GSC Advanced Research and Reviews

eISSN: 2582-4597 CODEN (USA): GARRC2

Cross Ref DOI: 10.30574/gscarr

Journal homepage: https://gsconlinepress.com/journals/gscarr/

(Research Article)

Carcinogenic and non-carcinogenic risk assessment of selected heavy metals in soil and groundwater at mechanic workshops in Ilesa, Nigeria

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GSC Advanced Research and Reviews, 2025, 22(01), 169-181

Publication history: Received on 03 December 2024; revised on 12 January 2025; accepted on 14 January 2025

Article DOI: https://doi.org/10.30574/gscarr.2025.22.1.0005

Abstract

This study examines heavy metal pollution and associated health risks in soil and groundwater at mechanic workshops in Ilesa, south western Nigeria. Heavy metals analyzed (Pb, Fe, Cu, Cr, Co, Ni, Zn, As) were quantified using atomic absorption spectrophotometry. Soil concentrations exceeded target values for most metals, while groundwater levels surpassed permissible limits, except for Cu and Fe. Health risk assessments showed total hazard index (HI) values of 1.81×10^{3} for children, indicating high non-carcinogenic risks, while adult HI was 2.1×10^{-1}, below the threshold. Carcinogenic risks for Cr, Ni, and Pb exceeded the acceptable range for both age groups, with ingestion being the primary exposure pathway. Groundwater posed significant non-carcinogenic and carcinogenic risks, particularly from Pb and Cr, while as remained within safe limits. Children were found to be at greater risk than adults.

Keywords: Human health risks; Daily exposure; Hazard index; Llesa

1. Introduction

One of the major challenges in both developed and developing countries is environmental pollution, resulting from the deliberate or accidental release of pollutants through industrialization, urbanization, and primarily anthropogenic activities [1,2]. Auto mechanic workshops contribute significantly to hazardous pollution in Nigeria. Activities within these workshops involve artisans engaging in tasks such as panel beating, battery charging, engine transmission repairs, painting, brake and steering adjustments, welding, and soldering. These activities generate various wastes, including asbestos from brake pads, spent engine oil, gasoline, diesel, paint residues, used batteries, spent lubricants, and worn-out spare parts from abandoned automobiles.

Due to improper waste management practices, the wastes generated in auto mechanic workshops are often deliberately or accidentally disposed of within the available space of the workshop. This contributes to elevated pollution levels, particularly with hazardous substances such as heavy metals in the surrounding environment [3]. Heavy metal pollutants are especially concerning due to their toxicity even at low concentrations, bioaccumulation potential, and persistence in the environment. These contaminants pose significant threats to human health and ecological integrity [4,5].

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High levels of heavy metal exposure can adversely affect human health, potentially impairing the kidneys, liver, and central nervous system [6]. For instance, Olalade et al. [7] examined the distribution and evaluation of selected heavy metals in the soil of auto mechanic workshops in Akoka, southwest Nigeria. Their findings revealed high concentrations of metals, except zinc, in potentially bioavailable fractions. Similarly, Ayodele and Afolarin [8] investigated heavy metal contamination in soils from automobile repair workshops in Ibadan, southwest Nigeria. Their study categorized the contamination index of the area as ranging from moderately contaminated to severely polluted, with manganese (Mn), lead (Pb), zinc (Zn), and chromium (Cr) being prominent pollutants.

Heavy metal exposure poses significant health risks. Lead (Pb) affects the central nervous system, leading to reduced cognitive function, behavioral issues, and, in severe cases, seizures or coma. Children are particularly vulnerable, with long-term exposure causing developmental delays and reduced IQ. Cadmium (Cd) primarily damages the kidneys, causing proteinuria and chronic kidney disease. It also disrupts calcium metabolism, leading to bone demineralization and fractures. Mercury (Hg), especially as methylmercury, harms the nervous system, resulting in tremors, memory loss, and developmental delays in children. Arsenic (As) exposure is linked to skin lesions, cancers (skin, bladder, lung), and cardiovascular diseases. Nickel (Ni) and chromium (Cr) are recognized carcinogens associated with lung and nasal cancers [5].

The persistent presence of heavy metals in the environment and their bioaccumulation potential mean these contaminants pose both immediate and long-term threats to human health and ecological systems. Addressing these risks requires stringent waste management practices, particularly in industries such as auto mechanic workshops, to mitigate heavy metal contamination in soil and water.

