Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: https://atbuscienceforum.com.ng/index.php/jpas
https://doi.org/10.70882/smgz7975

GIS-Based Spatial Assessment of Outdoor Background Ionizing Radiation and Associated Radiological Risk Indices in Major Markets of Dutsin-Ma, Katsina State, Nigeria

Emmanuel Joseph, Hezekiah Bawa
Department of Physics, Federal University Dutsin-Ma, Katsina State, Nigeria.

Abstract
Terrestrial background ionizing radiation constitutes a continuous source of human exposure, and elevated levels may increase long-term radiological risks in densely occupied environments. This study applied Geographic Information System (GIS) techniques to evaluate terrestrial background radiation and associated radiological risks in Wednesday and Old Markets, Dutsin-Ma, Katsina State, Nigeria, where population density and commercial activities are increasing. In-situ measurements were obtained at 20 systematically selected locations using a calibrated Bosean FS-5000 Geiger–Müller survey meter, while geographic coordinates were recorded with a handheld GPS receiver. Mean outdoor dose rates ranged from 0.09–0.19 μSv h^{-1}, with average values of 0.147, 0.163, and 0.155 μSv h^{-1} for Wednesday Market, Old Market, and both markets combined, respectively. Corresponding absorbed dose rates ranged from 86.7–193.3 nGy h^{-1} and exceeded the worldwide outdoor terrestrial gamma-radiation average of 59 nGy h^{-1} at all sampled locations. These elevated levels may partly reflect the regional Precambrian Basement Complex geology. The annual effective dose equivalent ranged from 0.106–0.237 mSv y^{-1}, with an overall mean of 0.190 mSv y^{-1}. Excess lifetime cancer risk varied from 0.372–0.830 × 10^{-3} and averaged 0.666 × 10^{-3}, exceeding the commonly adopted worldwide reference value of 0.29 × 10^{-3}. GIS-based interpolation delineated localized radiation and cancer-risk hotspots within both markets. Estimated adult organ doses were highest for the gonads and lowest for the liver. These findings establish baseline geospatial radiological data for Dutsin-Ma and underscore the need for periodic environmental radiation monitoring and systematic risk assessment as local population density and commercial activities continue to increase.

Keywords
Terrestrial background radiation;
GIS;
Absorbed dose rate;
Annual effective dose;
Excess lifetime cancer risk;
Radiological risk;
Dutsin-Ma.

Corresponding Author: Emmanuel Joseph., Department of Physics, Federal University Dutsin-Ma, Katsina State, Nigeria.
Email: ejoseph@fudutsinma.edu.ng

1. Introduction

Since the formation of the Earth approximately 4.5 billion years ago, humans have lived in an environment containing naturally occurring radioactive materials. Primordial radionuclides that originated in the early universe persist today because of their extremely long half-lives. The principal terrestrial contributors to outdoor ionizing radiation are the uranium-238 (^{238}U) and thorium-232 (^{232}Th) decay series together with potassium-40 (^{40}K), which are distributed throughout the Earth's crust, rocks and soils (UNSCEAR, 2000; Harb et al., 2014). Cosmic rays form an additional natural component. According to the United Nations Scientific Committee on the Effects of Atomic Radiation, approximately 85 % of the average annual radiation dose received by the global population arises from natural sources (UNSCEAR, 2000). Although these background levels are generally low, prolonged exposure can produce stochastic health effects, including an elevated lifetime risk of cancer and potential genetic damage (ICRP, 2007; Ugbede et al., 2020).

International organisations such as UNSCEAR, the International Commission on Radiological Protection (ICRP), the World Health Organization (WHO) and the International Atomic Energy Agency (IAEA) have established dose limits and radiation-protection standards for both the general public and occupationally exposed individuals. The recommended effective dose limit for members of the public is 1 mSv y^{-1} (ICRP, 2007). When ambient radiation levels persistently exceed recommended values, the cumulative absorbed dose may pose measurable risks to human health. Systematic quantification of outdoor dose rates is therefore essential for establishing radiological baselines, identifying elevated-exposure zones and supporting evidence-based public-health decision-making (Agbalagba & Uzochukwu, 2021).

The intensity of terrestrial gamma radiation varies spatially according to local geology, soil type and geochemical composition, primarily because rocks and soils contain varying concentrations of naturally occurring radionuclides such as ^{238}U, ^{232}Th and ^{40}K (UNSCEAR, 2024). Granitic and other crystalline igneous formations may contain enhanced concentrations of uranium-, thorium-, and potassium-bearing minerals, while weathering and geochemical redistribution can influence the radionuclide content of residual and ferruginous soils (UNSCEAR, 2024; Abba et al., 2021; Garba et al., 2023). In Nigeria, regional surveys have documented outdoor terrestrial gamma dose rates that often exceed the global population-weighted average of approximately 59 nGy h^{-1} (UNSCEAR, 2000).

Within Katsina State, in-situ measurements across diverse geological formations and soil types have yielded a mean terrestrial gamma radiation dose rate of 116 nGy h^{-1}, a value that is nearly twice the world average, with the elevated values linked to silicified sheared rocks and lithosols/ferruginous soils (Abba et al., 2021; Garba et al., 2023). Dutsin-Ma, a rocky town in north-western Nigeria, lies within this geological setting. Previous analyses of rock samples from the area reported average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K that were generally below or comparable to world averages, with correspondingly low radiological hazard indices (Joseph et al., 2023). Nevertheless, the spatial distribution of outdoor dose rates in high-occupancy public spaces remains poorly characterised.

Major market areas constitute particularly relevant exposure environments. These locations function as focal points of daily economic and social activity where traders, buyers, porters and residents may spend many hours each day. Continuous low-level external exposure under such occupancy conditions can contribute meaningfully to individual annual effective dose, especially for occupational groups whose time spent outdoors exceeds the factors commonly assumed for the general public. In Dutsin-Ma, this relevance has intensified in recent years due to the rapid expansion of the Federal University Dutsin-Ma (FUDMA).

The growing student population has driven a corresponding increase in the town's overall population and commercial activity, resulting in higher daily footfall and prolonged occupancy in the major markets (Wednesday Market and Old Market). This demographic and economic shift elevates the potential for cumulative radiation exposure among a larger and more diverse group of people, including students, traders and local residents. Despite the recognised importance of background-radiation mapping in Nigerian urban and commercial centres (Agbalagba et al., 2020; Esi et al., 2024), focused investigations that combine high-resolution spatial data with explicit public-health risk metrics for market environments remain scarce in the north-western region, particularly under conditions of rapid population growth linked to tertiary-institution expansion.

