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## Article

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# Assessments of Radiological Risks in the Buildings and Surroundings of Federal University Wukari (FUW) Campus, Taraba State, Nigeria

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## Abstract

This study carried out indoor and outdoor assessment of terrestrial radionuclides and their associated radiological implications in the buildings and surroundings of Federal University Wukari (FUW) campus, Taraba State, Nigeria. In-situ measurements were performed with a portable NaI(Tl)/BGO gamma survey meter (GF instruments, 2016), and the geographic coordinates were obtained with a Garmin GPS. The results showed the mean outdoor concentration of potassium-40 (<sup>40</sup>K) is  $561.1 \pm 30.4$  Bq/kg and the mean indoor activity is  $785.3 \pm 30.7$  Bq/kg. The mean outdoor activity concentration of uranium-238 (<sup>238</sup>U) is  $35.7 \pm 1.5$  Bq/kg, while that of the mean indoor activity is  $44.5 \pm 2.1$  Bq/kg. The mean outdoor activity concentration of thorium-232 (<sup>232</sup>Th) is  $31.1 \pm 1.4$  Bq/kg, and the corresponding mean indoor activity is  $37.2 \pm 1.9$  Bq/kg. The evaluated mean indoor and outdoor radium

equivalent activities are  $158.2 \pm 6.4$  Bq/kg and  $123.3 \pm 4.5$  Bq/kg, respectively. The average indoor ADR is  $76.4 \pm 3.1$  nGy/h, while the average outdoor ADR is  $59.3 \pm 2.1$  nGy/h. The ratio of indoor to outdoor ADR at FUW campus is 1.3, falling within the established common average hovering around 1.2 to 1.5. While the average outdoor HI is 0.3, the average indoor HI is 0.5, representing low index. The estimated mean indoor and outdoor AED are  $0.37 \pm 0.02$  mSv/y and  $0.07 \pm 0.00$  mSv/y, respectively. For both indoor and outdoor exposure, the average ELCR are  $1.03 \pm 0.04$  mSv and  $0.20 \pm 0.01$  mSv. The campus's average total ELCR is  $1.23 \pm 0.05$  mSv. The correlation analysis revealed that all the indoor activity concentrations of primordial radionuclides and outdoor  $^{40}\text{K}$  strongly correlated with their corresponding radiological hazard parameters, while  $^{238}\text{U}$  and  $^{232}\text{Th}$  of outdoor exposure moderately correlated with their corresponding radiological risks. The upper floors of upstairs buildings in the campus recorded the mean activity of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  about 34.6%, 33.0%, and 32.8% lower than their corresponding ground floor. The highest activity concentrations of  $^{238}\text{U}$  and  $^{232}\text{Th}$  as well as the highest radiological parameters were found in a building with extremely poor ventilation. However, a good ventilated building had the lowest radiological parameters and the lowest activity concentrations of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  in the study area. Hence, it is advised that the future buildings in FUW campus to be upstairs with very good ventilation.

### **Keywords:**

Terrestrial radiation, Primordial radionuclides, Outdoor exposure, Indoor exposure, Radiological hazards, Buildings, FUW campus.

### **Introduction**

Background radiation is the radiation present in the living environment, which are from both natural and anthropogenic sources. Radiation from the natural sources comprises terrestrial and cosmic radiations (UNSCEAR, 2000). Terrestrial radiation emanate from the activities of the  $^{40}\text{K}$ ,  $^{238}\text{U}$  and  $^{232}\text{Th}$ , which are present in all earthly materials and landforms. (Odoh et al., 2018). These primordial radionuclides constantly release ionizing radiations which affect all living organisms in the environment. About 85% of ionizing radiations humans receive about 85% come from natural sources, of which terrestrial radionuclides alone account for about 68% of it, while 17% is accounted from the cosmic radiations (UNSCEAR, 2000).

Since the earth's formation, terrestrial radionuclides – mainly  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  – have been the natural radioactive elements in the crust till today. Through gamma emission and radon decay, they greatly contribute to background radiation. They are domicile in soil, rocks, building materials, air, food and more. The level at which these radionuclides are present in any region are influenced by the local geology of that region and varies from place to place (Okeyode et al., 2019; Odoh et al., 2025). These radiations are inevitably present in our surroundings and constantly interact with people and other living things.

Ionizing radiations from terrestrial sources are responsible for the major human exposure to natural radiation. When high-energy ionizing radiation passes through matter, it ionizes, creating ions that can interfere with biological processes. For example, genetic mutations, various forms of cancer and diseases have been linked to high energy ionizing gamma radiation exposure (Taskin et al., 2009; Ugbede et al., 2018). Depending on the state of the

health effects, acute or chronic radiation exposure can result in illnesses. Chromosome abnormalities, production of free radicals, bone necrosis, and cataracts were linked to exposures to high elevated ionizing radiations (Avwiri, 2011; Aziz et al., 2014; Esi et al., 2024; Odoh et al., 2025; Odoh et al., 2026).

In Taraba, Odoh et al., (2025) reported high elevated terrestrial gamma radiation dose rates in state, particularly in the vicinity of uranium deposit and its mining sites. Also, laboratory gamma assessment of some samples from the nearby local government area of Wukari revealed potassium and thorium concentrations in the range of 4.26 to 6.26% and 47.3 to 3654 mg/kg, respectively, a radiometric survey in some parts of the state revealed a peak count rate of 1200 counts per minute (cpm) against the mean background count of about 30 cpm (NUMCO, 1986). The daily and yearly effective dose rates were found to be between  $3.5 \times 10^{-8}$  to  $33.3 \times 10^{-8}$  nGy/h and 0.059 to 0.758 mSv/y, respectively in an in-situ assessment at farmland near Mission Quarters in Wukari (Onudibia et al., 2020). Tyovenda et al., (2022) had reported that the average activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  in Wukari soil samples were 25.37, 87.23, and 199.21 Bq/kg, respectively.

To the best of the authors' knowledge, only a small number of the aforementioned studies were conducted in and around Wukari, and none of them took place on Federal University Wukari (FUW) campus, a home of roughly 30,000 people. It is a place where university employees and students work, study, and stay for academic and other purposes. It was challenging to determine the university community's exposure rate to terrestrial gamma radiation due to a lack of thorough data. Furthermore, this knowledge gap impedes efficient land-use planning, agricultural safety, and public health protection as the campus's population and land use grow.

To determine possible radiological risks and create a reference database for legislators and environmental health authorities, a systematic evaluation is required. Therefore, the aim of this work is to assess the radiological conditions of the FUW campus's buildings and surroundings. This study measures the indoor and outdoor activity concentrations of the primordial radionuclides, their exposure rates, and related radiological hazards and risks; and statistically examined the null hypothesis, "There is no significant relation between the activity concentrations of primordial radionuclides and their associated radiological hazards and risks on the campus."

Wukari is one of the local government areas (L.G.A.) in Taraba State, Nigeria, which was previously identified as a state of moderate to high elevated terrestrial gamma dose rates (Odoh et al., 2025) and as one of the states with a high incidence of cancer cases in Nigeria (Dugule, 2022). The authors believe that the activities of terrestrial radionuclides in the area may be one of the contributing factors, even though there is no epidemiological study in the region to ascertain the real cause of the high incidence of cancer risk in the area. Thus, this study is very important.