Abegunde and Adelekan [9] evaluated groundwater and soil contamination by heavy metals in an auto repair workshop in Ibadan. Their results indicated that while heavy metal levels in water samples were generally within WHO's acceptable limits, copper (Cu) exceeded the threshold. In soil samples, heavy metals were above acceptable values except for lead (Pb) and cadmium (Cd), which were below the limit, and nickel (Ni), which was undetectable. Similarly, Ipeaiyeda and Dawodu, [10] investigated heavy metal contamination in topsoil around auto repair workshops in Iwo, Osun State. They found that lead (Pb), nickel (Ni), and mercury (Hg) concentrations exceeded permissible limits, with their dispersion following the order: Pb > Ni > Hg > Cr > Zn. In Abraka, Delta State, Osakwe [11] studied heavy metal profiles in soil from auto repair shops. The physical properties of the soil samples exceeded acceptable limits, except for lead, which was lower than the control site. The contamination index suggested that soils within automobile workshops were moderately contaminated, except for zinc, which was slightly contaminated.

The increasing rate of indiscriminate siting of auto mechanic workshops within residential areas in Osun State, southwest Nigeria, exacerbates environmental pollution caused by these activities. Despite the significant concentrations of heavy metals released into the environment in these areas, little attention has been given to examining the potential health effects of exposure to heavy metals through soil and groundwater contamination. Therefore, this study aims to evaluate and investigate the non-carcinogenic and carcinogenic risks associated with heavy metals in groundwater and soil around auto mechanic workshops in Ilesa, southwest Nigeria.

2. Materials and method

2.1. Study Area

This study was conducted in the Ilesa region of southwest Nigeria, located at latitude 7°37′N and longitude 4°43′E. The region's climate is classified as humid tropical and is regulated by the interaction of tropical marine and continental air masses. According to Tijani and Onodera [12], the climate is characterized by two distinct seasons: the dry season, which spans from November to early March, and the rainy season, which occurs from late March to early November. The area receives an annual rainfall of 1335 mm [13]. The average wind speed is approximately 2.3 m/s, with the wind direction shifting to the southwest during the rainy season and to the northwest during the dry season.

2.2. Soil sampling

Between December 2017 and February 2018, soil samples were collected from three of the busiest auto mechanic workshops in Ilesa. Each workshop was divided into three quadrants, with three soil samples taken from sampling points spaced approximately 10 to 30 meters apart within each quadrant. These samples were subsequently homogenized to create a composite sample. A soil auger was used when necessary to collect samples from a depth of 0 to 15 cm below the surface. Before sampling, weeds and plant debris were removed using a cutlass to ensure clean soil collection. Control soil samples were obtained from Isokun, a location about 4 km away from the study sites, free from any auto mechanic workshops or related activities. This served as a baseline to assess the impact of the workshops. All collected soil samples were carefully placed in well-labeled, self-sealing polythene bags for subsequent analysis.

