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Assessment of Natural Radioactivity and Radiation Hazard in Soil and Rock Samples from Mining Sites within North-Eastern Nigeria

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Abstract

There have been potential public health risks associated with the use of soil and rock from mining locations in North-Eastern Nigeria. This research evaluates the natural hazard parameters of soil and rock specimens obtained from mining locations in North-Eastern Nigeria, using grammar-ray spectroscopy. A total of twenty-eight samples were systematically gathered from Nahuta and Kashere locations. Through gamma spectrometry employing a NaI (TI) detector, the natural radioactivity levels of ^{238}U, ^{232}Th and ^{40}K were determined for each sample. The findings indicated that the mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Nahuta are 46.13±4.78 Bq/Kg, 34.10±3.02 Bq/Kg and 473.94±5.41 Bq/Kg for the soil samples respectively, and 32.91±0.49 Bq/Kg, 40.70±0.41 Bq/Kg, and 578.18±4.28 Bq/Kg for the rock samples respectively. The corresponding mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Kashere are 17.99±4.18 Bq/Kg, 23.73±1.78Bq/Kg, and 191.65±3.15 Bq/Kg, for the soil samples, and 20.24±3.72 Bq/Kg, 29.09±1.78 Bq/Kg, and 148.36±3.15 Bq/Kg, for the rock samples respectively. An analysis of radiation risk parameters (D, AEDE, Raeq, Hex, Hin, AGDE, and ELCR) has been explored. While the samples from the Kashere region fall within the international recommended levels, elevated readings of certain radiation health parameters are observed in the Nahuta region, posing serious public health risks due to the utilization of the soil and rock from this area in construction activities.

Keywords: Gamma Spectrometry; Radioactivity; Radiological hazard; Mining Sites.

I. INTRODUCTION

Natural occurring radionuclides have been present in the Earth since its formation and are widely distributed throughout the Earth. A plethora of naturally occurring radionuclides, such as radioisotopes of the uranium and thorium series, as well as natural potassium-40, can be found in the environment [1]. These natural radionuclides are present in various environmental components including water, soil, sediment, plants, and air. The soil is a significant reservoir of natural radioactivity, posing radiation hazards to the population and facilitating the migration and transfer of radionuclides into the environment. Consequently, the natural radioactivity of soil is regarded as a fundamental indicator of radiological contamination [2].

Research has shown that about 87% of the radiation absorbed by humans originates from ambient sources, particularly from ^{238}U, ^{232}Th, their progenies, and natural potassium (^{40}K) [3]. Soil and rocks stand out as the primary reservoirs of these primordial radionuclides, serving as pathways for their migration into various environmental compartments [4]. The human environment is constantly subjected to radiation from diverse sources, including cosmic radiation, natural occurring radionuclides present in water, air, plants, and soil, as well as artificial radioactivity resulting from activities such as nuclear testing and medical procedures. External exposure to gamma radiation, originating from natural radionuclides and cosmic rays, occurs alongside internal exposure through inhalation and ingestion of substances in food and water [5]. Prolonged inhalation of uranium and radium can lead to a range of health issues [6].

Radioactive elements are commonly found throughout the earth's environment and vary based on geological and geographical factors. The level of natural radioactivity differs from region to region around the globe, as indicated by [7].

The presence of radioactivity in the soil is significant as it can spread into water and air, as well as through plants and other living organisms. The levels of natural radioactivity are influenced by geological factors, particularly by the composition of rocks and soil [8]. Naturally occurring radionuclides in soil add to the population's overall radiation exposure. The terrestrial element of natural background radiation relies on the makeup of soils and rocks, which contain natural radionuclides [9]. Therefore, it is crucial to measure the natural radioactivity and assess the radiological hazard indices of soil and rock samples in the study area, as natural radiation is the primary source of external dose for the global population.

Extensive research on the radioactivity of the study areas and the attendant risks is currently unavailable. High levels of radiation can lead to cancer risks and various illnesses, which require urgent mitigation measures. Thus, the detection of radioactivity sources helps manage the environment to reduce contamination and conserve the ecosystem. In this regard, data on radioactivity levels will assist the regulatory agencies in maintaining compliance and safety measures in mining, quarrying, and agricultural practices. Also, the result of this research added to the body of information on natural radioactivity in Nigeria which would be useful for other studies and policy formulation. The research quantified the levels of the different radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in the soil and rock samples collected from Nahuta and Kashere. It determined the absorbed dose rate to ascertain instant radiation exposure threat and the annual effective dose equivalent to decide the long-term threat. The study also identified external and internal hazard indices, which accessed potential health risk, and radium equivalent activity to measure the overall radioactive level as well as the excess lifetime cancer risk.

II. Materials and Methods

A. Study Area

Fig. 1 and 2 depict the maps of the study areas.

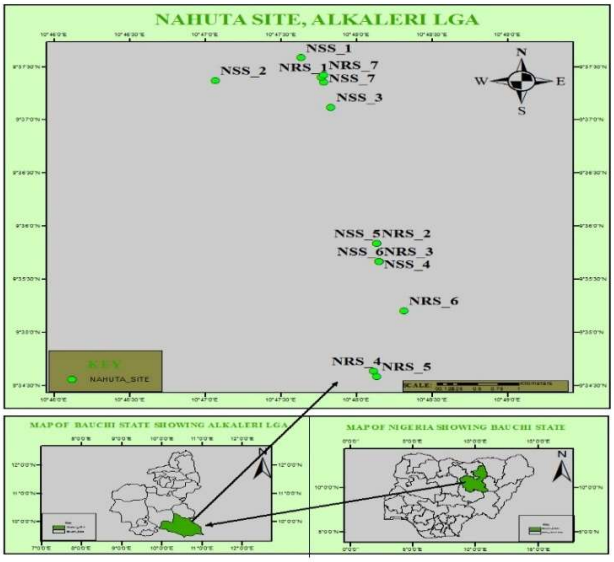

Fig. 1. Location map of the study area 1.