Geographic Information Systems (GIS) offer a robust platform for the spatial analysis and visualisation of environmental radiation data. By integrating georeferenced dose-rate measurements with cartographic layers, GIS enables the identification of radiation hotspots, the generation of continuous surface maps through interpolation techniques, and the clear communication of risk patterns to regulators and the public (Esi et al., 2024; Awokoya et al., 2024). When paired with calibrated portable survey instruments and Global Positioning System (GPS) receivers, GIS-based assessments produce reproducible, location-specific datasets suitable for radiological baseline establishment and long-term monitoring.

The present study addresses this knowledge gap by conducting a GIS-based spatial assessment of terrestrial background ionizing radiation in the two principal market areas of Dutsin-Ma (Wednesday Market and Old Market), Katsina State, Nigeria. In-situ dose-rate measurements were performed with Bosean F-S 5000 Geiger-Müller radiation survey meter which is equipped with a J321 GM tube, calibrated with reference to cobalt-60 (^{60}Co), while geographic coordinates were recorded using a calibrated GPS land meter CM84 model.

The resulting data are used to map spatial variability, compute mean dose rates and ranges, and evaluate associated public-health risk indicators. The findings are intended to provide a scientifically robust baseline for radiological surveillance, inform public-health decision-making, and contribute to the national radiation-protection database for commercial environments in northern Nigeria, especially in the context of increasing market activity driven by the expanding university community.

2. Materials and Methods

2.1 Geology of the Study Area

Dutsin-Ma is located in the central part of Katsina State, north-western Nigeria, within latitudes approximately 12°27′N and longitudes 7°29′–7°30′E (Figure 1). The area forms part of the Nigerian Basement Complex, which is dominated by Precambrian crystalline rocks. The dominant lithologies include migmatite-gneiss complexes, older granites (Pan-African granite suites), schists, and subordinate quartzites. These rocks have undergone multiple phases of deformation and metamorphism, particularly during the Eburnean and Pan-African orogenies (approximately 650 ± 150 Ma). The landscape is characterised by rocky outcrops, inselbergs, and residual hills formed by differential weathering of the granitic and migmatitic basement. The soils are largely residual, derived from the weathering of these crystalline rocks, and include lithosols and ferruginous tropical soils. The underlying geology is known to influence terrestrial gamma radiation levels due to the presence of naturally occurring radionuclides in the rock-forming minerals.

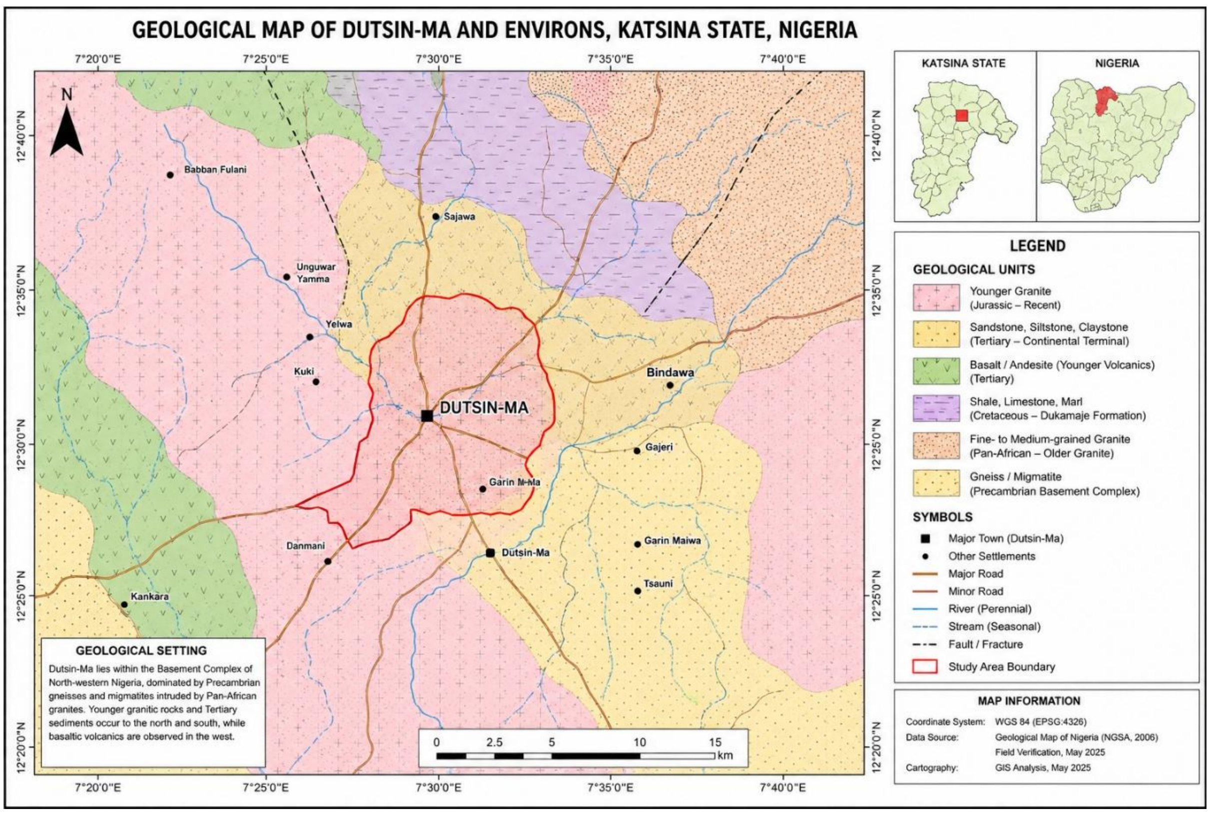

Figure 1. Geological Map of the Dutsin-Ma Study Area, Katsina State, Northwestern Nigeria

2.2 Data Collection

In-situ measurements of terrestrial background ionizing radiation dose rates were carried out in the two major market areas of Dutsin-Ma: Wednesday Market (WM) and Old Market (OM). Ten sampling points were systematically selected within each market to ensure adequate spatial coverage of the trading areas. At each sampling point, three replicate readings of ambient dose rate (in

μSv/h) were recorded at approximately 1.0 *m* above ground level using a calibrated Bosean F-S 5000 Geiger-Müller radiation survey meter. The instrument is sensitive to beta, gamma, and X-ray radiation, with a dose-rate measurement range of 0.01 μSv/h to 50 mSv/h and a relative error of less than 10%. Geographic coordinates (latitude and longitude) of each sampling location were recorded using a calibrated Global Positioning System (GPS) receiver. All measurements were performed under stable weather conditions to minimise external interference. The mean of the three replicate readings at each point was computed and used for subsequent analysis and mapping.

