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RADIOLOGICAL RISK OF NORM AND HEAVY METAL EXPOSURE IN SOIL OF MIRINGA, NORTH-EASTERN NIGERIA

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ABSTRACT
The observed low background radiation, as reported in the aerial survey of the Miringa community, does not always reflect low soil activity concentrations. Factors such as environmental dilution and shielding can significantly attenuate gamma radiation flux, potentially concealing high activity sources within the ground. Given the impact of rapid urbanization and agricultural expansion, a comprehensive ground-level assessment was conducted to establish a reliable public health baseline. Radionuclide activity concentrations, determined via NaI (Tl) scintillation detection, averaged 32.37, 56.82, and 241.27 Bq/kg for 226Ra, 232Th, and 40K, respectively. Heavy metal analysis using atomic absorption spectrometry revealed that while lead, zinc, manganese, and nickel remain within WHO safety margins, levels of arsenic, copper, chromium, and cadmium exceeded recommended thresholds. Cadmium exhibited the most significant contamination, exceeding safety limits by 341%. Ecological risk assessments identified cadmium and arsenic as the primary drivers of localized contamination. Although the average Pollution Load Index (0.94) classifies the area as unpolluted, localized enrichment of thorium and cadmium indicates emerging environmental and long-term health concerns. These findings underscore that ground-level monitoring is vital for precise environmental management and the protection of community health.

Keywords: Activity concentration, radiation exposure, soil contamination, heavy metal, cadmium contaminant

INTRODUCTION

Human livelihood depends heavily on the use of resources such as soil and water. However, these materials contain heavy metals and emit radiation due to their mode of formation and the radionuclides they contain. These naturally occurring radiations are typically safe and within acceptable limits. However, anthropogenic, geological, and other associated agencies often result in increased radionuclide activity and heavy metal content of water and soil (Chernysh et al., 2024). When cultivated, such soil can impact plant and, consequently, animal and human life and expose humans to health risks associated with cancer (Reytor-González et al., 2025). Naturally Occurring Radioactive Materials (NORM) and heavy metals often occur together in polluted environments due to mining, industrial activities, and waste disposal, posing combined risks to ecosystems and human health. Their persistence in soil and water enables bioaccumulation in plants and animals, while NORM introduces radiological hazards, and heavy metals such as cadmium, lead, and mercury contribute to chemical toxicity. The interaction of these pollutants can intensify harmful effects, necessitating integrated approaches that account for geochemical behavior, ecological exposure, and long-term monitoring to safeguard public health and environmental sustainability (Chen & Ding, 2023).

Two major survey approaches are usually employed to measure the activity concentration of soil: offline and in situ (onsite) using Thallium-doped Sodium Iodide [NaI(Tl)] scintillation or High Purity Germanium (HPGe) detectors (Igwe et al., 2025; Yu et al., 2026). In situ monitoring has high accuracy; it's time-consuming and labor-intensive, and it raises accessibility concerns for difficult terrains. However, offline monitoring is relatively cheaper and less time-consuming. Some common techniques for determining heavy metals include atomic absorption spectroscopy (AAS), one of the most widely used methods due to its sensitivity, accuracy, availability, and relative cost.

Rilwan et al. (2022) conducted a survey of the background radiation in Bui (including Miringa) using an inspector alert nuclear radiation monitor in Southern Borno State, Nigeria, and their findings suggest that the radiation level in the area is below the maximum threshold and hence safe (Rilwan et al., 2022). However, an area with a low air radiation level can have a high radiation level undetected due to environmental factors such as soil moisture, ground cover, and water bodies acting as effective shielding materials, significantly attenuating gamma radiation and potentially leading to the underestimation of terrestrial background levels during aerial surveys (Nowak et al., 2015). Assessing the soil in an environment with low aerial radiation levels provides decisive evidence of the area's radiation safety.

The current study considers the activity and heavy metal concentrations in soil samples collected from Miringa town in the Biu local government area, Borno, Nigeria, to investigate and evaluate the associated health hazards, enabling comparison with reported aerial survey results. This will highlight the importance of a follow-up ground soil survey of the target area with known aerial radiation levels. NaI(Tl) scintillation detectors and atomic absorption spectroscopy (AAS) are both employed for offline measurements of radionuclide activity and heavy metal concentrations.