Additionally, this study will generate baseline data on the rates of terrestrial radionuclides exposure for both indoors and outdoors on the FUW campus, which crucial for assessing health risks and radiological impacts. It will also serve as a working document and protective

measures for decision-makers and health professionals at the university, state, and Nigeria as a whole.

## **MATERIALS AND METHODS**

### **The study area**

The Federal University Wukari (FUW) campus, which is situated in Wukari town of Wukari L.G.A. of Taraba State, Northeast Nigeria, is where this study was conducted. Situated on approximately 200 hectares of land, the FUW campus is home to approximately 30,000 employees, students, and visitors. It is located between the geographic coordinates of 7°50'0"N and 7°51'0"N, and 9°45'0"E and 9°47'0"E (Figure 1) at a height of 152 m above sea level. Staff quarters, academic buildings, dorms, administrative offices, laboratory, open fields, road networks, and farm areas are just a few of the various structural and environmental settings that make up the university environment.

The campus geology is characterized by undifferentiated sedimentary rocks of the thick and extensive series of sandstones, clays of the Bima sandstones and continental grits. These rocks primarily consist of poorly bedded grits, conglomerates, sandstones, shales, clays, mudstones, etc. that are known to host natural radioactive materials, even though at low concentration. Wukari's sedimentary rocks are part of the Middle Benue Basin/trough subgroup, also known as the Makurdi and Wukari Basins. These rocks are part of the sedimentary series that covers roughly half of Nigeria's land area. According to Tsang et al. (2018) and Oruonye and Ahmed (2018), the sedimentary materials that fill the basins vary in thickness and frequently display single or multiple cycles of development characterized by basal continental facies and sediments.

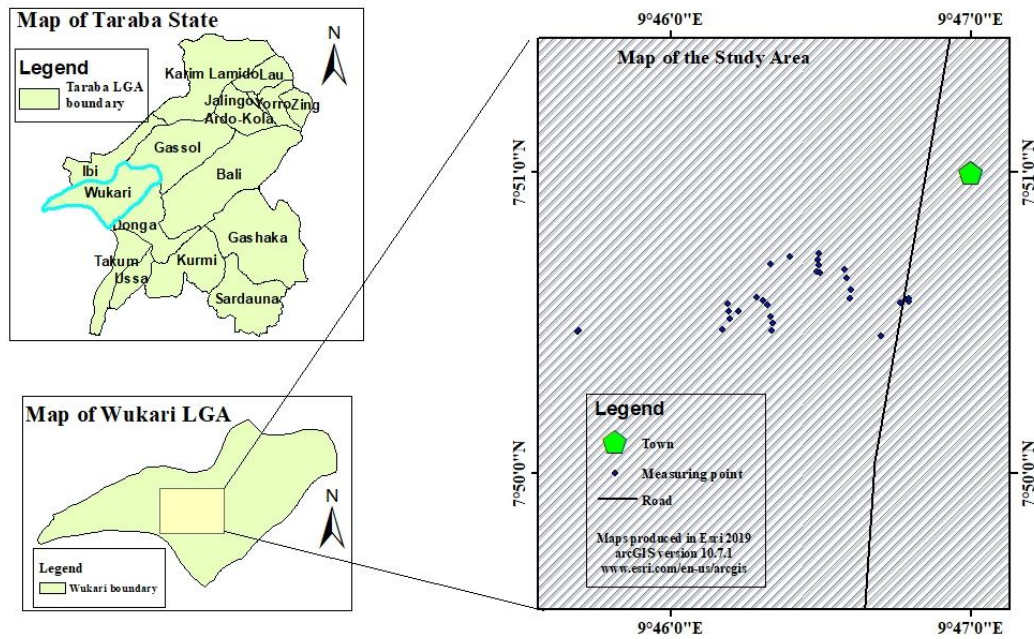


Figure 1: Map of the Study Area

## Instruments

Global Positioning System (GPS) and a Compact Gamma Surveyor (CGS) by GF Instruments were used for the measurements. CGS is a gamma-ray multi-channel spectrometer, capable of measuring both artificial and natural radioisotopes was used. It is a scintillator type detector capable of measuring the entire spectrum, determine the concentrations of the elements  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$ , and measure the count per second (cps) in the regions of interest (ROIs), four of which represent the counts  $^{40}\text{K}$ ,  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and total counts (TOT) in cps.

While the measurements of  $^{238}\text{U}$  and  $^{232}\text{Th}$  were based on the detection of radioactive isotopes of  $^{214}\text{Bi}$  and  $^{208}\text{Tl}$ , which are daughter products of the  $^{238}\text{U}$  and  $^{232}\text{Th}$  series, respectively, in milligrams per kilogram (mg/kg), the instrument directly determines the concentration of  $^{40}\text{K}$  in percentage. The measured concentrations of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  in % and mg/kg were converted to Bq/kg using IAEA/Scientific Standards of (1 mg/kg of  $^{238}\text{U} \approx 12.35 \text{ Bq/kg}$  of  $^{238}\text{U}$ , 1 mg/kg of  $^{232}\text{Th} \approx 4.06 \text{ Bq/kg}$  of  $^{232}\text{Th}$ , and 1% of  $^{40}\text{K} \approx 313 \text{ Bq/kg}$  of  $^{40}\text{K}$ ) (IAEA, 2016). Also, the natural dose rate value ( $\text{nGyh}^{-1}$ ) was directly evaluated by the meter using the measured concentrations of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  according to IAEA (2016) recommendations (1% of  $^{40}\text{K}$  concentration contributes  $13.078 \text{ nGyh}^{-1}$ , 1 mg/kg of  $^{238}\text{U}$  concentration contributes  $5.675 \text{ nGyh}^{-1}$ , and 1 mg/kg of  $^{232}\text{Th}$  concentration contributes  $2.494 \text{ nGyh}^{-1}$ ).

### Instrument calibration

An “assay” calibration on the four calibration pads ( $^{40}\text{K}$ ,  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and the meter’s background) was carried out prior to measurements. The probe was positioned in the centre of the calibration pad and actual calibration type was selected from the menu. The geometry of the calibration pad was used to enter and adjust the actual known concentrations of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$ . Equation 1 (User Guide v1.3) was used to estimate the geometrical factors value (G) of the calibration pad, which was then multiplied by the concentrations of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$ .

$$G = 1 - \frac{h}{r} \quad 1$$

where r is the diameter of the pad and h is the height of the middle of the detector above the pad.

When the peak stabilisation was completed, the calibration began after the measurement time was set to 30 minutes in accordance with the manual. At the completion of the measurements, the generated data for calibration was saved in the probe, which brought to an end of the calibration process. The metre then resumed its normal operation using the new calibration settings as standard.

### Measurements of the concentrations of the primordial activities and gamma dose rates

Primordial activity concentrations and gamma dose rates were measured both indoors and outdoors on the FUW campus. All of the lecture halls, administrative offices, laboratories, staff quarters, student hostels, etc. that were functional as the time of this study were targeted for indoor assessments. These indoor spaces serve as typical places where university employees and students spend roughly 80% of their daily time. The open fields, parking lots, roadsides, and surroundings of the lecture halls, administrative offices, laboratories, staff quarters, and hostels etc. within the campus were targeted for outdoor measurements. These locations reflect areas with a high volume of human activity, where the institution’s staff and students spent at least 20% of their time campus daily. While outdoor measurements were done in an open setting where background radiation from soil and cosmic sources is expected to be dominant, indoor measurements were done inside enclosed buildings where background radiation from natural and construction materials may be dominant.

