MENTORSHIP, SCHOLARSHIP, AND SERVICE: A SPECIAL ISSUE HONOURING PROFESSOR ADAMU N. BABA-KUTIGI, FNIP ON HIS RETIREMENT

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Environmental Radiotoxical Dosimetry of Soil Samples of Selected Locations in Federal College of Education (Technical) Gusau Zamfar State

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ABSTRACT
Naturally occurring radioactive materials (NORMs) in soils constitute an important source of environmental radiation exposure and may pose potential health risks to populations occupying affected environments. This study presents a baseline radiological assessment of soils within the Federal College of Education (Technical), Gusau, Zamfara State, Nigeria, providing essential reference data for future environmental monitoring and radiation protection in an institutional setting. Twenty soil samples were collected from strategically selected locations across the campus and analyzed using gamma-ray spectrometry with a NaI(Tl) detector to determine the activity concentrations of ^{40}K,^{226}Ra, and ^{232}Th, as well as associated radiological hazard indices. The mean activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th were 390.09, 22.68, and 30.29 Bq kg^{-1}, respectively. These values are below the corresponding global average values reported by UNSCEAR, indicating low natural radioactivity within the study area. Radiological hazard assessment showed mean values of 95.67 Bq kg^{-1} for radium equivalent activity (Ra_{eq}), 44.41 nGy h^{-1} for absorbed dose rate, 0.258 for the external hazard index (H_{ex}), and 0.319 for the internal hazard index (H_{in}). The average annual effective dose equivalents were 0.222 mSv y^{-1} for indoor exposure and 0.055 mSv y^{-1} for outdoor exposure. Excess lifetime cancer risk values remained within internationally accepted safety limits. The measured radiological parameters were generally lower than the recommended thresholds established by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the Organisation for Economic Co-operation and Development (OECD), and the International Commission on Radiological Protection (ICRP). These findings indicate that the soils within the study area do not present significant radiological health concerns. The study establishes a valuable baseline radiological database for educational institutions in Zamfara State and contributes to ongoing environmental radiation surveillance in regions influenced by diverse geological and anthropogenic activities.

Keywords: NORMs, Environmental radioactivity, Radiological hazards, Gamma spectrometry, Soil, Zamfara State

1.0 INTRODUCTION

Human exposure to ionizing radiation is an inevitable consequence of living in an environment containing naturally occurring radioactive materials (NORMs). The principal contributors to terrestrial background radiation are potassium-40 (^{40}K), uranium-238 (^{238}U), and thorium-232 (^{232}Th), which occur naturally in rocks, soils, water, and vegetation. These radionuclides continuously emit gamma radiation and contribute significantly to external radiation exposure, while their decay products may also enter the human body through inhalation, ingestion, and dermal contact pathways (UNSCEAR, 2020). Consequently, the assessment of natural radioactivity in environmental media has become an important component of environmental monitoring and public health protection. Soil serves as the primary reservoir of natural radionuclides and is widely used as an indicator of environmental radioactivity. The distribution of radionuclides in soil is strongly influenced by geological composition, mineralogical characteristics, weathering processes, and anthropogenic activities such as mining, agriculture, and industrial operations (Orosun et al., 2022; Tadesse et al., 2022). Variations in radionuclide concentrations may therefore reflect both natural geological conditions and human-induced environmental disturbances. Gamma radiation emitted from radionuclides present in soil contributes a substantial proportion of the annual effective dose received by the general population and is commonly used as an indicator of radiological safety (UNSCEAR, 2020).

Several studies worldwide have reported considerable spatial variability in natural radioactivity levels and associated radiological hazards. In Thailand, Kritsananuwat et al. (2015) reported radionuclide concentrations largely controlled by geological formations, while Kumar et al. (2018) observed significant variations in radionuclide distribution across Himalayan soils due to differences in lithology and environmental conditions. Similar investigations in Bangladesh (Nafisa et al., 2022), Iraq (Tarbool et al., 2022), and China (Yan et al., 2023) demonstrated that local geology remains the dominant factor governing natural radioactivity levels, although agricultural practices and industrial activities may further modify radionuclide distribution.

In Nigeria, increasing attention has been directed toward environmental radioactivity studies because of expanding mining and agricultural activities. Investigations conducted in Owo, Ondo State (Aladeniyi et al., 2019), Ota, Ogun State (Oyeyemi et al., 2021), the Niger Delta region (Ezekiel and Esi, 2023), and abandoned mining sites in Nasarawa State (Idris et al., 2024) reported varying concentrations of ^{40}K,^{226}Ra, and ^{232}Th, reflecting differences in geology, mineral exploitation, and land-use practices. Particularly in mining-impacted environments, elevated radionuclide concentrations have been linked to the redistribution of naturally occurring radioactive materials, resulting in increased radiological exposure to nearby populations (Orosun et al., 2022).