MATERIALS AND METHODS

Materials

Materials used in the study include; hand gloves, plastic container, molecular sieve, digging hoe, beaker, 50 cl plastic bottles, global position system (GPS), Sodium Iodide activated with Thallium, 2.5 L Hydrochloric acid (sigma Aldrich, US), Nitric acid (99.5%, GHTECH, Guangdong, China), sulphuric acid 99.7%, JHD

Guangdong, China), distilled water, filter paper, spectrophotometer (Unicam solar 969 model).

Study Area

Miringi is the study area. It is a modest-sized town south of the Biu Local Government Area (LGA), in the southern part of Borno State, Nigeria. It has an estimated population of 12,117, according to the National Population Commission (NPC, 2006). Biu LGA lies on what is known as the Biu Plateau at an average elevation of 626 meters (Rilwan et al., 2022). The region is semi-arid and is located between latitudes 10°3730" N and 10°500" N and longitudes 12°50" E and 12°1730" E (see Fig. 1).

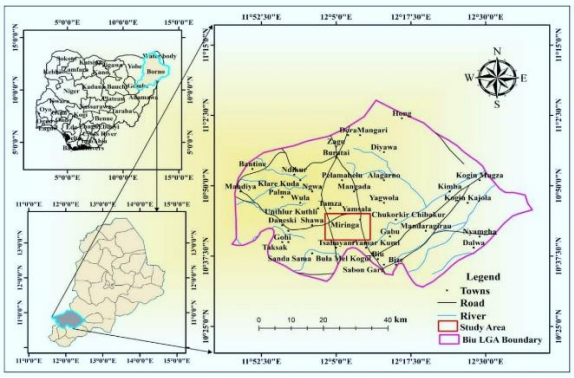

Figure 1. Location map of the study area

Sample Collection and Analysis

A total of 15 soil samples were collected from 15 different sampling points. The soil samples were randomly collected from the ground in Maringa at a depth of about 15 cm each, targeting agricultural fields, residential settlement areas, and roadside locations, and the corresponding GPS coordinates were recorded (Table 1). The soil samples were placed in clean, airtight plastic bottles and clearly labeled by sampling point. The collected samples were then transported to the laboratory for testing.

Table 1: Sampling points in the study area

	Sampling Location	
Samples	**Latitude (N)**	**Longitude (E)**
S1	10° 43' 46.38"	12° 8' 48.3"
S2	10° 43' 45.92"	12° 8' 44.29"
S3	10° 43' 40.42"	12° 8' 40.09"
S4	10° 43' 34.14"	12° 8' 31.42"
S5	10° 43' 34.14"	12° 846.52"
S6	10° 43' 34.12"	12° 8' 36.52"
S7	10° 43' 26.72"	12° 9' 6.76"
S8	10° 43' 36. 40"	12° 8' 57.20"
S9	10° 43' 28 .73"	12° 9' 6.73"
S10	10° 43' 51.92"	12° 8' 39.12"
S11	10° 43' 17.74"	12° 934.30"
S12	10° 43' 26.72"	12° 9' 6.768"
S13	10° 43' 17.94"	12° 9' 35.20"
S14	10° 43' 41.77"	12° 9' 34.08"
S15	10° 41' 25.72"	12° 9' 6.76"

Instrumentation and Calibration

Determination of radionuclide concentrations was performed using a gamma-ray spectrometer with a NaI (Tl) scintillation detector available at the Ahmadu Bello University Center for Energy Research and Training, Nigeria. The same procedure as in Igwe et al. (2025) was followed; energy calibration was performed using 60-Co and 137-Cs as point sources. The detector was enclosed in a 6 cm lead shield with cadmium and copper sheets. Mixed radionuclide standard material with serial number MW 652 from AEA Technology within the energy range 60 keV to 1836 keV was used (Igwe et al., 2025). Energy calibration curve carried out using a 500 ml Marinelli beaker and a counting time of 10,800 seconds. This arrangement was aimed at minimizing the effects of background and scattered radiation. The data acquisition software used was the Canberra Nuclear Products´ MAESTRO package. The samples were measured for 29000 seconds each. The peak area at each energy in the spectrum was used to compute the activity concentration for each sample using Equation (1).