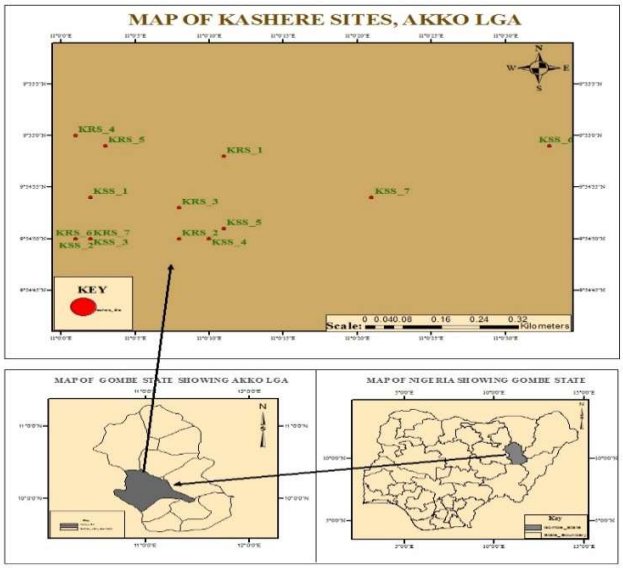

Fig. 2. Location map of the study area 2.

Galena Mining Area at Nahuta is located at latitude 10° 48' 42" E and longitude 9° 34' 45" N along Futuk Road near Yalo in Alkaleri Local Government Area of Bauchi State. Kashere is in Akko local government area of Gombe state, Northeastern Nigeria. It is situated in the Southwestern part of Gombe State and lies between latitudes N9º 46' 0" N and longitudes 10º 57' 0". The study areas fall within the Northern

Basement complex with adjoining metasedimentary rocks, migmatites, granites, quartz monzonite, and diorite, which are likely to be the primary sources of higher radiation levels. The regions of Nahuta and Kashere in North-Eastern Nigeria are very much exposed to anthropogenic activities such as rock mining, quarrying and big-scale agriculture. Such activities affect soil and rock formations and lead to the liberation of radionuclides into the environment, making the occurrence of natural radioactivity in the environment a health risk to the public.

B. Materials

Materials used include soil and Rock samples, a Gamma-Ray Spectrometer (GRS), and Containers. Other materials used for this research are Global Positioning System (GPS), Plastic Hand Trowel, Polythene bags, pen and papers, and Weighing Balance.

C. Methods

1) Sample Collection and Preparation

Samples of soil and rock were aggregated from various parts of the study area. These specimens were accurately labelled with their GPS coordinates. The study area was purposefully stratified into multiple sections to ensure widespread sampling as well as to obtain representative samples across the locations.

The sampling technique used was the random method to improve the statistical sensitivity of the samples. The top layer of soil was scraped off at each sampling location to a depth of 20 cm to eliminate any potential contamination from human activities. Foreign materials such as pebbles, stones, and plant parts were cleared and removed from the soil specimens. A 5 kg soil sample was gathered from a depth of 5 cm using a plastic hand trowel to prevent the introduction of any major, minor, or trace elements from a metallic trowel into the field samples. The soil samples collected were mixed thoroughly, sieved, and placed in a polythene bag properly labelled for easy identification.

The polythene bags were used to store and label the samples. The soil and rock specimens were crushed and passed through a 150 µm mesh to achieve a fine powder. The sieved pieces were subsequently desiccated at 110ºC for 24 hours to eliminate moisture and then placed in polythene bags.

The 200 g dried samples were packed in high-density polyethene containers to encase any possible radioactive gases. These containers had rubber gasket lids that were tightly screwed, and the entire top was covered with parafilm. The seal integrity was checked by floating the container in water and observing whether there were any bubbles. Cylindrical containers with diameter of approximately 10 cm and a height of 15 cm were used. This geometry was selected to fit into the available space of the gamma-ray spectrometer detector to have proper contact and effectively measure the radioactivity levels.

The samples underwent a 30-day storage period before analysis, to ensure that ^{226}Ra, ^{232}Th, and their short-lived decay products reached secular equilibrium. Radionuclides in the samples were measured using a gamma-ray spectrometer equipped with a NaI (Tl) detector and its component electronics. The NaI (Tl) detector was calibrated in terms of energy by exposing it to a standard source with known gamma-ray energy (Cesium-137). The background count was measured by running the NaI (Tl) detector without any sample for 24 hours. The background count measurement showed no significant difference from the ambient radiation levels. Therefore, no additional background reduction techniques were necessary. Standard sources were used to calibrate the NaI (Tl) detector as this was essential for obtaining accurate activity concentrations of the radionuclides. Using the background signal level of the reference materials, the detector's Detection limit was then determined according to [10].

The three reference standard materials are RGU-1 (prepared from a dilution of Uranium ore (BL-5) with silica sand), RGTh-1 (prepared from a dilution of Britholite material (OKA-2) with silica sand), and RGK-1 (prepared from potassium Sulphate). The outcome revealed the suitability and optimal performance of the detector system, which gave confidence in going further with the measurements of the radionuclides in the obtained environmental samples. The Genie™ Spectroscopy Software Suite was used in acquiring and analysing gamma spectra.