The gamma surveyor was positioned 1 m above the ground and programmed to count for 5 minutes, which is sufficient time for the meter to examine the peak values. Because radioactivity is random, five readings were made at each location, and the average of the five readings was noted. The measurements were made in nano-Gray per hour ( $\text{nGy h}^{-1}$ ). The measurements were done across the entire buildings and its surroundings that were functional as at the time of this study.

### Risks Evaluation

Radiological parameters: radium equivalent activity ( $\text{Ra}_{\text{eq}}$ ), hazard index (HI), annual effective dose (AED) rates, and excess lifetime cancer risks (ELCR) of the study area were evaluated using the activities of the primordial radionuclides measured in the study area.

$Ra_{eq}$  is the sum-weighted activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  that amounts to 370  $\text{Bqkg}^{-1}$  of  $^{238}\text{U}$ , which results in an annual effective dose rate of 1 mSv (Tufail, 2012). It was assumed that 1  $\text{Bqkg}^{-1}$  of  $^{238}\text{U}$ , 0.7  $\text{Bqkg}^{-1}$  of  $^{232}\text{Th}$ , and 13  $\text{Bqkg}^{-1}$  of  $^{40}\text{K}$  produce the equal gamma-ray dose rate (UNSCEAR, 2000), because neither  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  produces equal activities nor are uniformly distributed in any environment (Sharma *et al.*, 2015). This parameter was determined using equation 2 (Beretka and Mathew, 1985; Innocent *et al.*, 2014; Nabil *et al.*, 2015; Ragbu *et al.*, 2015; Sharma *et al.*, 2015; Garba *et al.*, 2016b).

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \quad 2$$

A crucial radiological metric that measures the degree of gamma radiation exposure is the hazard index (HI) (Girigisu *et al.*, 2013). This was used to evaluate the degree of gamma radiation risk related to naturally occurring radionuclides that people are exposed to in the surroundings. Equations 3 and 4 define it for outdoor and indoor assessments, respectively (Innocent *et al.*, 2014; Ragbu *et al.*, 2015; Garba *et al.*, 2016a).

$$HI_{out} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad 3$$

$$HI_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad 4$$

Where the activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  are respectively represented by  $A_U$ ,  $A_{Th}$  and  $A_K$  in  $\text{Bqkg}^{-1}$ .

A long-term risk of ionizing radiation exposure to humans was evaluated using annual effective dose (AED) rates. This was estimated using the occupancy factors (OF) of 0.2 and 0.8 for outdoor and indoor, respectively, and the conversion coefficient (CC) from the absorbed dose in air to the effective dose ( $0.7 \times 10^{-6} \text{ mSv nGy}^{-1}$ ), as suggested by UNSCEAR (2000). Equation 5 (UNSCEAR, 2000; Nabil *et al.*, 2015) was thus used to determine the annual effective dose.

$$AED \text{ rates } (\text{mSvy}^{-1}) = \text{ADR } (\text{nGyh}^{-1}) \times 8760 \text{ hy}^{-1} \times OF \times CC \quad 5$$

where ADR is the value of absorbed dose rate.

The United States Environmental Protection Agency (USEPA, 2012) states that while low radiation exposure may not have an immediate negative impact on health, but may slightly raise the lifetime risk of cancer. Excess lifetime cancer risk (ELCR) may vary from person to person, but is influenced by a number of factors, including the energy at which the radiation is released, the type of radiation, its activity (frequency of emission), the type of exposure (indoor or outdoor), the rate at which the body breaks down and gets rid of the radionuclides, where the radionuclides concentrate in the body, and how long they stay there (USEPA, 2023). This risk is the number of additional cancer anticipated in a specific population after exposure to a carcinogen at a specific dose. Equation 6's relationship was used to calculate the risk (Avwiri *et al.*, 2012).

$$ELCR = AED \text{ rates} \times DL \times RF \quad 6$$

where RF is the risk factor, or the fatal cancer risk per Sievert, which is assumed to be 0.05 in this study according to ICRP-106 (ICRP, 2008); AED rate is the annual effective dose rate; DL is the average lifespan for Nigerians, which is approximately 55 years (Omidiji, 2025; Africanews, 2025; Macrotrends, 2024).

## Results and Discussions

### Activity concentrations of the primordial radionuclides at FUW campus.

Table 1 summarizes the primordial radionuclide activity in the study area for both indoor and outdoor assessments. While the outdoor concentration of  $^{40}\text{K}$  varied from 259.8 to 888.9 with an average value of  $561.1 \pm 30.4$  Bq/kg, the indoor activity varied from 419.4 to 1151.8 with an average value of  $785.3 \pm 30.7$  Bq/kg. While the outdoor activity concentration of  $^{238}\text{U}$  ranged from 19.8 to 69.2 with a mean value of  $35.7 \pm 1.5$  Bq/kg, the indoor activity ranged from 25.9 to 80.3 with a mean value of  $44.5 \pm 2.1$  Bq/kg. Also, while outdoor activity concentration of  $^{232}\text{Th}$  changed from 11.8 to 54.0 with an average value of  $31.1 \pm 1.4$  Bq/kg, the indoor activity changed from 16.7 to 72.3 with an average value of  $37.2 \pm 1.9$  Bq/kg.

The obtained mean values for  $^{40}\text{K}$  and  $^{238}\text{U}$  are 86.98% and 34.84%, respectively, higher than the corresponding world mean values of 420 Bq/kg and 33 Bq/kg (UNSCEAR, 2000) for indoor and 33.60% and 8.18%, respectively, for outdoor. However,  $^{232}\text{Th}$  is 17.33% and 31% less than the corresponding world average value of 45 Bq/kg (UNSCEAR, 2000) for indoor and outdoor, respectively.

On the FUW campus, about 2.7% of buildings had activity concentrations of  $^{40}\text{K}$  below the corresponding global average, and 16.2% and 81.1% of the buildings had activity concentrations of  $^{238}\text{U}$  and  $^{232}\text{Th}$ , respectively, lower than their corresponding global average. However, the Science Complex building had highest activity concentration of  $^{40}\text{K}$  (1151.8 Bq/kg), whereas the library building had the highest activities of  $^{238}\text{U}$  and  $^{232}\text{Th}$ . These high values could be caused by the type of building materials used, which could come from regions with high levels of natural radioactive materials.

Table 1: The summary of activity concentrations of the primordial radionuclides and Radium equivalent activity in the study area.

