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Terrestrial gamma radiation dose (TGRD) levels in northern zone of Bauchi, Nigeria: mapping and statistical relationship between gamma dose rates and geological formations

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Abstract

This present study aims to obtain baseline data of environmental terrestrial radiation and to assess the corresponding health risk in the ambient environment in Bauchi north. The Terrestrial gamma radiation dose rates (TGRD) of study area were measured on-site using a portable Radiation alert milli roentgen (mR) survey meter, with a total of 280 measured points which covered all geological formations of the study area. The TGRD ranged from 60.90 $nGyh^{-1}$ to 313.20 $nGyh^{-1}$ with a mean value of 165.48 $nGyh^{-1}$, which is about two times higher than the world average value of 59 $nGyh^{-1}$. Geological formation (Granites) was found to have the highest mean TGRD value of 194.88 $nGyh^{-1}$. Likewise, Geological formation (Quartenary sedimentary) appeared to have the lowest mean TGRD value of 151.82 $nGyh^{-1}$. The map for the distribution and exposure rate due to TGRD for the study area was also plotted using Golden surfer 12 software. One-way ANOVA was used to investigate the variation of the significant difference between the geological formations with TGRD, which shows the influence of geological formation on the measured TGRD values of the study area. Measured data could further be used to evaluate the public radiation exposure and in formulating safety standards and radiological guidelines.

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1.0 Introduction

The radiation sources can be classified into two: Natural and artificial sources. The terrestrial radiation and cosmic rays are natural sources, while the radiation sources as a result of human activities are artificial (Saleh *et al*., 2013). The natural sources are the primary means through which humans are exposed to ionizing radiation (Faanu *et al*., 2016). The ionizing radiations emitted from radionuclides are alpha, gamma and beta particles (Khandaker *et al*., 2021). Since natural radiation is the largest contributor of external radiation dose to population, an assessment of gamma radiation from natural sources is of utmost importance (Garba *et al*., 2015).

The terrestrial gamma dose rate (TGDR) relies primarily on geological formation and soil type of a particular area, which greatly influence the dose distribution from natural terrestrial radiation (Ademola, 2008). Igneous rocks, like granite, are associated with higher radiation levels, while sedimentary rocks have lower levels (Ramli, 1997). For few phosphate rocks and shales, exception exists since they contain considerably high amount of radionuclides (Norbani *et al*., 2014). The assessment of the radiation hazard effect in the environment

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requires knowledge of the absorbed dose (Abdulkadir *et al*., 2021).

Natural gamma radiation levels, for most of Nigerian environment, has not been established; consequently, attempt to assess the health risk associated with gamma radiation has not been made (Faanu *et al*., 2016). Based on existing literature, extensive field measurement of TGRD of this kind has not been conducted and the current work forms part of the pioneer attempts relate the gamma dose rate of the Bauchi north with the areas' underlying geology. The results obtained are expected to serve as a reference-data on environmental gamma dose rates for the area which could be used for future investigation and monitoring of environmental background radiations. It could also be used to ascertain the possible changes in the levels of background gamma radiation due to anthropogenic and other human activities.

2.0 Materials and methods

2.1 The study area

Bauchi north is located in the Bauchi state in northern Nigeria, with a coordinates 12°300″N and10°450″E. It has a total land mass of 1630 km^2 and population of 1602,985 (Makama, 2007). The study area its characterise by three geological formations (Figure 1) which are; Chad-basin (Quartenary sedimentary) which is found in local government area of Gamawa, Itas-Gadau Jamaare, Katagum and Zaki. Keri-keri formation which is in Giade Local government and Intracrustals (Granite, Gneis, Migmatite) Geological formation which is found in Shira Local Government area respectively (Gerrard, 2014).