2) Assessment of absorbed dose rate

The quantified levels of activity for ^{226}Ra, ^{232}Th, and ^{40}K are transformed into doses utilizing the factors of transformation 0.462, 0.604, and 0.0417 for ^{226}Ra, ^{232}Th, and ^{40}K respectively. These coefficients are employed in the computation of the overall dose rate (D) ($nGyh^{-1}$) as per (1) [7].

$$D = 0.429C_{Ra} + 0.666C_{Th} + 0.042C_K(nGyh^{-1}) \quad (1)$$

Here, C_{Ra}, C_{Th}, and C_K represent the radionuclide concentration (Bq/Kg) for ^{226}Ra, ^{232}Th, and ^{40}K in soil and rock, accordingly.

3) Estimation of the annual effective dose equivalent

The Annual effective dose equivalent (AEDE) was computed utilizing a factor of conversion of $0.7SvGy^{-1}$ which was applied to transform the absorbed dose rate to the human effective dose equivalent with an outdoor presence of 20% [11]. The AEDE was evaluated utilizing (2).

$$AEDE = Absorbed\ Dose \times 8760h \times 0.7SvGy^{-1} \times 0.2 \times 10^{-3}(mSvy^{-1}) \quad (2)$$

4) Calculation of Radium equivalent activities (Ra_{eq})

Ra_{eq} serves as a commonly used risk indicator, and it can be computed using (3) [12].

$$Ra_{eq}(Bq/Kg) = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (3)$$

Here, C_{Ra}, C_{Th}, and C_K indicate the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/Kg, respectively.

5) Hazard Indices (H_{ex} and H_{in})

Reference [12] introduced two indices, Hex and Hin, which are indicators of external and internal radiation hazards aiming to restrict radiation exposure to a limit of 1 mSv/y equivalent. These indices were determined using (4) and (5) [13].

$$H_{ex} = (C_{Ra}/370 + C_{Th}/259 + C_K/4810) \leq 1 \quad (4)$$

$$H_{in} = (C_{Ra}/185 + C_{Th}/259 + C_K/4810) \leq 1 \quad (5)$$

6) Annual Gonadal Dose Equivalent (AGDE)

The AGDE calculates the impact of 226Ra, 232Th, and 40K activities on organs like gonads, bone marrow, and bone cells. Equation 6, as developed by [14], was employed to compute AGDE using conversion factors for the respective isotopes.

$$AGDE(\mu Sv/y) = 3.09C_{Ra} + 4.18C_{Th} + 0.314\,C_K \quad (6)$$

7) Excess lifetime cancer risk (ELCR)

Excess Lifetime Cancer Risk (ELCR) is the likelihood of cancer development due to radiation exposure over a lifetime [15]. Equation (7) modelled according to [6] was used to calculate ELCR considering the annual effective dose equivalent, life expectancy (LE), and risk factor (RF).

$$ELCR = AEDE \times LE \times RF \quad (7)$$

III. Results and Discussions

The activity concentration of Soil and Rock samples taken from Nahuta and Kashere are shown in Tables I, II, III, and IV, while a comparison of the activity concentration is shown in Fig. 3, 4, 5 and 6.

Table I. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/Kg for soil specimens taken from Nahuta.

S/N	Specimen ID	Coordinates	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
1	NHU 1	9° 37’35” N, 10° 47’38” E	53.94±4.72	47.16±3.11	364.61±9.94
2	NHU 2	9° 37’22” N, 10° 47’47” E	68.23±3.91	37.96±2.05	141.89±2.44
3	NHU 3	9° 37’07” N, 10° 47’50” E	45.41±3.53	19.55±3.34	1126.53±8.22
4	NHU 4	9° 35’40” N, 10° 48’09” E	97.67±5.33	17.37±1.07	619.28±3.90
5	NHU 5	9° 35’50” N, 10° 48’08” E	22.09±6.42	62.71±4.37	76.40±4.53
6	NHU 6	9° 35’40” N, 10° 48’09” E	19.38±5.34	40.97±3.92	239.38±0.40
7	NHU 7	9° 37’21” N, 10° 47’47” E	16.20±4.26	13.02±3.32	749.5±8.44
		Mean	46.13±4.78	34.10±3.02	473.94±5.41
		Minimum	16.20±4.26	13.02±3.32	76.4±8.44
		Maximum	53.94±4.72	62.71±4.37	1126.53±8.90
		Worldwide average	32	45	420

NHU = Nahuta Soil Sample; Bq/kg = Becquerel Per Kilogram.

Table II. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K given in Bq/Kg for rock samples taken from Nahuta.

S/N	Specimen ID	Coordinates	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
1	NHU 1	9° 37’24” N, 10° 47’46” E	21.36±0.17	19.41±0.12	1136.50±5.54
2	NHU 2	9° 35’50” N, 10° 48’08” E	17.78±0.28	39.19±0.97	310.45±3.73
3	NHU 3	9° 35’40” N, 10° 48’09” E	27.92±0.69	71.04±0.10	36.67±6.05
4	NHU 4	9° 34’38” N, 10° 48’07” E	9.74±1.26	14.33±0.26	816.90±5.72
5	NHU 5	9° 34’35” N, 10° 48’08” E	31.46±0.64	44.37±0.07	570.13±5.66
6	NHU 6	9° 35’12” N, 10° 48’19” E	29.36±0.17	71.41±0.12	735.20±1.95
7	NHU 7	9° 37’24” N, 10° 47’47” E	92.78±0.28	25.19±0.97	441.51±3.57
		Mean	32.91±0.49	40.70±0.41	578.19±4.44
		Minimum	9.74±1.26	14.33±0.26	36.67±6.05
		Maximum	92.78±0.28	71.04±0.10	1136.50±5.54
		Worldwide average	32	45	420

NHU = Nahuta Rock Sample; Bq/kg = Becquerel Per Kilogram.

