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Geological Formation and Soil Type Impact on Terrestrial Gamma Radiation Dose: A Statistical Approach of Dange Shuni (LGA) Sokoto State Nigeria

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Background radiation information is a viable tool for mitigating negative influence of the Terrestrial Gamma Radiation Dose rate (TGRD) on humans and their livelihood, Terrestrial gamma radiation plays significant role in background radiation which largely depends on the type of soil and fundamental geological pattern in a location. Several In situ evaluation of gamma radiation dose of the varied geological formations were performed in the area. Handheld Geiger Muller (GM) radiation survey meter (RADOS RDS-31) was used in evaluating the terrestrial gamma radiation dose while one way (ANOVA) variance analysis was employed to determine and compare the TGRD at different geological and soil formations. The external radiation dose which ranges from 15 - 270 nGy/h having an overall mean value of 91.95635 nGy/h throughout the geological formations was assessed where the mean value exceeded the global limit of 59 $nGyh^{-1}$ by 200%, furthermore, external gamma radiation dose rates ranging from 40 to 270 nGy/h with overall mean value of 120.0893 nGy/h. TGRD across the existing soil types was also evaluated. It was found out that the Dange formation has highest mean TGRD value of 161.1111 $nGyh^{-1}$. The assessment reveals significant influence of geological formation and soil type formation on the evaluated TGRD rates of Dange Formation.

Keywords: Terrestrial Gamma Radiation Dose Rate (TGRD), Dange Formation, Acrisols, Aeronosols.

1. Introduction

Natural background radiation is inevitably present in our environment. The radionuclides, which consist of the Naturally occurring radionuclides materials (NORMs), with half-lives comparable with the age of the earth (such as ^{40}K and the decay series of ^{238}U and ^{232}Th) are identified as terrestrial/primordial radionuclides, predominantly found in the earth's crust, in volcanic rocks (especially granite), hydrothermal deposits and pragma tides (Langat, 2012). Human beings are continuously exposed to gamma-radiation emitted from the NORMs within the soils and earth surface media. While some level of exposure can be permitted, excessive exposure can fatally injure human tissues and other biological systems (Ahijjo and Umar, 2015). This means that there is a quest for individual protection by determining exposure limits or regulations on the risk of eminent exposure to radiological impacts in the environment (Ahijjo and Umar, 2015). Environmental natural background information is necessary for assessing any possible changes in the level of background radiation due to local and international releases from nuclear practice. Radioactivity exposures arise in the mining sites and their neighborhood through three significant pathways which include external gamma radiation from ores, inhalation of dust containing long-lived alpha-emitting radionuclides, and inhalation of the short-lived decay progenies of some radionuclides (UNSCEAR, 2000).

The knowledge of the absorbed dose rates at the environmental level is necessary for the determination of radiation hazard effects (Langat, 2012). Specific levels of terrestrial gamma radiation dose (TGRD) from soils are related to the type of rocks or geological formations from which the soils are derived (Tzortzis *et al.,* 2003). Granitic type of igneous rocks is found to be associated with higher TGRD rates compared to low-grade metamorphic and sedimentary rocks (UNSCEAR, 2000). On the other hand, some shale and phosphate rocks are relatively rich in natural radionuclides (UNSCEAR, 1993). Such information indicates that environmental TGRD rates primarily depend on geological settings, chemical contents, and geographical conditions of the location (Garba *et al.,* 2015).

Considering the aforementioned situation, studies of natural radiation and environmental radioactivity has attracted great interest in recent time. Therefore, many countries are conducting countrywide surveys for the level of background radiation or TGRD rates in human beings by using offline or in situ gamma-ray spectrometry. Specifically, the importance of baseline TGRD data, obtained via in situ gamma-ray spectrometry, is demonstrated by different researchers (Kogbe, 1979; Al-Jundi, 2002; Aliyu and Ramli, 2015; Bello *et al.,* 2019; Karahan, 2010; Garba et al., 2021). It is worth mentioning that the offline γ-ray spectrometry equipped with an HPGe detector provides relatively more accurate data; however, it is a laborious, time-consuming, and expensive technique.

Although some studies on natural radioactivity (^{40}K) and the associated health hazards have been conducted in Dange-Shuni local government by some researchers (Ahijjo and Umar, 2015), the wide gap that still needs to bridge is to investigate the influence of geological formations and overlaying soil types of Dange-Shuni local government to the total terrestrial gamma radiation dose rates. Therefore, this study is a pioneer within the study area, aimed at finding out statistically the extent to which the geology and soil types in Dange-Shuni local government influenced TGRD rates levels.

2. Materials and Methods

2.1. Study Area

Dange–shuni local government Area (LGA) is one of the twenty-three (23) Local Governments Areas of Sokoto State. It is located between longitudes 5^{0}10’00’’ E and 5^{0}40’02’’E and latitudes 12^{0}39’00’’ N and 13^{0}0’00’’N. It shares common boundaries with Tureta LGA in the South, Bodinga LGA in the West, Rabah LGA in the East, Kware LGA in the North, and Sokoto South, and Wamakko LGAs in the northwest. It has a total land area of 1,210 km^2 and lies twenty–five kilometers to the Southeast of Sokoto, the State Capital.

