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ORIGINAL ARTICLE

Assessing Contamination Levels and Risk of Toxic Elements in Soils from Automobile Workshop Centre in Asante Mampong, Ghana

Emmanuel Dartey[1] · **Opoku Gyamfi**[1]

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Abstract
This study assessed the contamination and human and ecological risk of potentially toxic elements in soils from automobile workshops in Asante Mampong, Ghana. Concentrations were determined using a Varian Spectra AA220 Zeeman atomic absorption spectrophotometer. Mean potentially toxic elements concentrations in soils from the automobile workshop Centre had the order: Hg < Cd < Cr < As < Pb < Mn < Cu < Zn < Fe. The mean concentrations of Cd and Pb exceeded the EU guideline limit for Cd (0.35 mg/kg) and Pb (7.2 mg/kg) in soils whereas the mean Hg content was lower than the soil quality criteria limit of 0.3 mg/kg set to protect fauna and flora. The study revealed that the automobile workshop centre is moderately polluted with Cd and highly contaminated with Zn. The Cd levels recorded could pose considerable risks to the ecological environment whilst the other PTEs pose no ecological risks. Cd showed a strong correlation with Pb, Mn and As. Principal Component analysis classified the PTEs into two groups with their sources being the natural geology and vehicle repair activities undertaken at the centre. The concentrations of PTEs measured are not likely to pose non-carcinogenic adverse health effects as the hazard quotients and hazard index computed are all less than unity.

Keywords Vehicle repair · Soil contamination · Principal components · Potentially toxic elements · Index of geo-accumulation

1 Introduction

Heavy metal pollution in air and soil is of great concern because of the dangers posed to workers, inhabitants and the environment [1–3]. Therefore, the inhabitants, including children and numerous workers residing and working in these polluted environments, are at serious risk of heavy metals toxicity. Greater awareness of this issue is needed to help reduce the incidence of heavy metal intoxication among inhabitants [4–6]. Heavy metals do not contaminate only the surface environment but also contribute to air pollution, as they may become airborne and also enter drainage systems to affect aquatic ecosystems [7].

In general, the presence of heavy metals in high concentrations in the environment has resulted in health hazards such as adverse effects on the nervous system, blood formation, and renal and reproductive systems [8]. Other effects include; reduced intelligence, attention deficit and behavioural abnormality. Heavy metals have also contributed to cardiovascular diseases in adults and children [9]. For children, ingestion of contaminated soil is found to be the most significant pathway into the body [10].

Soils may become contaminated by heavy metals due to accumulation from auto-mechanic workshops during their daily operations [11, 12]. The activities at auto-mechanic workshops include electrical repair of automobiles, repair of brakes and steering, automatic or standard transmission engine, spray painting of vehicles, recharging of auto batteries, welding and soldering among others. Where such activities are not properly monitored and regulated, they may lead to higher levels of heavy metals in the environment that may affect quality of food production. Therefore, there is a need to continually monitor their nature, volume, harmful effects and current methods of disposal as well as potential impacts on the environment [13].

Gyimah et al. [12] and Asamoah et al. [28] have studied potentially toxic elements contamination in soils of vicinities of auto-mechanic workshops in two different regions

✉ Opoku Gyamfi
Opokugyamfi1000@gmail.com; ogyamfi@aamusted.edu.gh

[1] Department of Chemistry Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Asante Mampong, Ghana

of Ghana. Auto-mechanic workshops have sprung up in many parts of Asante Mampong as clusters in open ground. Wastes such as metal scraps, used batteries, worn-out vehicle parts generated by auto-mechanic workshops and their activities are dumped indiscriminately into the environment. Asante Mampong is a major contributor to food production in Ghana. No study has investigated the extent of potentially elements contamination in the soils of vicinities of auto-mechanic workshops in the Asante Mampong municipal and their human health risks. The present study aims to determine the levels of toxic elements in soil from different artisan locations within the Asante Mampong auto-mechanic workshop centre; identify the possible sources of toxic elements as well as assess the environmental and human health risk of the toxic elements from the investigated area.

This research is intended to raise awareness of the issue of heavy metal contamination at auto-mechanic workshop sites and find out the contributions from known activities such as vehicular body works and welding, repair of lead-acid batteries, vehicle paint spraying, vehicle engine repair and food vending locations within the auto-mechanic workshop center. Assessing the levels of heavy metal pollution at the auto-mechanic workshops would also help establish the environmental and health impact of these metals at the workshops.

2 Materials and Methods

2.1 Study Area

The study was carried out at the Asante Mampong auto-mechanic workshop center in the Ashanti Region of Ghana. Asante Mampong is the administrative capital of the Asante-Mampong Municipality and it is about 57 km north of Kumasi. The municipality is located within longitudes 0° 05″ W and 1° 30″ W and latitudes 6° 55″ N and 7° 30″ N, covering a total land area of about 23.9 km^2. The population of the Municipality according to the 2021 Population and Housing Census stands at 116,632 with 56,965 (48.84%) males and 59,667 (51.16%) females [14].

The Asante Mampong auto-mechanic workshop center (Fig. 1) is made up of a cluster of small-scale workshops with a specialty in vehicle body works and welding, vehicle upholstery, repair of lead-acid battery, vehicle paint spraying, vehicle engine repair, sale of vehicular spare-parts, vulcanizing work and women who sell food items in the vicinity of these workshops.