|                                  |             | Indoor                     |                             |                              |                 | Outdoor                    |                             |                              |                 |
|----------------------------------|-------------|----------------------------|-----------------------------|------------------------------|-----------------|----------------------------|-----------------------------|------------------------------|-----------------|
|                                  |             | $^{40}\text{K}$<br>(Bq/kg) | $^{238}\text{U}$<br>(Bq/kg) | $^{232}\text{Th}$<br>(Bq/kg) | Raeq<br>(Bq/kg) | $^{40}\text{K}$<br>(Bq/kg) | $^{238}\text{U}$<br>(Bq/kg) | $^{232}\text{Th}$<br>(Bq/kg) | Raeq<br>(Bq/kg) |
| Mean $\pm$ SE                    |             | 785.3 $\pm$ 30.7           | 44.5 $\pm$ 2.1              | 37.2 $\pm$ 1.9               | 158.2 $\pm$ 6.4 | 561.1 $\pm$ 30.4           | 35.7 $\pm$ 1.5              | 31.1 $\pm$ 1.4               | 123.3 $\pm$ 4.5 |
| 95% Confidence Interval for Mean | Lower Bound | 723.0                      | 40.3                        | 33.4                         | 145.2           | 499.4                      | 32.7                        | 28.2                         | 114.2           |
|                                  | Upper Bound | 847.6                      | 48.7                        | 41.1                         | 171.1           | 622.8                      | 38.7                        | 33.9                         | 132.5           |

|                                      |            |           |           |            |            |           |           |            |
|--------------------------------------|------------|-----------|-----------|------------|------------|-----------|-----------|------------|
| Minimum Value                        | 419.4      | 25.9      | 16.7      | 89.4       | 259.8      | 19.8      | 11.8      | 72.8       |
| Maximum Value                        | 1151.8     | 80.3      | 72.3      | 266.3      | 888.9      | 69.2      | 54.0      | 181.3      |
| <b>World average (UNSCEAR, 2000)</b> | <b>420</b> | <b>33</b> | <b>45</b> | <b>370</b> | <b>420</b> | <b>33</b> | <b>45</b> | <b>370</b> |

### Radium Equivalent Activity (Raeq)

The study area's indoor and outdoor radium equivalent activities ranged from 89.4 to 266.3 with a mean value of  $158.2 \pm 6.4$  Bq/kg and from 72.8 to 181.3 with an average of  $123.3 \pm 4.5$  Bq/kg, respectively (Table 1). These values are below an upper reference limit of 370 Bq/kg, which means the gamma radiation dose at FUW buildings and surroundings is less than 1 mSv/y. Therefore, this indicates that the raw materials used to construct the buildings meet radioactivity standards; as a result, FUW buildings and surrounding environment may be deemed safe.

### Absorbed dose rates (ADR)

Table 2 provides an overview of the indoor and outdoor ADR as well as the ratio of indoor to outdoor ADR measured at the FUW campus. The indoor ADR ranged from 43.3 to 126.3 with an average of  $76.4 \pm 3.1$  nGy/h, while the outdoor ranged from 36.2 to 87.4 with an average of  $59.3 \pm 2.1$  nGy/h. While the mean outdoor ADR is marginally higher than the corresponding global average by 0.3 nGy/h, the mean indoor ADR is 7.6 nGy/h lower.

On the FUW campus, 32.43% of the buildings had indoor ADR above the global average (84 nGy/h) (UNSCEAR, 2000), and 13.51 % of buildings had indoor ADR above 100 nGy/h. The preponderance of earth material used during the building constructions, most likely from high natural radioactive materials or the geometry of the buildings' poor ventilation may be the cause of the high values of indoor absorbed dose rates. The indoor ADR at the campus is 12% higher than the outdoor ADR, according to a comparison of the two parameters (Figure 1), which showed a 12% difference.

The ratio of indoor to outdoor ADR at FUW campus varied from 1.0 to 2.0, with an average value of 1.3, falling within the established common range of 0.8 to 2.0, with common average hovering around 1.2 to 1.5 (UNSCEAR, 2000). At FUW campus, all the indoor ADRs were generally higher than their outdoor counterparts. This is to be expected given that building materials such as concrete, cement, bricks and stones contain natural radionuclides that increase exposure when compared to the outdoors. These depicted the actual external exposure conditions on the FUW campus.

Table 2: The summary of ADR and the ratio of indoor to outdoor ADR in FUW campus.

|      | <b>Indoor ADR (nGy/h)</b> | <b>Outdoor ADR (nGy/h)</b> | <b>Ratio</b> |
|------|---------------------------|----------------------------|--------------|
| Mean | $76.4 \pm 3.1$            | $59.3 \pm 2.1$             | 1.3          |

|                                      |             |           |           |            |
|--------------------------------------|-------------|-----------|-----------|------------|
| 95% Confidence interval for mean     | Lower Bound | 70.2      | 55.0      | 1.2        |
|                                      | Upper Bound | 82.6      | 63.6      | 1.4        |
| Minimum                              |             | 43.3      | 36.2      | 1.0        |
| Maximum                              |             | 126.3     | 87.4      | 2.0        |
| <b>World Average (UNSCEAR, 2000)</b> |             | <b>84</b> | <b>59</b> | <b>1.4</b> |

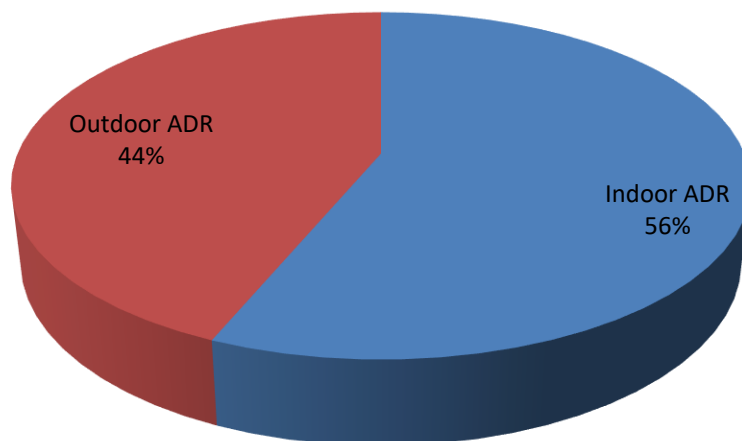


Figure 1: Comparing the indoor and outdoor ADR at FUW campus

## Risks assessment due the activities of Primordial radionuclides at FUW campus

### Hazard index (HI)

Figure 2 shows a comparison of the outdoor and indoor HI results at the FUW campus. The outdoor HI is normally distributed, while the indoor HI is right-skewed, according to the box-and-whisker plots. But compared to the outdoor HI, the indoor HI is more scattered. The highest indoor HI recorded in the school library building, which is outside the range, is the actual indoor HI outlier.

While the outdoor HI varied from 0.2 to 0.5 with an average value of roughly 0.3, the evaluated indoor HI varied from 0.3 to 0.9 with an average value of roughly 0.5 (Figure 2). Both indoor and outdoor primordial radionuclide activities at FUW buildings and surroundings contribute negligible hazards to the university's community, resulting in insignificant natural gamma radiation exposure to the general public, because all of the calculated HI results in the study area were less than the recommended unity value.

