

Estimation of terrestrial gamma radiation (TGR) dose rates in characteristic geological formations of Jos Plateau, Nigeria

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Abstract

A study was conducted to estimate the terrestrial gamma radiation (TGR) dose rates due to the natural radionuclides ²³⁸U, ²³²Th and ⁴⁰K in the characteristic geological formations of Jos Plateau. A total of 51 surface soils samples from all the geological units were collected and measured using high-resolution gamma ray spectrometry system. From the measured activity concentrations of ²³⁸U, ²³²Th and ⁴⁰K, TGR dose rates in air outdoors 1 m above the ground surface, were estimated to be in the range of 36 nGy h⁻¹ to 456 nGy h⁻¹, depending on the geological formation, with an overall mean value of 143 nGy h⁻¹. The estimated mean value is by a factor of two higher than the world average value of 59 nGy h⁻¹. Geological formation G8 (younger granites) appeared to have the highest mean TGR dose rate while G7 (sandstone, clay and shale) show the lowest mean TGR dose rate. The results of this study inferred that, TGR dose rates outdoors for Jos Plateau varies with the diversity of geological formations and is significantly contributed by ²³²Th. An isodose map for TGR dose rates due to natural sources was also plotted using ArcGIS software. The data here presented can be used to evaluate public radiation dose and can be useful for geochemical exploration.

Keywords: Geological formation, Gamma spectrometry, TGR dose rate, isodose map, Jos Plateau.

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INTRODUCTION

Natural environmental radiation mainly arises from primordial and cosmogenic radionuclides. Radionuclides formed due to cosmic activities in the earth's atmosphere such as ²²Na, ³H, ¹⁴C and ⁷Be are known as cosmogenic radionuclides (Tzortzis *et al.*, 2003). Radionuclides with half-lives comparable with the age of the earth (Primordial) e.g. ⁴⁰K and decay series of ²³⁸U and ²³⁴Th within the soils are the largest contributors to the terrestrial background radiation (Dragović *et al.*, 2006).

Human being are continuously exposed with or without their consent to radiation from the cosmic source and terrestrial radionuclides occurring in trace amount in all ground formations (Directive, 1996). Specific levels of terrestrial gamma radiation (TGR) from soils are related to the type of rocks or geological formations from which the soils are derived (Tzortzis, *et al.*, 2003). Therefore, environmental TGR dose rates primarily depend on geological make-up, chemical contents and geographical conditions of the location (Florou and Kritidis, 1992). Granitic type of igneous rocks is found to be associated with higher TGR dose rates compared to low-grade metamorphic and sedimentary rocks (UNSCEAR, 2000). However, some shale and phosphate rocks are relatively rich in natural radionuclides (UNSCEAR, 1993).

Measurement of TGR dose rates have received global interest and led to extensive survey in many countries (UNSCEAR, 2008). Baseline data on TGR dose rate is required for many reasons as reported by

several authors (Al-Jundi, 2002; Ramli, 1997; Saleh *et al.*, 2013; Tzortzis, *et al.*, 2003). Despite the global interest, radioactivity levels and gamma radiation for most of Nigerian environment has not been established.

At the outset of this study, existing literatures indicated that there is a data gap to investigate the contribution of terrestrial radionuclides in characteristic geological formations of Jos Plateau to the total terrestrial gamma radiation dose rates. Therefore, the current study aimed to evaluate the contribution of each geological formation to the terrestrial gamma radiation dose rates in Jos Plateau based on the specific activity concentrations of ²³⁸U, ²³²Th and ⁴⁰K in soil samples. The data presented here, is expected to serve as a reference-data records 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 nuclear power plant accidents (e.g. the recent Fukushima accident), nuclear atmospheric weapon testing, industrial and other human activities.

EXPERIMENTAL

Materials and methods

The study area

The area Jos Plateau, is geographically situated between the latitudes of 8° 30' – 10° 10' N and longitudes of 8° 20' – 9° 30' E on an

altitude of 1100 m above sea level in the north-central region of Nigeria (Hassan *et al.*, 2015; Olise *et al.*, 2014). The climate is classified as tropical rainy characterised with the wet and dry type of weather (Olowolafe, 2008). The study area consist of nine local government areas (LGAs) with a total population of 1933505 (NPC, 2006).