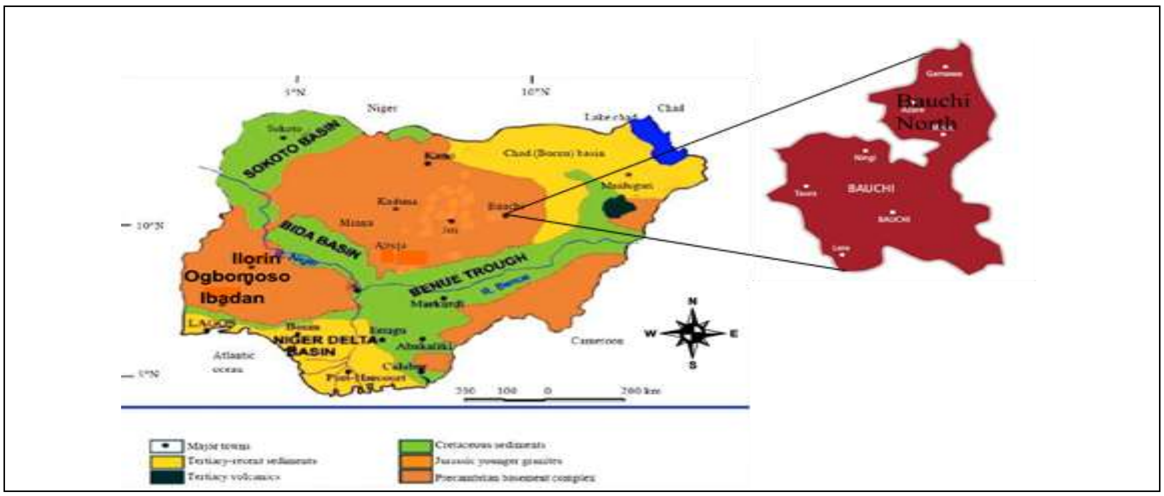

Figure 1. Generalized geology of Nigeria showing the study area (Oni and Adagunodo, 2019).

2.2 Measurement of terrestrial gamma radiation dose (TGRD) rates

A total of 280 gamma dose rate were measured on-site covering all underlying geological formations of the study area as shown in (Figure 1). Three set of readings were taken at each measuring location in order to minimize measurement error with the average of each set recorded for each location alongside its coordinates. The (TGRD) at each location was measured and recorded at a height of 1 m above the ground, using portable detector, Radiation alert (mR) meter, manufactured by Radiagem, 2000 Geiger-Mueller counter. The device is designed for a wide range of applications including on-site radiation dose measurements, in nuclear industry and for protection against radiological hazards by personnel in working environment. The longitude and latitude of each sample point were recorded using Global positioning system (GPS). The meter readings were in milli roentgen per hour (mRh^{-1}), and the mean TGRD readings were converted to nGyh^{-1} using the recommended conversion factor of 1 mR h^{-1} to 8700 nGyh^{-1} (Garba *et al*., 2021).

2.3 Geological mapping of (TGDR)

The Surfer 12 software was used for digitizing the soil and geological maps of Bauchi north, to extract the maps of the study area and select sampling points based on geological formations. The contour and 3D surface maps depicted locations that are likely prone to an increase Terrestrial gamma dose (Sanusi *et al*., 2014).

3.0 Results and Discussion

3.1 Terrestrial gamma radiation dose (TGRD)

The gamma dose rates were measured in a unit of mR h^{-1}, the readings were then converted to nGy h^{-1} using conversion factor (1 mR h^{-1} = 8.7 x 10^3 nGy h^{-1}) (Saleh *et al*., 2013). The mean values of gamma dose for seven LGAs of the study are presented in Table 1, shows the external gamma dose rates ranged from 60.90 nGyh^{-1} to 313.20 nGyh^{-1} with a mean value of 165.48 nGyh^{-1}. The lowest mean dose is found to be

139.42 nGyh^{-1} in Itas-Gadau local government. The highest value was obtained in the Shira local government.

The highest value of gamma dose was obtained in the area of Shira which was underlied by Intracrustal geological formation. This geological formation is formed from granites and magmatite. Previouly scholars like (Abba *et al*., 2017) and (Alomari *et al*., 2019) reported that highest gamma dose rate are associated with silica rich igneous rocks such as granites; these rocks are relatively rich in radioactive minerals. The Chad-basin (Quartenary sedimentary) geological formation gave the lowest gamma dose which is found in area of Itas-Gadau local government, which is in agreement with silimar studies conducted by Lee *et al*. (2009); Taskin *et al*. (2009).