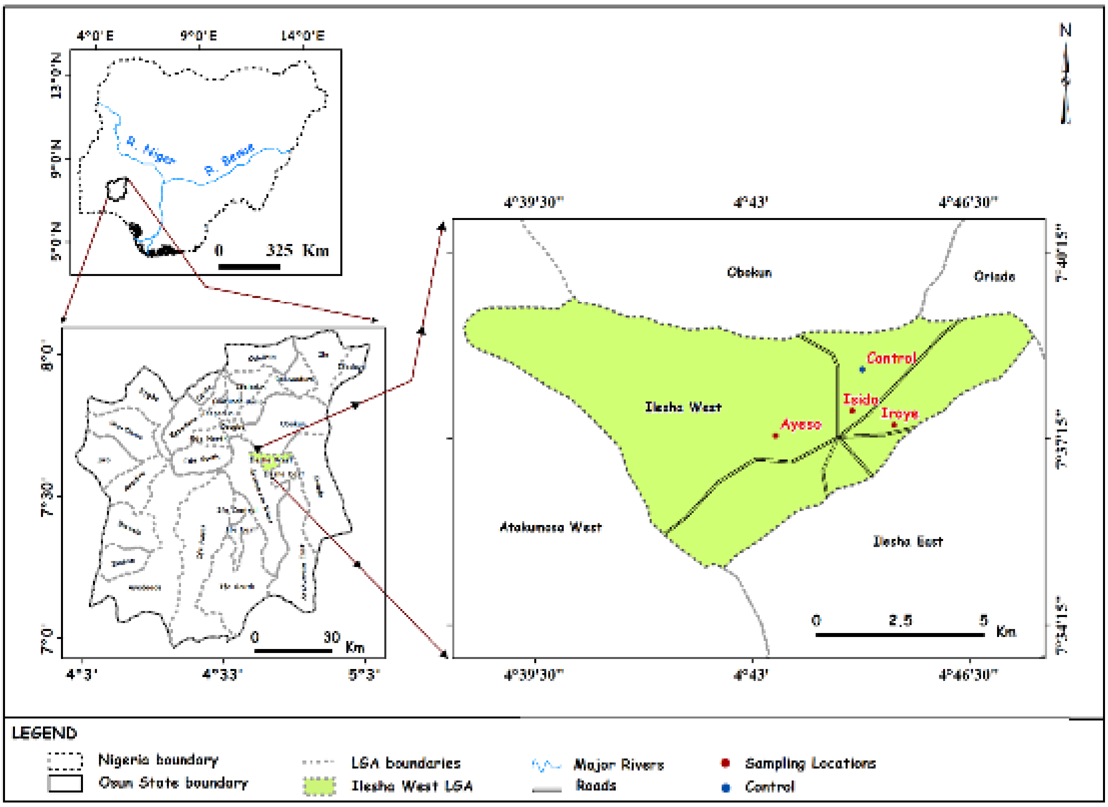

Figure 1 A Map of Ilesa East Local Government Area of Osun State Showing the Sampling Site

2.2.1. Soil sample preparation

The composite soil samples were air-dried at room temperature for three weeks. Once dried, they were gently crushed using a porcelain pestle and mortar to break them into smaller particles. The fine earth fraction (<2 mm) was then obtained by sieving the samples through a 2-mm nylon mesh screen. This fine fraction was subsequently used for various analytical determinations.

2.3. Water Sampling

Groundwater samples were collected from the study area during the dry season, spanning three months (December 2018 to February 2019), with sampling conducted once per month. The samples were obtained from hand-dug wells in Ayeso (L1), Isida (L2), and Iroye (L3) in Ilesa. The study area was divided into three zones, and each zone contributed a composite water sample by collecting water from three randomly selected wells each month. This process yielded a total of nine water samples, which were collected in pre-treated bottles to ensure sample integrity.

For the control sample, a hand-dug well in Isokun, a location unaffected by auto mechanic activities, was selected, and groundwater was collected using the same method.

2.4. Heavy metal Analysis

All glassware, Teflon beakers, and polypropylene tubes were thoroughly washed with soap and rinsed with distilled water. Subsequently, they were soaked in 10% HNO_3 (v/v) for 48 hours. After soaking, the items were washed with soap again and thoroughly rinsed with double-distilled water to ensure cleanliness and remove any residual contaminants. This preparation method followed the procedure described by Ogunfowokan et al. [14].

2.4.1. Water sample preparation for analysis of heavy metals

The digestion process followed the method described by VanLoon [15]. Water samples were first filtered using a Whatman No. 42, 9 cm filter paper. A 100 mL portion of the filtrate was transferred into a beaker, to which 10 mL of

50% concentrated hydrochloric acid and 15 mL of concentrated nitric acid were added. The mixture was heated on a hot plate until nearly evaporated and then further heated for 10 minutes after adding 7 mL of 50% concentrated hydrochloric acid. Once cooled, distilled water was added to the solution, and it was filtered into a 100 mL Pyrex volumetric flask. The volume was adjusted to 100 mL using distilled water. These prepared 100 mL water samples were then analyzed to determine the presence of heavy metals.

2.4.2. Digestion of soil samples

Following the methodology described by Olayinka et al. [16], 0.5 grams of each soil sample was weighed into a beaker, and 6 mL of freshly prepared aqua regia (HNO_3:HCl in a 1:3 ratio) was added. The beaker was covered with a watch glass, and the sample was heated on a digesting block for approximately 30 minutes. The mixture was then allowed to cool and simmer.

The digested content was quantitatively filtered and transferred into a 100 mL volumetric flask, with the volume adjusted to 100 mL using distilled water. The prepared solution was transferred into a sterilized reagent bottle and stored until analysis. Heavy metal concentrations were determined using an atomic absorption spectrophotometer (Perkin Elmer Analyst 400, S/N 201S12051104).

