

Evaluation of Radionuclide Contents in the Soil of Oloru Town, Moro Local Government Area, Kwara State, Nigeria

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ABSTRACT

Naturally occurring radionuclides in soil, particularly ^{226}Ra , ^{232}Th , and ^{40}K , are a recognized public-health and environmental protection concern, as soil serves as a major reservoir and transfer pathway to plants, water, and humans via external irradiation and ingestion. Localized radiological data for Oloru Town, Moro Local Government Area, Kwara State, Nigeria, an agrarian community with potential soil-groundwater interaction, remain limited. This study therefore evaluated ^{226}Ra , ^{232}Th , and ^{40}K concentrations in Oloru soils and estimated the associated radiological hazard indices and population dose. 50 soil samples were collected across ten stratified locations. A well calibrated gamma spectrometry detector was used for the assessment of the radionuclide contents. Absorbed dose rate, annual effective dose equivalent, radium equivalent activity, external and internal hazard indices, gamma representative index, and excess lifetime cancer risk (ELCR) were subsequently estimated. It was observed that ^{40}K was the dominant radionuclide ($347.2\text{--}654.8\text{ Bqkg}^{-1}$), while ^{226}Ra ($8.87\text{--}22.00\text{ Bqkg}^{-1}$) and ^{232}Th ($4.50\text{--}20.42\text{ Bqkg}^{-1}$) remained below world averages. Absorbed dose rate ($27.73\text{--}38.94\text{ nGyh}^{-1}$), annual effective dose ($0.034\text{--}0.048\text{ mSvy}^{-1}$), radium equivalent activity, hazard indices, gamma index, and ELCR ($0.119\text{--}0.167 \times 10^{-3}$) were all well below internationally recommended limits at every location. The soils of Oloru Town pose no significant radiological health risk from external exposure, supporting continued safe habitation and agricultural use, and the findings establish essential baseline data for future environmental radiation monitoring and land-use planning in the community and comparable settlements.

Keywords:

Natural radioactivity,
Soil,
Radiological hazard indices,
Annual effective dose,
Excess lifetime cancer risk.

INTRODUCTION

Environmental radioactivity is an important public-health and environmental protection concern because naturally occurring radionuclides in soil can contribute to human radiation exposure through external irradiation and ingestion pathways. Radionuclides such as ^{226}Ra , ^{232}Th , and ^{40}K are widely distributed in the environment, while soil serves as an important reservoir and pathway for their transfer to plants, animals, food, and water. Oloru, within Moro Local Government Area, is situated in the Precambrian Basement Complex terrain of southwestern Nigeria, which comprises predominantly igneous and metamorphic rocks and may influence the distribution and abundance of lithogenic radionuclides such as uranium- and thorium-series radionuclides and ^{40}K in the overlying soils. Evidence from Nigeria indicates considerable spatial variability in natural radionuclide concentrations,

including elevated ^{40}K in parts of Moro Local Government Area, whereas other studies have reported variable radiological characteristics in soils across different regions (Adegbulugbe *et al.*, 2025; Ilori *et al.*, 2024). However, localized radiological information for Oloru Town, Moro LGA, Kwara State, remains limited, despite the community predominantly depending on an agricultural setting. The potential interaction between groundwater and surrounding soil is a possible pathway for naturally occurring radionuclides to enter drinking water. Ingestion of contaminated groundwater may result in internal radiation exposure, highlighting the need for site-specific assessment of soil. Accordingly, this study evaluates the concentrations of ^{226}Ra , ^{232}Th , and ^{40}K in soil from Oloru and estimates the associated radiological hazard indices and potential radiation dose to the population.

