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Estimation of Radiation Dose in Building Materials Used In Federal University Gusau Using Gamma-Ray Spectroscopy Analysis

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ABSTRACT

This study estimated the radiation dose in building materials (sand, cement, and granite) in Federal University Gusau, Zamfara State, Nigeria, through gamma-ray spectrometry system using a Sodium Iodide Thallium activated "NaITl" detector in a low background configuration. The range of the average activity concentration of ²²⁶Ra was found to be $56.65 \pm 0.75 \text{ Bqkg}^{-1}$ to $159.45 \pm 2.68 \text{ Bqkg}^{-1}$, which was higher than that of the world mean value for soil 35 Bqkg^{-1} , for ²³²Th the range was $46.65 \pm 0.45 \text{ Bqkg}^{-1}$ to $79.32 \pm 1.68 \text{ Bqkg}^{-1}$, all the samples, were found to be higher than that of the world mean for soil 30 Bqkg^{-1} . While the activity concentrations of ²³²Th levels of blocks, granite, and sand samples are all above the world range, except the cement which was within the worldwide range $194.84 \pm 1.31 \text{ Bqkg}^{-1}$ to $656.84 \pm 0.76 \text{ Bqkg}^{-1}$. The average activity concentration of ⁴⁰K for cement, sand, and blocks was within the worldwide range, with granite samples slightly higher than the world mean value for soil 400 Bqkg^{-1} . The results have been compared with the world mean values of 35, 30, and 400 Bqkg^{-1} specified by the UNSCEAR (2016). Concerning radiological risk to human health, the absorbed gamma dose rate (D) was estimated to be above the world average range of 55 nGyh^{-1} ; the outdoor annual effective dose equivalent (AEDE) were, estimated to be below the permissible limit of 0.07 mSvy^{-1} . The values of Raeq, Hex, and Hin for all the samples in the present work are lower than the accepted safety limit value of 370 Bqkg^{-1} and below the limit of unity, respectively.

Keywords: Radionuclide, Gamma-ray Spectrometry, Building Materials, Federal University Gusau Zamfara, Nigeria.

1.0 INTRODUCTION

Because of the public's worry about radioactive effects, research has been done over the past 40 years on the occurrence of natural radioactivity and the radiological hazard of building materials. Since then, a wide range of models for the radiological evaluation of naturally occurring radioactivity in building materials have been proposed, and a large amount of data has been gathered globally (Majid et al. 2012). To accomplish this purpose, the effects of ionizing radiation coming from various sources must be investigated. The primary goal of radiation scientists is to guarantee radiation protection and safety by scientific study and recommendations. A region's geology, parent magma's chemical makeup, mode of formation, and other factors can all influence the presence of radioactive elements (⁴⁰K, ²²⁶Ra, and ²³²Th) and other minerals in rocks (Alausa et al., 2020). Human activities that increase the risk of ionizing radiation exposure

include mining, quarrying, the disposal of radioactive waste, and the explosion of radioactive compounds (Olabamiji et al. 2023). Roughly eighty percent of human life is spent indoors. For this reason, understanding natural radiation is becoming more and more crucial in today's world. Increased radiation exposure is a result of the activity concentration of building materials containing NORM elements in two different methods (Sas Z 2017, Dodge-Wan 2021). There are two ways in which the activity concentration of building materials containing NORM elements contributes to the increased radiation exposure (Sas Z 2017, Dodge-Wan 2021). Ionizing radiation exposure can occur from human operations such as mining, quarrying, the disposal of radioactive waste, or the explosion of radioactive compounds (Faanu et al., 2016). In Nigeria, the use of crushed rocks (stones) in building construction is growing in popularity. Concurrently, engineers and building

contractors mistakenly called all types of rocks granite. In addition, several types of rocks are currently being ground into dust or smaller sizes and utilized to make blocks for wall casting and flooring (Alausa et al., 2019). The majority of these rocks are also utilized as architectural ornaments in places like schools, labs, and homes. In addition, weathering patterns, sedimentation processes, absorption from flowing groundwater, dilution with other materials, and soil porosity can all have an impact on the radioactivity levels of naturally occurring radioactive material present in the soil (Oladejo, 2023). Since humans are exposed to natural radioactivity due to its widespread distribution in terrestrial materials, natural environmental radioactivity—particularly in agricultural soils—has attracted significant attention in research from the perspective of human health and for regulatory purposes (Oladejo et al., 2023). In everyday life, humans are exposed to radiation from the ground, building materials, air, water, the universe, and even radionuclides within their bodies (Garba et al., 2023). Natural radiation sources, which have existed since the earth's creation, are the primary source of radiation exposure to the general public (Garba et al., 2023). The current work is thus focused on estimating the presence of radioactive elements (^{226}Ra , ^{232}Th , and ^{40}K) in some selected building materials used at Federal University Gusau, as well as assessing radiological hazards to human health and understanding its impact on the environment, and comparing it to data reported for other countries. The findings will be critical in the creation of a database on the use and management of building materials in the study area. Analytical techniques based on gamma-ray spectroscopy were used in this study.

