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OCCUPATIONAL HEALTH AND TOXICOLOGICAL RISK OF EXPOSURE TO TOXIC ELEMENTS (TEs) IN TOP SOIL FROM RESIDENTIALLY SITUATED AUTOMOBILE WORKSHOPS (AWs)

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Background: Undoubtedly the biggest single cause of pollution, automobile emissions have a variety of negative occupational and human health impacts. Chemicals, paints, primers, and other hazardous products are frequently used in auto workshops' operational procedures. Substances like petrol, diesel, solvents, lubricants, and grease can be unintentionally or purposely release/exposed to the terrestrial environment. Numerous rock oil products consist of organic compounds that are capable of causing significant risk to soil, organisms, and humans due to their high toxicity. **Objectives:** The study aims to assess the occupational and toxicological risk of exposure to toxic elements (TEs) in topsoil from residentially situated automobile workshops (AWs) in Abeokuta, Ogun State, Nigeria. **Methods:** 12 composite soil samples were strategically collected and transported to the laboratory. 1 g of the processed sample was digested using aqua regia, namely a mixture of nitric acid and hydrochloric acid, optimally in a molar ratio of 1:3, while toxic elements analyses were done using an atomic absorption spectrometer (AAS). **Results:** The result showed the presence of arsenic (As = 0.67 – 5.63 mg/kg), cadmium (Cd = 8.92 – 134 mg/kg), cobalt (Co = 6.21 – 71.22 mg/kg), nickel (Ni = 1.89 – 9.18 mg/kg), and lead (Pb = 32.6 – 211 mg/kg) in the soil. The concentrations of Cd and Pb in 66.7% and 58.3% of the sample are higher than the Canada soil guideline value (CSGV) (for Cd 22 and for Pb 140 mg/kg) respectively. Contamination factors (CF) indicate very high soil contamination from Cd and Pb, and the significant association between the TEs (Pb, Cd, Co, Ni and As) $p < 0.01$, suggests an emergence from an anthropogenic origin. Hazard index (HI) values for the TEs were < 1, except for Pb (27.8) in the children, indicating a significant non-cancer-related effect on exposure, while the total cancer risk (TCR) value was within the threshold limit. **Conclusions:** The investigated topsoil is polluted with Cd and Pb, and there is a non-cancer-related effect on children with prolonged exposure to Pb. Therefore, AWs should be cited away from residential homes, while remediation of the polluted soil should be considered.

Keywords: automobile workshops; health risk; topsoil; toxic elements; environmental hazard.

INTRODUCTION

In Nigeria, automobile emissions are responsible for around 80% of metal contamination or pollution. These emissions contain Cadmium (Cd), Lead (Pb), Nickel (Ni) and Zinc (Zn), with Pb from petrol and Zn from tires being the most significant sources of contamination (Anapuwa, 2014). AWs provide a variety of maintenance services, from quick and easy oil changes to intricate engine rebuilds. When necessary, they offer welding, spraying, electrical, and auto body repair services. Chemicals, paints, primers, and other hazardous products are frequently used in auto workshops' operational procedures. Although the process of automobile refinishing makes the vehicle seem better, it also produces hazardous pollutants that need to be disposed of properly (Sam et al., 2015). Substances like petrol, diesel, solvents, lubricants, and grease can be unintentionally or purposely release/exposed to the terrestrial environment. Numerous rock oil products consist of organic compounds that are capable of causing significant risk to soil, organisms, and humans due to their high toxicity (Sam et al., 2015).

The term "toxic elements" (TEs) refers to heavy metals because of their nucleon number and/or high density (Rehman et al., 2020). Among the TEs, Cu, Zn, Pb, Mn, Cr, Cd, Ni, and Fe are the ones that should be of outmost concern (Appiah-Adjei et al., 2019). The primary sources of these TEs in soil are various man-made activities such as urbanization, industrialization, waste disposal and incineration, vehicular emissions, fertilizer applications, mining, metal and steel refining and fabrication and metallurgical processes, among others (Appiah-Adjei et al., 2019; Umoren et al., 2024).

