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Assessment of the Radiation Hazard Indices from Terrestrial Radiation in Mining Sites in Benue State, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Authors AIO and GOA designed the study. Author AIO performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author GOA supervised and managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

The assessment of the radiation hazard indices of solid minerals and sand in mining sites of Benue State, Nigeria was carried out using well calibrated radalert-50 and 100 meters and a Global Positioning System (Garmin 765). The sites investigated are Lessle (Barite), Gboko (Limestone), Owukpa (Coal) and Akuana (Salt) deposits fields. The mean background radiation ionization exposure rate of 0.019±0.004, 0.019±0.004, 0.014±0.002 and 0.023±0.005 mRh^{-1} were obtained respectively. The mean of absorbed dose rates estimated for the mining fields are 161.53, 169.40, 120.35 and 201.84 nGy/hr respectively. Estimated values of the annual effective dose equivalent (AEDE) for outdoor exposures 0.25, 0.26, 1.61, and 2.71 mSv/yr respectively while the mean excess lifetime cancer risk calculated for the mine fields values are (0.82, 0.86, 5.33 and 8.94) x 10^{-3} respectively. The obtained values for background ionizing radiation were higher than the recommended standard limits by ICRP while the AEDE calculated in the entire mine fields are

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within safe values but the absorbed dose (D) and excess lifetime cancer risk (ELCR) estimated were higher than their world permissible values of 89 nGy/hr and 0.29 $x10^{-3}$ respectively. The work indicated that there is tendency for the residents near the mining sites to get high radiation doses and could develop radiation-related illness after a long time exposure.

Keywords: Solid minerals; radalert-(50 and 100); radioactivity; excess lifetime cancer risk and effective dose.

1. INTRODUCTION

Mining industries have been viewed as key drivers of economic growth and the development process [1]. Due to the presence of mineral deposits of economically viable grades, mining and extraction of metals are carried out in such mineralised zones of Benue State, Nigeria. Mining activities all over the world have contributed immensely to the disequilibrium of mineral elements and therefore affect the terrestrial ecosystem due to the excavation of large amount of sands [2].

Natural radioactivity is widespread in the earth environment and it exists in various geological formations such as earth crust, rocks, soils, plants, water and air. When rocks are disintegrated through natural process, radionuclides are carried to soil by rain and flows [3]. The ways minerals incorporate the radionuclide depend on several geological conditions, but is most strongly dependent on the mineral species and geological formation from which they originate.

Exposure to all these radiations from the mineral mining sites that has been contaminated with radioactive waste may pose a threat to human health. Furthermore, consuming water and fishery resources may cause internal exposure which can lead to radiation related sicknesses like cancer, turmour and sterility [4]. Several studies of radiological survey have been carried out in some mineral mining sites in Nigeria and outside the country to monitor radiation level and it's associated radiation risk [5-10]. None of the investigations done in similar environment in Nigeria determined level of radiological burden for different range of minerals of exposure to such background radiations. Hence, there is need to investigate the present radioactivity status of the mineral mining sites.

This work assessed the background radiation level of mining sites in Benue State and its surroundings and to estimate the radiation risk parameters in order to assess its biological effect to exposed populace.

2. MATERIALS AND METHODS

2.1 Study Area

The study areas are located in Benue State which lies within the lower river Benue trough in the middle belt region of Nigeria and are within the geographical points situated on longitude 7° 47' and 10°0' East and Latitude 6°25' and 8°8' North. The geology of the study area is principally of sedimentary formation with pockets of basement complex which is made up of sandstones, mudstones and limestone that influences both surface and ground water availability [11,12]. Benue State is endowed with solid mineral resources such as industrial minerals – barites, kaolin, gypsum, limestone; Energy mineral – coal, Chemical mineral – brine; Metallic mineral – wolframite, bentonite clay, lead and zinc etc, which are evenly distributed over the existing geographical location, some of which are not yet being mined but are being investigated [13]. Fig. 1 shows the location map of the study area.

