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Occupational and Environmental Implications of Harmful Elements (HEs) in Top Soil from Artisanal Battery Repair Workshops

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Abstract
Occupational hazards are one of the rapidly emerging areas of interest for environmental health researchers. The study aimed to determine the concentration, intensity of pollution, and the health risk associated with harmful elements (HEs) in topsoil from a battery repair workshop in Sagamu, Ogun State, Nigeria. Ten (10) composite soil samples were collected, then transported to the laboratory for further processing. Exactly, 1 g of the sample was digested using *Aqua regia* solution, while the HE analysis was carried out using Atomic Absorption Spectroscopy. The findings revealed an extremely high level of lead (Pb) across the samples, which were obviously linked to the occupational activities in the workshops dealing mainly with Lead accumulated batteries. Although copper (Cu), zinc (Zn), cobalt (Co), chromium (Cr), and cadmium (Cd) concentrations were all below the stipulated soil guideline values. The geo-accumulation index and enrichment factor suggest Pb and Cd as the major pollutants in the soil emanating from a man-made source. The I-geo and EF value for the HEs both appear similar in the descending order of Pb>Cd>Cu>Zn>Cr> Fe>Co>Mn. Occupational/Human health risk assessment suggests a significant non-cancer risk of exposure to Pb and a cancer risk to both Pb and Cd in the top soil. These findings emphasize the urgent need for intervention to prevent long-term environmental degradation and adverse health outcomes for both workers and the surrounding community.
Keywords: Battery Repair; Harmful Elements; Health Hazard; Occupational; Top Soil

Introduction
Emission of harmful elements (HEs) into the environment (air, water, and soil) is one of the most significant environmental problems caused by man-made activities such as road construction, waste incineration, quarrying, agriculture, sewage disposal, bush burning, automobile workshops, etc. The presence of HEs has been considered a useful chemo-indicator for contamination in sediments, dusty environments, and surface soil [1,2]. Harmful elements (HEs) are non-degradable substances that contaminate the environment and contribute to air pollution, as they can become airborne and enter drainage systems, impacting aquatic ecosystems [3]. When released into soil, HEs can persist for long periods, leaching into deeper layers and aquifers, or being absorbed by plants [4]. Their movement in soils depends on soil properties and the solubility of the HEs [5].

Prolonged exposure to these toxic elements is associated with various health issues, including developmental retardation, carcinogenicity, atherosclerosis, renal disorders, gastrointestinal problems, pulmonary issues, and cardiac diseases [6,7]. Assessing soils contaminated with HEs typically involves measuring their concentrations in different soil horizons and evaluating their mobility [8]. Top soils at artisanal battery repair workshops may accumulate harmful elements (HEs), notably Pb, Cd, Ni, Cu, and Zn, from plate scraping, electrolyte spills, and informal waste handling, potentially exposing workers and nearby residents via dust inhalation and hand-to-mouth contact. While lead's toxicity and the absence of a safe exposure threshold are well established, most evidence in low- and middle-income countries focuses on large ULAB recycling plants, leaving small repair workshops under-characterized despite their ubiquity [9,10]. Recent studies around Nigerian auto-mechanic clusters report elevated topsoil HEs and spatial hotspots linked to workshop activities, suggesting plausible occupational and community health risks, but with limited quantification of exposure pathways and risk indices specific to battery repair operations [7,11-13]. This research aims to determine the concentrations of HEs in topsoil at artisanal battery repair workshops, and to estimate associated non-cancer and cancer risks for workers and surrounding households, thereby informing targeted, low-cost controls and policy [9,14].

Materials and Methods

Description of the Study Area

Sagamu is a conglomeration of thirteen towns located in Ogun state, south western Nigeria, located along the river Ibu and the Eruwuru stream between Lagos and Ibadan. It is the capital of the Remo kingdom. The region is underlain by major deposits of limestones, which is used in the production of cement in the city`s major industries. There are also agricultural products such as cocoa and kola nut. They serve as the largest kola nut collecting center in the nation. Sagamu has an estimated population of 228,382 as at the last population census. The map of Ogun state, showing Sagamu, is presented in **Figure** 1.

