Nigerian Journal of Theoretical and Environmental Physics (NJTEP)
ISSN Print: 3026-9601
ISSN Online: 1597-9849
DOI: https://doi.org/10.62292/njtep.v3i3.2025.83
Volume 3(3), September 2025

Evaluation of Effective Doses from Natural Radioactivity in Soil and Plant Samples at Federal University Dutsin-Ma, Main Campus, Katsina State, Nigeria

*[1]Abdulrahman Z. Namadi, [2]Mathew N. Agu and [3]Raphael U. Ugbe

[1]Department of Physics, Faculty of Physical Sciences, Federal University Dutsin-Ma, Katsina State, Nigeria.
[2]Department of Physics, Faculty of Science, Nigerian Defence Academy, Kaduna State, Nigeria.
[3]Groundwater Department, National Water Resources Institute, Kaduna State, Nigeria.

*Corresponding author's email: nabdulrahman@fudutsinma.edu.ng

ABSTRACT
The presence of naturally occurring radioactive materials (NORMs) such as ^{40}K, ^{226}Ra, and ^{232}Th in soil and plant is a common environmental phenomenon due to their geogenic origin. Assessing their concentrations is essential for understanding radiological exposure risks, particularly within institutional and residential environments. This study investigated the levels of ^{40}K, ^{226}Ra, and ^{232}Th in soil and plant samples from the Federal University Dutsin-Ma (FUDMA) main campus using gamma-ray spectroscopy. In soil, activity concentrations ranged from 20.36–47.86 Bq/kg (^{226}Ra), 21.03–64.57 Bq/kg (^{232}Th), and 81.56–234.84 Bq/kg (^{40}K), with mean values of 33.43, 43.16, and 164.32 Bq/kg. Compared to UNSCEAR global averages, levels of ^{226}Ra and ^{232}Th were slightly elevated, while ^{40}K was lower. Plant samples showed lower activity: 13.73–43.91 Bq/kg (^{226}Ra), 16.67–50.96 Bq/kg (^{232}Th), and 19.63–75.61 Bq/kg (^{40}K), with averages of 25.06, 33.10, and 37.30 Bq/kg. Outdoor gamma dose rates ranged from 19.63–75.61 nGy/h (soil) and 17.93–47.90 nGy/h (plant), while indoor levels reached 134.09 nGy/h. Annual effective doses (AEDγ) from soil ranged from 0.64–1.43 mSv/yr (mean: 0.92), and from plant 0.20–0.50 mSv/yr (mean: 0.35), within the ICRP 1 mSv/yr public dose limit. Ingestion dose estimates (AED_{ing}) revealed ^{232}Th as the dominant contributor: 9.93×10^{-4} mSv/yr (soil) and 1.52×10^{-3} mSv/yr (plant). AGED values ranged from 198.37–490.59 mSv/yr in soil and 122.12–327.20 mSv/yr in plant, with soil averaging 334.64 mSv/yr above the global average of 300 mSv/yr. Locations near the Senate Building and Faculty of Life Sciences suggest potential localized risk, emphasizing the importance of regular monitoring and precautionary measures in high-occupancy zones.

Keywords:
Effective Doses,
FUDMA,
NORMs,
Plant,
Soil.

INTRODUCTION

Naturally occurring radioactive materials (NORMs) contribute significantly to human exposure through ingestion, inhalation, and external irradiation. Assessing the effective dose from NORMs is essential for evaluating potential health risks and ensuring compliance with radiological protection standards (IAEA, 2004; UNSCEAR, 2000). Radionuclides have been essential constituents of the earth, since its creation. Human beings are continually exposed to ionizing radiation from naturally occurring radionuclides known to be present in varying proportions in rocks and soil of different geological formations around the world (UNSCEAR, 2000). This natural radiation comes from two main sources: cosmogenic radionuclides (^{3}H, ^{14}C, etc) and long-lived primordial radionuclides, also called naturally occurring radioactive materials (NORMs) (^{40}K, ^{238}U, and ^{232}Th) and their daughters also called naturally occurring radioactive materials (NORMs). The amount of these cosmogenic radionuclides is basically constant because of equilibrium between their rate of creation by cosmic radiation and their radioactive decay (Mikhail, 2008). Although the amount of primordial radionuclide keeps decreasing slowly with time due to radioactive decay, quite a significant amount still remains in the earth crust today and onward due to their long half-lives. Their concentrations and associated exposure in different environments depend primarily on the geology and geographical conditions of such environments (Dawood, 2011). The measurement of natural gamma radioactivity levels is paramount in implementing precautionary measures whenever the source is found to exceed the recommended limits. The most common radiation induced health effects are incidence of cancers and genetic effects. Lung cancer induction is the most common effect due to inhalation radiation exposure (WHO, 2009).