Numerous investigations have determined that human exposure to particulate matter may occur by ingestion, skin contact, or respiration (Devi & Yadav, 2018). In addition to polluting the environment, the massive rise in TEs has negative health implications for humans (Iwegbue et al., 2019). Exposure to TEs like Zn, Cd, Pb, and Cr has been linked to myriad array of diseases, including neurological disorders, cardiovascular disease, haematological and bone-associated diseases, renal dysfunction, brain injuries, gingivitis, blood disorders and cancer (Olujimi et al., 2015; Mansour et al., 2019). Additionally, TEs such as Arsenic (As) and Fe have the potential to cause cardiac damage and are carcinogenic (Mansour et al., 2019).

In Nigeria, gasoline-powered automobiles emit smoke, which produces dust and metallic oxides, primarily lead oxide (Eludoyin & Ogbe, 2017). While there has been a decrease in the use of leaded petrol in some nations, the decrease in vehicle-based lead (II) ion (Pb^{2+}) generation has been offset by an increase in the number of automobiles. Automobile waste and other variables are responsible for the augmentation of micronutrients in soil (Rakib et al., 2017). In addition, automobile-related activities have been seen in workshops near and around residential areas in Abeokuta, with most of the workers without wearing personal safety equipment. As a result, the goal of this study was to ascertain the topsoil's TEs (As, Cd, Co, Ni, and Pb) concentration and degree of contamination. Furthermore, since information on these TEs is crucial to assessing both the toxicological risk of exposure and workers' health on the job, it was assessed in others to meet the Global Goals 3 and 15.

MATERIALS AND METHODS

Study area

The investigation was conducted in Abeokuta (7.1475° N, 3.3619° E), Ogun State, Nigeria in May 2020. Owing to rising urbanization and quick population expansion, Abeokuta's land area, roughly 2320 km^2 has continued to rise in all directions (Olayinka et al., 2015). Abeokuta is home to 593,140 people in total. The area's products are primarily electronics casings, series abattoir effluents, and steel, and mechanical wastes (Umoren et al., 2024). There are also many traditional quarry processors in the area. The city was built on a rocky ledge that towered over the savanna with surrounding woods. It is located in Nigeria's tropical rain forest zone, which is distinguished by tall trees, a dense canopy of grass, and two separate seasons. Abeokuta has a mean monthly temperature 25.7 – 30.2 °C, relative humidity > 50%, and annual rainfall 2,000 mm respectively (Olayinka et al., 2015). The automobile workshops used for the study were selected due to their location within and near residents. All study sites were of the same soil type (sandy loamy) and well-drained. The descriptive map of Abeokuta in Ogun state, Nigeria adopted from Oyedepo et al. (2015) is presented in Figure 1.

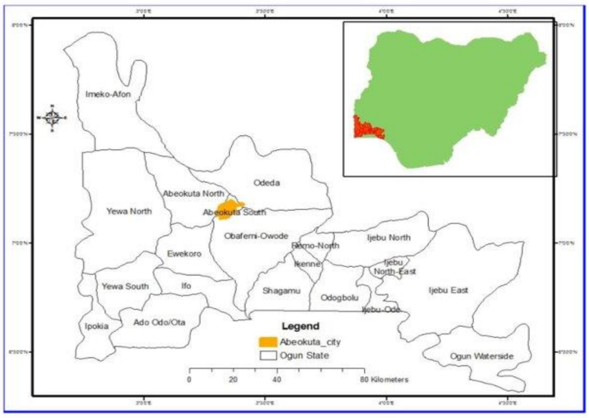

Figure 1. Map of Abeokuta city in Ogun State, South Western, Nigeria

Sample collection and processing

Twelve composite soil was sampled the month of May 2020, from twelve strategically selected automobile workshops with are within and in very proximity to residences (homes) in Abeokuta city. Hand auger was used to for the soil sampling which consist of five subsamples. Plant matters and other dirt were hand-picked from samples. Almost 300 g of bulked sample storage was done in labelled, airtight polythene bags. Samples were subjected to repeated reduction (coning and quartering), further air-dried for 72 h, then sieved using a 1 mm mesh size before acid digesting.