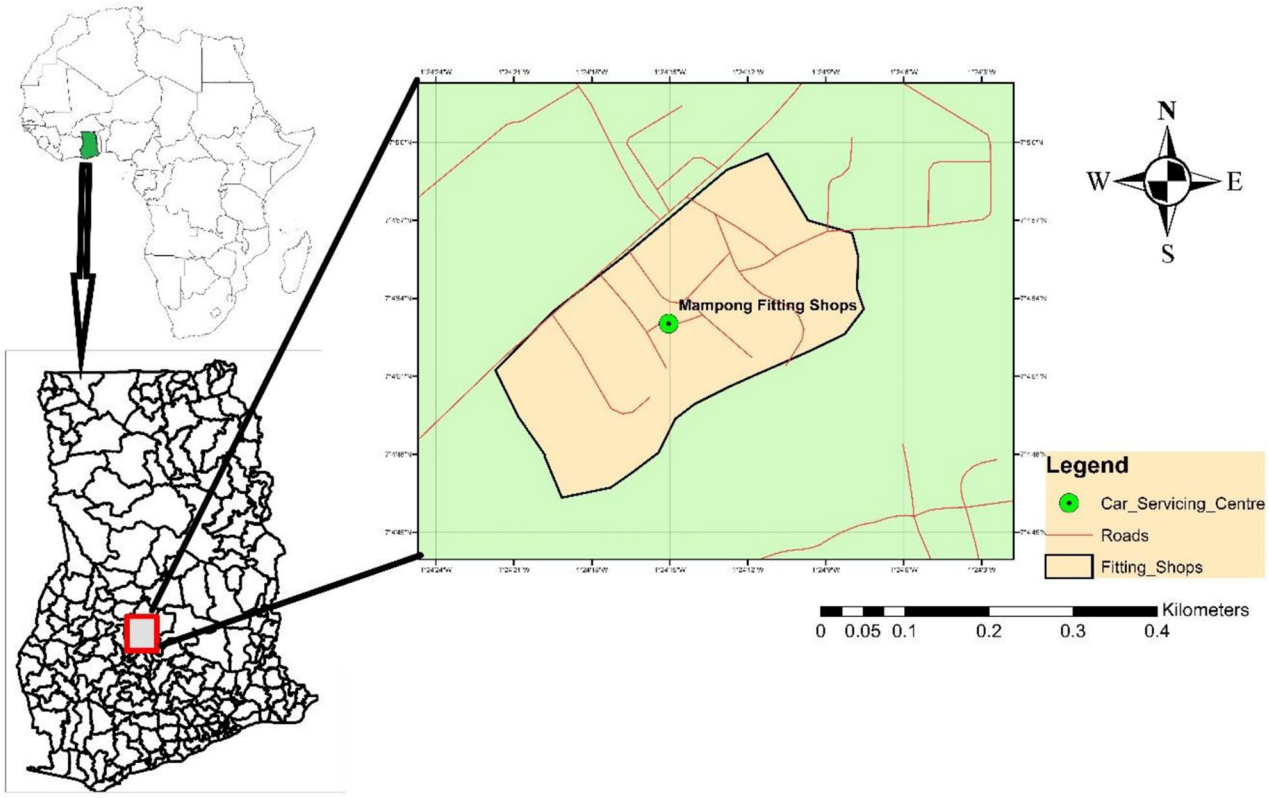

Fig. 1 Map of Asante Mampong in Ghana showing the study area

2.2 Sampling

Forty-eight (48) composite soil samples were collected from three workshops belonging to each of the following categories: Vehicle Body Works (VBW), Upholstery Work (UPW), Battery Repair Work (BRW), Vehicle Spraying Work (VSW), Food Vending Area (FVA), Engine Repair Work (ERW), Sale of Automobile Parts (SAP), and Vulcanizing Work (VCW). Two composite soil samples were collected from each of the two parts of three workshops belonging to a particular category. The two parts in each workshop are the activity area and rest area. Five different samples were collected from each area and combined to form a composite. The control was collected at the AAMUSTED campus for data comparison and to evaluate the extent of heavy metal pollution and enrichment in soils at the workshops studied. The soil samples were collected at (0–0.20 m depth) at the selected location. The soil samples were collected with a plastic spoon, placed in sealed polythene bags and transported to the laboratory of the Soil Research Institute of the Council for Scientific and Industrial Research (CSIR-SRI), Kumasi, Ghana for elemental analysis. The plastic spoon was washed with distilled water and wiped dry after every sample to prevent cross-contamination.

2.3 Preparation and Analysis of Samples

2.3.1 Preparation of Samples

The soil samples were air-dried for 6 days at room temperature, homogenized and made lump free by gently crushing repeatedly using an acid-pre-washed mortar and pestle. The samples were then sieved using a 2 mm plastic nylon mesh sieve to remove coarse soil fraction prior to the analysis.

2.3.2 Analysis of Soil Samples

One gram of the dried fine soil sample was weighed and transferred into an acid washed 100 mL volumetric flask. A 10 mL mixture of HNO_3, H_2SO_4 and $HClO_4$ (9:4:1 v/v) was added. The mixture was slowly evaporated at 90 °C for one hour on a hot plate. The flask was placed on a hot plate in the fume hood and heated at the temperature range of 90–200 °C until the fumes of $HClO_4$ were completely evaporated. The mixture was allowed to cool to room temperature and then filtered using Whatman No.42 filter paper into a 50 mL volumetric flask. The reacting vessels were rinsed to recover any residual metal. The filtrate was then made up to the mark by adding deionized water. Heavy metals concentrations were determined using a Varian Spectra AA220 Zeeman Atomic Absorption Spectrophotometer (ZAAS) [15] at the Council for Scientific and Industrial Research-Soil Research Institute (CSIR-SRI), Kumasi, Ghana.

The instrument was calibrated using standard solutions of the respective metals. Blanks were analyzed after every 10 samples. Certified Reference Materials (Channel BCR-320R Sediment) provided by Institute for Reference Materials and Measurements, Belgium) was used to validate the method. Replicate analysis of the reference material showed good accuracy and recovery rates which ranged from 85 to 112%.