Table III. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K given in Bq/Kg for soil samples taken from Kashere.

S/N	Specimen ID	Coordinates	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
1	KSH 1	9° 54’54” N, 11° 0’02” E	15.56±0.17	19.56±1.01	313.01±0.89
2	KSH 2	9° 54’50” N, 11° 0’01” E	28.52±1.22	34.60±0.71	85.74±6.03
3	KSH 3	9° 54’50” N, 11° 0’02” E	10.40±1.02	17.52±0.23	273.40±3.56
4	KSH 4	9° 54’50” N, 11° 0’10” E	16.44±9.01	26.17±6.23	95.03±0.93
5	KSH 5	9° 54’51” N, 11° 0’11” E	7.09±1.26	31.11±3.45	134.10±5.32
6	KSH 6	9° 54’59” N, 11° 59’57” E	29.56±8.91	22.56±0.36	124.30±2.33
7	KSH 7	9° 54’54” N, 11° 0’21” E	18.40±4.51	14.60±0.47	316.00±2.99
		Mean	17.99±4.18	23.73±1.78	191.65±3.15
		Minimum	7.09±1.26	14.60±0.47	85.74±6.03
		Maximum	29.56±8.91	34.60±0.71	316.00±2.99
		Worldwide average	32	45	420

KSH = Kashere Soil Sample; Bq/kg = Becquerel Per Kilogram.

Table IV: Activity concentrations of 226Ra, 232Th, and 40K given in Bq/Kg for rock samples taken from Kashere.

S/N	Specimen ID	Coordinates	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
1	KSH 1	9° 54'58" N, 11° 0'11" E	21.71±1.02	30.41±0.23	93.56±3.56
2	KSH 2	9° 54'50" N, 11° 00'08" E	11.07±8.91	42.43±0.36	326.89±2.33
3	KSH 3	9° 54'53" N, 11° 00'08" E	16.30±4.51	27.31±0.36	13.77±2.99
4	KSH 4	9° 55'0" N, 11° 0'01" E	23.62±1.22	19.47±0.71	295.50±6.03
5	KSH 5	9° 54'59" N, 11° 0'03" E	38.06±0.17	34.39±1.01	84.99±0.89
6	KSH 6	9° 54'50" N, 11° 0'01" E	13.30±1.26	36.21±3.45	109.32±5.32
7	KSH 7	9° 54'50" N, 11° 0'02" E	17.62±9.01	13.47±6.23	114.50±0.93
		Mean	20.24±3.72	29.09±1.78	148.36±3.15
		Minimum	11.07±8.91	13.47±6.23	13.77±2.99
		Maximum	38.06±0.17	42.43±0.36	326.89±2.33
		Worldwide average	32	45	420

KSH = Kashere Rock Sample; Bq/kg = Becquerel Per Kilogram.

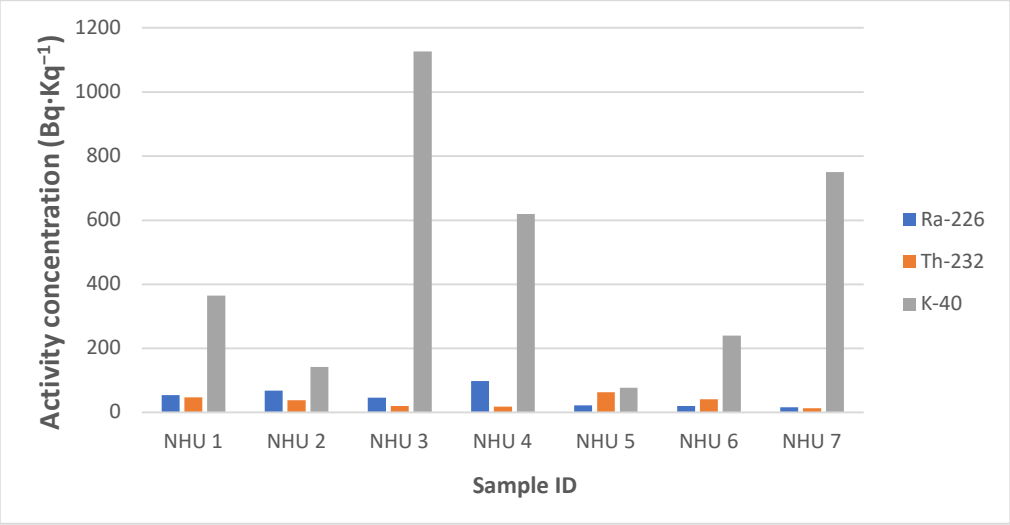

Fig. 3. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K for soil samples collected from Nahuta.