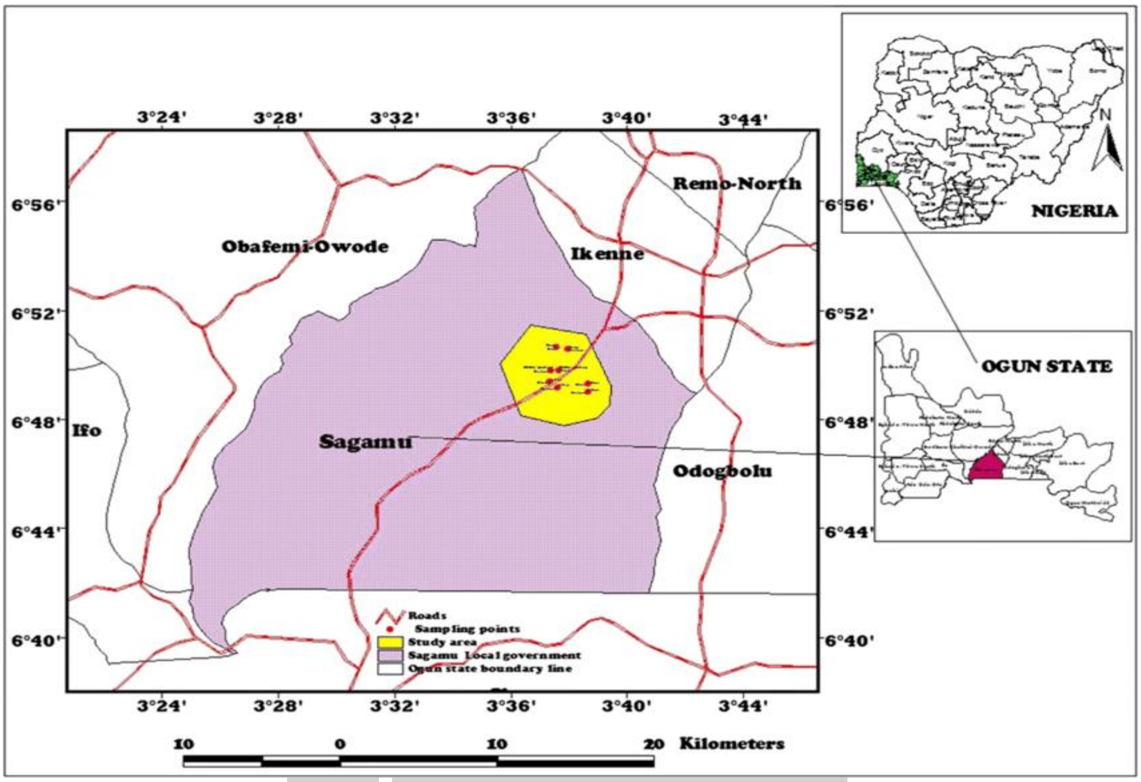

Figure 1: Map of Ogun state showing Sagamu [15].

Collection of Samples and Processing

Composite top soil samples were collected using a soil auger fifteen (15) cm deep from ten (10) battery repair workshops, with their coordinates given in **Table 1**. The soil samples were then placed inside a clean sampling bag then transported to the laboratory for processing. At the laboratory, the samples were air-dried until moisture-free, crushed, and sieved through a 1 mm mesh sieve. The sieved soil samples were further kept in different polyethylene sampling bags and labelled appropriately.

Table 1: Geographical coordinates of the sampling sites

Sample	Coordination
BRW01	6.858367,3.626491
BRW02	6.856973,3.633142
BRW03	6.850961,3.638562
BRW04	6.846160,3.636065
BRW05	6.856711,3.630262
BRW06	6.840061,3.631391
BRW07	6.840389,3.631769
BRW08	6.384031,3.638570
BRW09	6.834813,3.643753
BRW10	6.841542,3.650168

Harmful Element Analysis

To estimate the potential toxic element contamination in the soil, *aqua-regia* (matrix concentration of 1 Nitric acid (HNO_3): 3 Hydrochloric acid (HCl) was employed for the digestion process. Digestion flasks for each of the soil samples were oven-dried at 35° C for 15 minutes. Exactly, 1g of soil sample was weighed and transferred into a well-labelled and oven-dried digestion flask, and 20 mL of *aqua regia* was added to each flask. The mixture was gently stirred to create a homogeneous solution and was then heated inside a fume cupboard until the sample became clear. After cooling, the sample was diluted with 80 mL of deionized distilled water, filtered using Whatman No. 42 filter paper, and transferred into a 100 mL measuring cylinder for volume measurement. The filtrate was stored in a well-labeled 120 mL sterile specimen bottle for elemental estimation using an Atomic Absorption Spectrophotometer.