$$Activity\ Conc.(Bq/kg) = \frac{C_n}{C_f} \quad (1)$$

where C_n is the count rate, and C_f is the calibration factor of the detecting system. Calibration of the system for energy and efficiency was carried out using two-point sources, i.e., 137Cs and 60Co. These were done with the amplifier gain that gives 72% energy resolution for the 661.16 keV line of 137Cs, and were counted for 30 minutes.

Measurement of Activity Concentration of 40K, 226Ra, and 232Th in Soil Samples using Thallium-doped Sodium Iodide detector

The samples were prepared, and measurements were made following a procedure similar to that of Igwe et al. (2025). Each soil sample collected was dried and crushed into a fine powder. Packaging of the samples into radon–impermeable cylindrical plastic containers, which were selected based on the space allocation of the detector vessel. The sealing process included smearing the inner rim of each container lid with Vaseline jelly, filling the lid-and-assembly gap with candle wax to seal the gap between the lid and container, and tightly sealing the lid and container with masking adhesive tape. Radon and its short-lived progeny were allowed to reach secular radioactive equilibrium by storing the sample for 1 month before gamma-spectroscopy measurement.

Hazard Assessment due to 40K, 226Ra, and 232Th in Soil Samples

The exposure to radiation from radionuclides in soil can be determined using parameters such as absorbed dose rate, radium equivalent activity, annual effective dose, and excess lifetime cancer risk.

Absorbed dose rate

The absorbed dose rate was determined from Equation 2.

$$D = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (2)$$

Where ARa, ATh, and AK are the activity concentrations due to radium, thorium, and potassium in the soil samples, respectively

Radium Equivalent Activity

The radium equivalent activity, Raeq, is defined as the weighted uniform activities of 40K, 226Ra, and 232Th in the soil sample based on the assumption that 4810 Bq/kg of 40K, 370 Bq/kg of 226Ra, and 259 Bq/kg of 232. Th produce the same gamma radiation dose. It was evaluated using Equation 3 (Kanmi et al., 2025)

$$Ra_{eq} = A_{Ra} + 1.4\ A_{Th} + 0.077A_K \quad (3)$$

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Where A_{Ra}, A_{Th}, and A_K are the activity concentrations due to radium, thorium, and potassium in the soil samples, respectively.

Annual Effective Dose (AED)

$$AED = D \times 8760\,h \times 0.2 \times 0.7\,SvG\,y^{-1} \times 10^{-6} \quad (4)$$

Where 0.2 is taken as the adult occupancy factor in an outside environment, D is absorbed dose rate, 0.7 SvG/y is the dose conversion factor, and 8760 h is the total hours in a year (Igwe et al., 2025)

Excess Lifetime Cancer Risk (ELCR)

$$ELCR = AED \times DL \times RF \quad (5)$$

Where AED is the annual effective dose, DL is the exposure duration (70 years), and RF is the risk factor (0.05).

External Hazard Index

The external hazard limit for the soil samples of the target area of study was determined from Equation 3 (Ofomola et al., 2023)

$$HI = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

Statistical analysis

Descriptive statistical analysis was made on the measured activity concentration and other radiological hazard parameters. The analysis includes minimum and maximum values, skewness and kurtosis, standard deviation and standard error, coefficient of variation, etc. The statistical analysis also includes a normality test on the activity concentration and the dose rate. The results were tabulated.

Measurement of heavy metal concentration using an atomic absorption spectrophotometer (AAS)

Soil samples were air–dried at ambient laboratory temperature, ground with a mortar and pestle, sieved to pass through a 2 mm sieve, and stored for analysis. Using a spatula and a weighing bottle, 0.5 g of each soil sample was obtained with a sensitive balance. This was placed in a Teflon beaker and transferred to a fume cupboard for digestion. The digestion of the soil samples was carried out using concentrated nitric acid (10 ml) and concentrated perchloric acid (5 ml) in a 2:1 ratio, and the oven was maintained at 200 °C. After 1 hour, the mixture was allowed to cool before the residue was leached with 5 cm^3 of 20% nitric acid. Digested samples were then filtered and made up to 100 mL with deionized water.