2.2 Geological and Soil structure of the area

Dange–shuni is underlain by four geological formations, as shown in Figure 1, namely: Kalambaina Formation (G1), which is a Paleocene deposit (marine in nature) and belongs to the Sokoto Group. It consists of marine yellowish, clayey limestone and shale. Petrographic studies of the Kalambaina reveal that the limestone is mud supported and consists of carbonate rocks including bioclastic wackestone and Algae wackestone. The carbonate rocks in the type section have been diagenetically altered to varying degrees ranging from early to late diagenesis due to the presence of parry calcite that indicates the degree of diagenesis (Beck, 1964); Dange Formation (G2), which formed the lower unit of the Sokoto Group. The formation is exposed at the bottom of the Dange scarp in a bed as much as 18.28 meters thick near Sokoto. The formation weakens southward in outcrop but turns out to be much more prominent in boreholes down dip. Lithologically, consists of marine clay shale, typically having peeling texture and yellowish to greenish-grey color (Yunusa, 2018). The upper part is comprised of phosphatic nodes and gypsum, and the lower part is composed of calcareous with irregular limestone bands. A bright pistachio green clay, less than 1.5 meters thick, usually marks the bottom of the Dange Formation (Beck, 1964).

Rima group (G3), which is visible in the northern part of the Sokoto basin, reaches a thickness of 122 meters, and comprises white fine-grained friable sandstone containing some thin intercalated beds of carbonaceous mudstone (Yunusa, 2018). The Gundumi Formation (G4), which contains clays, sandstones, and pebbles beds, supposed to be lacustrine and fluviatile in derivation. Its maximum depth is reported to be up to 300 meters, near the Niger boundary. It is a fluviolacustrine deposit, superimposing the basement complex uncomfortably; the connection with the basement is conglomeratic (Offodile, 2000). The lithology is largely false-bedded, huge, feldspathic, clayey grits, clays, and pebbly sand, conglomeratic in places. The Gundumi Formation lies unconformable on the basement and contains basal conglomerates, and gravels with sand and variegated clays swelling upwards; the maximum depth is about 350 meters (Offodile, 2000).

Different types of soil exist in the landscape that cover the geographical area of Sokoto State. However only two quaternary types of soil exist in Dange-Shuni L.G.A (Study area) Figure 2. The two types of soil are: arenosol and acrisol soil. Arenosol**.** One of the 30 soil groups in the classification system of the Food and Agriculture Organization (FAO). Arenosols are sandy-textured soils that lack any significant soil profile development. Acrisols form on old landscapes that have an undulating topography and a humid tropical climate. They occupy just under 8 percent of the continental land surface on Earth, covering areas throughout central and northern Latin_America, Southeast Asia, and West Africa. The age, mineralogy, and extensive leaching of these soils have led to low levels of plant nutrients, excess aluminum, and high erodibility, all of which make agriculture problematic.

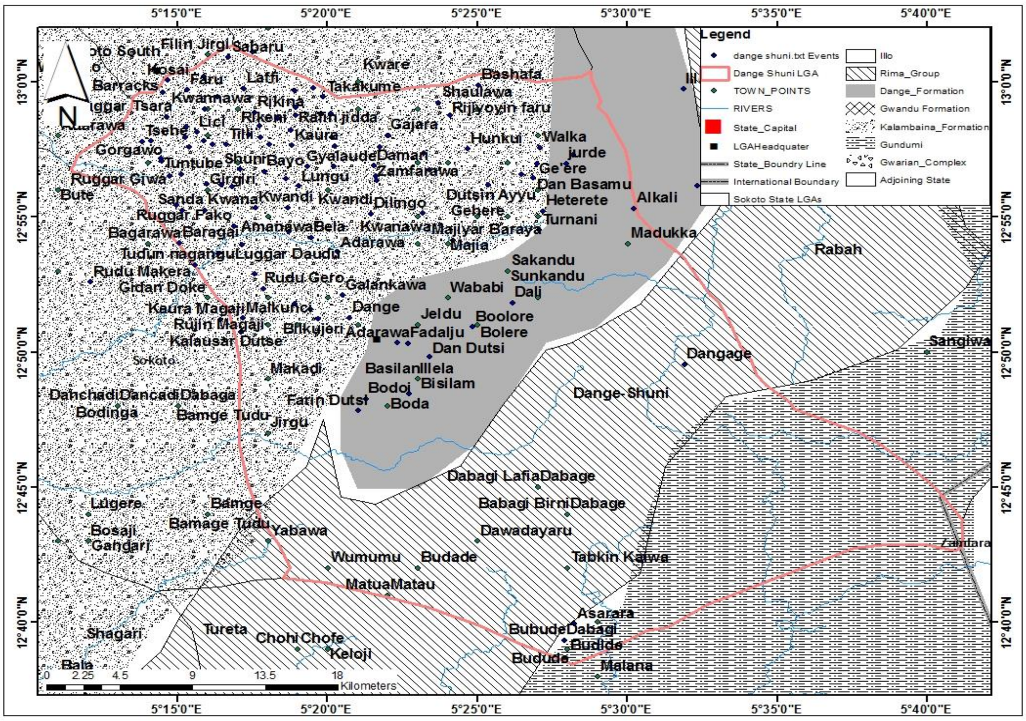

Figure 1. Geological map of the study area (Geography Department UDUS).