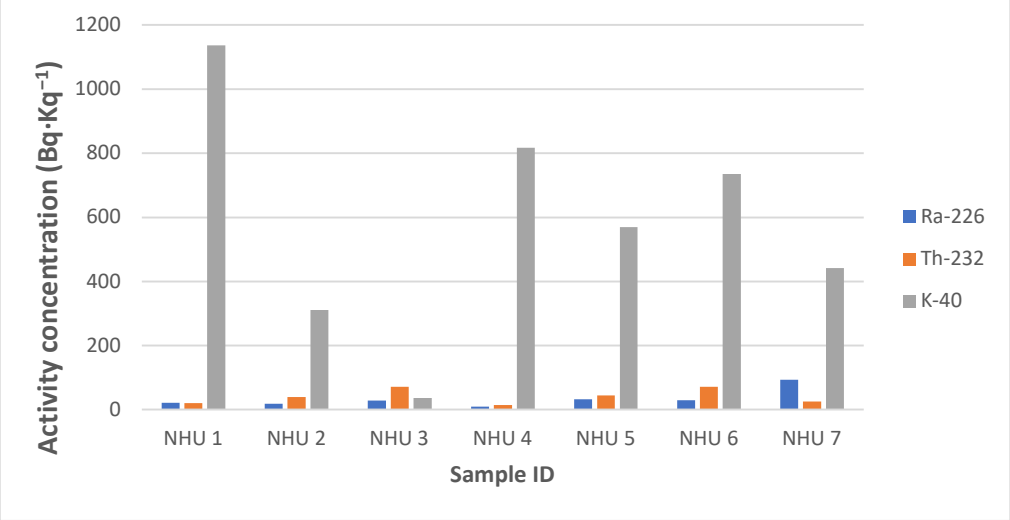

Fig. 4. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K for rock samples collected from Nahuta.

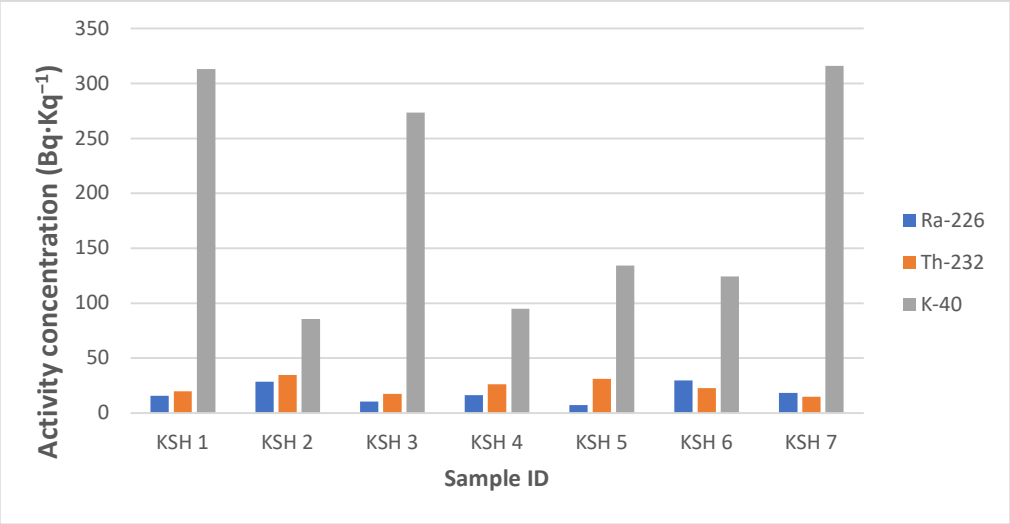

Fig. 5. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K for soil samples collected from Kashere.

Fig. 6. Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K for rock samples collected from Kashere.

Higher activity concentration values for both soil and rock samples are found in Nahuta when compared with same for Kashere (see Table V and Fig. 7). In Nahuta, the ranges of radionuclide concentration for ^{226}Ra, ^{232}Th, and ^{40}K are 16.20±4.26 to 53.94±4.72 Bq/Kg with an average 46.13±4.78 Bq/Kg, 13.02±3.32 to 62.71±4.37 with an average 34.10±3.02 Bq/Kg and 76.4±8.44 to 1126.53±8.90 Bq/Kg with an average 473.94±5.41 Bq/Kg, respectively. Conversely, the radionuclide concentration of ^{226}Ra, ^{232}Th, and ^{40}K in Kashere ranges from 17.99±4.18 to 29.56±8.91 Bq/Kg with an average 17.99±4.18 Bq/Kg, 14.60±0.47 to 34.60±0.71 Bq/Kg with an average 23.73±1.78 Bq/Kg, and 85.74±6.03 to 316.00±2.99 Bq/Kg with an average 191.65±3.15 Bq/Kg, respectively.

The activity concentration in rock samples is higher in Nahuta, with values for ^{226}Ra, ^{232}Th, and ^{40}K ranging from 9.74±1.26 to 92.78±0.28 Bq/Kg with an average 32.91±0.49 Bq/Kg, 14.33±0.26 to 71.04±0.10 Bq/Kg with an average 40.70±0.41, and 36.67±6.05 to 1136.50±5.54 Bq/Kg with an average 578.18±4.28, respectively. In Kashere, the ranges are 11.07±8.91 to 38.06±0.17 with an average 20.24±3.72 Bq/Kg for ^{226}Ra, 13.47±6.23 to 42.43±0.36 Bq/Kg with an average 29.09±1.78 Bq/Kg for ^{232}Th, and 13.77±2.99 to 326.89±2.33 Bq/Kg with an average 148.36±3.15 Bq/Kg for ^{40}K.

Results of soil and rock samples from the Kashere region indicate that the average radionuclide concentrations of ^{226}Ra, ^{232}Th, and ^{40}K are lower than the global averages of 32, 45, and 420 Bq/kg as reported by [7], suggesting no imminent radiological threat to the local population. Conversely, the average activity concentration of ^{226}Ra and ^{40}K in soil and rock samples from Nahuta exceeds the worldwide averages. These

elevated levels are attributed to mining activities in the study area.

The calculated mean activity concentration of ^{226}Ra is higher in the soil sample collected from Nahuta compared to Kashere. Nevertheless, compared to Nahuta, Kashere has slightly elevated levels in samples derived from rocks. This implies that the geological formation and mining exploration in Nahuta may have resulted in higher concentrations of radium than in Kashere where the rocks may contain higher concentrations of ^{226}Ra. The mean activity concentrations of ^{232}Th in the soil and rock samples collected from Nahuta are higher than those obtained for Kashere. The higher ^{232}Th levels in Nahuta could be ascribed to the rocks that make up the formations present in the area. The mean activity concentrations of ^{40}K are higher in the soil and rock samples collected from Nahuta compared to Kashere. ^{40}K being present in many rocks occurs at higher concentrations in Nahuta, signifying a higher concentration of potassium-bearing minerals in the area.