Zamfara State is recognized for extensive artisanal and small-scale mining activities, especially involving gold-bearing mineral deposits. Previous environmental studies in the region have largely focused on heavy metal contamination and mining-related health concerns, while comparatively limited attention has been given to the characterization of natural radioactivity in institutional environments. Educational institutions represent unique exposure settings because students, academic staff, and administrative personnel spend substantial periods within these environments. Consequently, soil radioactivity within school premises can contribute to long-term external radiation exposure and may serve as an important indicator of environmental quality and radiological safety.

Despite the growing body of radiological investigations in Nigeria, there remains a scarcity of baseline radiological data for educational institutions in Zamfara State. Furthermore, no comprehensive assessment has been reported for the Federal College of Education (Technical), Gusau, despite its location within a region influenced by complex basement geology and mining-related activities. Establishing baseline radionuclide concentrations and radiological hazard indices for this environment is essential for future environmental surveillance, risk assessment, and regulatory decision-making.

Therefore, the present study aims to determine the activity concentrations of ^{40}K,^{226}Ra, and ^{232}Th in soil samples collected from selected locations within the Federal College of Education (Technical), Gusau, using gamma-ray spectrometry. The study further evaluates key radiological hazard parameters, including radium equivalent activity (Ra_{eq}), absorbed dose rate (D_r), external hazard index (H_{ex}), internal hazard index (H_{in}), annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR), and compares the results with internationally recommended safety limits. The findings provide a baseline radiological database for institutional environments in Zamfara State and contribute to the broader understanding of natural background radiation levels in northwestern Nigeria.

2.0. MATERIALS AND METHOD

2.1. Study Area

Figure 1, shows the map of Gusau LGA and Federal college of Education Technical Gusauas the study area The study was conducted within the Federal College of Education (Technical), Gusau, located in Gusau Local Government Area, northwestern Nigeria. The geographical coordinates of the study area are approximately latitude 12.150°N and longitude 6.720°E. The area is bounded by Jauri in the north, Damba in the northeast, Geba and Zamfarawa villages in the southeast, and Marerin Fulani in the southwest. The total landmass of the study area is approximately 412 km². Geologically, the region is characterized by Precambrian Basement Complex formations overlain by sedimentary deposits. The topography is dominated by extensive floodplains associated with inland river systems, with an average elevation of about 150 m above sea level. The soil composition varies from gravelly to clayey alluvial deposits, which become saturated during the rainy season, enhancing the mobility and redistribution of radionuclides. These geological and hydrological conditions significantly influence the spatial distribution of naturally occurring radioactive materials (NORMs) in the environment (Orosun *et al.,* 2022; Abdullahi *et al.,* 2023).

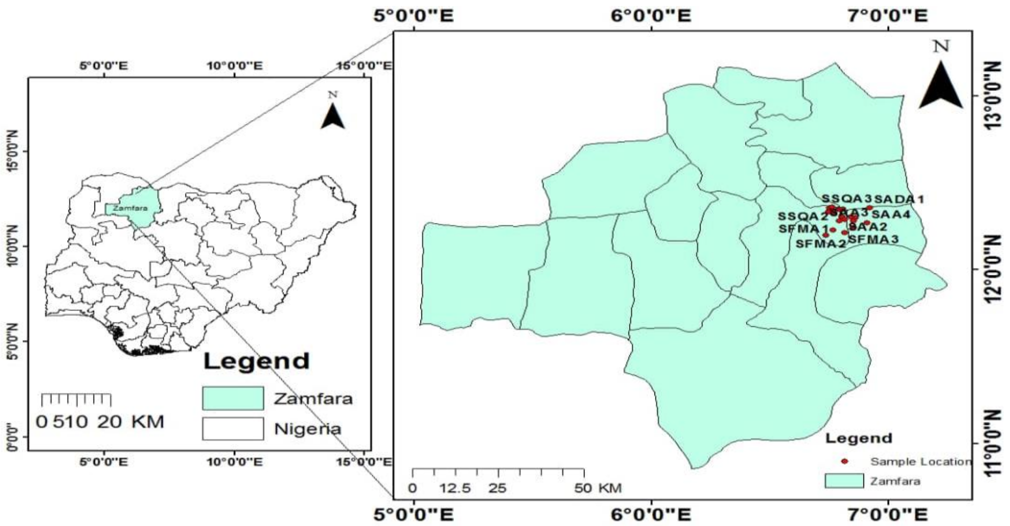

Figure 1: Shows the Map of the study area

2.2. Sample Collection and Preparation

The 20 soil samples collected were dried using a specialized oven at a temperature of (60^{0}C) so for 24 hours so as to get rid of any residual humidity from the samples crushed to fine powder using pulverizer. Packaging of the samples into radon-impermeable cylindrical plastic containers which were selected based on the space allocation of the detector vessel which measures 7.6cm by 7.6cm in dimension (geometry) was also carried out. In order to prevent radon-222 escaping, the packaging in each case was triple sealed. The sealing process included smearing of the inner rim of each container lid with Vaseline jelly, filling the lid assembly gap with candle wax to block the gaps between lid and container, and tight-sealing lid-container with masking adhesive tape. Radon and its short-lived progenies were allowed to reach secular radioactive equilibrium by storing the samples for 30 days prior to gamma spectroscopy measurements.

