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ORIGINAL ARTICLE

Mapping of natural gamma radiation (NGR) dose rate distribution in tin mining areas of Jos Plateau, Nigeria

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Abstract An extensive study was conducted to measure the natural gamma radiation (NGR) dose rates for the tin mining areas of Jos Plateau with an objective to establish a reference data record on the levels and distribution of natural background gamma radiation. The measurement was carried out using a portable NaI(Tl) scintillation survey meter. The results obtained, varied significantly for different soil types and for geological features of the study area. NGR dose rates values ranged between 40 nGy h^{-1} measured on *Ferric Luvisols–Ferric Luvisols* (*S13*) soil type, underlain by geological formation G7 (sandstone, clay and shale) and 1265 nGy h^{-1} recorded on, *Haplic Acrisols* (*S27*), underlain by geological formation G8 (Younger granites) with overall mean value of 250 nGy h^{-1}. This is by a factor of four higher than the reported world average value of 59 nGy h^{-1}. Mean indoor and outdoor annual effective dose for the public was estimated to be 1.2 and 0.31 mSv/y, respectively. An isodose map for the distribution and exposure rate due to natural sources radiation for the study area was also plotted using ArcGis software. The data here presented can use to prepare a national radiological map for the country.

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Keywords Natural gamma radiation (NGR) dose rate · Mean dose rate · Isodose map · Jos Plateau

Introduction

Human beings are constantly exposed to natural background gamma radiation due to terrestrial and cosmic sources (Taskin et al. 2009). According to United Nations Scientific Committee on the Effects of Atomic Radiation report (UNSCEAR 2000), the greatest contribution to mankind's exposure comes from natural background radiation, and the global average annual effective dose is 2.4 mSv. Natural gamma radiation (NGR) which represents the main source of irradiation to human body (UNSCEAR 1993a, b) is strongly related to the composition of local geology and geographical conditions of a particular region in the world (UNSCEAR 2000). This in turn depends on the specific levels and content of the terrestrial radionuclides U, Th and K within the crustal rocks and soils (Tzortzis and Tsertos 2004). Silica over saturated rocks such as granitic type of igneous rocks is associated with higher gamma radiation dose rates (Tzortzis et al. 2004) due to their high elemental concentrations of U and Th (Faure 1986) compared to other types of rocks such as low-grade metamorphic and sedimentary rocks which are known to present low dose rates (Sanusi et al. 2014).

There has being a global interest toward the measurement of environmental natural radiation to established a reference data record for local and international interest (Al-Masri et al. 2006). Measurements of NGR have been conducted for different regions in many countries of the world as reported by several authors (Ademola 2008; Al-Jundi 2002; Karahan and Bayulken 2000; Kurnaz 2013; Mollah et al. 1987; Rafique 2013; Ramli 2007; Ravisankar et al. 2015; Sadiq

Aliyu et al. 2015; Saleh et al. 2013a, b), and more is going on worldwide for many reasons (Sohrabi 1998). Information on environmental natural gamma radiation is relevant and important for the purpose of formulating safety standards and national guidelines for local and global needs in line with international recommendations. Specifically, Nigerian government has passed a legislation to establish a body whose mandate is to provide guidelines and to monitor all activities involving the use, transportation and disposal of radioactive materials (Jibiri 2001). These can only be achieved if the baseline data on natural background radiation for its environment have been established.

Based on the previous literature, extensive radiometric survey has not been conducted to measure the natural background gamma radiation taken into cognisance the different local geological structures and soil types of Jos Plateau. In an effort to bridge the data gap, the present work is undertaken with the objective to measure the natural background gamma radiation based on the local geology and soil types of Jos Plateau and also to plot an isodose map for the distribution of NGR and the exposure rate for the study area. For national interest, the data here presented can serve as a baseline data on environmental radioactivity and can be used to produce radiological map, if the need arise for Nigeria.

Materials and methods

Study area

The area of Jos Plateau is located on a granitic plateau that is approximately 1100 m above sea level covering latitude 8° 30″–10° 24″ N and longitudes 8° 20″–9° 30″ E in the north-central part of Nigeria (Hassan et al. 2015; Olise et al. 2014). The area under study consists of nine local government areas of Plateau state covering a total land area of 8600 Km^2 and has a population of about 22,988,110 as of 2006 census (NPC 2006).

