac{C_m \times ABS_d \times E_v}{AT_{ca}} \times 10^{-6} \quad (11)$$

$$CDI_{inhalation-ca} = \left(\frac{DAIR_c \times EFO_c \times EFI_c}{BW_c} + \frac{DAIR_a \times EFO_a \times EFI_a}{BW_a}\right) \times \frac{C_m \times PM10 \times PIAF \times fspo \times fspi}{AT_{ca}} \times 10^{-6} \quad (12)$$

Furthermore, the risk characterization models assume that, even in sensitive populations, there is a limit of exposure below which a detrimental effect will not be demonstrated during a specified exposure period to environmental toxicants (USEPA, 2002). As a result, the dose of reference (R_fD) is considered the threshold amount of toxicant that poses no significant risk of harmful consequences in a population

(USEPA, 2010). In this study, the non-carcinogenic and carcinogenic risks were characterized for both children and adults' exposure to the analyzed metals of soils using their respective R_fD values (presented in Table 3) and the soil allocation factor (SAF; shown in Table 2). Hazard quotient (HQ) is an index used to estimate the non-carcinogenic risk ensuing from chemical exposure. The HQ compares the CDI of a metal to its R_fD, according to Eqs. (13)–(15).

$$HQ_{ingestion} = \frac{CDI_{ingestion-nc}}{RfD_O \times SAF} \quad (13)$$

$$HQ_{dermal} = \frac{CDI_{dermal-nc}}{RfD_d \times SAF} \quad (14)$$

$$HQ_{inhalation} = \frac{CDI_{inhalation-nc}}{RfD_i \times SAF} \quad (15)$$

where RfD_O, RfD_d, and RfD_i denote the R_fD values for oral, dermal, and inhalation, respectively.

Considering exposure to metals through different routes of exposure. The non-carcinogenic effect is an additive effect termed as hazard index (HI) (USEPA, 2010). The HI was calculated using Eq. (16).

$$HI = \sum_{i=1}^{n} H\,Qi \quad (16)$$

where HQi represents the hazard quotient for the ith metal calculated for the various routes of exposure.

Noteworthily, $HI > 1$ indicates that heavy metals have a non-carcinogenic deleterious effect, whereas $HI \leq 1$ indicates that heavy metals have no harmful effect on the exposed population (USEPA, 2013; Wang et al., 2011).

In addition, the carcinogenic effect was estimated by multiplying the CDI for carcinogenic risk (CR) by the cancer slope factor (CSF) of each metal following the respective exposure route, according to the Eqs. (17–19):

$$CR_{ingestion} = CDI_{ingestion-ca} \times CSF_o \quad (17)$$

$$CR_{dermal} = CDI_{dermal-ca} \times CSF_d \quad (18)$$

$$CR_{inhalation} = CDI_{inhalation-ca} \times CSF_i \quad (19)$$

where CSF represents the cancer slope factors for heavy metals. The subscripts *o*, *d*, and *i* denote ingestion, skin contact, and inhalation, respectively; the CSF values are listed in Table 3. In comparison to trivalent chromium (Cr^{3+}), hexa chromium (Cr^{6+}) is more unstable in nature and causes cancer in humans (Kartz & Salem, 1994). Therefore, the reference value of Cr used in the present study, to estimate both carcinogenic and non-carcinogenic effects, is that of Cr^{6+}.

Statistical analysis

SPSS 22.0 (IBM, Chicago, IL, USA) was used to conduct all statistical analyses. Origin 8.0 (Origin Lab Corporation, USA) was used to create graphical representation of data. The Kolmogorov–Smirnov one-sample test and Levene's test were used to check for normality and homogeneity of data variance. A one-way analysis of variance (ANOVA) was used to compare the sample's results to the control group. The significance level was set at $p < 0.05$ in all cases. The data is presented as mean ± standard error (S.E.).

Table 3 Reference doses and cancer risk factors of heavy metals non-carcinogenic and carcinogenic risk assessments of metals in soils

Heavy metal	Reference dose (RfD)			Cancer slope factor (CSF)		
	Oral	Dermal	Inhalation	Oral	Dermal	Inhalation
Pb	3.50×10^{-3}	5.25×10^{-4}	3.52×10^{-2}	8.50×10^{-3}	N/A	4.20×10^{-2}
Fe	7.0×10^{-1}	N/A	N/A	N/A	N/A	N/A
Cu	3.70×10^{-2}	3.70×10^{-2}	N/A	N/A	N/A	N/A
Cd	5.00×10^{-4}	1.00×10^{-5}	5.00×10^{-5}	3.80×10^{-1}	2.00×10^{0}	3.29×10^{2}
Cr	3.60×10^{-3}	6.00×10^{-5}	3.60×10^{-5}	5.00×10^{-1}	-	4.20×10^{1}
Ni	2.00×10^{-1}	5.6×10^{-3}	9.00E−05	1.7×10^{0}	N/A	0.84×10^{0}
Mn	4.60E−02	1.40E−05	2.39E−03	N/A	N/A	N/A