2.3. Data Analysis-

2.3.1. Gamma-Ray Spectrometric Analysis and Quality Assurance

Gamma-ray spectrometric measurements were performed using a 76 mm × 76 mm NaI(Tl) scintillation detector coupled to a photomultiplier tube and a multichannel analyzer operating under MAESTRO software. The detector assembly was enclosed within a graded shielding system consisting of lead, cadmium, and copper layers to reduce background radiation and Compton-scattered photons. Each sealed sample was counted for 29,000 s under identical geometric conditions.

2.3.2 Energy and Efficiency Calibration

Energy calibration was performed using certified point sources of ^137Cs (661.66 keV) and ^{60}Co (1173.2 and 1332.5 keV). Detector performance was verified by monitoring the full-width at half maximum (FWHM) of the 661.66 keV photo peak of ^{173}Cs, which was consistent with the manufacturer's specifications for NaI(Tl) detectors.

Efficiency calibration was established using IAEA-certified reference materials: RGK-1 (^{40}K), RGU-1 (^{226}Ra series), and RGTh-1 (^{232}Th series), packed in the same geometry as the environmental samples. The full-energy peak efficiency (ε) was determined as a function of gamma-ray energy and fitted using a polynomial efficiency calibration curve. Activity concentrations were calculated according to:

$$A = \frac{S}{\epsilon.T.I_{\gamma}.m} \quad \text{(1a) (ICRP, 2007).}$$

where:

A = activity concentration (Bq kg^{-1});

S is the Net count of the full-energy peak (total counts minus background) Counts

ε is the Detector efficiency for that specific gamma energy Decimal (e.g., 0.15)

T Counting live-time Seconds (s)

I_γ is the gamma Gamma emission probability (intensity) for that isotope Decimal (e.g., 0.1079 for K-40)

m is the Mass of the sample Kilograms (kg)

Activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th were determined using the 1460.8 keV, 1764.5 keV (^{214}Bi), and 2614.5 keV (^{208}Tl) gamma lines, respectively. The radionuclide concentrations were assumed to be in secular equilibrium with their decay products following a minimum storage period of 30 days.

2.3.3. Spectral Interference and Measurement Corrections

Potential spectral interferences associated with NaI(Tl) detectors were considered during peak identification. Particular attention was given to the ^{214}Bi (1764.5 keV) and ^{208}Tl (2614.5 keV) photo-peaks used for the quantification of the ^{238}U and ^{232}Th decay series, respectively. Because NaI(Tl) detectors possess lower energy resolution than HPGe systems, peak integration windows were carefully selected to minimize overlap and Compton background contributions. Coincidence summing effects were considered negligible because of the relatively large source-to-detector distance and low counting geometry. Self-attenuation effects were minimized through sample homogenization, uniform density preparation, and geometry matching between samples and reference standards.

2.3.4. Uncertainty and Detection Limit Analysis

Measurement uncertainties were estimated by propagating counting statistical errors, detector efficiency uncertainty, calibration uncertainty, sample mass uncertainty, and background fluctuations according to the law of error propagation. The combined uncertainty was reported at one standard deviation (±1σ)

2.3.5. Minimum detectable activity (MDA)s

Minimum detectable activity (MDA) values were calculated following the Currie method:

$$MDA\left(\frac{Bq}{Kg}\right) = 2.71 + 4.55\sqrt{B} \quad (1b) \quad \text{(UNSCEAR, 2008).}$$

where B represents background counts in the corresponding photopeak region, Detection limits were evaluated separately for ^{40}K,^{226}Ra, and ^{232}Th and used to verify the reliability of reported activity concentrations.