2.2 Field Measurements

The *in situ* measurements of the terrestrial radiation from the surface of the soil of the mine fields were done directly in an undisturbed manner. Using a well calibrated rad-monitor, Digilert – 50 and Radalert – 100 nuclear radiation monitoring meter (S.E. International Incorporation, Summer Town, USA), containing a Geiger-Muller tube capable of detecting alpha, beta, gamma and X-rays within the temperature range of 10℃ and 50℃. The Giegermuller tube generates a pulse current each time radiation passes through the tube and causes ionization [14]. Each pulse is electronically detected and registered as a count. The radiation meters were calibrated with a ^{137}Cs source of a specific

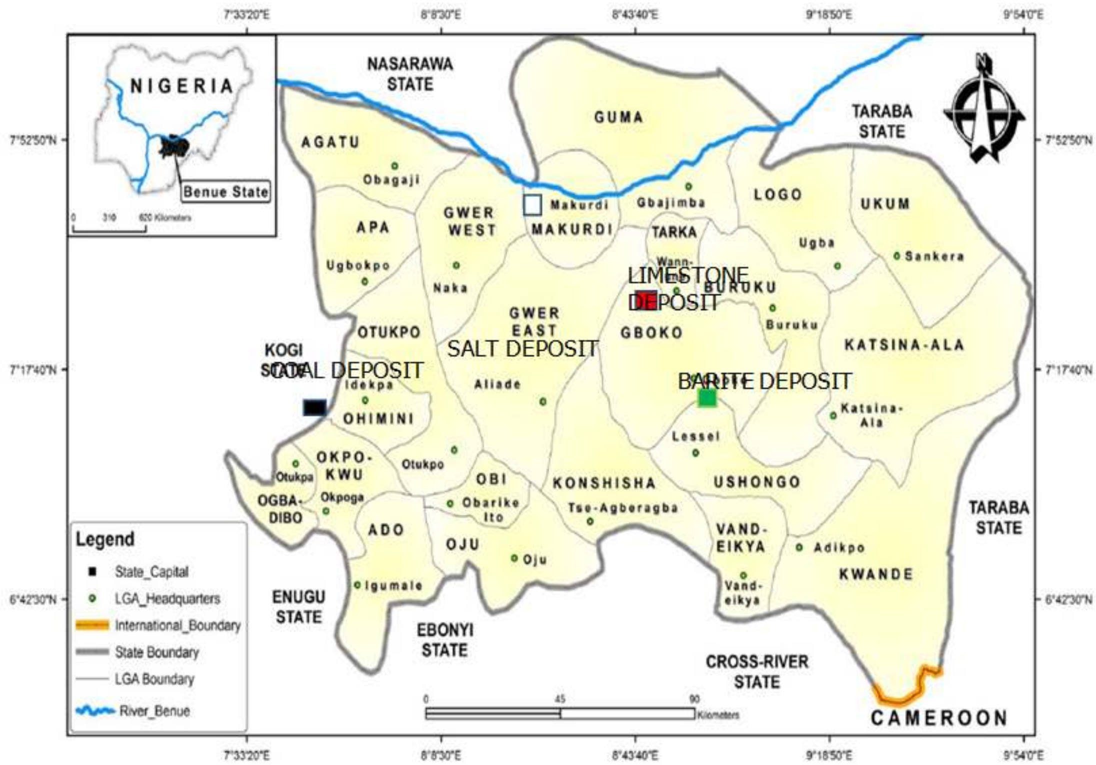

Fig. 1. Map of the study area

energy and set to measure exposure rate in milli-Roentgen per hour ($mRhr^{-1}$). The meter has an accuracy of ±15%. The measurements were carried out by positioning the radiation meter at the targeted sample (rock aggregates and surface samples) located at varying distance from the mineral deposit mine field(s) established by Geographical Positioning System (GPS). Measurements were taken within the hours necessary since exposure rate meter has a peak response to environmental radiation within these hours, then the background radiation level was recorded. In order to ensure quality assurance the provisions taken include: Two measuring instruments was deplored to field and standardization of the measuring instruments before use was done, multiplicity of measurement for each sample point (n = 4 for radiation measurements for each sample point). The switch (knob) was turned to return the meter to zero after each measurement.

