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Radiological Assessment of Soil Samples Collected from Mining Sites in Ijero Ekiti, Ekiti State, Southwest, Nigeria

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ABSTRACT

Measurements of radioactivity in soil samples from mining sites are vital for assessing environmental safety and public health risks. The primary radionuclides of concern in soil samples from mining areas are uranium-238, thorium-232, and potassium-40. Ijero-Ekiti, a prominent mining area in southwestern Nigeria, is known for the extraction of minerals. However, these mining activities can disturb naturally occurring radioactive materials leading to increased levels of radioactivity in soils. Prolonged exposure to such radionuclide can pose health risks to miners and residents. Present study aim to evaluate the levels of radioactivity in soil samples from the mining site in Ijero Ekiti in order to assess potential environmental and health risks using NaI(Tl) gamma ray spectrometer that is interfaced with a series of 10 plus Canberra Multi-channel Analyzer. The results of the findings show that the mean radioactivity concentration of K-40, Th-232, U-238 in the soil samples were of values 296.172 ± 10.94 ($Bqkg^{-1}$), 8.68 ± 18.84 $Bqkg^{-1}$ and 92.40 ± 93.41 respectively. The resulting radiation dose values obtained were low and may carry no serious radiological implications to the workers and the population in the vicinity of the mining sites. It is therefore recommended that further study should be carried out in the study area to ascertain the safety of the populace due to continuous mining activities in the area and the used of modern mining equipment which may contribute to the radioactivity level of the soil.

Keywords:
Environmental Safety,
Public Health,
Miners,
Residents,
Uranium-238,
Thorium-232,
Potassium-40.

INTRODUCTION

Radioactivity is the unstable atomic nuclei that spontaneously emit energy and subatomic particles, Encyclopedia (2025). Naturally occurring radioactivity has been a part of our environment, Gaffney & Marley (2006); Oladejo et al., (2020); Taheri et al. (2019). The most commonly found radioactive elements in rocks and soils include uranium (238U), thorium (232Th), and potassium (40K), Alasadi & Abojassim (2022); Joel et al., (2021); Uzorka (2022). If uranium rich material lies close to the surface of the earth, there can be high radium exposure hazards, UNSCEAR, (1993).

Natural occurring radioactivity in soil holds significant importance due to its contribution on human health and environmental sustainability, Kulikov et al., (2022); Strumińska & Falandysz (2021). Soil samples serve as important matrices for studying radionuclide contamination for several reasons, such as long-term accumulation and exposure, Sahoo et al., (2024); Kapil et al. (2023). Also, soils reflect local contamination patterns and can provide insights into the spatial distribution of radionuclides in populated areas, which humans can ingest through inhalation, ingestion, or direct contact routes, Lu et al., (2011); Rice et al., (2014); Bortey-Sam, et al., (2015); Ogundele et al., (2021); Adewumi & Ogundele (2024). The distribution of radionuclides in these matrices is influenced by various factors, including geological characteristics of the area, proximity to natural or artificial sources of radionuclides, atmospheric transport and deposition patterns, physical and chemical properties of the radionuclides, local climate and weather conditions and human activities such as construction and land use changes, Baldık et. al., (2011); Yadav et al., (2023).

To evaluate the possible effects natural occurring radioactivity in soil and its health implication, numerous researches have been done over the past years and there is a need to fit in the current study to better understand the interactions of naturally occurring radioactivity like Potassium-40 (^{40}K), Uranium-238 (^{226}Ra) and Thorium-232 (^{232}Th) levels in soil samples. Some of previous researches include investigation into radioactivity levels in soil samples from wheat cultivation sites in Kapchorwa district Uganda. The researchers observed that the radiation risks related to the radionuclides that are found in the soil are within acceptable bounds. The radiation hazard indices were computed based on the measured activity concentrations of 238U, 232Th and 40K in the research area. The average values of the radiation hazard indices Hin and Hex were 0.79 ± 0.04 and 0.66 ± 0.04 respectively, Sead, et al., (2024). Also, estimation of radioactivity in some sand and soil samples was examined. The findings of the study revealed that activity for 238U, 232Th and 40K satisfy the universal standards limiting the radioactivity within the safe limits of 1000, 1000 and 4000 Bq kg^{-1} for U238, Th232 and K40, respectively, Monika et al., (2010).

MATERIALS AND METHODS

Study Area

Ijero-Ekiti mining site is located in the Northwestern part of Ekiti State, Southwest Nigeria, specifically within the Ijero Local Government Area, which lies between coordinates 7^0 48' 00" – 8^0 00' 00" N and 5^0 3' 00'' – 5^0 15' 00''E It is characterized by basement complex rocks, including pegmatite, charnockite, and schist, which hold various industrial and metallic minerals.