Pollution indexing

Geo-Accumulation

The evaluation of soil or sediment enrichment can be done in a variety of methods. The index of geo-accumulation (Igeo) and the Enrichment Factors (EF) are two of the most common [16]. The Igeo and EF were used to assess HE distribution and contamination in the soil in this investigation. The geo-accumulation index established by Muller was used to create a quantitative estimate of the level of metal pollution in the analyzed soil. The base 2 logarithm of the measured total concentration of the HE over its background concentration is derived using the following mathematical calculation to produce the heavy metal index (Igeo).

$$\text{Igeo} = \log_2\left[{}^{C_n}/_{1.5\ \times \text{Bn}}\right] \qquad \text{Eqn. 1}$$

Where, Cn is the measured total concentration of the element n in the mud grain size fraction, Bn is the average (crustal) concentration of the element in shale (background), and 1.5 is the factor compensating for the background data (correction factor) due to lithogenic effects. According to Famuyiwa *et al.* [6], the following are the interpretations for the geo-accumulation index: Igeo<0 = practically unpolluted, 0<Igeo<1 = unpolluted to moderately polluted, 1<Igeo<2 = moderately polluted, 2<Igeo<3 = moderately to strongly polluted, 3<Igeo<4=strongly polluted, 4<Igeo<5= strongly to extremely polluted, and Igeo>5 = extremely polluted.

Enrichment factor

Several researchers have used the enrichment factor (EF) to assess contamination in various environmental media [17]. The following is the version that has been adapted to analyze the pollution of various environmental media:

$$\text{EF} = \frac{C_n / C_{\text{ref Sample}}}{B_n / B_{\text{ref background}}} \qquad \text{Eqn. 2}$$

C_n = Concentration of the examined element in the sample, C_{ref} = Concentration of the reference element in the sample, B_n = Background concentration of the examined element, and B_{ref} = Background concentration of the reference element. The contamination categories are recognized on the basis of the enrichment factor: EF<2 states deficiency to minimal enrichment, EF = 2-5 moderate enrichment, EF = 5-20 severe enrichment, EF = 20-40 very high enrichment, EF>40 extremely high enrichments.

Health Risk Assessment Model

The potential occupational and environmental health risk due to exposure to the HEs in the soil through inhalation (via mouth and nose), dermal contact, and ingestion pathways was calculated according to Zheng *et al.* [18] and Umoren et *al.* [19]. Exposure calculation for daily estimation was achieved using the following equations:

$$\text{ED}_{\text{ing}} = \text{C} \times \left[\frac{\text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}\right] \times 10^{-6} \qquad \text{Eqn. 3}$$

$$\text{ED}_{\text{inh}} = \text{C} \times \left[\frac{\text{InhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}}\right] \qquad \text{Eqn. 4}$$

$$\text{ED}_{\text{dermal}} = \text{C} \times \left[\frac{\text{SL} \times \text{SA} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}\right] \times 10^{-6} \qquad \text{Eqn. 5}$$

The health risk posed by human exposure to HEs in the soil was assessed using the Hazard Index (HI) technique and the cancer risk approach, where daily estimation (ED) (mg kg-1 day-1) is the dose contacted through ingestion (EDing), inhalation (EDinh), and dermal contact (EDdermal). Before computing HI, a hazard quotient (HQ) based on non-cancer harmful risk for each element was computed using equation 6. Additionally, the details of each parameter used in calculating individual exposure paths are shown in Table 2.

$$\text{Hazard quotients (HQ)} = \frac{\text{ED}}{\text{RfD}} \qquad \text{Eqn. 6}$$

In order to assess the overall potential of non-carcinogenic effects posed by more than one HE, the calculated values of HQ for each metal were summed, which expressed the Hazard Index (HI).

Hazard's index (HI) = Sum of all hazard quotients (HQ)

To interpret the results of HQ and HI, values greater than 1 indicate that there is a chance for non-carcinogenic effects, and hazard risk values of greater than 1 indicate that there is no significant risk for non-carcinogenic health effects [20]. The carcinogenic risks that range between 10^{-4} and 10^{-6} are considered to be acceptable.