Jos Plateau has attracted a lot of researchers' attention because of its substantial deposits of valuable minerals such as tin and columbite in commercial quantity. These minerals are associated with high contents of naturally occurring radioactive materials (NORMs). There are eight lithological formations classified under three geological groups. These includes: Younger granite ring complexes, tertiary basaltic volcanic and Precambrian basement complex rocks of north central Nigeria (Macleod *et al.*, 1971). The descriptions of the geological types and the digitized map are presented in Table 1 and Figure 1, respectively (NGSA, 1956).

Table 1 Geological formations of the study area (NGSA, 1956)

Code	Geological Name	Description/Composition
G1	Undifferentiated basement complex with pebble beds	Metamorphosed Pre-Cambrian sedimentary and volcanic rocks.
G2	Fine and medium grained Biotite	Dark phyllosilicate mica mineral and medium-grade metamorphic rock
G3	Older Granite	Mostly felsic acidic intrusive igneous rock.
G4	Rhyolite	Fine-grained porphyritic igneous rock dominated by phenocrysts (60%) and quartz (40%) in groundmass.
G5	Older Basalt of Jos	Fine-grained, igneous rock.
G6	Newer Basalt and trachyte	Occurs as cones and lavas clay overlaid by a thick cap of lateritic ironstone.
G7	Sandstone, sandy clay and shale	composed of medium to coarse grained sandstone covered by sediments
G8	Younger Granite	composed coarse grained Biotite microgranites and some basic rocks.

Samples collection and preparation

Soil samples were collected across the geological formations of the area for radiometric analysis. For each geological formation, certain number of soils were collected. At each sampling location, samples were obtained at a depth of 1-3 cm from four different points, thoroughly mixed together to obtain a representative sample for that location. A total of 51 soil samples were collected, which covered the eight geological formations of the study area (Fig. 1). To estimate the true natural TGR dose rate at each location, samples were collected from undisturbed open spaces far away from public structures (Jibiri and Bankole, 2006). Coordinates of the sampling locations were recorded by Global Positioning System (GPS) device (Garmin Corporation, 2008). Labelled polythene bags were used to packed the soil samples and thereafter transported to laboratory.

The samples were dried to a constant weight in an oven at 110 °C for 24 hrs and sieved through a 0.2 cm mesh-sized sieve to remove stones, pebbles and other micro-impurities. The homogenized samples were then weighted and packed into a standard 500 mL Marinelli beakers and stored for about thirty days before analysis to ensure secular equilibrium between radium and its daughter nuclides (Mollah *et al.*, 1987; Saleh *et al.*, 2013a).

The experiments was carried out at Nuclear Physics Laboratory of the Department of Physics, Universiti Teknologi Malaysia, using a high-resolution gamma-ray spectrometry counting system. Fig. 2 shows the locations where soil samples were picked.

Gamma spectrometry analysis

Soil samples were measured for 6 hours using a coaxial high purity germanium (HPGe) detector (GC2018-7500 SL) with a efficiency of 20 % relative to a 7.62 cm × 7.62 cm NaI (TI) detector and a resolution of 1.8 keV for the 1332 keV gamma ray emission of ⁶⁰Co. Genie 2000 software was used to analysed the energy spectra from the gamma emitting radioanuclides. At equilibrium, the energy peaks considered in the present analysis of the measured gamma-ray spectra are: ²¹⁴Pb (352 keV) and ²¹⁴Bi (609), for ²³⁸U and ²⁰⁸Tl (583.1 keV) and ²²⁸Ac (911.2 keV), for ²³²Th and that of ⁴⁰K was determined directly from it energy emission of 1461.8 keV. The background at the laboratory site was determined using an empty Marinelli beaker under the same conditions of measurements. Background count was subtracted from the measured gamma peak of each sample. The value of Minimum Detectable Activity (MDA) was calculated to be 13 ± 2 Bq kg⁻¹ for ⁴⁰K, 1 ± 02 Bq kg⁻¹ for ²³⁸U and 2 ± 07 Bq kg⁻¹ for ²³²Th.