As of February 2025, Federal University Dutsin-Ma (FUDMA) hosts about 30,000 undergraduate and postgraduate students across its two campuses. The university community, including students and staff, interacts extensively with the environment, and staff members are allotted plots of land for seasonal farming in the main campus. These activities emphasize the potential risk of exposure to Naturally Occurring Radioactive Materials (NORMs), which are present in rocks, soils, plant, water, and air (Ajayi and Kuforiji, 2001; UNSCEAR, 2000). The concentrations and impacts of these radionuclides, including ^{40}K, ^{226}Ra, and ^{232}Th require careful study to ensure the safety of the campus population and neighboring communities. Excessive levels of ^{226}Ra have been linked to severe health effects such as anaemia, cataracts, and bone cancer, particularly due to its deposition in bone tissue after exposure (ATSDR, 1990; IAEA, 2015). ^{232}Th, when inhaled in dust form during activities like farming or construction, poses a significant risk of respiratory diseases, including lung cancer, and may lead to genetic mutations in body cells over time (ATSDR, 1990; ICRP, 2008).^{40}K, though essential for biological functions, may become harmful when its levels exceed normal biological thresholds. Elevated potassium concentrations could result in hyperkaliemia, contributing to metabolic disorders, kidney diseases, and diabetes (UNSCEAR, 2000). The farming practices carried out by staff on campus land, coupled with the possibility of consuming contaminated plant, can increase the likelihood of radionuclide exposure. This exposure is not limited to the university community but could also affect neighboring communities reliant on agricultural produce from the area. For instance, the bioaccumulation of NORMs in crops could create a pathway for these radionuclides to enter the food chain, posing risks of chronic health conditions over time (Ajayi and Kuforiji, 2001; IAEA, 2015).

Additionally, the degradation of local soil and water quality by NORMs can further compound these risks, necessitating continuous monitoring and statistical analysis to evaluate and mitigate exposure levels. Understanding the distribution of NORMs in soil and plant in FUDMA campuses is thus critical. On the Federal University Dutsin-Ma campus and surrounding farmlands, the available plants collected include Siam weed (*Chromolaena odorata*), Goat weed (*Ageratum conyzoides*), Pigweed (*Amaranthus spinosus*), Nut grass (*Cyperus rotundus*), and Wild sunflower (*Tithonia diversifolia*), which often invade cultivated fields and open spaces, competing with useful plant. The implications for public health emphasize the importance of conducting thorough measurements, applying statistical analyses, and implementing preventive measures to safeguard the university population and its surroundings. The goal of this research was to measure and analyse natural radioactivity and other radiological parameters in the Federal University Dutsin-ma campus, Katsina state, Nigeria.

MATERIALS AND METHODS

Study Area

Dutsin-Ma is a Local Government Area in Katsina State, North-Western Nigeria. It lies on latitude 12°26'N and longitude 07°29'E. It is bounded by Kurfi and Charanchi LGAs to the north, Kankia LGA to the East, Safana and Dan-Musa LGAs to the West, and Matazu LGA to the Southeast.

On 7th February, 2011 the Federal University Dutsin-Ma and eight other Federal Universities were founded in order to address the issue of insufficient enrollment space for qualified applicants in certain states with lower educational attainment due to the lack Federal Universities. The State Government assisted in identifying both the take-off and permanent sites; the main campus was situated at Kilometer-Sixty Katsina-Kankara road in the Dutsin-Ma Local Government Area of Katsina State, while the take-off site is situated in Dutsin-Ma town (FUDMA, 2015).

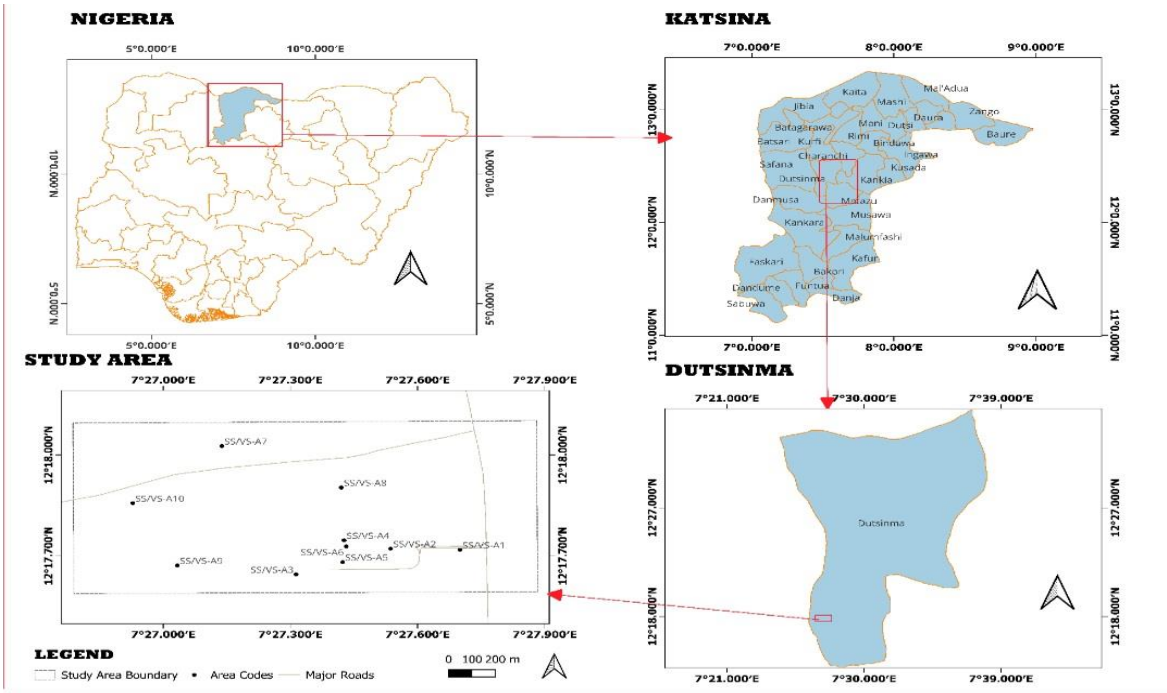

Figure 1: Location map of the study area showing Nigeria, Katsina state, Dutsin-ma local government and sampling points (Google, 2024; QGIS Development Team, 2024; ArcGIS 2025)

