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Assessment of Background Ionizing Radiation Level and Radiological Mapping of Funakaye and Nafada Local Government Areas of Gombe State, North-Eastern Nigeria

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Abstract- This study assessed background ionizing radiation (BIR) levels and produced a radiological map of Funakaye and Nafada Local Government Areas (LGAs) of Gombe State, North-Eastern Nigeria. In-situ measurements of absorbed dose rate (ADR) were carried out at 240 strategically selected sampling points (10 per LGA) corresponding to the official electoral wards of each LGA using a Radiacode 110 (RC110) survey meter. Geographic coordinates of each point were recorded with a GPS-enabled device. Radiological health risk indices, annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) were computed from the measured ADR values. Spatial distribution of radiation levels was visualized using GIS-based Kriging interpolation in ArcGIS. Mean ADR values ranged from 67.11 to 144.13 nGy h^{-1} in Nafada LGA (overall mean ≈ 102.4 nGy h^{-1}) and from 66.09 to 144.65 nGy h^{-1} in Funakaye LGA (overall mean ≈ 103.0 nGy h^{-1}). Corresponding mean AEDE values were 0.33–0.71 mSv y^{-1} (Nafada) and 0.32–0.71 mSv y^{-1} (Funakaye), all below the ICRP recommended public dose limit of 1.0 mSv y^{-1}. ELCR values ranged from 1.2 × 10^{-3} to 2.7 × 10^{-3} across both LGAs. Elevated levels were recorded around Barwo/Nasarawo (Nafada) and Bage, Kupto and Ashaka (Funakaye), areas associated with mining/quarrying and intensive agriculture. The radiological map identifies these locations as relative hotspots. The study provides the first comprehensive ward-level baseline data and radiological map for Funakaye and Nafada LGAs, supporting future environmental monitoring and public-health decision-making in North-Eastern Nigeria.

Keywords— Background ionizing radiation; Radiological mapping; Absorbed dose rate; Annual effective dose; Excess lifetime cancer risk; Funakaye; Nafada; Gombe State

I. INTRODUCTION

Background ionizing radiation (BIR) is the naturally occurring ionizing radiation present in the environment. It originates primarily from three sources: cosmic rays that enter the Earth's atmosphere from outer space, terrestrial (primordial) radionuclides such as ^{40}K, ^{238}U and ^{232}Th that are present in rocks, soils and water, and internal radioactivity within the human body itself (UNSCEAR, 2008). In addition, human activities including mining, quarrying, industrial processes, medical applications and the use of phosphate fertilizers in agriculture can enhance local radiation levels by mobilizing naturally occurring radioactive materials (NORMs) to the surface (Awokoya et al., 2024; Usikalu et al., 2024).

Although low-level background radiation is a constant feature of the environment, prolonged or elevated exposure increases the probability of stochastic health effects, principally cancer and genetic mutations (Sambo et al., 2022). Consequently, the International Commission on Radiological Protection (ICRP) has established a recommended public dose limit of 1 mSv y^{-1}, while the ALARA (As Low As Reasonably Achievable) principle guides radiation-protection practice worldwide. Regular assessment of environmental radioactivity is therefore essential for establishing baselines, detecting anomalous elevations, and supporting evidence-based public-health and environmental policy.

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Globally, the average annual effective dose from natural background radiation is approximately 2.4 mSv y^{-1}, with substantial spatial variation driven by geology, altitude and anthropogenic activity (UNSCEAR, 2021). In Nigeria, numerous studies have quantified BIR levels in the South-South and South-West geopolitical zones (Agbalagba et al., 2016, 2020; Agbalagba & Okorodudu, 2025; Adeojo et al., 2023; Usikalu et al., 2024). Comparable comprehensive assessments remain scarce in North-Eastern Nigeria. Within Gombe State, limited work has been reported for selected towns (Abdulkadir et al., 2022) and for the Gombe State Polytechnic campus at Bajoga (Idris et al., 2024), but no systematic, ward-level survey covering entire Local Government Areas has been published.

Funakaye and Nafada Local Government Areas lie in the northern part of Gombe State within the Cretaceous sedimentary sequences of the Gongola Arm of the Upper Benue Trough. These geological formations contain variable concentrations of primordial radionuclides. In addition, limestone quarrying and cement production at Ashaka (Funakaye LGA) and intensive agricultural practices across both LGAs constitute potential anthropogenic sources of elevated radiation. The absence of a detailed radiological baseline for these two LGAs therefore constitutes a significant gap in environmental monitoring and public-health protection for the region.