Jos Plateau has a near temperate climate with an average temperature between 18 and 22 °C. The mean annual rainfall varies from 131.75 cm in the southern part to 146 cm on the Plateau. The highest rainfall is recorded during the wet seasons, in the months of July and August (Adiuku-Brown 1999). The study area is underlain by eight (8) geological formations as described in Table 1 and shown in Fig. 1. The geologies are overlain by twenty-seven (27) soil types classified in accordance with the FAO/UNESCO soil taxonomy (Gerrard 2000) (see Fig. 2).

NGR dose rates measurement

An in situ NGR dose rates measurement was conducted using a portable NaI(Tl) scintillation survey meter (Ludlum micrometer, model 19) manufactured by Ludlum Measurement, USA (Ludlum Measurement 1993). The meter uses (2.54 × 2.54 cm^2) sodium iodide (NaI) crystal doped with thallium (Tl) as detector. Measurements were conducted randomly at 1 m above soil surface at 811 different locations. Geographical coordinates of the measurement locations were recorded by Global Positioning System (GPS), Garmin eTrex 10 model. The meter displays dose rate reading in μ. R h^{-1} which was subsequently converted to nGy h^{-1} using a conversion factor 1 μR $h^{-1} \approx$ 8.7 nGy h^{-1} (Saleh et al. 2013a). The relatively linear energy response of the detector between the gamma rays energies of 0.08 and 1.2 meV makes its excellent for field measurements (Knoll 2010). Figure 3 shows the measurement locations. To minimize errors, dose rate readings were recorded when the meter pointer was stable, and least four set of readings were taken at a given point within the domain of the geological formations and soil types. Thereafter, the mean value for each location was computed from the set of the readings. To measure the actual NGR dose rates, measurements were made in an undisturbed open fields and far away from mines and mining installations or facilities. Figure 3 shows the measurement locations.

Plotting of isodose map

The data set on NGR dose rate measurements plus the coordinates for all data points were used in plotting an isodose map which represents the distribution of NGR and exposure rates for the study area using ArcGIS version10.3—a mapping and spatial analysis software. Kriging technique was adopted for the plotting (Aziz Saleh et al. 2014; Gerrard 2000). This technique uses decreasing weight for the interpolation based on a semivariogram of survey points (Apriantoro 2008). The datum used for the GPS was set up to the world geodetic system (WGS) 1984 and synchronized with coordinates of survey points, this methodology was adopted in earlier studies (Hassan et al. 2015; Lee et al. 2009).

Results and discussion

The summary of the basic statistics for the data set on 811 dose rates obtained for this study is given in Table 2. The values for the outdoor dose rate measurements were in the range of 40–1265 nGy h^{-1}, with a mean value of 250 nGy h^{-1}. The mean value is four times fold the calculated value of 59 nGy h^{-1} from the available data worldwide as reported by UNSCEAR (2000). Majority of the dose rates recorded for this study (50%) were between 189 and 287 nGy h^{-1} as shown in Fig. 4 by the frequency distribution histogram.

Table 1 Geological features of the study area (NGSA 1956)

Label	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 granites	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 granites	Composed coarse-grained biotite microgranites and some basic rocks

