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Quantitative Assessment of Carcinogenic and Non-Carcinogenic Risks of Heavy Metal Exposure Among Adults and Children at Katsina Youth Craft Village, Nigeria

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ABSTRACT

Despite growing evidence of heavy metal toxicity in occupational environments, data on exposure risks among young vocational trainees and ambient child populations in northern Nigeria remain scarce. This study investigated the concentrations and associated health hazards of cobalt, chromium, lead, cadmium, and copper in soils from the Youth Craft Village, Katsina. Elemental concentrations were determined using Flame Atomic Absorption Spectrophotometry (FAAS). Among the heavy metals detected, chromium recorded the highest mean concentration, followed by cobalt, copper, lead, and cadmium in descending order, with respective values of 0.608 ± 0.660, 0.225 ± 0.0531, 0.105 ± 0.297, 0.0382 ± 0.0265, and 0.00431 ± 0.00310 mg/kg, which are below the WHO/FAO permissible limits (Cr: 43.4; Co: 5.00; Cu: 31.6; Pb: 35.8; Cd: 0.99 mg/kg). Hierarchical cluster analysis (HCA) reveals automobile mechanics activities and construction materials as the most dominant source of pollution in the area. Hazard Index (HI) and Hazard Quotient (HQ) estimates across ingestion, inhalation, and dermal exposure pathways were below unity for both adults and children, indicating that non-carcinogenic hazards associated with heavy metal exposure remained within acceptable limits. Assessment of carcinogenic risk indicated that chromium exposure resulted in mean total lifetime cancer risks (TLCR) of 4.01×10^{-6} for children, exceeding the USEPA acceptable threshold (1.0×10^{-6}). These elevated risks, particularly for children population, underscore the imperative for environmental monitoring and public health interventions to reduce chronic exposure due to heavy metals present in the environment.

Keywords: Cancer risk, Heavy metals, Health risk, Carcinogenic effect, Non-carcinogenic effect.

1.0 INTRODUCTION

Heavy metals are of global environmental and public health concern, owing to their persistence in natural systems, resistance to biodegradation, and tendency to bioaccumulate across trophic levels, with consequent adverse effects on ecosystem integrity and public health. (Afolayan *et al.*, 2021; Khatoon *et al.*, 2025). Sub-Saharan Africa is experiencing accelerated urbanisation and industrialisation in parallel with inadequate waste-management infrastructure, resulting in widespread contamination of soil, water and food webs by these metals (Samaila *et al.*, 2023; Akinola *et al.*, 2025). Although some of these elements are essential micronutrients, chronic exposure above guideline thresholds is unequivocally associated with nephrotoxicity, neurotoxicity, immunosuppression, developmental impairment and carcinogenesis (Bello *et al.*, 2019; Khatoon *et al.*, 2025; Oni *et al.*, 2022). Exposure pathways comprise of ingestion of contaminated food or water, inhalation of resuspended dust, and dermal contact. Children and young adults are more susceptible to exposure effects because they have high intake rates relative to body weight and they exhibit behavioural patterns that increase contact frequency (Ibrahim & Samaila, 2025; Carroquino *et al.*, 2012).

Quantitative risk assessments across Nigeria and other developing regions corroborates these concerns. Emurotu *et al.* (2024) reported Cd and Pb concentrations in edible animal offal obtained from Lokoja abattoir that exceeded WHO limits, with hazard indices (HI) and carcinogenic risks (CR) surpassing USEPA safety benchmarks. Alsafran *et al.* (2021) reported CR values for arsenic as high as 6.97×10^{-3} in leafy vegetables from irrigated farms in Qatar, while Bello *et al.* (2019) identified Cr and As as dominant carcinogenic contributors near artisanal gold-mining communities in Shanono and Bagwai. Akinola *et al.* (2025) found HI values well above 1.0 for children exposed to soils and groundwater living close to automobile mechanic shops in Ilesa, Nigeria and Khatoon *et al.* (2025) reported lifetime cancer risks for Ni, Cr and Cd in drinking water that exceeded WHO/USEPA guidelines in Gilgit-Baltistan, Pakistan. Despite its dual role as a year-round vocational training centre for young people and a temporary host to thousands of graduates of the mandatory national service programme (NYSC), the Katsina Youth Craft Village, Katsina State, Nigeria, remains an under-studied environment, particularly with respect to the heavy metal exposure risks faced by its workers and

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trainees, as well as the children who regularly hawk and sell food items within its premises. The area is characterised by anthropogenic activities, waste generation, and frequent land disturbance; conditions that can promote the accumulation and mobilisation of heavy metals in soil (Akinola *et al.*, 2025). Although some studies in the region have reported metal concentrations below World Health Organization (WHO) limits (Ibrahim & Samaila, 2025; Yaradua *et al.*, 2020; Samaila *et al.*, 2023), no targeted investigation has yet been conducted within the camp, leaving potential health risks unassessed.