2.4 Radiological Hazard Assessment

The radiological implications of natural radionuclides in soil were evaluated using internationally accepted hazard indices. The equations employed are:

Radium Equivalent Activity

$$Ra_{eq} = A_{Ra} + 1.434\,A_{Th} + 0.077A_K \quad (2)$$

where A_{Ra}, A_{Th} and A_K represent the activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

Absorbed Gamma Dose Rate

$$D_r = 0.462A_{Ra} + 0.604\,A_{Th} + 0.0417A_K \quad (3)$$

where D_r is expressed in (nGy h^{-1})

External Hazard Index (H_{ex})

$$H_{ext} = \frac{A_{Ra}}{370} + \frac{A_{th}}{259} + \frac{A_K}{4810} \quad (4)$$

Internal Hazard Index (H_{in})

$$H_{int} = \frac{A_{Ra}}{185} + \frac{A_{th}}{259} + \frac{A_K}{4810} \quad (5)$$

Gamma Representative Index

$$I_r = \frac{A_{Ra}}{150} + \frac{A_{th}}{100} + \frac{A_K}{1500} \leq 1 \quad (6)$$

Annual effective Dose Equivalent (AEDE)

$$AEDE\,(mSvy^{-1}) = D_r \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (7)$$

Excess life cancer rate (ELCR) -

$$ELCR = AEDR \times DL \times Rf \quad (8)$$

Where DL is average period of life time (estimated to be 70 years), and Rf is the conversion factor and its value used by ICRP for the public is 0.05Sv^{-1} and, 0.7 Sv Gy^{-1} is the dose conversion coefficient and 0.2 and 0.8 represent outdoor and indoor occupancy factors, respectively.

2.5. Study Limitations and Future Research Needs

Although the present study provides important baseline radiological data for the Federal College of Education (Technical), Gusau, several limitations should be acknowledged. First, the sampling density (n = 20) may not fully capture small-scale spatial heterogeneity in radionuclide distribution across the study area. Second, only surface soils (0–15 cm) were investigated; therefore, vertical migration patterns of radionuclides were not assessed. Third, sampling was conducted during a single campaign, and seasonal variations associated with rainfall, erosion, and soil redistribution were not evaluated. The study also mentions Geographic Information System (GIS) applications; however, advanced geostatistical analyses such as semivariogram modelling, kriging interpolation, spatial autocorrelation, and hotspot analysis were beyond the scope of the present investigation. Future studies should incorporate higher sampling densities, multi-depth sampling, seasonal monitoring, and robust geostatistical modelling to improve understanding of radionuclide transport and spatial variability within the region.

3.0. RESULTS AND DISCUSSION

3.1. Results

The activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th measured in twenty soil samples collected from selected locations within the Federal College of Education (Technical), Gusau, Zamfara State, are presented in Table 4.1. The activity concentration of ^40K ranged from 262.68 ± 5.75 to 544.79 ± 5.75 Bq kg^{-1}, with a mean value of 390.09 ± 6.04 Bq kg^{-1}. The highest concentration was observed in sample SSHA2, while the lowest was recorded in sample SFMA4. The mean concentration was slightly lower than the worldwide average value of 412 Bq kg^{-1} recommended by UNSCEAR.

For ^{226}Ra, activity concentrations varied between 16.57 ± 2.55 and 33.94 ± 1.51 Bq kg^{-1}, with an average value of 22.68 ± 2.33 Bq kg^{-1}. Similarly, the activity concentration of ^{232}Th ranged from 14.60 ± 1.71 to 47.89 ± 3.99 Bq kg^{-1}, with a mean value of 30.29 ± 3.31 Bq kg^{-1}. The average concentrations of both radionuclides were below the global reference values of 35 Bq kg^{-1} for ^{226}Ra and 45 Bq kg^{-1} for ^{232}Th reported by UNSCEAR (2008). Overall, the observed radionuclide concentrations indicate that natural radioactivity within the study area is primarily controlled by the local geological environment and remains within the range commonly reported for soils worldwide.

3.2. Radiological Hazard Indices

The calculated radiological hazard parameters are presented in Table 4.2. Radium equivalent activity (Ra_eq) ranged from 65.95 to 123.42 Bq kg^{-1}, with an average value of 95.67 Bq kg^{-1}. All values were substantially lower than the recommended safety limit of 370 Bq kg^{-1}, indicating that the soils do not pose significant radiological hazards. The absorbed dose rate (D_r) varied from 25.18 to 58.47 nGy h^{-1}, with a mean value of 44.40 nGy h^{-1}, which is below the global average value of 55 nGy h^{-1} reported by UNSCEAR. The external hazard index (H_{ex}) and internal hazard index (H_{in}) ranged from 0.178–0.333 and 0.231–0.412, respectively. All values were below the recommended limit of unity, suggesting negligible external and internal radiation hazards.

The gamma representative index ($I\gamma$) varied between 0.394 and 0.776, with an average value of 0.613, remaining below the recommended threshold value of 1.0. The annual effective dose equivalent (AEDE) ranged from 0.154–0.287 mSv y^{-1} for indoor exposure and 0.038–0.072 mSv y^{-1} for outdoor exposure, yielding average values of 0.222 mSv y^{-1} and 0.056 mSv y^{-1}, respectively. The corresponding total annual effective dose averaged 0.278 mSv y^{-1}, considerably lower than the public exposure limit of 1 mSv y^{-1} recommended by the ICRP. The excess lifetime cancer risk (ELCR) ranged from 0.673×10^{-3} to 1.255×10^{-3}, with values comparable to those reported for natural background radiation environments in other parts of Nigeria and elsewhere.