2.3. Description of Rados-31 (RDS-31)

The RDS-31 alarm monitor is intended for stationary or fixed installation in premises where people may be exposed to ionizing radiation. The RDS-31 advanced survey meter is the main instrument, with one internal GM counter that overs the dose rate from 0.01 mSv/h to 10 Sv/h. The system can be equipped with any GMP-12 series H*(10) probes to increase the upper dose rate level up to 10 Sv/h max. The RDS-31 meter can be configured for dual display function thus the results from both the internal and external detector are then simultaneously shown in the graphic display. The casing, box type 17/16L3, includes one relay board with potential-free changeover contacts for external alarm equipment or driving other external equipment, such as door control units, etc. External alarm equipment and indication warning lights are usually monitored on top of the casing. The system is powered by a 230VAC/12VDC power supply. The internal batteries are used for backup power supply of the RDS-31 meter in case of mains failures (the external alarm equipment is not backed up). Radiation it can detected are gamma X-rays, alpha and beta.

2.4 Measurement of terrestrial gamma radiation dose (TGRD) rate

The terrestrial gamma radiation dose (TGRD) rates within the study area were measured at various locations based on geological formations and soil types. Measurements were carried out using a handheld radiation survey meter (RADOS RDS-31), developed by Mirion Technologies. The device is designed for a wide range of applications including the insitu dose rate measurement in field conditions, in the nuclear industry, and for protection against radiological hazards by personnel in the working environment. A measurement campaign was conducted for a duration of 2 weeks, starting from 29th January 2022 to 14 February, 2022. The data was taken approximately 1m above the ground at each of the locations. The set of three readings were taken from each point with a 5-min interval and an average of these values was recorded to minimize the error. A global positioning system (GPS) was used to record the geographical coordinates of each measurement point. The meter readings were in micro-Sievert per hour, and the TGRD readings were converted to nGy/h, using the recommended conversion factor of 1 mSv/h which is equal to 1000 nGy/h. The meter has a linear response to ionizing radiation from low energy Photons to a certain photon of higher energies

3. Results and Discussion

A total of 129 TGRD rates were measured in situ, which widely covers all the geological formations and all the soil types within the study area (Figure 2). About 84 measurements were taken in Kalambaina formation, 27 measurements in Dange formation, 3 measurements in Rima group (which most of the settlements were inaccessible due to serious security situations as a result of bandit's persistent attacks in the area), and 15 measurements in Gundumi formation. Also, 105 measurements were taken in Arenosols (Ar) and 24 measurements in Acrisols (Acr) for the soil types (Tables 1 and 2).

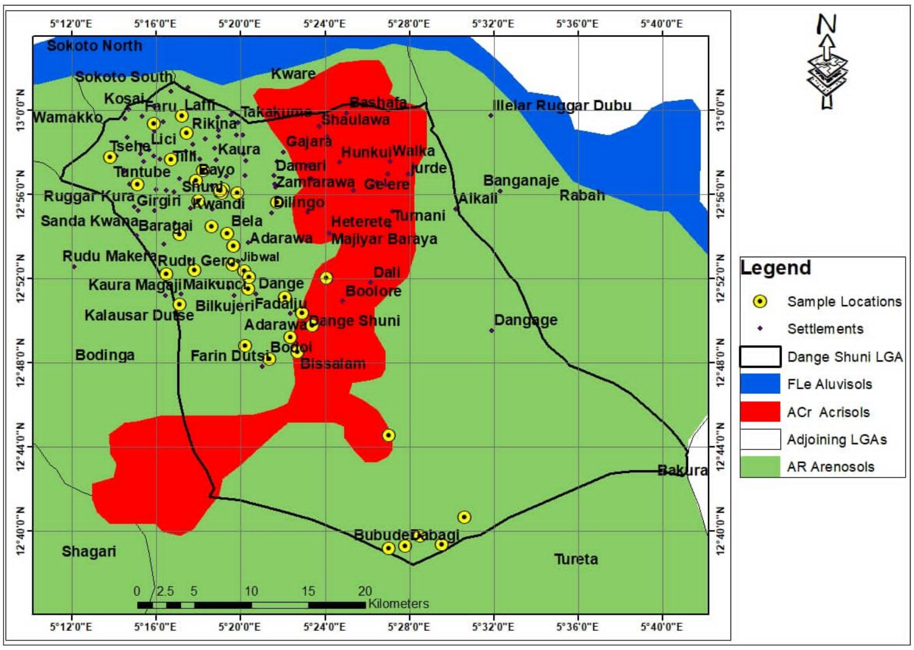

Figure 2: Soil map of the study area (Geography Department UDUS).