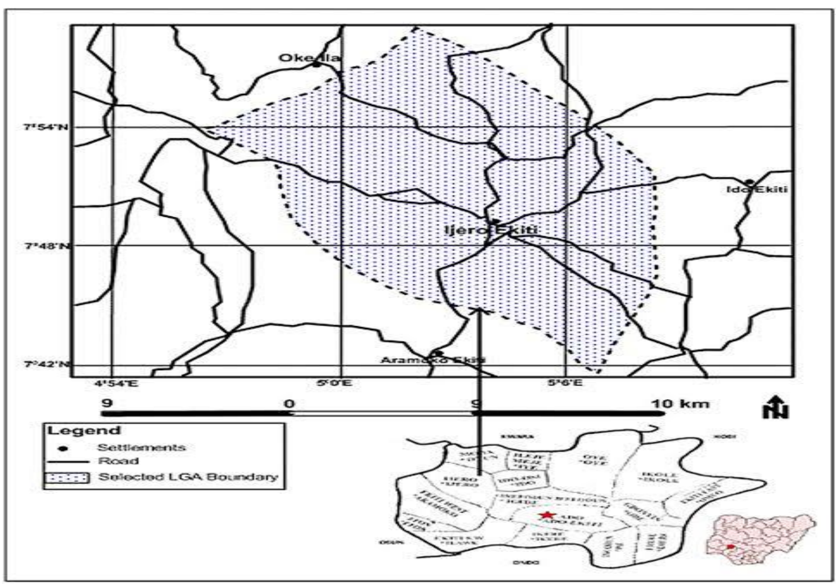

Figure 1: Geological map showing Ijero Ekiti minig site, Falade & Oyeneyin, (2023)

Methodology

The following materials were used to prepare the sample for this study. NaI(Tl) gamma ray spectrometer, Polythene bags, grinding stone, Sieve, 250 ml air tight PVC container.

Sample Collection and Preparation

Four sampling locations were chosen from all over the town to conduct the radiometric study. Out of these, sample of black soil, red soil, loam soil and sandy soil were collected from the four different locations respectively. The soil samples were collected in uncultivated grass covered level areas and in remote locations from man-made structures such as roads and buildings to prevent any external influence on the results. Each soil sample was collected from a minimum of distance of 12 m from each other. The samples were collected in polythene bags. The soil samples were sun dried at 35 – 40^0 C for about 10 hours. The dried samples were ground with grinding stone and the sieved. In order to maintain radioactive equilibrium between ^{226}Ra and its daughter. The soil samples were then packed in a 250 ml air tight PVC container and stored for a period of one month for equilibrium. Each sample was then counted using a gamma spectroscopy device for about 10 hours.

RESULTS AND DISCUSSION

The radioactivity concentration levels in the soil samples collected from the area surveyed is presented in table 1. The three primordial radionuclides K-40, U-238 and Th-232 have been detected and measured in the sample collected. The activity of the radionuclide in the soil is expressed as:

$$C\ [BqKg^{-1}] = \frac{C_k}{A_k} A \qquad (1)$$

Where C = activity concentration of the radionuclide in the soil

C_k = activity concentration of the radionuclides in the standard reference sample [$BqKg^{-1}$]

A = area count after background correction in the spectrum of the radionuclide

A_k = area count after background correction under the spectrum of the radionuclide in the standard reference sample

Table 1: Radioactivity Concentration in the Soil Samples

S/N	Sample Description	K-40	U-238	TH-232
1	BGD	1789 ± 10.37	71 ± 92.13	1320 ± 10.96
2	Soil A	9016 ± 3.186	1712 ± 11.16	832 ± 18.87
3	Soil B	7376 ± 3.557	1552 ± 12.5	951 ± 16.27
4	Soil C	6301 ± 4.017	1727 ± 11.01	1477 ± 10.52
5	Soil D	9574 ± 3.114	943 ± 23.60	10.15 ± 15.21

Where BGD is the background count

The absorbed dose rate D (nGy/hr) in air at 1 m above the ground level due to concentration of the radionuclides in the soil sample is evaluated using the relation below, UNSCEAR (2000):

$$D = a.C_u + b.\ C_{th} + c.\ C_k + d.C_{cs} \qquad (2)$$

Where:

a = dose rate per unit ^{238}U activity concentration (4.27×10^{-10} $Gyh^{-1}/BqKg^{-1}$)

Cu = concentration of ^{238}U in the sample

b = dose rate per unit ^{232}Th activity concentration (6.62×10^{-10} $Gyh^{-1}/BqKg^{-1}$)

C_{th} = concentration of ^{232}Th in the sample

C = dose rate per unit ^{40}K activity concentration (0.43×10^{-10} $Gyh^{-1}/BqKg^{-1}$)

Table 2: Activity Concentration levels of the Radionuclides and the Total Absorbed Dose Rates of Different Samples