2.3 Radiological Risk Parameters

The measured mean dose rates were used to evaluate the following radiological risk indices in accordance with standard conversion factors recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Commission on Radiological Protection (ICRP):

Equivalent Dose Rate (EDR) - The equivalent dose rate was obtained from the measured ambient dose rate values (μSv/h). The outdoor annual equivalent dose rate was calculated as (UNSCEAR, 2000; Agbalagba et al., 2016):

$$\text{EDR (mSv/y)} = \text{Dose rate } (\mu\text{Sv/h}) \times 8760 \text{ h/y} \times 0.2 \tag{1}$$

where 8760 is the number of hours in a year and 0.2 is the outdoor occupancy factor (UNSCEAR, 2000; Agbalagba et al., 2016).

Absorbed Dose Rate (D) - The absorbed dose rate in air was determined using the conversion (UNSCEAR, 2000; Ugbede & Benson, 2018):

$$D\,(\text{nGy/h}) = \text{Dose rate } (\mu\text{Sv/h}) \times 1000 \tag{2}$$

Annual Effective Dose Equivalent (AEDE) - The outdoor annual effective dose equivalent was calculated as (UNSCEAR, 2000; ICRP, 2007):

$$\text{AEDE (mSv/y)} = D\,(\text{nGy/h}) \times 8760 \text{ h/y} \times 0.2 \times 0.7 \times 10^{-6} \tag{3}$$

where 0.7 Sv/Gy is the conversion coefficient from absorbed dose in air to effective dose for adults, and 0.2 is the outdoor occupancy factor (for a market-worker exposure scenario or sensitivity analysis in this study).

Excess Lifetime Cancer Risk (ELCR) - The excess lifetime cancer risk was estimated using (ICRP, 2007; Taskin et al., 2009; Agbalagba et al., 2016):

$$\text{ELCR} = \text{AEDE (Sv/y)} \times DL \times RF \tag{4}$$

where DL is the average duration of life (70 years) and RF is the fatal cancer risk factor (0.05 Sv^{-1}) for the general population.

Effective Dose Rate to Organs (D_{organ}) - The effective dose delivered to specific organs and tissues was calculated as (ICRP, 2007; Agbalagba et al., 2016; Esi et al., 2024):

$$D_{\text{organ}}\,(\text{mSv/y}) = \text{AEDE} \times F \tag{5}$$

where F is the organ conversion factor. Typical values of Fused include 0.82 (gonads/testes), 0.64 (liver), 0.60 (bone marrow), 0.46 (kidney), and 0.32 (lungs), following ICRP recommendations (ICRP, 2007; Agbalagba et al., 2016; Esi et al., 2024). These organ-specific doses provide insight into the differential radiosensitivity of body tissues under outdoor exposure conditions in the market environments.

3. Results and Discussion

The results obtained from the assessment of terrestrial background ionizing radiation in Wednesday Market and Old Market, Dutsin-Ma, were further evaluated graphically and spatially to facilitate comparison with established radiological reference levels and to demonstrate spatial variations in radiation exposure. The graphical and GIS-based results are presented in Figures 2–6.

3.1 Terrestrial Background Ionizing Radiation Dose Rates

The measured outdoor ambient dose rates in the two major markets of Dutsin-Ma are summarised in Table 1. In Wednesday Market (WM), the mean dose rates ranged from 0.09 μSv/h (WM10) to 0.19 μSv/h (WM5 and WM9), with an overall market mean of 0.147 μSv/h. In Old Market (OM), the values ranged from 0.13 μSv/h (OM3 and OM10) to 0.19 μSv/h (OM1 and OM2), yielding a higher overall mean of 0.163 μSv/h. The grand mean dose rate across all 20 sampling points was 0.155 μSv/h.

Figure 2 presents a comparative bar chart of the mean terrestrial background radiation dose rates measured at the ten sampling locations in Wednesday Market (WM1–WM10) and the ten locations in Old Market (OM1–OM10). The figure clearly illustrates the variation in mean dose rates across individual sites, with values ranging from 0.09 μSv/h (WM10) to 0.19 μSv/h (WM5, WM9, OM1 and OM2). Error bars represent 95% confidence intervals derived from the reported ranges of the triplicate readings, indicating generally low intra-site variability and stable measurement conditions. The side-by-side display of the two markets facilitates rapid visual comparison of radiation levels and highlights the slightly higher overall dose rates recorded in Old Market relative to Wednesday Market.

The observed dose rates are consistent with the elevated terrestrial gamma radiation levels previously reported for Katsina State, where mean terrestrial gamma radiation dose (TGRD) rates of approximately 116 nGy/h (nearly twice the world average of 59 nGy/h) have been linked to the dominant basement complex geology comprising migmatite-gneiss, older granites and associated soil types (Abba et al., 2021; Garba et al., 2023).

Within Dutsin-Ma itself, earlier assessments of ambient radiation on the Federal University Dutsin-Ma (FUDMA) campuses and of rock samples from the locality have similarly indicated the influence of the local crystalline basement on outdoor dose rates (Tikyaa et al., 2023; Joseph et al., 2023; Namadi et al., 2025). The slightly higher average recorded in Old Market compared with Wednesday Market may reflect differences in the age of market structures, soil disturbance, density of permanent stalls, or the presence of construction materials containing naturally occurring radionuclides.

Comparable dose-rate elevations have been reported in other Nigerian commercial environments. Studies of major markets in Port Harcourt recorded mean exposure rates slightly above the 0.013 mR/h reference and absorbed dose rates of approximately 114–119 nGy/h, with AEDE values remaining below 1 mSv/y (Ononugbo & Anekwe, 2020). Similar patterns of elevated outdoor dose rates relative to the world average, yet AEDE values within regulatory limits, have been documented in Asaba and Agbor (Agbalagba et al., 2020), Sapele, Oghara and Koko (Esi et al., 2024), and along commercial corridors in Ogun State (Asere et al., 2021). Outside Nigeria, outdoor gamma dose rates of similar magnitude have been reported in urban settings in India (mean ≈ 124 nGy/h in Bengaluru) and in parts of Italy and Pakistan, where geological and urban factors likewise produce spatial heterogeneity (Rafique et al., 2020).