Toxic element analysis

All glassware used for the study was pre-treated with 5% trioxonitrate (IV) acid (HNO_3) then cleaned with distilled water. Aqua regia was used to digest the prepared sample in a digestion flask, which have oven-dried at 35 °C for 15 min. 1 g of the sample was transferred into the flask with 20 cm^3 of aqua regia. The mixture was cautiously stirred and then heated in a fume hood for several hours without time reference. The samples were cooled, filtered and diluted with deionized water to mark 50 cm^3 in a volumetric flask then analysed for TEs (As, Co, Cd, Pb and Ni) using an AAS (Model: ICE3000 series).

Contamination factor (CF)

The degree of contamination/pollution in a soil can be estimated using by various methods, the present study adopted the contamination factor (CF) for estimating the degree of TE contamination in soil (Famuyiwa et al., 2022a). The degree of TE contamination in the soil was estimated using Equation 1:

$$\mathrm{CF} = \frac{\mathrm{TE\ Conc._{\,Sample}}}{\mathrm{TE\ Conc._{Crustal\ region}}}, \quad (1)$$

where $\mathrm{TE\ Conc._{\,Sample}}$ is the TEs concentration in the soil sample near the automobile workshops; $\mathrm{TE\ Conc._{Crustal\ region}}$ is the TEs concentration in the reference level.

The classifications used for the degree of contamination is described as: CF < 1 is low, 1 ≤ CF < 3 is moderate, 3 ≤ CF < 6 is considerable, 6 ≤ CF is very high.

Potential risk assessment

An estimation was made of the health risk that results from humans being exposed to TEs from the soil via the skin, oral, and respiratory pathways (Famuyiwa et al., 2022a; Umoren et al., 2024). Exposure pathways calculation for chronic daily intake (CDI) was estimated using equations 2 – 4:

$$\mathrm{CDI_{Oral}} = \mathrm{TE\ Conc._{\,Sample}} \cdot \left(\frac{\mathrm{OralR \cdot EF \cdot ED}}{\mathrm{MBW \cdot AT}}\right) \cdot 10^{-6}, \quad (2)$$

$$\mathrm{CDI_{Respire}} = \mathrm{TE\ Conc._{\,Sample}} \cdot \left(\frac{\mathrm{RespireR \cdot EF \cdot ED}}{\mathrm{PEF \cdot MBW \cdot AT}}\right), \quad (3)$$

$$\mathrm{CDI_{Skin}} = \mathrm{TE\ Conc._{\,Sample}} \cdot \left(\frac{\mathrm{SA \cdot DAF \cdot SAF \cdot EF \cdot ED}}{\mathrm{MBW \cdot AT}}\right) \cdot 10^{-6}, \quad (4)$$

where $\mathrm{CDI_{Oral}}$ is the chronic daily intake on exposure via oral, mg/(kg·day); $\mathrm{CDI_{Respire}}$ – via respiration, mg/(kg·day); $\mathrm{CDI_{Skin}}$ – via skin contact, mg/(kg·day); OralR (oral rate) is 20 and 200 mg/day for children and adults respectively; RespireR (respiration rate) is 7.63 and 20 m^3/day for children and adults respectively (Umoren et al., 2024); EF is the exposure frequency which is 180 and 365 days/year for children and adults respectively; ED is the exposure duration which is 6 and 30 years for children and adults respectively; MBW is the average body weight which is 15 and 60 kg for children and adults respectively; AT is the average exposure time/life expectancy which is 61.33 years (Chen et al., 2014); 10^{-6} mg/kg is conversion factor; SA is the exposed skin surface area which is 2100 and 5800 cm^2 for children and adults; SAF is the skin adherence factor which is 0.2 and 0.07 mg/cm^2/day for children and adults; DAF is the dermal absorption factor used in this study is 0.1 for both children and adult respectively; PEF is the particle emission factor which is $1.36 \cdot 10^{-9}$ m^3/kg for both children and adult (Umoren et al., 2024).