MATERIALS AND METHODS

Study Area

Oloru is located in Moro Local Government Area, Kwara State, Nigeria. It is situated in the western part of the central region of Nigeria and bounded by Latitudes $8^{\circ}27'N$ and $8^{\circ}30'N$ and longitudes $4^{\circ}9'E$ and $4^{\circ}36'E$. The town is bordered by communities like Oke-Oyi, Shao,

Malete, Kanbi, and the route to Niger State, as shown in Figure 1. It is positioned at a strategic point between the densely populated south-western and the sparsely populated middle belt of Nigeria. It is at an elevation of 304 m above sea level. There are rocks, hills and steep slopes in the study area, which was cited on the basement rocks of Nigeria (Rahama, 1988; Haruna, 2017).



Figure 1: Map of Kwara State Showing the Study Area

Sampling and Sample Collection

The study area was stratified into ten locations so as to have a good representative sample. Five sampling points were then identified at each of the locations based on factors like the population density, location of residential areas, and schools. A total of fifty soil samples (five samples from each location) were collected at an average distance of 100 metres across the study area. The list of the sampling locations that are very close to residents is presented in Table 1. The samples were collected from

open spaces that had previously been used for agricultural practices but are now being used for residential housing. The soil samples were collected by clearing the surface vegetation at each location, after which a soil auger was used to collect the samples up to 10 cm depths. This was done so as to determine the presence of Cesium (Cs) that may be present in the top layer of the soil (Akinloye *et al.*, 2012). Each sample was packaged in a black polypropylene bag and then taken to the laboratory for further preparation and analysis.

Table 1: Sampling Locations and Samples Collected

S/N	Sampling Location	Sample	Sample Code
1	Oloru Central Market	5 soil samples	S ₁ , S ₂ , S ₃ , S ₄ , S ₅
2	Oloru Express Road	5 soil samples	S ₆ , S ₇ , S ₈ , S ₉ , S ₁₀
3	Oloru Primary Health Centre	5 soil samples	S ₁₁ , S ₁₂ , S ₁₃ , S ₁₄ , S ₁₅
4	Oloru Secondary School	5 soil samples	S ₁₆ , S ₁₇ , S ₁₈ , S ₁₉ , S ₂₀
5	Alangua Palace	5 soil samples	S ₂₁ , S ₂₂ , S ₂₃ , S ₂₄ , S ₂₅
6	Oloru Police Station	5 soil samples	S ₂₆ , S ₂₇ , S ₂₈ , S ₂₉ , S ₃₀
7	Oloru Central Mosque	5 soil samples	S ₃₁ , S ₃₂ , S ₃₃ , S ₃₄ , S ₃₅
8	Gaa Abeya	5 soil samples	S ₃₆ , S ₃₇ , S ₃₈ , S ₃₉ , S ₄₀
9	Ogun Edun	5 soil samples	S ₄₁ , S ₄₂ , S ₄₃ , S ₄₄ , S ₄₅
10	Chief Imam Oloru Compound	5 soil samples	S ₄₆ , S ₄₇ , S ₄₈ , S ₄₉ , S ₅₀

Sample Preparation

The soil samples were dried at room temperature of 32°C to remove the moisture content until a constant weight was achieved. The samples were then pulverized and sieved through a 2 mm mesh, after which the samples were set for laboratory analysis. 250 g of each soil sample was packed into a cylindrical polypropylene container that matches the geometry of the detector and tightly sealed. The prepared soil samples were kept for a period of 28 days, which was sufficient time required to attain a state of secular radioactive equilibrium between radium isotopes and their respective daughters before their gamma spectrometry (Akinloye *et al.*, 2012).