The present study was designed to address this gap. Its aim is to assess background ionizing radiation levels across Funakaye and Nafada LGAs and to produce a radiological map of the study area. The specific objectives are: (i) to measure absorbed dose rates at representative locations corresponding to the official electoral wards of each LGA; (ii) to evaluate the associated radiological health risk indices (annual effective dose equivalent and excess lifetime cancer risk); (iii) to generate a GIS-based radiological map that visualizes the spatial distribution of radiation and identifies relative hotspots; and (iv) to provide a scientifically robust baseline dataset that can support future monitoring programmes and policy decisions in North-Eastern Nigeria.

II. MATERIALS AND METHODS

1. Study Area

Funakaye and Nafada Local Government Areas are located in the northern part of Gombe State, North-Eastern Nigeria, within the Sudan Savannah vegetation zone of the Upper Benue Trough geological province. Funakaye LGA has its headquarters at Bajoga (approximately 10°51′N, 11°26′E) and covers an area of about 1,415 km^2. Nafada LGA has its headquarters at Nafada town (approximately 11°06′N, 11°20′E) and spans approximately 1,586 km^2. The two LGAs are contiguous and share similar climatic, topographic and geological characteristics.

The 2006 census recorded populations of 236,087 (Funakaye) and 138,185 (Nafada). The population is predominantly Fulani, with significant Hausa, Bolewa and other ethnic groups. The main economic activities are subsistence and smallholder agriculture, livestock rearing and, in Funakaye, limestone quarrying and cement production at Ashaka.

The climate is hot semi-arid (BSh). Mean annual rainfall is approximately 850 mm, concentrated between April and October.

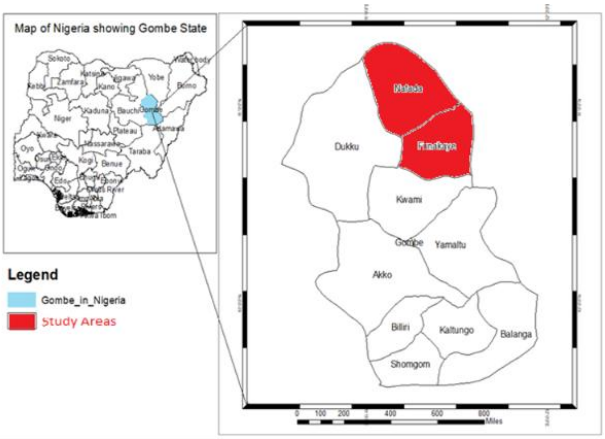


Figure 1: Map showing the study area.

The dry season (November–March) is characterized by harmattan winds. The underlying geology consists of Cretaceous sedimentary sequences of the Gongola Arm of the Upper Benue Trough, which contain variable concentrations of the primordial

radionuclides ^{40}K, ^{238}U and ^{232}Th. Limestone, gypsum and other mineral deposits create the potential for elevated levels of naturally occurring radioactive materials (NORM).

2. Sampling Design and Measurement Points

A purposive sampling design was adopted. Ten to twenty representative measurement locations were selected within each of the ten official electoral wards of Nafada LGA and each of the ten official electoral wards of Funakaye LGA, giving a total of 240 sampling points. The values of each ward were calculated. Ward boundaries and names were obtained from Independent National Electoral Commission (INEC) records. The geographic coordinates of the primary settlement associated with each ward were used as the measurement reference point (Tables 1 and 2).

At each point, the survey meter was held 1 m above ground level. Multiple readings were taken and averaged to obtain the mean absorbed dose rate for that location. Geographic coordinates were recorded simultaneously using a GPS-enabled device linked to the survey meter via Bluetooth.

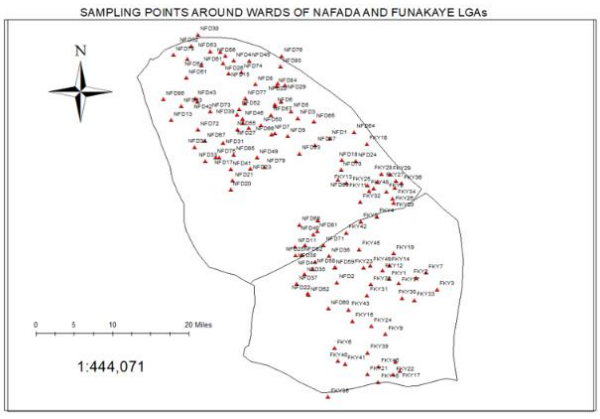


Fig 2 Map showing sampling points

3. Instrumentation

Background ionizing radiation was measured in situ with a Radiacode 110 (RC110) radiation survey meter. The instrument is equipped with a Geiger-Müller detector and provides real-time dose-rate readings. A smartphone with GPS capability, connected to the RC110 via Bluetooth, was used to log geographic coordinates (latitude and longitude) at each measurement point. Field notes were recorded in a standard notebook. All instruments were checked for proper function before and after each field campaign.