Hazard quotient (HQ) and hazard index (HI) according to Famuyiwa et al. (2022b) were employed for estimating the non-cancer risk of TEs in the soil (USEPA, 2011). HQ is an indicator of the health risk of non-cancerous side effects from TE exposure:

$$\mathrm{HQ_i} = \frac{\mathrm{CDI_i}}{\mathrm{RfD_i}}, \quad (5)$$

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where RfD_i is the reference dose for a particular TEs.

The highest daily TEs dose that can be administered to humans without endangering their health during their lifetime is known as RfD_i. Reference dose RfD_{Oral} (mg/kg/day) for ingestion, RfD_{Skin} (mg/kg/day) for skin contact, and $RfD_{Respire}$ (mg/m^3) for respiration are the three forms of RfD_i that are used for exposure pathways.

The hazard index measures the cumulative risk of specific chemicals from multiple exposures (HI):

$$HI = \sum HQi, \quad (6)$$

where the index i denotes different exposure pathways.

When HI is less than 1, it indicates that there is no appreciable chance of non-cancer side effects. On the other hand, major harmful non-cancer impacts are likely when HI > 1 (USEPA, 2011). The reference dose (RfD_i) multiplied by the corresponding cancer slope factor (CSF) in mg/kg is used to determine the cancer risks to people. A cancer slope factor, calculated using Equation 7, is the upper bound likelihood that a person would get cancer as a result of respiration, skin contact, and oral exposure to contaminated soil during their lifetime:

$$TCRs = RfD_i \cdot CSF_i, \quad (7)$$

where TCR is total cancer risk, that is the likelihood that a person will get any kind of cancer from lifetime exposure to cancer-causing factors.

If TCR less than $1 \cdot 10^{-6}$ specifies negligible cancer risk, while above $1 \cdot 10^{-4}$ recommends high cancer risk to humans on exposure.

Statistical analysis

Data were analysed using SPSS (vs 21) to descriptive statistics while Microsoft Excel (vs 2016) was used for computing the contamination level, risk assessment and data visualizations. The source of the elements in the soil was estimated using the Pearson correlation. $p < 0.05$.

RESULTS AND DISCUSSIONS

Concentration of toxic elements (TEs)

The concentration of TE in the soil is represented in Table 1, due to the unavailability of soil guideline values (SGVs) for specific TE in Nigeria, the comparison to the widely used UK environmental agency SGV (EA, 2013) and Canada soil guideline value (CSGV, 2009) was used. The concentration of As, Co, Cd, Pb and Ni from the study varied from 0.67 – 5.63, 6.21 – 71.2, 8.92 – 134, 32.6 – 211 and 1.89 – 9.20 mg/kg with a mean of 3.16, 46.0, 80.0, 127 and 5.52 mg/kg respectively. The oxidative states and chemical structures of different types of arsenic have a significant impact on their toxicity. As absorbed and passed up through the food chain, the inorganic forms of As found in soil prove to be hazardous, impacting a variety of living species (Shrivastava et al., 2015). The highest As concentration was recorded in sample AW05 (5.63 mg/kg) followed by AW06 (5.56 mg/kg), although As concentration in all samples were below the SGVs by UK (40.0 mg/kg) (EA, 2013) and CSGV (12,040.0 mg/kg) (CSGV, 2009). Constant exposure to As can result in a variety of clinical symptoms, the most common of which are epidermal lesions (Shrivastava et al., 2015). Huang et al. (2009) have identified several clinical symptoms linked to arsenic, such as keratosis, melanosis (hyperpigmentation) and leucomelanosis. According to the International Agency for Research on Cancer (IARC, 2012), As is a well-known carcinogen that can lead to malignancies of the skin, bladder, lungs, liver, and kidney. Other conditions include ischemic heart disease, carotid atherosclerosis, and diminished motor and cognitive function (Shrivastava et al., 2015).