This study quantified the concentrations of cadmium (Cd), chromium (Cr), lead (Pb), cobalt (Co), and copper (Cu) in surface soil samples of the Katsina Youth Craft Village, Katsina State, Nigeria, and characterised the associated carcinogenic and non-carcinogenic health risks among workers, trainees, and children using USEPA-recommended exposure and toxicity models. Hierarchical cluster analysis (HCA) was further employed to delineate the dominant sources of heavy metal contamination across the study area. The findings in this study have provides critical evidence for environmental management, health-policy formulation and the design of monitoring protocols for vocational centres across Nigeria and similar regions.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was carried out at the Youth Craft Village in Katsina State, located in north-western Nigeria. The Village is situated at approximately 12°57′59″ N latitude and 7°39′02″ E longitude. It serves as a centre for training youth in various vocational skills and crafts, and also hosts the NYSC Orientation Camp, which temporarily accommodates large numbers of graduates for the mandatory national service program each year. Katsina State lies in the semi-arid savannah zone, characterized by sandy-loam soils and seasonal rainfall, creating conditions that can promote the spread and accumulation of pollutants (Ibrahim & Samaila, 2025; Kabir *et al.*, 2024). The role of the Youth Craft Village as both a skills training hub and a residential camp warrants the importance of assessing potential heavy metal pollution and related health risks within the area. The geographical location of the study area is illustrated in Fig. 1.

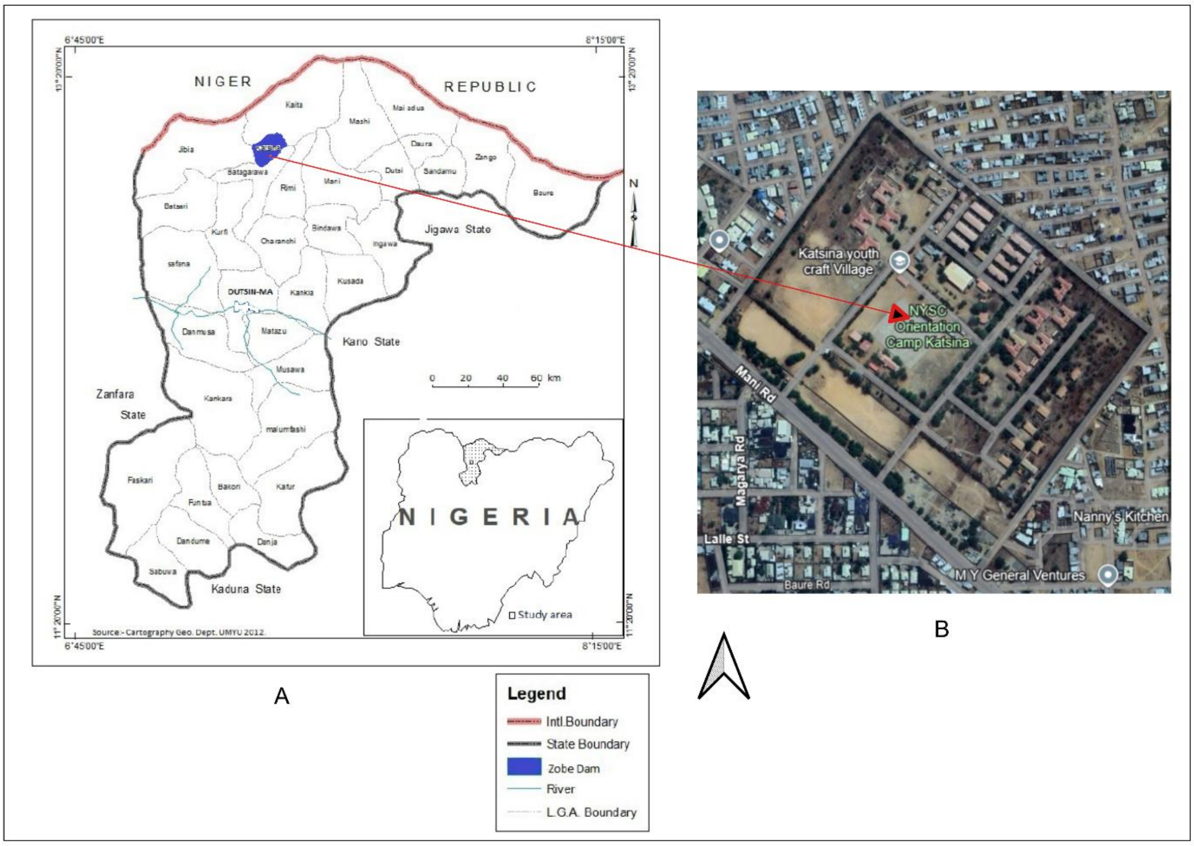

Fig. 1: Map showing the location of the Katsina Youth Craft Village, Katsina State, Nigeria.: (A) Katsina State (Terdoo, 2014; modified) (B) NYSC orientation camp, Katsina (Google Earth, 2025)