Calculation of activity concentrations

Following the spectrum analysis, specific activity of each radionuclide measured was calculated using equation 1 (Ademola and Farai, 2006; Isinkaye, 2013).

$$C(\text{Bqkg}^{-1}) = \frac{C_n}{\epsilon P_\gamma M_s} \quad (1)$$

where, C is the specific activity concentration of the radionuclide in the sample, C_n is the count rate for the corresponding energy peak, ϵ is the efficiency of the detector at the specific gamma ray energy, P_γ is the absolute transition probability of the specific γ -ray and M_s is the mass of the sample in kg.

Estimation of TGR dose rate

Assuming the contribution from the radionuclide ¹³⁷Cs is considered negligible, absorbed gamma dose rate in air at 1 m above the ground surface for the uniform distribution of ²³⁸U, ²³²Th and ⁴⁰K was estimated based on the guidelines provided by UNSCEAR (2008) and was estimated by equation 2 (Akiba *et al.*, 2012).

$$D_R = (0.462A_U + 0.604A_{Th} + 0.0417A_K) \text{ nGy h}^{-1} \quad (2)$$

where, 0.462, 0.604 and 0.0417 are the activity concentration to dose rate conversion factors of ²³⁸U, ²³²Th and ⁴⁰K, respectively (UNSCEAR, 1998), and A_{Th} , A_U and A_K are the average activity concentrations of ²³²Th, ²³⁸U and ⁴⁰K in Bq/kg, respectively.

RESULTS AND DISCUSSION

The statistical summary for the activity concentrations of the naturally occurring radionuclides ²³⁸U, ²³²Th and ⁴⁰K determined in soils samples collected from all the geological units of Jos plateau are presented in Table 2. About 50% of the activity concentrations of ²³⁸U ranged between 81-98 Bq kg⁻¹, while 75% ranged between 188-457 Bq kg⁻¹ for ²³²Th and 123-1005 Bq kg⁻¹ for ⁴⁰K, respectively. The arithmetic mean values computed from all the soil samples are 88, 157 and 215 Bq kg⁻¹ for U, Th and K, respectively while the mean values derived from all data available worldwide (UNSCEAR, 2008) are 40, 45 and 400 Bq kg⁻¹, respectively. This revealed that the mean activity concentration from the naturally occurring radionuclides measured in Jos Plateau are higher than the corresponding values obtained worldwide for ²³⁸U and ²³²Th and lower for ⁴⁰K.

The TGR dose rates estimated from the measured activity of ²³⁸U, ²³²Th and ⁴⁰K for this study was found to be in the range of 36 nGy h⁻¹ to 456 nGy h⁻¹ with overall mean value of 143 nGy h⁻¹, which is by a factor of two higher than the corresponding worldwide average value of 59 nGy h⁻¹ (UNSCEAR, 2000). Frequency distribution curve of the dose rates is represented by a histogram as shown in Figure 3, where most of the dose rates estimated ranged between 85-125 nGy h⁻¹ (25%).