Studies on the toxicity of cobalt (Co) to humans and animals have extensively examined the toxic potential of Cobalt and the associated health risks. Prior reviews have frequently concentrated on the effects of Co on a particular physiological system in various Co exposure environments (Catalani et al., 2012; Leyssens et al., 2017) or one particular exposure setting and the associated Co intake routes, toxicity mechanisms, and clinical consequences (Zywiel et al., 2016; Leyssens et al., 2017). The sample with the greatest Co level was observed in AW05 (71.3 mg/kg) followed by sample AW06 (68.9 mg/kg). Excessive cobalt exposure can have gastrointestinal, hematologic, central and peripheral nervous system, metabolic, cardiovascular and endocrine consequences in acute toxicity. Hardmetal illness and occupational asthma are two respiratory disorders brought on by repeated inhalation exposures (Catalani et al., 2012).

According to the ATSDR list, cadmium (Cd) is the sixth hazardous element (Negahdari, et al., 2021). Prolonged exposure to Cd causes cellular mutagenesis, lung damage, and testicular harm (Faridi et al., 2015). The highest Cd concentration was recorded in sample AW06 (134 mg/kg) followed by AW05 (122 mg/kg). Burning petroleum fuels, plastics, glass, welding electrodes used by body work specialists and pigments used in paints for vehicle bodywork, are typically sources of Cd (Lawal et al., 2015). The level of Cd in 66.7% of the samples was above the CSGV (22 mg/kg) while 100% were below the UK (150 mg/kg) respectively (CSGV, 2009; EA, 2013).

Lead (Pb) poisoning results from Pb exposure and impacts the human body, potentially leading to problems in the brain, bowels, and stomach (Umoren et al., 2024). The highest Pb level was recorded in sample AW02 (211 mg/kg) followed by AW06 (189 mg/kg). The concentration of Pb in 58.3% of the samples was higher than the CSGV (140 mg/kg) while 100% was lower than the UK (450 mg/kg) respectively (CSGV, 2009; EA, 2013). AWs are frequently surrounded by battery professionals, or "battery chargers", as they are known throughout Nigeria, and they are a significant source of Pb. Additional sources include the gas exhaust from the majority of cars that are being serviced at these AWs (leaded gasoline and additive use are still prevalent) (Lawal et al., 2015).

Nickel (Ni), a trace element, is used by the human body for sustenance (Taiwo et al., 2019). According to Umoren et al. (2024), nickel has several toxicity mechanisms, including sensitizing and allergenic qualities. Additionally, it's a cancer-causing agent that can cause teratogenicity, chronic bronchitis, pulmonary embolism (PE), heart issues, and cancers of the prostate, throat, and nose. The highest Ni concentration was recorded in sample AW06 (9.18 mg/kg) followed by AW06 (8.32 mg/kg). The level of Ni in 100% of the samples was below the UK standard (200 mg/kg) (EA, 2013). The detected indicators are presented in Table 1.

Contamination factor (CF)

The contamination factor of TEs in the soil is presented in Table 2, revealing that the soil has low contamination with As (0.24) and Ni (0.08), moderate with Co (2.42) and very high with Cd (265) and Pb (6.34). CF value in the descending order of Cd > Pb > Co > As > Ni.

Correlation matrix

The relationship between TEs can give important suggestion about their emerging origins (Famuyiwa et al. 2022a). The relationship between TEs is presented in Table 3, which reveals that Pb has a positive correlation with Cd (r = 0.847), Co (r = 0.941), Ni (r = 0.815) and As (r = 0.814) p < 0.01, Cd has a positive association Co (r = 0.961), Ni (r = 0.739) and As (r = 0.874) p < 0.01. Co has a positive association with Ni (r = 0.856) and As (r = 0.937) p < 0.01 while Ni has a positive correlation with As (r = 0.836) p < 0.01. The TEs that are highly or considerably connected show a similar origin. The substantial correlation between Pb, Cd, Co, Ni and As suggests that these elements have a common anthropogenic (man-made) origin.