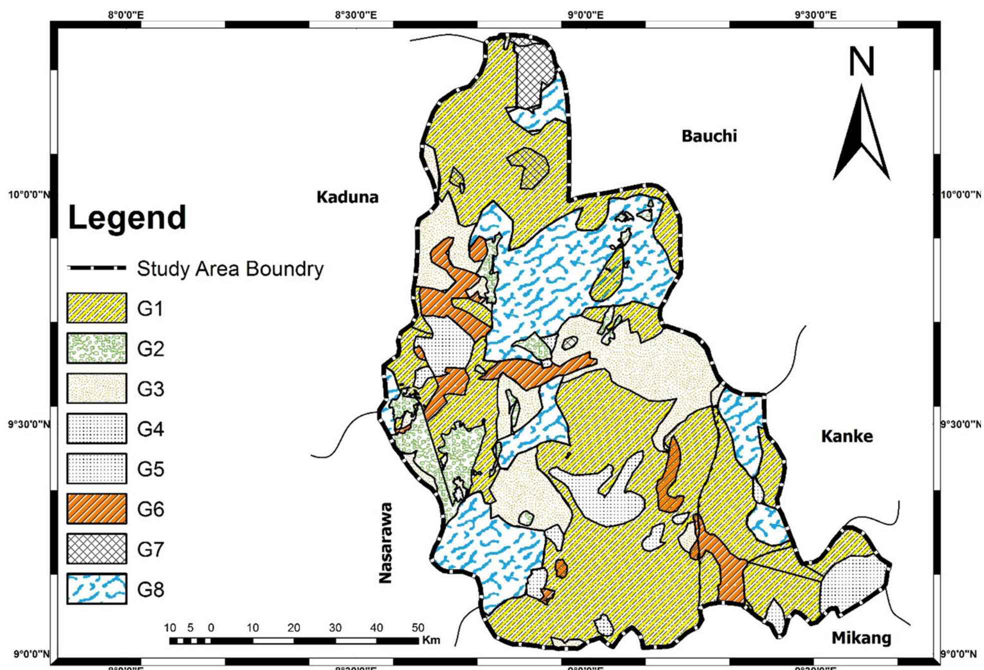


Fig. 1 Geological formations of the study area (NGSA 1956)

The summary of basic statistics of dose rates for the twenty-seven soil types for the study area is presented in Table 3. The highest dose rate was measured over *Haplic Acrisols* (*S27*) soil type underlain by granitic rock formation (G8) while the lowest was recorded on soil type *Ferric Luvisols–Ferric Luvisols* (*S13*) underlain by sandstone, clay and shale formations, G7 (sedimentary rocks). Soils derived from granitic parent material are known to contribute to higher dose rates (UNSCEAR 2000) compared to soils developed as a result of decomposition of organic matter such as peat, muck and shale which shows low TGR dose rates (Sanusi et al. 2014). This is because, the minerals that carry U and Th are generally associated with felsic intrusive rocks, particularly with Younger granites compared to ultramafic and volcanic rocks (Amadi et al. 2012). It was also stated by Amadi et al. (2012), U and Th exist in high concentration in few accessory minerals of igneous rocks such as zircon, sphene and apitite and are naturally distributed erratically in wide spread, in other highly radioactive minerals like monazite, allanite, uraninite, thorite and pyrochlore in constituents of rocks. The concentrations of these radionuclides in rocks are reported to increase generally with acidity of the rock type, with the highest in found in pegmatite (Grant 1982).

The results of this study are in general agreement with similar studies conducted by Ramli et al. (2009), Saleh et al. (2013a, b), Lee (2007), and Garba et al. (2015) whom reported dose rates of higher values for soils of igneous