Table 1. Measured TGRD (nGyh^{-1}) for geological formations within the study area.

Geological formations	Latitude (°)	Longitude (°)	No of measurements (N)	Mean	Min.	Max.
G1 Kalanbaina formation	12.939	5.35	84	105.7143	60	270
G2 Dange formation	12.864	5.425	27	116.1111	110	240
G3 Rima group	12.787	5.479	03	70	70	70
G4 Gundumi formation	12.74	5.574	15	76	15	110
Total			129	91.95635	15	270

It can be observed from the Table 1 that the Measured TGRD (nGyh^{-1}) for geological formations within the study area that, G2 (Dange formation) comprising of phosphatic nodes and gypsum, having a lower part composed of calcareous with irregular limestone bands has the highest mean TGRD with a value of 161.1111 nGyh^{-1} while geological formation, G3 (Taloka formation) which comprises of white fine-grained friable sandstone was observed to have the lowest mean TGRD value of 70 nGyh^{-1}.

Table 2. Measured TGRD (nGyh^{-1}) for soil types within the study area.

Soil types	Latitude (°)	Latitude (°)	Number of measurement (N)	Mean	Min.	Max.
Arenosols	12.779	5.51	105	111.4286	40	270
Acrisols	12.88	5.43	24	128.75	70	220
Total			129	120.0893	40	270

While table 2 from Measured TGRD (nGyh^{-1}) for soil types within the study area shows Soil type Acrisols (Acr), which is classified as acidic by FAO/UNESCO, was observed to have the highest mean TGRD value of 128.75 nGyh^{-1}, while soil type Arenosols (Ar), which is derived from recent sedimentary deposition according to FAO/UNESCO, has the lowest mean TGRD with a value of 111.4286 nGyh^{-1}. The variations in the mean TGRD values could be attributed to the parent materials from which the soils were derived. Soils, derived from acidic rocks (like granite) have higher TGRD contributions compared to soils derived from other rock types (Sharma *et al.,* 2014) The results of this work were found to be in good agreement with those previously reported from different places with similar soil settings (Florou and Kritidis 1992; Garba *et al.,* 2014; Garba *et al.,* 2020).

Table 3. Descriptive statistics of the measured TGRD rates within the study area.
Descriptive data from *n* = 129 measurements in geological formations and soil types

Descriptive data from n = 129 measurements in geological formations and soil types			Statistics	Std. Error
Gamma dose rate (nGyh^{-1})		Mean	113.9535	4.67761
	95% Confidence Interval for mean	Lower bound	35.324	
		Upper bound	278.010	
	5% Trimmed mean		110.4878	
	Median		100.0000	
	Std. Deviation		53.12748	
	Minimum		40.00	
	Maximum		270.00	
	Range		230.00	
	Interquartile Range		50	
	Skewness		1.328	.213
	Kurtosis		1.119	.423

Table 3 presents the descriptive statistics of the measured TGRD within the study area which ranged between 40 and 270 nGyh^{-1} with a mean value of 113.9535 nGyh^{-1}. The mean value is about 2 times higher than the world average TGRD value of 59 nGyh^{-1} reported by UNSCEAR (UNSCEAR 1993). A 95% confidence interval for the mean, kurtosis, and skewness of the measured data are also presented. It can be observed from the table that, the measured TGRD has kurtosis and skewness values of 1.119 and 1.328, respectively. It indicates positively skewed data with a mean kurtosis value that lies within the acceptable range of moderately normal distribution criteria. The data therefore can be used to derive reliable conclusions.

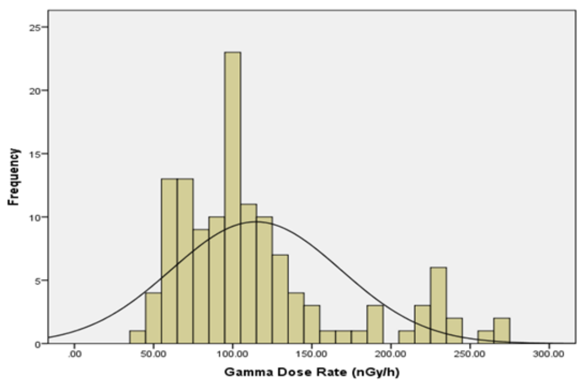

Figure 3. Frequency distribution for the measured TGRD data.

It can be observed from Figure 3 that, the measured TGRD data show a better fitting with the bell-shaped distribution which is an indication that the data are normally distributed.