Table 1: Spatial distribution of terrestrial background ionizing radiation dose rates and associated radiological risk indices in the major market areas of Dutsin-Ma, Katsina State, Nigeria

S/N	Site	Coordinates	Mean dose rate (μSv h^{-1})	Range (μSv h^{-1})	Absorbed-dose proxy (nGy h^{-1})	AEDE (mSv y^{-1})	ELCR ($\times 10^{-3}$)
1	WM1	N 12°27.67418′ E 7°29.22858′	0.17	0.17–0.18	173.3	0.213	0.744
2	WM2	N 12°27.62172′ E 7°29.21664′	0.16	0.15–0.17	163.3	0.200	0.701
3	WM3	N 12°27.58590′ E 7°29.26878′	0.13	0.11–0.15	130.0	0.159	0.558
4	WM4	N 12°27.56610′ E 7°29.27922′	0.16	0.16–0.17	163.3	0.200	0.701
5	WM5	N 12°27.60522′ E 7°29.28084′	0.19	0.19–0.19	190.0	0.233	0.816
6	WM6	N 12°27.46811′ E 7°29.29123′	0.12	0.12–0.13	123.3	0.151	0.529
7	WM7	N 12°27.48233′ E 7°29.23412′	0.11	0.10–0.11	106.7	0.131	0.458
8	WM8	N 12°27.77121′ E 7°29.26123′	0.15	0.14–0.15	146.7	0.180	0.630
9	WM9	N 12°27.11230′ E 7°29.22138′	0.19	0.18–0.20	186.7	0.229	0.801
10	WM10	N 12°27.31023′ E 7°29.31408′	0.09	0.08–0.09	86.7	0.106	0.372
11	OM1	N 12°27.21786′ E 7°30.06714′	0.19	0.19–0.20	193.3	0.237	0.830
12	OM2	N 12°27.24120′ E 7°30.16860′	0.19	0.18–0.19	186.7	0.229	0.801
13	OM3	N 12°27.22721′ E 7°30.12718′	0.13	0.12–0.16	133.3	0.164	0.572
14	OM4	N 12°27.13778′ E 7°30.23144′	0.18	0.18–0.18	180.0	0.221	0.773
15	OM5	N 12°27.26122′ E 7°30.26612′	0.17	0.16–0.18	173.3	0.213	0.744
16	OM6	N 12°27.32731′ E 7°30.22124′	0.15	0.14–0.15	146.7	0.180	0.630
17	OM7	N 12°27.33124′ E 7°30.22124′	0.14	0.13–0.14	136.7	0.168	0.587
18	OM8	N 12°27.36216′ E 7°30.27312′	0.18	0.18–0.19	183.3	0.225	0.787
19	OM9	N 12°27.38922′ E 7°30.20347′	0.17	0.17–0.17	170.0	0.209	0.730
20	OM10	N 12°27.31287′ E 7°30.21641′	0.13	0.12–0.14	130.0	0.159	0.558

3.2 Spatial Distribution of Dose Rates

The spatial distribution of the measured terrestrial background radiation is illustrated in Figure 3 using GIS-based interpolation. The map reveals the geographical pattern of radiation intensity across Wednesday Market and Old Market and identifies localized areas of relatively elevated dose rate. These spatial variations may reflect differences in building materials, soil characteristics, commercial activities, waste accumulation, and the distribution of naturally occurring radionuclides within the market environment. The identified hotspots should therefore be interpreted as areas of comparatively higher radiation intensity rather than evidence, by themselves, of unsafe exposure. The utility of GIS for revealing such intra-site variability has been demonstrated in recent Nigerian radiometric mapping studies (Esi et al., 2024; Awokoya et al., 2024) and aligns with broader international practice in environmental radiation assessment.

3.3 Radiological Risk Indices

The calculated radiological risk parameters are summarised in Table 1. The estimated absorbed dose rates (86.7–193.3 nGy h^{-1}) were above the UNSCEAR worldwide population-weighted mean outdoor terrestrial gamma dose rate of approximately 59 nGy h^{-1}. This comparison indicates an elevated local natural background relative to the worldwide mean but does not, by itself, signify exceedance of a regulatory dose limit. This elevation may partly reflect the influence of the underlying Precambrian basement geology of the Dutsin-Ma area (Joseph et al., 2023; Abba et al., 2021). Comparable or higher mean absorbed dose rates have been reported in other parts of northern Nigeria, including Sokoto (Dange-Shuni LGA) and Kebbi State, where geological control on terrestrial gamma dose rates is similarly pronounced.

Figure 4 compares the mean absorbed dose rates with the worldwide outdoor terrestrial gamma-radiation reference level. This comparison places the measurements obtained from Dutsin-Ma within the broader global context of natural background radiation. Differences between the two markets may indicate spatial heterogeneity in terrestrial gamma radiation arising from variations in local geology, soil composition, construction materials, and other environmental characteristics.

The outdoor annual effective dose equivalent (AEDE) ranged from 0.106 mSv/y (WM10) to 0.237 mSv/y (OM1), with overall means of 0.180 mSv/y (WM), 0.200 mSv/y (OM) and 0.190 mSv/y (combined). All AEDE values remained well below the ICRP recommended public dose limit of 1 mSv/y (ICRP, 2007). Consequently, the measured radiation levels do not pose an immediate deterministic health risk to market users under normal occupancy conditions. This pattern of elevated dose rates relative to the world average yet AEDE values within the public limit, is quite consistent with findings from markets and urban centres in Port Harcourt (Ononugbo & Anekwe, 2020), Asaba/Agbor (Agbalagba et al., 2020), Enugu urban areas (Ugbede et al., 2020), and several other Nigerian localities (Ugbede & Benson, 2018; Agbalagba et al., 2016). International comparisons similarly show that many urban outdoor environments yield AEDE values of 0.10–0.25 mSv/y while remaining below the 1 mSv/y threshold.

The excess lifetime cancer risk (ELCR) ranged from 0.372×10^{-3} to 0.830×10^{-3}, with mean values of 0.631×10^{-3} (WM), 0.701×10^{-3} (OM) and 0.666×10^{-3} (overall). These figures are higher than the world average of 0.29×10^{-3} (UNSCEAR, 2000; Taskin et al., 2009), indicating a moderately elevated probabilistic risk of stochastic effects over a 70-year lifetime. Similar elevations in ELCR have been reported in other Nigerian studies conducted in areas underlain by basement complex rocks or in commercial settings (Agbalagba et al., 2016; Esi et al., 2024; Ononugbo & Anekwe, 2020). Local assessments at FUDMA campuses have also indicated elevated ELCR relative to the global average under certain exposure assumptions (Namadi et al., 2025).

Figure 5 presents the GIS-based spatial distribution of the calculated excess lifetime cancer risk across the study area relative to the adopted global average value. The map is particularly important because it integrates radiation exposure with assumptions concerning duration of exposure and lifetime risk. Areas displaying relatively elevated ELCR correspond to locations where the estimated cumulative radiological risk is comparatively higher. Nevertheless, ELCR represents a modeled long-term risk indicator and should not be interpreted as a prediction that exposed individuals will develop cancer.