2.2 Materials

All reagents used were of analytical grade. Heavy metal concentrations in the digested soil samples were determined using a flame atomic absorption spectrophotometer (FAAS). Soil digestion was carried out with concentrated HNO_3, $HClO_4$, H_2SO_4, and HCl,

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and distilled water was used for dilution. Standard laboratory glassware, including 100 mL volumetric flasks, boiling tubes, funnels, and filter papers, was used for sample preparation. Field equipment comprised a hand auger, GPS device, tape measure, sieves, and polythene bags for soil collection and storage. (Samaila *et al.*, 2023).

2.3 Collection, Preparation, and Chemical Analysis of Soil Samples

The total study area of approximately 238,648.39 m² was systematically subdivided into ten grids, arbitrarily designated A1 to A10, to ensure representative spatial coverage of the facility. Within each grid, one surface soil sample was collected at a depth of 0–5 cm using a stainless-steel trowel, homogenised, and transferred into a clean, pre-labelled polyethylene bag. Samples were thereafter sealed, placed in an ice-cooled chest, and transported to the laboratory where they were stored at 4°C pending preparation and heavy metal analysis.

For the analysis, soil samples were air-dried at ambient temperature until a constant mass was achieved, then a stainless-steel sieve (2mm) was subsequently used to remove coarse particles and debris from the dried soil samples. The dried soil samples were then homogenized using a mortar and pestle to achieve a fine, uniform powder suitable for chemical analysis. For digestion, an accurately weighed 0.5 g aliquot of each processed sample was transferred into a Teflon beaker.

A 2:1 (v/v) mixture of concentrated $HClO_4$ and HNO_3 was used for acid digestion. The samples were heated at 200°C in an oven to facilitate complete organic matter decomposition. After cooling, the residues were dissolved in 5 mL of 20% HNO_3, filtered, and diluted with deionized water to a final volume of 100 mL. To ensure safe handling of corrosive acids, all digestions were performed in a fume hood.

Prior to atomic absorption spectrometry (AAS) analysis, a blank determination was performed to establish baseline instrument readings. The digested samples were then aspirated into the FAAS, and a second blank test was conducted to verify measurement accuracy and to minimize matrix interference. Absorbance values were recorded, and calibration curves were generated to quantify metal concentrations, in accordance with the procedure described by Samaila *et al.* (2023).

2.4 Assessment of Health Risk from Heavy Metals

2.4.1 Non Cancer Effect Evaluation

The principal routes through which humans are exposed to heavy metals in contaminated soils are ingestion, inhalation, and dermal absorption. Health risk characterization for each exposure pathway is predicated on the estimation of the chronic daily intake (CDI), which provides a quantitative basis for evaluating the magnitude of potential adverse health effects. The CDI is estimated using the following equations (Ibrahim & Samaila, 2025; Aguilera *et al.*, 2021, Olagunju *et al.*, 2020):

$$CDI_{ing} = \frac{(C \times IR_{ing} \times EF \times ED \times CF)}{(BW \times AT)} \quad (1)$$

$$CDI_{inh} = \frac{(C \times IR_{inh} \times EF \times ED)}{(PEF \times BW \times AT)} \quad (2)$$

$$CDI_{dermal} = \frac{(C \times SA \times DAF \times EF \times ED \times SAF \times CF)}{(BW \times AT)} \quad (3)$$

$$CDI = CDI_{ing} + CDI_{inh} + CDI_{dermal} \quad (4)$$

In the above expressions, C denotes the heavy metal concentration in soil (mg/kg), as determined in the present study. IR_{ing} and IR_{inh} represent the ingestion rate (mg/day) and inhalation rate (m³/day), respectively. EF and ED refer to the exposure frequency (days/year) and exposure duration (years), respectively, while SA refers to the exposed skin surface area (cm²). SAF and DAF denote the soil adherence factor (mg/cm²) and dermal absorption factor (dimensionless), respectively, and PEF represents the particulate emission factor (m³/kg). BW and AT correspond to body weight (kg) and average exposure time (days), respectively. CF is the unit conversion factor (10^{-6}), and CDI represents the chronic daily intake of the metal under investigation (Ibrahim & Samaila, 2025; Aguilera *et al.*, 2021; Olagunju *et al.*, 2020). The numerical values assigned to these parameters in the present study are presented in Online Resource 1.