Table 1. Toxic element (TE) level in topsoil from automobile workshops

Sample ID	As	Co	Cd	Pb	Ni
AW01	4.18	64.3	113	147	6.92
AW02	3.15	62.4	107	211	8.32
AW03	2.96	48.1	100	162	4.68
AW04	4.02	60.4	111	180	7.02
AW05	5.63	71.3	122	169	7.81
AW06	5.46	68.9	134	189	9.18
AW07	1.48	34.2	82.5	100	2.17
AW08	5.01	66.5	125	169	5.89
AW09	1.79	18.3	15.6	49.0	2.45
AW10	0.67	6.21	8.92	32.6	1.89
AW11	2.02	28.2	21.7	61.9	5.67
AW12	1.56	22.8	20.1	50.2	4.24
Minimum	0.67	6.21	8.92	32.6	1.89
Maximum	5.63	71.2	134	211	9.20
Mean	3.16	46.0	80.0	127	5.52
Standard deviation	1.69	22.8	48.6	63.8	2.47
EA (2013)	40.0	-	150	450	200
CSGV (2009)	12.0	-	22.0	140	-

Table 2. Contamination factor for toxic element (TE) in topsoil

TEs	Mean	CF value	Grade	Degree of Contamination
As	3.16	0.24	CF < 1	Low
Cd	80.0	267	CF > 6	Very High
Co	46.0	2.42	1 ≤ CF < 3	Moderate
Ni	5.52	0.08	CF < 1	Low
Pb	127	6.34	CF > 6	Very High

Table 3. Correction matrix of toxic elements

	Pb	Cd	Co	Ni	As
Pb	1				
Cd	0.947**	1			
Co	0.941**	0.961**	1		
Ni	0.815**	0.739**	0.865**	1	
As	0.814**	0.874**	0.937**	0.836**	1

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

Potential Health Risks

Chronic daily intake (CDI)

The chronic daily intake (CDI) of TEs is presented in Table 4, the CDI for TEs in the soil reveals that the TE intake appears in the order $CDI_{Oral} > CDI_{Skin\ contact} > CDI_{Respire}$, with Co and Cd being the most dosed for children and adults. This further shows that children are at a more venerability to exposure than adults. The CDI for the TEs is in the order of Co > Cd > Pb > As > Ni for children and adults in the environment.

Non-cancer and Cancer risk

Cancer and non-cancer risk associated with TE in soil revealed

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that the HI value for toxic elements was < 1, except for Pb for children, what amounted to 27.8 suggesting a significant non-cancer risk for individuals exposed to Pb. The HI values for the toxic elements appear in the order of Pb > Co > Cd > As > Ni (Figure 2). The total cancer risk (TCR) associated with toxic elements exposure in the soil revealed that TCR values for all TEs were within the threshold limit ($< 1 \cdot 10^{-6}$), indicating that the exposed humans are free from the likelihood of getting cancer after being exposed to TEs in the soil. The TCR values for the toxic elements appear in the order of As > Pb > Cd > Co > Ni for children and As > Ni > Pb > Co > Cd for adults (Figure 3).

Table 4. Chronic daily intake, cancer and non-cancer risk

TEs	CDIOral	CDIRespire	CDISkin	HQOral	HQRespire	HQSkin	HI	TCR=∑CRi
Receptor: Children								
As	2.08E-04	7.90E-12	5.82E-07	2.08E-04	7.90E-12	5.82E-07	6.95E-01	2.67E-05
Cd	5.26E-03	2.00E-10	1.47E-05	5.26E-03	2.00E-10	1.47E-05	5.85E+00	1.08E-10
Co	3.02E-03	1.15E-10	8.46E-06	3.02E-03	1.15E-10	8.46E-06	1.64E+00	9.65E-11
Ni	3.63E-04	1.38E-11	1.02E-06	3.63E-04	1.38E-11	1.02E-06	3.53E-02	3.66E-12
Pb	8.34E-03	3.17E-10	2.33E-05	8.34E-03	3.17E-10	2.33E-05	2.78E+01	6.07E-06
Receptor: Adults								
As	2.23E-05	4.45E-12	5.14E-07	2.23E-05	4.45E-12	5.14E-07	7.59E-02	1.15E-05
Cd	5.64E-04	1.13E-10	1.30E-05	5.64E-04	1.13E-10	1.30E-05	1.08E+00	2.43E-10
Co	3.24E-04	6.48E-11	7.48E-06	3.24E-04	6.48E-11	7.48E-06	1.33E+00	2.18E-10
Ni	3.89E-05	7.78E-12	8.98E-07	3.89E-05	7.78E-12	8.98E-07	5.58E-03	1.36E-06
Pb	8.93E-04	1.79E-10	2.06E-05	8.93E-04	1.79E-10	2.06E-05	2.98E+00	2.60E-06