2.3 Data Analysis/Conversion

The generated data were converted to absorbed dose rate nGy h^{-1} using the relation for the external exposure rate by [9].

$$1\mu R/h = 8.7\ nGy/h = 8.7 \times 10^{-3}\mu Gy/(1/8760\, y),$$

The results are presented as means and standard deviations while the bar chart illustrations were carried out to determine the significant relationships between the radiations from different sample types as shown in Tables 1-4.

3. RESULTS AND DISCUSSION

3.1 Results

The results for the *in-situ* measurement of terrestrial radiation level and the calculated values for gamma dose, annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) of the barite, limestone, coal and salt mining fields are presented in Tables 1-4 and while Table 5 presents the summary of parameters calculated. Figs. 2 and 3 show the comparison of excess lifetime cancer risk with average world standard value for barite, limestone, coal and salt mining fields respectively.

3.2 Radiation Risk Parameters

The data obtained for the radiation exposure rate and the absorbed dose does not actually provide the exact indication about the total radiation hazards. The γ radiation hazards as a result of the exposure to background ionizing radiation in selected mining fields and its environs are estimated by calculating radiation risk parameters.

Table 1. The mean radiation exposure rate and estimated radiation risk parameters of the barite mineral deposits fields in Lessle area

Sample location	Geographical positions	AVE. RAD. value $mRhr^{-1}$	Absorbed dose nGy/hr	AEDE (mSv/yr)	ELCR $X\ 10^{-3}$
Lessle area	N07°08'11.2'' E009°01'28.1''	0.021±0.004	182.7	0.2401	0.7922
Ge-Mbagwa area	N07°07'46.4'' E009°00'49.7''	0.019±0.005	165.3	0.2667	0.8802
Akegh-Dyege area	N07°08'01.7'' E009°01'00.1''	0.032±0.005	278.4	0.4268	1.4084
Ushongo	N07°08'07.4'' E009°01'20.8''	0.019±0.008	165.3	0.2267	0.7482
Mbakoa	N07°08'34.4'' E009°01'24.5''	0.018±0.004	156.6	0.2667	0.8802
Nyamge area	N07°08'19.5'' E009°01'30.2''	0.017±0.003	147.9	0.1867	0.6162
Ushongo community(Host)	N07°08'11.0'' E009°01'16.4''	0.011±0.008	95.7	**0.1467**	**0.4841**
Mean field value		0.019±0.004	161.5	0.2476	0.8172

Table 2. The mean radiation exposure rate and estimated radiation risk parameters of the limestone mineral deposits fields in Gboko area

S/N	Geographical positions	AVE. RAD. value $mRhr^{-1}$	Absorbed dose nGy/hr	AEDE (mSv/yr)	ELCR $X\ 10^{-3}$
Amua	N07°24'38.2'' E008°59'01.0''	0.021±0.005	182.7	0.2267	0.7482
Limestone deposit Ridge	N07°24'45.7'' E008°58'43.1''	0.019±0.005	165.3	0.1734	0.5722
Gboko-Yandev	N07°24'52.2'' E008°58'27.9''	0.018±0.003	156.6	0.1600	0.5281
Gboko community 1	N07°24'36.0'' E008°58'55.2''	0.017±0.008	147.9	0.3068	1.0123
Limestone deposit Pit	N07°24'17.1'' E008°58'42.8''	0.020±0.005	174.0	0.2667	0.8802
Gboko factory	N07°24'00.8'' E008°58'31.9''	0.031±0.001	269.7	3.6218	11.952
AMUA community(Host)	**N07°24'38.2'' E008°59'01.0''**	**0.013±0.007**	**113.1**	**0.1734**	**0.5722**
Mean field value		0.019	169.36	0.25963	0.8567

Table 3. The mean radiation exposure rate and estimated radiation risk parameters of the coal mineral deposits fields in Owukpa-Orokam area