3.4 Estimated Organ-Related Dose Indices

The estimated organ-related doses for adults in Wednesday Market and Old Market are presented in Figure 6. The results demonstrate variations in the estimated doses among the organs considered and between the two market environments. These differences primarily reflect the organ-specific conversion factors adopted in the dose estimation, which account for variations in radiation exposure and tissue response (ICRP, 2007).

Among the organs evaluated, the gonads received the highest estimated dose, followed by bone marrow and the whole body, whereas the liver received the lowest estimated dose. This pattern corresponds directly to the adopted organ conversion factors, with the gonads having the highest factor (0.82) and the liver the lowest (0.46). Therefore, the observed ranking should be interpreted principally as a consequence of the dose-conversion methodology rather than as direct evidence of preferential deposition of terrestrial gamma radiation in particular organs. Comparable variations in organ-dose estimates have been reported in environmental radiation studies in Nigeria (Agbalagba et al., 2020; Esi et al., 2024).

Although the estimated organ doses were relatively low and below 1 mSv y^{-1}, this comparison should be interpreted cautiously. The ICRP public dose limit of 1 mSv y^{-1} applies to effective dose from planned exposure situations and excludes natural background radiation and medical exposure (ICRP, 2007). Consequently, organ doses below this value should not be interpreted as confirming the absence of health risk or as an organ-specific safety threshold. Rather, the results indicate that the estimated organ doses from the measured terrestrial background radiation are relatively low on an annual basis. Nevertheless, because traders and other regular occupants may spend prolonged periods within these market environments, continued radiation monitoring remains appropriate, particularly at locations where elevated dose rates and excess lifetime cancer risk were identified.

3.5 Integrated Assessment and Radiological Health Significance

Taken together, Figures 2–6 provide complementary evidence concerning the magnitude, spatial distribution, radiological significance, and potential health implications of terrestrial background radiation in Wednesday and Old Markets. Figures 2 and 4 provide direct comparisons with established reference or benchmark values, whereas Figures 3 and 5 reveal the spatial distribution of radiation dose and associated ELCR. Figure 6 extends the analysis to estimated adult organ doses.

The combined graphical and spatial analyses are particularly useful because reliance on mean values alone can obscure localized variations within a study area. Consequently, the occurrence of relatively elevated values at particular sampling locations should be considered alongside the GIS-derived radiation hotspots and ELCR distribution. This integrated approach shows that this study provides a more comprehensive characterization of terrestrial background radiation exposure in the two major markets and is consistent with recent GIS-supported radiometric assessments both within Nigeria and internationally (Esi et al., 2024; Awokoya et al., 2024).

The public-health relevance of these findings is heightened by the rapid growth of Dutsin-Ma associated with the expansion of the Federal University Dutsin-Ma (FUDMA). Previous radiation surveys on the university campuses have already highlighted the importance of local geological and environmental factors (Tikyaa et al., 2023; Namadi et al., 2025). The increasing student population has intensified commercial activity and prolonged human occupancy in both Wednesday Market and Old Market. Traders, students, and residents who spend extended periods in these environments may accumulate higher cumulative doses than the general outdoor population assumed in standard occupancy factors (UNSCEAR, 2000). Although the calculated AEDE values remain within safe limits, the elevated ELCR relative to the world average warrants continued radiological surveillance, particularly as market activity continues to expand (Agbalagba & Uzochukwu, 2021; Ononugbo & Anekwe, 2020).

The results of our findings have clearly indicated that the terrestrial background ionizing radiation levels in the major markets of Dutsin-Ma are elevated above global averages due to geological factors characteristic of the north-western Nigerian basement complex, yet remain below regulatory dose limits for the public. The combination of in-situ measurements, GPS georeferencing, GIS spatial analysis, and radiological risk assessment provides a robust baseline for future environmental radiation monitoring and radiological-protection assessments in Dutsin-Ma, Katsina State, Nigeria, and contributes to the growing body of comparative data from commercial environments across Nigeria and elsewhere.

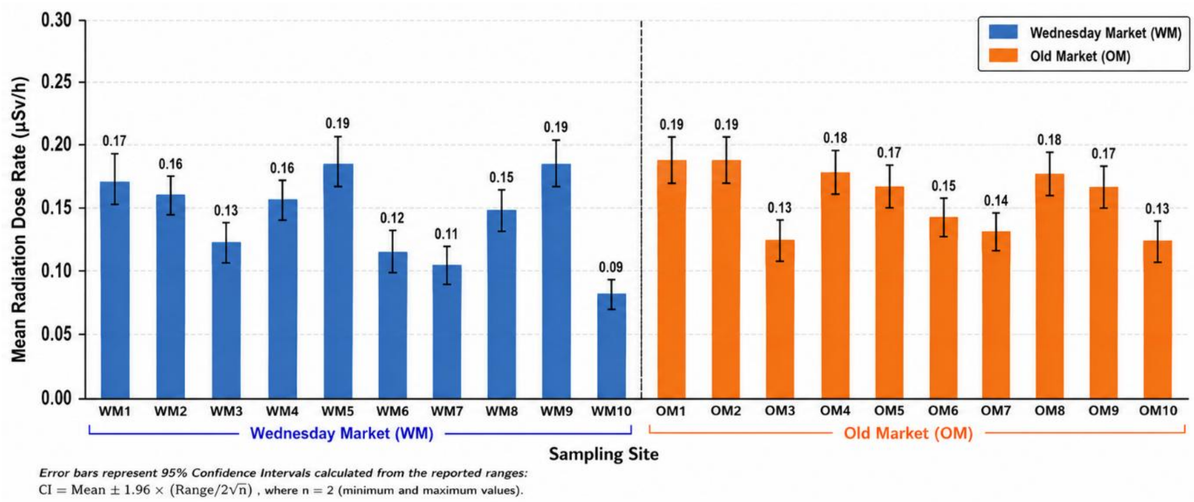

Figure 2. Spatial Variation in Mean Terrestrial Background Radiation Dose Rates across Sampling Locations in Wednesday and Old Markets, Dutsin-Ma, Katsina State, Nigeria

