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Radiation hazards from granite and bitumen in construction material site in Aniocha South Local Government Area of Delta State, South-South Nigeria

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H I G H L I G H T S

- Granite and bitumen from different geographical location have different radiation levels.
- Most workers in construction/material deposit sites are not aware of the impact of ionizing radiation.
- The ADR was 3 times higher than the world average.
- The effective lifetime cancer risk (ELCR) was above the acceptable risk band (10^{-6} to 10^{-4}).

A B S T R A C T

The study is aimed at measuring the background ionizing radiation (BIR), the absorbed dose rate (ADR), the annual effective dose (AED) and excessive lifetime cancer risk (ELCR) at four sites in the Aniocha South local government area (LGA) of Delta State, denoted as A to D. The study was performed using a calibrated Geiger-Muller (GM) detector (Radiation Alert Inspector) as well as a geographic positioning system (GPS) to determine the longitude and latitude of each site. The average (range) outdoor BIR, ADR, and AED were 0.021 ± 0.01 (0.01 to 0.04) mR.hr^{-1}, 181.6 ± 77.7 (60.9 to 322.8) nGy.hr^{-1}, and 0.22 ± 0.10 (0.07 to 0.40) mSv.yr^{-1}, respectively. Among the processing sites, the average AED for granite, bitumen, and staff residential areas were 0.31, 0.12, and 0.17 mSv.yr^{-1}, while surface measurements at the "burnt stone" had the highest AED (0.41 mSv.yr^{-1}). ADR and AED were both considerably higher than the world average of 59 nGy.hr^{-1} and 0.07 mSv.yr^{-1}. The average effective lifetime cancer risk (ELCR) was 7.7×10^{-4} (1 in 1,300), with the highest in the granites. The ELCR risk grade was high ($> 10^{-4}$), suggesting that remedial action be taken to ensure safety in the granite sites based on the environmental protection agency (EPA) United States report.

K E Y W O R D S

Background ionizing radiation
Global positioning system
Radionuclide
Granite
Bitumen

H I S T O R Y

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1 Introduction

Many radioactive elements are naturally occurring within the earth's crust as deposits (Abed et al., 2022). All soils contain trace levels of terrestrial radionuclides, resulting in radiological exposures outdoors (Ahmad et al., 2019; Doyi et al., 2017). There are specific levels for different types of soil determined by the rock. Granite is an igneous rock with higher radiation levels, while sedimentary rocks have low levels (Roy et al., 2022; Kapanadze et al., 2021). The exception comes from certain rocks, such as shales and phosphates, which contain a lot of radionuclides (Missimer et al., 2019; Boryło et al., 2017).

The primary sources of Potassium 40 (K-40), Uranium 238 (U-238), and Thorium 232 (Th-232) are rock, soil, and groundwater. Radium (Ra-228, Ra-226, and Ra-224) and Radon (Rn) undergo spontaneous disintegration to produce daughter particles with alpha, beta, or gamma-ray emission (Joel et al., 2021; Mathuthu et al., 2021; Degu Belete and Alemu Anteneh, 2021; Napoli et al.,

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2021).

Radiation protection in the environment is poorly understood by the public (Hobbs et al., 2018; Slovic, 2012). We also found this to be true in an interview with granite and bitumen workers at various sites. However, they have virtually no awareness of radiation protection. An individual's educational background may also limit their knowledge, although this fact hasn't been explored. Over the years, the numbers of granite and bitumen processing sites for road constructions have increased due to large deposit of granite, limestone, laterite and bitumen in Nigeria (Oyedele et al., 2016; Akpan et al., 2011; Magaji et al., 2020).

Many surveys have been conducted to determine the background levels of radionuclides in granites, which can be related to the absorbed dose rates in the air. Many of which have been found to vary based on geographical location (UNSCEAR, 2000; Shahbazi-Gahrouei et al., 2013).

The average of absorbed dose rate (ADR) and annual effective dose (AER) from terrestrial gamma radiation was 59 nGy.hr^{-1} and 0.07 mSv.yr^{-1}, respectively based on the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report from large surveys (UNSCEAR, 2000). Extremely high values have been recorded in places in Kerala in India with up to 70 mGy.yr^{-1} (Nair et al., 2009), while another study in same area by Sudheer et al. have reported an average AER of < 1 to 45 mGy.yr^{-1} (Sudheer et al., 2022), however, there has been no evidence of cancer-related cases in places where these values are high but chromosome aberration have been identified from samples collected (Gh et al., 2019).