Results and discussion

Physical properties of soil—pH and EC

The soil pH is critical in influencing the mobility and the bioavailability of heavy metals in the soil (Asare et al., 2019). High soil pH (neutral to alkaline) lessens desorption of metals in soils, whereas low pH (acidic) enhances heavy metal mobility (Violante et al., 2010). The pH of soils of the study area ranged from slightly acidic (4.9 ± 0.02) in zone A to slightly neutral (7.2 ± 0.01) in zone D, compared with the control (5.9 ± 0.02) (Fig. 2A). Findings indicate that soils at the Bogoso Junction might have slow mobility of heavy metals, hence the greater tendency of retention to the topsoil. Electrical conductivity (EC) is a measure of inorganic ions present in the soil (Asamoah et al., 2021). While the control soil had an EC value of 151.62 ± 12.03, EC values of 1149.32 ± 21.56, 1169.32 ± 12.32, 1675 ± 56.23, and 1326.31 ± 32.52 were recorded for soils of zones A, B, C, and D, respectively (Fig. 2B). Altogether, results of the soil pH and EC depict that soils at the Bogoso Junction automobile shops have lesser desorption for heavy metals.

Heavy metal concentration of soil

The metal concentrations of soil samples collected from the various sampling zones at the Bogoso Junction automobile shops, as well as the control, are presented in Fig. 3A–G. The concentrations of metals in soils were compared to the European Union standards, as reported by Hong et al. (2014). Noteworthily, the concentration of heavy metal in the control soil samples was below the respective EU recommended values (Fig. 3A–G). This observation indicates that the control sample could be used as a reference for assessing the metal contamination profile of soils of the study area.

In general, the mean concentration of potentially toxic metals analyzed in this study varied from the various zones as depicted in Fig. 3. The variations in metal levels could be attributed to the difference in anthropogenic activities. The mean concentration of Ni recorded in soils from all zones was significantly higher than in the control sample (3.4 mg/kg) (Fig. 3A). Zone A recorded the highest Ni concentration (108.80 ± 10.02 mg/kg), whereas zone D recorded the lowest Ni concentration (70.60 ± 1.05 mg/kg), compared with the EU set value of 75.0 mg/kg. Zone A is characterized by vehicle maintenance, welding and fabrication, and disposal of waste batteries. The highest level of Cr was recorded in zone D ranging from 7.2 to 11.28 mg/kg, with a mean concentration of 10.24 ± 2.05 mg/kg, whereas zone C recorded the lowest concentration (6.92 ± 0.25 mg/kg) of Cr (Fig. 3B). Although the mean level of Cr recorded in soils from all zones was markedly below the EU values (180.0 mg/kg), it exceeded that of the control sample (1.48 mg/kg). Zone C at the study area is well noted for spraying of vehicles which might contribute to the observed levels of Cr. Chromium contamination of soils has been associated with metal plating, dyes and pigment, and anodizing (Asamoah et al., 2021). The levels of Cr recorded in all soil samples within the various zones of Bogoso Junction automobile shops were higher than the mean value 2.40 ± 0.05 mg/kg ($n = 20$) recorded for soils of automechanic shops at Asafo, Kumasi, Ghana (Agyemang et al., 2022). These results indicate that the natural levels of Cr in topsoils of Bogoso Junction automobile shops have been influence by anthropogenic activities such as car body spraying. Soils of zone A had the highest level of Cu (1045.60 ± 33.56 mg/kg),

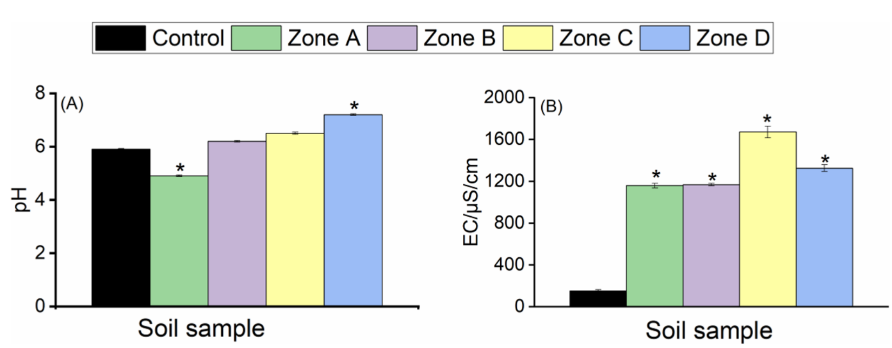

Fig. 2 Characteristics (pH (**A** and electrical conductivity (EC, **B**)) of soils at the various sampling zones (A–D) of Bogoso automobile mechanic shops. Data represented as mean ± standard error ($n = 3$). *Significant difference with the control at $p < 0.05$