Hazard assessment of heavy metals in soil samples

Hazard assessment of heavy metal concentrations in the soil is evaluated using parameters such as the pollution load index and ecological risk factor (Weissmannová & Pavlovský, 2017).

Pollution Load Index (PLI)

The soil heavy metal pollution load index (PLI) is a simple statistical technique used to determine the elemental contents in the soil that exceed a reference concentration and to provide information about the metal toxicity in the sample. PLI can be determined using Equation (7).

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)^{1/n} \quad (7)$$

where CF is the contamination factor given by C_i/C_m with C_i as measured metal concentration of where CF is the contamination factor given by with Ci as measured metal concentration of a target area and Cm the standard reference value in (mg/kg) or background concentration of the metal, and n is the number of elements (n=8 for the current study). The PLI can be interpreted through scaled criteria valued in the range of 1 to 6, with 0 = none; 1=none to medium; 2 = moderate; 3 = moderate to strong; 4 = strongly polluted; 5 = strongly to very strongly; and 6 = very strongly (Ofomola et al., 2023; Weissmannová & Pavlovský, 2017).

Ecological Risk Factor

The ecological risk factor associated with metals in the soil samples can be evaluated using Equation (8)

$$E_R = T_r CF \quad (8)$$

Where CF is the contamination factor, T_r is the toxic response factor for each metal. The Tr values for Pb, Zn, Cd, and Cr are 5, 1, 30, and 2, respectively (Ofomola et al., 2023).

RESULTS

Here results of measured activity concentration for 40K, 226Ra, and 232Th radionuclides present in soil samples of Miringa town including the concentration of eight heavy metals namely lead (Pb), arsenic (As), zinc (Zn), copper (Cu), manganese (Mn), chromium (Cr), cadmium (Cd) and nickel (Ni), in each of the soil samples. The results were further used to analyze the soil samples and assess health risks from absorption and contamination.

Measured Radionuclide Activity Concentration

The concentrations of 40K, 226Ra, and 232Th in the soil samples are shown in Figure 1.

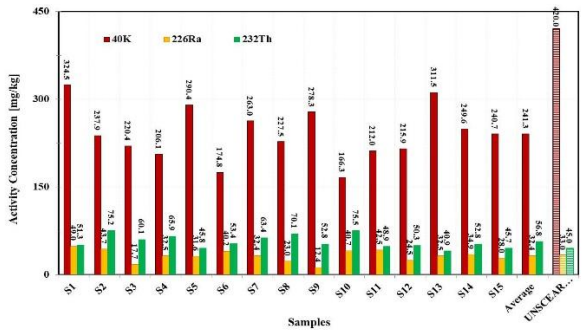

Figure 2: Gamma activity concentration due to 40K, 226Ra, and 232Th radionuclides in Miringa soil samples

The 40K level is below the UNSCLEAR limit in all soil samples, while 226Th is high and above the limit in some samples and below the limit in others. Similarly, for 232Th, only S13 had values below the limit; all other soil samples had values above the limit. The average measured activity concentration from Ra in the soil was slightly below the UNSCLEAR limit (33 Bq/kg). While the average activity due to Th in the soils of the target area is 26% higher than the UNSCLEAR limit of 45 Bq/kg, activity due to Ra is only about ~2% higher than the standard limit of 33 mg/kg, and that due to 40K is ~43% less than the standard maximum limit of 420 Bq/kg.