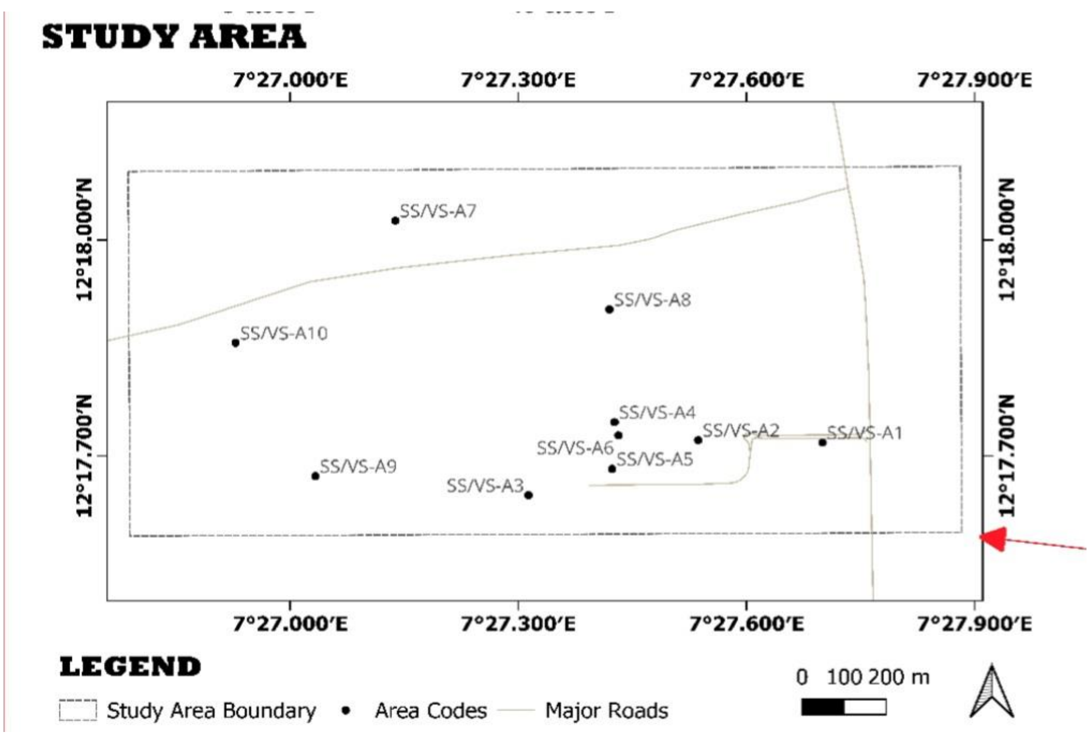

Figure 2: Map of the study area showing sampling points (SS/VSA01-SS/VSA10) (Google, 2024; QGIS Development Team, 2024; ArcGIS 2025)

Materials used in Gamma Spectroscopy

Soil and plant samples, Polythene Bag, Hand auger, Digger, shovel, surgical gloves, indelible ink, masking tape, tissue paper, candle wax, plastic container, sieve, hydraulic pressure system, geographical positioning system (GPS), gamma spectrometry system (Sodium iodide activated with thallium).

Sample Collection

On Thursday 18th July, 2024, at about 11:30 am, Soil samples were collected from ten (10) different locations as listed in table 2, within the university. The soil samples were taken using a mechanical hand auger to a depth of 5-10 cm. At each sampling location, soil samples were taken into labeled plastic bags. One kilogram (1 kg) of each sample was collected for analysis. In the same locations where soil samples were collected, plant samples were collected with each sample collected within a grid area of 1m x 1m. The samples were also packaged in plastic bags and labelled with identification marks. The coordinates of each sampling location that corresponded to the soil samples earlier discussed were recorded for traceability (Kamunda, 2017).

Sample Preparation for Gamma Radioactivity Measurements

The sample preparation method was adopted from Ibeanu, (1999). Each of the soil samples as well as the plant samples were sealed in a polyethylene bags, firmly tied and labelled to avoid cross contamination of the samples. Samples were spread on cardboard sheets and "all foreign materials" were removed. The samples were then oven dried at a temperature of 110˚C for 12-18 hours. The samples were then grinded into a fine powder and sieved using 2 mm sieve. The homogenized samples were filled into 25 g plastic containers (7.2 cm diameter by 6 cm height) which were hermetically sealed with the aid of PVC tape to prevent the escape of airborne ^{222}Rn and ^{220}Rn from the samples. The dimensions of the plastic containers were chosen in such a way that it suited the optimal soil mass of 350 g for analysis of bulk samples. The samples were then sealed and stored for over 24 days to allow secular equilibrium to be reached between radon and its daughters. The IAEA reference materials for gamma spectrometry (RGK-1, IAEA-448 and RGTh-1) were prepared exactly as the samples.

Gamma Spectrometric Analysis

The NaI(Tl) detector, situated at low background laboratory of the Center for Energy Research and Training, Ahmadu Bello University, Zaria, was used for the gamma spectrometric measurements. The detector has a 6 cm thick lead shield, cadmium lined assembly with copper sheets for the detection of background radiation. The detector has pulse resolving time of about 0.25 s, an incorporated preamplifier and a 1 kV external source which permits its use for high counting rates. The detector was coupled to a computer based multichannel analyser Maestro program from ORTEC for the acquisition and analysis of the gamma spectra. The detector was calibrated with the prepared IAEA reference materials RGK-1, IAEA-448 and RGTh-1 for the quantitative determination of ^{40}K, ^{238}U and ^{232}Th respectively in the samples. Each of the prepared samples was counted for 30,000 seconds in the outlined detector geometry in order to mitigate the influence of background radiation from radioactive contaminants within the shielding materials of the detector assembly. The spectral energy windows used for the analysis of the NORMs were presented in Table 1. The obtained data in counts per second were converted to conventional units of Bq/kg using calibration factors to determine the activity concentration of ^{226}Ra (^{238}U), ^{232}Th and ^{40}K.