2.4 Quantification of Soil Pollution

2.4.1 Geoaccumulation Index

Igeo, a geochemical criterion introduced by [16], was used to evaluate soil contamination by comparison with current and preindustrial concentrations. Unlike other methods of pollution assessment, Igeo takes the natural diagenetic process into account, which makes its assessments more realistic. Igeo is calculated using the following equation:

$$\text{Igeo} = \log 2(\text{Cn}/1.5 \times \text{Bn}) \quad (1)$$

where Cn is the measured concentration of the potentially toxic elements in soil (mg/kg), Bn is the geochemical background value of the corresponding potentially toxic element (mg/kg), and the coefficient 1.5 is used due to potential variation in the baseline data [17]. According to [16], Igeo values fall into seven classes. The corresponding relationships between Igeo and the pollution level are listed (Table 1).

2.4.2 Contamination Factor (CF)

The contamination factor reflects the extent of anthropogenic input in elemental pollution [18]. It is widely used to measure the overall PTE contamination of soil. Mathematically, it is expressed as:

$$C_F = C_{metal}/C_{background\ value} \quad (2)$$

where C_{metal} is the concentration of the metal examined in soil samples and $C_{background\ value}$ is the geochemical background concentration of the metal. The index ranges from $C_F < 1$ refers to low contamination; $1 < C_F < 3$ indicates moderate contamination; $3 < C_F < 6$ indicates considerable

Table 1 Contamination categories on the basis of Igeo values

Igeo values	Igeo ≤ 0	0 ≤ Igeo ≤ 1	1 ≤ Igeo ≤ 2	2 ≤ Igeo ≤ 3	3 ≤ Igeo ≤ 4	4 ≤ Igeo ≤ 5	Igeo ≥ 5
Categories	Unpolluted	Unpolluted to moderately	Moderately	Moderately to heavily	Heavily	Heavily to extremely	Extremely

contamination and $C_F > 6$ indicates very high contamination [19, 20].

2.4.3 Ecological Risk Assessment Method

The method introduced by Hakanson was adopted to assess the ecological risks posed by potentially toxic element pollution in the topsoil of the study area. Hakanson [20] developed the following quantitative approach, and this method was used in many other studies to assess the ecological risks of potentially toxic elements in soils [19, 21]. The potential ecological risk factor of a given contaminant (E(i)) is defined as:

$$EI(i) = T(i) \times C_i/C_0 \quad (3)$$

where Ti is the toxic-response factor for a given substance, C_i represents potentially toxic element content in the topsoil, and C_0 is the regional background potentially toxic element content of topsoil [22]. The sum of the individual potential risk factors (EI(i)) is the potential ecological risk index (RI), which represents the potential risk in a region. RI can be expressed as:

$$RI = \sum_{i=1}^{n} EI(i) \quad (4)$$

2.5 Human Health Risk Assessment

Human Health Risk posed by Potentially Toxic Elements (PTEs) was estimated using the model recommended by the United States Environmental Protection Agency [23]; non-carcinogenic risk and carcinogenic risk were considered in this method. Non-carcinogenic risks for adults and children were considered in this study. Ingestion, inhalation, and dermal contacts are three pathways by which humans can be exposed to risk. The average daily exposure dose (ADD) of PTE is considered was calculated using Eqs. 5, 6 and 7 respectively.

$$ADDing = c \times IngR \times CF \times EF \times ED/(BW \times AT) \quad (5)$$

$$ADDinh = c \times IngR \times EF \times ED/(PEF \times BW \times AT) \quad (6)$$

$$ADDderm = c \times SA \times SL \times ABS \times CF \times EF \times ED/(BW \times AT) \quad (7)$$

where ADDing, ADDinh, and ADDderm are the average daily exposure doses of PTEs for the three exposure pathways (ingestion of soil and food, air inhalation and dermal absorption respectively); C is the PTE concentration in surface soils; IngR is the ingestion rate (mg/d); InhR is the inhalation rate (m^3/d); CF is a conversion factor (10^{-6}, kg/mg); EF is the exposure frequency (d/a); ED is the exposure duration (a); BW is the average body weight (kg); SA is the exposed skin area (cm^2); SL is the skin adherence factor (mg/(cm^2 d)); PEF is the particle emission factor (m^3/kg); ABS is the dimensionless dermal absorption factor; AT is the average time (d); and ED × 365 days for non-carcinogenic risk and 72 × 365 days for carcinogenic risk. The detailed reference values of these parameters are given in Table 2.

For non-carcinogenic risk, the hazard index (HI) is the summation of the hazard quotients (HQ), the total hazard index (THI) is the summation of the HI of potentially toxic elements considered, and HQ is the quotient of ADD to its associated toxicity threshold (dose (RfD, mg/(kg d)).

When HQ < 1 or HI < 1, the non-carcinogenic risk is negligible. HI and HQ were calculated using Eqs. 7 and 8 respectively.

$$HI = HQing + HQinh + HQderm \quad (8)$$

$$THI = \sum n\,j = 1HIj \quad (9)$$

For carcinogenic risk, the total carcinogenic risk (TCR) is the summation of the carcinogenic risk (CR) of PTEs, and the CR and TCR were calculated using Eqs. 10 and 11 respectively

$$CR = ADD \times CSF \quad (10)$$

$$TCR = \sum_{j=1}^{n} CR_j \quad (11)$$

where CSF represents cancer slope factor (mg/(kg d)) [7]. If $CR < 1 \times 10^{-6}$, carcinogenic risk is negligible. Reference values of RfD and CSF are indicated in Table 3. This study considered Cd, Cr, Pb and As due to their potential carcinogenicity.

3 Results and Discussion

3.1 Potentially Toxic Elements (PTEs) Distribution

The levels of PTEs assessed in this study varied across the various locations in the study area (Table 4).