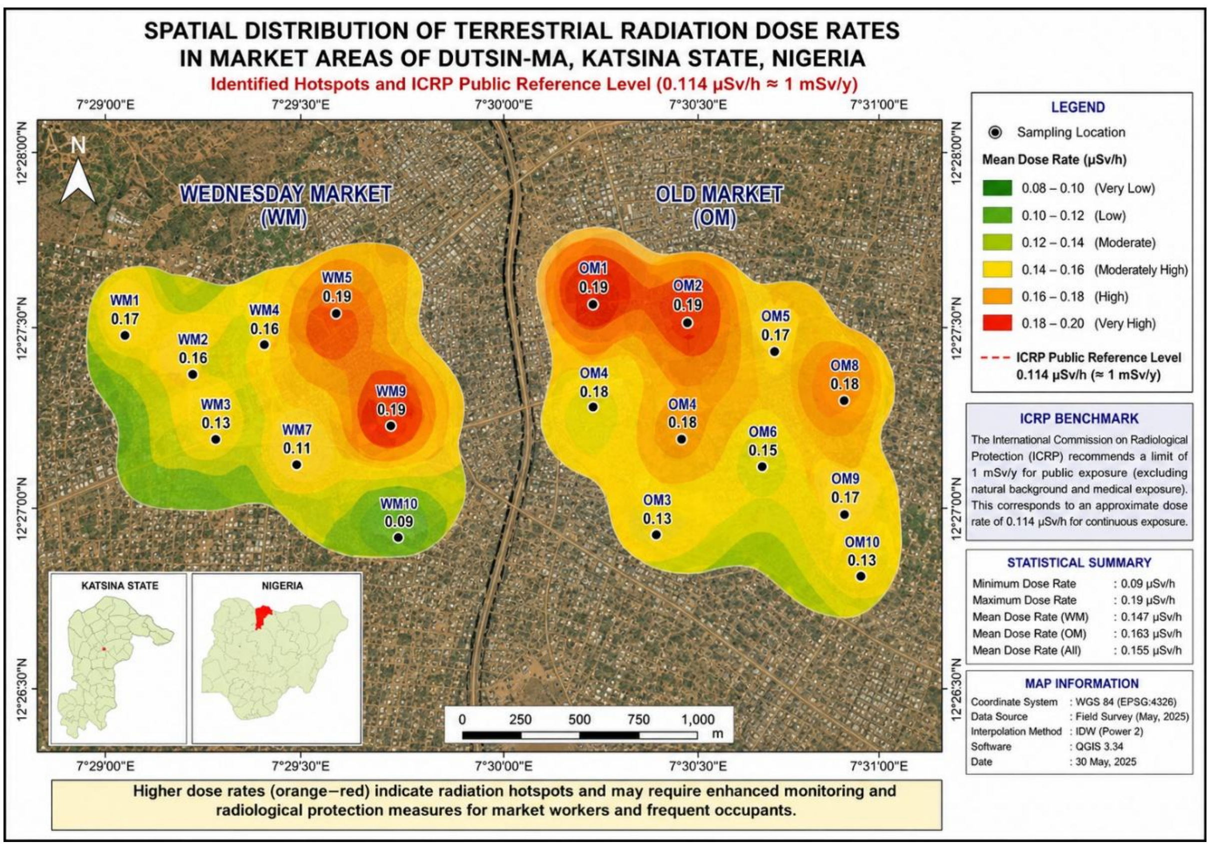

Figure 3. GIS-Based Spatial Distribution of Terrestrial Background Ionizing Radiation Dose Rates and Radiation Hotspots in Major Market Areas of Dutsin-Ma, Katsina State, Nigeria

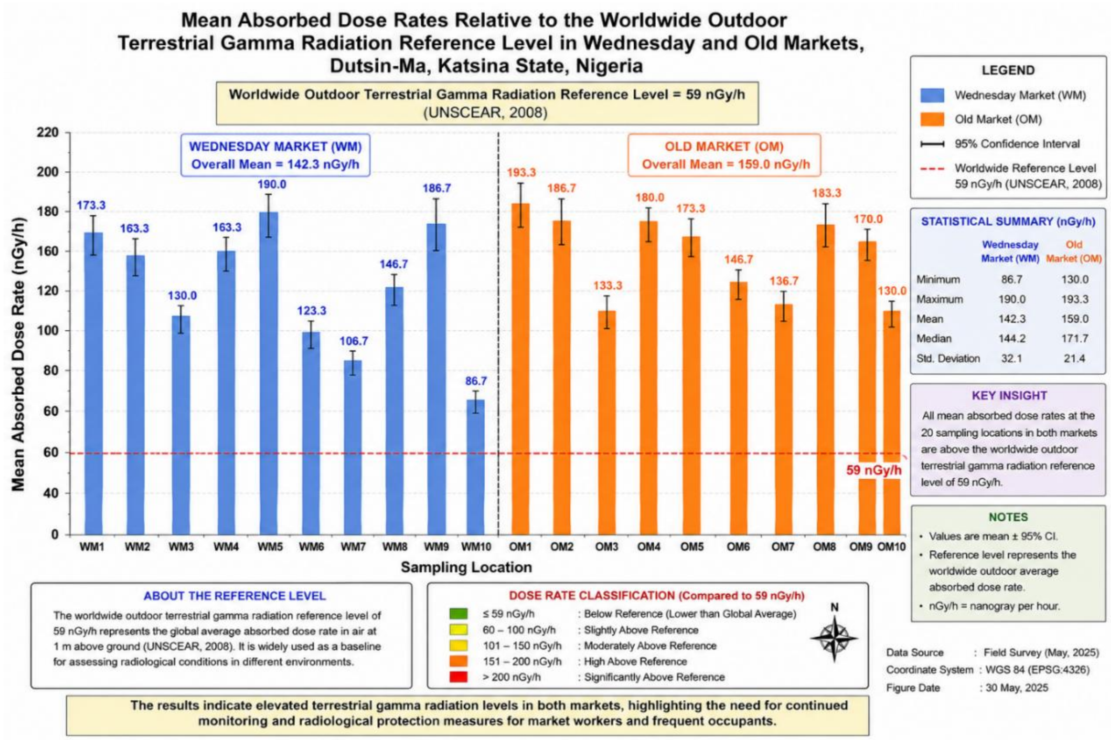

Figure 4. Comparison of Mean Absorbed Dose Rates with the Worldwide Outdoor Terrestrial Gamma Radiation Reference Level in Wednesday and Old Markets, Dutsin-Ma, Katsina State, Nigeria