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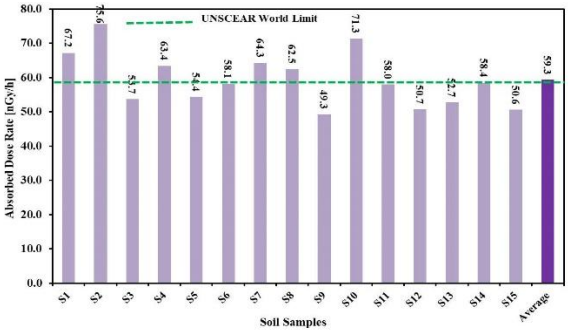

Figure 3: Estimated absorbed gamma dose rate for the soil samples

The absorbed gamma dose rate of the soil samples from a target geographical area (Miringa) is a measure of external radiation exposure due to the presence of radioactive nuclides. As shown in Figure 2, soil samples S2 and S9 had the highest and lowest values, respectively, with the target area having an average gamma dose rate of 59.3 nGy/h. This is 0.5%, slightly above the UNSCEAR limit of 59 nGy/h. With an average of 59.3 nGy/h, the soil samples are about the same as the UNSCLEAR limit. The soils of the study area have no safety margin, as they are at or slightly above the threshold. Prolonged or cumulative exposure is a potential risk to residents of the area.

Table 2: Radiological parameters of soil samples from the target study area

Samples	Ra_eq	AED	ELCR	HI
S1	145.8	0.082	0.29	1.08
S2	167.4	0.093	0.32	0.83
S3	118.9	0.066	0.23	0.68
S4	140.6	0.078	0.27	0.70
S5	118.1	0.067	0.23	0.92
S6	128.4	0.071	0.25	0.64
S7	141.5	0.079	0.28	0.85
S8	138.7	0.077	0.27	0.72
S9	107.8	0.060	0.21	0.81
S10	159.2	0.087	0.31	0.62
S11	127.3	0.071	0.25	0.75
S12	111.6	0.062	0.22	0.69
S13	113.8	0.065	0.23	0.98
S14	128.0	0.072	0.25	0.82
S15	110.6	0.062	0.22	0.77
Average	**130.5**	**0.073**	**0.25**	**0.79**

Descriptive statistics

The descriptive statistics for the activity concentration, dose rate, and other radiological parameters are shown in Table 3.

Table 3: Descriptive statistics of the estimated parameters of soil samples of the study area

Statistical Parameter	40K	226 Ra	232 Th	D	Ra_ eq	AED	EL CR	HI
Mean	241.27	32.38	56.83	59.34	130.51	0.073	0.25	0.79
Standard Error	11.87	2.61	2.83	2.04	4.66	0.003	0.01	0.03
Median	237.90	32.49	52.83	58.10	128.05	0.071	0.25	0.77
Standard Deviation	45.98	10.09	10.95	7.91	18.06	0.010	0.03	0.13
Sample Variance	2114.17	101.80	119.87	62.52	326.06	0.000 009	0.00 012	0.02
Kurtosis	-0.47	-0.29	-0.88	-0.40	-0.38	-0.400	-0.40	0.33
Skewness	0.25	-0.35	0.53	0.63	0.64	0.627	0.63	0.83
Range	158.20	36.58	34.57	26.31	59.56	0.032	0.11	0.45
Coefficient of Variation	19.1	31.2	19.3	13.3	13.8	13.3	13.3	16.2
Minimum	166.33	12.42	40.94	49.26	107.82	0.060	0.21	0.62
Maximum	324.52	49.00	75.51	75.57	167.38	0.093	0.32	1.08
Sum	3619.08	485.67	852.39	890.14	1957.69	1.092	3.82	11.83
Count	15	15	15	15	15	15	15	15

The coefficient of variation (CV) of 226Ra is the highest of the three radionuclides, signifying that its activity concentration fluctuates more between soil samples, and the CVs of ~19% for 40K and 232Th show they are relatively more stable. 40K, 232Th, and the hazard indices show positive skewness, while 226Ra has negative skewness. Kurtosis is mostly negative (platykurtic), indicating that the distributions are flatter than a normal distribution. The recorded ranges indicate that some soils have relatively low radionuclide content, while others have significantly higher radionuclide content.

Normality test

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Table 4: Normal test

Parameter	Degree of Freedom	Shapiro-Wilk	
		Statistic	P-value
40-K	15	0.97260	0.89528
226-Ra	15	0.97422	0.91486
232-Th	15	0.92466	0.22680
D	15	0.9419	0.4064

The normality test in Table 4 shows that all p-values are >0.05, implying normality for all the parameters.