2.4.2 Non-Carcinogenic Risk Assessment

The hazard quotient (HQ) provides a dimensionless measure of non-carcinogenic risk by relating the estimated exposure dose of an individual contaminant to its established reference dose. Within the context of human health risk assessment for heavy metals, the HQ was evaluated using the following expression (Akinola *et al.*, 2025; Aguilera *et al.*, 2021; Olagunju *et al.*, 2020):

$$HQ = \frac{\text{CDI}}{\text{RFD}} \quad (5)$$

Where CDI is the chronic daily intake ($mgkg^{-1}day^{-1}$) through various exposure routes (ingestion, inhalation, and dermal contact), and RfD is the reference dose for the specific pollutant ($mgkg^{-1}day^{-1}$), established from toxicological data. The RfD values adopted in this study are provided in Online Resource 2.

The hazard index (HI) represents the summation of HQ values for all pollutants detected in the soil, indicating the combined non-carcinogenic risk from multiple contaminants.

$$HI = HQ_1 + HQ_2 \ldots\ldots + HQ_n \quad (6)$$

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An HI value ≤ 1 indicates that exposure levels are within acceptable limits, whereas an HI value > 1 suggests a potential health risk. (Akinola *et al.*, 2025; Alsafran *et al.*, 2021).

2.4.3 Carcinogenic Risk Assessment

Carcinogenic risk characterization involves estimating the incremental lifetime probability of cancer development in individuals chronically exposed to metals with established carcinogenic classifications. The lifetime cancer risk (LCR) associated with each exposure pathway was determined using the expressions outlined below:

$$LCR_i = ADI \times CSF_i \quad (7)$$

Where i represent the exposure routes via ingestion, inhalation, and dermal routes. CDI is the chronic daily intake, while CSF_i is the cancer slope factors for the relevant exposure routes (Khatoon *et al.*, 2025). The specific CSF values applied in this study are listed in Online Resource 2.

The total lifetime cancer risk (TLCR) is obtained by the summation of the LCR values for all exposure pathways.

$$TLCR = \sum LCR_i \quad (8)$$

An LCR above 1.0×10^{-4} indicates an unacceptable cancer risk, whereas regulatory guidelines consider lifetime cancer risks greater than 1.0×10^{-6} to be above threshold limits (Khatoon *et al.*, 2025; Pavilonis *et al.*, 2017; Niknejad *et al.*, 2023).

2.4.4 Statistical Analysis

We used the IBM SPSS Software (Version 25) to conduct the descriptive and multivariate statistical analyses. Prior to multivariate analysis, Shapiro–Wilk test was used to assess the normality of data distribution. Hierarchical cluster analysis (HCA), employing Ward's linkage method with squared Euclidean distance as the dissimilarity measure, was subsequently applied to identify and discriminate potential sources of heavy metal contamination across the sampled locations. Graphical outputs were generated using OriginPro 2025, and the study area map was produced and cartographically refined in QGIS software (Version 3.30.3).

3.0 RESULTS AND DISCUSSIONS

3.1 Results of Heavy Metal Concentrations

Table 1 presents the mean concentrations of selected heavy metals for cobalt, chromium, lead, cadmium and copper in samples obtained from the research area. The concentrations ranged from 0.119 to 0.190 mg/kg for Co, 0.0046 to 1.96 mg/kg for Cr, 0.0021 to 0.0917 mg/kg for Pb, 0.0003 to 0.0074 mg/kg for Cd, and 0.0001 to 0.995 mg/kg for Cu. The corresponding mean concentrations (± standard deviation) were 0.160 ± 0.0202 mg/kg for Co, 0.554 ± 0.688 mg/kg for Cr, 0.0280 ± 0.0288 mg/kg for Pb, 0.00231 ± 0.00182 mg/kg for Cd, and 0.104 ± 0.297 mg/kg for Cu. The boxplot in Fig. 2 illustrates the distribution and variation of heavy metals concentrations across the sampling sites. Notably, chromium and copper exhibited broader interquartile ranges and noticeable outliers. According to mean concentrations, the descending order of heavy metal abundance in the study area was Cr > Cu > Co > Pb > Cd.