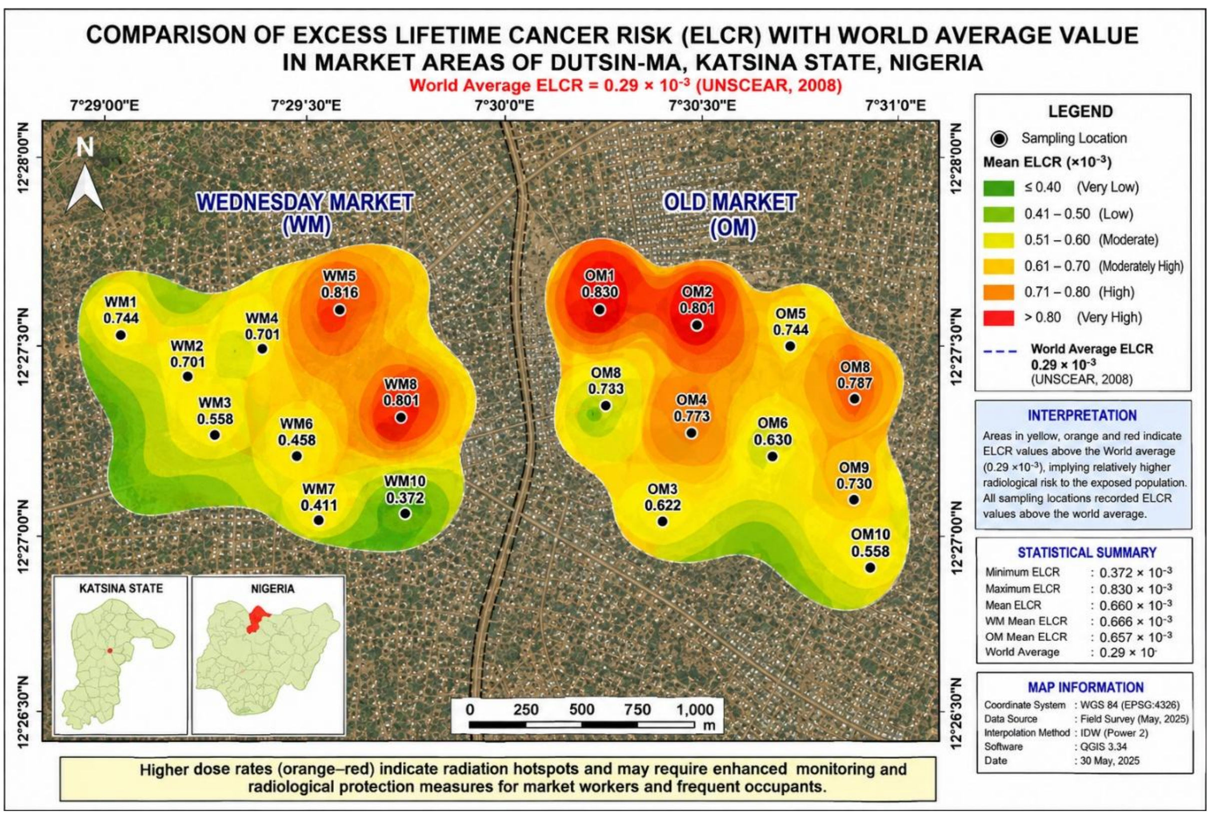

Figure 5. GIS-Based Spatial Distribution of Excess Lifetime Cancer Risk (ELCR) Relative to the Global Average in Major Market Areas of Dutsin-Ma, Katsina State, Nigeria

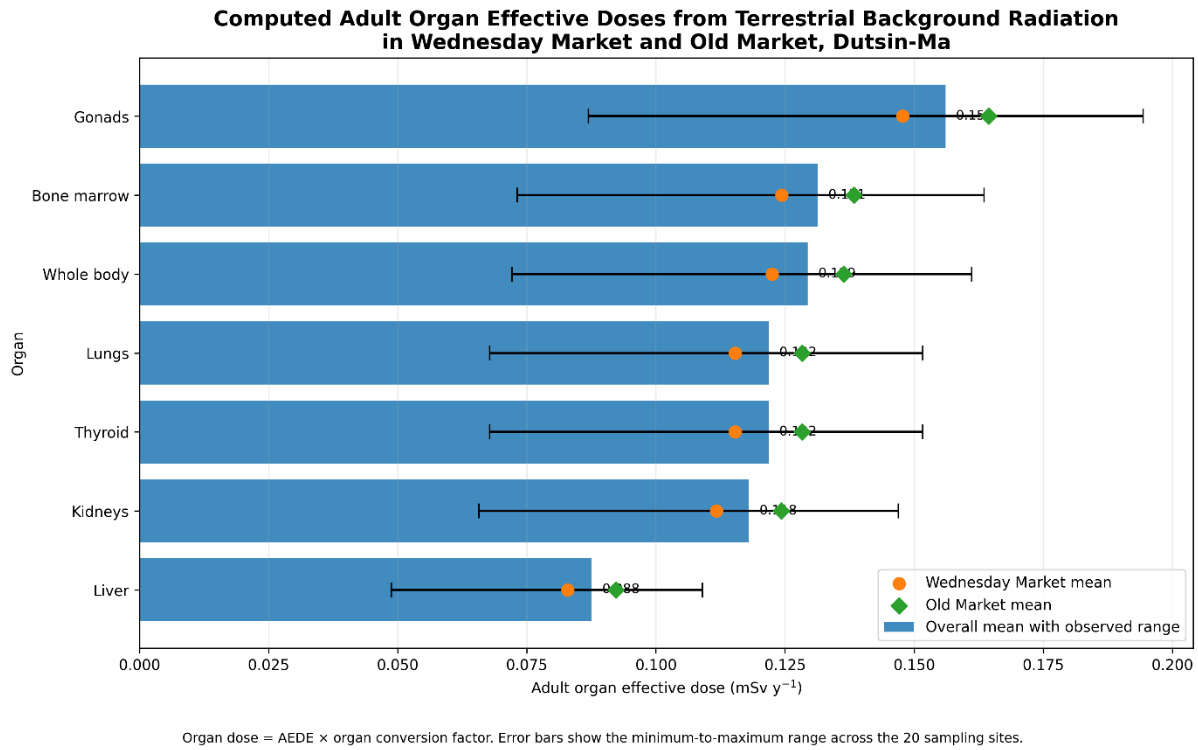

Figure 6. Computed Adult Organ Effective Doses Associated with Terrestrial Background Radiation in Wednesday Market and Old Market, Dutsin-Ma, Katsina State, Nigeria

4. Conclusion

This study has successfully conducted a GIS-based spatial assessment of terrestrial background ionizing radiation and associated public health risks in the major market areas of Dutsin-Ma, Katsina State, Nigeria. In-situ measurements revealed outdoor dose rates ranging from 0.09 to 0.19 μSv/h, with overall means of 0.147 μSv/h in Wednesday Market and 0.163 μSv/h in Old Market.

The corresponding absorbed dose rates exceeded the worldwide outdoor terrestrial gamma-radiation average of 59 nGy h^{-1}, suggesting relatively elevated natural background radiation that may be partly associated with the regional Precambrian Basement Complex geology. However, radionuclide-specific measurements would be required to establish the geological contribution conclusively.