Sample area	Geographical positions	AVE. RAD. value $mRhr^{-1}$	Absorbed dose nGy/hr	AEDE (mSv/yr)	ELCR X 10^{-3}
Otukpo area	N06°58'44.1'' E007°37'05.3''	0.011±0.002	95.7	1.5188	5.0121
Orokam area	N06°58'40.9'' E007°36'45.7''	0.014±0.002	121.8	1.7525	5.7832
Otupka area	N06°57'12.4'' E007°37'00.4''	0.024±0.004	208.8	2.8040	9.2532
Owupka area	N06°57'18.2'' E007°37'12.5''	0.021±0.002	182.7	2.4535	8.0965
Bagba area	N06°57'24.4'' E007°37'54.0''	0.016±0.005	139.2	2.4535	8.0965
Bagba community	N06°57'32.5'' E007°37'03.4''	0.013±0.002	113.1	1.6357	5.3977
Owupka community (Host)	N06°56'58.1'' E007°37'22.3''	**0.008±0.003**	**69.6**	**0.9347**	**3.0844**
Mean field value		0.014	120.35	1.61	5.33

Table 4. The mean radiation exposure rate and estimated radiation risk parameters of the salt mineral deposits fields in Akuana area

Sampled area	Geographical positions	AVE. RAD. value $mRhr^{-1}$	Absorbed dose nGy/hr	AEDE (mSv/yr)	ELCR X 10^{-3}
Akuana phase 1	N07°47'02.6'' E009°09'48.3''	0.025±0.006	217.5	2.57	8.48
Akuana salt lake	N07°47'04.8'' E009°09'35.6''	0.034±0.004	295.8	3.97	13.11
Akuana phase 2	N07°47'01.5'' E009°09'42.5''	0.022±0.002	191.4	3.15	10.40
Akuana phase 3	N07°47'58.0'' E009°09'49.9''	0.021±0.005	182.7	3.04	10.02
Akuana phase 4	N07°47'05.6'' E009°09'53.3''	0.031±0.005	269.7	3.62	11.95
Akuana community (Host)	**N07°47'08.1'' E009°09'53.4''**	**0.016±0.007**	**139.2**	**1.87**	**6.17**
Mean field value		**0.023**	**201.8**	**2.71**	**8.94**

Table 5. Summary of the measured exposure rate and the estimated radiation hazard parameters

Samples/ areas	Background ionizing radiations (Mean) ($mRhr^{-1}$)	Absorbed dose rates (Mean) ($nGyhr^{-1}$)	Annual effective dose equivalent (Mean) ($mSvyr^{-1}$)	Excess lifetime cancer risk (10^{-3}) (Mean)
Barite (Lessle)	0.017-0.032 **(0.019)**	147.9-278.4 **(161.53)**	0.19-0.43 **(0.25)**	0.62-1.41 **(0.82)**
Limestone (Gboko)	0.017-0.031 **(0.019)**	147.9-269.7 **(182.70)**	0.27-3.62 **(0.26)**	0.88-1.36 **(0.86)**
Coal (Orokam)	0.011-0.024 **(0.013)**	95.7-208.8 **(120.35)**	1.52-2.80 **(1.62)**	5.01-9.25 **(5.33)**
Salt (Akuana)	0.021-0.034 **(0.023)**	182.7-295.8 **(201.84)**	2.57-3.97 **(2.71)**	8.48-13.11 **(8.94)**