2.0 MATERIALS AND METHODS

At the Federal University of Gusau, samples of granite, sand, blocks, and cement were gathered in four distinct locations. Ten distinct samples in all were gathered, and each one was properly leveled, tied, and placed into a polyethylene bag. To avoid sample breakage and cross-contamination, each sample was placed in two bags. The samples of building materials that were gathered were air dried for seven hours at a temperature of 270 degrees Celsius in the laboratory, with an average relative

humidity of 70% (Aku and Yusuf, 2015). After that, the sample was ground and packed into a cylindrical that had already been weighed. Each sample's mass was measured and noted prior to sealing. To stop the ^{222}Rn gas from escaping, the sample containers were sealed in three steps using adhesive masking tape, candle wax, and Vaseline wax. Before beginning their gamma spectroscopy analysis, the samples were kept in storage for a minimum of four weeks in order to attain an approximate secular equilibrium between Rn and Th, and their respective progeny. Using a NaI (Tl) gamma ray detector, the prepared samples were examined for the activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K at Ahmadu Bello University in Zaria's Center for Energy Research and Training. The detector measures 7.62 x 7.62 cm and is housed in a 10 cm thick assembly lined with copper sheets to reduce background radiation and shielded from lead and cadmium. A MAESTRO computer system program was used for data acquisition and spectrum analysis. The quantitative analysis of the ^{226}Ra , ^{232}Th , and ^{40}K , respectively, was conducted using IAEA standard reference materials (Garba et al., 2023). Each prepared sample was counted for approximately 8 hours, with the activity concentration of ^{226}Ra determined using the gamma energy line of ^{214}Bi (1760 keV), ^{232}Th determined using ^{208}Tl (2614 keV), and ^{40}K determined directly from its 1460 keV gamma line. Calibration of energy and efficiency was performed using a point source a 500 mL of ^{60}Co (1173 and 1332 keV), ^{241}Am (59.54 keV), and ^{137}Cs (661.62 keV) multi-nuclide standard solution. The background was subtracted from the net number of counts under each photo peak of interest using the time correct spectrum taken with the blank container.

2.1 Radiological Hazards Assessment

2.1.1. Radium Equivalent Activity (Ra_{eq})

Radium equivalent activity is a term used to describe a single quantity that represents the specific activities of ^{226}Ra , ^{232}Th , and ^{40}K while accounting for the radiation hazards associated with them. This first index can be computed as follows (Suleiman et al., 2022),

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (1)$$

C_{Ra} , C_{Th} , and C_K are the activity concentrations in building materials samples in $Bqkg^{-1}$ of ^{226}Ra , ^{232}Th , and ^{40}K , respectively. The Ra_{eq} is related to the external gamma dose and internal dose due to radon and its daughters.

2.12. Gamma-Absorbed Dose Rate (D)

The gamma-absorbed dose rate in outdoors at 1m above the ground can be calculated by using the obtained concentration of the specific activities of ^{40}K , ^{226}Ra , and ^{232}Th from the sample as described by (Suleiman et al.,2022) is given as:

$$D(nGyh^{-1}) = 0.461C_{Ra} + 0.623C_{Th} + 0.041C_K \quad (2)$$

Where C_K , C_{Ra} , and C_{Th} are the specific activities of ^{226}Ra , ^{232}Th , and ^{40}K in $Bqkg^{-1}$.

2.13. Annual Effective Dose Equivalent

To estimate or calculate the values of annual effective dose rates, the conversion coefficient from absorbed dose in air to effective dose ($0.7 SvGy^{-1}$) and outdoor occupancy factor (0.2) was used (UNCEAR , 2021).The effective dose rate in units of $mSvy^{-1}$ was calculated by the following formulaas suggested by Suleiman *et al.*(,2022).

$$ADE(mSvy^{-1}) = D(nGyh^{-1}) \times 8760h \times 0.2SvGy^{-1} \times 10^{-6} \quad (3)$$

AEDE is the Annual effective dose equivalent.

