MAPPING AND ASSESSMENT OF TERRESTRIAL GAMMA RADIATION EXPOSURE IN NORTHERN ZAMFARA STATE, NIGERIA

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Abstract: This study measured and mapped terrestrial gamma radiation (TGR) exposure in seven local government areas of Northern Zamfara State, Nigeria. The assessment was carried out using a portable survey meter, Inspector Alert Nuclear Radiation Monitor and a global positioning system (GPS). Due to the random nature of radioactivity, five measurements were taken per each location to minimize the error, with the survey meter held 1 m above the ground. A total number of 166 average measurements were evaluated and recorded. Statistical analyses were carried out on the results using Statistical Package for Science Study (SPSS) version 23. The mean terrestrial gamma radiation exposure rate in the study area was found to be 32 nGy h^{-1}. KauraNamoda local government area has the highest mean value of TGR exposure rate of 38 nGy h^{-1}, while Bakura local government area has the lowest mean value of TGR exposure rate of 28 nGy h^{-1}. Gamma radiation distribution map which shows the distribution of TGR exposure in the study area was plotted using ArcGIS software version 10.3. Exposure and risk; outdoor annual effective dose rate, mean population weighted dose rate, annual collective effective dose, lifetime dose and excess lifetime cancer risk were computed as 0.04 mSv y^{-1}, 32.45 nGy h^{-1}, 59.33 Sv y^{-1}, 2.75 mSv, and 1.38×10^{-4}, respectively.

Keywords: Exposure, gamma, mapping, radiation, terrestrial, Zamfara

Introduction

Terrestrial gamma radiation (TGR) is a major source of human exposure to ionizing radiation (UNSCEAR, 2000). Ionizing radiations can have serious health effect on human when exposure beyond normal background level. The more human receives high radiation dose, the greater probability of developing cancer of various organs, haematological depression, incidence of chromosome aberrations, serious risk of infections, severe damage to central nervous system etc. (Christian, 2014).

Human activities in the environment such as mining, making and using fertilizers, oil and gas production etc., can increase the risk of radiation exposure beyond normal background level (WNA, 2016). A thorough investigation showed that people of Zamfara State engaged in illegal gold mining as a means of their livelihood. They extract and process it themselves through unsafe and unregulated means (Udoka, 2010). This may results in contamination and pollution of soil and air of the area, which is an issue that need a great attention because it can cause serious health hazard. For this reason, it is important to monitor the level of terrestrial gamma radiation exposure in our environment for radiological safety and protection.

In Zamfara State, there are no available information on TGR and data on public exposure, and has not been subjected to radiological regulatory control. Therefore, there is need to check out the TGR exposure level in Zamfara State and have a documented data on radiation exposure, which will create awareness to all the stake holders of the state, local population, as well as the relevant regulatory authorities.

This study measured TGR exposure rates and produced a radiation distribution map of Northern Zamfara using ARCGIS software.

Materials and Methods

Study area

The study area lies within 5° 00′E and 7° 15′E longitudes and 12° 00′N and 13° 15′N latitudes, which covered Maradun, Bakura, TalataMafara, Shinkafi, Zurmi, KauraNamoda and Birnin-Magaji local government areas of Northern Zamfara State, with total population of 1,509,741 according to the 2006 population census (NPCN, 2006). The study area is characterized by Granites, Granite-Gneiss, Aglomorate, Biotite, Quartzites, Meta-Conglomerates etc., type of rocks (Fig. 1) (NGSA, 2013).

Methods

The terrestrial gamma radiation exposure rates were measured with a survey meter, Inspector Alert™ Nuclear Radiation Monitor. The survey meter has 45 mm diameter with mica window density 1.5 – 2.0 mg cm^{-2} in a halogen-quenched Geiger-Mueller tube. It has gamma ray sensitivity of 3500 CPM per 1 mR h^{-1} as referenced to Cs -137 (IMI, 2015). It was positioned 1m above the ground and set to count. The counts recorded by meter fluctuate due to the varying nature of radiation. For this reason, five readings were taken at each survey point to reduce the error, and an average of the five readings were determined and recorded. The average readings were initially recorded in milli roentgen per hour (mR h^{-1}) and were later converted to nano-Gray per hour (nGy h^{-1}) with a conversion factor of 1 **µ**R h^{-1} = 8.7 nGy h^{-1}. A Global Positioning System, Garmin (GPS Map78), on other hand, was used to determine the coordinates of each location. The measurements were carried out in 166 different locations randomly (Fig. 2).