As observed in Fig. 7, there are higher concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, particularly in the soil samples obtained from Nahuta, which may pose a radiological health hazard to the inhabitants of the area, because prolonged exposure to these radionuclides contributes to cancer risk and other illnesses. Also, the higher concentrations of these radionuclides detected indicate the need for environment management and monitoring systems, which should mitigate the effects of mining and other agricultural activities. The results obtained highlight the importance of adhering to legal radiation safety rules in areas where there are anthropogenic activity.

Table V: Variation of the mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K given in Bq/Kg for Soil and Rock samples in the study locations.

Location	Sample Type	Mean activity concentrations (Bq/kg)		
		^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
Nahuta	Soil	46.13±4.78	34.10±3.02	473.94±5.41
Nahuta	Rock	32.91±0.49	40.70571429	578.1942857
Kashere	Soil	17.99±4.18	23.73±1.78	191.65±3.15
Kashere	Rock	20.24±3.72	29.09±1.78	148.36±3.15

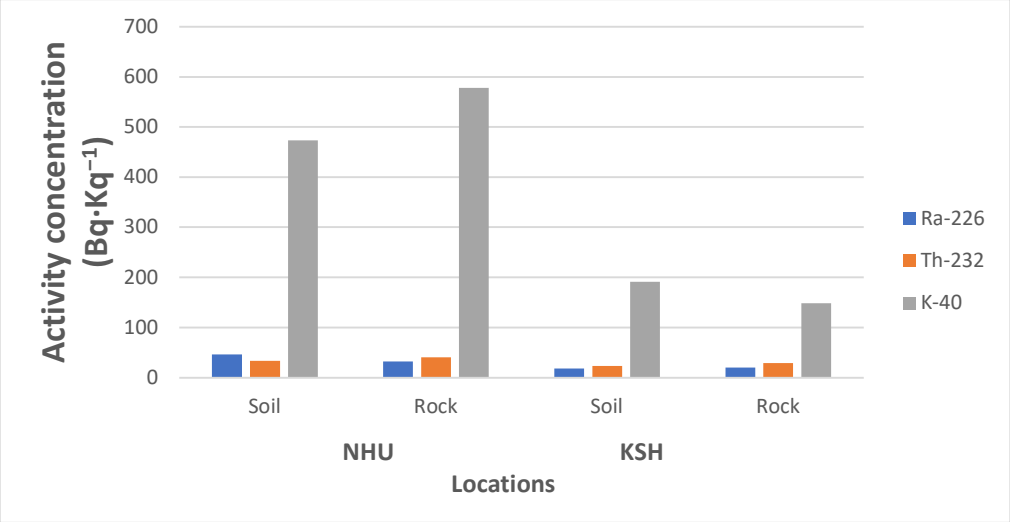

Fig. 7. Variation of the mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K given in Bq/Kg for Soil and Rock samples in the study locations.

The computed values for soil and rock specimens are presented in Tables VI, VII, VIII, and IX respectively. The absorbed dose rate for soil samples ranged from 45.654 to 79.8545 at Nahuta, 27.61272 to 38.87976 at Kashere, and 46.76706 to 91.032 at Nahuta and 21.339 to 46.73679 at Kashere for rock samples respectively.

The mean absorbed dose rate of the examined samples for both soil and rock at Nahuta surpasses the international average value of 57 $nGyh^{-1}$ [7]. This implies a higher risk of exposure to ionizing radiation that is potentially capable of causing adverse health effects.

From the determined values of AEDE in Tables X, XI, XII, and XIII, it is apparent that the mean values of outdoor AEDE for soil and rock samples from Nahuta are marginally higher than the global mean value of 70 $\mu Sv/y$, indicating that the inhabitants of the community are at greater risk of exposure to

radiation. Conversely, the average AEDE outdoor values for the soil and rock samples in Kashere are below the worldwide average value.

Table VI. Dose rates, Annual effective dose equivalent and Radium equivalent for soil samples in Nahuta.

S/N	Sample ID	Coordinate	Absorbed Dose Rate ($nGyh^{-1}$)	Annual Effective Dose Equivalent. AEDE (mSv/y)	Radium Equivalent Ra_{eq} (Bq/Kg)
1	NHU 1	9° 37′35″ N, 10° 47′38″ E	69.86244	85.6793	149.1237
2	NHU 2	9° 37′22″ N, 10° 47′47″ E	60.51141	74.21119	133.1726
3	NHU 3	9° 37′07″ N, 10° 47′50″ E	79.81545	97.88567	159.9725
4	NHU 4	9° 35′40″ N, 10° 48′09″ E	79.47861	97.47257	170.0721
5	NHU 5	9° 35′50″ N, 10° 48′08″ E	54.45027	66.77781	117.2091
6	NHU 6	9° 35′40″ N, 10° 48′09″ E	45.654	55.99007	96.11257
7	NHU 7	9° 37′21″ N, 10° 47′47″ E	47.10012	57.76359	92.43896
		Mean	62.41033	76.54003	131.1574
		Minimum	45.654	55.99007	92.43896
		Maximum	79.81545	97.88567	170.0721
		Worldwide average	57	70	370

NHU = Nahuta Soil Sample

Table VII. Dose rates, Annual effective dose equivalent and Radium equivalent for rock samples in Nahuta.