The concentration of Cd ranged from 0.14 mg/kg in the FVA to 0.92 mg/kg in the VBW. The maximum Cd level in the soil exceeds the world average Cd level of 0.41 mg/kg [24]. The Cd levels in this study are higher than levels of Cd recorded in automobile mechanic workshops in Benin City (0.00–0.05 mg/kg), Nigeria [25]. Cadmium levels recorded in VBW (0.92 ± 0.31 mg/kg), BRW (0.74 ± 0.15 mg/kg), VSW (0.56 ± 0.08 mg/kg) and ERW (0.43 ± 0.14 mg/kg)

Table 2 Definitions and units of parameters used in determining the exposure in each pathway [37]

	Unit	Parameter	Value	
ADD_x	mg/kg/day	Dose	ADD_{ing}, ADD_{inh}, and ADD_{der}*	
C	mg/kg	Concentration	Concentration of PTE in soil (exposure point concentration)	
			Children	Adults
IngR	mg/day	Ingestion rate	400	100
InhR	mg/day	Inhalation rate	10	10.4
EF	days/year	Exposure frequency	365	365
ED	Year	Exposure duration	6	30
SA	cm^2	Exposure skin area	4200	13,110
SL	$mg/cm^2/day$	Skin adherence factor	0.2	0.07
ABS	Unitless	Dermal absorption factor	0.1	0.1
PEF	mg/kg	Particle emission factor	725,000,000	322,000,000
BW	kg	Average body weight	15	70
AT	days	Average time	2190	10,950

*Dose contacted through ingestion (ADD_{ing}) and inhalation (ADD_{inh}) of substrate particles, and absorbed through dermal contact with substrate particles (ADD_{der})

Table 3 Reference doses and slope factors for ingestion, inhalation and dermal of metals by adults and children

Metal	Reference dose (mg/kg/day)			Slope factor		
	Ingestion	Inhalation	Dermal	Ingestion	Inhalation	Dermal
Cd	0.001	0.00001	0.00001	0.501	6.3	200
Hg	0.0003	0.000086	0.0003			
Pb	0.0035	0.00352	0.000525	0.0085		
Fe						
Cu	0.04	0.0402	0.012			
Zn	0.3	0.3	0.06			
Mn	0.024	0.00143	0.024			
Cr	0.003	0.0000286	0.00006		42	
As	0.0003	0.0003	0.000123	1.5	15.1	3.66

Table 4 Mean level of trace metals (mg/kg) from soils at various locations in the Asante Mampong Automobile workshop

	Cd	Hg	Pb	Fe	Cu	Zn	Mn	Cr	As
VBW	0.92 ± 0.31	0.18 ± 0.03	22.91 ± 4.2	508.68 ± 25.1	90.55 ± 10.63	467.55 ± 19.62	154.12 ± 9.6	1.52 ± 0.2	2.07 ± 0.3
UPW	0.26 ± 0.0.14	0.14 ± 0.05	6.56 ± 2.3	196.22 ± 7.2	40.62 ± 8.8	242.30 ± 12.1	25.14 ± 6.2	0.86 ± 0.04	1.14 ± 0.06
BRW	0.74 ± 0.15	0.31 ± 0.04	40.63 ± 8.5	105.61 ± 7.1	72.48 ± 9.7	314.46 ± 11.9	96.11 ± 8.3	1.04 ± 0.05	2.13 ± 0.12
VSW	0.56 ± 0.08	0.16 ± 0.01	14.28 ± 3.3	244.13 ± 8.8	101.74 ± 10.2	219.82 ± 14.4	40.89 ± 7.8	1.12 ± 0.03	1.45 ± 0.08
FVA	0.14 ± 0.02	0.08 ± 0.02	7.82 ± 1.9	280.36 ± 14.6	55.46 ± 12.4	305.60 ± 12.6	14.96 ± 3.3	0.92 ± 0.1	0.83 ± 0.05
ERW	0.43 ± 0.14	0.11 ± 0.04	11.15 ± 3.4	374.32 ± 10.8	114.39 ± 16.1	266.11 ± 18.7	30.24 ± 5.1	1.32 ± 0.12	1.55 ± 0.11
SAP	0.18 ± 0.05	0.28 ± 0.06	10.11 ± 1.8	178.54 ± 12.7	60.66 ± 4.4	198.71 ± 15.4	9.34 ± 2.3	0.92 ± 0.06	0.68 ± 0.04
VCW	0.29 ± 0.11	0.09 ± 0.02	4.22 ± 0.9	281.77 ± 9.2	36.84 ± 6.7	126.44 ± 10.33	13.57 ± 3.1	0.61 ± 0.04	1.17 ± 0.06
Control	ND	0.03 ± 0.01	0.28 ± 0.05	22.41 ± 3.5	6.4 ± 1.63	30.48 ± 7.2	2.42 ± 0.51	0.12 ± 0.01	0.31 ± 0.04

VBW vehicle body works, *UPW* upholstery work, *BRW* battery repair work, *VSW* vehicle spraying work, *FVA* food vending area, *ERW* engine repair work, *SAP* sale of automobile parts, *VCW* vulcanizing work

are comparable with levels (0.38–0.91 mg/kg) reported in [12] in soils from auto-mechanic workshops in Tarkwa, Ghana. These levels also exceed the EU standard for soils of 0.35 mg/kg [12]. The concentration of Hg was lowest (0.08 mg/kg) in the FVA and highest (0.31 mg/kg) at BRW. It is worthy of note that the lowest level exceeded the average background value (0.004 mg/kg) of mercury in Ghana [26]. The lowest value of Pb (4.22 mg/kg) in this study was recorded at the VCW whereas the highest value (40.63 mg/kg) occurred at the BRW. The Pb levels far exceed the range of values reported by [25] in Nigeria (0.21–13.60 mg/kg) and [27] in Asafo auto-mechanic workshop in Kumasi, Ghana (3.65 mg/kg). The Pb levels are however lower than levels (0.54–501.10 mg/kg) reported by [28] in soils from auto-mechanic workshops from Sunyani in Ghana. The mean and maximum levels of Pb in this study are higher than the EU standard of Pb (7.2 mg/kg) permitted in soils [12]. The minimum Fe concentration (105.61 mg/kg) occurred at the BRW while the highest (508.68 mg/kg) at the VBW. Although Fe is naturally abundant in the Earth's crust, levels of Fe recorded in all the sampled sites were significantly higher than in the control sample. Irrespective of the possible geogenic source of Fe in soils at Mampong, activities such as metal casting, welding and fabrication could be responsible for the elevated Fe levels. The levels of Fe in this study are below that reported in Tarkwa (39,031–52,084 mg/kg) [12] and Suame Magazine (2050–2350 mg/kg) [29]. In this study, the concentration of Cu ranged from 36.84 mg/kg in VCW soil to 114.39 mg/kg in ERW soil and showed a marked difference with the control sample. The levels recorded are higher than Cu levels in soils of auto mechanic workshops in Benin City, Nigeria (0.00–10.00 g/kg) [25] and Asafo auto mechanic workshop in Kumasi, Ghana (1.84 mg/kg) [27]. Again, this study reports high Cu levels than what is reported by [28]. This may be due to the release of copper connecting wires and rusted materials that contains Cu into the soil.