The excessive lifetime cancer risk (ELCR) have been divided into 4 groups of very high ($> 10^{-64}$), high (10^{-4} to 10^{-5}), moderate (10^{-5} to 10^{-6}) and low ($< 10^{-6}$) from the development of a nationwide excessive lifetime cancer risk in Korea (Kang et al., 2021). The United States has adopted the use of the environmental protection agency report, which has graded ELCR as negligible ($< 10^{-6}$), acceptable (10^{-6} to 10^{-4}) and remediation may be desirable ($> 10^{-4}$) (EPA, 2014).

The focus of this study is in the Aniocha South Local Government Area, which lies in the Northern region of Delta State with an area of 868 square kilometers (km^2). The purpose of the study is to estimate the average background ionizing radiation (BIR), annual dose rate (ADR), annual effective dose (AED) and excessive lifetime cancer risk (ELCR) from granite (crushed to different sizes), bitumen and staff residential areas within the processing sites in the above LGA. Similarly, this study compared the results with locally and internationally.

2 Materials and Methods

This research was a prospective and experimental based study, which was carried out for 3 months, in 4 construction dump sites (A and D = Otulu, B and C = Ubulu Okiti) in Aniocha South LGA of Delta state. Convenience sampling method was used in the selection process. A global positioning system (GPS) instrument and an Inspector USB survey meter calibrated in a Secondary Standard Dosimetry Laboratory (SSDL) in the National Institute of Radiation Protection and Research (NIRPR), University of Ibadan, Oyo State, Nigeria.

Radiation measurements were performed with a calibrated inspector USB survey meter. Inspection USB survey meter (S.E. International, Inc.), is health and safety instrument that detects low levels of radiation. Specifically, the instrument measures ionizing radiation, including Alpha and Beta particles, Gamma rays, and X-rays (Fig. 1). There are two different units of measurement for the survey meter: milliroengens per hour (mR.hr^{-1}) and counts per minute (CPM), or microsieverts per hour (Sv.hr^{-1}) and counts per second (CPS) with an operating range of 0.001 (1 μR) to 100 mR.hr^{-1} or 0 to 350,000 CPM (Table 1). The Global Positioning System (GPS) application software was downloaded and used to measure the longitudes, latitudes, and elevations of points in all the studied areas (Fig. 2).

Figure 1: Geiger Muller survey meter (back and front side).

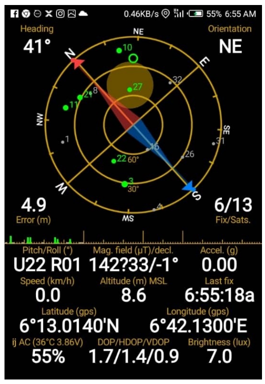

Figure 2: GPS system.

Figure 3: The construction dump sites for bitumen and granite.

2.1 Set-up for measurements

The survey meter was switched to the total timer (CPM or CPS) mode in order for the device to record reading electronically in count per minute (CPM) mode for a minimum time of 60 seconds. The sensitive area of the device was positioned in such a way that it faces the sample and it is about 30 cm (0.3 m) away from it. Simultaneously, the GPS device was activated to record the longitude, latitude and altitude of the point for BIR measurement. A total of 3 measurements were made per point in the sites (Fig. 3) and the average BIR was calculated.

The survey meter was used on the CPM mode and measurement was timed for a total of 180 seconds (3 measurements at 60 s). Conversion to milliroentgen per hour (mR.hr^{-1}) was carried out using the meter's calibration factor (3340 CPM.mR^{-1}.hr^{-1}). The relationship between CPM and mR.hr^{-1} was given as (Omojola et al., 2020):

$$\text{mR.hr}^{-1} = \frac{x\ \text{CPM}}{3340\ \dfrac{\text{CPM}}{\text{mR.hr}^{-1}}} \tag{1}$$

where x is the count recorded by the survey meter in CPM.

Measurement with both detectors was done simultaneously on the same point and data was entered in a record book for documentation. The BIR measurement was computed in CPM and was converted to mR.hr^{-1} using Eq. (1).