S/N	Sample ID	Coordinate	Absorbed Dose Rate ($nGyh^{-1}$)	Annual Effective Dose Equivalent. AEDE (mSv/y)	Radium Equivalent Ra_{eq} (Bq/Kg)
1	NHU 1	9° 37′24″ N, 10° 47′46″ E	69.8235	85.63154	136.4909
2	NHU 2	9° 35′50″ N, 10° 48′08″ E	46.76706	57.35512	97.45202
3	NHU 3	9° 35′40″ N, 10° 48′09″ E	60.83046	74.60248	131.8335
4	NHU 4	9° 34′38″ N, 10° 48′07″ E	48.03204	58.90649	93.03289
5	NHU 5	9° 34′35″ N, 10° 48′08″ E	66.99222	82.15926	138.4985
6	NHU 6	9° 35′12″ N, 10° 48′19″ E	91.0329	111.6427	187.5868
7	NHU 7	9° 37′24″ N, 10° 47′47″ E	75.12258	92.13033	162.6216
		Mean	65.51439	80.34685	135.3595
		Minimum	46.76706	57.35512	93.03289
		Maximum	91.0329	111.6427	187.5868
		Worldwide average	57	70	370

NHU = Nahuta Rock Sample

Table VIII. Dose rates, Annual effective dose equivalent and Radium equivalent for soil samples in Kashere.

S/N	Sample ID	Coordinates	Absorbed Dose Rate ($nGyh^{-1}$)	Annual Effective Dose Equivalent. AEDE (mSv/y)	Radium Equivalent Ra_{eq} (Bq/Kg)
1	KSH 1	9° 54′54″ N, 11° 0′02″ E	32.84862	40.28555	67.49565
2	KSH 2	9° 54′50″ N, 11° 0′01″ E	38.87976	47.68214	84.35778
3	KSH 3	9° 54′50″ N, 11° 0′02″ E	27.61272	33.86424	56.38276
4	KSH 4	9° 54′50″ N, 11° 0′10″ E	28.47324	34.91958	60.99722
5	KSH 5	9° 54′51″ N, 11° 0′11″ E	29.39307	36.04766	61.68523
6	KSH 6	9° 54′59″ N, 11° 59′57″ E	32.9268	40.38143	71.23398
7	KSH 7	9° 54′54″ N, 11° 0′21″ E	30.8892	37.88251	63.5078
		Mean	31.57477	38.7233	66.52292
		Minimum	27.61272	33.86424	56.38276
		Maximum	38.87976	47.68214	84.35778
		Worldwide average	57	70	370

KSH = Kashere Soil Sample

Table IX. Dose rates, Annual effective dose equivalent and Radium equivalent for rock samples in Kashere.

S/N	Sample ID	Coordinate	Absorbed Dose Rate ($nGyh^{-1}$)	Annual Effective Dose Equivalent. AEDE (mSv/y)	Radium Equivalent Ra_{eq} (Bq/Kg)
1	KSH 1	9° 54'58" N, 11° 0'11" E	33.49617	41.0797	72.18755
2	KSH 2	9° 54'50" N, 11° 00'08" E	46.73679	57.318	96.61842
3	KSH 3	9° 54'53" N, 11° 00'08" E	25.7595	31.59145	56.22242
4	KSH 4	9° 55'0" N, 11° 0'01" E	35.511	43.55069	74.07931
5	KSH 5	9° 54'59" N, 11° 0'03" E	42.80106	52.49122	93.5412
6	KSH 6	9° 54'50" N, 11° 0'01" E	34.413	42.2041	73.24447
7	KSH 7	9° 54'50" N, 11° 0'02" E	21.339	26.17015	45.60431
		Mean	34.29379	42.0579	73.0711
		Minimum	21.339	26.17015	45.60431
		Maximum	46.73679	57.318	96.61842
		Worldwide average	57	70	370

KSH = Kashere Rock Sample.

Tables X and XI present the values of H_{ex} and H_{in}, ranging from 0.249875 to 0.459787 and 0.293659 to 0.72376 for soil samples and 0.251486 to 0.507914 and 0.277811 to 0.690562 for rock samples in Nahuta respectively, while Tables XII and XIII depicts the values for Kashere with the values falling within the recommended limits.

The AGDE mean values for soil and rock samples in Nahuta were $433.9256\ \mu Sv/y$ and $453.408\ \mu Sv/y$, respectively, which exceed the international standard of $300\ \mu Sv/y$, except for samples from Kashere (see Tables X and XI). These high values in Nahuta point to potential genetic and reproductive health risk.

With the recommended worldwide ELCR value given as 0.29×10^{-3} [16], the ELCR range was determined to be $0.196 \times 10^{-3} - 0.343 \times 10^{-3}$, averaging at 0.27×10^{-3} for soils samples at Nahuta and $0.119 \times 10^{-3} - 0.167 \times 10^{-3}$, with an average of 0.14×10^{-3} for soils samples at Kashere. Similarly, for rock samples, the ELCR range was found to be $0.200 \times 10^{-3} - 0.39075 \times 10^{-3}$, with an average of 0.28×10^{-3} for Nahuta and $0.092 \times 10^{-3} - 0.201 \times 10^{-3}$, averaging at $0.15 \times 10^{-3}3$ for samples at Kashere. These mean values of ELCR although observed to be below the global average as presented in Tables X, XI, XII, and XIII, should be regularly monitored especially at Nahuta to ensure that the levels remain within safe limits.