The annual effective dose equivalents were relatively low and below 1 mSv y^{-1}, the ICRP dose limit for planned public exposure. Nevertheless, the elevated absorbed dose rates and associated lifetime risk estimates warrant continued environmental radiation monitoring, particularly considering the prolonged occupancy of traders and increasing market activity. However, excess lifetime cancer risk values were elevated above the global average of 0.29×10^{-3}, signalling a moderately increased long-term probabilistic risk. GIS mapping effectively identified spatial hotspots of relatively higher dose rate and ELCR within both markets.

Organ-specific effective doses were highest for the gonads and lowest for the lungs, all remaining within safe limits. Given the increasing population and commercial activity driven by the expansion of the Federal University Dutsin-Ma, continuous radiological monitoring of these high-occupancy environments is recommended. The data generated provide a valuable baseline for future surveillance, environmental management, and public-health decision-making in Dutsin-Ma and similar market settings across northern Nigeria.

References

Abba, H. T., Hassan, W. M. S. W., & Saleh, M. A. (2021). Statistical analysis of terrestrial gamma radiation dose rates in relation to different geological formations and soil types of Katsina State, Nigeria. *International Journal of Environmental Analytical Chemistry*, *103*(14), 3251–3263. https://doi.org/10.1080/03067319.2021.1905806

Agbalagba, E. O., Avwiri, G. O., & Chad-Umoren, Y. E. (2020). Radiometric mapping of terrestrial gamma radiation and evaluation of radiological health risk on the residents in Nigeria state commercial and capital cities. *Environmental Forensics, 22*(1–2), 75–90. https://doi.org/10.1080/15275922.2020.1836079

Agbalagba, E. O., Avwiri, G. O., & Ononugbo, C. P. (2016). Evaluation of radiation levels and associated health hazards in selected solid mineral mining sites in southeastern Nigeria. *Environmental Earth Sciences, 75*, Article 1–12.

Agbalagba, O. E., & Anekwe, L. U. (2021). Radiometric mapping of terrestrial gamma radiation and evaluation of radiological health risk on the residents in Nigeria state commercial and capital cities. Environmental Forensics, 22(1–2), 75–90. https://doi.org/10.1080/15275922.2020.1836079

Asere, A. M., Owolabi, T. O., Alafe, B. D., Alabi, O. P., & Alimi, M. B. (2021). Assessment of excess gamma dose exposure level in typical Nigeria commercial building materials distribution outlets. *Journal of the Nigerian Society of Physical Sciences, 3*, 216–223.

Awokoya, S. O., Ayanlola, P. S., Olatunji, A., Ojeniyi, F. A., Agbelusi, O. I., Orodiran, O. T., & Isola, G. A. (2024). Application of geostatistical kriging model in assessing exposure to background ionizing radiation and its radiological hazard indices. *Malaysian Journal of Science and Applied Technology, 4*(4), 464–471.

Esi, O. E., Avwiri, G. O., & Ononugbo, C. P. (2024). Forensic GIS γ-radiation mapping and associated radiological health risk assessment of the premier cities of Sapele, Oghara and Koko; South-South Nigeria. *Environmental Forensics, 26*(1), 17–34. https://doi.org/10.1080/15275922.2024.2366781

Garba, N. N., Rabi'u, N., Dewu, B. B. M., & Sadiq, U. (2023). In situ assessment of terrestrial gamma radiation dose and associated radiological hazards in Katsina State, Nigeria. *Isotopes in Environmental and Health Studies, 59*(1), 112–125. https://doi.org/10.1080/10256016.2023.2172001

Harb, S., El-Kamel, A. H., Abd El-Mageed, A. I., Abbady, A., & Rashed, W. (2014). Radioactivity levels and soil-to-plant transfer factor of natural radionuclides from protectorate area in Aswan, Egypt. World Journal of Nuclear Science and Technology, 4(1), 7–15. https://doi.org/10.4236/wjnst.2014.41002

International Commission on Radiological Protection. (2007). *The 2007 recommendations of the International Commission on Radiological Protection* (ICRP Publication 103). *Annals of the ICRP, 37*(2–4).

Joseph, E., Atsue, T., & Adams, S. (2023). Natural radionuclide distribution and analysis of associated radiological concerns in rock samples from a rocky town (Dutsin-Ma) in the North-Western region of Nigeria. *African Scientific Reports, 2*(3), Article 125. https://doi.org/10.46481/asr.2023.2.3.125

Namadi, A. Z., Agu, M. N., & Ugbe, R. U. (2025). Dosimetric evaluation of terrestrial gamma radiation and associated cancer risk in Federal University Dutsin-Ma, Nigeria. *Journal of Basics and Applied Sciences Research, 3*(2). https://doi.org/10.4314/jobasr.v3i2.3

Ononugbo, C. P., & Anekwe, U. L. (2020). Background gamma radiation in Nigerian market environment. *American Journal of Environmental Sciences, 16*(3), 48–54. https://doi.org/10.3844/ajessp.2020.48.54

Rafique, M., Tareen, A. D. K., Mir, A. A., Nadeem, M. S. A., Asim, K. M., & Kearfott, K. J. (2020). Delegated regressor, a robust approach for automated anomaly detection in the soil radon time series data. *Scientific Reports, 10*, Article 3004. https://doi.org/10.1038/s41598-020-59881-9

Taskin, H., Karavus, M., Ay, P., Topuzoglu, A., Hidiroglu, S., & Karahan, G. (2009). Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. *Journal of Environmental Radioactivity, 100*(1), 49–53. https://doi.org/10.1016/j.jenvrad.2008.10.012

Tikyaa, E. V., Atsue, T., & Adegboyega, J. (2017). Assessment of the ambient background radiation levels at the take-off campus of Federal University Dutsin-Ma, Katsina State-Nigeria. FUDMA Journal of Sciences, 1(1), 58–68. https://fjs.fudutsinma.edu.ng/index.php/fjs/issue/view/18

Ugbede, F. O., & 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, 13*(20), 265–272. https://doi.org/10.5897/IJPS2018.4763

Ugbede, F. O., Akpolile, A. F., & Mokobia, C. E. (2020). In-situ assessment of background gamma radiation dose levels in outdoor environment of Enugu urban areas, Enugu State, Nigeria. *Environmental Forensics, 23*(3–4), 334–345. https://doi.org/10.1080/15275922.2020.1850562

United Nations Scientific Committee on the Effects of Atomic Radiation. (2000). *Sources and effects of ionizing radiation* (UNSCEAR 2000 Report to the General Assembly, with scientific annexes). United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). (2024). *Sources, effects and risks of ionizing radiation: UNSCEAR 2024 Report, Volume II, Scientific Annex B—Evaluation of public exposure to ionizing radiation.* United Nations.