2.5. Assessment of Health Risk

Assessing health risks to humans involves evaluating the nature and extent of health impacts on both adults and children exposed to harmful substances in contaminated areas. In this study, health risk assessments were conducted following the methodology outlined by the United States Environmental Protection Agency (USEPA). The potential health risks associated with heavy metal exposure for adults and children were evaluated using the concentrations of heavy metals detected. The USEPA exposure equations were employed to estimate intake across different pathways, including oral ingestion (I_ingestion), inhalation (I_inhalation), and dermal contact (I_dermal), based on the average concentrations of heavy metals [17]. These pathways were considered to determine cancer and non-cancer risk assessments. The intake for each exposure route was calculated using the following formulas.

$$\text{Intake}_{\text{ingestion}} = \frac{C\ X\ lngR\ X\ EF\ X\ ED}{BW\ X\ AT} X 10^{-6} \qquad \text{……………………1}$$

Where EF is the frequency of exposure (day/year), C is the contaminant concentration in the soil (mg/kg), and IngR is the ingestion rate (mg/day).BW stands for average body weight (kg), AT for average time (days), and ED for exposure duration (years) [18]

$$\text{Intake}_{\text{inhalation}} = \frac{C\ X\ inhR\ X\ EF\ X\ ED}{PEF\ X\ BW\ X\ AT} \qquad \text{……………………2}$$

Where PEF is the particle emission factor (m3/kg) and InhR is the inhalation rate [19].

$$\text{Intake}_{\text{dermal}} = \frac{C\ X\ SA\ X\ SAF\ X\ ABS\ X\ EF\ X\ ED}{BW\ X\ AT} X 10^{-6} \qquad \text{……………………3}$$

SAF stands for skin adherence factor for soil (mg/cm3), whereas SA is the surface area of the skin that meets the soil (cm3). Dermal Absorption Factor is also known as ABS [20]

2.5.1. Non Carcinogenic and Carcinogenic Risk Assessment

By dividing the daily dose by a certain reference dose, the hazard quotient (HQ) based on the toxic risk of cancer and non-cancer was determined as follows [17]

$$HQ = \frac{Intake}{RfD} \qquad \text{……………………4}$$

Total Hazard Index (HI) The Hazard Index is the sum of the Hazard Quotients (HQ) for all exposure pathways and heavy metals assessed. It is a dimensionless value used to evaluate the potential non-carcinogenic health risks associated with exposure to multiple hazardous substances.

The total risk that an element poses of not being carcinogenic is indicated by the hazard index (HI), which is the sum of the hazard quotient HQ [21].

$$HI_{ex}P = \sum HQexP \qquad ……………………5$$

(HI = ∑HQ = HQPb + HQCr + HQCd + HQFe + HQZn + HQCu + HQAs + HQNi)

The reference dose RfD (mg/kg/day) represents the estimated value of daily exposure where exp and other exposure pathways are different. If HI is less than 1, there is no significant risk of non-carcinogenic effects; if HI is greater than 1, there is a chance of non-carcinogenic effects occurring and a maximum permissible risk to the human population, including sensitive subgroups (children).The danger of exposure to heavy metals for human health will be evaluated using HI. The exposure parameters are displayed in Tables 1 for a typical residential exposure scenario using various exposure routes.

2.5.2 Cancer risk (CR) The Carcinogenic Risk represents the probability of developing cancer over a lifetime as a result of exposure to a carcinogenic substance. It is typically calculated using the exposure dose and the cancer slope factor of the contaminant.

The average daily consumption (measured in mg/kg/day) was multiplied by a cancer slope factor (CSF) to determine the cancer risk. Using equation 6, cancer risk is calculated as the incremental probability of a person acquiring cancer over their lifetime.

$$CR = CSF*CDI \qquad ……………………6$$

The acceptable limits for a single carcinogenic element and multi-element carcinogens are thought to be 10^{-6} and $<10^{-4}$, respectively [22]

Table 1 Exposure parameters for average dose estimation

Parameter	**units**	**Children**	**Adult**	**reference**
Body weight (BW)	kg	15	70	[17]
Exposure frequency (EF)	days/year	250	250	[23].
Exposure duration (ED)	years	6	25	[17].
Ingestion rate (IR)	mg/day	200	100	[17].
Inhalation rate (IRair)	m3/day	10	20	[24].
Skin surface area (SA)	cm3	2800	3300	[17].
Soil adherence factor (SAF)	mg/cm3	0.2	0.2	[17].
Dermal absorption factor (ABS)	none	0.001	0.001	[25]
Particulate emission factor (PEF)	m^3/kg	$1.316 X 10^{-9}$	$1.316 X 10^{-9}$	[17].
Average time (AT)	days	EDX365		[17].