Gamma Spectrometry Analysis

Gamma spectrometric analysis was performed using a 3" × 3" NaI(Tl) detector (Princeton Gamma Tech., USA) housed within a cylindrical lead shield and coupled to a GS-2000 Pro multichannel analyzer, with Thermo software used for spectrum acquisition and analysis. The system was energy calibrated using gamma-emitting point sources of known energies, while qualitative and quantitative calibration employed an RSS8 gamma source set (Spectrum Techniques LLC, USA) and reference radionuclide standards. Detector efficiency was calibrated using the IAEA-385 reference material, prepared in a container having the same geometry as the samples, to establish the full-energy peak efficiency required for activity determination. Prior to sample measurement, an empty container of identical geometry was counted for 36,000 s to determine the laboratory background, after which the sealed samples were counted individually for 36,000 s following attainment of secular equilibrium. The activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K were determined from their characteristic gamma-ray emissions, specifically the 1764.5 keV line of ²¹⁴Pb for the ²²⁶Ra series, the 2614.7 keV line of ²⁰⁸Tl for the ²³²Th series, and the 1460.0 keV line of ⁴⁰K, using net peak area, emission probability, full-energy peak efficiency, counting time, and sample mass in the activity calculation. Equation 1 was used to identify radionuclides in the samples

$$A \text{ (Bq kg}^{-1}\text{)} = \frac{C_{\text{net}}}{P_{\gamma} \times \epsilon \times m \times t} \quad (1)$$

where A is the activity concentration in Bqkg⁻¹, C_{net} is the net peak area, P_γ is the absolute gamma-ray emission probability, ε is the obtained full-energy peak efficiency for each identified radionuclide, m is the sample mass, and t is the counting time.

The Minimum Detectable Activity (MDA) was calculated at a 95% confidence level and was based on Currie's derivation (Currie, 1968; Canberra, 2010). For each radionuclide, ²²⁶Ra, ²³²Th, and ⁴⁰K, was calculated using Equation 2:

$$\text{MDA} = \left(\frac{2.71 + 4.66(\sigma)}{P_{\gamma} \times \epsilon \times m \times t} \right) \quad (2)$$

Where σ is the standard deviation of the background collected during time t over the energy range of interest, P_γ is the absolute gamma-ray emission probability, ε is the full-energy peak efficiency of the detector, and w is the mass of the sample. The MDA are 10.05 Bq/kg (K-40), 2.72 Bq/kg (Ra-236) and 1.58 Bq/kg (Th-232). No

Radiological Parameters and Hazard Indices

Absorbed Dose Rate due to External Exposure was estimated using Equation 3

$$\text{ADRA} (\text{nGy h}^{-1}) = C_{\text{Ra}} A_{\text{Ra}} + C_{\text{Th}} A_{\text{Th}} + C_{\text{K}} A_{\text{K}} \quad (3)$$

where C_{Ra} is 0.462, C_{Th} is 0.604, and C_K is 0.0417 are the conversion coefficients, and A_{Ra}, A_{Th}, and A_K are the activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K, respectively (Akinloye *et al.*, 2012; Otewoma *et al.*, 2013). Annual Effective Dose Equivalent was estimated using Equation 4

$$\text{AEDE} (\mu\text{Sv y}^{-1}) = \text{ADRA} \times O_f \times C_c \times T \quad (4)$$

where ADRA is the absorbed dose rate due to the external exposure as given in Equation (3), O_f is the outdoor occupancy factor (0.2), C_c is the dose conversion coefficient (0.7 SvGy⁻¹), and T is the time of exposure for a year (8760 h). The constants were obtained from (Otwoma *et al.*, 2013)

Radium Equivalent Activity was estimated using Equation 5

$$R_{\text{eq}} \left(\frac{\text{Bq}}{\text{kg}} \right) = A_{\text{Ra}} + 1.43 A_{\text{Th}} + 0.077 A_{\text{K}} \quad (5)$$

Where A_{Ra}, A_{Th}, and A_K are the activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K, respectively.