Table 1: Spectral Energy used in the Gamma Spectrometric Analysis (Adapted from Iaea, 2004)

Element analysed	Isotope used	Gamma energy (keV)	Energy windows (keV)
^{40}K	^{40}K	1460.0	1380-1510
^{226}Ra	^{214}Bi	1764.0	1690-1820
^{232}Th	^{208}Tl	2614.5	2590-2710

Assessment of effective doses due to norms.

External Gamma Radiation Doses (D)

The absorbed dose at 1 meter above the ground both outdoor (D_{out}) and indoor (D_{in}) were calculated from the measured specific activities of ^{226}Ra, ^{232}Th and ^{40}K (Bqkg^{-1}) in soil using Equations 1 and 2 respectively (Ramasamy, 2009; UNSCEAR, 2000; European Commission, 1999).

$$D_{out}\ (\text{nGyh}^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (1)$$

$$D_{in}\ (\text{nGyh}^{-1}) = 0.92A_{Ra} + 1.1A_{Th} + 0.081A_K \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations (in Bqkg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K in the samples, respectively. The numerical values 0.462, 0.604 and 0.041 in nGyh^{-1}Bq^{-1}kg^{-1} are conversion factors of γ-radiation emanating from ^{226}Ra, ^{232}Th and ^{40}K outdoor respectively, while 0.92, 1.1 and 0.081 in nGyh^{-1}Bq^{-1}kg^{-1} are conversion factors of γ-radiation emanating from ^{226}Ra, ^{232}Th and ^{40}K indoor respectively.

Annual Effective Dose due to External Gamma Radiation (AED_γ)

The annual effective dose is of two types. The outdoor annual effective dose (E_{out}) and indoor annual effective dose (E_{in}). The Total annual effective doses due to external radiation from ^{226}Ra, ^{232}Th and ^{40}K in Bqkg^{-1} (AED_γ) were evaluated by summing up outdoor and indoor effective doses. It was assumed that ^{137}Cs, ^{90}Sr and ^{235}U radioactivity decay series have no noticeable contribution to the total dose from environmental background (Qureshi *et al.*, 2014). Equations 3, 4 and 5 were used in evaluating E_{out}, E_{in} and AED_{γ} (Hafezi *et al.,* 2005; Ramasamy *et al*., 2009 UNSCEAR, 2000).

$$E_{out}(mSvyr^{-1}) = D_{out} \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (3)$$

$$E_{in}(mSvyr^{-1}) = D_{in} \times 8760 \times 0.8 \times 0.7 \times 10^{-6} \quad (4)$$

$$AED_{\gamma}(mSvyr^{-1}) = E_{out} + E_{in} \quad (5)$$

where D is dose rate in nGyh^{-1}, the value 8760 are the hours in a year, the conversion coefficient from the absorbed dose in the air to the effective dose is 0.7 SvGy^{-1}, outdoor and indoor occupancy factors are 0.2 and 0.8 respectively (UNSCEAR, 2000).

Annual Effective Dose due to Ingestion of Soil and Plant (AED_{ing})

The annual effective dose from ingestion of radionuclides ^{226}Ra, ^{232}Th and ^{40}K through soil, and plant were estimated from the mean activity concentrations of each individual radionuclides using Equation 6 (UNSCEAR, 2000).

$$AED_{ing}(mSv/yr) = A_R IR_{ing} \sum_{j=1}^{3} DCF_{ing} \quad (6)$$

where, A_R is the mean activity concentration of radionuclides in a sample (Bqkg^{-1}); IR_{ing} is the soil, plant consumption rate per year which had a value of 100 kgyr^{-1} and 200 kgyr^{-1} for soil, and plants respectively (DEA, 2010). DCF_{ing} is the effective dose coefficient in SvBq^{-1} for the ingestion of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K with values of 4.50×10^{-8}, 2.30×10^{-7} and 6.20×10^{-9} respectively (ICRP, 2008).

Annual Gonadal Equivalent Dose (AGED)

This is a measure of threat to gonads and other radiation most sensitive cells from exposure to a particular level of NORMs radiation. These sensitive cells include the gonads, surface cells and the bone marrow. Annual gonadal equivalent dose was calculated using the Equation 7 (UNSCEAR, 2018):

$$AGED(mSvyr^{-1}) = 3.09A_{Ra} + 4.18A_{Th} + 0.31A_K \quad (7)$$

RESULTS AND DISCUSSION

Table 2: Area Code, Area Locations and Geographical Coordinates

S-No	Area Code	Area Location	Geographical Coordinates	
			Latitude	Longitude
1	SS/VS-A1	School Gate	N12°17'43.1"	E7°27'.42.0"
2	SS/VS-A3	Senate Building	N12°17'43.3"	E7°27'32.2"
3	SS/VS-A3	School Clinic	N12°17'38.7"	E7°27'18.8"
4	SS/VS-A4	University Main Library	N12°17'44.8"	E7°27'25.6"
5	SS/VS-A5	Faculty of Physical Sciences	N12°17'40.9"	E7°27'26.4"
6	SS/VS-A6	Faculty of Life Sciences	N12°17'43.7"	E7°27'25.9"
7	SS/VS-A7	Faculty of Health Science	N12°18'01.6"	E7°27'08.3"
8	SS/VS-A8	Faculty of Engineering	N12°17'54.2"	E7°27'25.2"
9	SS/VS-A9	Female Hostel	N12°17'40.3"	E7°27'02.0"
10	SS/VS-A10	Male Hostel	N12°17'51.4"	E7°26'55.7"