Table 2 Reference doses (RFD) (mg/kg/day) of heavy metals via ingestion, inhalation, dermal exposure routes and used for the non-carcinogenic health risk assessment and cancer slope factor (CSF) used for carcinogenic health risk assessment

Heavy metals	**Pb**	**Fe**	**Cu**	**Cr**	**Co**	**Ni**	**Zn**	**As**
RFD Inhalation	0.0035	0.8	0.045	0.00003	0.0000057	0.025	0.35	0.35
RFD Ingestion	0.0035	0.7	0.04	1.5	0.02	0.02	0.3	0.0003
RFD Dermal	0.000525	0.7	0.04	0.003	0.0000057	0.02	0.3	0.0003
CSF	0.0085			0.5		1.7		

3. Result and discussion

Table 3 Mean concentration ± standard deviation and ranges of heavy metals of soil and groundwater

HEAVY METALS	Soil(mg kg -1)			water(mgL^{-1})		
		Control	Target Value(mg kg^{-1})		Control	
Pb	440.77 ± 417.77 39.70 – 1045.00	0.0	85	0.02 0.00 – 0.05	0.015	0.01
Fe	1019.76 ± 8.15 1006.44 –1031.76	BDL	38000	0.05 ± 0.13 0.00 – 0.41	0.03	0.1
Cu	174.22 ± 128.85 56.00 – 470.00	BDL	36	0.00 ± 0.00 0.00 – 0.00	0.5	2.0
Cr	541.44 ± 20.20 520.00 – 580.00	0.10	100	2.36 ± 0.01 2.35 – 2.39	0.10	0.050
Co	91.86 ± 6.01 84.10 – 99.10	0.05	20	0.36 ± 0.00 0.36 – 0.37	BDL	0.050
Ni	137.06 ± 394.53 0.10 – 1189.00	0. 01	35	0.06 ± 0.16 0.00 – 0.49	0.02	0.02
Zn	1124.44 ± 128.17 880.00 – 1260.00	BDL	140	5.56 ± 0.53 4.80 – 6.15	1.5	3.0
As	0.58 ± 0.25 0.20 – 0.90	0.001	1.0	0.002 ± 0.000 0.001 – 0.004	BDL	0.001

BDL: below detection limit

3.1. Heavy metals in soil samples within the mechanic workshop

The heavy metal concentrations in the soil samples used for this study are presented in Table 3. Iron (Fe) was found to be within the permissible limits set by the World Health Organization (WHO), while other heavy metals such as copper (Cu), chromium (Cr), lead (Pb), cobalt (Co), zinc (Zn), nickel (Ni), and arsenic (As) exceeded the target values. Lead (Pb) had the highest concentration of heavy metals in the studied area, while iron (Fe) was found to have the lowest concentration of heavy metals. The elevated Pb concentration may be linked to the indiscriminate disposal of waste engine oil and expired motor batteries by artisans within the available spaces in the mechanical workshops.

The findings of this study are consistent with those of Aloysius et al. [26] and Famuyiwa et al. [27], who also observed high concentrations of As, Cu, Co, Pb, Ni, Zn, and Cr in urban soils near automobile workshops in Lagos and Gboko, respectively. Exposure to these heavy metals, through ingestion, inhalation, or skin contact, may negatively affect human health. For instance, exposure to Pb may lead to symptoms such as weight loss, fatigue, hypertension, renal tumors, and memory imbalance [28]. Nickel (Ni) exposure can impair pulmonary function, cause fibrosis, and lead to kidney diseases [28, 29]. While Cu and Cr are essential elements in the body, excessive exposure can be toxic. High levels of Cu in water can cause toxic effects in infants, known as "pink disease," while excessive exposure to Cr may lead to skin conditions like eczema [28].

3.2. Heavy metals in groundwater samples within the mechanic workshop

Table 3 shows the heavy metal concentrations in the groundwater samples obtained from the study area. The concentrations of copper (Cu) and iron (Fe) were found to be within the acceptable limits set by the World Health Organization (WHO) [30]. These findings are consistent with the results obtained by Tajudeen et al. [31], who also reported low concentrations of Cu and Fe in groundwater in Lagos, Nigeria. However, the concentrations of zinc (Zn), lead (Pb), and nickel (Ni) in the study area exceeded the WHO's acceptable levels. These results are similar to those reported by Nwachukwu et al. [32].

The elevated levels of Pb, Zn, and Ni in the groundwater samples may pose adverse health effects on individuals in the vicinity of the mechanic workshops if the water is consumed without proper treatment. High concentrations of Pb in the body can lead to hypertension, disrupted calcium metabolism, and neurological disorders [31]. Exposure to Ni has been linked to renal and cardiovascular disorders. The high levels of heavy metals in the groundwater could be attributed to the leaching of waste materials from the mechanical workshops in the study area.