Table 1: Activity concentrations of natural radionuclide's in soil samples determined by gamma spectrometry

S/No.	Sample ID	K-40d (CPS)	Error ± (CPS)	K-40 (Bq kg⁻¹)	Error ± (Bq kg⁻¹)	Ra-226 (CPS)	Error ± (CPS)	Ra-226 (Bq kg⁻¹)	Error ± (Bq kg⁻¹)	Th-232 (CPS)	Error ± (CPS)	Th-232 (Bq kg⁻¹)	Error ± (Bq kg⁻¹)
1.	SAA1	0.1980	0.0053	307.9316	8.2426	0.0180	0.0020	20.8526	2.3170	0.0244	0.0023	27.8221	2.6226
2.	SAA2	0.2300	0.0055	357.6983	8.5537	0.0187	0.0017	21.6640	1.9694	0.0152	0.0022	17.3318	2.5086
3.	SAA3	0.3140	0.0063	488.3359	9.7978	0.0167	0.0033	19.3466	3.8230	0.0128	0.0015	14.5952	1.7104
4.	SAA4	0.1860	0.0021	289.8911	3.2659	0.0185	0.0016	21.4319	1.8536	0.0326	0.0043	37.1722	4.9031
5.	SADA1	0.2099	0.0013	326.4386	2.0218	0.0194	0.0013	22.4745	1.5060	0.0275	0.0067	31.3569	7.6283
6.	SADA2	0.2668	0.0048	414.9300	7.4650	0.0201	0.0015	23.3086	1.7377	0.0356	0.0031	40.5929	3.2360
7.	SADA3	0.3123	0.0056	485.6921	8.7092	0.0183	0.0025	21.2002	2.8962	0.0314	0.0031	35.8030	3.5348
8.	SADA4	0.3324	0.0041	516.9518	6.3764	0.0143	0.0022	16.5663	2.5487	0.0335	0.0024	38.1984	2.7366
9.	SFMA1	0.2082	0.0013	323.8569	2.0220	0.0161	0.0018	18.6747	2.0853	0.0355	0.0057	40.5245	6.4994
10.	SFMA2	0.1441	0.0030	224.1213	4.6656	0.0293	0.0013	33.9435	1.5060	0.0420	0.0035	47.8905	3.9909
11.	SFMA3	0.2002	0.0024	311.3530	3.7325	0.0154	0.0012	17.8406	1.3902	0.0288	0.0031	32.8392	3.5346
12.	SFMA4	0.1689	0.0037	262.6750	5.7543	0.0168	0.0025	19.4741	2.8962	0.0161	0.0011	18.3580	1.2543
13.	SSHA1	0.2759	0.0043	429.0824	6.6874	0.0236	0.0017	27.3401	2.0042	0.0227	0.0017	25.8837	1.9042
14.	SSHA2	0.3503	0.0037	544.7900	5.7543	0.0210	0.0014	24.3049	1.6219	0.0132	0.0015	15.0513	1.7446
15.	SSHA3	0.3139	0.0050	488.1804	7.7761	0.0181	0.0020	20.9685	2.3170	0.0326	0.0024	37.1722	2.7366
16.	SSHA4	0.1979	0.0043	307.7760	6.6874	0.0185	0.0025	21.4666	2.8962	0.0326	0.0019	37.1722	2.1665
17.	SSQA1	0.2733	0.0035	425.0389	5.4432	0.0200	0.0030	23.2159	3.4754	0.0173	0.0024	19.7263	2.6579
18.	SSQA2	0.3163	0.0028	491.9129	4.3546	0.0250	0.0021	28.9620	2.4328	0.0347	0.0029	39.5667	3.3067
19.	SSQA3	0.2516	0.0041	391.2908	6.3764	0.0162	0.0014	18.7674	1.6219	0.0148	0.0025	16.8757	2.8164
20.	SSQA4	0.2773	0.0046	431.2597	7.1540	0.0277	0.0015	32.0899	1.7377	0.0227	0.0027	25.8837	3.0445
Max value				491.9129± 4.3546				28.9620± 2.4328				39.5667± 3.3067	
Min value				262.6750± 5.7543				19.4741± 2.8962				18.3580± 3.3067	
Average value				390.0861± 6.042				22.6849± 2.332				30.2855± 3.3067	
World Average				412				35				45	

Values are reported as measured activity concentrations with associated analytical uncertainties. K-40, Ra-226 and Th-232 activities are expressed in Bq kg⁻¹.