Table 3: Activity Concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Soil Samples from FUDMA Main Campus and Worldwide Average

S/No.	Sample ID	Area Location	Activity concentration (Bqkg^{-1})		
			^{226}Ra	^{232}Th	^{40}K
1.	SS-A01	University Gate	33.01±2.78	34.05±2.46	143.13±4.96
2.	SS-A02	Senate Building	47.86±2.20	64.57±2.24	234.84±4.94
3.	SS-A03	University Library	28.05±2.78	53.67±2.51	209.36±5.55
4.	SS-A04	University Clinic	30.21±2.68	35.88±1.26	81.56±4.88
5.	SS-A05	Faculty of Physical Sciences	37.97±3.54	47.81±2.41	154.96±2.89
6.	SS-A06	Faculty of Life Sciences	24.48±1.27	27.48±1.53	129.08±3.27
7.	SS-A07	Faculty of Health Sciences	42.94±5.57	45.61±2.01	193.98±2.52
8.	SS-A08	Faculty of Engineering	20.36±2.47	51.78±2.14	174.50±2.95
9.	SS-A09	Female Hostel	46.22±3.38	49.74±3.71	196.33±3.03
10.	SS-A10	Male Hostel	23.16±2.12	21.03±1.46	125.49±2.47
		MINIMUM	20.36±2.47	21.03±1.46	81.56±4.88
		MAXIMUM	47.86±2.20	64.57±2.24	234.84±4.94
		AVERAGE	33.43	43.16	164.32
		WORLDWIDE AVERAGE	30.00	35.00	400.00

Table 3 presents the activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th, and ^{40}K in soil samples collected from various locations within the FUDMA main campus. The measured concentrations ranged from 20.36 to 47.86 Bq/kg for ^{226}Ra, 21.03 to 64.57 Bq/kg for ^{232}Th, and 81.56 to 234.84 Bq/kg for ^{40}K. The highest values for all three radionuclides were recorded at the Senate Building, indicating a potential concentration of naturally occurring radioactive materials (NORMs) in that area. The average activity concentrations across all samples were 33.43 Bq/kg for ^{226}Ra, 43.16 Bq/kg for ^{232}Th, and 164.32 Bq/kg for ^{40}K. When compared to the global averages reported by UNSCEAR 30 Bq/kg for ^{226}Ra, 35 Bq/kg for ^{232}Th, and 400 Bq/kg for ^{40}K the FUDMA campus shows slightly elevated levels of ^{226}Ra and ^{232}Th, but significantly lower levels of ^{40}K. These findings suggest the local geology is moderately enriched in uranium and thorium series radionuclides, while potassium-bearing minerals may be less prevalent.

Table 4: Activity Concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Plant Samples from FUDMA Main Campus and Worldwide Average

S/No.	Sample ID	Area Location	Activity concentration (Bqkg^{-1})		
			^{226}Ra	^{232}Th	^{40}K
1.	VS-A01	University Gate	32.98±2.79	30.86±1.49	48.01±4.40
2.	VS-A02	Senate Building	14.46±1.51	16.67±1.51	25.04±3.00
3.	VS-A03	University Library	43.91±2.48	32.85±3.59	56.10±4.51
4.	VS-A04	University Clinic	26.09±3.61	33.88±4.45	30.95±3.30
5.	VS-A05	Faculty of Physical Sciences	22.81±1.26	19.74±2.85	75.61±4.04
6.	VS-A06	Faculty of Life Sciences	34.93±2.16	49.90±2.63	34.48±3.14
7.	VS-A07	Faculty of Health Sciences	13.73±1.09	36.34±2.20	29.08±2.20
8.	VS-A08	Faculty of Engineering	19.10±1.41	50.96±3.37	19.63±1.96
9.	VS-A09	Female Hostel	26.49±2.87	32.27±3.31	24.06±2.51
10.	VS-A10	Male Hostel	16.10±2.33	27.57±2.17	30.02±3.73
		MINIMUM	13.73±1.09	16.67±1.51	19.63±1.96
		MAXIMUM	43.91±2.48	50.96±3.37	75.61±4.04
		AVERAGE	25.06	33.10	37.30
		WORLDWIDE AVERAGE	30.00	35.00	400.00

Table 4 illustrates the activity concentrations of the same radionuclides ^{226}Ra, ^{232}Th, and ^{40}K but in plant samples collected from corresponding locations. Here, the activity concentrations ranged from 13.73 to 43.91 Bq/kg for ^{226}Ra, 16.67 to 50.96 Bq/kg for ^{232}Th, and 19.63 to 75.61 Bq/kg for ^{40}K. The highest concentration of ^{226}Ra was found at the University Library, while ^{232}Th peaked at the Faculty of Engineering, and ^{40}K was highest at the Faculty of Physical Sciences. The average values 25.06 Bq/kg for ^{226}Ra, 33.10 Bq/kg for ^{232}Th, and 37.30 Bq/kg for ^{40}K are lower than both the soil values and global averages. These results reflect the selective uptake of radionuclides by plants, which depends on several factors including root depth, soil-to-plant transfer coefficients, species-specific absorption traits, and the chemical form of the radionuclides in the soil. Notably, ^{40}K, despite being essential for plant nutrition, remains significantly below the global average of 400 Bq/kg, hinting at limited availability or uptake from the soil.