4. Calculation of Radiological Health Indices

Three radiological quantities were evaluated following standard protocols (UNSCEAR, 2000; Abdulkadir et al., 2022):

- Absorbed dose rate (ADR) in nGy h^{-1} was obtained directly from the survey-meter readings (or converted from exposure rate using the factor 8.7 nGy μR^{-1} where necessary).
- Annual effective dose equivalent (AEDE) in mSv y^{-1} was calculated as:
- AEDE (mSv y^{-1}) = ADR (nGy h^{-1}) × 8760 h × 0.7 Sv Gy^{-1} × 0.8 × 10^{-6}
- where 0.8 is the outdoor occupancy factor and 0.7 Sv Gy^{-1} is the conversion coefficient from absorbed dose in air to effective dose.
- Excess lifetime cancer risk (ELCR) was estimated as:

$$ELCR = AEDE \times DL \times RF$$

- where DL is the average lifespan (70 years) and RF is the risk factor (0.05 Sv^{-1} or 5.5 × 10^{-2} Sv^{-1} as applied in the present calculations following ICRP recommendations).

5. Spatial Analysis and Radiological Mapping

Geographic coordinates and corresponding ADR values were imported into ArcGIS (Spatial Analyst extension). Ordinary Kriging interpolation was applied to generate continuous surface maps of absorbed dose rate across the two LGAs. The resulting radiological map was used to visualize spatial patterns and to identify relative hotspots of elevated background radiation.

III. RESULTS

1. Absorbed Dose Rate, AEDE and ELCR in Nafada LGA

Table 1 presents the mean absorbed dose rate (ADR), annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) for the ten wards of Nafada LGA. ADR values ranged from 67.11 nGy h^{-1} (Nafada East) to 144.13 nGy h^{-1} (Barwo/Nasarawo). The overall mean ADR for Nafada LGA was

approximately 102.4 nGy h^{-1}. Corresponding AEDE values ranged from 0.329 mSv y^{-1} to 0.707 mSv y^{-1} (mean ≈ 0.50 mSv y^{-1}). ELCR values ranged from 1.3 × 10^{-3} to 2.7 × 10^{-3}.

Table 1. Mean absorbed dose rate (ADR), annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) for wards in Nafada LGA

S/N	WARD	WARD ID	ADR mean (nGy h^{-1})	AEDE mean (mSv y^{-1})	ELCR mean (×10^{-3})
1	Barwo / Nasarawo	NFD1	144.13	0.707	2.7
2	Barwo Winde	NFD2	115.03	0.564	2.2
3	Birin Bolewa	NFD3	81.93	0.402	1.5
4	Birin Fulani East	NFD4	101.62	0.499	1.9
5	Birin Fulani West	NFD5	97.02	0.476	1.8
6	Gudukku	NFD6	124.23	0.609	2.3
7	Jigawa	NFD7	91.53	0.449	1.7
8	Nafada Central	NFD8	111.25	0.546	2.1
9	Nafada East	NFD9	67.11	0.329	1.3
10	Nafada West	NFD10	90.53	0.444	1.7

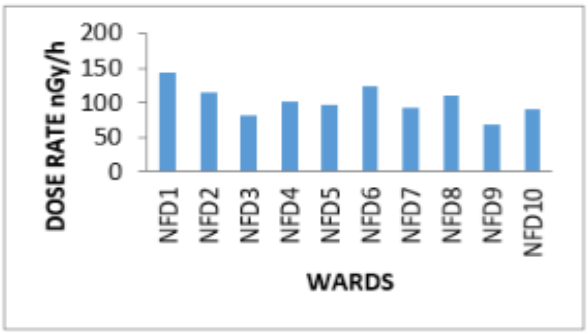


Fig 3: Chart of Absorbed dose against the location of Nafada LGA

The highest values in Nafada were recorded at Barwo/Nasarawo (NFD1) and Gudukku (NFD6). The lowest values occurred at Nafada East (NFD9). Fig 3.