2.14. The External Hazard Index (Hex)

Then, the external hazard index calculated in this work as suggested by(Suleiman et al.,2022)

$$\frac{C(40K)}{4810Bqkg^{-1}} + \frac{C(226Ra)}{370Bqkg^{-1}} + \frac{C(232Th)}{259Bqkg^{-1}} < 1 \quad (4)$$

C_K , C_{Ra} , and C_{Th} are the specific activities of ^{226}Ra , ^{232}Th , and ^{40}K in $Bqkg^{-1}$ respectively

2.15 Internal Hazard Index (Hin)

Then the internal hazard index calculated in this work was suggested by(Suleiman et al.,2022)

$$\frac{C(226Ra)}{180Bqkg^{-1}} + \frac{C(232Th)}{259Bqkg^{-1}} < 1 \quad (5)$$

C_K , C_{Ra} , and C_{Th} are the activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K , respectively, in $Bqkg^{-1}$. The calculated index values must be less than unity means that less than one to keep the radiation insignificant.

3.0 RESULT AND DISCUSSION

Table 4.1 displays the average concentration of the measured radioactivity concentrations (^{226}Ra , ^{232}Th , ^{40}K). The average activity concentration of ^{226}Ra in cement, block, sand, and granite samples was found to be higher than the global mean of $35Bqkg^{-1}$ in soil. Furthermore, the average ^{232}Th concentrations in all samples were found to be higher than the global mean for soil ($30Bqkg^{-1}$)

(UNSCEAR, 2021).The average activity concentration of ^{40}K for cement, sand, and block samples was found to be within the global range, while the granite samples were found to be slightly higher than the global mean for soil $400Bqkg^{-1}$. The activity concentration levels of blocks, granite, and sand samples are all above the world range, with the exception of cement, which was found to be within the worldwide range.

Table 1.0: The Average value of mean activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K for building materials used in the study area and that of World Mean

S/NO	Sample	$^{40}K(Bqkg^{-1})$	$^{226}Ra(Bqkg^{-1})$	$^{232}Th(Bqkg^{-1})$
1	CEMENT	368.58±0.915	56.65±0.74	46.65±0.45
2	SAND	194.84±1.306	159.45±2.68	79.32±1.68
3	GRANITE	656.84±0.775	100.75±2.74	69.95±2.130
4	BLOCKS	238.65±1.390	55.05±1.58	77.93±0.83

5	WORLD MEAN	400	35	30
6	WORLD RANGE	140 to 850	17 to 60	11 to 64

The average values of radium equivalent activity(R_{eq}), absorbed dose rate (D), external hazard indices (Hex), internal hazard indices (Hin), and annual effective dose equivalent (AEDE) are presented in Table 2

Table 2. The Mean (R_{eq}), (D), (Hex), (Hin), and (AEDE) for the building materials In Federal University Gusau.

Materials	$R_{eq}(Bqkg^{-1})$	D(nGyh ⁻¹)	Hex	Hin	AEDE(mSvy ⁻¹) ¹
Cement	151.64±1.98	70.25±0.90	0.41±0.005	0.57±0.009	0.0008±0.00001
Sand	234.63±5.18	106.36±6.64	0.95±0.014	0.89±0.022	0.001±0.00008
Blocks	199.34±2.87	90.35±1.31	0.54±0.015	0.74±0.012	0.001±0.000016
Granite	251.22±4.99	116.89±2.25	0.68±0.027	0.97±0.021	0.001±0.00003
World M	<370	55	<1	<1	0.07

The calculated value of radium equivalent activity (R_{eq}) for the building materials was found to be within the range of 151.64±1.98 to 251.22±4.99Bqkg⁻¹ and these values are less than370Bqkg⁻¹, which are acceptable for safe use (UNSCEAR, 2021). Also, The average values of absorbed dose rates (D) range from 70.25±0.90 to 116.89±2.25 and are comparable to the world average of 55nGyh-1 (UNSCEAR, 2021). The annual effective dose equivalent (AEDE) for the various building materials samples in this study ranged from 0.001±0.00003 to 0.0008±0.00001mSvy⁻¹, which is comparable to the worldwide effective dose of 0.07mSvy-1 (UNSCEAR, 2021) and was found to be below the allowable limit.

