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Radiation Hazard Assessment of Natural Radionuclides in the Soil Samples from the Quarry Area of Shira, Bauchi State, Nigeria

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ABSTRACT

The mining activities has significantly enhanced the naturally occurring radionuclides (NORMs) above the background level, which is harmful to human health and the ecosystem. The specific activities of ^{238}U, ^{232}Th and ^{40}K of the soil samples collected in the quarry area were analysed using gamma spectrometer. The concentrations of the radionuclides varies from $6.19 \pm 0.08\ BqKg^{-1}$ to $37.23 \pm 2.02\ BqKg^{-1}$ with a mean value of $19.7 \pm 1.6\ BqKg^{-1}$ for ^{226}R, $7.97 \pm 0.86\ BqKg^{-1}$ to of $38.91 \pm 2.63\ BqKg^{-1}$ with a mean value of $23.3 \pm 1.7\ BqKg^{-1}$ for ^{232}Th and $76.32 \pm 4.52\ BqKg^{-1}$ to $423.51 \pm 15.15\ BqKg^{-1}$ with a mean value of $211.6 \pm 9.9\ BqKg^{-1}$, which is below the recommended worldwide limit of 35, 30 and 400 $BqKg^{-1}$, respectively. The potential health risks associated with radionuclides were determined. The result for Radium equivalent activity (Ra_{eq}) is 184.8 $BqKg^{-1}$, external hazard index (H_{ex}) is 0.5, annual effective dose (E_{aed}) is 0.3 mSv y^{-1} and excess lifetime cancer risk (ELCR) is 0.17×10^{-3} , respectively. According to (UNSCEAR, 2000), the computed radiation hazard indices are below the allowable limits. Thus, there is no significant risk of radiation exposure to the public as a result of the quarry activities in the study area.

Keywords: Quarry, Radionuclides, Gamma rays, Geological formations, Hazard parameters.

INTRODUCTION

The exposure to ionized radiation is from two types sources: natural and artificial source. Natural radioactive substances in our surroundings are mostly from terrestrial radioactivity and extra-terrestrial sources, such as cosmic radiation. The main naturally occurring radionuclide (NORM) are ^{226}Ra, ^{232}Th, and ^{40}K and their specific activities vary depending on the soil type and geology of the place, and they are mostly emanated from rock soil and water (Khandaker et al., 2021). The sources of artificial radionuclides which include ^{137}Cs, ^{131}I and ^{90}Sr are from nuclear weapons tests, nuclear power accidents such as (Fukushima nuclear disaster and three-mile island accident), and also due to mining and medical applications. Both naturally occurring and artificially created radionuclides can be absorbed by plants and animals once they are in the environment (Agbalagba et al., 2012).

Gamma radiation emitted from the radionuclides is directly responsible for the external exposure, while alpha particles are internally exposed to the respiratory tract through inhaling radioactive inert gases such as thoron (^{220}Rn) and radon (^{222}Rn) and their short-lived products (Turhan, 2008). The types of rocks from which terrestrial background radiation originates determine its specific activity, the fast expanding industrial growth makes readily to redistribute the prevailing concentrations of NORMs (Md Sirajul Islam et al., 2023). Leukemia, mutation of cells, lung and kidney cancers are the risks linked to prolonged exposure to ionized radiation (Ode et al., 2017[i]).

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The environment and human health have been significantly damaged by mining operations and the exploitation of natural resources. Granite quarries produce radioactive elements, which are release into the air, water, plants, and other living things, contaminating the surrounding, food crops, and soil surface (Nduka et al., 2022). The recommended worldwide limit of Radium, Thorium and potassium are 35, 30 and 400 Bq/Kg^{-1}, respectively (Asano et al., 2001). Understanding the distribution of these naturally occurring radioactive elements is beneficial for knowing the radiological consequences.

With a view to ascertain the risks from the exposure to radiation from naturally occurring radionuclides in the environment, numerous researches have been conducted in Nigeria and other nations worldwide. According to the literature that is currently available, no study has been carried out to evaluate the potential health risks to the general public due to exposure to radionuclides (^{228}U, ^{232}Th and ^{40}K) from the granite quarry in the Shira, Bauchi State. This study, therefore, seeks to evaluate the concentrations of (^{228}U, ^{232}Th and ^{40}K) in the study area and also to estimate the radiological health risk parameters from the exposure of radioactive elements.