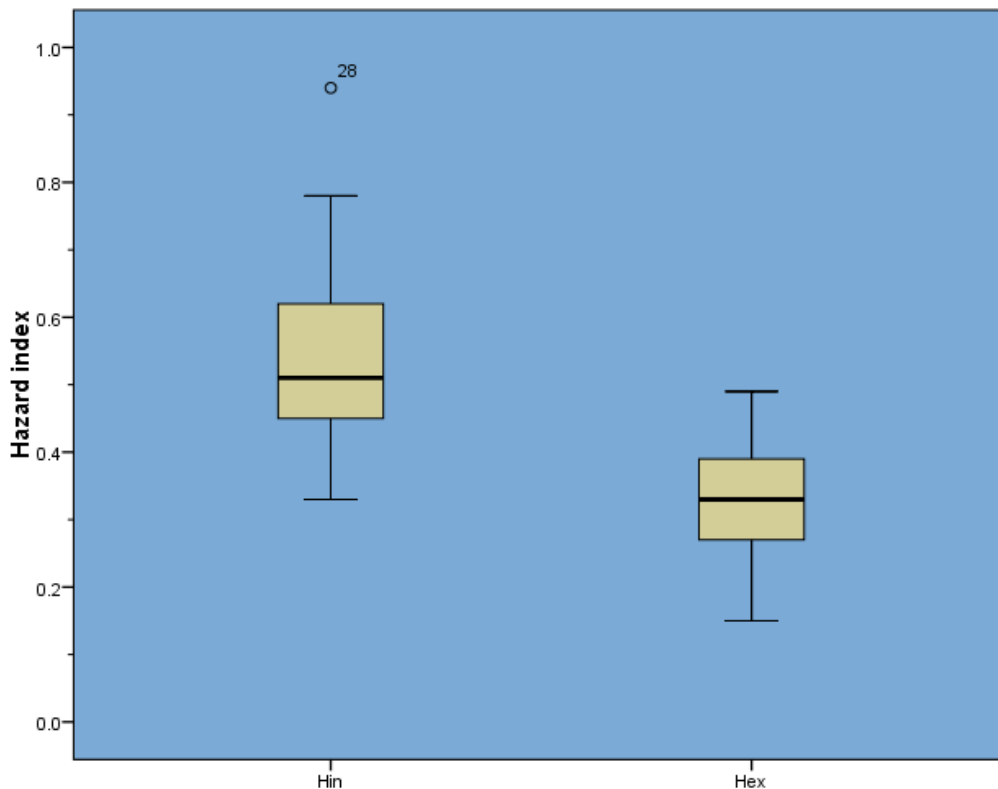


Figure 2: Box plots comparing the indoor and outdoor HI at FUU campus

### Annual Effective Dose (AED) rates

Figure 3 shows a comparison of the indoor, outdoor, and overall AED rates caused by primordial radionuclide activity at the FUU campus. The box-and-whisker plots showed that while indoor and total AED rates were right-skewed, outdoor AED rates were more normally distributed. On the other hand, compared to the outdoor AED rates, the indoor and overall AED rates at the FUU campus were more scattered. The highest computed AED rate found at the school library building, which is outside the range, constitute the actual outlier in the indoor AED rates.

The study area's estimated indoor and outdoor AED rates varied from 0.21 to 0.62 with a mean value of  $0.37 \pm 0.02$  mSv/y and from 0.04 to 0.11 with a mean value of  $0.07 \pm 0.00$  mSv/y, respectively. While the outdoor AED rate is in line with the 0.07 mSv/y world average value, the computed mean indoor AED rate was 0.04 mSv/y lower than the 0.41 mSv/y world average value (UNSCEAR, 2000). The campus's overall (indoor + outdoor) AED rates ranged from 0.26 to 0.70, with an average of  $0.45 \pm 0.02$  mSv/y. This indicates that the total equivalent dose to different tissues, weighted by their vulnerability to radiation damage from both indoor and outdoor exposures, is 0.07 mSv/y below the world average reference of 0.52 mSv/y (UNSCEAR, 2000) and 0.55 mSv/y below the dose limit for the Nigerian public established by the Nigeria Nuclear Regulation Authority (NNRA, 2012). Because there are few and negligible health risks compared to the Nigerian acceptable limit for public exposure, the FUU campus's indoor and outdoor terrestrial gamma radiation exposure levels are generally regarded as safe and acceptable for the university's community.

Even though the indoor AED rates in eight of the campus's buildings are higher than the global average, they are still below the dose limit for Nigerians. These high AED rates in those buildings may be attributed to the geometry and poor ventilation in those structures.

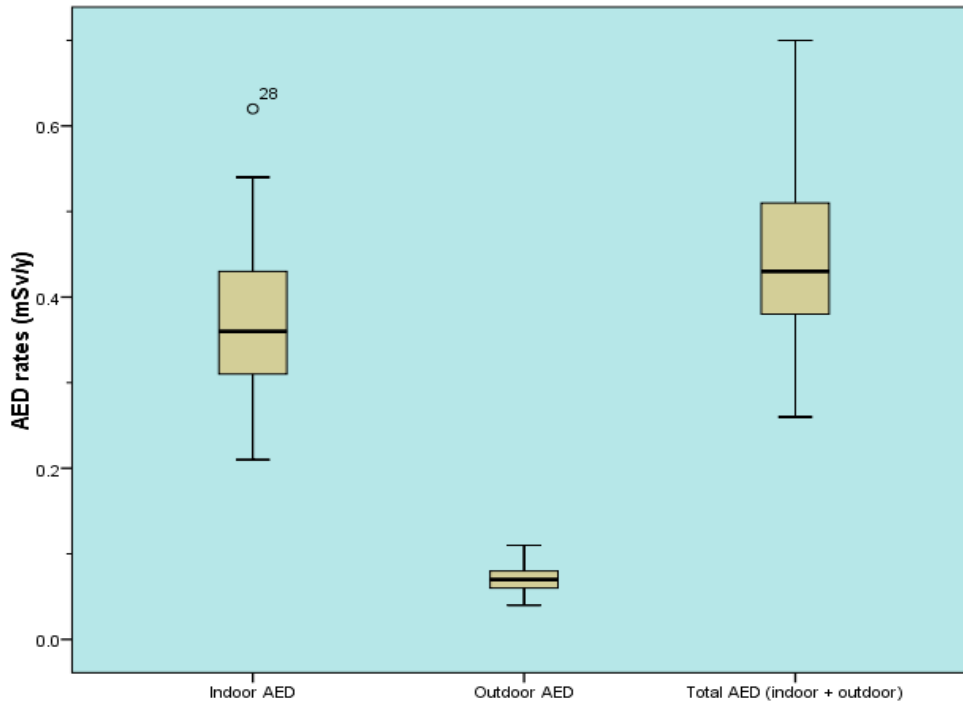


Figure 3: Box plots comparing the indoor, outdoor and total AED in the study area.

### Excess Lifetime cancer risk (ELCR)

Figure 4 shows a comparison of the indoor, outdoor, and total ELCR due to the primordial radionuclides at the FUW campus. In contrast to the indoor and total ELCR, which were right-skewed, the box-and-whisker plots showed that the outdoor ELCR was more normally distributed. Nonetheless, compared to the outdoor ELCR, the indoor and overall ELCR at the FUW campus were more dispersed. The highest estimated cancer risk found, which is outside the range, is represented by the outlier in both indoor and total ELCR.

For both indoor and outdoor exposure, the ELCR ranged from 0.58 to 1.70, with an average of  $1.03 \pm 0.04$  mSv, and from 0.12 to 0.29, with an average of  $0.20 \pm 0.01$  mSv. The campus's total ELCR (indoor + outdoor) varied from 0.72 to 1.93, with an average value of  $1.23 \pm 0.05$  mSv. All of these values exceeded the 0.106 mSv USEPA threshold value (USEPA, 2004), but they are below the 1.45 mSv world average value (UNSCEAR, 2000).

According to the USEPA threshold value, the results showed a comparatively higher risk of developing cancer as a result of the stochastic radiation effect, particularly for FUW employees who work on campus and spend a significant amount of years there.