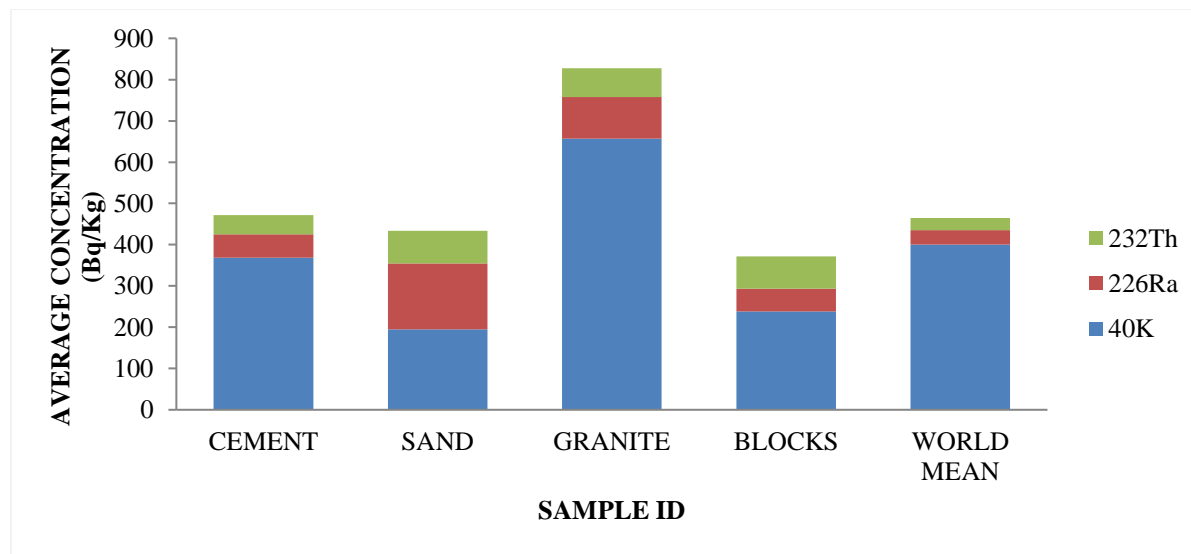


Figure 4.1 Average Activity Concentration and World Mean of ⁴⁰K, ²³²Th, and ²²⁶Ra in the building materials samples

Figure 4.1 displays the variation of the average activity concentration and world mean in the samples of ⁴⁰K, ²³²Th, and ²²⁶Ra. According to the figure, granite has the highest concentration of ⁴⁰K with an average concentration of 656.84Bqkg⁻¹,

which was found to be greater than the world average value of 400Bqkg⁻¹, followed by cement with an average concentration of 282.19Bqkg⁻¹ and blocks with an average concentration of 238.65Bqkg⁻¹, and sand with a concentration of

194.08Bqkg⁻¹, which was found to be less than the world average value. The higher concentration of ²²⁶Ra was found in the sand samples from 159.44Bqkg⁻¹ with a lower concentration of 55.05Bqkg⁻¹ in blocks samples, which were found to be below the world mean value of 35Bqkg⁻¹ and also the higher concentration of ²³⁶Th were found in the block samples with an average value of 77.93Bqkg⁻¹ and the lower concentration were found in the cement sample with an average concentration of 46.65Bqkg⁻¹.

4.0 SUMMARY AND CONCLUSION

The data collected in this study can be used to create a database for assessing radiological hazards to people living in the study area. The gamma-ray spectroscopic analysis results showed that the levels of natural radioactivity in some selected building materials used at Federal University Gusau ranged from lower to higher than the international recommended limits, with the average activity concentration of ⁴⁰K found in the range of 194.84±1.31 to 656.84±0.77Bqkg⁻¹, and the activity concentrations of ²²⁶Ra in the range of 56.65±0.74 to 159.45± 2.68Bqkg⁻¹ being granite and sand was found to be higher than the world average of 60Bqkg⁻¹, and the average activity concentration of ²³²Th is in the range of 46.65±0.45 to 79.32±1.68Bqkg⁻¹, with the cement being lower than the world average, but all of the remaining samples being higher. The average absorbed gamma dose rates (D) ranged from 70.25±0.90 to 106.36±6.64 nGyh⁻¹, which were found to be higher than the allowable limit. The average annual effective dose equivalent (AEDE) ranges from 0.001 ±0.00003 to 0.001±0.00008mSvy⁻¹, which is less than the allowable limit. The radium equivalent (Raeq) is between 151.64±1.98 and 251.22±4.99 times lower than the recommended limit of 370Bqkg⁻¹ (UNSCEAR, 2021). Furthermore, in the investigated samples, both the external and internal hazard indices are less than one. As a result, because these materials are below the recommended limits for their gamma dose rate, they can be used in all types of buildings.

The study found that levels of radioactivity concentration in building materials samples are not harmful for current construction. Furthermore, the radiation dose was far below the allowable limit, confirming the suitability of the materials (sand, block, cement, and granite) for construction purposes.

Previously, no work was done at the Federal University of Gusau to measure the radioactivity of a building material sample. As a result, this work can be used as a starting point for future research.

4.1 RECOMMENDATION

More detailed studies involving the collection of a larger number of samples are required to establish comprehensive and highly reliable reference data for identified elements. It is also critical to assess the risk associated with the drinking water, soils, and radioactive element levels in the study area. Additional research is required.

If the composition of radioactive elements in both disturbed and undisturbed soils can be determined, a complete reference data set for building materials and soils can be established.

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