MATERIAL AND METHODS

Study Area

The Shira area situated in the Bauchi North Nigeria, with a coordinate, 11 ° 30’15’’N 10°1’2’’E. Shira has a land mass of 1,321 km^2 and, and is densely populated with a population of 234,014. It characterizes by two seasons, which are dry and rainy seasons, with a temperature varies from -8^{o}F to 74^{O}F. The Shira district is underlying by two geological formations, tertiary Kerri–Kerri and Intracrustals (Granite, Migmatite) geological formation as shown in figure 1(Ibrahim et al., 2023).

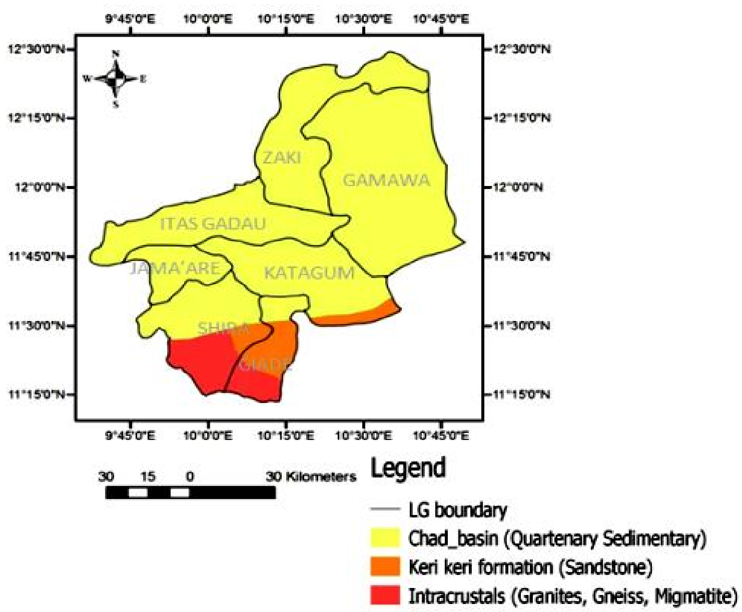

Figure 1. Geological map of Shira

Sample Collection and Preparation

soil samples at 10 different locations were randomly taken at a depth of 15cm to ensure

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equal sampling chance to each of the sample across the study area. The distance between the successive samples point is approximately 500 meters. To prevent cross-contamination, the samples were spread out on the cardboard sheets, and any foreign items were taken out before they were repacked, sealed, tightly tied, and labeled in a polyethylene. After being air-dried for 24 hours at room temperature, they were ground into fine powder and then dried at 110 °C to get rid of any remaining moisture. Then, the prepared samples were brought to laboratory at National Institute of Radiation Protection and Research (NIRPR), University of Ibadan, Nigeria for analysis.

Sample Measurement

The samples at (NIRPR) laboratory were put in the beaker, which is sealed to prevent ^{222}Rn and ^{220}Rn from escaping to the surrounding. The samples were kept for 28 days in the Marinelli beaker to reach radioactive secular equilibrium between ^{226}Ra and its short-lived daughters (Ali et al., 2021). The activity concentrations of the radionuclides in the soil samples were measured using gamma-ray spectroscopy coupled with high purity germanium (HPGe) . The radiation spectrum of the radionuclides was obtained using multichannel analyzer. A gamma reference source (ENV94084-200g) of mixed radionuclides was used to calibrate the energy and efficiency of the gamma spectrometry apparatus. The detector operated at an energy resolution of 8% at 0.662 MeV of ^{137} Cr. The activity concentration of ^{238} Ra was measured from the gamma-ray emission ^{214} Bi (1764 KeV), while for ^{232}Th was used determine from the γ-emission of ^{208}TI (2614.5 KeV) and 1460 KeV gamma-emission of ^{40}K was used in the assessment of activity concentration of ^{40}K.