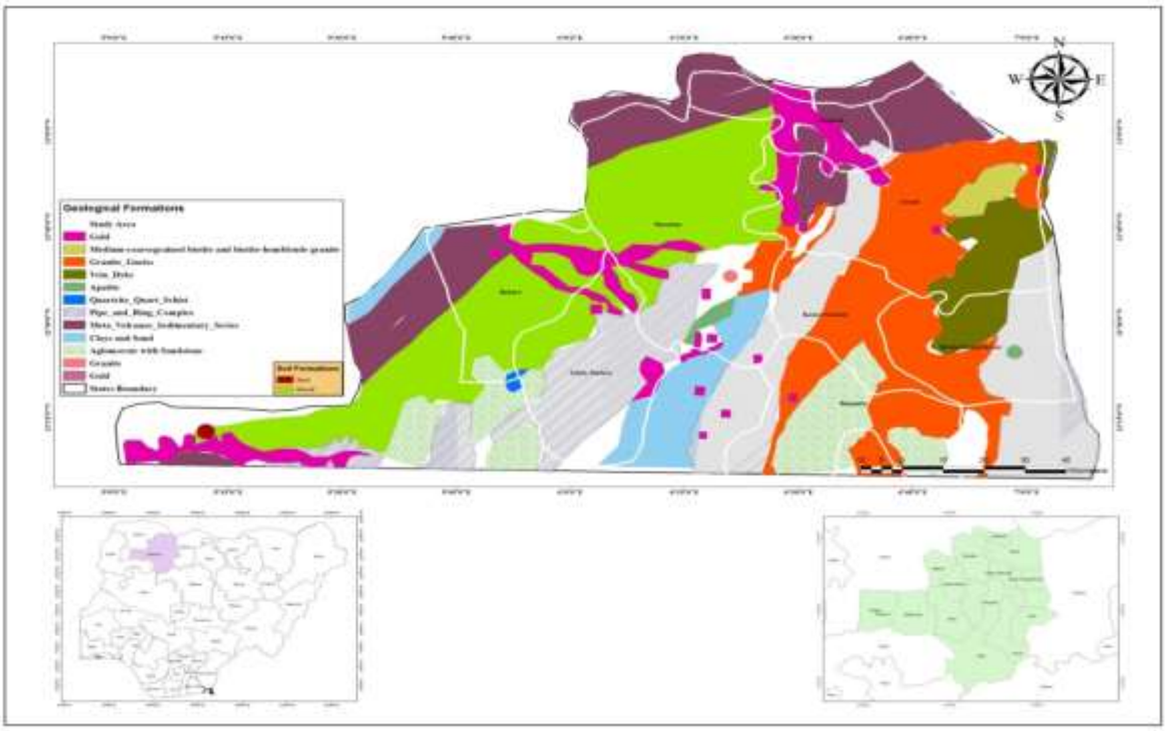

Fig. 1: Digitize map of the study area

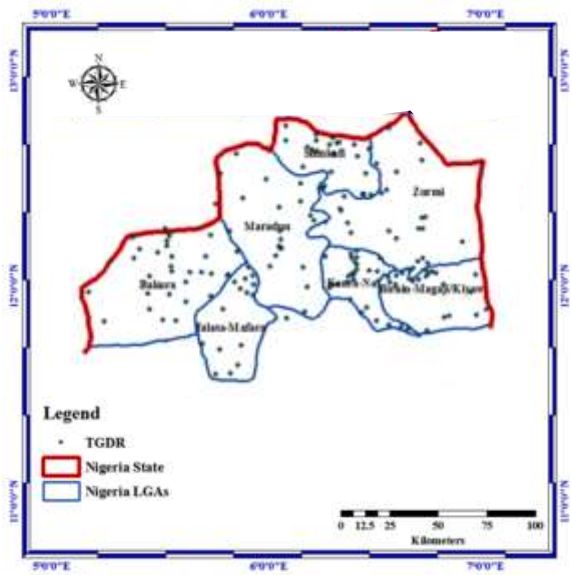

Fig. 2: Locations of TGR rates measurements

Gamma radiation distribution mapping

ArcGIS 10.3 software – mapping and spatial analysis software was used to plot the gamma radiation distribution map of the study area. Gamma radiation distribution map is very important in determining the gamma radiation status of an area (Gabdo *et al.*, 2014). The coordinates of the survey points recorded in degree minute second using Global Positioning System, Garmin (GPS Map 78) and were converted to decimal coordinates. World Geodetic System of 1984 was used in defining the coordination system and also generates the contour lines of gamma radiation exposures in the study area.