All observed mean values were below the permissible limits recommended by the World Health Organization (WHO) and Food and Agriculture Organization (FAO), which are 5.00 mg/kg for Cobalt, 43.4 mg/kg for Chromium, 35.8 mg/kg for Lead, 0.99 mg/kg for Cadmium, and 31.6 mg/kg for Copper (Kawichai *et al.*, 2023). This indicates that, overall, the soils in the area are not contaminated at levels that pose significant ecological risks, which are consistent with findings from similar studies in Katsina State (Ibrahim & Samaila, 2025; Samaila *et al.*, 2022; Yaradua *et al.*, 2022). The relatively low metal concentrations observed in the present study are attributable predominantly to natural geogenic contributions and the attenuation of contaminant levels through rainfall-induced leaching and surface runoff. Though, the elevated concentrations of chromium at A6 and copper at A3 suggest possible anthropogenic inputs, potentially linked to activities such as automotive repair or improper disposal of electronic waste.

Table 1: Heavy metals concentration values in (mg/Kg) found in the soil samples of the study area.

SAMPLE CODES	COBALT Co	CHROMIUM Cr	LEAD Pb	CADMIUM Cd	COPPER Cu
A1	2.85E-01	1.18E-01	5.16E-02	1.16E-02	2.30E-03
A2	2.54E-01	8.83E-02	1.26E-02	5.10E-03	1.14E-02
A3	3.13E-01	5.46E-02	3.37E-02	5.40E-03	9.95E-01
A4	1.95E-01	8.69E-02	9.17E-02	4.00E-03	1.00E-03
A5	2.66E-01	9.56E-02	7.19E-02	2.00E-03	1.73E-02
A6	2.24E-01	1.96E+00	1.06E-02	2.70E-03	1.36E-02
A7	1.57E-01	6.49E-01	4.10E-03	5.00E-04	2.10E-03

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A8	1.85E-01	1.38E+00	2.25E-02	2.30E-03	4.90E-03
A9	2.36E-01	3.26E-01	4.13E-02	2.10E-03	1.70E-03
A10	1.40E-01	1.32E+00	4.18E-02	7.40E-03	2.90E-03
Mean	2.25E-01	6.08E-01	3.82E-02	4.31E-03	1.05E-01
S.D.	5.31E-02	6.60E-01	2.65E-02	3.10E-03	2.97E-01
Min.	1.40E-01	5.46E-02	4.10E-03	5.00E-04	1.00E-03
Max.	3.13E-01	1.96E+00	9.17E-02	1.16E-02	9.95E-01
WHO/FAO	5.00E+00	4.34E+01	3.58E+01	9.90E-01	3.16E+01

S.D. = Standard deviation, Min. = Minimum, Max. = Maximum

Additionally, the mean concentrations of metals measured in this study are lower than those reported at Lambun Sarki by Armaya'u *et al.* (2020), where Pb and Cd reached 0.0253 and 0.0336 mg/kg, respectively. They are also well below levels reported by Adamu (2023) at Ajiwa Fadama, particularly for Chromium, Cr (0.673 mg/kg) and Lead, Pb (0.805 mg/kg). In comparison to agricultural soils assessed by Yaradua *et al.* (2020), the current study Cd and Pb levels are lower, though Cr (0.554 mg/kg) measured in this study exceeds their reported maximum value of 0.344 mg/kg. These results suggest low contamination at the current study site.