Computation of Specific Activity of Radionuclides

The gamma photon peaks and the intensity in the analyzed samples used to determine the specific activity of ^{238}U, ^{232}Th, and ^{40}K in Bq/kg using the relation (Khandaker et al., 2018).

$$A_C = \frac{N \times 1000}{\varepsilon_\gamma I_\gamma t_s m_s} \quad 1$$

Where A_C stands for specific activities for the radioactive elements in the samples, N is the total counts rate related to the photo-peak, I_γ gamma-ray intensity, ε_γ the efficiency of gamma-ray detector, t_s time counter for the soil sample in seconds and m_s represents the weight in grams.

Estimation of Radiation Hazard Parameters

Radiation hazard parameters which include: radium equivalent activity (Ra_{eq}), absorbed gamma dose (D_{air}), cancer risk (ELCR) and total hazard indices (H_{ex} and H_{in}) have been assessed in order to determine any potential effects on human health.

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$$A_C = \frac{N \times 1000}{\varepsilon_\gamma I_\gamma t_s m_s} \quad 2$$

Where A_C stands for specific activities for the radioactive elements in the samples, N is the total counts rate related to the photo-peak, I_γ gamma-ray intensity, ε_γ the efficiency of gamma-ray detector, t_s time counter for the soil sample in seconds and m_s represents the weight in grams.

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RESULTS AND DISCUSSION

Radioactivity of Soil Samples

The specific activities of radioactive elements from the soil samples collected from 10 different sampling points at the quarry area of Shira are tabulated in the Table 1. The specific activity of the radionuclides ranged from $6.19 \pm 0.08\, BqKg^{-1}$ to $37.23 \pm 2.02\, BqKg^{-1}$ with a mean value of $19.7 \pm 1.6\, BqKg^{-1}$ for ^{226}R, $7.97 \pm 0.86\, BqKg^{-1}$ to of $38.91 \pm 2.63\, BqKg^{-1}$ with a mean value of $23.3 \pm 1.7\, BqKg^{-1}$ for ^{232}Th and $76.32 \pm 4.52\, BqKg^{-1}$ to $423.51 \pm 15.15\, BqKg^{-1}$ with an average value of $211.6 \pm 9.9\, BqKg^{-1}$. The findings of this investigation indicate the specific activities of radionuclides increases in the order ^{226}Ra < ^{232}Th < ^{40}K. Owing to the insoluble nature of thorium in water and low geochemical mobility, the activity of ^{232}Th in the study is observed to be greater than the concentration of ^{226}Ra (Isinkaye and Emelue, 2015). In the examined samples, ^{40}K distinctly has the highest activity concentration than the other radionuclides. This is because most continental rocks naturally contain a significant amount of potassium. The measured values exhibit a significant variation with respect to the sampling locations, which suggests the radioactive elements are not uniformly distributed as shown in the Fig. 2. The variation could be attributed to different geology of the area.

The results demonstrate that the three radionuclides' mean activity concentrations are lower than recommended global average values (35, 30 and 400 Bq/kg, for ^{226}Ra, ^{232}Th, and ^{40}K, respectively)(UNSCEAR, 2000). However, higher activity concentrations of radionuclides are obtained at the sample points SP5 and SP8 that is above the maximum limit, which could be attributed to the quarry activities in the area. The points SP5 and SP8 are at close proximity to the quarry operations compare to other sample locations. The area is underlain by Intracrustals (Granite, Migmatite) geological formation. The area could be used for uranium exploitation due high concentration of radionuclides. The results obtained from present work are compare with values reported by other researchers worldwide as shown in the Table 2. The mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K from this study are relatively higher than results obtained by (Fallah et al., 2019) and (Awad et al., 2022). The results are comparably lower than those reported by (Srilatha et al., 2015) and (Leuangtakoun et al., 2020), but is in close agreement with values reported by (Tran et al., 2020) and (Faanu et al., 2011), respectively.