Hazard Indices, both external and internal, were estimated using Equations 6 and 7, respectively

$$H_{\text{ex}} = \frac{A_{\text{Ra}}}{370} + \frac{A_{\text{Th}}}{259} + \frac{A_{\text{K}}}{4810} \quad (6)$$

$$H_{\text{in}} = \frac{A_{\text{Ra}}}{185} + \frac{A_{\text{Th}}}{259} + \frac{A_{\text{K}}}{4810} \quad (7)$$

The gamma representative index (I_γ) was estimated using Equation 8

$$I_{\gamma} = \frac{A_{\text{Ra}}}{150} + \frac{A_{\text{Th}}}{100} + \frac{A_{\text{K}}}{1500} \quad (8)$$

Excess Lifetime Cancer Risk was estimated using Equation 9

$$\text{ELCR} = \text{AEDE} \times D_L \times R_f \quad (9)$$

Where D_L is the average duration of human life (70 y), and R_f is the risk factor (0.05 Sv⁻¹)

RESULTS AND DISCUSSION

Activity Concentration of the Identified Radionuclides in the Soil Samples

The results in Table 2 show that ⁴⁰K was the most prominent radionuclide in soil, with location means ranging from 347.2 ± 53.94 Bqkg⁻¹ (Oloru Central Market) to 654.8 ± 101.21 Bqkg⁻¹ (Gaa Abeya). Relative to the worldwide soil mean of about 400 Bqkg⁻¹, three locations fell below this benchmark, while seven exceeded it, with the elevated value at Gaa Abeya attributed to a locally enhanced potassium-bearing

mineral component consistent with the known dependence of natural radioactivity on geology. The predominance of ^{40}K parallels southwestern Nigerian findings, though the present means are intermediate between the 393.73 Bqkg^{-1} reported by Ibikunle *et al.* (2019) and the 711.26 Bqkg^{-1} reported by Adegbulugbe *et al.* (2025). As ^{40}K is a naturally occurring biologically essential element, its elevation is not itself evidence of

contamination, though continued monitoring is warranted at Gaa Abeya and Ogun Edun (Ibikunle *et al.*, 2019; Adegbulugbe *et al.*, 2025; Orosun *et al.*, 2022). The Chief Imam Oloru Compound showed marked within-location heterogeneity in ^{40}K , as reflected by its relatively high value ($375.0 \pm 224.4 \text{ Bq kg}^{-1}$), suggesting substantial spatial variability in potassium-bearing materials within the sampling location.

Table 2: Mean Activity Concentration of the Identified Radionuclides for the Studied Locations

Location	^{40}K (Bqkg^{-1})	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})
Oloru Central Market	347.20 ± 53.90	8.87 ± 1.55	14.75 ± 8.30
Oloru Express Road	371.60 ± 85.80	14.58 ± 14.00	17.64 ± 2.44
Oloru Primary Health Centre	429.80 ± 170.40	21.96 ± 15.25	9.55 ± 4.57
Oloru Secondary School	453.40 ± 113.90	13.36 ± 5.90	20.42 ± 7.75
Alangua Palace	509.80 ± 123.70	18.14 ± 13.94	14.98 ± 10.11
Oloru Police Station	426.60 ± 159.30	22.00 ± 7.56	11.54 ± 7.03
Oloru Central Mosque	553.80 ± 172.60	19.07 ± 2.43	8.81 ± 9.20
Gaa Abeya	654.80 ± 101.20	15.49 ± 2.31	6.56 ± 3.04
Ogun Edun	591.00 ± 113.70	9.88 ± 1.05	4.50 ± 1.34
Chief Imam Oloru Compound	375.00 ± 224.40	12.62 ± 3.72	13.91 ± 6.49
World Average limit	400	35	30

The ^{226}Ra activities were consistently lower, with all location means ($8.87\text{--}22.00 \text{ Bqkg}^{-1}$) falling below the worldwide reference value of about 35 Bqkg^{-1} , even where individual sample ranges exceeded it, indicating localized rather than site-wide elevation. These means are marked below the 52.91 Bqkg^{-1} reported by Ibikunle *et al.*, (2019) and the $57.66\text{--}156.67 \text{ Bqkg}^{-1}$ range reported by Adegbulugbe *et al.*, (2025), reducing the uranium series' contribution to gamma dose, though spot monitoring remains advisable given radium's role in radon generation (World Health Organization, 2018; Ibikunle *et al.*, 2019; Adegbulugbe *et al.*, 2025).