Measured heavy metal concentration

The assessed heavy metals and their average concentrations in the soil samples collected from the target area are presented in Figure 3, alongside their respective WHO limit values (in Red).

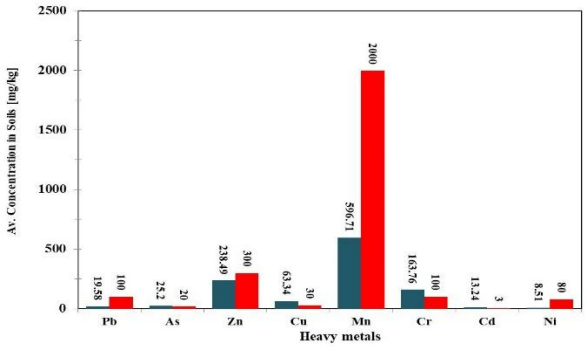

Figure 4: Mean heavy metal concentration in soil samples relative to the WHO limit values

Lead (Pb), zinc (Zn), manganese (Mn), and nickel (Ni) in the soil samples were below the WHO limits, while arsenic (As), copper (Cu), chromium (Cr), and cadmium (Cd) levels in the soil samples were higher than their respective WHO limit values. The arsenic level is 26% higher, copper is 111% higher, chromium is 64% higher, and cadmium is 341% higher.

Assessment of Hazard Risk due to heavy metals in the soil

Table 5 shows the results of the calculated contamination factor and pollution load index of the soil samples of the target area (Miringa)

Table 5: Evaluated pollution load indices for Miringi soil samples

Samples	Ecological Risk Factor								PLI
	Pb	As	Zn	Cu	Mn	Cr	Cd	Ni	
S1	6.05	10.21	0.62	6.15	1.12	2.56	34.51	11.22	1.17
S2	5.75	9.80	0.61	4.75	1.13	2.54	32.10	7.05	1.04
S3	5.32	8.10	1.90	8.35	1.11	2.60	15.31	6.45	1.13
S4	5.20	8.12	1.77	6.15	1.11	1.51	14.41	5.20	0.97
S5	2.35	15.02	0.78	3.40	0.92	1.28	30.92	5.63	0.85
S6	2.35	8.10	0.77	3.30	0.95	1.5	30.90	5.69	0.83
S7	2.10	9.01	0.45	4.71	1.29	2.42	44.10	5.05	0.88
S8	4.65	9.30	0.86	2.75	0.84	2.60	45.92	3.15	0.91
S9	6.50	12.40	0.69	3.21	1.04	1.28	20.19	2.43	0.79
S10	7.20	9.30	1.31	7.10	0.67	1.88	18.01	4.05	0.97
S11	6.05	9.31	1.31	5.05	0.71	1.88	16.80	3.85	0.92
S12	6.05	9.30	1.61	5.12	0.71	1.88	20.11	3.95	0.95
S13	4.26	12.80	0.89	5.05	1.13	2.48	55.20	2.20	1.01
S14	5.05	10.51	0.45	6.40	1.18	1.3	39.90	1.95	0.84
S15	6.20	8.50	0.99	3.61	1.09	2.26	31.20	7.15	1.04
Mean	**5.00**	**9.91**	**1.00**	**5.01**	**1.02**	**2.01**	**29.96**	**4.99**	**0.94**
Min	**2.10**	**8.12**	**0.45**	**2.75**	**0.67**	**1.28**	**14.41**	**1.95**	**0.79**
Max	**7.29**	**15.27**	**1.92**	**8.35**	**1.29**	**2.61**	**55.20**	**11.20**	**1.17**