Table X. Hazard indices (Hex, Hin, AGDE, and ELCR) for soil samples (Nahuta)

S/N	Sample ID	Coordinates	H_{EX}	H_{IN}	AGDE	ELCR ($\times 10^{-3}$)
1	NHU 1	9° 37'35" N, 10° 47'38" E	0.403671	0.549455	478.2909	0.299878
2	NHU 2	9° 37'22" N, 10° 47'47" E	0.360468	0.544873	414.057	0.259739
3	NHU 3	9° 37'07" N, 10° 47'50" E	0.432418	0.555148	575.7663	0.3426
4	NHU 4	9° 35'40" N, 10° 48'09" E	0.459787	0.72376	568.8608	0.341154
5	NHU 5	9° 35'50" N, 10° 48'08" E	0.31771	0.377413	354.3755	0.233722
6	NHU 6	9° 35'40" N, 10° 48'09" E	0.260331	0.312709	306.3041	0.195965
7	NHU 7	9° 37'21" N 10° 47'47" E	0.249875	0.293659	339.8246	0.202173
		Mean	0.354894	0.479574	433.9256	0.26789

NHU = Nahuta Soil Sample.

Table XI. Hazard indices (Hex, Hin, AGDE, and ELCR) for rock samples (Nahuta)

S/N	Sample ID	Coordinates	H_{EX}	H_{IN}	AGDE	ELCR ($\times 10^{-3}$)
1	NHU 1	9° 37'24" N, 10° 47'46" E	0.36895	0.42668	503.9972	0.29971
2	NHU 2	9° 35'50" N, 10° 48'08" E	0.263909	0.311963	316.2357	0.200743
3	NHU 3	9° 35'40" N, 10° 48'09" E	0.357369	0.432828	394.7344	0.261109
4	NHU 4	9° 34'38" N, 10° 48'07" E	0.251486	0.277811	346.5026	0.206173
5	NHU 5	9° 34'35" N, 10° 48'08" E	0.37487	0.459897	461.6988	0.287557
6	NHU 6	9° 35'12" N, 10° 48'19" E	0.507914	0.587265	620.069	0.39075
7	NHU 7	9° 37'24" N, 10° 47'47" E	0.439805	0.690562	530.6185	0.322456
		Mean	0.366329	0.455287	453.408	0.281214

NHU = Nahuta Rock Sample.

Table XII. Hazard indices (Hex, Hin, AGDE, and ELCR) for soil samples (Kashere)

S/N	Sample ID	Coordinates	H_{EX}	H_{IN}	AGDE	ELCR ($\times 10^{-3}$)
1	KSH 1	9° 54′54″ N, 11° 0′02″ E	0.18265	0.224704	228.1263	0.140999
2	KSH 2	9° 54′50″ N, 11° 0′01″ E	0.228497	0.305578	259.6772	0.166888
3	KSH 3	9° 54′50″ N, 11° 0′02″ E	0.152593	0.180701	191.2172	0.118525
4	KSH 4	9° 54′50″ N, 11° 0′10″ E	0.165232	0.209664	190.0296	0.122219
5	KSH 5	9° 54′51″ N, 11° 0′11″ E	0.167157	0.18632	194.0553	0.126167
6	KSH 6	9° 54′59″ N, 11° 59′57″ E	0.192838	0.27273	224.6714	0.141335
7	KSH 7	9° 54′54″ N 11° 0′21″ E	0.171797	0.221527	217.108	0.132589
		Mean	0.180109	0.228746	214.9836	0.135532

KSH = Kashere Soil Sample.

Table XIII. Hazard indices (Hex, Hin, AGDE, and ELCR) for rock samples (Kashere)

S/N	Sample ID	Coordinates	H_{EX}	H_{IN}	AGDE	ELCR ($\times 10^{-3}$)
1	KSH 1	9° 54′58″ N, 11° 0′11″ E	0.19554	0.254216	223.5755	0.143779
2	KSH 2	9° 54′50″ N, 11° 00′08″ E	0.261702	0.291621	314.2072	0.200613
3	KSH 3	9° 54′53″ N, 11° 00′08″ E	0.152361	0.196415	168.8466	0.11057
4	KSH 4	9° 55′0″ N, 11° 0′01″ E	0.200446	0.264284	247.1574	0.152427
5	KSH 5	9° 54′59″ N, 11° 0′03″ E	0.253314	0.356179	288.0425	0.183719
6	KSH 6	9° 54′50″ N, 11° 0′01″ E	0.198481	0.234426	226.7813	0.147714
7	KSH 7	9° 54′50″ N, 11° 0′02″ E	0.123434	0.171056	146.7034	0.091596
		Mean	0.197897	0.2526	230.7591	0.147203

KSH = Kashere Rock Sample.

IV. Conclusion

In this study, an investigation on the radioactivity levels in soil and rock specimens obtained from various locations within the Northeastern region of Nigeria utilizing a gamma ray Spectrometer, specifically a Sodium Iodine detector was carried out. Analysis of the results revealed that the natural radioactivity content from Nahuta exceeded the recommended average levels. Conversely, samples from Kashere demonstrated values below the average, suggesting no radiological threat to the local population. Various radiation risk parameters (D, AEDE, Raeq, Hex, Hin, AGDE and ELCR) were computed and analysed, with notably higher values detected in Nahuta that surpass the upper international thresholds. This anomaly is attributed to the existence of naturally occurring radioactive elements due to mineral exploration in the area. To mitigate the accumulation of radionuclides in the soil, farmers in Nahuta are encouraged to utilize organic fertilizers over inorganic alternatives. Also, stringent safety protocols should be enforced to regulate the local mining operations in Nahuta.

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Conflict of Interest

The authors have no conflicts of interest to declare.

Data Availability

The data for this study are included in this article. All the outcomes have been presented in this manuscript and there are no raw data that have been excluded.

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