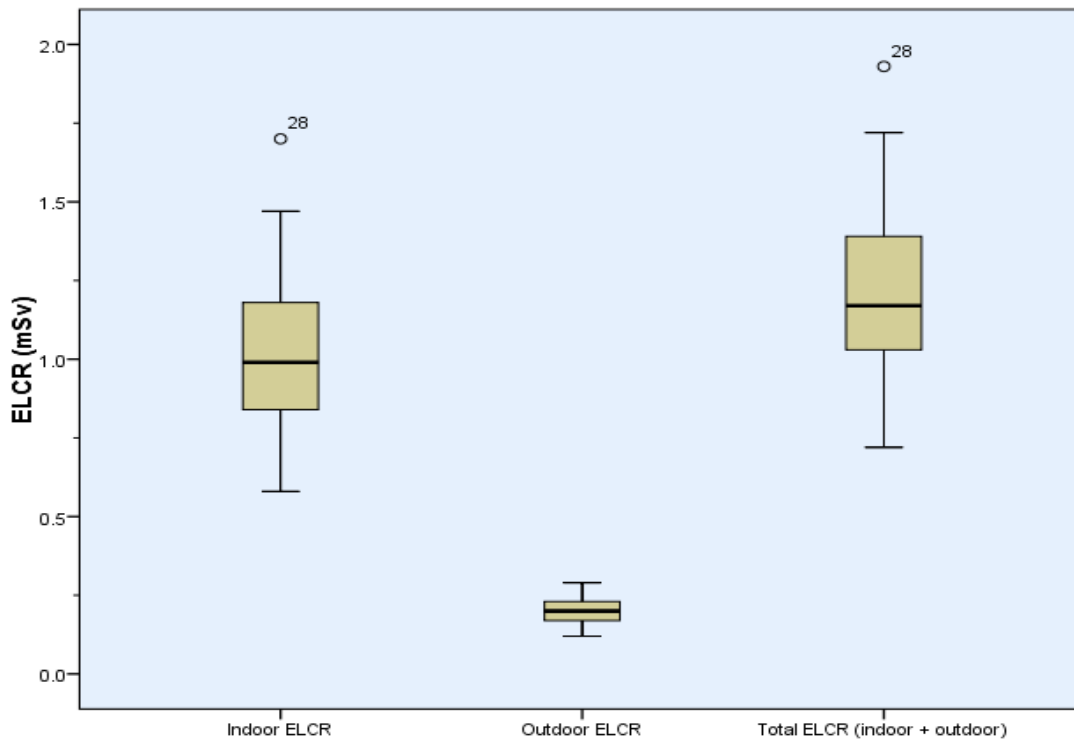


Figure 4: Box plots comparing indoor, outdoor and total ELCR in the study area

### Statistical analysis

Pearson correlations were performed to determine the relationships between the primordial radionuclide activities and the ADR, AED rates, and ELCR in the study area. Tables 3 and 4 show the indoor and outdoor Pearson correlation results, respectively. With Pearson correlation coefficients of  $[r(37) = .878, p = .01]$ ,  $[r(37) = .888, p = .01]$ , and  $[r(37) = .892, p = .01]$ , respectively (Table 3), showed a strong correlation between indoor  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  and indoor ADR, AED rates, and ELCR. The indoor radiological parameters and the indoor activities of the primordial radionuclides at the FUW campus showed a perfectly significant positive relationship, as indicated by the p-values of 0.01. This means that the FUW campus's indoor primordial radionuclide activities are closely linked to the campus's indoor radiological risks and hazards.

Furthermore, Table 4 showed that outdoor  $^{40}\text{K}$  has a strong correlation with outdoor ADR, AED, and ELCR, with a Pearson correlation coefficient of  $[r(37) = .888, p = .01]$ , while outdoor  $^{238}\text{U}$  has a moderate correlation with outdoor ADR, AED rates, and ELCR with Pearson correlation coefficient of  $[r(37) = .685, p = .01]$ , and outdoor  $^{232}\text{Th}$  also has a moderate correlation with outdoor ADR, AED rates, and ELCR with a Pearson correlation coefficient of  $[r(37) = .682, p = .01]$ . This indicates that at the FUW campus, the outdoor  $^{40}\text{K}$  has a strong correlation with the radiological parameters, whereas the outdoor  $^{238}\text{U}$  and  $^{232}\text{Th}$  have a moderate correlation. The outdoor  $^{40}\text{K}$  has a strong correlation with the radiological hazards and risks at the FUW campus, whereas the outdoor  $^{238}\text{U}$  and  $^{232}\text{Th}$  have a partial correlation, according to the p-value of 0.01, which indicates that the correlations are statistically significant.

**Table 3: Pearson Correlations for indoor assessment**

|                   | K-40<br>(Bq/kg) | U-238<br>(Bq/kg) | Th-232<br>(Bq/kg) | ADR<br>(nGy/h) | AED<br>(mSv/y) | ELCR<br>(mSv) |
|-------------------|-----------------|------------------|-------------------|----------------|----------------|---------------|
| K-40<br>(Bq/kg)   | 1               |                  |                   |                |                |               |
| U-238<br>(Bq/kg)  | .656**          | 1                |                   |                |                |               |
| Th-232<br>(Bq/kg) | .666**          | .736**           | 1                 |                |                |               |
| ADR<br>(nGy/h)    | .878**          | .888**           | .892**            | 1              |                |               |
| AED<br>(mSv/y)    | .878**          | .888**           | .892**            | 1.000**        | 1              |               |
| ELCR<br>(mSv)     | .878**          | .888**           | .892**            | 1.000**        | 1.000**        | 1             |

\*\* . Correlation is significant at the 0.01 level (2-tailed).

**Table 4: Pearson Correlations for outdoor assessment**

|                   | K-40<br>(Bq/kg) | U-238<br>(Bq/kg) | Th-232<br>(Bq/kg) | ADR<br>(nGy/h) | AED<br>(mSv/y) | ELCR<br>(mSv) |
|-------------------|-----------------|------------------|-------------------|----------------|----------------|---------------|
| K-40<br>(Bq/kg)   | 1               |                  |                   |                |                |               |
| U-238<br>(Bq/kg)  | .500**          | 1                |                   |                |                |               |
| Th-232<br>(Bq/kg) | .414*           | .207             | 1                 |                |                |               |
| ADR<br>(nGy/h)    | .888**          | .685**           | .682**            | 1              |                |               |
| AED<br>(mSv/y)    | .888**          | .685**           | .682**            | 1.000**        | 1              |               |
| ELCR<br>(mSv)     | .888**          | .685**           | .682**            | 1.000**        | 1.000**        | 1             |

\*\* . Correlation is significant at the 0.01 level (2-tailed).

\* . Correlation is significant at the 0.05 level (2-tailed).

## Effect of height of floors on the activity concentrations and radiological hazards and risks

Ten upstairs buildings in all were considered in this study. Table 5 displays the mean indoor activity concentrations of the primordial radionuclides along with their mean radiological parameters. The mean indoor values of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  at the buildings' upper floors were found to be 34.6%, 33.0%, and 32.8% lower than those at the ground floor. Furthermore, the upper floors' mean indoor ADR, AED rates, and ELCR were all 33.3% lower than the ground floors' corresponding values. These results are consistent with the Okeyode et al. (2019) report.