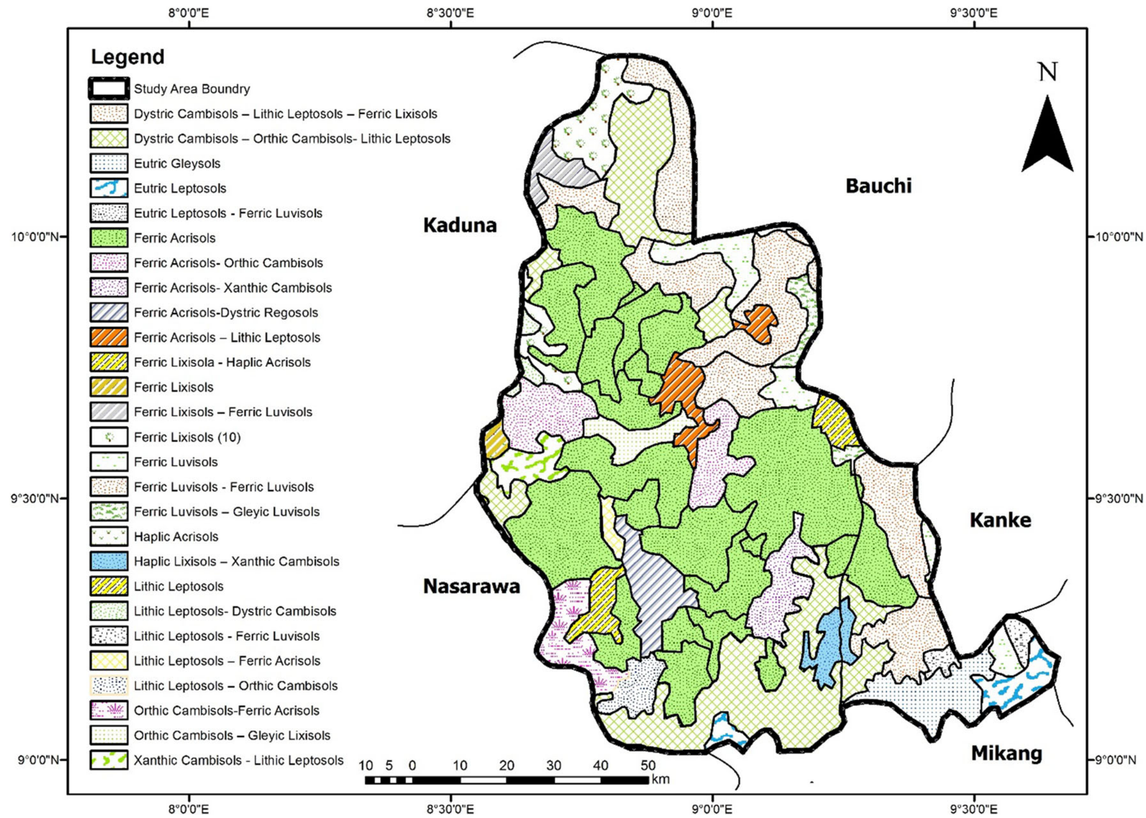
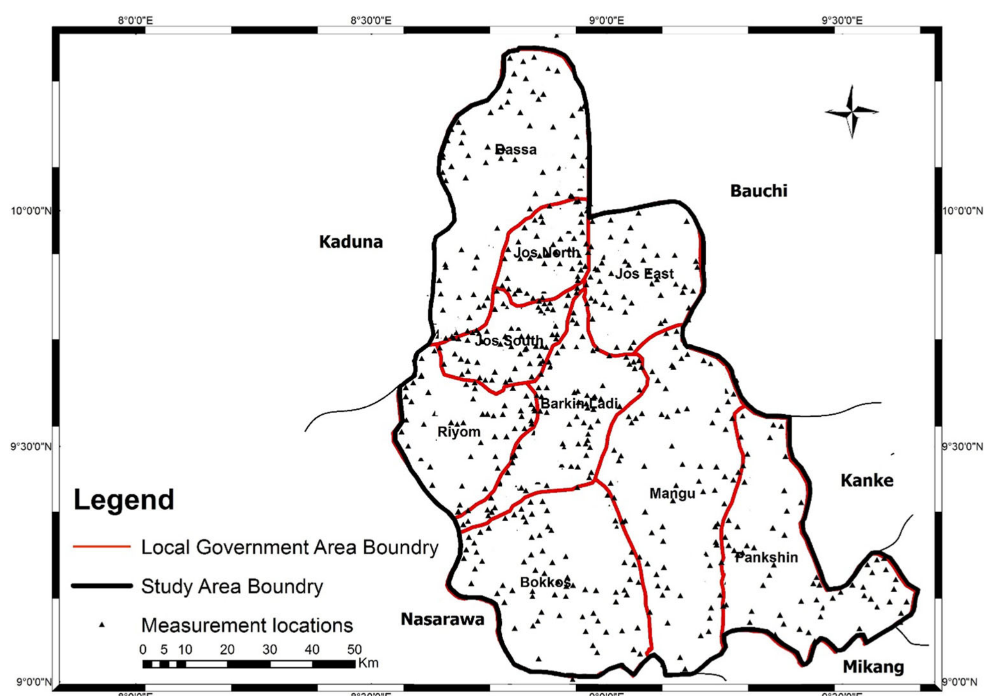


Fig. 2 Soil types of the study area

Fig. 3 Survey points for this study area



origin. Dose rate as low as 8.7 nGy h^{-1} was reported by Tzortzis et al. (2004) for soil of sedimentary rocks in Cyprus. The mean value for this study was found to be higher than values obtained for the city of Istanbul (Karahan and Bayulken 2000), for Greece (Anagnostakis et al. 1996) and south-west Nigeria (Jibiri et al. 2016).