The annual dose rate (ADR) was estimated based on the Canadian Health and Safety Code 35 for the installation, use, and control of X-ray equipment, which is given as (Health-Canada, 2008):

$$1\ \text{mR.hr}^{-1} = 8700\ \text{nGy.hr}^{-1} \tag{2}$$

The annual effective dose (AED) was given as:

$$\begin{aligned} \text{AED (Outdoor) (mSv.hr}^{-1}) =& \\ &\text{ADR (nGy.hr}^{-1}) \times 8760\ (\text{hr}^{-1}) \\ &\times 0.7\ (\text{Sv.Gy}^{-1}) \times 0.2 \end{aligned} \tag{3}$$

AED was calculated using the dose conversion factor of 0.7 Sv.Gy^{-1} as recommended (UNSCEAR, 1993) for the conversion coefficient from the absorbed dose in air to the effective dose received by adults and an occupancy factor of 0.2 for outdoor exposure (UNSCEAR, 1993). The excessive lifetime cancer risk (ELCR) was estimated as:

$$\begin{aligned} \text{ELCR} = &\ \text{ADR (nGy.hr}^{-1}) \\ &\times \text{Average duration of life (DL)} \\ &\times \text{Risk factor (RF)} \end{aligned} \tag{4}$$

Where AEDE is the annual effective dose equivalent, DL is duration of life (70 years) and RF is the fatal cancer risk factor (Sv^{-1}). For low-dose background radiation, this is considered to produce stochastic effects, the fatal cancer risk factor value of 0.05 for public exposure (Sievert and Failla, 1959).

2.2 Statistical Analysis

The study used descriptive statistics (average, median and standard deviation), a One-Sample t-test, One-Way ANOVA and Pearson correlation to analyze the results. $P < 0.05$ was considered to be statistically significant and vice versa.

3 Results and Discussion

The map in Fig. 4 indicates the points of measurement from the 4 construction dump sites in Otulu and Ubulu Okiti, denoted as A to D, while Fig. 5 shows the BIR contour map. In site A, four sizes of granite stones were measured. The average (range) altitude was 199 (141 to 222) m and the maximum ADR (322.8 nGy.hr^{-1}) and AED (0.4 mSv.yr^{-1}) were measured on the surface of the burnt stone. The values were approximately 6 times higher than the world average (UNSCEAR, 2000). Measurements around the bitumen area showed the least AED, which was lower than measurements in the staff residential areas. A One-Sample T-test showed that there was a statistically significant difference in BIR, ADR, and AED ($P < 0.001$) (Table 2).

This study measured three sizes of granite stones at site B at altitude of 240 (195 to 256) m. No matter how big or small the granite was, the BIR and AED measurements were identical. Furthermore, the average BIR was twice as high as the world average, while the average ADR and AED were three times as high. It was found that measurements near bitumen tanks had the lowest ADR (60.9 nGy.hr^{-1}) and AED (0.07 mSv.yr^{-1}), which is similar to the UNSCEAR 2000 report (UNSCEAR, 2000), where 59 nGy.hr^{-1} and 0.07 mSv.yr^{-1} were reported. One-Sample T-Test results indicated that altitude ($P = 0.001$), BIR ($P = 0.001$), ADR ($P = 0.001$), and AED ($P = 0.001$) were statistically significantly different (Table 3).

Measurements of 4 sizes of granite stones were made at site C at altitude of 253 (248 to 255) m. Of the four sizes of granite stones, the $\frac{3}{4}$ inch stone showed the highest dose rate. AED and BIR measurements were essentially the same regardless of granite size (2 and 1 decimal place, respectively). The lowest dose rate was recorded around the bitumen and staff quarters, which was above the global average (Table 4).

A similar trend is evident in Table 5 for granite, which showed the highest dose rate. Both bitumen and residential areas received the same dose rate. Based on the One-Sample T-test, the dose rate parameters were statistically different among them. The One-Way ANOVA test revealed that there was no significant difference in the average measurements taken at each of the four construction dump sites in Aniocha South LGA ($P > 0.05$). Granite had a dose rate that was 3 times higher than bitumen and 2 times higher than the staff residential areas. Only 3% of the AED matched the global average value. A correlation in AED was also found between sites A and C ($P = 0.008$) and A and D ($P = 0.002$), indicating a close association between the measurements. Comparison