Table 2: Radiological hazard indices and dose assessment parameters for the investigated soil samples

S/No.	Sample ID	Ra_{eq} (Bq/kg)	D_r (nGy/h)	H_{ex}	H_{in}	I_γ	$AEDE_{in}$(mSv/y)	$AEDE_{out}$ (mSv/y)	$AEDE_{totla}$ (mSv/y)	ELCR X 10^{-3}
1.	SAA1	84.3489	39.7521	0.2278	0.2842	0.5214	$1.9500X10^{-1}$	$4.8800X10^{-2}$	$2.4380X10^{-1}$	0.8533
2.	SAA2	73.9913	35.6878	0.1998	0.2584	0.4512	$1.7510X10^{-1}$	$4.3800X10^{-2}$	$2.1890X10^{-1}$	0.7661
3.	SAA3	77.8196	25.1802	0.2102	0.2625	0.5067	$1.8820X10^{-1}$	$4.7100X10^{-2}$	$2.3530X10^{-1}$	0.8235
4.	SAA4	96.9097	45.0739	0.2617	0.3196	0.6039	$2.2110X10^{-1}$	$5.5300X10^{-2}$	$2.7640X10^{-1}$	0.9593
5.	SADA1	92.4506	43.4683	0.2497	0.3104	0.5721	$2.1320X10^{-1}$	$5.3300X10^{-2}$	$2.6650X10^{-1}$	0.9320
6.	SADA2	113.3060	53.2793	0.3060	0.3690	0.7249	$2.6140X10^{-1}$	$6.5300X10^{-2}$	$3.267X10^{-1}$	1.1441
7.	SADA3	109.7967	52.2815	0.2965	0.3538	0.7204	$2.5650X10^{-1}$	$6.4100X10^{-2}$	$3.2060X10^{-1}$	1.1221
8.	SADA4	110.9953	52.9317	0.2997	0.3445	0.7567	$2.5970X10^{-1}$	$6.4900X10^{-2}$	$3.246X10^{-1}$	1.1361
9.	SFMA1	101.5617	47.2981	0.2743	0.3247	0.6551	$2.2020X10^{-1}$	$5.5000X10^{-2}$	$2.7520X10^{-1}$	0.9632
10.	SFMA2	119.6842	54.7677	0.3232	0.4150	0.6900	$2.6870X10^{-1}$	$6.7200X10^{-2}$	$3.3590X10^{-1}$	1.1756
11.	SFMA3	88.7748	41.6189	0.2397	0.2880	0.5684	$2.0420X10^{-1}$	$5.1000X10^{-2}$	$2.5520X10^{-1}$	0.8932
12.	SFMA4	65.9520	31.3505	0.1781	0.2308	0.3941	$1.5380X10^{-1}$	$3.8400X10^{-2}$	$1.9220X10^{-1}$	0.6727
13.	SSHA1	97.3931	46.5976	0.2630	0.3360	0.5946	$2.2860X10^{-1}$	$5.7100X10^{-2}$	$2.8570X10^{-1}$	0.9999
14.	SSHA2	87.7770	43.3018	0.2371	0.3028	0.5579	$2.6060X10^{-1}$	$5.3100X10^{-2}$	$2.6550X10^{-1}$	0.9293
15.	SSHA3	111.7146	53.1285	0.3017	0.3584	0.7353	$2.2480X10^{-1}$	$6.5200X10^{-2}$	$3.2580X10^{-1}$	1.1403
16.	SSHA4	98.3215	45.8354	0.2655	0.3235	0.6159	$1.9970X10^{-1}$	$5.6200X10^{-2}$	$2.8100X10^{-1}$	0.9835
17.	SSQA1	84.1525	33.7351	0.2273	0.2900	0.5228	$2.8680X10^{-1}$	$4.9900X10^{-2}$	$2.4960X10^{-1}$	0.8736
18.	SSQA2	123.4196	58.4651	0.3333	0.4115	0.7763	$1.7400X10^{-1}$	$7.1700X10^{-2}$	$3.5850X10^{-1}$	1.2547
19.	SSQA3	73.0290	35.4671	0.1952	0.2480	0.5579	$2.3980X10^{-1}$	$4.3500X10^{-2}$	$2.1750X10^{-1}$	0.7612
20.	SSQA4	102.3105	48.8828	0.2763	0.3631	0.7353	$2.3980X10^{-1}$	$5.9900X10^{-2}$	$2.9970X10^{-1}$	1.0489
	Max value	123.419	58.4641	0.3333	0.4115	0.7763	0.2868	0.0717	0.3585	
	Min value	65.9520	25.1802	0.1781	0.2480	0.3941	0.1538	0.0384	0.1982	
	Average value	95.6712	44.4041	0.2583	0.3192	0.6130	0.2222	0.0555	0.2776	
	World Average	<370	55	<1	<1	≤ 1	0.42	0.08	0.50	