Table 2 Summary of the basic statistics for external gamma dose rates

Statistics	Dose rate (nGy h^{-1})
Mean	250
Range	40–1265
SE	5.1
SD	145
Median	213
Mode	189
95% Conf. interval for mean	239–260
World average value	59

However, values reported by Ademola (2008) in the same region, by Faanu et al. (2016) for central region of Ghana and by Ramli et al. (2009) for district of Selama, Malaysia, are found to be higher than our value. Higher values of dose rates were observed in few areas, and this could be probably attributed to the impact of tin mining activities on the environment for decades which was reported to enhance the level of background radiation within the mines and around the mining and processing facilities of some mining locations (Farai and Jibiri 2000; Jibiri et al. 2007a, 2009; Jwanbot et al. 2013). Figure 5 presents, in the form of isodose map, the distribution of NGR and exposure rate for the study area.

The mean values of dose rates for the nine LGAs of the study area are presented in Fig. 6. The results are compared with world average and the overall mean value of the study as indicated by the two solid horizontal lines. The highest mean dose rate (293 ± 19 nGy h^{-1}) was recorded in Jos South LGA, an area predominantly underlain by acidic intrusive Younger granites (Buchanan et al. 1971) mostly covered by *Ferric Acrisols* soil type. The lowest mean dose rate (193 ± 7 nGy h^{-}1) was observed in Pankshin LGA, overlain by soil types mostly from sedimentary formations (Macleod et al. 1971). These types of soil show low dose rates due to their low content of radionuclides (Lee et al. 2009; Sanusi et al. 2014). Table 4 presents the comparison of the mean values of natural gamma radiation dose rates for this study and other regions of the world (Furukawa and Shingaki 2012; UNSCEAR 1993a, b, 1998, 2000, 2008).

Estimation of annual effective dose (AED)

The regional mean dose rate was used to compute the mean indoor and outdoor annual effective doses due to exposure to natural sources of background gamma radiation. The parameters were estimated by assuming the conversion coefficient for the absorbed dose in air to effective dose of 0.7 Sv Gy^{-1}, and the indoor and outdoor occupancy factors of 0.8 and 0.2, respectively, as recommended by UNSCEAR (2000). The indoor and outdoor annual effective dose equivalent was estimated using Eqs. 1 and 2, respectively.