Table 5: Comparing the mean values obtained in the down and upstairs buildings.

|                           | Mean value<br>(ground floor) | Mean value<br>(second floor) | Per cent Change |
|---------------------------|------------------------------|------------------------------|-----------------|
| $^{40}\text{K}$ (Bq/kg)   | 940.9                        | 699.2                        | 34.6            |
| $^{238}\text{U}$ (Bq/kg)  | 48.4                         | 36.4                         | 33.0            |
| $^{232}\text{Th}$ (Bq/kg) | 40.5                         | 30.5                         | 32.8            |
| ADR (nGy/h)               | 86.9                         | 65.2                         | 33.3            |
| AED (mSv/y)               | 0.4                          | 0.3                          | 33.3            |
| ELCR (mSv)                | 1.2                          | 0.9                          | 33.3            |

## Effect of good and poor Ventilations at FUW campus

By diluting the indoor air with fresh outdoor air, ventilation greatly lessens the impact of indoor radioactivity. It restricts the accumulation of radioactive gases and their by-products but does not lessen the source of radioactivity from concrete walls and building materials. At the FUW campus, it was noted that buildings with inadequate ventilation had higher activities, risks, and hazards compared to the good ventilated ones. For example, the highest activity levels of  $^{238}\text{U}$  and  $^{232}\text{Th}$  as well as the highest radiological parameters were found in a building with extremely poor ventilation. In contrast, a building with very good ventilation had the lowest radiological parameters and the lowest activity levels of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  in the study area. The indoor ADR of a poorly ventilated building is 48% higher than that of a well-ventilated building, according to the Figure 4, which compares the indoor ADR of both well- and poorly ventilated buildings at the FUW campus. This indicates that a building on the FUW campus with inadequate ventilation accumulates radioactive gases and their by-products 48% more than a building with adequate ventilation. Therefore, maintaining adequate ventilation is advised to lower the health risks related to terrestrial gamma radiation dose rates on the FUW campus.

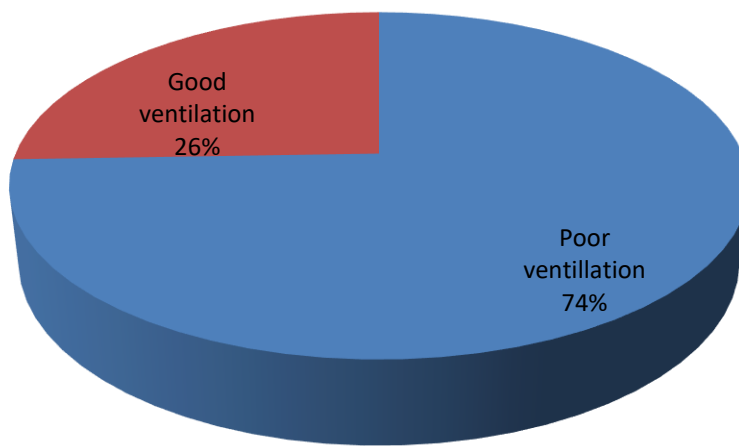


Figure 4: Comparing the indoor ADR of poorly and well-ventilated buildings at FUW campus

### Conclusion

Using a Compact Gamma Surveyor by GF instruments, this study evaluated the indoor and outdoor activity levels of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  in the buildings and surrounding areas of the FUW campus. With the exception of  $^{232}\text{Th}$ , whose concentration was found to be below its corresponding world reference value, the obtained average indoor activity levels of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  were all above their corresponding world average values. The activities of the  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  in the buildings and surroundings of the FUW campus pose negligible risks to the university community because the evaluated indoor and outdoor hazard indices were all below their corresponding suggested upper limit value.

While the mean indoor AED rate is below the global average and the mean outdoor AED rate is equal to the global average, the campus's mean indoor and outdoor ADR were 7.6 nGy/h lower and 0.3 nGy/h higher than their respective world reference values. The campus's mean indoor and outdoor ELCR values were found higher than the USEPA threshold value but lower than the global average. These showed that the primordial radionuclides' activities in the FUW campus's buildings and surroundings might not immediately endanger the community's health, but they might eventually do so in a long period of time.

At a p-value of 0.01, all of the campus's indoor activity concentrations of primordial radionuclides have a strong statistical correlation with radiological hazard parameters. For outdoors, however, only the  $^{40}\text{K}$  exhibits a strong correlation with the corresponding radiological parameters, whereas the  $^{238}\text{U}$  and  $^{232}\text{Th}$  exhibit a moderate correlation with their corresponding radiological parameters at a statistically significant p-value of 0.01. Given this, we accept the alternative and reject the null hypothesis.

Based on these findings, the authors suggest that future buildings at the FUW campus to be upstairs and well-ventilated because the activities of primordial radionuclides and their associated radiological hazards were reduced to approximately 33.3% and above at the

second (upper) floor and compared to the measurements at the ground (first) floor. Additionally, a well-ventilated building could reduce the build-up of radioactive gases, their daughter products, and the associated health risks by 48%. The authors also advise the university management to use more of well ventilated upstairs buildings for staff offices, where their employees spent a lot of times for years as they are capable of reducing the effect of radioactive gases and their daughter products on them by 81.3%. Finally, the authors recommended future study in the campus to assess the radiological risks in the water sources in the campus and the surrounding towns, for this will help the researcher, policy makers and health officers of the local government area to have more radiological data to work on.

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## Data availability statement

The datasets gathered and processed in this study are not publically available due to privacy issues in a small, closely connected group. Data are accessible from the corresponding author on a legitimate request.

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**Conflict of Interests:** No potential conflicts of interest were declared by the authors.

## References

- Avwiri, G. O., Osimobi, J. C., and Agbalagba, E. O. (2012). "Estimation of Radiation Hazard Indices and Excess Lifetime Cancer Risk associated with river water, Soil and sediments from Mini-Okoro/Oginigba Creek, Port Harcourt, River State, Nigeria" *Comprehensive Journal Earth Environmental Science*, 3(1): 53- 63.
- Beretka, J. and Mathew, P. J. (1985). "Natural Radioactivity of Australian Building Materials, Industrial Wastes and By-Products". *Health Physics*. 48 (I): 87 – 95.
- Dugule, D. S. (2022). "Knowledge, Risk Factors and Preventive Strategies of Cervical Cancer Among Tertiary Students in Taraba State, Nigeria" *Int. J. Bio. & Medic. Science*. 05 (04): 08-15. Doi: <https://doi.org/10.5281/zenodo.6767304>
- Garba, N. N., Ramli, A. T., Saleh, M. A., Sanusi, S. M., and Gabdo, H. T. (2016a). "Radiological Mapping of Kelantan, Malaysia, Using Terrestrial Radiation Dose Rate" *Isotope Environ Health Studies*. 52(3): 214 - 218. doi:10.1080/10256016.2016.1095189
- Garba, N. N., Ramli, A. T., Saleh, M. A., Sanusi, M. S., Gabdo H.T., and Aliyu A. S., (2016b). "The Potential Health Hazards of Chronic Exposure to Low - dose Natural Radioactivity in Terengganu, Malaysia" *Springer – Verlag Berlin Heidelberg*. doi 10.1007/s12665-015-5217-6.