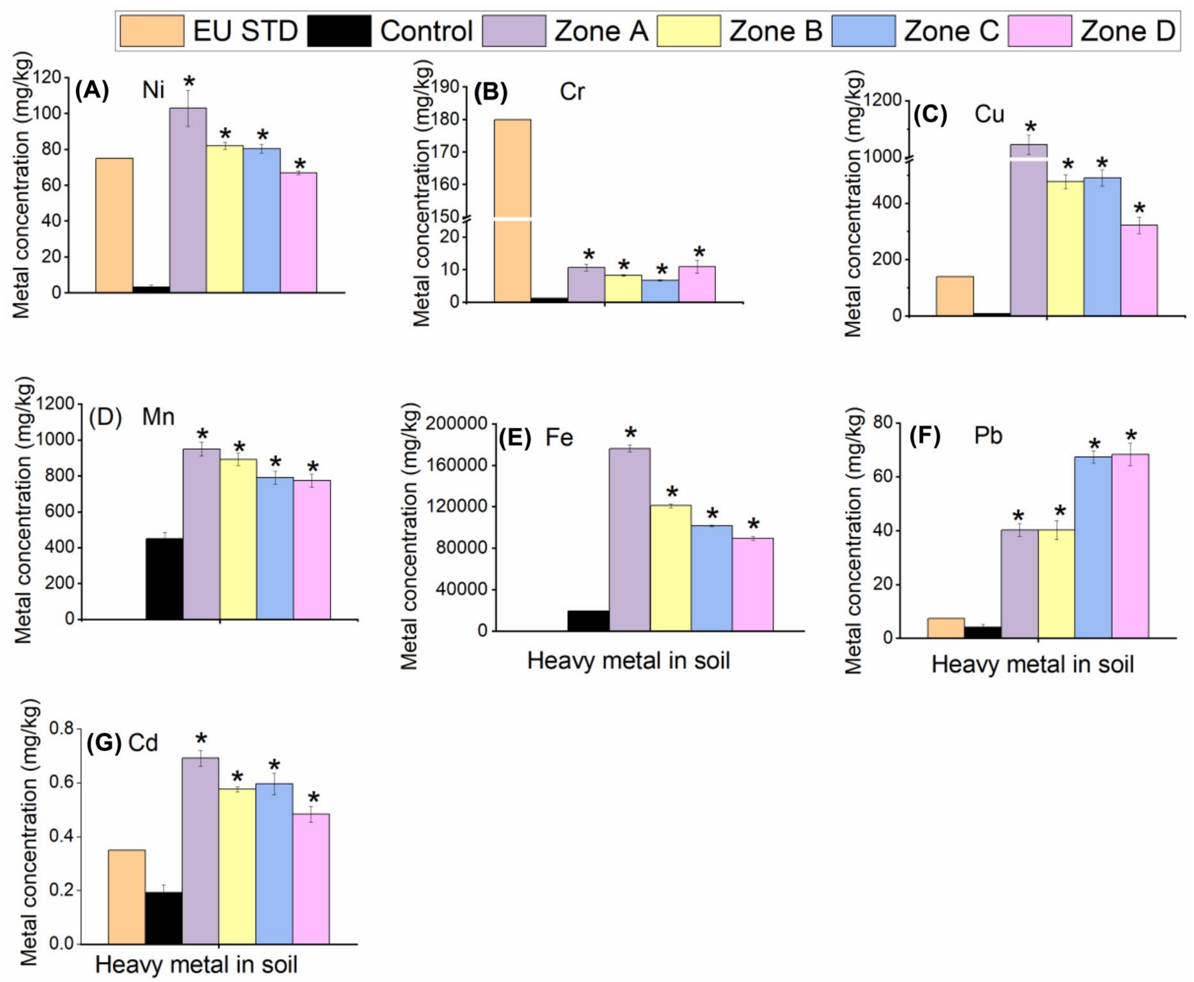

Fig. 3 Mean heavy metal (Ni, Cr, Cu, Mn, Fe, Pb, Cd, **A**–**G** respectively) concentration of soils at the various sampling zones (A–D) of Bogoso automobile mechanic shops. Data represented as mean ± standard error ($n = 3$). *Significant difference with the control at $p < 0.05$