Table 5: External Gamma Radiation Doses (D)

Area Code	Area Location	D_{out} (SS) (nGyh^{-1})	D_{in} (SS) (nGy h^{-1})	D_{out} (VS) (nGyh^{-1})	D_{in} (VS) (nGyh^{-1})
SS-01 and VS-01	University Gate	48.01	79.42	36.14	68.18
SS-02 and VS-02	Senate Building	25.04	134.09	17.93	33.67
SS-03 and VS-03	University Library	56.10	101.81	42.77	81.08
SS-04 and VS-04	University Clinic	30.95	73.87	33.98	63.78
SS-05 and VS-05	Faculty of Physical Sciences	75.61	100.08	26.02	48.83
SS-06 and VS-06	Faculty of Life Sciences	34.48	63.21	47.90	89.82
SS-07 and VS-07	Faculty of Health Sciences	29.08	105.39	29.66	54.97
SS-08 and VS-08	Faculty of Engineering	19.63	89.83	40.53	75.22
SS-09 and VS-09	Female Hostel	24.06	113.14	32.87	61.82
SS-10 and VS-10	Male Hostel	30.02	54.61	25.51	47.58
	MINIMUM	19.63	54.61	17.93	33.67
	MAXIMUM	75.61	134.09	47.90	89.82
	AVERAGE	37.30	91.55	33.33	62.50

Table 5 presents outdoor and indoor gamma dose rates D_{out} and D_{in} derived from both soil and plant. The values range from 19.63 to 75.61 nGy/h for soil and 17.93 to 47.90 nGy/h for plant in outdoor measurements. Indoor doses are consistently higher due to enclosed space accumulation, peaking at 134.09 nGy/h (Senate Building). This observation is in line with the protective shielding effect of buildings, which reduce cosmic radiation but can enhance terrestrial gamma exposure due to building material accumulation. On the average, soil contributes 37.30 nGy/h outdoors and 91.55 nGy/h indoors, while plant contributes 33.33 nGy/h and 62.50 nGy/h respectively. The results emphasize the contribution of soil as a more significant source of terrestrial gamma radiation, with some zones exceeding UNSCEAR's recommended global outdoor average of 59 nGy/h.

Table 6: Annual Effective Dose due to External Gamma Radiation (AED_γ)

Area Location	E_{out} (SS) ($mSvyr^{-1}$)	E_{in} (SS) ($mSvyr^{-1}$)	AEDγ (SS) ($mSvyr^{-1}$)	E_{out} (VS) ($mSvyr^{-1}$)	E_{in} (VS) ($mSvyr^{-1}$)	AEDγ (VS) ($mSvyr^{-1}$)
University Gate	0.59	0.39	0.98	0.05	0.33	0.38
Senate Building	0.31	0.66	0.97	0.03	0.17	0.20
University Library	0.69	0.50	1.19	0.06	0.40	0.46
University Clinic	0.38	0.37	0.75	0.05	0.31	0.36
Fac. of Physical Sciences	0.93	0.50	1.43	0.04	0.24	0.28
Faculty of Life Sciences	0.43	0.32	0.75	0.06	0.44	0.50
Faculty of Health Sciences	0.36	0.52	0.88	0.04	0.27	0.31
Faculty of Engineering	0.25	0.45	0.70	0.05	0.37	0.42
Female Hostel	0.30	0.56	0.86	0.05	0.30	0.35
Male Hostel	0.37	0.27	0.64	0.04	0.23	0.27
MINIMUM	0.25	0.27	0.64	0.03	0.17	0.20
MAXIMUM	0.93	0.66	1.43	0.06	0.44	0.50
AVERAGE	0.46	0.45	0.92	0.05	0.31	0.35

Table 6 shows the annual effective dose (AEDγ) resulting from gamma radiation exposure due to NORMs in soil and plant. For soil samples, values ranged from 0.64 to 1.43 mSv/yr, with the highest at the Faculty of Physical Sciences. For plant, doses were lower, ranging from 0.20 to 0.50 mSv/yr, with the Faculty of Life Sciences recording the maximum. The average AED from soil was 0.92 mSv/yr and from plant 0.35 mSv/yr. While these values remain within the International Commission on Radiological Protection (ICRP) recommended limit of 1 mSv/year for the general public, the near-threshold soil values in certain areas call for caution. Repeated or prolonged exposure, especially for those who spend considerable time in these environments, may necessitate further monitoring or mitigation strategies.