DISCUSSION

The relatively high thorium in the soil, while radium and potassium remain below the maximum threshold, can result in a significant contribution to gamma exposure, since thorium is a strong gamma emitter. It can be a concern for long-term exposure. A combined radiological assessment, based on the radium equivalent activity or dose rate, better estimates the radiological safety of the soils. With a mean of ≈ 130 Bq/kg, the Radium equivalent activity is below the recommended safe limit of 370 Bq/kg. The annual effective dose of 0.073 is at the threshold of the global average outdoor exposure of ~0.07 mSv/y. The mean excess lifetime cancer risk is within acceptable risk levels. At the same time, the hazard index is below unity. It indicates no significant radiological hazard overall. With Ra_{eq} < 370 Bq/kg and HI < 1, the soil samples of Miringa are radiologically safe for habitation and agriculture (Chernysh et al., 2024), although continuous monitoring is important since 232Th levels are elevated. The mean radium equivalent activity of 130 Bq/kg obtained in the current study is less than 251.11 Bq/kg obtained by Zarma et al. (2023) for the soil samples of Michika, Adamawa, North-Eastern Nigeria (Zarma et al., 2023). Similarly, Rabiu et al. (2021) reported a radium equivalent activity for the soil sample from Maiganga, North-Eastern Nigeria, at 43.51 Bq/kg, which is also below the limit of 370 Bq/kg (Rabiu et al., 2026).

The mean ecological risk factors (ERF) for the metals followed the order Cd > As > Cu>Pb > Ni > Cr > Mn > Zn. The ecological risk assessment shows cadmium (Cd) as the dominant pollutant, with mean ecological factor (ERF) values far exceeding those of other metals. Cd content in the soils ranged from 14.41 to 55.20, indicating localized enrichment likely linked to anthropogenic activities such as waste disposal or agricultural activities (Weissmannová & Pavlovský, 2017). Arsenic (As) and lead (Pb) also posed moderate risks, while copper (Cu) and nickel (Ni) posed modest risks. In contrast, zinc (Zn), manganese (Mn), and chromium (Cr) remained near background levels, suggesting minimal ecological concern. The pollution load index (PLI) averaged 0.94, below unity, confirming that the soils are generally unpolluted. The PLI values at a few sampling points indicate localized contamination. Statistical analysis revealed Cd and As as the primary drivers of overall risk, while other metals displayed limited variability. This is consistent with findings by Alkali et al. (2025) on the heavy metal contamination of the soil of Bauchi,

North-Eastern Nigeria. They reported Cd and As as the dominant contaminants in the soil (Alkali et al., 2025). In a similar study, Kobbe et al. (2025) reported Cd as the dominant contaminant in the soil of Bauchi (Kobbe et al., 2025).

In general, the soils of Miringa exhibit low to moderate heavy-metal contamination, with Cd posing the greatest ecological hazard. Although the PLI values indicate acceptable soil quality, the elevated Cd and As concentrations warrant targeted monitoring and management to prevent long-term environmental and health impacts.

Conclusion

This study assessed the activity concentrations of natural radionuclides (40K, 226Ra, 232Th) and heavy metals in soils from Miringa, with their associated radiological and ecological risks. The results show that while 40K and 226Ra remain largely below or near UNSCEAR limits, 232Th is elevated and contributes significantly to the external gamma dose rates. The mean absorbed dose rate (59.3 nGy/h) is essentially at the UNSCEAR threshold, leaving no safety margin for prolonged exposure. Nevertheless, the radium equivalent activity (< 370 Bq/kg), annual effective dose (~0.073 mSv/y), and hazard index (< 1) indicate that the soils are radiologically safe for habitation and agriculture, although continuous monitoring is recommended considering the elevated thorium levels. Heavy-metal analysis revealed that Pb, Zn, Mn, and Ni concentrations were below WHO limits, whereas As, Cu, Cr, and especially Cd exceeded recommended values. Ecological risk assessment identified Cd as the dominant pollutant, with As and Pb contributing moderate risks. The pollution load index averaged below unity, confirming that soils are generally unpolluted, although localized contamination exists. Therefore, the soils of Miringa exhibit low to moderate contamination, with radiological safety parameters within acceptable limits but ecological risks driven by cadmium and arsenic contaminants. These findings underscore that ground-level monitoring is vital for precise environmental management and the protection of community health. Sustained monitoring and targeted management are essential to mitigate long-term environmental and health impacts and ensure soil quality and safety for the Miringa population.

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