whereas zone D recorded the lowest Cu concentration (322.56 ± 29.84 mg/kg; Fig. 3C). However, levels of Cu in all soil samples were significantly higher than that of the control, and exceeded the EU recommended limit (140 mg/kg). The observed levels of Cu in topsoils of Bogoso Junction automobile shops were higher than the mean values obtained by Akoto et al. (9.67 mg/kg), who investigated the levels of heavy metals at railway servicing workshops in the Kumasi Metropolis (Akoto et al., 2008). Activities such as engine repair, car straightening, and welding carried out at zone A could lead to the relatively high levels of Cu. Soils from zone A recorded the highest mean concentration for Mn (951.48 ± 40.02 mg/kg) with a range of 590–1149 mg/kg. However, zone D recorded the lowest mean Mn concentration (774.48 ± 1.05 mg/kg; Fig. 3D). Noteworthily, levels of Mn of soils in all sample zones were higher compared with the mean value for the control (507.8 ± 35.02 mg/kg). In addition, the mean values of Mn recorded in soils from all sampling zones exceeded the mean value recorded by Asamoah et al. (0.53 mg/kg) of soils at Sunyani Magazine in the Bono region (Asamoah et al., 2021). Although Fe is naturally predominant in the Earth's crust, levels of Fe recorded in soils from all zones were significantly higher than in the control (Fig. 3E). The highest mean Fe concentration (52,084.4 ± 89.53 mg/kg) was recorded in soils of zone A, whereas soils of zone D recorded the lowest Fe concentration (39,031.6 ± 51.05 mg/kg). Despite the possible geogenic source of Fe in soils at Tarkwa, the elevated levels of soils at the study site could be attributed to grinding, metal casting, and welding and fabrication. Noteworthily, the mean Fe levels recorded in soils of the various zones of automobile mechanic shops at Bogoso Junction were higher than those reported from other regions. For example, Fe concentrations ranging from 2050 to 2350 mg/kg of soils from artisanal automobile workshop were reported (Appiah-Adjei et al., 2019). As shown in Fig. 3F, Pb concentrations recorded in the study area exceeded the EU standard for soils (7.2 mg/kg) and were markedly higher than the level recorded in the control (4.57 ± . 0.25 mg/kg). Soil samples of zone D recorded the highest Pb concentration (67.40 ± 4.15 mg/kg) which indicates that the artisanal activities such as soldering and overhauling of vehicle engines carried out might be detrimental to the soil quality. Levels of Cd in soils from all zones exceeded the EU standard for soils (0.35 mg/kg) and were significantly higher than in the control soil sample (0.19 ± 0.03 mg/kg) (Fig. 3G). Soils of zone A recorded the highest mean Cd concentration (0.69 ± 0.03 mg/kg) on a range of 0.47–0.91 mg/kg, whereas soils of zone D recorded the lowest Cd concentration (0.48 ± 1.05 mg/kg) with a range of 0.38–0.75 mg/kg. However, the mean values of Cd in all sampling zones exceeded the EU recommended value of 0.35 mg/kg. Levels of Cd recorded in all sample zones in the present study were lower than the 1.92 mg/kg recoded by Agyemang et al. (2022). Our current findings reveal that vehicle maintenance, welding and fabrication, and the improper disposal of waste batteries could have detrimental effect on the soil quality at Bogoso Junction automobile mechanic shops.

Data of the present study indicate that the quality of soil at the Bogoso Junction is deteriorating by the artisanal activities at the auto-mechanic shops. Although the present study did not compare differences in metal concentrations within the study area, the results evidently reveal that similar artisanal activities are diffused within the automobile sittings at the Bogoso Junction. In assessing the extent to which the artisanal activities have impacted the soil quality, several pollution indices were evaluated.

Principal component analysis

The present study employed PCA to investigate the association among the analyzed metals with their sampling zones. This multivariate tool could help in identifying the possible sources of metal contamination of the soils at the automobile mechanic shops. The component analysis was applied on standardized data through *z*-scale transformation (Kunwar Singh et al., 2004). Three components were extracted with a total variance of 74.36% on eigenvalues greater than 1 (Kaiser Criterion) (Fig. 4a; Table S3a and 3b). As depicted in Fig. 4a, PC1 is explained by high loadings of Ni, Cu, Mn, Pb, and Cd which contributed 35.81% of the total variance. This indicates their possible sources' origination, and their elevated levels could be attributed to similar anthropogenic influences. For example, increased levels of Mn, Pb, and Cd at the study site might result from indiscriminate disposal of waste batteries. PC2 (23.74% variance) and PC3 (14.87% variance) had high positive loadings with Cr (0.86) and Fe (0.79), respectively, indicating their unique source of pollution. The PCA biplot presented in Fig. 4b reveals the association of the analyzed metals with the sampling zones. Current findings show that Cd, Mn, and Ni are closely associated with zone A, which depicts that the activities in zone A such as vehicle maintenance, welding and fabrication, and disposal of waste batteries may contribute hugely to Cd, Mn, and Ni pollution of automobile mechanic shops. Lead (Pb) was distinctively linked to zone D while Fe was concomitant with zone B and zone C, an indication of their varying sources of pollution to the soil.