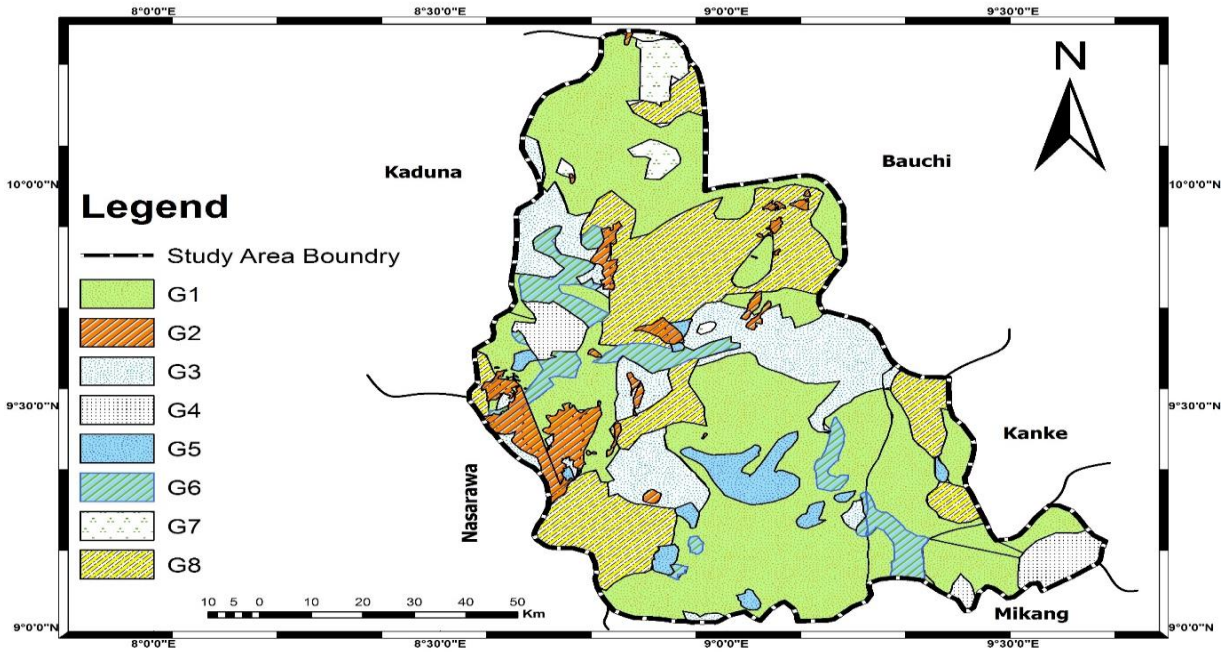


Fig. 1 Geological formations of the study area (NGSA, 1956).

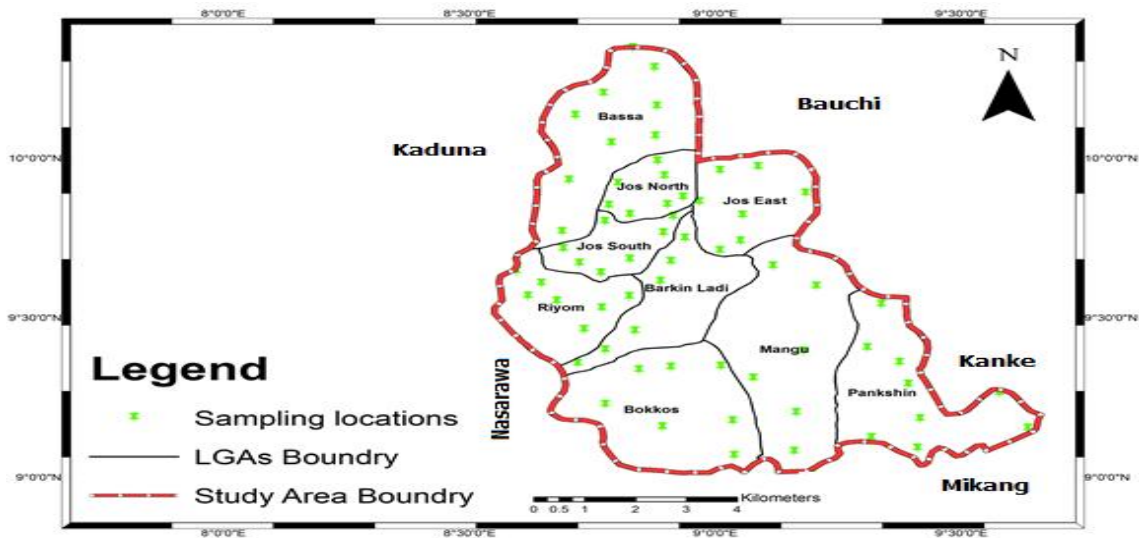


Fig. 2 Sampling locations.

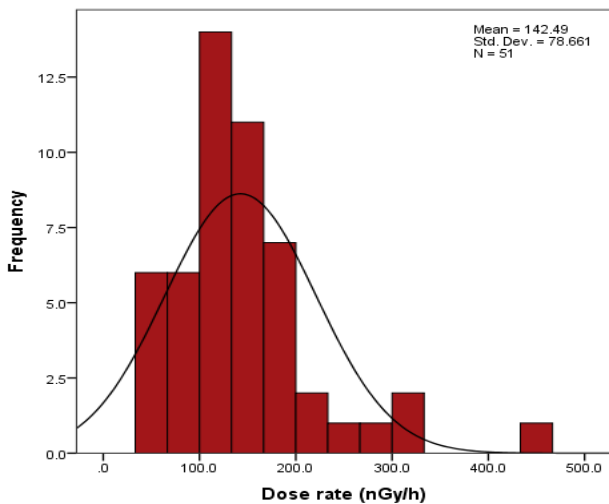


Fig. 3 TGR dose rates frequency distribution curve.