Zinc showed its lowest level (126.44 mg/kg) at the vulcanizing workshop whereas the highest (467.55 mg/kg) appeared at the vehicle body workshop. The maximum Zn content in this study exceeds the permissible guideline value by the Canadian Council of Ministers of the Environment (200 mg/kg) [30] and Dutch Target (140 mg/kg) [31]. Zinc in auto-mechanic workshops may come from mechanical abrasion of vehicular parts, motor oils and worn-out vehicle body parts. Zinc showed higher levels in this study than Cu reported by [25] in Nigeria and [28] in Ghana. Zinc and copper are essential elements however, elevated levels can cause important side effects such as abdominal cramps, anaemia, headaches, metabolic disorders, and liver and kidney damage [32].

The lowest Mn level (9.34 mg/kg) occurred at the area automobile spare parts shop whereas the highest (154.12 mg/kg) occurred at the vehicle body workshop. The Cr content is lowest (0.61 mg/kg) at the vulcanizing workshop and highest (1.52 mg/kg) at the vehicle body workshop. The levels are far lower than the permissible Cr content in soils set by international agencies. The auto-mechanic workshops and others dealing with steel and metal plating in the area could serve as a possible source of the metal. Chromium is a metal with low mobility especially close to neutral pH values where there are moderate oxidizing and reducing conditions. Arsenic was lowest (0.68 mg/kg) at the sales area and highest (2.13 mg/kg) at the battery repair workshop. The As contents could originate from other anthropogenic activities observed around the study area and were associated with metallurgical and chemical activities as indicated by [24]. Most of the metals analysed recorded higher mean concentrations at the VBW station. This is expected because the body of vehicles is mostly made of metallic substances. The repair works on the body of vehicles and worn-out body parts normally results in the release of metals into the soil.

3.2 Pollution Estimation

The extent of soil pollution was estimated using pollution indices (Table 5). The Index of geoaccumulation assesses the level of elemental accumulation in soils against a background concentration. The Igeo measured for Cd were below 1. This indicates that the soils are unpolluted with Cd except those sampled from VBW (Igeo of 1.032) were moderately polluted with Cd. The study area is unpolluted with respect to Pb, Cu, Mn, Cr, As and Hg. The estimated Igeo values in respect of Pb, Cu, Mn, Cr, As and Hg are all less than 1. Zn recorded Igeo of 1.17, 1.14 and 1.10 at VBW, BRW and FVA sites respectively. These show VRW, BRW and FVA environments were moderately polluted with Zn. The other sites viz VPW, VSW, ERW, SAP and VCW are unpolluted with Zn. Cadmium and Zn recorded the highest C_F of 3.06 and 4.92 respectively for VBW. Thus, with respect to Cd and Zn, the site (VBW) was highly contaminated.

Except UPW, the other locations in the study area recorded C_F values between 1 and 3 for Cu. This indicate that these sites were moderately contaminated with Cu. Similarly, Pb recorded the highest C_F of 2.03 and 1.14 at BRW and VBW respectively. These also indicate sites BRW and VBW are moderately contaminated with Pb.

The ecotoxicological impacts were assessed using the potential ecological risks factor and index [33, 34]. Cadmium concentrations detected pose a varied risk to the ecological environment. Approximately 13% of the sites sampled pose considerable risk to the ecological environment with ER value of 92. Thirty-seven per cent of the investigated sites would experience moderate ecological risk. Half of the sites would experience low ecological risk with respect to Cd. All the other elements would pose a low risk

Table 5 Contamination indices of the potentially toxic elements

	As	Cd	Cr	Cu	Hg	Mn	Zn
Calculated index of geoaccumulation values of the study area							
VBW	− 3.236	1.032	− 6.473	0.424	− 1.737	− 3.048	1.714
UPW	− 4.096	− 0.791	− 7.294	− 0.733	− 2.100	− 5.664	0.766
BRW	− 3.195	0.718	− 7.020	0.103	− 0.953	− 3.730	1.142
VSW	− 3.749	0.316	− 6.913	0.592	− 1.907	− 4.963	0.625
FVA	− 4.554	0.316	− 7.197	− 0.283	− 2.907	− 6.413	1.101
ERW	− 3.653	− 1.685	− 6.676	0.761	− 2.448	− 5.398	0.901
SAP	− 4.842	− 0.066	− 7.197	− 0.154	− 1.100	− 7.093	0.480
VCW	− 4.059	− 0.634	− 7.790	− 0.874	− 2.737	− 6.554	− 0.173
Calculated contamination factor values of the study area							
VBW	0.159	3.067	0.017	2.012	0.450	0.181	4.922
UPW	0.088	0.867	0.010	0.903	0.350	0.030	2.551
BRW	0.164	2.467	0.012	1.611	0.775	0.113	3.310
VSW	0.112	1.867	0.012	2.261	0.400	0.048	2.314
FVA	0.064	0.467	0.010	1.232	0.200	0.018	3.217
ERW	0.119	1.433	0.015	2.542	0.275	0.036	2.801
SAP	0.052	0.600	0.010	1.348	0.700	0.011	2.092
VCW	0.090	0.967	0.007	0.819	0.225	0.016	1.331
Calculated potential ecological risk values of the study area							
VBW	1.592	92	0.034	10.061	18	0.181	4.922
UPW	0.877	26	0.019	4.513	14	0.030	2.551
BRW	1.638	74	0.023	8.053	31	0.113	3.310
VSW	1.115	56	0.025	11.304	16	0.048	2.314
FVA	0.638	14	0.020	6.162	8	0.018	3.217
ERW	1.192	43	0.029	12.710	11	0.036	2.801
SAP	0.523	18	0.020	6.740	28	0.011	2.092
VCW	0.900	29	0.014	4.093	9	0.016	1.331