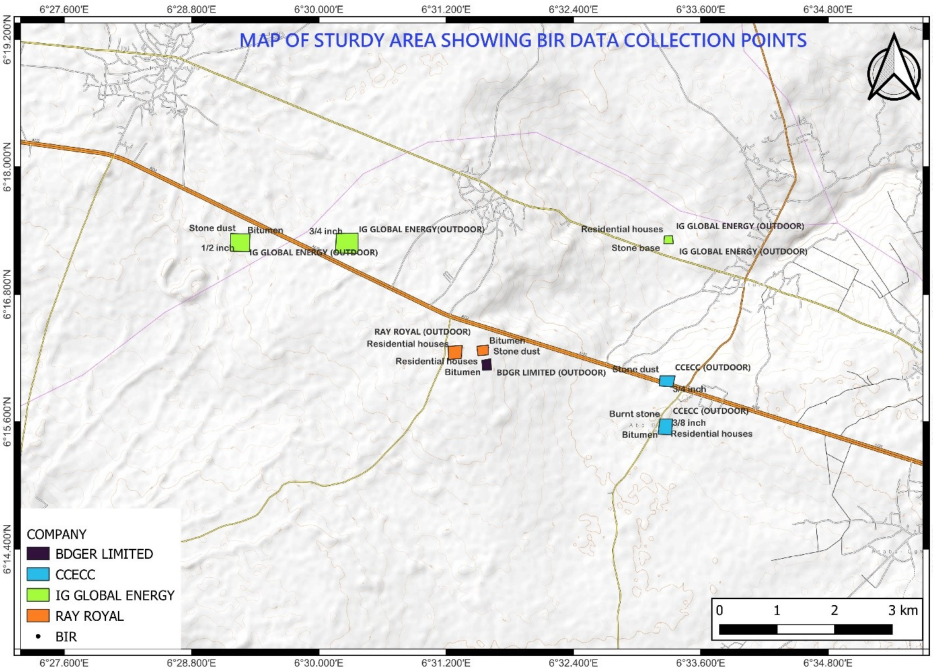

Figure 4: Map showing granite and bitumen construction sites A to D.

Table 1: Technical specifications of survey meter.

Display	Backlit 4 digit liquid crystal display with indicator. Display updates every 3 s
Alert set range	$mR.hr^{-1}$ 0.001-50, CPM 1 to 160,000
Count light	Red LED flashes with each radiation event
Audio indicator	Internally mounted beeper
Detector	Internal Halogen-Quenched uncompensated GM Tube with thin mica window 1.4 to 2.0 $mGy.cm^{-2}$ area density
Operating Range	$mR.hr^{-1}$ = 0.001 to 100 CPM = 0 to 350,000 $\mu Sv.hr^{-1}$ = 0.01 to 1000 CPS = 0 to 5,000
Total/Time	1 to 9,999,000 counts
Energy Sensitivity	Detect alpha down to 2 MeV and Beta down to 0.16 MeV Typical detection efficiency at 1 MeV is ∼ 25% Detect gamma down to 10 KeV through the window
Accuracy (Cs-137)	$mR.hr^{-1}$ ± 10% typical (NIST), 15% Max 0.001 to 100 $\mu Sv.hr^{-1}$ ± 10% typical (NIST), 15% Max 0.01 to 1000 CPM ± 10% typical (NIST), 15% Max 0 to 350,000
Power requirement	A 9 V alkaline batteries
Temperature	-10 °C to 50 °C (14 °F to 122 °F)

Table 2: The geographical location and average BIR, ADR, and AED measurements in granite and bitumen construction site (A) in Otulu, Aniocha LGA.

S/N	Gravel area	Geographical location	Altitude (m)	Average BIR ($mR.hr^{-1}$)	ADR ($nGy.hr^{-1}$)	AED ($mSv.yr^{-1}$)
1	3/8 inch	N060 15.59′, E060 33.25′	141	0.023	198.4	0.24
2	3/4 inch	N060 16.00′, E060 33.27′	194	0.033	282.8	0.35
3	Stone-dust	N060 16.00′, E060 33.27′	195	0.032	281.0	0.34
4	Burnt-stone	N060 15.58′, E060 33.28′	193	0.037	322.8	0.40
	Bitumen area					
1	In tanks	N060 15.57′, E060 33.26′	219	0.013	109.6	0.13
2	Around tanks	N060 15.57′, E060 33.25′	222	0.013	113.1	0.14
	Staff residence area					
1	Inside the houses	N060 15.58′, E060 33.25′	212	0.014	118.3	0.15
2	Around the houses	N060 15.58′, E060 33.25′	212	0.016	139.2	0.17