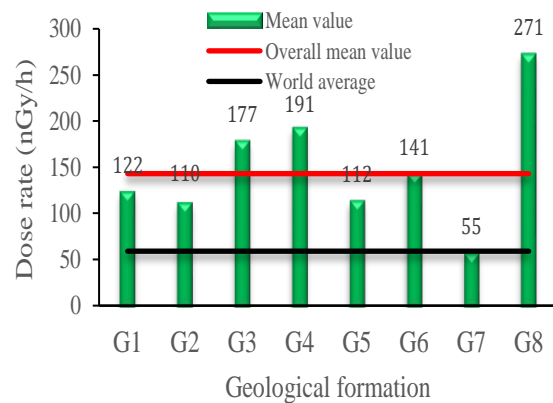


Fig. 4 Mean dose rate for each geological formation.

Table 2. Statistics for the activity concentrations of ²³⁸U, ²³²Th and ⁴⁰K

Statistics	²³⁸ U(Bq kg ⁻¹)	²³² Th (Bq kg ⁻¹)	⁴⁰ K (Bq kg ⁻¹)
Mean	88	157	215
Range	27-327	34-457	43-1055
Std. Error	6	13	32
Std. Dev.	46	92	232
Mode	85	215	280
Median	81	132	123
95% conf. interval	75-100	131-183	149-280

The mean TGR for each geological formation is presented in Figure 4. It can be seen from the Figure, that the highest mean TGR dose rate is associated with geological type G8 (Younger granites) which is reported to be relatively rich in U and Th radionuclides contents in its mineral uraninite, monazite and carnotite (UNSCEAR, 2000) compared to low-grade metamorphic and sedimentary rocks (Tzortzis, et al., 2003). TGR dose rates for the Younger granites ranged between 185 and 456 nGy h⁻¹, with a mean value of 271 nGy h⁻¹. This result agrees with a similar work conducted by Ramli et al. (2005), who also observed higher dose rates over granitic rocks of Melaka in Malaysia. The mean value of 271 nGy h⁻¹ obtained here is found to lower than the value obtained for granitic areas of Melaka, which was more than 350 nGy h⁻¹ (Ramli, et al., 2005). However, the mean value is higher than that reported by Garba et al. (2015) of 209 nGy h⁻¹ in Kelantan for the same geological formation.

The lowest mean value of TGR dose rate was 55 nGy h⁻¹, with ranges of values from 36 to 85 nGy h⁻¹ was observed to be associated with G7 geological type (sandstone, clay and shale) which belong to a sedimentary rock. Sedimentary and low-grade metamorphic rocks are identified to contribute to low dose rates (Sanusi et al., 2014). This value is comparatively higher than the value of 8.7 nGy h⁻¹ reported by Tzortzis et al. (2004) for sedimentary rocks of Cyprus. The mean TGR dose rates for the other geological formations of Jos plateau ranged between 110 nGy h⁻¹ and 191 nGy h⁻¹.

The contributions of ²³⁸U, ²³²Th and ⁴⁰K to the total TGR dose rates

for the study area is shown in Figure 5. ²³²Th (66 %) was found to contribute the the highest to the gamma dose rate in the area. This is because ²³²Th is insoluble and 3-4 times in natural environment compared to ²³⁸U (Ravisankar et al., 2015) and is the most abundant radionuclide in the mineral monazite associated with the granitic basement complex formations which underlain the largest land area of the area under investigation. ⁴⁰K contributes the least. In general, the results of this study show that, TGR dose rates outdoor 1 m above soil surface for Jos Plateau varies with the diversity of geological formations of the area and is significantly contributed by ²³²Th.