Results and Discussion

TGR exposure rates

The measured TGR exposure rates in the study area were found to range between 20 nGy h^{-1} to 61 nGy h^{-1}, with an average value 32 nGy h^{-1} (Table 1), which is less than the world average 59 nGy h^{-1} (Garba *et al*., 2016; UNSCEAR, 2000). KauraNamoda local government recorded the highest average value of TGR exposure rate 38 nGy h^{-1}, followed by BirninMagaji with mean value 34 nGy h^{-1}, and next is Zurmi local government with mean value 33 nGy h^{-1}.

Table 1: Mean TGR exposure rates for each of LGAs of Northern Zamfara

LGA	N	Terrestrial Gamma Radiation Exposure Rate (nGy h^{-1})						
		Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean: Lower Bound	95% Confidence Interval for Mean: Upper Bound	Minimum	Maximum
Shinkafi	22	30	4	1	28	32	21	37
Zurmi	23	33	11	2	29	38	20	61
KauraNamoda	28	38	8	2	35	42	27	60
BirninMagaji	22	34	6	1	32	37	24	56
Maradun	26	29	5	1	27	31	21	40
TalataMafara	14	30	7	2	26	34	21	50
Bakura	31	28	6	1	26	31	20	44
Northern Zanfara	**166**	**32**	**8**	**1**	**31**	**33**	**20**	**61**

The higher values of TGR exposure rates in those local governments are attributed to the Old Granite land formation covering about 70% land mass of the three local governments. The formation associated with igneous rocks, such as granites, granodiorites, monzorites and charnockites (UNSCEAR, 2000), which are enriched by rocks of moderate to high radioactive materials (Nuhu, 2009). On the other hand, Bakura local government recorded the lowest average value of TGR exposure rate of 28 nGy h^{-1}, followed by Maradun local government with average value 29 nGy h^{-1}, and next are Shinkafi and TalataMafara local governments with average value 30 nGy h^{-1}. The lower values of TGR exposure rates in those areas are traced to the Gundumi/Illo land formation covering about 90% land mass of the three local governments. The formation consists of basal conglomerates, gravels with sand, variegated clays, and interbedded clays and grits (Nuhu, 2009), which are formed from organic deposit. The mean value of TGR exposure rate of Northern Zamafara, other countries and the world are presented in Fig. 3.

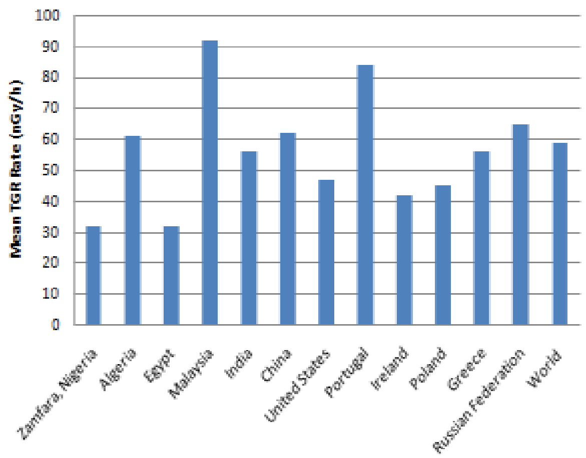

Fig. 3: Mean TGR exposure rate of Northern Zamfara and some other countries of the world

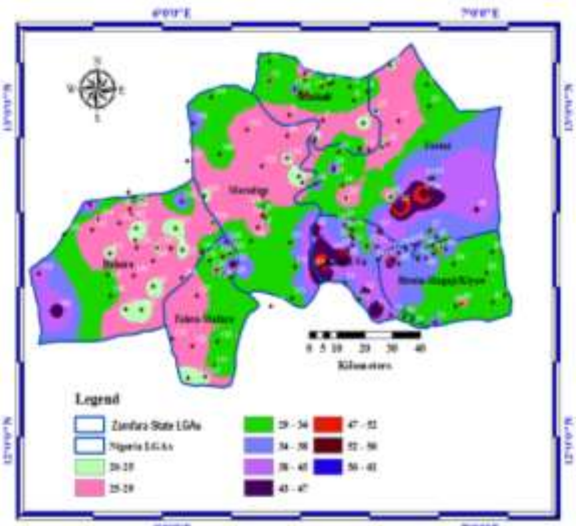

Fig. 4: Gamma radiation distribution map of Northern Zamfara

Gamma radiation distribution map

The gamma radiation distribution map of Northern Zamfara, State (Fig. 4) shows that about 70% land mass occupied by Zurmi, KauraNamoda and BirninMagaji local governments are exposure to TGRrates ranged from 34 nGy h^{-1} to 61 nGy h^{-1}, while the remaining 30% land mass of the same three local governments are exposure to TGR rates ranged from 25 nGy h^{-1} to 34 nGy h^{-1}. However, about 90% land mass of Shinkafi, Maradun, TalataMafara, and Bakura are exposure to TGR rates ranged from 20 nGy h^{-1} to 34 nGy h^{-1}. The map correlates with result in Table 1.