3.3. Discussion

The activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th measured in the soils of the Federal College of Education (Technical), Gusau, presented in table 4.1, indicate that natural radioactivity levels within the study area are generally low and remain within internationally accepted background ranges. The mean activity concentrations of ^{40}K (390.09 Bq kg^{-1}), ^{226}Ra (22.68 Bq kg^{-1}), and ^{232}Th (30.29 Bq kg^{-1}) were lower than the worldwide average values of 412, 35, and 45 Bq kg^{-1}, respectively, recommended by UNSCEAR. These results suggest that the geological materials underlying the campus environment do not contain anomalous enrichments of naturally occurring radionuclides and that radiological exposure arising from soil is relatively low.

The observed variations among sampling locations are likely attributable to differences in soil mineralogy, weathering processes, land-use activities, and localized redistribution of naturally occurring radioactive materials. Zamfara State is well known for artisanal and small-scale mining activities, which have been associated with environmental contamination in several communities. Although mining-related disturbances can enhance radionuclide mobility and redistribution, the radionuclide concentrations recorded in the present study did not indicate significant radiological enrichment. This observation suggests that the campus environment has not been substantially impacted by mining-derived radioactive contamination despite its location within a mining-influenced region. The calculated radiological hazard indices further support the conclusion of a low-radiation environment. The mean radium equivalent activity (95.67 Bq kg^{-1}) was substantially lower than the recommended limit of 370 Bq kg^{-1}, while the average absorbed dose rate (44.40 nGy h^{-1}) remained below the global average value of 55 nGy h^{-1}. Similarly, the external hazard index (H_{ex}= 0.258), internal hazard index (H_{in} = 0.319), and gamma representative index ($I\gamma$ = 0.613) were all below the critical value of unity, indicating that neither external gamma exposure nor internal exposure from radon progeny is likely to pose significant health risks to students, staff, or visitors. The annual effective dose equivalents for indoor (0.222 mSv y^{-1}) and outdoor (0.056 mSv y^{-1}) exposure were considerably lower than the public dose constraint of 1 mSv y^{-1} recommended by the International Commission on Radiological Protection (ICRP). These values are also lower than those reported in several mining-impacted regions and building-material studies where indoor doses have occasionally exceeded 1 mSv y^{-1} despite hazard indices remaining below unity. Consequently, the radiological environment of the study area can be considered safe for long-term educational, residential, and occupational activities. The low radiological hazard indices observed in the present study are consistent with findings reported for institutional and environmental soils in Nigeria and elsewhere, where radionuclide concentrations generally remained below internationally recommended limits despite geological variability and anthropogenic disturbances (Eke et al., 2022; Esan et al., 2022; Eke et al., 2024). Similar observations have been reported in mining and quarry environments in Niger and Ogun States, respectively, where radiological parameters remained within acceptable limits even though localized enrichment of naturally occurring radionuclides was observed (Muhammad & Abbasi, 2025; Jegede et al., 2025). Nevertheless, studies integrating radiological and geochemical assessments have demonstrated that low radiological risk does not necessarily preclude potential chemical toxicity arising from heavy metals and other contaminants (Kaintura et al., 2024; Popoola et al., 2025). Consequently, future environmental monitoring programmes in Zamfara State should adopt an integrated framework that combines radiological indices with heavy-metal pollution and human health risk assessments to provide a more comprehensive evaluation of environmental quality and public health implications.

Comparison with previous studies conducted in Nigeria and other countries from table 4.3, reveals a generally consistent pattern. The radionuclide concentrations and hazard indices obtained in the present study are comparable to values reported for soils in Nasarawa State, southwestern Nigeria, Iraq, and Thailand, but substantially lower than values reported in some mining-intensive environments and industrialized regions. Such differences are largely controlled by geological formations, mineral composition, mining intensity, and anthropogenic activities that influence radionuclide distribution in soils.

While the radiological assessment demonstrates negligible radiation-related health risks, it is important to recognize that radiological safety does not necessarily imply complete environmental safety. Zamfara State has experienced documented cases of heavy-metal contamination, particularly involving lead, cadmium, arsenic, and other toxic elements associated with mining activities. Therefore, the relatively low radiological risk observed in this study should be interpreted alongside the potential for chemical toxicity from non-radioactive contaminants. Future environmental monitoring programs should integrate radiological assessments with heavy-metal pollution studies and human health risk assessments to provide a more comprehensive evaluation of environmental quality and public health risks.

The present study provides an important baseline radiological dataset for an institutional environment in Zamfara State. Such baseline information is essential for detecting future environmental changes, evaluating the impact of expanding mining activities, and supporting evidence-based environmental management decisions. Given the increasing anthropogenic pressure on environmental resources within the region, periodic radiological monitoring is recommended to ensure continued protection of the campus population and surrounding communities.