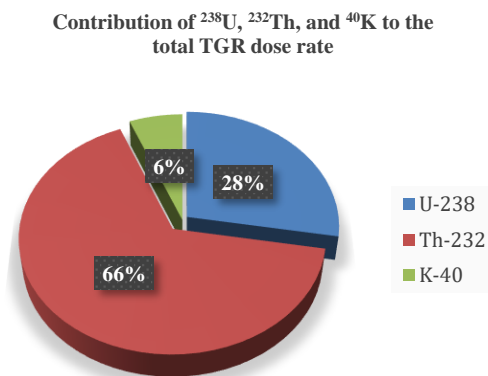


Fig. 5 TGR dose rates contribution of ²³⁸U, ²³²Th, and ⁴⁰K in Jos Plateau.

The coordinates of the sampling locations and the corresponding TGR dose rate values were used to produced an isodose map for gamma radiation exposure rates for the study area using ArcGIS software (Fig. 6). It can be seen that, areas around Jos South, Jos North and Barkin Ladi LGAs appeared to have the higher dose rates. These areas are predominantly underlain by igneous rocks of granitic and basaltic compositions. Areas around Mangu and Pankshin LGAs show TGR dose rates of lower values, this is due to the fact that the areas are underlain by sedimentary rocks such as sandstone, clay and shale.

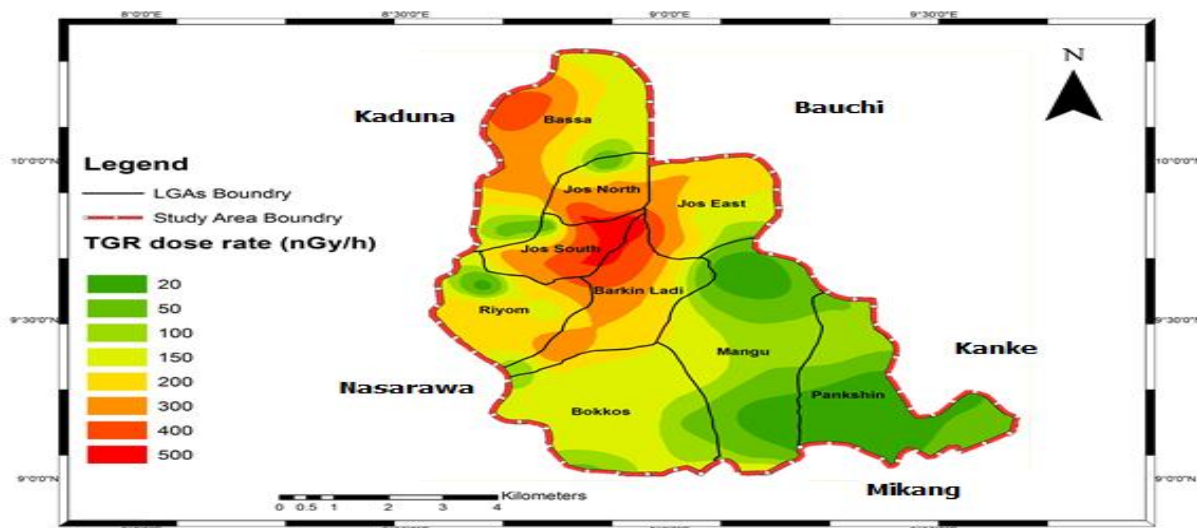


Figure 6 Isodose map of the TGR dose rates.

CONCLUSION

Gamma spectrometry technique was used to measure the concentrations of ^{238}U , ^{232}Th and ^{40}K in soil samples collected across the geological characteristics of Jos plateau. TGR dose rates in air outdoors 1 m above the ground surface is estimated from the specific activity concentrations and was found to be in the range of 36 nGy h⁻¹ to 456 nGy h⁻¹, with an overall mean value of 143 nGy h⁻¹. The estimated mean value is two times higher than the world average value of 59 nGy h⁻¹. Among the geological formations present, Younger granites (igneous rocks) presents the highest dose rates. The lowest TGR dose rates was observed in areas of sandstone, clay and shale (sedimentary rocks). The results also revealed that TGR dose rates for Jos Plateau varies with the diversity of the existing geological characteristics and is significantly contributed by radionuclides ^{232}Th compared to ^{238}U and ^{40}K . The data presented here is expected to serve as reference-data records which can used to evaluate public dose. It can also be used for geochemical exploration and can be useful towards producing radiological map for Nigeria.

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