Table 2: Exposure parameters used for the health risk assessment [19]

Parameter	Unit	Child	Adult
Body weight (BW)	Kg	15	70
Exposure frequency (EF)	days/year	180	365
Exposure duration (ED)	Years	6	24
Ingestion rate (IngR)	mg/day	20	200
Inhalation rate (InhR)	m^3/day	7.63	20
Skin surface area (SA)	cm^2	2800	3300
Soil adherence factor (AF)	mg/cm^2	0.2	0.7
Dermal Absorption factor (ABS)	None	0.1	0.1
Particulate emission factor (PEF)	m^3/kg	1.36×10^9	1.36×10^9
Conversion factor (CF)	kg/mg	10^{-6}	10^{-6}
Average time (AT)	Days	25550	2555 0

Results and Discussions

Concentration of HE in Battery Workshop Soil

The concentration, range and standard deviation of HEs (Mn, Fe, Cu, Zn, Co, Pb and Cd) in soil sample from battery repair workshop in Sagamu metropolis in comparison to the international soil guideline values (UK Environmental Agency, Canada Soil Guideline value (CSGV) and the Dutch Intervention Value (DIV)) are given in **Tables 3** and **4**. The mean concentrations of Mn, Fe, Cu, Zn, Co, Cr, Pb, and Cd are 41.5, 4650, 22.4, 2.31, 16.8, 31800, and 6.82 mg/kg, respectively.

The HE concentration ranges from 19.7-82.0, 1090-9440, 21.5-88.5, 12.5-49.8, 0.59-5.49, 9.65-23.5, 5540-71200, and 2.55-11.2 mg/kg. The mean concentration of Cu, Zn, Cr and Cd in the soil samples were all below the stipulated soil guideline values (Cu= CSGV-140, UK-190 mg/kg), (Zn= CSGV-360, DIV-750 mg/kg), (Cr= UK-200, DIV-380 mg/kg), (Cd= UK-150, CSGV-22, DIV-12 mg/kg) while the concentration of Pb in all the sample were higher than the soil guideline values (Pb= UK-450, CSGV-140, DIV-530 mg/kg). The extremely high concentration of Pb recorded across the samples was obviously due to the activities carried out in the workshops, since workers deal mainly with Pb from accumulated batteries. Lead toxicity can result in a wide range of health problems such as gastrointestinal and brain disorders [21].

In comparison to other HE studies in soil, mean concentration for Fe (4650 mg/kg) was lower than the report from Ikorodu, Lagos (16200 mg/kg, [22]) and Abeokuta, Nigeria (11000 mg/kg, [19]) but higher than the report from Oyo, Nigeria (21.30mg/kg, [23]). The concentration of Cr (16.8 mg/kg) and Co (2.31 mg/kg) was higher than the report from Oyo, Nigeria (0.046 and 0.03 mg/kg), respectively [23].

The concentration of Pb exceeded largely the concentration of various studies, such as Accra, Ghana (121 mg/kg, [24]) and Cracow, Poland (49.0 mg/kg, [25]). The concentration of Zn and Mn was lower than the concentration reported from Ikorodu, Lagos (328 mg/kg and 154 kg/kg, respectively [22] and Accra, Ghana (343 mg/kg and 391mg/kg, respectively [24]).

The concentration of Cu (45.2 mg/kg) was lower than the report from Dhaka, Bangladesh (82.0 mg/kg, [26]) but higher than the concentration reported from Lagos, Nigeria (8.0 mg/kg [6]) and Abeokuta, Nigeria (23.6 mg/kg, [9]). Finally, the concentration of Cd was higher than the concentration reported from Ikorodu, Lagos (0.68 mg/kg, [22]) and Accra, Ghana (2.09 mg/kg, [24]).

Table 3: Concentration of HE in soil

Study Area	Fe	Pb	Cu	Cr	Cd	Zn	Co	Mn	Reference
Sagamu, Nigeria	4650	31800	45.2	16.8	6.82	22.4	2.31	41.5	*Current study*
Abeokuta, Nigeria	11000	23.6	12.3	-	0.83	335	-	49.4	[19]
Abeokuta, Nigeria	-	127	-	-	80.0	-	46.0	-	[7]
Ikorodu, Nigeria	16200	58	30	-	0.69	573	-	154	[22]
Oyo, Nigeria	21.30	0.17	0.01	0.046	-	0.43	0.03	0.39	[23]
Lagos, Nigeria	7690	17.0	8.0	20.0	-	86.0	-	132	[6]
Accra, Ghana,	8751	121	-	87.9	2.09	343	-	391	[24]
Dhaka, Bangladesh	-	49.0	82.0	20.0	-	-	-	-	[26]
Accra, Ghana	18380	-	9.58	96.7	-	67.7	-	157	[2]