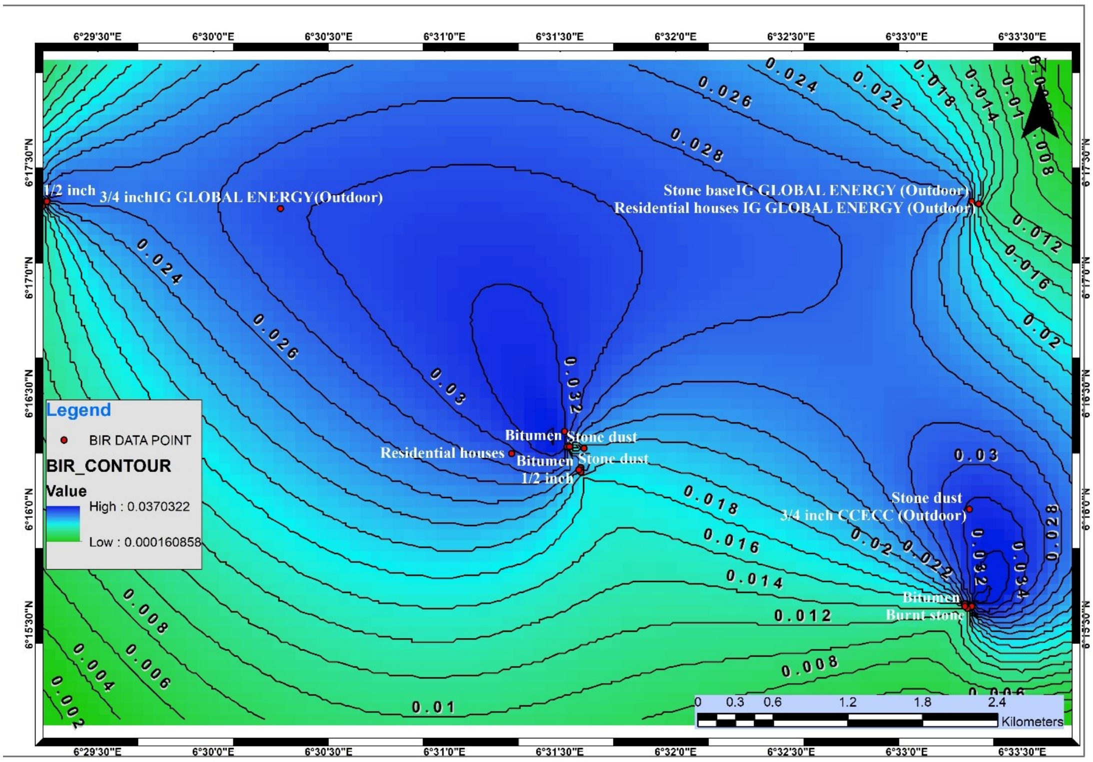

Figure 5: Map showing BIR measurements.

Table 3: The geographical location and average BIR, ADR, and AED measurements in granite and bitumen construction site (B) in Ubulu Okiti, Aniocha LGA.

S/N	Gravel area	Geographical location	Altitude (m)	Average BIR (mR.hr^{-1})	ADR (nGy.hr^{-1})	AED (mSv.yr^{-1})
1	3/8 inch	N060 16.25′, E060 31.53′	253	0.030	260.13	0.32
2	Small-stone	N060 16.27′, E060 31.53′	250	0.028	240.99	0.30
3	Stone-dust	N060 16.28′, E060 31.54′	195	0.029	249.69	0.31
	Bitumen area					
1	In tanks	N060 16.27′, E060 31.54′	256	0.009	76.56	0.09
2	Around tanks	N060 16.27′, E060 31.52′	247	0.007	60.9	0.07
	Staff residence area					
1	Inside the houses	N060 16.24′,E060 31.29′	242	0.029	252.3	0.31
2	Around the houses	N060 16.24′,E060 31.29′	240	0.025	217.5	0.27

Table 4: The geographical location and average BIR, ADR, and AED measurements in granite and bitumen construction site (C) in Ubulu Okiti, Aniocha LGA.