to the ecological environment as they all recorded ER values of less than 40.

3.3 Correlation Analysis of PTEs

Correlation analysis when applied to environmental studies helps to reveal the relationship that exists between multiple variables. The correlation matrix is presented in Table 6. In this study, correlation coefficients > 0.8, 0.6 < r < 0.8 and < 0.6 were considered strong, moderate and weak correlations respectively as indicated in a study by [35]. Generally, the geology of an area plays a significant role in defining its environmental chemistry [36]. Chemical ions including many metallic ions in an environment are attributed to

Table 6 Pearson's correlation

Variable	Cd	Hg	Pb	Fe	Cu	Zn	Mn	Cr	As
Cd	–								
Hg	0.526	–							
Pb	0.811**	0.770*	–						
Fe	0.554	− 0.053	0.097	–					
Cu	0.686*	0.373	0.488	0.640	–				
Zn	0.776*	0.434	0.640	0.711*	0.648	–			
Mn	0.930***	0.452	0.764*	0.527	0.479	0.817**	–		
Cr	0.783*	0.462	0.560	0.781*	0.904***	0.889**	0.679*	–	
As	0.958***	0.509	0.831**	0.524	0.694*	0.761*	0.846**	0.779*	–

*Correlation is significant at the 0.05 level (2-tailed) p < .05

**Correlation is significant at the 0.01 level (2-tailed) p < .01

geogenic origins. However, the levels of potentially toxic elements in the control sample used in this study suggest that the heavy metals could not be linked to geogenic origins, as there are no geologic deposits rich in the analysed PTEs. Cd correlated strongly with Mn and As. Though Cr has a strong correlation with Cu and Zn it had a moderate correlation with As and Mn. Fe also had a moderate correlation with Cr and weak correlations with Hg, Pb, Cu, Zn, Mn and As. Pb showed a strong correlation with Cd and As whereas it moderately correlated with Hg. Although Fe contents of the soils were low, its weak correlation with Hg, Pb, Cu, Mn, and As except Zn and Cr suggests that its presence in the soil did not originate from the same source as that from where Hg, Pb, Cu, Mn, and As originated. The origins of the potentially toxic elements in the soils may be attributed to activities at the automobile mechanic workshops such as engine repairs, industrial plants, Pb-acid batteries, car body spraying and air conditioning coolants replacements.

3.4 Principal Component Analysis of Potentially Toxic Elements

Principal Component Analysis (PCA) was employed to investigate the association between the analysed PTEs and the sampled sites. This multivariate analytical tool helped to identify the possible sources of PTEs contamination in the soils at the studied environment. Principal components were extracted with eigenvalues > 1 through Varimax rotation. Two principal components with a total variance of 85.8%. As is indicated in Fig. 2 and Table 7, PC1 is explained by high loadings of Fe, Cu, Zn, Cr and Cd contributed a variance of 69.4% to the total variance. This indicates that Fe, Cu, Zn, Cr and Cd emerged from the local geology. Very high Fe loading suggest that it may have originated from a source other than that from where Hg, Pb, Cu, Zn, Mn, Cr and As may have been into the environment. These sources could be scrap metal and metal fabrication activities done at the auto-mechanic workshops. PC2 is positively loaded with Pb, Hg, As, Mn and Cd. This account for 16.4% of the variance. Pb and Hg had high loadings and could be released from Lead-acid battery recharging and repair activities observed in the study sites. Cd, Mn and As also had positive loadings in the PC2. Thus vehicular repair, maintenance, welding, and fabrication, waste electrical and electronic equipment may be responsible for elevated levels of Cd, Mn and As recorded.

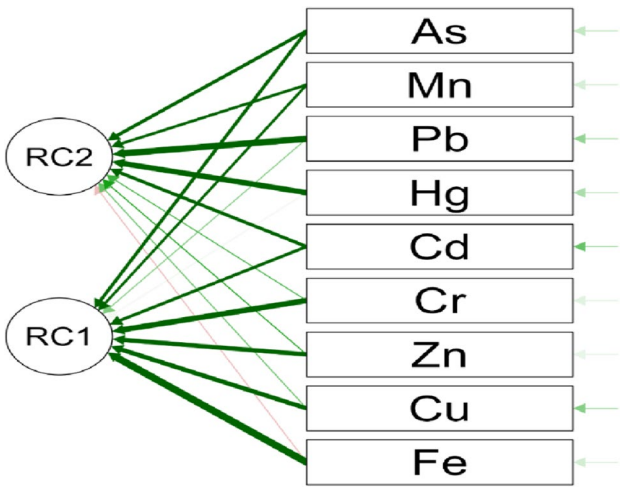

Fig. 2 Principal components of the analysed PTEs

Table 7 Component loadings

Element	PC1	PC2	Uniqueness
Fe	0.962		0.058
Cr	0.882		0.078
Zn	0.793		0.161
Cu	0.784		0.294
Cd	0.666	0.686	0.086
As	0.647	0.684	0.114
Mn	0.607	0.649	0.210
Pb		0.946	0.043
Hg		0.874	0.235

Applied rotation method is varimax

3.5 Human Health Risk Assessment of Toxic Metals

Carcinogenic and non-carcinogenic risks estimated are presented in Tables 8 and 9. The assessment revealed that none of the PTEs poses health risk to workers as well as the inhabitants near the auto-mechanic workshops. The hazard quotient and hazard index computed were all below unity Table 8. However, this does not eliminate all risk of the exposure to heavy metals. Thus, the disposal of used vehicle parts should be properly managed and activities regulated to minimize release of PTEs into the soil. In all instances, children are exposed to higher risks than adults because the hazard quotients and indices computed were all higher for children than adults in all the pathways considered. The dermal contact pathway is the largest contributor to the overall risk followed by the ingestion pathway. This leads to an additional concern for children as they are more likely to play in the soil as well as practice hand to mouth activities.