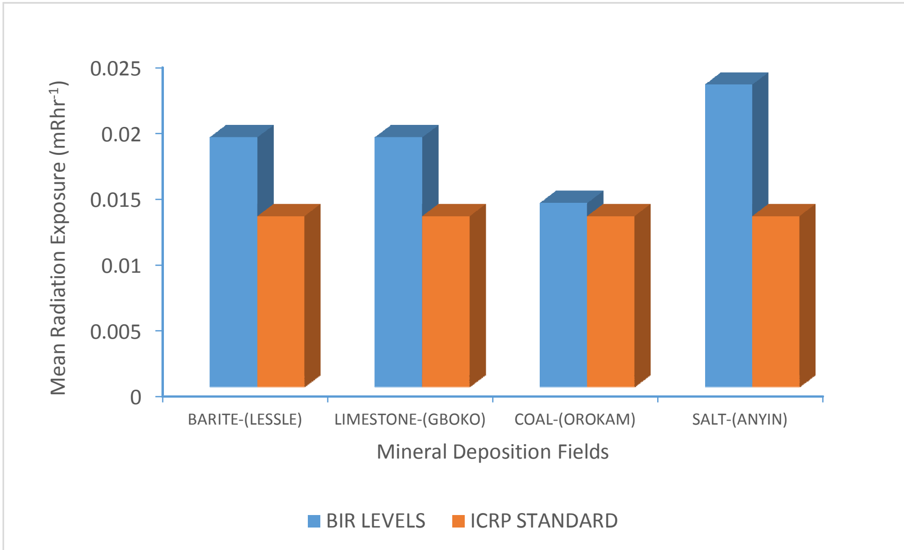

Fig. 2. Comparison of measured BIR levels with standard

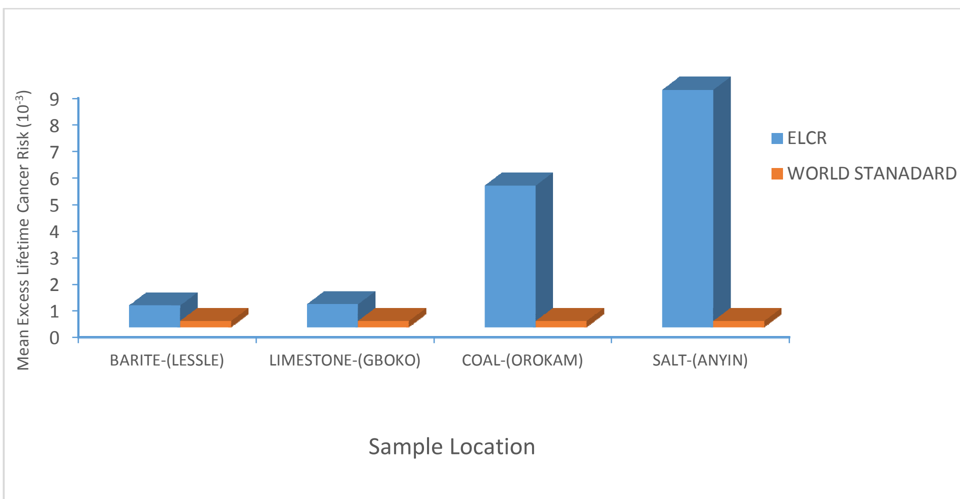

Fig. 3. Comparison of mean ELCR of mineral deposition field with World Safe limit value

3.2.1 Annual effective dose equivalent (AEDE)

The AEDE can give a clue on indication of radiological contamination in an outdoor environment which may result to inhalation of high level of radon gas emitted and its progeny from the mining activity that can lead to lung cancer from accumulated doses [15]. Measured absorbed gamma dose rates were used to calculate the annual effective dose equivalent (AEDE) received by individuals within and around the selected mining fields. In calculating AEDE, dose conversion factor of 0.7 Sv/Gy and the occupancy factor for outdoor of 0.25 (6/24) was used. The occupancy factor for outdoors was calculated based upon interviews with peoples of the area. People of the study area spend almost 6 hours outdoors due to the nature of their routine. The annual effective dose equation was estimated using the following relation [16]:

$$\text{AEDE (outdoor) (mSv/y)} = \text{Absorbed dose rate (nGy/h)} \times 8760\ \text{h} \times 0.7\text{Sv/Gy} \times 0.25 \quad (2)$$

The annual effective dose equivalent for the barite, limestone, lead, coal and salt deposition fields of Benue state ranges from 0.19 to 0.43 $mSvy^{-1}$, 0.27 to 3.62 $mSvy^{-1}$, 1.52 to 2.80 $mSvy^{-1}$, and 3.04 to 3.97$mSvy^{-1}$ respectively.