Table 4: Concentration of HEs in soil compared to other studies

Samples	Mn	Fe	Cu	Zn	Co	Cr	Pb	Cd
BRW01	37.0	1090	24.3	14.7	1.55	14.8	61500	10.5
BRW02	82.0	4190	41.7	49.8	2.45	22.3	6050	8.25
BRW03	19.7	3740	39.1	17.1	1.23	20.9	33600	9.55
BRW04	22.4	5690	88.5	15.9	5.49	23.5	29600	11.2
BRW05	40.8	1550	26.3	39.2	2.55	9.65	71200	6.37
BRW06	57.6	6660	58.5	12.5	3.45	14.3	65800	5.55
BRW07	22.9	2590	44.3	21.4	2.15	11.3	25400	5.25
BRW08	69.1	7820	21.5	17.2	2.11	17.8	5540	6.21
BRW09	35.8	9550	38.5	16.5	0.59	13.2	10300	2.55
BRW10	27.3	3580	69.5	20.1	1.55	20.3	8540	2.70
Minimum	19.7	1090	21.5	12.5	0.59	9.65	5540	2.55
Maximum	82.0	9550	88.5	49.8	5.49	23.5	71200	11.2
Mean	41.5	4650	45.2	22.4	2.31	16.8	31800	6.82
Std. Dev.	21.4	2750	21.3	12.2	1.37	4.84	25800	3.03
[27]	-	-	-	-	-	200	450	150
[28]	-	-	140	360	-	-	140	22
[29]	-	-	190	750	-	380	530	12

Pollution Indexing

Geo-accumulation Index and Enrichment Factor

The geo-accumulation index of HE in soil from battery repair workshops is given in **Table 5**. Iron, Cr, Zn, Mn, Co, and Cu fall under practically unpolluted, while Pb is strongly polluted, and Cd is moderately polluted. The soil from the workshops was unpolluted by the majority of the HEs because their values were less than 1. Enrichment factor in the soil given in **Table 6**, showed that Fe, Cr, Mn, and Co fall within the category of minimal enrichment, Zn is moderately enrichment, and Cu was severely enrichment, while Pb and Cd belong to the extremely high enrichment in the soil. EF value for Pb, Cd, and Cu in the soil was less than 10, suggesting that it emerged from a man-made source, while Fe, Cr, and Zn were less than 10 (fig. 10), suggesting a partial man-made and natural source. Mn and Co possess a value lower than 1, which suggests an emergence primarily from a natural source. I-geo and EF value for the HEs both appear similar in the descending order of Pb>Cd>Cu>Zn>Cr>Fe>Co>Mn.

Table 5: Geo-accumulation index (I-geo) of HEs in soil

HE	Average	I-geo value	I-geo grade	Pollution Level
Fe	4650	-1.18	0	Unpolluted
Pb	31760	3.02	0	Strongly polluted
Cr	16.8	-0.91	0	Unpolluted
Zn	22.4	-0.80	0-1	Unpolluted
Mn	41.5	-1.49	0	Unpolluted
Co	2.31	-1.09	0	Unpolluted
Cu	45.2	-0.17	0	Unpolluted
Cd	6.82	1.18	1-2	Moderately polluted

Table 6: Enrichment factor (EF) of HEs in soil

HE	Average	EF Value	EF Scale	EF Grade
Fe	4650	1	EF<2	Minimal Enrichment
Pb	31760	16100	EF>40	Extremely High Enrichment
Cr	16.8	1.89	EF<2	Minimal Enrichment
Zn	22.4	2.39	EF = 2-5	Moderate Enrichment
Mn	41.5	0.49	EF<2	Minimal Enrichment
Co	2.31	1.23	EF<2	Minimal Enrichment
Cu	45.2	10.2	EF = 5-20	Severe enrichment
Cd	6.82	231	EF>40	Extremely High Enrichment

Human Health Risk Assessment

The estimated average dose is employed to evaluate the amount of HE dosage exposure in the battery repair workshop soil (**Table 7**). Using the human health risk model of the United State Environmental Protection Agency (US EPA), It indicated that of all the studied possible exposure pathway (Ingestion, inhalation and dermal contact), the ingestion pathway was the identified major exposure pathway, furthermore the pathway for the children population were higher than the adult population. Indicating that the children are at a higher risk of HEs exposure than adults.