Table 1: The Mean TGRD in each local Government in Northern Bauchi

Local Government	N	Gamma radiation dose rate (nGyh^{-1})				
		Mean	**Std. deviation**	**Std. error**	**Max**	**Min**
Gamawa	40	158.12	48.34	7.64	261.00	69.60
Giade	40	151.82	44.89	7.45	278.40	95.70
Itas-Gadau	40	139.42	55.64	8.79	243.60	69.60
Jamaare	40	172.60	61.34	9.70	269.70	78.20
Katagum	40	171.17	47.71	7.54	287.10	60.90
Shira	40	195.75	58.01	9.17	313.20	104.4
Zaki	40	169.87	44.32	7.00	252.30	87.00
Average value		165.48	55.23	3.29		

Figure 2 shows the mean value of gamma dose rate at seven local government in the study area, it can be inferred the elevated area was observed in Shira area with mean value of 195.75 nGyh^{-1} , which can be attributed to the mining of granite and gravel taken place in the area. The lowest value was found in the Itas-Gadau local government.

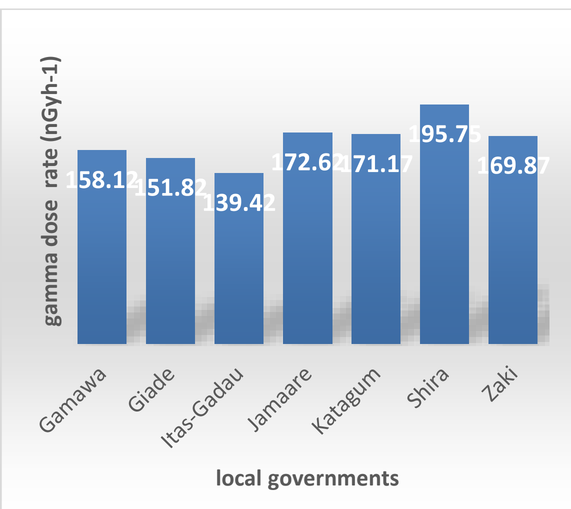

Figure 2: Mean gamma dose in different local government.

The mean of gamma radiation dose obtained from the study is about three times the average worldwide dose rate (59 nGyh^{-1}) (Radiation, 2000), which is in agreement with other studies as shown in the Table 2. The mean value of gamma dose rate obtained from this study was compared with the values obtained by other scholars of different nationalities. It can be clearly seen from Table 2, the dose rate in Malaysia is almost in agreement with study, while in Ghana is higher and in some countries is lower than the present work.

Table 2: Mean dose rate for this study compared to other countries of the world

S. No	Country	Gamma radiation dose rate (nGyh^{-1})	References
1	Ghana	741	(Faanu *et al*., 2016)
2	Brazil	125	(Freitas and Alencar, 2004)
3	Jordan	90	(Alomari *et al*., 2019)
4	Nigeria	116	(Abdulkadir *et al*., 2021)
5	Malaysia	155	(Garba *et al*., 2021)
6	Bauchi North	165.48	Present Study

3.2 Geological Mapping of Terrestrial Gamma Dose Radiation

The terrestrial gamma radiation dose (TGRD) rates within the study area were measured at various locations based on the three geological formations. Table 3 shows the results obtained in situ measurements of terrestrial gamma radiation dose

(TGRD) in 40 different locations in each of the geological formations.

Table 3: Terrestrial gamma dose rate (TGRD) in different locations geological formations.

Geological formations	N	Gamma radiation dose rate (nGyh-1)				
		Mean	**Std. deviation**	**Std. error**	**Minimum**	**Maximum**
Quaternary Sedimentary	40	151.82	48.34	7.64	69.60	261.00
Sand stone	40	158.17	47.12	7.45	60.90	278.40
Granite migmatite	40	194.88	56.45	8.93	104.40	304.50
Average		168.26	53.86	4.92	60.90	304.50

From the Table 3 above, The granite migmatite geological formation has the highest value of mean gamma dose rate, and its found around Shira community, the highest value can be attributed to the mining activities in the area (Quarry) as reported by (Al-Masri *et al*., 2006).