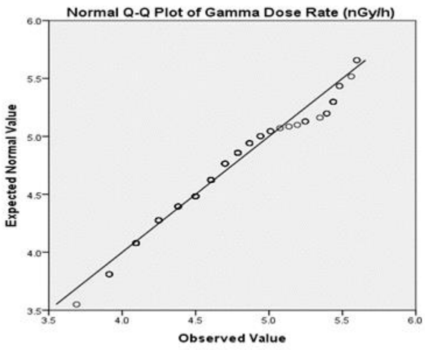

Figure 4. Normal Q-Q plot for the measured TGRD data

The Q-Q plot of Figure 4 shows that the distribution of the measured gamma dose rates approximately fits in a straight line, this shows that the data are approximately normally distributed and therefore can be used to draw reliable conclusions.

Table 4. ANOVA analysis for the measured TGRD (nGyh^{-1}) data of the geological formations and soil types.

Sampling type	Parameters	Sum of squares (SS)	Degree of freedom (df)	Mean squares, MS = SS/df	F	Sig.
Geological Formations	Between Groups	39.851	21	1.898	2.334	.003
	within Groups	86.986	107	.813		
	Total	126.837	128			
Soil Types	Between Groups	5.922	21	.282	2.217	.004
	Within Groups	13.613	107	.127		
	Total	19.535	128			

Table 4 presents a one-way analysis of variance (ANOVA) of the measured TGRD data of the geological formations and soil types. It was used to examine the TGRD values concerning geological formations and soil types. The results indicate that there exists a strongly significant difference in the TGRD values between the various geological formations and soil types.

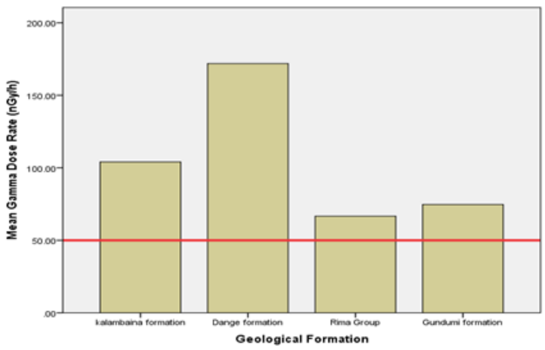

Figure 5. Measured TGRD based on geological formations of the study area.

The measured TGRD for the different geological formations within the study area is presented in Figure 5. It can be observed that the mean TGRD values for all the geological types are higher than the UNSCEAR-reported world average value of 59 nGyh⁻¹ which is seen by the reference line passing horizontally across the figure. G2 (Dange formation) comprising phosphatic nodes and gypsum, having a lower part composed of calcareous with irregular limestone bands and geological formation, G3 (Rima group) which comprises white fine-grained friable sandstone was observed to have the highest and lowest mean TGRD value of 161.1111 nGyh⁻¹ and 70 nGyh⁻¹ respectively. The higher TGRD value indicates the geological formation (G2) is acidic. This is because, acidic intrusive rocks are generally associated with a higher concentration of natural radionuclides and consequently high TGRD rates. The lower TGRD value characterizes the G3 geological formation as white fine-grained friable sandstone, and consequently lower TGRD rates (UNSCEAR 2000; Anderson & Ogilbee). These results are in agreement with those reported previously for different locations across the globe (Al-Jundi, 2002; Sharma *et al.,* 2014; Saleh et al., 2015 Sadiq and Agba, 2011; Al-Ghorabie 2005).

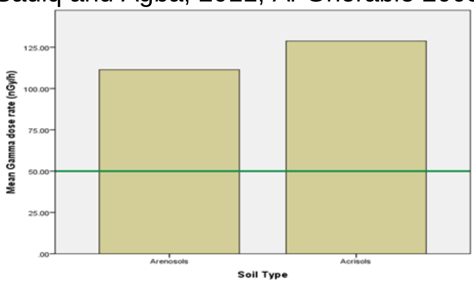

Figure 6. Measured TGRD based on soil types of the study area.

The measured TGRD values based on different soil types within the study area are presented in Figure 6. It can be observed from the figure that, all the soil types have mean TGRD values that are higher than the world's average value of 59 nGyh⁻¹ (Kogbe, 1979) as demonstrated by the horizontal line passing through the bar diagram. This figure shows that from the two soil types, ACr has the highest and Ar has the lowest mean TGRD values of 111.4286 nGyh⁻¹ and 128.75 nGyh⁻¹, respectively. These TGDR values indicate that the soil type Ar (Arenosols) is largely acidic and belongs to the soil class Alfisols according to FAO/UNESCO, and the soil type ACr (Acrisols) is formed from recently deposited sediments and classified as Ultisols according to FAO/UNESCO. The higher TGRD value from soil type (ACr) are attributed to the parent materials from which the soil was derived as soils derived from acidic intrusive rocks are characterized to have high TGRD value compared to those from the soil type (Ar) which is derived from sedimentary deposits (Kogbe, 1979; Ramli *et al.,* 2005; Dragović *et al.,* 2006).