3.4. Comparison with Global Averages and Previous Studies

Table 3 compares the mean radionuclide concentrations and radiological hazard indices obtained in the present study with worldwide averages and selected studies from Nigeria and other countries. The mean activity concentration of ^{40}K (390.09 Bq kg^{-1}) was comparable to values reported for soils in Thailand, Iraq, and Bangladesh but substantially lower than those observed in some mining-affected regions of the Niger Delta. Similarly, the mean concentrations of ^{40}Ra and ^{232}Th were below the worldwide averages and generally lower than values reported for mining environments in Bangladesh and parts of northern Nigeria. The mean absorbed dose rate (44.40 nGy h^{-1}), annual effective dose (0.278 mSv y^{-1}), and hazard indices were also lower than those reported in several mining and industrial environments. For example, studies conducted in Karbala, Iraq, and other radiologically characterized regions reported higher absorbed dose rates and annual effective doses while still maintaining hazard indices below the recommended safety threshold. The comparatively lower values observed in the present study suggest minimal radiological impact and reflect the predominance of natural background radioactivity.

Furthermore, investigations of building materials and indoor environments in Cyprus and other regions have reported annual effective dose values exceeding 1 mSv y^{-1} despite hazard indices remaining below unity. In contrast, the present study recorded substantially lower indoor and outdoor dose values, providing additional evidence that the study area poses no significant radiological threat to students, staff, or residents of the institution. Overall, the radiological parameters obtained in this study indicate that the soils within the Federal College of Education (Technical), Gusau, are radiologically safe and suitable for continued educational, residential, and administrative activities.

Table 3: Mean radionuclide concentrations and radiological hazard indices obtained in the present study with worldwide averages and selected studies from Nigeria and other countries

S/N	Country	^{40}K Average specific Activity in Bq/kg	^{226}Ra Average specific Activity in Bq/kg	^{232}Th Average specific Activity in Bq/kg	Ref.
1.	Turkey	342	310	37	Karahan and Balyukan 2000
2.	Al-Najaf (Iraq)	201.47	10.17	5.91	Tarbool et al., 2022
3.	Delta (Nigeria)	1586.82	27.26	37.67	Ezekiel and Esi, 2023
4.	China	75.78	8.69	3.30	Yan Shi et al.,2023
5	Nasarawa (Nigeria)	277.62	5.66	0.90	Idris et al., 2024
6.	Bangladesh	494.2	63.6	103.4	Ahosan Habib etal.,2018
7	Iraq	354.11	10.85	5.81	Hussien Mraity et al., 2020
8.	Present study	290.96	22.68	30.28	

4.0. CONCLUSION

This study evaluated the activity concentrations of naturally occurring radionuclides (^{40}K, ^{226}Ra, and ^{232}Th) and associated radiological hazard indices in soil samples collected from selected locations within the Federal College of Education (Technical), Gusau, Zamfara State, Nigeria. The mean activity concentrations of all radionuclides were below the worldwide average values reported by UNSCEAR, indicating that the soils are characterized by normal background radioactivity levels.

The calculated radiological parameters, including radium equivalent activity (Ra_{eq}), absorbed dose rate (D_r), external hazard index (H_{ex}), internal hazard index (H_{in}), gamma representative index ($I\gamma$), annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR), were all below internationally accepted safety limits. These findings demonstrate that the study area does not present significant radiological health risks to students, staff, or residents.

Importantly, this work establishes the first comprehensive baseline radiological database for the Federal College of Education (Technical), Gusau, and contributes to the limited body of radiological data available for institutional environments in Zamfara State. Although the radiological risk is negligible, future environmental assessments should incorporate heavy-metal characterization and integrated human health risk assessments to account for potential chemical contaminants associated with mining activities within the region. Overall, the study confirms that the campus environment is radiologically safe and provides a scientific basis for future environmental surveillance, regulatory assessment, and sustainable environmental management in northwestern Nigeria.

5.0. CONTRIBUTION TO KNOWLEDGE

The major contributions of this study are as follows:

i. It provides the first baseline dataset on natural radioactivity levels and radiological hazard indices for soils within the Federal College of Education (Technical), Gusau, Zamfara State, Nigeria.

ii. It expands the existing database of environmental radioactivity measurements in northwestern Nigeria, a region where radiological information remains relatively scarce.

iii. It demonstrates that despite the mining-influenced nature of Zamfara State, radionuclide concentrations and associated radiological risks within the study area remain below internationally recommended limits.

iv. It establishes reference values that can be used for future environmental monitoring, trend analysis, and impact assessment associated with mining, urbanization, and land-use changes.
v. It provides scientific evidence supporting the radiological safety of educational and residential activities within the campus environment.

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