The ^{232}Th concentrations were low to moderate ($4.50\text{--}20.42 \text{ Bqkg}^{-1}$) with all means below the worldwide benchmark of about 30 Bqkg^{-1} , indicating a smaller thorium-series contribution to overall radioactivity than ^{40}K . This is consistent with Orosun *et al.*, (2022) but contrasts sharply with the 76.79 Bqkg^{-1} mean of Ibikunle *et al.*, (2019) and the $131.68\text{--}213.96 \text{ Bqkg}^{-1}$ range of Adegbulugbe *et al.*, (2025), differences plausibly attributable to geology, land use, and mineral heterogeneity. Figure 2 confirms the dominance of ^{40}K over ^{226}Ra and ^{232}Th across all locations. In all the samples investigated ^{137}Cs was not detected.

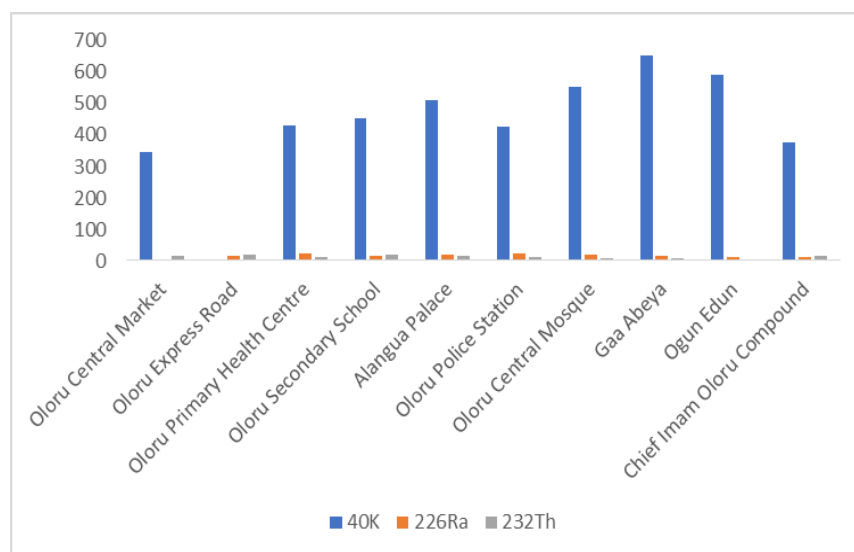


Figure 2: Comparison of activity concentrations of the identified radionuclides

Mean Value of Radiological Indices in the Soil Sample

The absorbed dose rate (D) in Table 3 ranged from 27.73 to 38.94 nGyh⁻¹ per-location, remaining below the worldwide outdoor value of 59 nGyh⁻¹ at every location and sample, broadly consistent with Omeje *et al.* (2020) and Adegbulugbe *et al.* (2025) and considerably lower than the 86.44 nGyh⁻¹ mean of Ibikunle *et al.* (2019) (Ibikunle *et al.*, 2019; Omeje *et al.*, 2020; Adegbulugbe *et al.*, 2025). Correspondingly, the annual effective dose equivalent (AEDE) ranged from 0.034 to 0.048 mSvy⁻¹ per-location, well below both the worldwide reference of 0.07 mSvy⁻¹ and the 1 mSvy⁻¹ public-exposure limit, and below the 0.1060 mSvy⁻¹ reported by Ibikunle *et al.*, (2019), indicating a modest external radiation burden that should nonetheless serve as baseline data for future comparison. The Radium equivalent activity (Ra_{eq}), ranging from 56.67 to 78.82 Bq kg⁻¹ per-location, remained far below the 370 Bqkg⁻¹ screening criterion and below the 191.34 Bq kg⁻¹ mean reported by Ibikunle *et al.*, (2019), though it is noted that Ra_{eq} is a screening indicator to be read alongside dose rate and hazard indices rather than a complete exposure assessment (Ibikunle *et al.*, 2019; Omeje *et al.*, 2020; Adegbulugbe *et al.*, 2025). The external (H_{ex}, 0.15–0.21 per-location) and internal (H_{in}, 0.18–0.26 per-location) hazard indices remained below the limit at all locations, representing only about 15–22% of the H_{ex} screening criterion and well below the