S/N	Sample description	K-40	U-238	TH-232	Total Dose ($nGyh^{-1}$)
1	Soil A (0.337 Kg)	340.96 ± 10.85	107.35 ± 92.80	7.21 ± 21.82	111.54
2	Soil B (0.381 Kg)	263.58 ± 10.96	96.88 ± 92.97	5.45 ± 19.63	91.83
3	Soil C (0.457 Kg)	212.87 ± 11.12	108.34 ± 92.78	2.32 ± 15.19	74.29
4	Soil D (0.286 Kg)	367.28 ± 10.83	57.05 ± 95.10	19.36 ± 18.74	169.84
	Mean	296.172 ± 10.94	92.40 ± 93.41	8.58 ± 18.84	111.875

The samples measurement of the radionuclides ^{40}Ka, ^{238}U and ^{232}Th to its dose in the environment varies. To account for the radiation hazard of these radionuclides, radium equivalent activity (Ra_{eq}) is been introduced as:

$$Ra_{eq} = C_u + 1.43\ C_{Th} + 0.077\ C_k \qquad (3)$$

Where C_u, C_{Th}, C_k are the activity concentration of ^{238}U, ^{232}Th and ^{40}K respectively. The value of the radium equivalent obtained are given in table 1.3 below;

Table 3: Radium Equivalent (Ra_{eq})

S/N	Sample Description	Radium Equivalent (Bq/Kg)
1	Soil A (0.337 Kg)	143.91 ± 124.84
2	Soil B (0.381 Kg)	124.96 ± 121.88
3	Soil C (0.457 Kg)	128.04 ± 115.35
4	Soil D (0.286 Kg)	66.79 ± 39.91
	Mean	115.925 ± 100.495

A widely used hazard index (reflecting the external exposure) called the external hazard index H_{ex} is defined as follows:

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} \frac{A_k}{4810} \leq 1 \qquad (4)$$

The internal exposure to uranium and its daughter products quantified by the internal hazard H_{in} is given by:

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259}\frac{A_k}{4810} \leq 1 \quad (5)$$

Also, the alpha index values are calculated using:

$$\propto -index = \frac{C_U}{200}\, Bq/Kg \quad (6)$$

And finally, gamma index is calculated using:

$$\gamma - index\ \frac{C_U}{300} + \frac{C_{Th}}{200}\frac{C_k}{3000} \quad (7)$$

Table 4: External Hazard Index (H_{Ex}), Internal Hazard Index (H_{IN}), Alpha Index ($\propto -index$) and Gamma Index ($\gamma - index$)

S/N	Sample Description	External Hazard Index (H_{Ex})	Internal Hazard Index (H_{IN})	Alpha Index ($\propto -index$)	Gamma Index ($\gamma - index$)
1	Soil A (0.337 Kg)	0.388 ± 0.337	0.522 ± 0.478	0.53 ± 0.054	0.49 ± 0.42
2	Soil B (0.381 Kg)	0.337 ± 0.329	0.457 ± 0.467	0.48 ± 0.055	0.43 ± 0.41
3	Soil C (0.457 Kg)	0.346 ± 0.312	0.475 ± 0.442	0.54 ± 0.056	0.44 ± 0.39
4	Soil D (0.286 Kg)	0.305 ± 0.331	0.401 ± 0.470	0.28 ± 0.054	0.39 ± 0.41
	Mean	0.344 ± 0.327	0.463 ± 0.464	0.456 ± 0.055	0.436 ± 0.406

Discussion

The mean radioactivity concentration of K-40, Th-232, U-238 in the soil samples as presented in table 1 were of values 296.172 ± 10.94 $Bqkg^{-1}$, 8.68 ± 18.84 $Bqkg^{-1}$ and 92.40 ± 93.41 respectively. The resulting radiation dose values obtained were low and may carry no serious radiological implications to the workers and the people in the vicinity of the mining sites. Gamma absorbed dose rates in air outdoors were calculated to be in range 74.29 $nGyh^{-1}$ to 169.84 $nGyh^{-1}$. Inhabitant of the studied area are subjected to an external gamma radiation exposure (effective dose) which ranges from 0.305 to 0.388 μSvy^{-1}. The calculated values of the average H_{ex} of the soil samples studied range between 0.344 ± 0.327. This value is less than the recommended safe levels. Hence, soils from the study area can be used as a construction material without posing any significant radiological threat to the populace.

CONCLUSION

The findings of the research showed that the calculated absorbed dose rates, radium equivalent activities, external hazard indices, internal hazard indices, alpha indices, and gamma indices were generally within internationally recommended safety limits. These findings indicate that the radiological impact of the measured radionuclides in the study area is relatively low and does not pose significant health risks to miners, residents, or the surrounding environment at present.

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