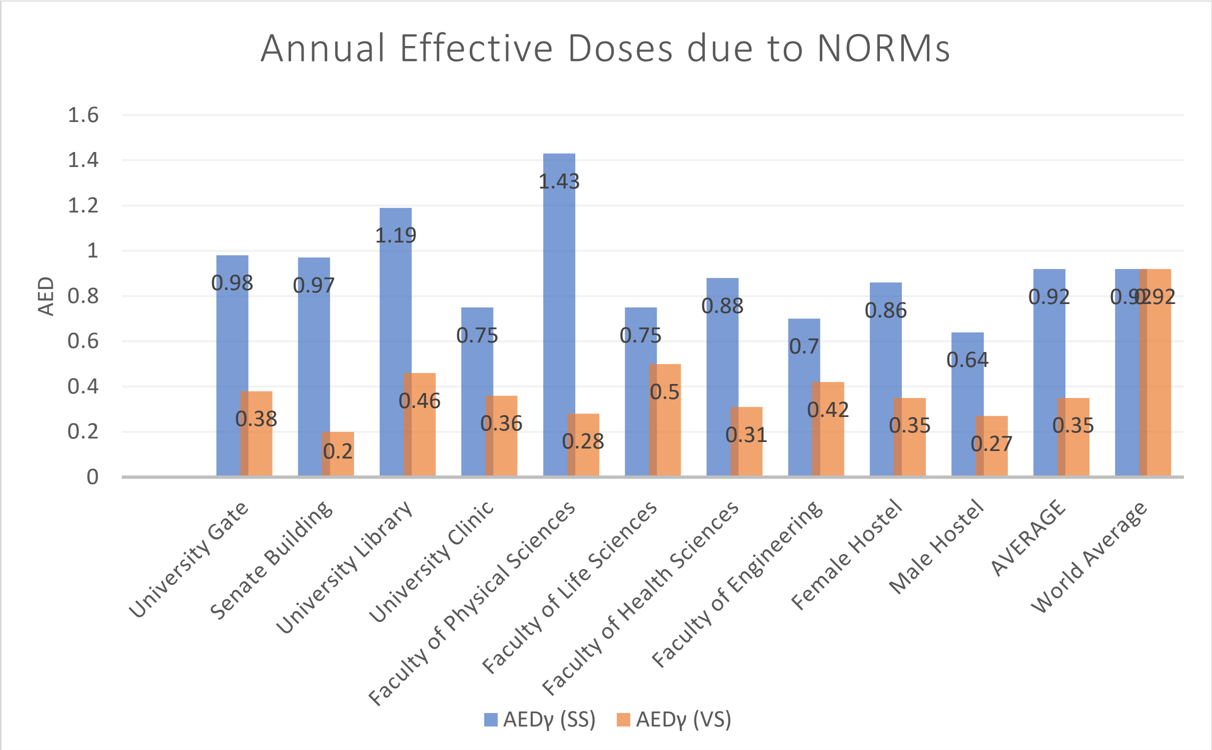

Figure 3: Annual Effectives Doses due to NORMs for soil and plant samples

Figure 3 provides a graphical overview of AEDγ values for both soil (SS) and plant (VS). It visually confirms that gamma radiation exposure from soil is significantly higher than from plant across all locations. Notable peaks in soil exposure are observed at the Faculty of Physical Sciences 1.43 mSv/yr and University Library 1.19 mSv/yr, while plant remains comparatively low with a maximum of 0.50 mSv/yr. This figure is instrumental for public health and safety planning, particularly for assigning radiation zoning and evaluating cumulative exposure risk for staff and students. It reinforces the importance of location-specific radiological assessments rather than relying on generalized values.

Table 7: Annual Effective Dose due to Ingestion of Soil and Plant (AED_{ing})

NORMs	Mean (Bq/Kg)	IR_{ing} (Kg/yr)	DCF_{ing} (Sv/Bq)	AED_{ing} (mSv/yr)
Ra-226 (SS)	33.43	100	$4.50x10^{-8}$	$1.50x10^{-4}$
Th-232 (SS)	43.16	100	$2.30x10^{-7}$	$9.93x10^{-4}$
K-40 (SS)	164.32	100	$6.20x10^{-9}$	$1.02x10^{-4}$
Ra-226 (VS)	25.06	200	$4.50x10^{-8}$	$2.26X10^{-4}$
Th-232 (VS)	33.1	200	$2.30x10^{-7}$	$1.52X10^{-3}$
K-40 (VS)	37.3	200	$6.20X10^{-9}$	$4.63X10^{-5}$

Table 7 assesses the annual effective dose due to ingestion (AED_{ing}) of radionuclides from soil and plant. The ingestion pathway is critical in radiological health assessments, particularly in agricultural or grazing zones. For soil samples, ingestion of ^{226}Ra mean 33.43 Bq/kg yields a dose of 1.50×10^{-4} mSv/yr, ^{232}Th 43.16 Bq/kg contributes the highest ingestion dose at 9.93×10^{-4} mSv/yr, and ^{40}K 164.32 Bq/kg results in 1.02×10^{-4} mSv/yr. For plant, with a doubled ingestion rate (200 kg/yr), doses increase of ^{226}Ra leads to 2.26×10^{-4} mSv/yr, ^{232}Th to 1.52×10^{-3} mSv/yr, and ^{40}K to 4.63×10^{-5} mSv/yr. These values, although low, show thorium as the dominant contributor due to its high dose conversion factor (2.30×10^{-7} Sv/Bq). While the ingestion doses are well below the permissible annual dose limits set by ICRP, these figures highlight the potential long-term risk of internal exposure, especially for individuals with habitual consumption of local flora or accidental soil ingestion, warranting continuous environmental and dietary surveillance.

Table 8: Annual Gonadal Equivalent Dose (AGED)

S/N	Area Location	AGED (SS) (mSv/yr)	AGED (VS) (mSv/yr)
1	University Gate	288.70	245.79
2	Senate Building	490.59	122.12
3	University Library	375.92	290.39
4	University Clinic	268.61	231.83
5	Faculty of Physical Sciences	365.21	176.44
6	Faculty of Life Sciences	230.52	327.20
7	Faculty of Health Sciences	383.47	203.34
8	Faculty of Engineering	333.45	278.12
9	Female Hostel	411.60	224.20
10	Male Hostel	198.37	174.30
	MINIMUM	198.37	122.12
	MAXIMUM	490.59	327.20
	AVERAGE	334.64	227.37
	WORLD AVERAGE	300.00	

Table 8 presents the annual gonadal equivalent dose (AGED), which estimates the radiation dose to reproductive organs and is critical in evaluating hereditary risk. The values range from 198.37 to 490.59 mSv/yr for soil, with the Senate Building recording the maximum value, suggesting a concentration of radionuclides in that location. Plant-based doses ranged from 122.12 to 327.20 mSv/yr, with the highest at the Faculty of Life Sciences. The average AGED for soil samples was 334.64 mSv/yr, while plant averaged 227.37 mSv/yr. The world average is 300mSv/yr. These findings are particularly relevant in determining whether specific campus zones especially those with higher student traffic or residential usage should be prioritized for remediation or regular monitoring.