In this study, As, Cd, Cr and Pb were assessed for their carcinogenic risk. As recorded total cancer risk range of 3.53×10^{-6} at SAP to 1.10×10^{-5} at VBW and 2.02×10^{-6} at SAP to 6.34×10^{-6} at VBW for children and adults respectively (Table 9). These levels are likely to pose significant cancer risk to both children and adults near the automobile workshops. From Table 9 it is inferred that Cd, Cr and Pb would pose no significant cancer risk because the total

Table 8 Hazard quotients and hazard indices for children and adults for analysed metals

Metal	Sample	Children				Adults			
		HQing	HQinh	HQderm	HI	HQing	HQinh	HQderm	HI
Cd	VBW	0.025	8.00E−05	0.515	0.540	0.001	4.25E−05	0.121	0.122
	UPW	0.007	2.00E−05	0.146	0.153	0.000	1.20E−05	0.034	0.035
	BRW	0.020	7.00E−05	0.414	0.434	0.001	3.41E−05	0.097	0.098
	VSW	0.015	5.00E−05	0.314	0.329	0.001	2.58E−05	0.073	0.074
	FVA	0.004	1.00E−05	0.078	0.082	0.000	6.46E−06	0.018	0.019
	ERW	0.011	4.00E−05	0.241	0.252	0.001	1.98E−05	0.056	0.057
	SAP	0.005	2.00E−05	0.101	0.106	0.000	8.31E−06	0.024	0.024
	VCW	0.008	3.00E−05	0.162	0.170	0.000	1.34E−05	0.038	0.038
Pb	VBW	0.175	6.00E−06	0.244	0.419	0.009	3.00E−06	0.009	0.018
	UPW	0.050	2.00E−06	0.070	0.120	0.003	8.60E−07	0.002	0.005
	BRW	0.310	1.00E−05	0.433	0.743	0.017	5.33E−06	0.015	0.032
	VSW	0.109	4.00E−06	0.152	0.261	0.006	1.87E−06	0.005	0.011
	FVA	0.060	2.00E−06	0.083	0.143	0.003	1.03E−06	0.003	0.006
	ERW	0.085	3.00E−06	0.119	0.204	0.005	1.46E−06	0.004	0.009
	SAP	0.077	3.00E−06	0.108	0.185	0.004	1.33E−06	0.004	0.008
	VCW	0.032	1.00E−−06	0.045	0.077	0.002	5.53E−07	0.002	0.003
Cu	VBW	0.060	2.00E−06	0.042	0.103	0.003	1.04E−06	0.010	0.013
	UPW	0.027	9.00E−07	0.019	0.046	0.001	4.66E−07	0.004	0.006
	BRW	0.048	2.00E−06	0.034	0.082	0.003	8.32E−07	0.008	0.011
	VSW	0.068	2.00E−06	0.047	0.115	0.004	1.17E−06	0.011	0.015
	FVA	0.037	1.00E−06	0.026	0.063	0.002	6.37E−07	0.006	0.008
	ERW	0.076	3.00E−06	0.053	0.130	0.004	1.31E−06	0.013	0.017
	SAP	0.040	1.00E−06	0.028	0.069	0.002	6.96E−07	0.007	0.009
	VCW	0.025	8.00E−07	0.017	0.042	0.001	4.23E−07	0.004	0.005
Zn	VBW	0.042	1.00E−06	0.009	0.050	0.002	7.19E−07	0.002	0.004
	UPW	0.022	7.00E−07	0.005	0.026	0.001	3.73E−07	0.001	0.002
	BRW	0.028	1.00E−06	0.006	0.034	0.002	4.84E−07	0.001	0.003
	VSW	0.020	7.00E−07	0.004	0.024	0.001	3.38E−07	0.001	0.002
	FVA	0.027	9.00E−07	0.006	0.033	0.001	4.70E−07	0.001	0.003
	ERW	0.024	8.00E−07	0.005	0.029	0.001	4.09E−07	0.001	0.002
	SAP	0.018	6.00E−07	0.004	0.021	0.001	3.06E−07	0.001	0.002
	VCW	0.011	4.00E−07	0.002	0.014	0.001	1.95E−07	0.001	0.001
Mn	VBW	0.171	1.00E−04	0.036	0.207	0.009	4.97E−05	0.008	0.018
	UPW	0.028	2.00E−05	0.006	0.034	0.002	8.11E−06	0.001	0.003
	BRW	0.107	6.00E−05	0.022	0.129	0.006	3.10E−05	0.005	0.011
	VSW	0.045	3.00E−05	0.010	0.055	0.002	1.32E−05	0.002	0.005
	FVA	0.017	1.00E−05	0.003	0.020	0.001	4.83E−06	0.001	0.002
	ERW	0.034	2.00E−05	0.007	0.041	0.002	9.76E−06	0.002	0.004
	SAP	0.010	6.00E−06	0.002	0.013	0.001	3.01E−06	0.001	0.001
	VCW	0.015	9.00E−06	0.003	0.018	0.001	4.38E−06	0.001	0.002
Cr	VBW	0.014	5.00E−05	0.142	0.155	0.001	2.45E−05	0.033	0.034
	UPW	0.008	3.00E−05	0.080	0.088	0.000	1.39E−05	0.019	0.019
	BRW	0.009	3.00E−05	0.097	0.106	0.001	1.68E−05	0.023	0.023
	VSW	0.105	4.00E−05	0.105	0.115	0.001	1.81E−05	0.025	0.025
	FVA	0.086	3.00E−05	0.086	0.094	0.000	1.48E−05	0.020	0.021
	ERW	0.012	4.00E−05	0.123	0.135	0.001	2.13E−05	0.029	0.030
	SAP	0.008	3.00E−05	0.086	0.094	0.000	1.48E−05	0.020	0.021
	VCW	0.005	2.00E−05	0.057	0.062	0.000	9.84E−06	0.013	0.014