Heavy metal pollution indices

Enrichment factor (EF) measures the anthropogenic influences on the soil (Amankwaa et al., 2021). It is worth mentioning that EF standardized metals with reference elements such as Fe (Wu et al., 2015). The EF of soils from the various sampling zones is presented in Table S4. However, the mean EF values of each analyzed metal of the soil at the study site are shown Fig. 5a. All analyzed metals, except Cu, have the mean $EF < 0.5$, indicating minor enrichment of such metals, suggesting geogenic processes as the main source of their occurrences (Kumar et al., 2021). Nonetheless, soils from the

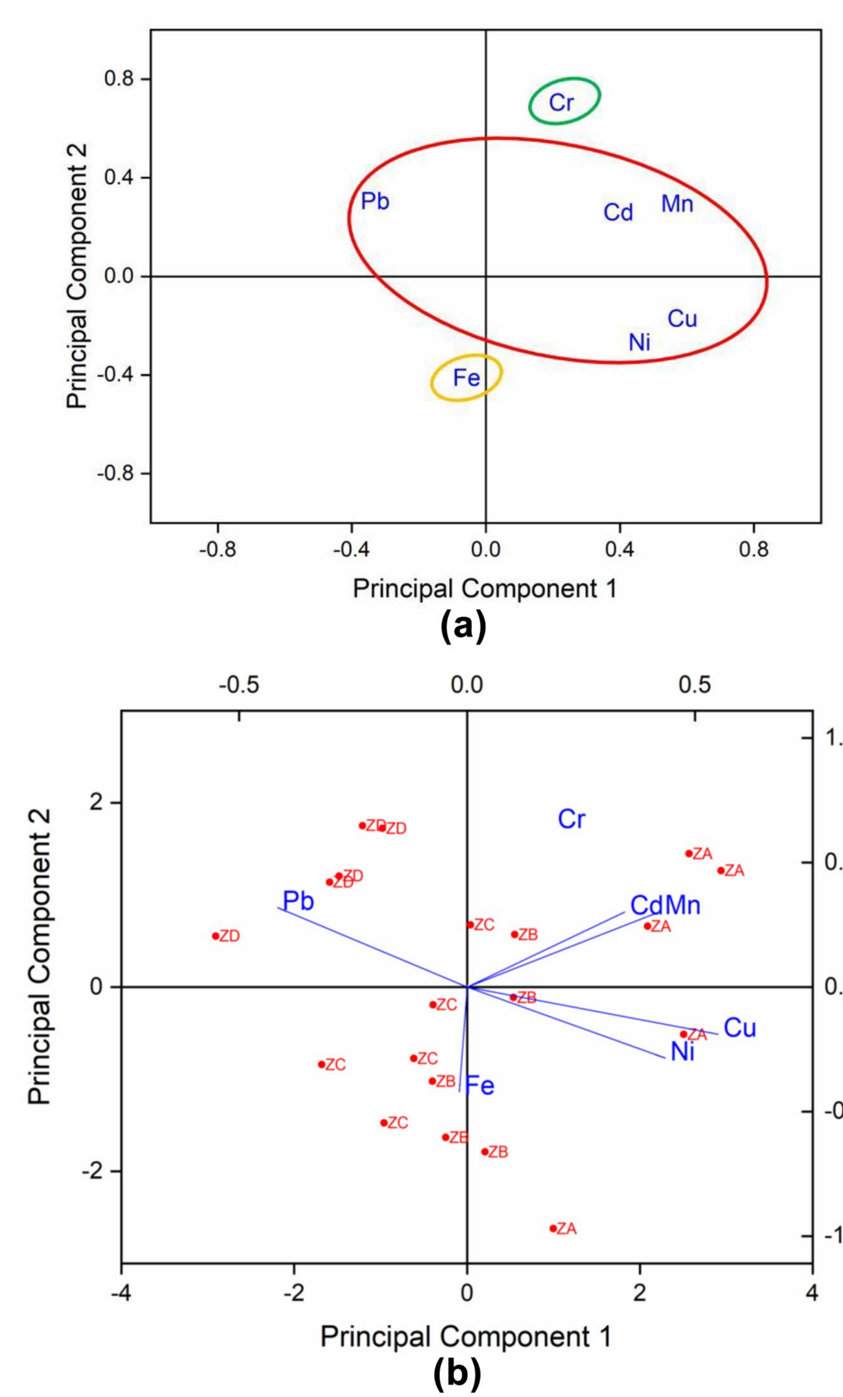

Fig. 4 Multivariate analysis of heavy metals in soils. **a** Loading of PCA. **b** Biplot of PCA showing the association of analyzed metals with the sampling zones

study area were enriched with Cu with an average EF of 2.21 (EF > 1.5) which invokes its anthropogenic origin. The descending order of the average EF values of all metals is Cu > Pb > Cr > Ni > Cd > Mn. Findings depict that anthropogenic activities such as metal welding, vehicle maintenance and fabrication, disposal of used batteries, and metal waste could contribute to the observed metal levels of soils at the study site. With respect to the