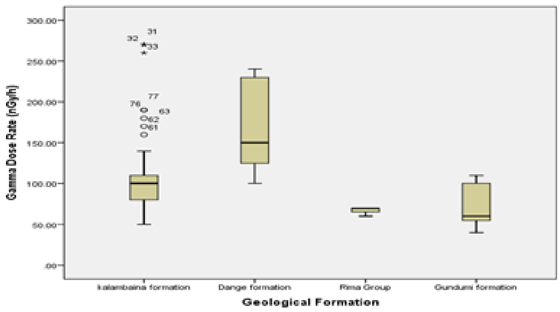

Figure 7. Box plot for the measured TGRD and geological formations.

The measured TGRD values based on different Geological Formations types within the study area are presented in Figure 7. It could be seen from the figure that, the median values for the measured TGRD of all the geological formations are less than 225 nGyh⁻¹. Outliers (0) were observed only in geological formations G1. Geological formations G2 and G3 have the highest and lowest mean TGRD values. It can also be seen that, geological formation G2 has the maximum TGRD value while G1, appeared to have the minimum TGRD values as indicated by the upper and lower whiskers, respectively.

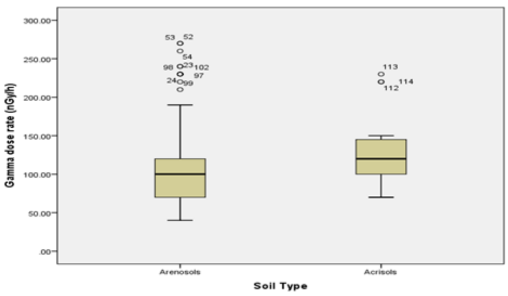

Figure 8. Box plot for measuring TGRD and soil types.

Figure 8 presents the box plot for the measured TGRD values for the soil types of the study area. It can be observed that the majority of the plots are positively skewed, which makes the data to be positively skewed. Soil types ACr and Ar appeared to have the highest and lowest TGRD values respectively. Maximum and minimum values were also observed for soil types ACr and Ar as indicated by the upper and lower whiskers, respectively. Outliers (0) were also obtained in all the soil types.

Table 5. Comparison of the mean TGRD values around the globe.

No.	Places	Dose Rate nGyh^{-1}	Reference
1	Dange Shuni Sokoto (Nigeria)	114	Present Study
2	Katsina State (Nigeria)	116	[26]
3	Zamfara State (Nigeria)	32	[12]
4	Kelatan State (Malaysia)	209	[18]
5	Kenya	440	[27]
6	Alaknanda and Ganges (India)	83	[16]
7	Tamil Nadu, India	115	[28]
8	Johor State (Malaysia)	163	[24]
9	At – Taif (Saudi Arabia)	468	[23]
10	Al- Hada (Saudi Arabia)	541	[23]
11	Ash- Shafa (Saudi Arabia)	780	[23]
12	Japan	50	[25]
13	Malaysia	92	[3]
14	Najaf and Dhi Qar (Iraq)	94	[29]
15	World	59	[3]

The comparison of the mean results of the measured TGRD within the study area with that of some other places reported in the literature presented in Table 5. It can be seen that the result, though higher than the world TGRD mean value, agreed very well with that reported in many places, especially that of Tamil Nadu, India (Furukawa and Shingaki, 2012).

This study provides the baseline data on terrestrial gamma-ray dose (TGRD) rates and their distribution over different underlying geological formations and soil types in Dange Shuni Local Government Area of Sokoto State, Nigeria. The data were obtained by in situ measurements of industrial-grade, handheld RADOS RDS-31 survey meter GM counter.

4. Conclusion

The average TGRD in the study area was found to be 113.9535 nGyh^{-1} with minimum of 40.00 nGyh^{-1} and maximum of 270.00 nGyh^{-1} which is two times higher than the World average value of 59 nGyh^{-1} reported by UNSCEAR. The result of this work shows a strong correlation between the measured gamma dose rates with underlying geological formations and soil types.

It can be observed from geological formation G2 (Dange formation) which comprising of phosphatic nodes and gypsum, having a lower part composed of calcareous with irregular limestone bands has the highest mean TGRD with a value of 161.1111 nGyh^{-1} and soil type Acrisols (ACr) were found to have the highest mean TGRD value of 128.75 nGyh^{-1}, while geological formation, G3 (Taloka formation) which comprises of white fine-grained friable sandstone was observed to have the lowest mean TGRD value of 70 nGyh^{-1} and soil type Arenosols (Ar), which is derived from recent sedimentary deposition according to FAO/UNESCO, has the lowest mean TGRD with a value of 111.4286 nGyh^{-1}.