3.3. Ecological risk assessment of the heavy metals

The assessment of ecological risk involves evaluating the nature, extent, and impact of pollutants on human health, particularly individuals who may have been exposed to toxic or harmful substances in a contaminated environment. Human exposure to heavy metals and other pollutants typically occurs through various pathways, such as inhalation of dust and aerosol particles, ingestion of food, drinking of contaminated water, and dermal absorption of heavy metals onto the skin [33].

In this study, the health risk assessment and exposure pathways for heavy metals in soil were determined using equations (1), (2), and (3) based on the mean concentrations of specific heavy metals and their potential routes of exposure. Table 4 presents the results for the hazard quotient (HQ), average daily intake (ADI), and hazard index (HI) for both adults and children, considering the pathways of ingestion, inhalation, and dermal contact.

With the exception of the inhalation pathway, where the adult ADI was higher than the child ADI, the values for ADI were higher for children across all three pathways. These findings align with the investigations of Akhigbe et al. [33] and Enyoh and Beniah [34], which also observed that children typically have higher ADI values than adults. This suggests that, when exposed to elevated concentrations of heavy metals through skin contact and oral ingestion, children in the study area are more likely to accumulate higher levels of heavy metals in their bodies compared to adults.

3.4. Non-carcinogenic health risk assessment for soil sample

The Hazard Quotient (HQ) and Hazard Index (HI) for non-carcinogenic health risks were calculated from the mean concentrations of specific heavy metals through different exposure pathways using Eqs. (4) and (5) for both children and adults. The results of the non-carcinogenic health risk assessment are presented in Tables 4 and 5, showing the HQ and HI values for both children and adults across various exposure pathways.

For heavy metals with HQ values less than 1, no significant health risk is posed to either children or adults. However, for metals with HQ values greater than 1, there is a significant probability of non-carcinogenic effects on the health of both children and adults. The Total Hazard Index (THI) values, where THI > 1, indicate a substantial likelihood of non-carcinogenic effects, while THI values less than 1 imply a low probability of such effects.

In this study, the HQ values were less than 1 for both children and adults through the inhalation and dermal exposure pathways. However, for the ingestion pathway, the HQ value was greater than 1, indicating a higher risk. The observed THI values for specific heavy metals in children (1.81×10^{-3}) were greater than 1, while the THI for adults (2.1×10^{-1}) was less than 1. This suggests that long-term exposure to contaminated soil in the study area poses a non-carcinogenic risk, with children being at a higher risk of exposure to heavy metals through contaminated soil than adults. These findings are consistent with the results of Akhigbe et al. [33], who also suggested that exposure to contaminated soil through various pathways presents a greater health risk to children than adults. Additionally, similar findings in China by Ying et al. [35] reported that children's THI values for soil from an abandoned open dumpsite ranged from 1.16 to 1.36, further supporting the observation that children are more vulnerable to non-carcinogenic health risks associated with contaminated soil.

3.5. Carcinogenic health risk assessment for soil sample

Using Equation (6), the excess lifetime cancer risks (CR) for children and adults were determined based on the mean concentrations of specific heavy metals through different exposure routes. According to the safe range recommended by the U.S. Environmental Protection Agency (USEPA), which is between 1×10^{-6} and 1×10^{-4}, there is no apparent health danger when the cancer risk (CR) is less than 1×10^{-6}. An acceptable risk is considered when CR falls between 1×10^{-6} and 1×10^{-4}, while a risk is deemed unacceptable if CR exceeds 1×10^{-4}.

The total cancer risk for Cr, Ni, and Pb in both adults and children was found to be 4.97×10^{-4} and 4.634×10^{-3}, respectively, both of which exceed the permissible range of 1×10^{-6} to 1×10^{-4}. This indicates that the soil samples from the study area pose a carcinogenic risk, with children being at a higher risk than adults due to their increased exposure.

Furthermore, the ingestion pathway, particularly for Cr, contributed significantly to the elevation of lifetime cancer risk, followed by inhalation and dermal exposure pathways.

These findings are consistent with results reported in Northern Tibet, China [36], Barkin Ladi, North Central Nigeria [37], and Lagos State, Nigeria [38], where similar risks related to heavy metal exposure were observed, further supporting the conclusion that long-term exposure to contaminated soil can pose a significant cancer risk, especially to children.