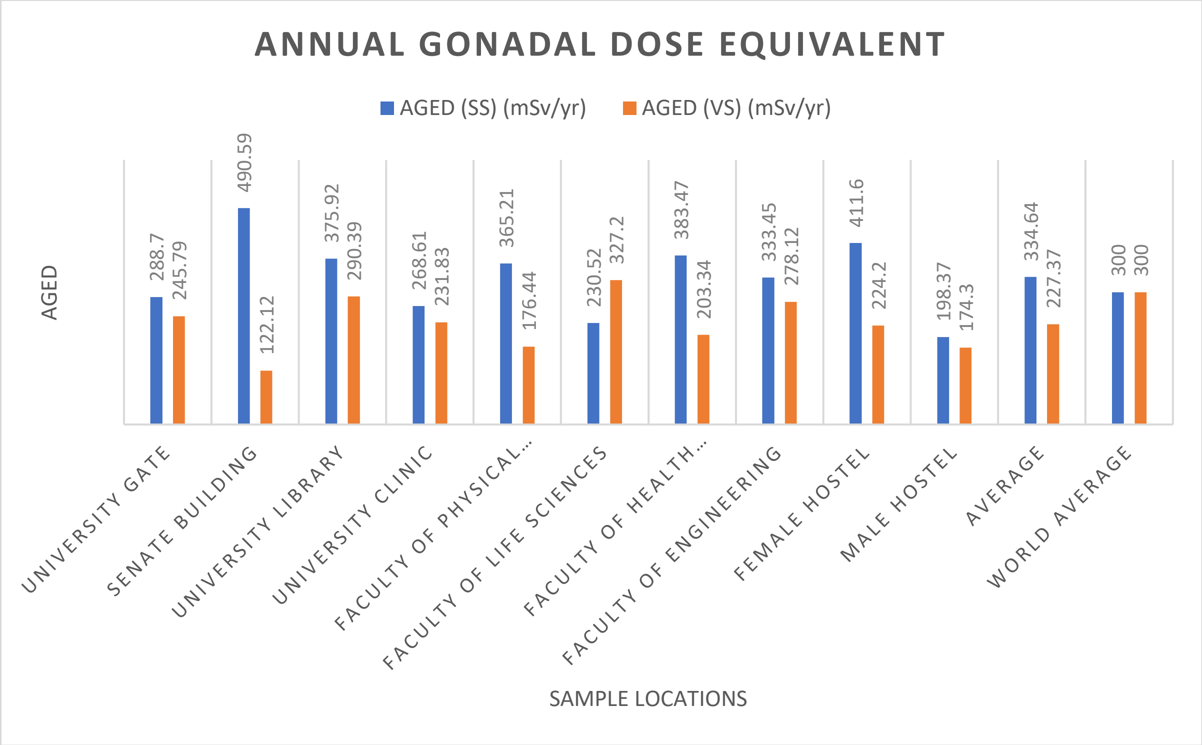

Figure 4: Annual gonadal dose equivalent for soil and plant samples

Figure 4 graphically depicts AGED for both soil (SS) and plant samples (VS). It vividly confirms that soil contributes significantly more to gonadal exposure than plant across nearly all locations. The Senate Building and University Library stand out, showing elevated AGED values, with soil contributing up to 490.59 mSv/year and plant up to 327.20 mSv/year. These findings support earlier tabular data and suggest that internal exposure from radionuclides residing in soil is a more prominent concern. Such graphical representation enables easy identification of high-risk zones and can be pivotal in planning land use, construction, and access regulation on campus. It also draws attention to potential long-term genetic impacts, even when annual doses fall within safe limits, underscoring the importance of sustained vigilance.

CONCLUSION

In this study, we have quantified the activity concentrations of naturally occurring radionuclides ^{40}K, ^{226}Ra, and ^{232}Th in both soil and plant samples collected from various locations on the main campus of Federal University Dutsin-Ma. The findings indicate that soil samples generally exhibited higher radionuclide concentrations than plant, consistent with the limited mobility and bioavailability of these radionuclides in terrestrial ecosystems. This study evaluated the radiological health risks associated with the observed radionuclide concentrations through a range of technical indices: absorbed dose rates, annual effective dose equivalents (AED_{γ}), ingestion doses (AED_{ing}), annual gonadal equivalent dose (AGED), The results indicate that while the overall radiological risk is within internationally accepted safety limits, several areas present values nearing or slightly exceeding reference thresholds. For instance, the maximum indoor AEDγ from soil reached 1.43 mSv/yr at the Faculty of Physical Sciences, marginally above the ICRP's recommended public dose limit of 1 mSv/yr, indicating the need for environmental control strategies in such locations. For plant, although ingestion doses were considerably lower, the cumulative risk, especially from locally sourced food or forage, warrants attention. The implications extend beyond the university boundaries to neighboring communities, especially those interacting with the campus ecosystem through agricultural activities or water usage.

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