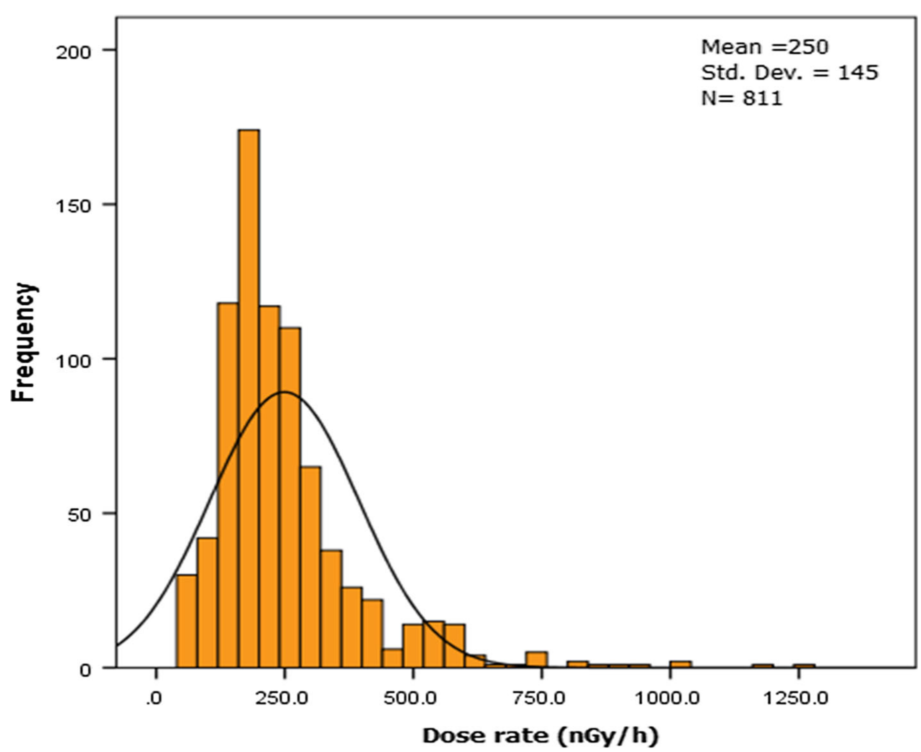


Fig. 4 Frequency distribution curve for dose rates

Table 3 Summary of statistics for dose rates for each soil type

Label	N^a	Dose rate ($nGy\ h^{-1}$)				
		Mean	SE	SD	Range	95% conf. interval for mean
S1	53	179	10	70	103–415	179–130
S2	80	228	12	106	59–743	219–356
S3	15	189	24	93	92–413	99–279
S4	12	207	21	74	125–334	129–294
S5	274	271	11	186	129–850	245–357
S6	16	185	39	158	147–598	142–228
S7	21	176	25	112	126–480	144–206
S8	48	183	14	100	89–551	163–203
S9	43	198	14	93	70–518	119–279
S10	13	199	16	58	109–327	126–273
S11	7	172	14	37	115–218	129–213
S12	46	322	15	103	67–262	315–408
S13	34	145	25	147	40–598	120–236
S14	14	244	13	48	152–316	183 -305
S15	6	168	9	23	137–200	144–192
S16	21	178	7	31	76–199	152–201
S17	14	258	29	107	104–450	225–308
S18	7	172	20	52	105–251	123–219
S19	8	169	15	41	117–230	118–220
S20	10	144	19	60	63–266	87–199
S21	11	49	11	36	41–167	39–60
S22	6	174	27	66	92–249	104–243
S23	12	201	23	80	127–370	146–253
S24	13	220	17	62	140–362	180–258
S25	12	195	16	57	111–257	142–248
S26	7	158	15	40	101–212	118–198
S27	8	267	47	133	232–1265	229–308
Overall mean		250	19	80		

[a] Number of readings per soil type

$$AED_{In}\left(mSv\ y^{-1}\right) = \text{mean dose rate}\left(nGy\ h^{-1}\right) \times 24\,(h) \times 365\,(\text{days}) \times 0.8 \times 0.7 \times 10^{-6} \quad (1)$$

$$AED_{Ex}\left(mSv\ y^{-1}\right) = \text{mean dose rate}\left(nGy\ h^{-1}\right) \times 24\,(h) \times 365\,(\text{days}) \times 0.2 \times 0.7 \times 10^{-6} \quad (2)$$

The mean indoor and outdoor AED for the public is estimated to be 1.2 and 0.30 mSv/y, respectively. The mean outdoor AED is higher than the Nigerian and global average annual effective dose of 0.098 mSv/y (Farai and Jibiri 2000) and 0.07 mSv/y (UNSCEAR 2000), respectively. While the mean indoor AED is higher than worldwide average of 0.46 mSv/y (UNSCEAR 2000). The result of the mean outdoor AED is within the range of values obtained by Jibiri et al. (2007b) and lower than that obtained by Ugodulunwa et al. (2008) in the region. The indoor AED is comparatively lower than the reported value of 1.64 mSv/y by Jwanbot et al. (2014) and 9.1 mSv/y by (Ibeanu 2003) for the same region, but is equivalent to the worldwide average annual effective dose of 1.2 mSv/y from all natural sources, excluding radon, as quoted in the UNSCEAR (2000) report. Therefore, from radiological point view, this value is within limit and do not imply any significant concerns about health effects for the local population.

Conclusion

A study was conducted to measure a natural gamma radiation (NGR) dose rates over different soil types and geological formations in tin mining areas of Jos Plateau, Nigeria. The results revealed that soils originated from the granitic complex as parent rock appear generally to have