Table 4 Exposure assessment through ingestion, inhalation and dermal in the soil

Metals	**ADD_{ing}**			**ADD_{inh}**			**ADD_{der}**		
	Children	adult		Children	adult		Children	adult	
Pb	0.004025	0.000431		1.53E-07	6.55E-08		1.13E-05	2.85E-06	
Fe	0.009313	0.000998		3.54E-07	1.52E-07		2.61E-05	6.59E-06	
Cu	0.001591	0.00017		6.05E-08	2.59E-08		4.45E-06	1.13E-06	
Cr	0.004945	0.00053		1.88E-07	8.05E-08		1.38E-05	3.5E-06	
Co	0.000839	8.99E-05		3.19E-08	1.37E-08		2.35E-06	5.93E-07	
Ni	0.001252	0.000134		4.76E-08	2.04E-08		3.5E-06	8.85E-07	
Zn	0.010269	0.0011		3.9E-07	1.67E-07		2.88E-05	7.26E-06	
As	5.3E-06	5.68E-07		2.01E-10	8.62E-11		1.48E-08	3.75E-09	

Average daily dose for inhalation (ADDinh) Average daily dose for ingestion (ADDing) and Average daily dose for dermal contact (ADDder)

Table 5 Non-Carcinogenic and Carcinogenic Risk Assessment results in children and adults in the soil within auto mechanic workshop in Ilesa, southwest Nigeria.

Metals	HQ_{ing}		HQ_{inh}		HQ_{der}		CR	
	Children	**adult**	**Children**	**adult**	**Children**	**adult**	**Children**	**adult**
Pb	1.15E+00	1.23E-01	4.37E-05	1.87E-05	0.02146825	0.0054	3.42E-05	3.6659E-06
Fe	1.33E-02	1.43E-03	4.42E-07	1.90E-07	3.72515E-05	9.407E-06		
Cu	3.98E-02	4.26E-03	1.34E-06	5.76E-07	0.000111374	2.812E-05		
Cr	3.30E-03	3.53E-04	6.26E-03	2.68E-03	0.004	0.00116	0.00247	0.00026
Co	4.19E-02	4.49E-03	5.59E-03	2.40E-03	0.412	0.104		
Ni	6.26E-02	6.71E-03	1.90E-06	8.15E-07	0.0001	4.425E-05	0.00212	0.00022
Zn	3.42E-02	3.67E-03	1.11E-06	4.78E-07	9.58427E-05	2.420E-05		
As	1.77E-02	1.89E-03	6.71E-07	2.87E-07	4.94368E-05	1.2485E-05		
HI	**1.36E+00**	**1.46E-01**	**1.19E-02**	**5.10E-03**	**0.438**	**0.1107**		
			Children	**adult**				
THI			1.813426	0.261904		**TCR**	0.004634	0.000496

Hazard Quotient ingestion (HQ_{ing}), Hazard Quotient inhalation (HQ_{inh}), Hazard cancer risks (LCR Quotient dermal (HQ_{del}) Hazard index (HI), Total Hazard index values (THI), cancer risks (LCR) Total cancer risks (TCR)

Table 6 Summary of the non-cancer and cancer health risk for selected heavy metals in the ground water within the mechanic workshop for children

METALS	ADD ing	ADD dermal	HQing	HQdermal	HI	CR
Pb	0.00115	0.000655067	0.328571429	0.181962963	0.510534	3.72878E-05
Fe	0.002875	0.016376667	0.004107143	0.11697619	0.121083	
Cu	0		0	0	0	
Cr	0.1357	1.545957333	0.113083333	0	0.113083	63.45210065
Co	0.0207		0	0	0	
Ni	0.00345	0.0039304	0.1725	0	0.1725	
Zn	0.3197	10.926512	1.065666667	0	1.065667	
As	0.000115	0.000655067	0.383333333	2.183555556	2.566889	0.001155101
		∑HQ=HI	2.067261905	2.482494709	4.549756614	

Average daily dose for ingestion (ADDing), Average daily dose for dermal contact (ADD_{der}) Hazard Quotient ingestion (HQ_{ing}), Hazard Quotient dermal (HQ_{del}) Hazard index (HI) and carcinogenic risk (CR)

3.6. Non-carcinogenic health risk assessment for groundwater sample

Table 7 Summary of the non-cancer and cancer health risk for selected heavy metals in the ground water within the mechanic workshop for Adult

METALS	ADD ing	ADD der	HQ_{ing}	HQ_{der}	HI	CR
Pb	0.0016	0.0005092	0.457142857	0.141444444	0.598587301	3.49864E-05
Fe	0.004	0.01273	0.005714286	0.090928571	0.096642857	
Cu	0		0	0	0	
Cr	0.1888	1.201712	0.157333333	0	0.157333333	49.364592
Co	0.0288		0	0	0	
Ni	0.0048	0.0030552	0.24	0	0.24	
Zn	0.4448	8.493456	1.482666667	0	1.482666667	
As	0.00016	0.0005092	0.533333333	1.697333333	2.230666666	0.0010038
		∑HQ=HI	2.876190476	1.929706349	4.805896824	