3.2.2 Excess life cancer risk (ELCR)

The probabilities of contacting cancer by the mine workers and residents of the study area who will spend all their life time in this environment can be estimated using the excess lifetime cancer risk (ELCR) even in the absence of outbreak radioactive components.

The linear no threshold (LNT) hypothesis extrapolation from evidence‑supported, high‑dose effects to low‑dose responses claims that all acute ionizing radiation exposures down to zero are harmful. The harm is proportional to dose and is cumulative throughout life, regardless of how low the dose rate is [17]. This study is based on the traditional worldwide radiation protection standards for late (stochastic) effects which are based on the LNT hypothesis [18].

The annual effective dose calculated was used to estimate the excess lifetime cancer risk (ELCR) is calculated using equation (3).

$$ELCR = AEDE \times \text{Average duration of life (DL)} \times \text{Risk factor (RF)} \quad (3)$$

Where AEDE, DL and RF is the annual effective dose equivalent, duration of life (70 years) and risk factor (Sv^{-1}), fatal cancer risk per sievert. For low dose background radiations which are considered to produce stochastic effects, ICRP 60 uses values of 0.05 for the public [3,19]. ELCR ranges from (0.62 to 1.41) x 10^{-3} with an average of 0.82 x 10^{-3} for barite deposit fields, from (0.88 to 11.95) x 10^{-3} with an average of 0.86 x 10^{-3} for limestone deposit fields while ELCR for coal deposit fields range from (5.01 to 9.25) x 10^{-3} with a mean value of 5.33 x 10^{-3}. The ELCR of salt deposit fields ranges from (8.48 to 13.11) x 10^{-3} with a mean value of 8.94 x 10^{-3}.

3.3 Discussion

The terrestrial radiation level and radiation parameters of the four mine deposit fields (Lessle, Gboko, Otukpo and Akuana) of Benue state and its environs was determined with two well-calibrated radiation meters and the results are presented in Tables 1 to 5. The values of radiation exposure level range from 0.017 (Nyamge area) to 0.032 (Akegh-Dyege) mRh^{-1} in theLesslebarite deposit fields. About 96.7% of the values obtained are higher than the ICRP standard of 0.013 mRh^{-1} for normal background ionizing radiation and for the host community with value of 0.011±0.008 mRh^{-1}. The results show that higher values are as a result of the anthropogenic activities in the field which have exposed radioactive elements in the mine fields. The highest radiation level recorded at Akegh-Dyege and Lessle mine sites may be attributed to the anthropogenic activities which have left loose the geology of the host rock (sandstone, basement gneisses) in the trough. The consistent high values obtained in the mine field and nearby communities may be seen from spatial vein deposits which cut across the communities. These vein barites are usually extracted as a by or co-product of lead-zinc mining and persisted into the basement complex [20]. The radiation exposure rates at the limestone and coal mine deposit fields of Benue state ranges from 0.017 (Gboko Community) to 0.031 (Gboko Factory) mRh^{-1}, and 0.011 (Otukpo area) to 0.024 (Otukpa area) mRh^{-1}. About 42%, of the limestone mine fields sampling points are higher than ICRP standard of 0.013 mRh^{-1} and 38%of the coal mine fields sampling points are higher than ICRP standard of 0.013 mRh^{-1} respectively. The values obtained at the limestone and coal mine deposit fields host communities (Amua community and Owukpa community) are quite lower than those obtained in the mine fields. In coal mining fields, Otukpa and Owukpa areas sample points have higher values of 0.024 $mRh^{-1}$and 0.021 mRh^{-1} radiation exposure. In Akuana mine fields, the value of radiation exposure rate for salt range from 0.021 to 0.034 mRh^{-1}. About 44% of the values recorded here are higher than the ICRP standard for normal background radiation level. The mean exposure rate of the four mine deposit fields were found to be higher than the value obtained in Akwa-Ibom state (0.007-0.015 mR/hr) [21]. Also values obtained are higher than the 0.018 ± 0.004 mRh^{-1} value reported for some solid minerals mining environment in Enugu state [22] and other previously reported value in solid mineral environment in Nigeria [23,24]. Results obtained here are relatively lower than the results obtained in mine tailings of Awo and Ede, Osun state [25] and in Akwanga, Jos, Plateaus state, Nigeria [26] where mining activities have spanned over many years.