Declaration

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Authors' Contributions

Conceptualization; Aminu Saidu; methodology; Sabiu Bala Muhammad; software; Aliyu Bala and Ibrahim Muhammad Danmallam; validation; Aminu Saidu, Sabiu Bala Muhammad; formal analysis, Junaid Aliyu, Abdullahi Musa Ibrahim, Bashir Abdullahi and Musa Adamu Wasagu; investigation; Junaid Aliyu, Abdullahi Musa Ibrahim, Bashir Abdullahi and Musa Adamu Wasagu; data curation, Aminu Saidu and Usman Abubakar; writing—original draft preparation; Junaid Aliyu, Abdullahi Musa Ibrahim, Bashir Abdullahi and Musa Adamu Wasagu; supervision; Aminu Saidu and Sabiu Bala Muhammad; project administration; Aminu Saidu and Usman Abubakar; All authors have reviewed the manuscript and agreed to the published version of the manuscript.

Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interest

The authors declare no conflict of interest.

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References

Ahijjo, Y. M., & Umar, S. (2015). A Theoretical

Model Of Health Implications Due To Potasium-40 Prevalence In Sokoto Basin: A Case Study Of Dange-Shuni. *Journal of Multidisciplinary Engineering Science Studies (JMESS)*, *1*(1), 2912–1309.

Al-Ghorabie, F. H. H. (2005). Measurements of environmental terrestrial gamma radiation dose rate in three mountainous locations in the western region of Saudi Arabia. *Environmental Research*, *98*(2), 160–166. https://doi.org/10.1016/j.envres.2004.06.004

Al-Jundi, J. (2002). Population doses from terrestrial gamma exposure in areas near to old phosphate mine, Russaifa, Jordan. *Radiation Measurements*, *35*(1), 23–28. https://doi.org/10.1016/S1350-4487(01)00261-X

Aliyu, A. S., & Ramli, A. T. (2015). The world's high background natural radiation areas (HBNRAs) revisited: A broad overview of the dosimetric, epidemiological and radiobiological issues. *Radiation Measurements*, *73*, 51–59. https://doi.org/10.1016/j.radmeas.2015.01.007

Almayahi, B., Algburi, J., Jarrah, N., Mohammed, K., Jaafar, A., & Alshabani, M. (2019). Evaluation the health impact of some heavy metals in milk from markets. *Prensa Medica Argentina*, *105*(11), 849–851. https://doi.org/10.47275/0032-745x-149

Almayahi, B., Hakeem, J. I., & Saheb, L. (2018). The impact of low-level exposure to radiation in natural ecosystems of Najaf and Dhi Qar Cities, Iraq. *Iranian Journal of Medical Physics*, *15*(1), 1–5. https://doi.org/10.22038/ijmp.2017.24540.1245

Anderson, H. R., & Ogilbee, W. (2016). *Aquifers in the Sokoto Basin, Northwestern Nigeria, With a Description of the Genercl Hydrogeology of the Region CONTRIBUTIONS TO THE HYDROLOGY OF AFRICA AND THE MEDITERRANEAN REGION*. *July*, 1–23.

Bello, S., Nasiru, R., Garba, N. N., & Adeyemo, D. J. (2019). Evaluation of the Activity Concentration of ^{40}K, ^{226}Ra and ^{232}Th in Soil and Associated Radiological Parameters of Shanono and Bagwai Artisanal Gold Mining Areas, Kano State, Nigeria. *Journal of Applied Sciences and Environmental Management*, *23*(9), 1655. https://doi.org/10.4314/jasem.v23i9.8.

Beck H. L. Spectrometric Techniques for Measuring Environmental Gamma Radiation, 1964; Vol. 150 (US Atomic Energy Commission, Division of Technical Information, New York).

Darwin, C. (1895). This is a reproduction of a library book that was digitized by Google as part of an ongoing effort to preserve the information in books and make it universally accessible. https://books.google.com. *Oxford University*, *XXX*, 60.

Dragović, S., Janković, L., Onjia, A., & Bačić, G. (2006). Distribution of primordial radionuclides in surface soils from Serbia and Montenegro. *Radiation Measurements*, *41*(5), 611–616. https://doi.org/10.1016/j.radmeas.2006.03.007

Furukawa, M., & Shingaki, R. (2012). Terrestrial Gamma Radiation Dose Rate in Japan Estimated before the 2011 Great East Japan Earthquake. *Medicine*, *1*(2), 11–16.

Garba N. N, Odoh C. M, Nasiru R, and Saleh M. A. Investigation of potential environmental radiation risks associated with the artisanal gold mining in Zamfara State, Nigeria. Environ. Earth Sci. 2021; **80**, 1 doi:10.1007/s12665-021-09367-2.