2. Absorbed Dose Rate, AEDE and ELCR in Funakaye LGA

Table 2 presents the corresponding results for Funakaye LGA. ADR ranged from 66.09 nGy h^{-1} (Bodor/Tilde) to 144.65 nGy h^{-1} (Bage). The overall mean ADR was approximately 103.0 nGy h^{-1}. AEDE values ranged from 0.324 mSv y^{-1} to 0.706 mSv y^{-1} (mean ≈ 0.50 mSv y^{-1}). ELCR values ranged from 1.2 × 10^{-3} to 2.7 × 10^{-3}.

Table 2. Mean absorbed dose rate (ADR), annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) for wards in Funakaye LGA

S/N	WARD	WARD ID	ADR mean (nGy h^{-1})	AEDE mean (mSv y^{-1})	ELCR mean (×10^{-3})
1	Ashaka / Magaba	FKY1	119.45	0.584	2.2
2	Bage	FKY2	144.65	0.706	2.7
3	Bajoga West	FKY3	67.21	0.329	1.2
4	Bajoga East	FKY4	81.78	0.397	1.5
5	Bodor / Tilde	FKY5	66.09	0.324	1.2
6	Jillahi	FKY6	130.44	0.638	2.4
7	Kupto	FKY7	143.76	0.702	2.7
8	Ribadu	FKY8	82.09	0.402	1.5
9	Tongo	FKY9	127.56	0.623	2.3
10	Wawa	FKY10	67.12	0.329	1.2

In Funakaye, the highest ADR values were observed at Bage (FKY2), Kupto (FKY7) and Ashaka/Magaba (FKY1). The lowest values were recorded at Bodor/Tilde (FKY5), Bajoga West (FKY3) and Wawa (FKY10). Fig 4

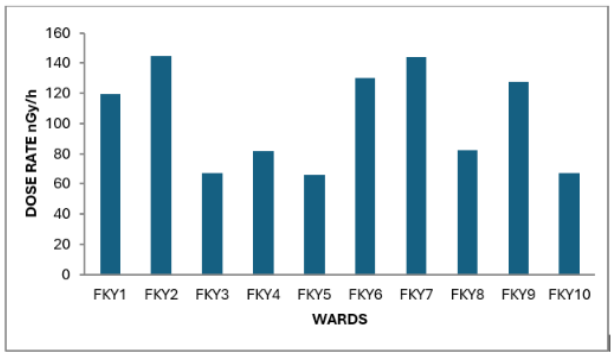


Fig 3: Chart of Absorbed dose against the location of Funakaye LGA

3. Spatial Distribution and Radiological Mapping

The Kriging-interpolated radiological map of the combined study area reveals clear spatial heterogeneity. Relative hotspots of elevated absorbed dose rate are concentrated around Barwo/Nasarawo and Gudukku in Nafada LGA and around Bage, Kupto, Jillahi, Tongo and Ashaka in Funakaye LGA. Lower dose rates are generally associated with the more central and southern portions of both LGAs (Nafada East, Bajoga West, Bodor/Tilde and Wawa). The map provides a visual baseline for identifying priority locations for further detailed investigation.

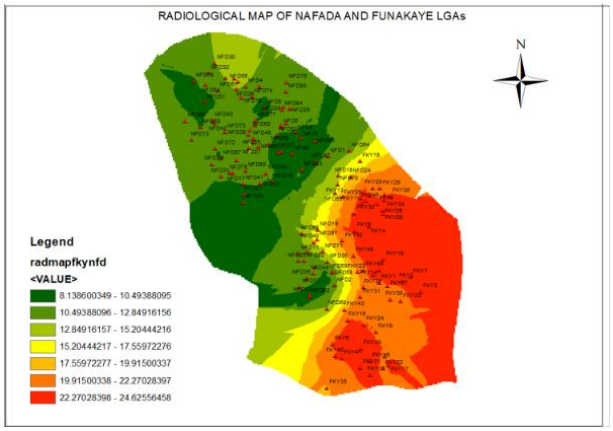


Fig 5: Radiological map of Nafada and Funakaye LGAs

IV. DISCUSSION

The mean absorbed dose rates obtained in both Nafada (≈ 102 nGy h^{-1}) and Funakaye (≈ 103 nGy h^{-1}) LGAs are higher than the world average outdoor absorbed dose rate of 59 nGy h^{-1} reported by UNSCEAR (2000, 2008). They are, however, comparable to values reported in several Nigerian studies conducted in areas with similar geological and anthropogenic characteristics.