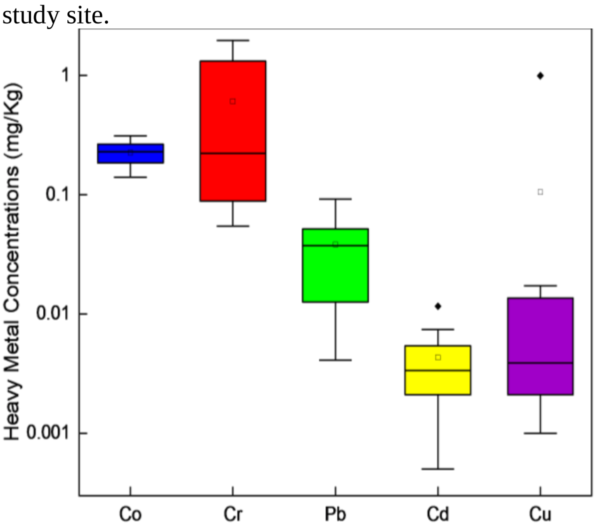

Fig. 2: Boxplot showing the heavy metals concentration at the study area

3.2 Hierarchical cluster analysis (HCA)

To investigate the spatial contamination patterns and potential source associations of Co, Cr, Pb, Cd, and Cu, hierarchical cluster analysis (HCA) was conducted using Ward's minimum variance linkage criterion and squared Euclidean distance as the measure of dissimilarity. The HCA resolved the dataset into four statistically distinct clusters, with each cluster representing a discrete pollution source signature characteristic of the study area. The Dendrogram (Fig. 3) illustrates the separation of metal signatures and the clustering of samples according to dominant anthropogenic activities. To further clarify these patterns, the cluster characteristics and their inferred sources are summarized in Online Resource 3. Samples associated with automobile mechanics' activities (A6, A8, A10) formed a well-defined cluster characterized by exceptionally high chromium concentrations, likely derived from brake linings, lubricants, or metal coatings (Khan *et al.*, 2023). In contrast, samples linked to construction materials (A1, A4, A5, A9) exhibited moderate cobalt and lead levels, consistent with construction-related particulate emissions (Iwegbue *et al.*, 2024; Hussain *et al.*, 2025). Samples tied to electronic waste disposal (A2, A3) displayed elevated cobalt and copper, reflecting the influence of discarded electronic components (Parvez *et al.*, 2021). Welding-related samples (A7) showed high Cr but were differentiated from automobile sources due to minimal Pb and Cd contributions (Khan *et al.*, 2023). These analysis highlights the efficacy of HCA in discerning pollution source fingerprints, supporting targeted environmental remediation strategies.

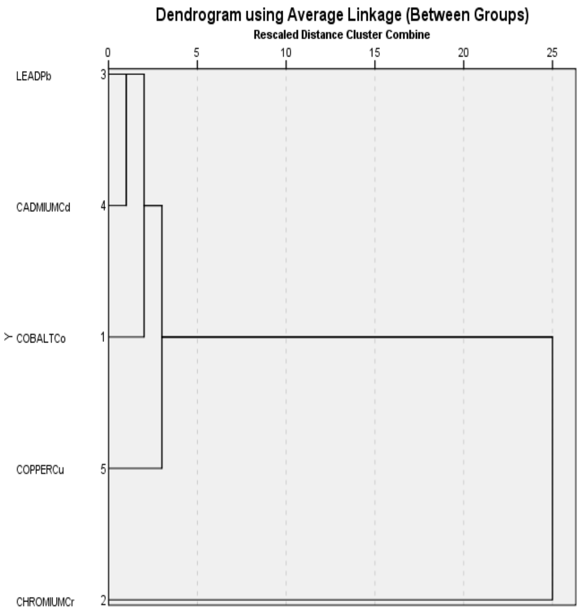

Fig. 3: Dendrogram showing the separation of metal signatures and the clustering of samples

3.3 Evaluation of Human Health Risks from Heavy Metals

3.3.1 Evaluation of Non-Carcinogenic Health Effects

The potential non-carcinogenic human health risks linked with heavy metal exposure through

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contaminated soils were evaluated using the Hazard Quotient (HQ), the magnitude of which is governed by the estimated daily intake of the respective metals (Niknejad *et al.*, 2023). As presented in Table 2, the mean total chronic daily intake (CDI_{total}) values (mgkg^{-1}day^{-1}), derived from Equation 4, were 2.97 × 10^{-6} for Co, 8.01 × 10^{-6} for Cr, 5.03 × 10^{-7} for Pb, 5.69 × 10^{-8} for Cd, and 1.38 × 10^{-6} for Cu in children. For adults, the corresponding values (mgkg^{-1}day^{-1}) were 3.21 × 10^{-7}, 8.67 × 10^{-7}, 5.45 × 10^{-8}, 6.15 × 10^{-9}, and 1.50 × 10^{-7}, respectively. The HQ values for heavy metals through ingestion, inhalation, and dermal exposure pathways are presented in Table 3. In children, as seen in Fig. 4, cobalt exhibited the highest HQ values, particularly through dermal contact (5.53 × 10^{-4}) and ingestion (1.48 × 10^{-4}), followed by lead via ingestion (1.43 × 10^{-4}), while other metals contributed negligibly across all exposure routes. Among adults, cobalt also recorded the highest HQ, especially through dermal exposure (2.59 × 10^{-4}), with chromium contributing moderately through dermal contact (3.50 × 10^{-6}); the remaining metals posed minimal risk (Fig. 4). The estimated HQ values for both children and adults across all exposure pathways were substantially below the threshold value of unity, indicating that heavy metal exposure through contaminated soils poses no appreciable non-carcinogenic health risk to public.

Among the three exposure pathways assessed, dermal contact yielded the greatest HI estimates for both children (5.64 × 10^{-4}) and adults (2.64 × 10^{-4}), with ingestion and inhalation representing progressively diminished risk contributions. The proportional contribution of individual metals to the cumulative HI decreased in the order Co > Pb > Cr > Cd > Cu across both demographic groups. These observations are broadly consistent with previous investigations conducted by Bello *et al.*, (2019), Mohammadi *et al.*, (2019) and Yaradua *et al.*, (2022).