The data set of gamma dose measurements plus coordinates for data points were used in plotting contour map of terrestrial gamma radiation, to depict the spatial distribution of gamma dose rate as shown in Figure 3 and 4 respectively, which represents the distribution of gamma dose and exposures rates for the sdudy area. The mapping was achieved using Surfer 12, is sotfware used for mapping and spatial distibution.

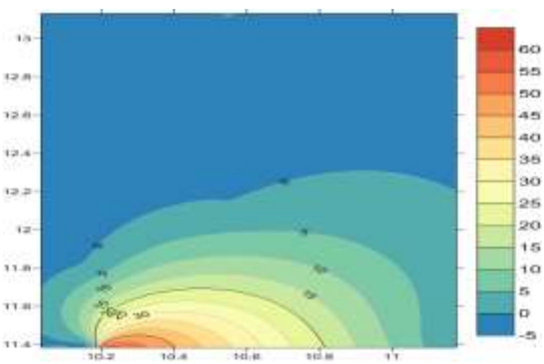

Figure 3: Contour map for (TGRD) in the study area in 1-dimension

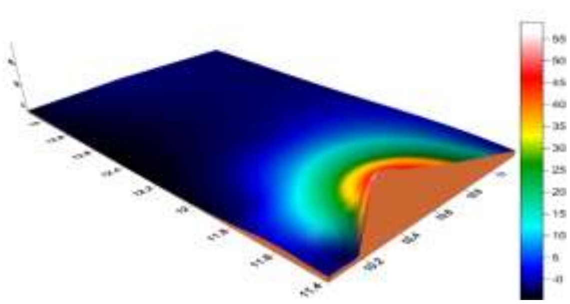

Figure 4: Contour map for (TGRD) in the study area in 3-dimension

3.3 Assessment of Radiological Health Risk Parameters

The annual effective dose received by the population due to gamma dose was determine by summing up the indoor and outdoor annual effective dose. The annual effective dose to the population was calculated using the conversion coefficient from the absorbed dose in air to the effective dose (0.7 Sv Gy^{-1}), and occupancy factor (0.2) for outdoors and (0.8) for indoors received by adults (Radiation, 2000). See equation (1), (2) and (3)

$$OAE(mSv\ y^{-1}) = Gamma\ dose\ rate(\text{nGy}h^{-1}) \times 24 \times 365 \times 0.7 \times 10^{-6} \times 0.2 \quad (1)$$

$$IAE(mSv\ y^{-1}) = Gamma\ dose\ rate(\text{nGy}h^{-1}) \times 24 \times 365 \times 0.7 \times 10^{-6} \times 0.8 \quad (2)$$

$$AE(mSv\ y^{-1}) = OAE + IAE \quad (3)$$

Where OAE is outdoor effective dose equivalent, IAE is the indoor annual effective dose equivalent and AE is the mean total annual effective dose equivalent.

The OAE and IAE were obtained to be 0.203 $mSv\ y^{-1}$ and 0.811 $mSv\ y^{-1}$ respectively, the total annual effective dose equivalent AE due to gamma dose is found to be 1.014 $mSv\ y^{-1}$. The result is comparatively lower than the reported value of 1.64 mSv/y by (Jwanbot *et al*., 2013) and 1.50 mSv/y by (Abba *et al*., 2017), and also is lower than the worldwide average of 2.4 mSv/y (Radiation, 1988).

The life time cancer risk (R) was calculated from equation (5)

$$R = AE \times AL_t \times R_F \quad (5)$$

Where AL_t is the average life time expentancy (70 years) and R_F is the risk factor (5.5× $10^{-2}\ Sv^{-1}$). The excess lifetime cancer risk is found to be 3.9×10^{-5} Sv/y, which is higher than the worldwide average 2.99×10^{-4} Sv/y (Tzortzis *et al*., 2003).

3.4 Statistical Analysis of TGDR

Statistical package of social science (SPSS) was used for analysing and describing the measured terrestrial gamma dose rate (TGDR), also it used to determine whether there is significant difference between the measured gamma dose at each geological formation (Saleh *et al*., 2019).