The variation of gamma dose rates from place to place may be attributed to changes in weathering conditions. UNSCEAR have related that change in weathering conditions causes alteration in radon posterity concentration in air due to soil moisture, rainfall and snow [27]. High absorbed dose rates were obtained in all the mineral deposition fields; these may be due to mining of the mineral composition of the rock forms which may be rich in radioactive bearing minerals [27]. The absorbed dose of radiation estimated in the barite deposit fields (Lessle) ranges from 95.7 to 278.4 $nGyh^{-1}$ with mean value of 161.53 $nGyh^{-1}$ and the limestone deposit fields (Gboko) ranges from 113.1 to 269.7 $nGyh^{-1}$ with mean value of 182.70 $nGyh^{-1}$ while the absorbed dose rate at the coal deposit fields (Owukpa-Orokam) ranges from 69.6 to 208.8 $nGyh^{-1}$ with mean value of 120.35 $nGyh^{-1}$while the absorbed dose rate for salt lake deposit fields (Akuana) ranges from 130.50 to 295.80 $nGyh^{-1}$with mean value of 201.84 $nGyh^{-1}$. The values reported for salt and limestone mine fields are higher than those reported barite and coal mine fields. Mean outdoor gamma dose rate measured for this study are higher than the values previously reported in South Lebanon [19], in Poonch District [8] (106 $nGyh^{-1}$ and 102 $nGyh^{-1}$) respectively. The measured outdoor gamma dose rates are also within the values reported in Turkey (78.3-135.7 $nGyh^{-1}$) [26]. The highest outdoor gamma dose rate measured at Akegh-Dyege (barite) (278.4 $nGyh^{-1}$), Gboko Factory (limestone) (269.7 $nGyh^{-1}$), Otupka Area (coal) (208.8 $nGyh^{-1}$) and Akuana Salt Lake (salt) (295.8 $nGyh^{-1}$) were higher than the values previously reported in South Lebanon(106 $nGyh^{-1}$) [19], and in Poonch District (102 $nGyh^{-1}$) [8]. The measured outdoor gamma dose rates are also higher than the values reported in Turkey (78.3- 135.7 $nGyh^{-1}$) [26]. This could be due to dissimilarities in the activities that enhance the exposure of the geologic constituent of different areas. The absorbed doses estimated are higher than the world permissible value of 89.0 $nGyh^{-1}$. The annual effective doses estimated in the four mineral deposition fields of Benue state (barite (Lessle), limestone (Gboko), coal (Owukpa-Orokam) and salt (Akuana)) were higher than the results obtained in Jhelum valley [9] and higher than world average of 0.48 $mSvy^{-1}$in the barite and limestone deposition fields and lower than the world average at the coal and salt lake deposition fields. Excess lifetime cancer risks estimated for the entire studied deposition fields were higher than the values obtained by in Ogun River [4], in Poonch, Turkey [8], and in Greece [28].

The values were found to be higher than average world standard of 0.29 x 10^{-3} as shown in Fig. 3. The consequence of this is that individuals exposed to this radiation may likely develop cancer within their lifetime due to ionization of tissues.

4. CONCLUSION

The terrestrial radiation due to solid minerals and sand in mining sites- Lessle, Gboko, Orokam and Akuana and the minerals fields of Benue State have been carried out. We conclude that

1. The Background ionizing radiation in all mineral deposition sites are above those of the host communities.
2. The mean absorbed dose rate (D) in all mineral fields are higher than the world average permissible value and greater than the world population weighted average dose rates.
3. The mean annual effective dose equivalent rate (AEDE) in all mineral fields is higher than the results obtained by other workers in similar environment and world average acceptable values.
4. The ELCR calculated in mineral fields are higher than safe value.

The high level of gamma dose rates obtained may not have any immediate health hazards but could lead to some radiological problems for long term exposure of people living or working around the mine fields, since the fields are radiologically degraded.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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