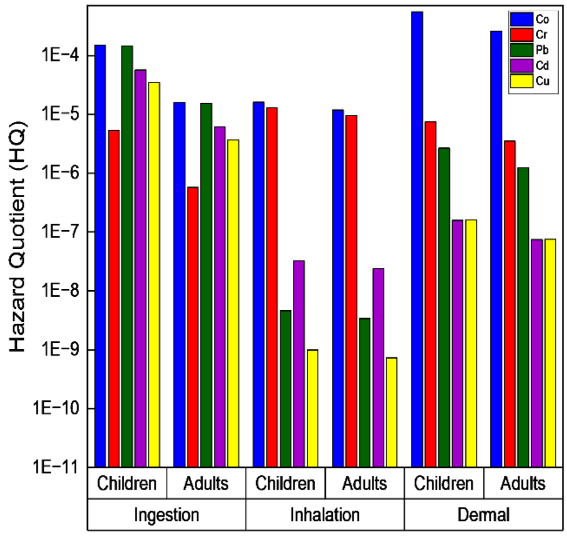

Fig. 4: Comparison of Hazard Quotients (HQ) for adults and children across the exposure pathways

Table 2: Chronic Daily intake (CDI) of heavy metals across all exposure routes.

Routes	Groups	Chronic Daily Intake, CDI (mgkg^{-1}day^{-1})				
		Co	**Cr**	**Pb**	**Cd**	**Cu**
INGESTION	Children	2.96E-06	7.99E-06	5.02E-07	5.67E-08	1.38E-06
	Adults	3.17E-07	8.56E-07	5.38E-08	6.07E-09	1.48E-07
INHALATION	Children	9.65E-11	2.6E-10	1.64E-11	1.85E-12	4.51E-11
	Adults	7.11E-11	1.92E-10	1.2E-11	1.36E-12	3.32E-11
DERMAL	Children	8.3E-09	2.24E-08	1.41E-09	1.59E-10	3.87E-09
	Adults	3.89E-09	1.05E-08	6.59E-10	7.44E-11	1.82E-09

Table 3: Estimated non-carcinogenic risk indices (HQ and HI) for heavy metal exposure via ingestion, inhalation, and dermal contact routes in children and adults.

Routes	Groups	Hazard Quotient (HQ)					Hazard Index (HI)
		Co	**Cr**	**Pb**	**Cd**	**Cu**	
INGESTION	Children	1.48E-04	5.33E-06	1.43E-04	5.67E-05	3.46E-05	3.88E-04
	Adults	1.59E-05	5.71E-07	1.54E-05	6.07E-06	3.71E-06	4.16E-05
INHALATION	Children	1.61E-05	1.30E-05	4.67E-09	3.24E-08	1.00E-09	2.91E-05
	Adults	1.18E-05	9.58E-06	3.44E-09	2.38E-08	7.38E-10	2.15E-05
DERMAL	Children	5.53E-04	7.46E-06	2.65E-06	1.59E-07	1.61E-07	5.64E-04
	Adults	2.59E-04	3.50E-06	1.24E-06	7.44E-08	7.57E-08	2.64E-04

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3.3.2 Evaluation of Carcinogenic Health Effects

To evaluate the long-term carcinogenic implications of heavy metal exposure through contaminated soils, total lifetime cancer risk (TLCR) values were estimated and are presented in Table 4. According to established risk assessment guidelines, chronic exposure to toxic pollutants like Cr, Pb, and Cd has been associated with increased cancer risk in humans (Sangeeta *et al.*, 2026; Akinola *et al.*, 2025; Kabir *et al.*, 2024; Pavilonis *et al.*, 2017). The TLCR values for children in the study area (Fig. 5) ranged from 3.61×10^{-7} to 1.30×10^{-5} for Cr, 4.58×10^{-10} to 1.03×10^{-8} for Pb, and 2.50×10^{-9} to 5.80×10^{-8} for Cd. For adults, TLCR values ranged from 7.94×10^{-8} to 2.85×10^{-6} for Cr, 2.31×10^{-9} to 5.17×10^{-8} for Pb, and 3.85×10^{-10} to 8.92×10^{-9} for Cd. The mean TLCR in children for chromium, exceeded the regulatory threshold of 1.0×10^{-6}, the mean TLCRs for the remaining metals remained within or close to acceptable limits, suggesting a generally low but non-negligible cancer risk from carcinogen metal exposure.