The frequency distribution plot of the TGRD values are presented in Figure 5, It can be observed that, the measured TGRD data show a better fitting with the bell-shaped distribution which is an indication that the data are normally distributed (Furukawa and Shingaki, 2012).

3.5 One-way ANOVA for mean gamma dose rates

The unbalanced one-way analysis of variance (ANOVA) was used to determine whether there is significant difference between gamma dose rate at each geological formation. Tests of significance were conducted among all geological formations, using the unbalanced one-way ANOVA as shown in Table 4. The results indicated strong significant differences of TGDR due to the different geological formations.

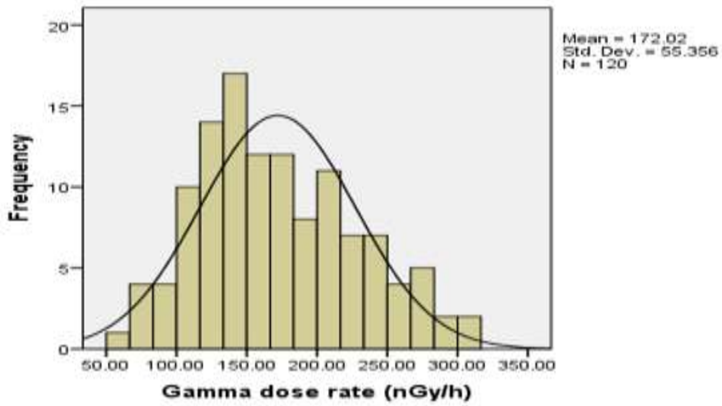

Figure 5: Frequency distribution curve for dose rates

Table 4: Analyses of Variance (ANOVA) of the mean gamma dose rates for each geological formation

Source of Variation (Geological formations)	Sum of Squares	Degree of freedom	Mean Square	F-test	Sig.
Between Groups	38283.445	2	19141.722	6.862	0.002
Within Groups	326367.042	117	2789.462		
Total	364650.487	119			

The significant value obtained as shown in table 4, is (0.002). The value is less than the critical significance level (0.05), which means rejection of null hypothesis, there is a significant difference of TGDR among the geological formations. The ANOVA result indicated strong significant differences of terrestrial gamma dose rate due to the different geological formations. The ANOVA result is in agreement with one reported by (Alomari *et al*., 2019).

4.0 Conclusion

This study provides baseline data for terrestrial gamma dose rate (TGDR) in Bauchi north. The (TGDR) were measured in on-site across various locations in the study area and its corresponding radiological health impact to the inhabitants were determined. The research findings has met the objectives of the study as follows; The measured gamma dose rate in the study area ranged from 60.90 ± 7.54 nGyh^{-1} to 313.20 ± 9.17 nGyh^{-1} with a mean value of 165.48 ± 3.29 nGyh^{-1}. The results show that mean gamma dose rate in study area is approxiamately three times higher than the worldwide average dose of (59 nGyh^{-1}). Shira LGA characterized with intrusive granitic rocks geological formations predominantly has the highest mean dose rate (293 nGy h^{-1}), while Itas- Gadau predominantly underlain by Chad- basin (Quartenary sedimentary) geological formation has the lowest mean dose rate (139.42 nGy h^{-1}), which is in agreement with the results reported by other researchers.The total annual effective dose due to gamma dose is found to be 1.014 $mSv\ y^{-1}$, which is lower than the worldwide average of 2.4 mSv/y. The Surfer 12 software was employed to generate a cotour map for TGDR in the Study area. The contour and 3D surface maps depicted the locations with higher gamma dose rate. Therefore, these locations should be properly monitored to curb the possibility of cancer risk.Measured data could further be used to evaluate the public radiation exposure and in formulating safety standards and radiological guidelines.

Declarations

Ethics approval and consent to participate

Not Applicable

Consent for publication

All authors have read and consented to the submission of the manuscript.

Availability of data and material

Not Applicable.

Competing interests

All authors declare no competing interests.

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