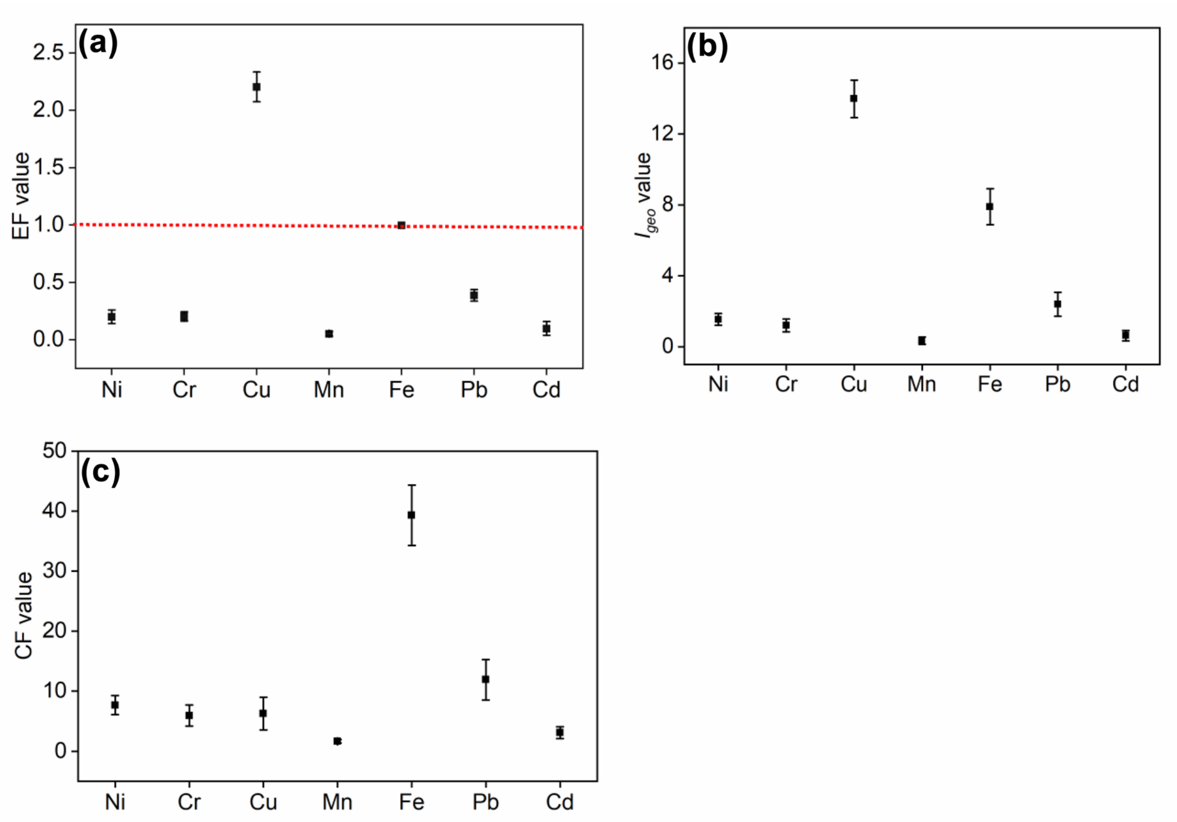

Fig. 5 **a** Variation of enrichment factor (EF). **b** Variation of geo-accumulation index (I_{geo}). **c** Variation of contamination factor (CF) of soils

intensity of metal pollution, I_{geo} was estimated for all metals of soils at the various sampling points and zones (Table S4). Figure 5b shows the average I_{geo} of soil at the study area relative to the background/control data. The mean I_{geo} of the analyzed metals was in the descending order Cu (13.98) > Fe (7.89) > Pb (2.39) > Ni (1.53) > Cr (1.19) > Cd (0.62) > Mn (0.33). The current findings show that soils from the automobile mechanic shops at the Bogoso Junction are extremely contaminated with Cu and Fe (I_{geo} > 5) (Muller, 1969). In addition, the toxic metal Pb exhibited moderate to heavy contamination of the soil, an indication that activities such as engine repairs and improper disposal of waste batteries at the study area could result in remarkable enrichment in the future. Compared with the EU soil quality guidelines, Pb and Cu are the main pollutants which increased by 7.42- and 4.60-folds in urban soils at the Bogoso Junction auto-mechanic shops, respectively. This observation may in part be due to activities such as engine repair, welding and soldering, vehicle overhauling, and oil exchange carried out at the study site. On the other hand, Cr enrichment of soils was 19–20 times lower than the EU international reference standard, but 7 times higher than the control soils. The inference could be that natural levels of Cr in topsoils at the Bogoso auto-mechanic shops have been influenced by activities such as spraying and anodizing (Asamoah et al., 2021).