0.52 mean reported by Ibikunle *et al.*, (2019). The gamma representative index (I_γ) varied from 0.44 to 0.61 per-location, remaining below the limit at all locations, although individual samples at several sites approached this criterion. Values were considerably lower than the 1.40 mean reported by Usikalu *et al.* (2019) for Ijero-Ekiti mining soils and lower than the more impacted land-use settings reported by Adegbulugbe *et al.* (2025), indicating that the elevated ⁴⁰K observed at some sites has not translated into limit-approaching I_γ values because ²²⁶Ra and ²³²Th remained comparatively low (Usikalu *et al.*, 2019; Omeje *et al.*, 2020; Adegbulugbe *et al.*, 2025). The excess lifetime cancer risk (ELCR) for soil ranged from 0.119 × 10⁻³ (Oloru Central Market, lowest) to 0.167 × 10⁻³ (Alangua Palace, highest), with all values below the worldwide benchmark of approximately 0.29 × 10⁻³. These values are substantially lower than the 1.02078 × 10⁻³ reported by Orosun *et al.* (2022), Lawal *et al.* (2023) reported 0.79 × 10⁻³ for Tanke-Ilorin, and 0.44 × 10⁻³ was reported by Ononugbo and Nwaka (2017) around Aluu and Rumuolumeni landfills, respectively. Alangua Palace, Gaa Abeya, Oloru Secondary School, and Oloru Central Mosque recorded the highest means, which may warrant closer environmental surveillance, though ELCR represents a stochastic risk estimate rather than a prediction of individual cancer occurrence.

Table 3: Mean Values of Radiological Indices for the Ten Locations in the Soil Sample

Location	D (nGyh ⁻¹)	AEDE (μSvy ⁻¹)	Ra _{eq} (Bqkg ⁻¹)	H _{ex}	H _{in}	I _γ	ELCR × 10 ⁻³
Oloru Central Market	27.73	0.034	56.67	0.15	0.18	0.44	0.12
Oloru Express Road	33.18	0.041	68.41	0.18	0.22	0.52	0.14
Oloru Primary Health Centre	34.00	0.042	68.71	0.19	0.24	0.53	0.15
Oloru Secondary School	37.57	0.046	77.04	0.21	0.24	0.59	0.16
Alangua Palace	38.94	0.048	78.82	0.21	0.26	0.61	0.17
Oloru Police Station	36.63	0.045	74.13	0.20	0.26	0.57	0.16
Oloru Central Mosque	37.37	0.046	74.30	0.20	0.25	0.58	0.16
Gaa Abeya	38.58	0.047	75.28	0.20	0.25	0.61	0.17
Ogun Edun	32.01	0.039	61.83	0.17	0.19	0.50	0.14
Chief Imam Oloru Compound	30.12	0.037	61.41	0.17	0.20	0.47	0.13
World Average limit	59	0.07	370	1.00	1.00	1.00	0.29

CONCLUSION

This study evaluated the natural radioactivity of soils in Oloru Town, Moro LGA, Kwara State, by determining the activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K and using these to estimate the associated radiological hazard indices and potential radiation dose to the population. The findings show that ⁴⁰K is the dominant radionuclide in the study area, while ²²⁶Ra and ²³²Th occur at comparatively low levels, and that all derived radiological hazard indices and dose parameters remain within internationally recommended safety limits. This indicates that the soils of Oloru Town do not currently pose a significant radiological health risk to residents from external exposure or associated pathways, and that the area can be

considered radiologically safe for continued human habitation and agricultural use. The study therefore provides essential baseline radiological data for Oloru Town, which can serve as a reference for future environmental radiation monitoring, land-use planning, and public health surveillance in the community and comparable agrarian settlements in the region.

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