Table 1. Activity concentrations of radionuclides in samples

Samples code	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
SP1	23.45 ± 1.86	23.12 ± 1.45	187.34 ± 10.08
SP2	12.34 ± 1.13	22.71 ± 1.72	345.12 ± 15.15
SP3	6.19 ± 0.08	19.23 ± 1.62	97.45 ± 5.32
SP4	30.71 ± 2.57	7.97 ± 2.15	234.65 ± 11.63
SP5	36.04 ± 2.83	38.91 ± 2.63	302.31 ± 13.17
SP6	7.18 ± 0.43	12.56 ± 1.08	76.32 ± 4.52
SP7	18.56 ± 1.37	26.72 ± 1.43	145.77 ± 9.13
SP8	37.23 ± 2.02	29.19 ± 0.86	423.51 ± 13.03
SP9	21.63 ± 1.92	32.41 ± 2.07	109.63 ± 6.71

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SP10	13.71 ± 1.53	21.03 ± 1.67	189.49 ± 9.76
Mean	20.70 ± 1.57	23.9 ± 1.67	211.16 ± 9.85

Table 2. Comparison of activity concentration of present work with other literature.

Country	Activity concentration (Bq kg^{-1})			References
	^{226}Ra	^{232}Th	^{40}K	
Iran	16.10	16.47	280.91	(Fallah et al., 2019)
Egpyt	8.8 ±3.9	30.8 ±12.2	106.9 ±46.8	(Awad et al., 2022)
Nigeria	30.31	92.42	482.79	(Avwiri and Ononugbo, 2012)
Iraq	32	45	412	(Ali et al., 2017)
Ghana	13.61 + 5.39	24.22 + 17.15	162.08 + 63.69	(Faanu et al., 2011)
Nigeria	19.76 ± 3.09	31.98 ± 5.10	494.64 ± 10.46	(Sowole and Egunjobi, 2019)
Malaysia	13 ± 1	11 ± 1	416 ± 19	(Shuaibu et al., 2017)
Laos	44.4 ± 3.2	63.3 ± 5.2	523 ± 18	(Leuangtakoun et al., 2020)
Jordan	49.9	26.7	291.1	(Al-Hamarneh and Awadallah, 2009)
India	33.78 ± 1.99	77.44 ± 2.37	791.58 ± 5.78	(Srilatha et al., 2015)
Cyprus	83.7	53.6	593.9	(Abbasi et al., 2020)
Vitenam	21.1 ± 1.3	36.6 ± 1.3	279 ± 29	(Tran et al., 2020)
Shira (Nigeria)	20.70 ± 1.57	23.9 ± 1.67	211.16 ± 9.85	Present study
Worldwide	35	30	400	(UNSCEAR, 2000)

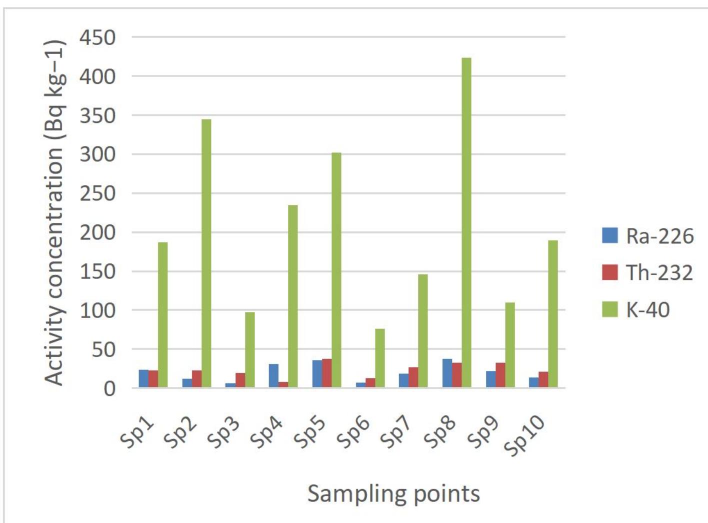

Figure 2: Variation of activity concentrations at the different sampling points.