Table 8 (continued)

Metal	Sample	Children				Adults			
		HQing	HQinh	HQderm	HI	HQing	HQinh	HQderm	HI
As	VBW	0.184	6.00E−06	0.094	0.278	0.010	3.18E−06	0.022	0.032
	UPW	0.101	3.00E−06	0.052	0.153	0.005	1.75E−06	0.012	0.018
	BRW	0.189	7.00E−06	0.097	0.286	0.010	3.28E−06	0.023	0.033
	VSW	0.129	4.00E−06	0.066	0.195	0.007	2.23E−06	0.016	0.022
	FVA	0.074	3.00E−06	0.038	0.112	0.004	1.28E−06	0.009	0.013
	ERW	0.138	5.00E−06	0.071	0.208	0.007	2.38E−06	0.017	0.024
	SAP	0.060	2.00E−06	0.031	0.091	0.003	1.05E−06	0.007	0.011
	VCW	0.104	4.00E−06	0.053	0.157	0.006	1.80E−06	0.013	0.018
Hg	VBW	0.016	2.00E−06	0.174	0.193	0.001	6.62E−07	0.027	0.028
	UPW	0.012	1.00E−06	0.135	0.150	0.000	5.15E−07	0.021	0.022
	BRW	0.028	3.00E−06	0.299	0.333	0.001	1.14E−06	0.046	0.048
	VSW	0.014	2.00E−06	0.154	0.172	0.001	5.88E−07	0.024	0.025
	FVA	0.007	9.00E−07	0.077	0.086	0.000	2.94E−07	0.012	0.012
	ERW	0.010	1.00E−06	0.106	0.118	0.000	4.04E−07	0.016	0.017
	SAP	0.025	3.00E−06	0.270	0.300	0.001	1.03E−06	0.041	0.043
	VCW	0.008	1.00E−06	0.087	0.097	0.000	3.31E−07	0.013	0.014

Table 9 Calculated cancer risk of analysed PTEs

Sample	As		Cd		Cr		Pb	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults
VBW	1.07E−05	6.16E−06	4.57E−10	1.15E−09	5.03E−09	1.26E−08	4.45E−07	1.19E−07
UPW	5.91E−06	3.39E−06	1.29E−10	3.24E−10	2.85E−09	7.14E−09	1.27E−07	3.41E−08
BRW	1.1E−05	6.34E−06	3.67E−10	9.22E−10	3.44E−09	8.64E−09	7.89E−07	2.11E−07
VSW	7.52E−06	4.32E−06	2.78E−10	6.98E−10	3.71E−09	9.3E−09	2.77E−07	7.43E−08
FVA	4.3E−06	2.47E−06	6.95E−11	1.74E−10	3.05E−09	7.64E−09	1.52E−07	4.07E−08
ERW	8.04E−06	4.62E−06	2.14E−10	5.36E−10	4.37E−09	1.1E−08	2.17E−07	5.8E−08
SAP	3.53E−06	2.02E−06	8.94E−11	2.24E−10	3.05E−09	7.64E−09	1.96E−07	5.26E−08
VCW	6.07E−06	3.48E−06	1.44E−10	3.61E−10	2.02E−09	5.07E−09	8.2E−08	2.2E−08

cancer risk recorded for these three metals were all below 1×10^{-6} which indicate acceptable cancer risk. Since children are more susceptible to adverse health effects because of less developed immune system it is not advisable to allow children to play in the soils near the automobile workshops (Table 9).

4 Conclusion

The study investigated concentration of Cd, Hg, Pb, Fe, Cu, Zn, Mn, Cr and As and their pollution profiles in soils from the auto-mechanic workshops in the Asante-Mampong of the Ashanti region of Ghana. Their ecological and human health risk were also evaluated. The study revealed that the PTEs recorded occurred at higher levels than those found in the control soil. Levels of investigated metals also exceeded guideline values prescribed by international regulatory agencies such as the European Union and the World Health Organization. Mean concentration of Pb and Cd were higher than their European Union limit of 7.2 mg/kg and 0.35 mg/kg respectively. The study revealed that the automobile workshop Centre is moderately polluted with Cd (contamination factor of 3.06) and highly contaminated with Zn (contamination factor of 4.09). Cadmium poses high risk to the ecological environment with risk factor greater than 92 whereas all other analysed PTEs pose low risk to the ecological environment. The levels of PTEs analysed are not likely to pose adverse health effects to humans at the time of the study because the HQs are less than unity. However, these PTEs are persistent and as such regular monitoring is necessary to ensure they do not accumulate to toxic levels. PTEs in soils can move to other spheres of the environment through leaching, run-off and

evasion where they may enter aquatic ecosystem and the food chain to cause adverse health effects on organisms. The District Assemblies and the Environmental Protection Agency should regulate the activities of the artisanal auto-mechanics in order to institute measures to reduce pollution to the environment.

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Data Availability The data is found in the manuscript or immediately available upon request from the authors.

Declarations

Conflict of interest The authors report that there is no conflict of interests or competing or financial interest to declare.

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