Average daily dose for ingestion (ADDing), Average daily dose for dermal contact (ADDder) Hazard Quotient ingestion (HQing), Hazard Quotient dermal (HQder) Hazard index (HI) and carcinogenic risk (CR)

Tables 6 and 7 summarize the values of the Hazard Index (HI) and Hazard Quotient (HQ) for heavy metals in ground water through dermal contacts and ingestion with child's and adults, According to the findings, the HQ value for both children and adults through ingestion exposure to heavy metals ranges from 5.71× 10^{-3} (minimal risk to one's health) to 1.4826 (elevated risk that is non-cancerous), [21] and 4.0× 10^{-3} (medium risk to one's health) to 11.0656 (high risk of non-carcinogenic) respectively, while the calculated HQ value for both child & adult through dermal exposure ranges from 9.09× 10^{-2} (high adverse health risk) to 1.6973(high adverse health risk) and 8.1× 10^{-1} (high adverse health risk) to 2.183 (high adverse health risk) respectively. both the adult and child total hazard index (HI) are 4.805 (high adverse health risk) to 4.549(high adverse health risk) respectively, This suggested that the results of heavy metals' daily consumption levels exceeded the acceptable limit (HI >1) this result show that the people living within the study area are liable to high adverse non carcinogenic risk; Additionally, According to the HI, As and Zn are the two primary heavy metals in groundwater samples that contribute to the total risk of non-carcinogenic human health, Consequently, there is a greater non-carcinogenic risk than what is deemed safe for adults and children when expose to heavy metals through ingestion

of ground water from the study area and dermal contact . Notably, children's higher HI values than adults' indicates that children were more susceptible to the non-carcinogenic danger of heavy metals than adults. These results align with those previously reported in Ondo State, Nigeria (Adesanya et al., 2020), northeast Iran (Alidadi H. et al, 2019) and South-eastern Nigeria River (Anyanwu, and Nwachukwu, 2020).

3.7. Carcinogenic risk health risk assessment for groundwater sample

Using equation (6), Tables 6 and 7 present an overview of the estimated target carcinogenic risk (TCR) values for the three carcinogenic metals under study (Ni, Cr, and Pb) in groundwater samples. The order of carcinogenic risk is as follows: Cr > Pb > As. The TCR values range from 0.001 to 49.3 for children and 0.0011 to 63.452 for adults. According to the safe range recommended by the USEPA, cancer risk should be between 1.0 × 10-6 and 1.0 × 10-4 [17]. The estimated cancer risks for adults and children who consume groundwater due to Pb and Cr were higher than the recommended limit of 1.0 × 10-4, while As remained within the safe limit. This may be due to the leaching of waste engine oil from the mechanic workshops around the study area. Continued use of the groundwater could pose cancer risks to water users in the area. The findings suggest that children are at a higher risk of developing cancer due to the presence of the heavy metals Pb and Cr. Because children weigh less, breathe more air, eat more food, and drink more water, they are more susceptible to health risks. These findings are consistent with results reported in Ondo State, Nigeria [39], northeast Iran [40], Ibadan metropolis, southwest Nigeria [42], and the southeastern Nigerian River [41].

4. Conclusion

This study, conducted in Ilesa metropolis, assessed heavy metal concentrations in groundwater and soil near auto-mechanic workshops and the associated health risks. Findings revealed that while iron (Fe) in soil remained within acceptable limits, other metals exceeded target values. In groundwater, metals like copper (Cu) and Fe were exceptions, but others surpassed permissible levels. Contamination from lead (Pb) and chromium (Cr) posed both non-carcinogenic and carcinogenic risks, with children at greater risk due to their higher exposure rates and lower body weight. This study highlights the primary source of contamination as waste oils from auto-mechanic activities and stresses the need for better waste disposal practices and regulations. Urgent intervention is required, including soil remediation, groundwater treatment, and public awareness campaigns. Children, particularly, need prioritization for protective measures due to their higher susceptibility.

Recommendations include enforcing stricter waste disposal regulations, implementing groundwater filtration systems, and using soil remediation techniques like phytoremediation. Regular environmental monitoring and public health education are essential to mitigate health risks. Policy changes, such as zoning regulations for mechanic workshops and stronger enforcement of hazardous materials management, can prevent further contamination. Additionally, health monitoring programs should screen for heavy metal exposure and promote better waste management in local communities.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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