- IAEA (2016). "Criteria for Radionuclide Activity Concentrations for Food and Drinking Water" *IAEA-TECDOC-1788*. ISBN: 978-92-0-103816-6
- Innocent, A. J., John, O., Ali, H., Onimisi, M. Y., Jonah, S. A., and Nwodo, N. A. (2014). "Radiological Safety Assessment of some Mine sites at Gusau and Environs, Nigeria" *Advancement in Scientific and Engineering Research* 2 (2): 23 - 28. ISBN 2384-7336 Research Paper. Science Web Publishing
- Macrotrends (2024). 'Nigeria Life Expectancy 1950 – 2024' Retrieved from <https://www.macrotrends.net/global-metrics/countries/NGA/nigeria/life-expectancy#:~:text=The%20current%20life%20expectancy%20or,a%200.57%25%20increase%20from%202021>
- Nabil, M. H., Nassif, A. M., Mohamed, F. H., and Ebrahim, S. (2015). "Assessment of Natural radioactivity in Fertilizers and Phosphate Ore Egypt" *Journal of Taibah University for Science*, 10: 296 - 306. <http://dx.doi.org/10.1016/j.jtusci.08.009>
- NUMCO (1986). "Nigerian Uranium Mining Company Annual Reports". <https://conferences.iaea.org/event/146/contributions/5146/contribution.pdf>
- Odoh, C. M., Garba, N. N., Rabi, N., Isma'il, M. and Onudibia, M. E. (2026). "Mapping and Assessment of Activity Concentration of  $^{222}\text{Rn}$  and its associated Exposures from the Drinking Water Sources of Taraba State, Nigeria" *Research Square* Doi: <https://www.doi.org/10.21203/rs.3.rs-9123878/v1>
- Odoh, C. M., Garba, N. N., Rabi, N., Saleh, M. A. and Ezekiel, Y. A. (2018). 'The Effect of Geological Formations on Natural Radioactivity and Radiological Hazards in the Northern Zamfara State, Nigeria' *Open Science Journal of Modern Physics*. 5(1): 18 – 23.
- Onudibia, M. E., Joseph, R. W., Opara, I. J., Odoh, C. M., Iseh, A. J., Mgbukwu, M. U. (2020). "Assessment of Radiation Dose Level in Farm Soils of Mission Quarters, Wukari, Taraba State, Nigeria" *International Research Journal of Advanced Science*. 1 (2): 47–52
- Oruonye, E. D. and Ahmed, M. Y. (2018). "Assessment of Environmental Effect of Abandoned Uranium Mine Site in Mika Village of Taraba State, Nigeria" *International Journal of Geography and Geology*. Vol. 6 (4): 70 – 78. ISSN(e): 2305-7041, ISSN(p): 2306-9872. Doi:10.18488/journal.10.2017.64.70.78
- Raghu, Y., Ravisankar, R., Chandrasekaran, A., Vijayagopal, P. and Venkataraman, B. (2015). "Assessment of Natural Radioactivity and Radiological Hazard in Building Materials used in the Tiruvannamalai District, Tamilnadu, India, using a Statistical Approach" *Journal Taibah University of Science*. doi.org/10.1016/j.jtusci.2015.08.004
- Sharma, N., Singh, J., Esakki, S. C. and Tripathi, R. M. (2015). "A Study of the Natural Radioactivity and Radon Exhalation Rate in Some Cements Used in India and its Radiological Significance. *Journal of Radiation Research and Applied Sciences*. <http://dx.doi.org/10.1016/j.jrras.2015.09.001>
- Tsang, H., Akhtar, S., Saif-ur-Rehman, Wu, Q., Lee, I., Sahir, N. and Yang, X. (2018). "The Uranium Prospects in Mika Region, Northeastern Nigeria". *Open Journal of Geology*.

8: 1043-1055. ISSN Online: 2161-7589, ISSN Print: 2161-7570.  
<http://www.scirp.org/journal/ojg>

Tyovenda, A. A., Ocheje, J. A., Terver, S. and Uttah, E. U. (2022). “Investigation of the Radiological Risk of Farmlands and the Transfer Factor from Soil to Crops in Jalingo and Wukari L.G.A of Taraba State, Nigeria”. *Journal of Environmental Protection*. 13: 1 – 14. ISSN Online: 2152-2219, ISSN Print: 2152-2197  
<https://www.scirp.org/journal/jep>

UNSCEAR (United Nations Scientific Committee of the Effect of Atomic Radiation) (2000). “Sources and Effects of Ionizing Radiation. Annex B: Exposure from Natural Radiation” *Report on General Assembly New York City: USA*. 1: 84 – 156, ISBN: 90-441-1195-7

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) (2008). “Sources and Effects Ionizing Radiation, Exposure from Natural Sources of Radiation”. Report to General Assembly with Scientific Annexes, Vol. 1. United Nations, New York.

USEPA (United States Environmental Protection Agency) (2004). “Guidelines for Water Reuse”. EPA/625/R-04/108

USEPA (United States Environmental Protection Agency) (2012). “A citizen’s guide to radon: the guide to protecting our self and your family from radon”. EPA402/K-12/002.

USEPA (United States Environmental Protection Agency) (2023), “Exposure Pathways”. Retrieved from <https://www.epa.gov/radiation/radiation-health-effects#>

Esri (2019). “ArcGIS Desktop: Release 10.7.1” *Environmental Systems Research Institute, Inc.* <https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview>

Odoh, C. M., Garba, N. N., Nasiru, R and Isma’il, M. (2025). “Assessment of Terrestrial Gamma Radiation Dose Rates and its associated Hazards in Taraba State, Nigeria”. *Scientific Reports*. (2025)15:39473. <https://doi.org/10.1038/s41598-025-22939-7>  
[www.nature.com/Scientificreports](http://www.nature.com/Scientificreports)

NNRA (Nigerian Nuclear Regulatory Authority). (2012). “The Nigerian basics ionizing radiation regulations, public exposure to ionizing radiation” Vol. 27

Okeyode, I. C., Oladotuna, I. C., Alatisea, O. O., Badab, B. S., Makindea, V., Akinboroa, F. G., Mustaphaa, A. O. and Al-Azmic, D. (2019). “Indoor gamma dose rates in the high background radiation area of Abeokuta, South Western Nigeria” *Journal of Radiation Research and Applied Sciences* 12 (1): 72–77.  
<https://doi.org/10.1080/16878507.2019.1594097>

Ugbede F. O. and Benson I. D. (2018). Assessment of outdoor radiation levels and radiological health hazards in Emene Industrial Layout of Enugu State, Nigeria. *International Journal of Physical Sciences, Academic journal (AJ)*. Vol. 13(20), pp. 265-272, 30 December, 2018. DOI: 10.5897/IJPS2018.4763.

- Taskin, H., Karavus, M, Ay, P., Topuzoglu, A., Hindiroglu, S., Karahan, G. (2009). Radionuclide concentrations in soil and lifetime cancer risk due to the gamma radioactivity in Kırklareli. Turkey Journal of Environmental Radioactivity 100:49-53.
- Esi, E.O., Nwabuoku A.O., Oduah E.C., Ugbede F.O., Okpilike J.C. (2024). Evaluation of Indoor and Outdoor Radiation Levels and its Health Hazard at Dennis Osadebay University, Asaba, Delta State, Nigeria. Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 10 No. 1c March 2024*. <https://dx.doi.org/10.4314/dujopas.v10i1c.2>
- Avwiri, G.O. (2011). Radiation – The Good, the Bad and the Ugly in our Environment. An Inaugural Lecture 79th Series University of Port Harcourt Press.
- Aziz AQ, Shahina T, Kamal UD, Shahid M, Chiara C, Abdul W (2014). Evaluation of excessive lifetime cancer risk due to natural radioactivity in the Rivers sediments of Northern Pakistan. Journal of Radiation Research and Applied Sciences 7:438 447.
- Omidiji, R. (2025). “UN: Nigeria tops list of countries with lowest life expectancy” <https://tribuneonlineng.com/un-nigeria-tops-list-of-countries-with-lowest-life-expectancy/>
- Africanews (2025). “Nigeria’s life expectancy ranked lowest globally”. <https://www.africanews.com/2025/10/07/nigeria's-life-expectancy-ranked-lowest-globally/>