Abdulkadir et al. (2022) reported hazard indices of background radiation in major towns of Gombe State and obtained values that are consistent in magnitude with the present findings. Idris et al. (2024) measured background radiation at Gombe State Polytechnic, Bajoga (within Funakaye LGA) and also recorded elevated levels relative to the global average, supporting the observation that parts of Funakaye exhibit higher terrestrial radiation. In the South-South and South-West regions of Nigeria, Agbalagba et al. (2016, 2020) and Agbalagba & Okorodudu (2025) documented elevated BIR around industrial and fossil-fuel facilities; the elevated values recorded around Ashaka (cement/limestone) and Bage/Kupto in the present study follow a similar pattern of anthropogenic enhancement of natural radiation.

The AEDE values for all twenty sampling points (0.32–0.71 mSv y^{-1}) remain below the ICRP recommended public dose limit of 1.0 mSv y^{-1}. Consequently, the immediate radiological risk to the general public from outdoor exposure is considered low. Nevertheless, the ELCR values (1.2–2.7 × 10^{-3}) exceed the world average of approximately 0.29 × 10^{-3} (UNSCEAR, 2000), indicating a modestly elevated lifetime cancer risk relative to the global mean. Similar exceedances of world-average ELCR have been reported by Adeojo et al. (2023) in Osun State and by Usikalu et al. (2024) in the Agbara industrial area of Ogun State.

The spatial pattern observed on the radiological map is consistent with the known geology and land-use activities of the study area. Limestone quarrying and cement production at Ashaka, together with intensive fertilizer use in agricultural wards, are plausible contributors to the higher dose rates recorded at those locations. The lower values in Nafada East, Bajoga West and Bodor/Tilde suggest relatively lower concentrations of terrestrial radionuclides or less disturbance of the natural soil profile.

Overall, the results fill an important regional data gap for North-Eastern Nigeria. Previous comprehensive BIR assessments have been concentrated in the southern and south-western geopolitical zones (Agbalagba et al., 2020; Adeojo et al., 2023; Isa et al., 2024). The present ward-level dataset and radiological map therefore constitute a useful baseline for future monitoring programmes and for environmental-health policy in Gombe State.

V. CONCLUSION AND RECOMMENDATIONS

1. Conclusion

Background ionizing radiation levels were measured across the ten official wards of Nafada LGA and the ten official wards of Funakaye LGA, Gombe State. Mean absorbed dose rates ranged from 67.11 to 144.13 nGy h^{-1} in Nafada and from 66.09 to 144.65 nGy h^{-1} in Funakaye, with overall means of approximately 102–103 nGy h^{-1}. All computed annual effective dose equivalents (0.32–0.71 mSv y^{-1}) lie below the ICRP public dose limit of 1 mSv y^{-1}, indicating that outdoor exposure does not currently pose an acute radiological hazard to the general population. However, excess lifetime cancer risk values ($1.2–2.7 \times 10^{-3}$) exceed the world average, suggesting a modestly elevated long-term risk. The GIS-based radiological map successfully delineates relative hotspots associated with mining/quarrying (Ashaka) and intensive agricultural zones (Bage, Kupto, Barwo/Nasarawo). The study provides the first systematic ward-level baseline of background radiation and a corresponding radiological map for Funakaye and Nafada LGAs, thereby contributing essential data for environmental management and public-health protection in North-Eastern Nigeria.

2. Recommendations

- Periodic monitoring of the identified hotspot wards (Barwo/Nasarawo, Gudukku, Bage, Kupto and Ashaka) should be instituted by the relevant state environmental and radiation-protection agencies.
- Detailed gamma-spectrometric analysis of soil and rock samples from the hotspot locations is recommended to quantify the specific activity concentrations of ^{40}K, ^{238}U and ^{232}Th and to confirm the contribution of NORMs.
- Public-awareness programmes on radiation safety should be conducted in communities living near limestone quarries and intensive farming areas.
- The radiological map generated in this study should be updated periodically and incorporated into land-use and environmental-impact assessment frameworks for Gombe State.
- Future studies should expand the sampling density within each ward and include indoor measurements to obtain a more complete picture of population exposure.

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