Radiological Hazard Assessment

To evaluate the radiation hazard risk resulting from exposure to naturally occurring radionuclides in the soil samples from the quarry area, radiation hazard parameters were computed and are presented in the Table 4. The radium equivalent activity (Raeq) varies from 56.3 to 315.5 Bq kg^{-1} with mean value of 184.8 Bq kg^{-1} which is within the recommended safe limit of 370 Bq kg^{-1}. There is no radiation risk to the general public from the quarry operations. The Absorbed dose rate (D_{air}) measured from the gamma emitters radionuclides ranged from 13.6 to 44.7 (nGy

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h^{-1}) with average value of 27.85 (nGy h^{-1}), similarly, the annual effective dose varies from 0.07 to 0.43 with a mean value of 0.27 (mSv y^{-1}). The mean values of absorbed dose rate and annual effective dose are below the safe limit of 55 nGy h^{-1} and 0.46 mSv y^{-1} for the general public exposure provided by (UNSCEAR, 2000). Moreover, the results show that there is no radiological risk to the general public and that the ionizing radiation from naturally occurring radionuclides has very little effect. However, accumulating low-level radiation due to ongoing exposure may have some negative effects on health in the future.

The external H_{ex} and internal H_{in} radiation hazard indices are computed, with H_{ex} varies from 0.23 to 0.83 with mean value of 0.49, Whereas, the H_{in} ranged from0.33 to 0.91 with an average value of 0.61 respectively. All the values of the radiation hazard indices are less than unity ($\leq$ 1), which is the permissible limit. Therefore, the radiological health risk from external and internal exposure is negligible. The Excess lifetime cancer (ELCR) values from 0.06×10^{-3} to 0.26×10^{-3} with a mean value of 0.17 $\times 10^{-3}$. The ELCR values are substantially less than the global average of 0.29×10^{-3} reported by (UNSCEAR, 2000), showing a minimal likelihood of developing cancer over a 70-year lifetime exposure.

Table 3: Radiation hazard parameters

Sampling point	Raeq(Bq kg^{-1})	Dr (nGy h^{-1})	Eaed(mSv y^{-1})	H_{ex}	H_{in}	ELCR $\times 10^{-3}$
Sp1	56.3	23.1	0.12	0.71	0.74	0.17
Sp2	115.8	44.7	0.09	0.59	0.79	0.21
Sp3	213.7	13.6	0.41	0.32	0.91	0.08
Sp4	96.2	17.6	0.34	0.86	0.33	0.23
Sp5	308.9	30.3	0.32	0.43	0.65	0.26
Sp6	274.8	37.9	0.18	0.18	0.37	0.15
Sp7	64.6	20.5	0.43	0.42	0.52	0.06
Sp8	189.4	29.7	0.07	0.83	0.67	0.21
Sp9	213.1	19.3	0.39	0.23	0.48	0.22
Sp10	315.5	41.8	0.33	0.37	0.64	0.11
Average	184.8	27.85	0.27	0.49	0.61	0.17

CONCLUSION

Long-term exposure to gamma rays from granite quarry operations can have a significant negative effect on both inhabitants and surrounding ecosystem due to their easy long-distance propagation and diffuse nature. The concentrations ^{226}Ra, ^{232}Th and ^{40}K from the quarry site were determined to ascertain the radiological health risks from the exposure of ionized radiation. The average concentrations of ^{226}Ra, ^{232}Th and ^{40}K are 20.70 ± 1.57, 23.9 ± 1.67 and 211.16 ± 9.85 Bq kg^{-1} , which are within the recommended safe limit reported worldwide value of 35, 30 and 400 $Bqkg^{-1}$. Two sampling locations which are SP5 and SP have higher activity concentrations above the published global average values by UNSCEAR. There is a significant variation in the measured data with the sampling locations, indicating that the distribution of radionuclides is not uniform, which is due to the different soil type and geological formations of the area. The radiation hazard parameters D_r, Eaed, Raeq, Hex and ELCR were computed from the measured specific activities of the ^{226}Ra, ^{232}Th and ^{40}K, the results obtained are lower than the set limit worldwide.

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The findings of the study indicate that the quarry activities may not present a substantial radiation risk to the local population, since all hazard metrics are within the recommended limits set by regulatory organizations. However, accumulating low-level radiation due to ongoing exposure may have some negative effects on health in the future. For the purpose of monitoring any potential future changes, the results outcome might serve as baseline data.

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