The estimation of CF and C_d revealed the extent of contamination for the analyzed metals of the soils from the various zones (Table S5). The highest mean CF (39.30) was recorded for Fe (Fig. 5c) among all the studied metals, and it ranged from CF values of 12.84 (in zone D; S2) to 60. 72 (in zone B; S2). The CF values of Pb in all sampling zones indicate considerable contamination ($3 \leq CF < 6$) to very high contamination ($CF \geq 6$) which ranged from 4.29 (zone B; S3) to 17.48 (zone D; S5). Altogether, the mean CF values for all analyzed metals ranked very high contamination for Fe (39.31), Pb (11.91), Ni (7.68), and Cu (6.27); considerable contamination for Cr (5.95); and moderate contamination for Cd (3.09) and Mn (1.66). Following the CF values, the degree of contamination C_d was estimated for soils at the various sampling zones (Table S5). Results showed that soils at the study site depict high degree of contamination ($C_d > 32$ for all zones). In further assessing and affirming the contamination of soils at the study area, the pollution load index (PLI) was characterized for soils at all sampling points within the zones (Table S5). According to Tomlinson et al. (1980), a PLI > 1 denotes a contaminated area. In the present study, the PLI values of all sampling sites were > 1, ranging from 1.73 to 1.92. Ultimately, PLI confirms heavy metal pollution of the study area as a progressive deterioration site (PLI > 1). Similarly, recent studies have reported PL1 > 1 for urban soils in auto-mechanic shops in Ghana: Sunyani Magazine (Asamoah et al., 2021) and Asafo (Agyemang et al., 2022).

Potential ecological risk

The results of the ecological risk assessments of analyzed metals are presented in Table 4. The mean potential ecological risk factor (Er) for individual heavy metals ranked in the decreasing order of Cd (91.88) > Pb (59.56) > Cu (31.34) > Cr (11.89) > Ni (15.36). Cadmium was identified as the richest element and offered a high ecological risk in all sampling sites with Er values ranging from 53.15 (moderate risk) to 144.06 (considerable risk). Similarly, the toxic metal Pb exhibited as the second richest metal with Er values ranging from 21.45 (low risk) to 87.42 (considerable risk). The occurrences of the toxic metals Cd and Pb in soils of automobile mechanic shops could be associated with their uses in car battery. Therefore, proper handling and disposal of car batteries at such place are very important to reduce Cd and Pb contamination of urban soils. The ecological risk index (RI) which measures the combined effects of all the metals showed moderate risk (150 < RI ≤ 300) for all sampling zones (Table 4).

Table 4 Toxicity response factors (T_r), ecological risks (Er), and potential ecological risk indices (RI) for the soil samples

Zones/sampling		**Ni**	**Cr**	**Cu**	**Pd**	**Cd**	**Ecological risk index (RI)**
Toxicity response factor (T_r)		*2*	*2*	*5*	*5*	*30*	
Zone A	S1	15.30	13.78	48.30	44.19	108.91	230.49
	S2	16.17	17.84	55.16	44.96	129.84	263.97
	S3	17.74	16.22	50.78	51.54	142.19	278.46
	S4	22.43	12.97	51.75	43.64	90.78	221.58
	S5	22.96	5.68	48.30	41.23	73.44	191.60
Zone B	S1	15.83	13.11	22.37	43.90	53.13	148.34
	S2	13.22	13.51	30.59	61.26	144.06	262.65
	S3	11.83	8.92	27.04	21.45	95.31	164.55
	S4	17.22	6.62	29.67	51.22	64.06	168.79
	S5	17.22	14.86	28.16	56.41	93.75	210.41
Zone C	S1	13.74	9.86	26.56	73.99	78.28	202.43
	S2	15.30	7.03	29.67	74.58	126.56	253.15
	S3	16.68	12.43	19.41	75.76	142.19	266.46
	S4	15.48	11.89	31.91	74.55	65.63	199.45
	S5	12.16	5.54	29.26	66.00	51.56	174.02
Zone D	S1	14.09	17.57	14.25	75.00	75.16	196.06
	S2	11.13	14.05	13.52	61.04	117.19	216.94
	S3	13.39	12.57	16.97	84.65	59.38	186.96
	S4	12.35	15.24	19.02	72.25	67.50	186.36
	S5	10.43	9.73	10.89	87.42	59.53	178.01

Table 5 Non-carcinogenic and carcinogenic risk of analyzed metals of urbanized soil of Bogoso Junction automobile shops