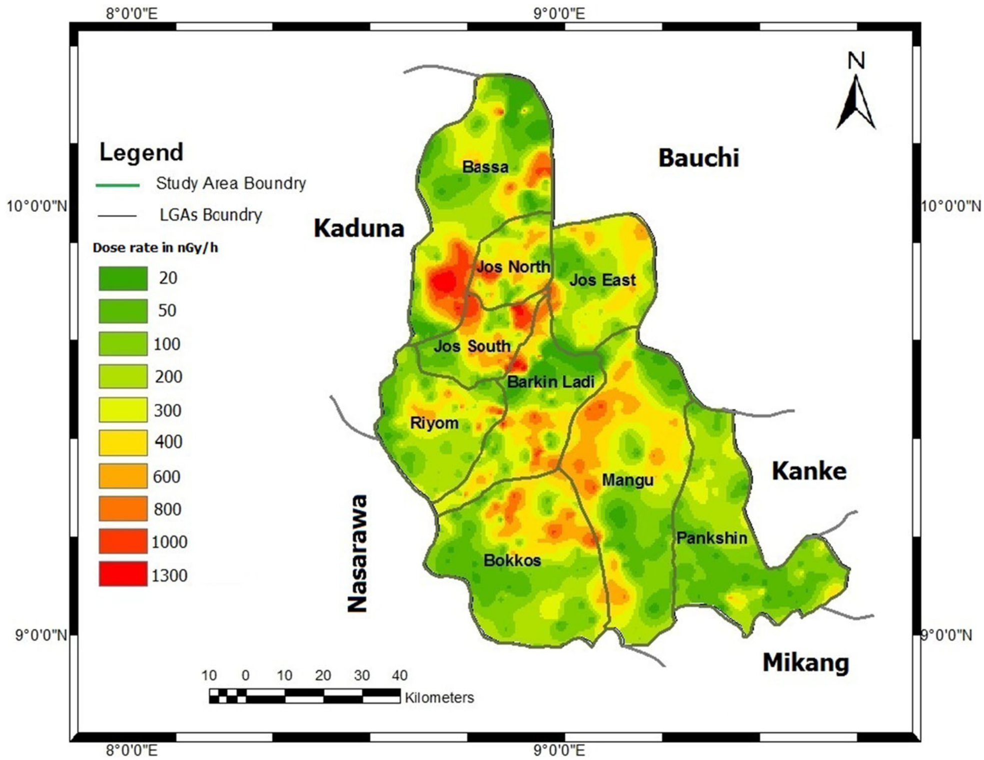


Fig. 5 Isodose map for the study area

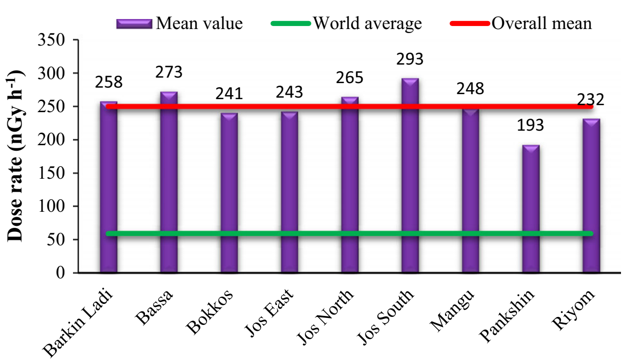


Fig. 6 Mean value of dose rates for the nine LGAs of the study area

higher dose rates, compared to those of sedimentary origin. *Haplic Acrisols* (*S27*) derived from Younger granites, G8, presents the highest dose rate of 1265 nGy h^{-1}, while soil type *Ferric Luvisols–Ferric Luvisols* (*S13*) derived from sandstone, clay and shale, G7 (sedimentary formation) indicated the lowest dose rate of 40 nGy h^{-1}. The overall mean value for this study is computed to be 250 nGy h^{-1}. This value falls within the highest range of those measured at worldwide scale by other authors and, more specifically, is by a factor of four higher than the reported world average values of 59 nGy h^{-1} in the UNSCEAR (2000) report.

Table 4 Mean dose rate for this study compared to other countries of the world

S. no.	Country/region	Dose rate (nGy h^{-1})	References
1	Ghana	741	Faanu et al. (2016)
2	South-west Nigeria	232	Jibiri et al. (2016)
3	Jos Plateau	13,500	Ademola (2008)
4	Kenya	40	Kebwaro et al. (2011)
5	Malaysia	92	UNSCEAR (2000)
6	Spain	76	UNSCEAR (1988)
7	Brazil	125	Freitas and Alencar (2004)
8	Iran	105	Baykara and Doğru (2009)
9	Portugal	84	UNSCEAR (2000)
10	India	56	UNSCEAR (2000)
11	USA	47	UNSCEAR (2000)
12	Jos Plateau	250	This study
13	World average	59	UNSCEAR (2000)

Jos South LGA characterized with intrusive granitic rocks predominantly overlaid by *Ferric Acrisols* soil type has the highest mean dose rate (293 nGy h^{-1}), while Pankshin predominantly underlain by sandstone, clay and shale, covered by *Cambisols and Lixisols* soil types has the lowest mean dose rate (193 nGy h^{-1}). The mean indoor and outdoor annual effective doses for the public were estimated to be 1.2 and 0.31 mSv/y, respectively. The isodose map for the distribution NGR and exposure rate for the study area was also plotted using ArcGIS software.

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