The HE dosage appeared in the descending pattern of Pb>Fe>Cr>Zn>Co>Mn>Cu>Cd. The health risk assessment (non-carcinogenic and carcinogenic risks) for exposure to the HEs in soil is presented in **Tables 8** and **9**. Hazard Index (HI) value, which is the sum of all possible exposure pathways to HEs in soil, was below 1, except for Pb (6.08E+02 and 7.38E+01), accounting for 100% in the overall studied HEs for children and adults, respectively. This outcome suggests a significant non-carcinogenic risk for children and adults who are exposed to Pb in the soil. The cancer risk assessment of children and adults on exposure to soil in the battery repair workshop showed that the children and adults are a risk of developing cancer from Pb (1.52E-03, 6.52E-04) and Cd (2.42E-04, 1.04E-04) exposure in the soil because their values are higher than the permissible limit (1.00E-06 to 1.00E-04). The total cancer risk for HEs in soil appeared in the descending Pattern of Pb> Cd>Cr for human populations.

Table 7: Estimated Daily Dose of HE in soil

Population	Pathways	Fe	Pb	Cr	Zn	Mn	Co	Cu	Cd
Children	ED_{ing}	3.06E-01	2.09E+00	1.10E-03	1.48E-03	2.73E-03	1.52E-04	2.97E-03	4.48E-04
	ED_{inh}	1.16E-08	7.93E-08	4.20E-11	5.61E-11	1.04E-10	5.77E-12	1.13E-10	1.70E-11
	ED_{derm}	8.56E-04	5.85E-03	3.09E-06	4.13E-06	7.63E-06	4.25E-07	8.33E-06	1.26E-06
Adult	ED_{ing}	3.27E-02	2.24E-01	1.18E-04	1.58E-04	2.92E-04	1.63E-05	3.19E-04	4.80E-05
	ED_{inh}	6.55E-09	4.47E-08	2.37E-11	3.16E-11	5.84E-11	3.25E-12	6.37E-11	9.61E-12
	ED_{derm}	7.56E-04	5.17E-03	2.73E-06	3.65E-06	6.75E-06	3.76E-07	7.36E-06	1.11E-06

Table 8: Non-cancer risk of HE in soil

Population	Exposure Pathway	Pb	Cr	Zn	Mn	Co	Cu	Cd
Children	HQ_{ing}	5.97E+02	3.67E-01	4.93E-03	2.09E-03	5.07E-01	7.43E-02	4.48E-01
	HQ_{inh}	2.25E-05	1.47E-06	1.87E-10	1.17E-09	1.01E-06	2.83E-09	1.70E-09
	HQ_{derm}	1.11E+01	5.15E-02	6.88E-09	4.82E-05	1.42E-03	6.94E-04	5.04E-02
	HI=ΣHQ	**6.08E+02**	**4.18E-01**	**4.93E-03**	**2.13E-03**	**5.08E-01**	**7.49E-02**	**4.98E-01**
Adult	HQ_{ing}	6.40E+01	3.93E-02	5.27E-04	1.95E-02	5.43E-02	7.98E-03	4.80E-02
	HQ_{inh}	1.27E-05	8.29E-07	1.05E-10	2.08E-09	5.70E-07	1.59E-09	9.61E-10
	HQ_{derm}	9.85E+00	4.55E-02	6.08E-09	5.45E-05	1.25E-03	6.13E-04	4.44E-02
	HI=ΣHQ	**7.38E+01**	**8.48E-02**	**5.27E-04**	**1.96E-02**	**5.56E-02**	**8.59E-03**	**9.24E-02**

Table 9: Cancer Risk of HEs in soil

Population	Exposure Pathway	Pb	Cr	Cd
Children	CR_{ing}	1.52E-03	4.74E-01	2.42E-04
	CR_{inh}	2.86E-10	1.48E-10	-
	CR_{derm}	-	-	-
	ΣCR	***1.52E-03***	***1.48E-10***	***2.42E-04***
Adult	CR_{ing}	6.52E-04	2.03E-05	1.04E-04
	CR_{inh}	6.43E-10	3.33E-10	-
	CR_{derm}	-	-	-
	ΣCR	*6.52E-04*	*3.33E-10*	*1.04E-04*

Conclusion

This study highlights the serious occupational and environmental health risks related to harmful elements (HEs) in top soils from battery repair workshops in Sagamu, Ogun State, Nigeria. The exceptionally high concentration of lead (Pb) in the soil, compared to other metals, emphasizes the significant effect of artisanal battery handling on soil quality and public health. The geo-accumulation index (I-geo) and enrichment factor (EF) analyses confirm Pb and Cd as the main pollutants of human origin. Additionally, health risk assessments show a substantial non-cancer risk from Pb exposure and potential cancer risks from both Pb and Cd. These results stress the urgent need for intervention to prevent long-term environmental damage and negative health outcomes for both workers and the nearby community.

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