Garba, N. N., Ramli, A. T., Saleh, M. A., Sanusi, M. S., & Gabdo, H. T. (2014). Assessment of terrestrial gamma radiation dose rate (TGRD) of Kelantan State, Malaysia: Relationship between the geological formation and soil type to radiation dose rate. *Journal of Radioanalytical and Nuclear Chemistry*, *302*(1), 201–209. https://doi.org/10.1007/s10967-014-3209-8

Garba, N. N., Ramli, A. T., Saleh, M. A., Sanusi, M. S., & Gabdo, H. T. (2015). Terrestrial gamma radiation dose rates and radiological mapping of Terengganu state, Malaysia. *Journal of Radioanalytical and Nuclear Chemistry*, *303*(3), 1785–1792. https://doi.org/10.1007/s10967-014-3818-2

Garba N. N, Odoh C. M, Nasiru R, and Saleh M. A. Investigation of potential environmental radiation risks associated with the artisanal gold mining in Zamfara State, Nigeria. Environmental Earth Science, 80:76. https://doi.org/10.1007/s12665-021-09367-2

Hameed, P. S., Pillai, G. S., Satheeshkumar, G., & Mathiyarasu, R. (2014). Measurement of gamma radiation from rocks used as building material in Tiruchirappalli district, Tamil Nadu, India. *Journal of Radioanalytical and Nuclear Chemistry*, *300*(3), 1081–1088. https://doi.org/10.1007/s10967-014-3033-1

I. A., K. A., & A., Y. (2021). Cretaceous Geology, Age-Differences and Economic Geology of Gidan Alfarma Environ, Northwestern Nigeria. *Engineering and Scientific International Journal*, *8*(3), 71–77. https://doi.org/10.30726/esij/v8.i3.2021.830

15

Karahan, G. (2010). Risk assessment of Baseline outdoor gamma dose rate levels study of natural radiation sources in Bursa, Turkey. *Radiation Protection Dosimetry*, *142*(2–4), 324–331. https://doi.org/10.1093/rpd/ncq217

Kankara, I. A., Adagba, T., & Yunusa, A. (2021). Cretaceous Geology, Age-Differences and Economic Geology of Gidan Alfarma Environ, Northwestern Nigeria. *Engineering and Scientific International Journal*, *8*(3). https://doi.org/10.30726/esij/v8.i3.2021.83015

Kogbe A C. Geology of the South-Eastern (Sokoto) sector of the Lullemmeden Basin. Bulletin of Department of Geology, Ahmadu Bello University, Zaria, Nigeria.1979; 2(1):355-359.

Langat, W. (2012). Gamma Ray Spectrometric Analysis of Sediment Deposits at the Shores of Lake Nakuru, Kenya. MSc. Thesis, Department of Physics, Kenyatta University, Nairobi, Kenya.

Muktar A, Nuraddeen N.G, Rabiu N, Muneer A.S, Suleiman B, and Mayeen U.K.: 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, 2021; DOI: 10.1080/03067319.2021.1905806

Offodile, M, E. Groundwater study and development in Nigeria, 2nd Edition. Jos: Mecon Geology and Engineering, Ltd. 2000.

Ramli, A. T., Hussein, A. W. M. A., & Wood, A. K. (2005). Environmental 238U and 232Th concentration measurements in an area of high level natural background radiation at Palong, Johor, Malaysia. *Journal of Environmental Radioactivity*, *80*(3), 287–304. https://doi.org/10.1016/j.jenvrad.2004.06.008

Sadiq, A. A., & Agba, E. H. (2011). Background Radiation in Akwanga, Nigeria. *Facta Universitatis-Series: Working and Living Environmental Protection*, *8*(1), 7–11. https://www.researchgate.net/publication/236014627

Saleh, M. A., Ramli, A. T., bin Hamzah, K., Alajerami, Y., Mhareb, M. H. A., Aliyu, A. S., & Hanifah, N. Z. H. B. A. (2015). Natural environmental radioactivity and the corresponding health risk in Johor Bahru District, Johor, Malaysia. *Journal of Radioanalytical and Nuclear Chemistry*, *303*(3), 1753–1761. https://doi.org/10.1007/s10967-014-3631-y

Sharma, P., Kumar Meher, P., & Prasad Mishra, K. (2014). Terrestrial gamma radiation dose measurement and health hazard along river Alaknanda and Ganges in India. *Journal of Radiation Research and Applied Sciences*, *7*(4), 595–600. https://doi.org/10.1016/j.jrras.2014.09.011

Shimboyo, S. A., & Oyedele J. A. (2015). Determination of Natural Radioactivity in soil of Henties Bay, Namibia. *International Science and Technology Journal of Namibia,* 5: 104-110. https://hdl.handle.net/11070/1427

Tzortzis, M., Tsertos, H., Christofides, S., & Christodoulides, G. (2003). Gamma-ray measurements of naturally occurring radioactive samples from Cyprus characteristic geological rocks. *Radiation Measurements*, *37*(3), 221–229. https://doi.org/10.1016/S1350-4487(03)00028-3

UNSCEAR. (1993). Sources and effects of ionizing radiation: UNSCEAR 1993 report to the General Assembly. In *New York, NY: United Nations*.

UNSCEAR. (2000). Sources and Effects of Ionizing Radiation Volume I: source. In *United Nations Scientific Committe on the Effects of Atomic Radiation: Vol. I*.