Heavy metal	Non-carcinogenic risks				Carcinogenic risks		
	HQing	HQderm	HQinh	HI	CRing	CRderm	CRinh
Pb	9.33E−04	1.74E−02	1.71E−03	2.01E−02	4.24E−06	-	2.09E−05
Fe	4.11E−03	-	-	4.11E−03	-	-	-
Cu	9.52E−04	2.66E−03	-	3.62E−03	-	-	1.30E−05
Cd	7.12E−05	9.96E−03	1.31E−02	2.32E−02	4.96E−06	6.23E−06	4.23E−05
Cr	1.53E−04	2.57E−01	2.82E−01	5.39E−01	1.83E−07	-	1.74E−05
Ni	2.51E−05	2.51E−03	1.03E+00	1.03E+00	4.19E−05	-	2.81E−05
Mn	1.12E−03	1.03E+01	3.97E−01	1.07E+01	-	-	-

Data shows that the soils from Bogoso Junction auto-mechanic shops evoke considerable risk for Cd, moderate risk for Pb and Ni, and low risk for Cr. Consistently, soils from the study area showed alarming data for Pb (a toxic metal) in respect of its EF, I_{geo}, CF, and Er values, an indication for stringent measures for the proper management of Pb contamination at the study area. This assertion is because extant literature has indicated that children are at a higher risk of Pb poisoning by ingesting 30% of 100 mg of soil daily (Linnik & Zubenko, 2000; Schoof, 2004; Abel et al., 2010; Rebelo & Caldas, 2016).

Health risk assessment

Estimations for non-carcinogenic and carcinogenic risk exposure to examined metals are presented in Table 5. The HQs of analyzed metals depict that Ni and Mn in urban soils of Bogoso Junction automobile mechanic shops may pose threat to children (HI > 1). Dermal contact and inhalation of soil particles are the main exposure routes for children susceptibility. The HI of Mn is 10 times higher compared with Ni. The recorded HQs for toxic metals such as Pb and Cd were less than 1, following children dermal exposure to Pb (1.74E−02) and inhalation of Cd (1.31E−02) which indicates that non-carcinogenic effects may not be observed. Nonetheless, the disposal of used car batteries at the workshop should be properly managed to ensure the safety of children, especially with Pb/Cd poisoning, within the vicinity. Similarly, a recent study by Agyemang et al. reported a risk of non-carcinogenicity of Pb and Cd of soils at automobile mechanic shops at Asafo, Ghana (Agyemang et al., 2022). As depicted in Table 5, the carcinogenic risks of Pb (CR_{inh}= 2.09E−05); Cu (CR_{inh} = 1.30E−05); Cd (CR_{inh} = 4.23E−05); Cr (CR_{inh} = 1.74E−05); and Ni (CR_{ing} = 4.19E−05, CR_{inh} = 2.81E−05) exceeded 10^{-6}, the acceptable limits for human carcinogenicity, signifying a plausible cancer risk associated with metal exposure to adults living at the automobile mechanic shops at the Bogoso Junction, Tarkwa. Cancer risk associated with Cd inhalation is 10 times greater than oral ingestion of Pb, showing a relatively high carcinogenic hazard to humans. Altogether, the current findings indicate that the human health risks associated with Cd and Pb of urban soils at the Bogoso Junction warrant significant consideration.

Conclusion

This study evaluates the pollution profile of Cu, Pb, Cd, Mn, Ni, Cr, and Fe and the potential ecological and human risk associated with metals, of urban soils at automobile mechanic shops at Bogoso Junction. Current findings showed that soil pH and EC at the Bogoso Junction automobile shops have lesser desorption of heavy metals. In addition, the levels of analyzed metals of soils were higher than both the control soil sample and the EU standards for soil quality. Assessment of soil pollution indices EF, I_{geo}, CF, and C_d indicates that the topsoil of the automobile mechanic shops was polluted by the analyzed metals to different levels which signifies that the soil quality of the auto-mechanic shops is threatened. The ecological risk index (RI) which measures the combined effects of all the metals showed moderate risk (150 < RI ≤ 300) for the analyzed metals for all sampling zones, with the toxic metals Cd and Pb being of significant concern. Furthermore, HQs of analyzed metals depict that Ni and Mn in urban soils of Bogoso Junction automobile mechanic shops may pose threat to children (HI > 1), with dermal contact and inhalation of soil particles as the main exposure routes for children susceptibility. Heavy metal exposure to residents of the automobile mechanic shops at the Bogoso Junction, Tarkwa, might implicate carcinogenic effects. Therefore, artisanal activities such as engine repair, welding and soldering, vehicle overhauling, and oil exchange at the automobile mechanic shops could deteriorate the soil quality, resulting in ecological and human health implications. Inferring from the current findings, expedient measures are required to monitor heavy metal pollution to protect environmental and human health in automobile mechanic shops in Ghana. Hence, the present study therefore recommends that metal speciation, bioavailability, and bioaccessibility tests should be considered, which could highlight the understanding on the human health and ecological risk assessments of heavy metals in automobile mechanic shops.

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Data availability Data, associated metadata, and calculation tools are available upon request from the corresponding author (sfosu@umat.edu.gh).

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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