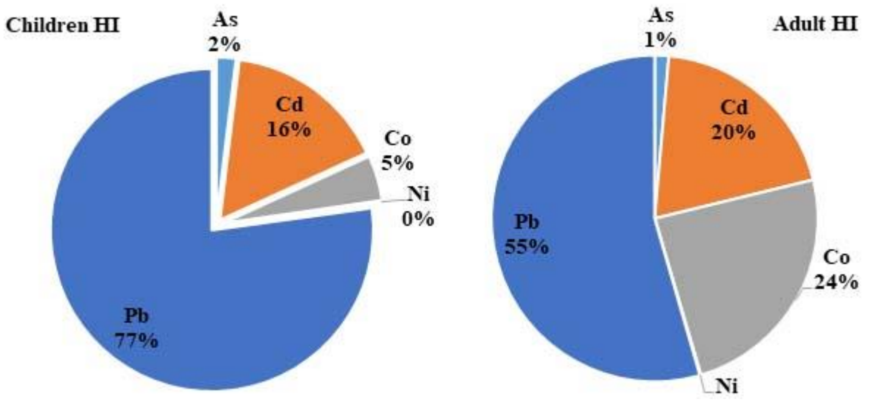

Figure 2. Percentage contribution of individual TE to HI

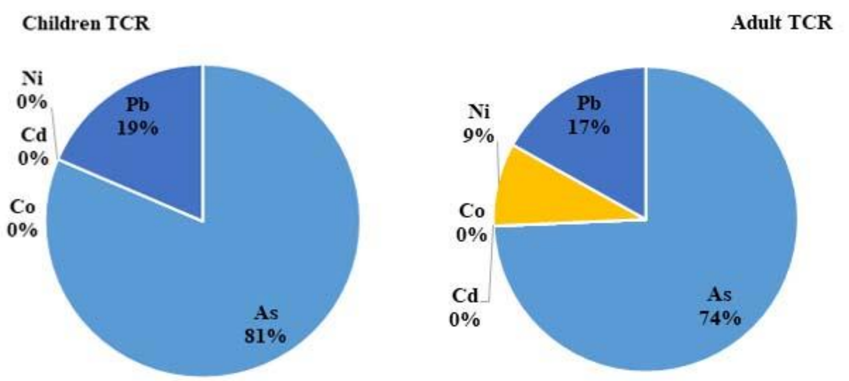

Figure 3. Percentage contribution of individual TE to TCR

CONCLUSION

The study has evaluated the amount of TEs present in the top soils of automobile workshop environments within and close to residences in Abeokuta, Ogun state, Nigeria. The investigated soil is polluted with Cd and Pb, and there is a non-cancer-related effect on children with prolonged exposure to Pb. The workers' attitude to auto maintenance and repairs, as well as their careless and improper disposal of waste, are the primary causes of the sites' gradual degradation. The activities contribute significantly to pollution in the soil which could be leached to surface and groundwater in the environment leading to negative effects on the environment and ill-health effects. In order to prevent the spread of this hazardous element, automobile workshops should be located distant from residential areas and bioremediation can be utilized to clean up the already contaminated soil.

Author's statements

Contributions

Conceptualization: O.D.U., A.O.F., G.O.A.; Data curation: all authors; Formal and statistical analysis: O.D.U., A.O.F., G.O.A.; Investigation: all authors; Methodology: all authors; Visualization: L.I.A.; Writing – original draft: L.I.A.; Writing – review & editing: all authors.

Declaration of conflicting interest

The authors declare no competing interests.

Financial interests

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Data availability statement

No data were used for the current study.

AI Disclosure

The authors declare that generative AI was not used to assist in writing this manuscript.

Ethical approval declarations

Not applicable.

Additional information

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