The mean lifetime cancer incidence per million people (calculated by multiplying TLCR by 1,000,000) was estimated for children as 4.01 cases for Cr, 0.004 for Pb, and 0.02 for Cd, while for adults it was 0.88 for Cr, 0.02 for Pb, and 0.003 for Cd. These values indicate that chromium poses the most significant carcinogenic threat among the metals studied, especially in children.

The higher TLCR values observed in children compared to adults are attributed to age-specific behavioural and physiological variables such as higher ingestion rates relative to body weight, increased gastrointestinal absorption of metals, and frequent hand-to-mouth activities (Oni *et al.*, 2022; Carroquino *et al.*, 2012). Therefore, people residing near the youth training centre are at a risk of long-term carcinogenic effects due to greater exposure potential from soil contact.

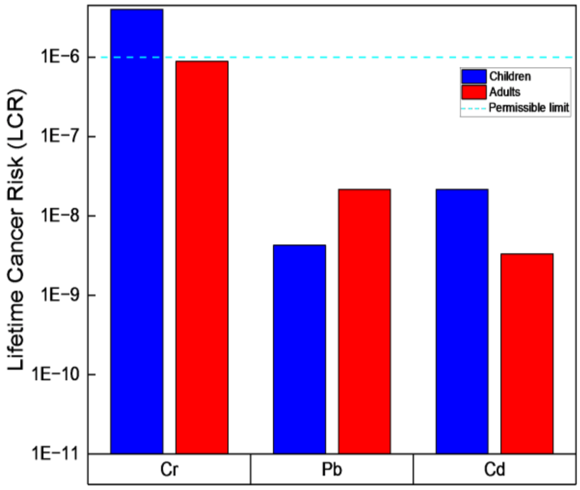

Fig. 5: Mean Total Lifetime Cancer Risk (TLCR) in Adults and Children

Table 4: Estimated Total Lifetime Cancer Risk (TLCR) associated with heavy metal exposure via ingestion, inhalation, and dermal contact routes in children and adults.

Sample Locations	LCR (Children)			LCR (Adults)		
	Cr	Pb	Cd	Cr	Pb	Cd
A1	7.81E-07	5.77E-09	5.80E-08	1.72E-07	2.91E-08	8.92E-09
A2	5.83E-07	1.41E-09	2.55E-08	1.28E-07	7.11E-09	3.92E-09
A3	3.61E-07	3.77E-09	2.70E-08	7.94E-08	1.90E-08	4.15E-09
A4	5.74E-07	1.03E-08	2.00E-08	1.26E-07	5.17E-08	3.08E-09
A5	6.32E-07	8.04E-09	1.00E-08	1.39E-07	4.06E-08	1.54E-09
A6	1.30E-05	1.19E-09	1.35E-08	2.85E-06	5.98E-09	2.08E-09
A7	4.29E-06	4.58E-10	2.50E-09	9.44E-07	2.31E-09	3.85E-10
A8	9.11E-06	2.52E-09	1.15E-08	2.00E-06	1.27E-08	1.77E-09
A9	2.15E-06	4.62E-09	1.05E-08	4.73E-07	2.33E-08	1.62E-09
A10	8.69E-06	4.67E-09	3.70E-08	1.91E-06	2.36E-08	5.69E-09
Mean	4.01E-06	4.27E-09	2.16E-08	8.83E-07	2.15E-08	3.32E-09
S.D.	4.36E-06	2.97E-09	1.55E-08	9.60E-07	1.50E-08	2.38E-09
Min.	3.61E-07	4.58E-10	2.50E-09	7.94E-08	2.31E-09	3.85E-10
Max	1.30E-05	1.03E-08	5.80E-08	2.85E-06	5.17E-08	8.92E-09

4.0 CONCLUSION

This study assessed heavy metal concentrations in soils from the Youth Craft Village, Katsina, Nigeria. All mean values were below WHO/FAO permissible limits, indicating low overall contamination. Non-carcinogenic risk assessments via ingestion, inhalation, and dermal pathways yielded Hazard Indices (HI) and Hazard Quotients (HQ) below the threshold of concern (HI, HQ < 1) for both age groups. However, lifetime cancer risk (LCR) analysis identified chromium as a potential carcinogenic threat to children and adults at specific locations, with LCR values exceeding the acceptable benchmark ($>10^{-6}$). We strongly recommend targeted mitigation strategies and continuous monitoring to protect sensitive populations in environments like vocational training centres.

Supplementary Materials: This manuscript is accompanied by supplementary tables that provides additional information to support the findings presented in the main text: https://drive.google.com/file/d/1eIvrhJaSqZ4CUukzyHPxEFNrR6Y-zm_x/view?usp=sharing

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