Table 2: Mean dose rate and population for each LGA

LGA	Mean TGR Exposure (nGy h^{-1})	Population (NPCN, 2006)
Bakura	28	187,141
BirninMagaji	34	184,083
KauraNamoda	38	285,363
Maradun	29	207,563
Shinkafi	30	135, 964
TalataMafara	30	215,650
Zurmi	33	293,977

Exposures and risk

i. Outdoor annual effective dose rate (H_R) assessment was carried out to determine annual hazard of TGR exposure on people living in Northern Zamfara State due to the outdoor exposure using equation (1) (UNSCEAR, 2000).

$$H_R\,(\text{mSv y}^{-1}) = \text{TGRD}\,(\text{nGy h}^{-1}) \times 8760\text{ h y}^{-1} \times O_{out} \times C \times 10^{-6} \quad (1)$$

Where O_{out} is the outdoor occupancy factor assumed to be 0.2, and C is the conversion coefficient (0.7 mSv nGy^{-1}) as contained in UNSCEAR 2000 report. The mean H_R value on people living in the northern part of Zamfarais 0.04 mSv y^{-1}, which is less than the world average value of 0.07 mSv y^{-1} (UNSCEAR, 2000).

ii. Mean population weighted exposure rate; D_w, which represents the exposure rate per individual living in study area was calculated from equation (2) (Gabdo*et al*., 2014).

$$D_w = \frac{\sum DP}{\sum P} \quad (2)$$

Where D and P are the mean dose rate and population respectively for each local government of Northern Zamfara State as summarised in Table 2. The calculated value for this parameter is 32.45 nGy h^{-1}.

iii. The sum of all annual individual effective exposures, otherwise known as the annual collective effective dose rate (SC) of the total population of Northern Zamfara was estimated through equation (3) (Garba *et al*., 2014; UNSCEAR, 2000).

$$SC = H_R \times P \quad (3)$$

Where P is the population of Northern Zamfara. The annual collective effective dose rate in Northern Zamfara is 59.33 Sv y^{-1}.

iv. Lifetime dose (LD) is dose accumulated by an individual living in the study area assuming one spend his or her lifetime in the Northern Zamfara. The parameter was calculated using equation (4) (Garba*et al*., 2014; UNSCEAR, 2000).

$$LD = H_R \times DL \quad (4)$$

Where DL is the average life expectancy assumed to be 70 years according to UNSCEAR (2000) report. The lifetime dose in Northern Zamfara is 2.75 mSv.

v. Excess lifetime cancer risk is the probability of developing cancer over a lifetime at a given exposure level. This health hazard was estimated using equation (5) (Garba*et al*., 2014).

$$ELCR = H_R \times DL \times RF \qquad (5)$$

Where RF is the risk factor that is fatal cancer risk per Sievet, assumed to be 0.05 Sv^{-1} in this work according to ICRP-106 (ICRP, 2008). The calculated value due to the exposure level in Northern Zamfara is 1.38×10^{-4}.

Conclusion

The assessment and mapping of TGR exposure rates in the study area was successfully carried out. The mean TGR exposure rate in the area is 32 nGy h^{-1}. BirninMagaji, KauraNamoda and Zurmi local government areas recorded higher value of TGR exposure rates than the rest four local government areas. The radiation distribution map shows that some parts of Zurmi, KauraNomada, BirninMagaji and Bakura local government areas are exposed to gamma radiation range from 34.00 to 61.43 nGy h^{-1}. This is because of the old granite formation that forms in those areas. The computed values of exposure and risk; annual effective dose, mean population weighted dose rate, collective effective dose, lifetime dose and excess lifetime cancer risk are 0.04 mSv y^{-1}, 32.45 nGy h^{-1}, 59.33 Sv y^{-1}, 2.75 mSv and 1.38×10^{-4} respectively, and they were all below the world average values for the parameters. Therefore, the rate of gamma radiation exposure may not have significant effect on the people of Northern Zamfara State.

Conflict of Interest

The authors declare that there is no conflict of interest in this study.

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Symbols and Units

nGy h^{-1}	–	nano-Gray per hour
mSv y^{-1}	–	milli-Sievert per year
mR h^{-1}	–	milli-Roentgen per hour
μR h^{-1}	–	micro-Sievert per hour
Sv y^{-1}	–	Sievert per year
mSv	–	milli-Sievert