S/N	Gravel area	Geographical location	Altitude (m)	Average BIR (mR.hr^{-1})	ADR (nGy.hr^{-1})	AED (mSv.yr^{-1})
1	3/4 inch	N060 17.30′, E060 30.29′	251	0.0298	259.3	0.32
2	1/2 inch	N060 17.33′, E060 29.27′	255	0.0255	221.9	0.27
3	Stone-dust	N060 17.33′, E060 29.28′	254	0.0293	254.9	0.31
4	Stone-base	N060 17.33′, E060 33.28′	254	0.0265	230.6	0.28
	Bitumen					
1	in tanks	N060 17.31′, E060 29.26′	253	0.0115	100.1	0.12
2	around tank	N060 17.31′, E060 29.25′	254	0.0117	101.8	0.13
	Staff residence					
1	Inside the houses	N060 17.32′, E060 33.31′	251	0.0113	98.3	0.12
2	Around the houses	N060 17.32′, E060 33.32′	248	0.0115	100.1	0.12

Table 5: The geographical location and average BIR, ADR, and AED measurements in granite and bitumen construction site (D) in Otulu, Aniocha LGA.

S/N	Gravel area	Geographical location	Altitude (m)	Average BIR ($mR.hr^{-1}$)	ADR ($nGy.hr^{-1}$)	AED ($mSv.yr^{-1}$)
1	3/4 inch	N060 16.18′, E060 31.59′	231	0.026	226.2	0.28
2	1/2 inch	N060 17.33′, E060 29.27′	255	0.026	221.9	0.27
3	Stone dust	N060 17.33′, E060 29.28′	254	0.029	254.9	0.31
4	Stone base	N060 17.33′, E060 33.28′	254	0.027	230.6	0.28
	Bitumen area					
1	in tanks	N060 17.31′, E060 29.26′	253	0.012	100.1	0.12
2	around tank	N060 17.31′, E060 29.27′	255	0.012	101.8	0.13
	Staff residence area					
1	Inside the houses	N060 17.32′, E060 33.31′	251	0.012	101.8	0.12
2	Around the houses	N060 17.32′, E060 33.33′	253	0.012	103.5	0.13

Table 6: Comparison of the average measurements in this study with other published articles and world average.

Study/Report	BIR ($mR.hr^{-1}$)	ADR ($nGy.hr^{-1}$)	AED ($mSv.yr^{-1}$)
This study	0.02 ± 0.01	181.6 ± 77.7	0.22 ± 0.10
(UNSCEAR, 2000)	0.01	59	0.07
(Ijabor et al., 2022)	0.01 ± 0.002	91.6 ± 19.5	0.11 ± 0.02
(Onwuka and Ononugbo, 2019)	0.026	228.4	0.28
(Akerblom and Mjones, 2000)	-	-	0.1 to 0.4
(Yousef et al., 2019)	-	129.2	-
(Okedeyi et al., 2012)	0.0015	2.3 to 19.4	0.0026 to 0.0024
(Samuel, 2018)	-	18.87	0.25
(Myatt et al., 2010)	-	-	0.005 to 0.18
(Orosun et al., 2019)	-	57.68	0.07

of this study with a similar work in Aniocha South Local Government Area by Ijabor et al., who investigated radiation level in 17 petrol stations, shows that the BIR, ADR and AED were doubled. Indicating that the radiation levels in the granites were higher compared to refined petroleum products (Ijabor et al., 2022).

This study is comparable to a work in Ebony State, Nigeria by Onwuka and Ononugbo, who determined dose rate measurement in quarry site. The average dose rate from their study was 0.026 $mR.hr^{-1}$, which was slightly above this study (0.021 $mR.hr^{-1}$). The average ADR (330 $nGy.hr^{-1}$) was twice and AED (2.21 $mSv.yr^{-1}$) was 6 times this study (Table 6). The geographical location and activities of the granite might cause the difference in dose rate (Onwuka and Ononugbo, 2019).

A study in Sweden by Akerblom and Mjones shows that workers in quarry site were exposed to 0.1 to 0.4 $mSv.yr^{-1}$, this value was 10 times in range higher compared to our study (0.01 to 0.04 $mSv.yr^{-1}$) from construction dump sites of granite and bitumen (Akerblom and Mjones, 2000) (Table 6).

The concentration of Radon and average annual effective dose for granite samples collected from Abu Rusheid area, South Eastern Desert, Egypt, were measured using passive technique with CR-39 and was found to be 129.2 $mSv.yr^{-1}$, this value was over 500 times higher compared to our study. The CR-39 is known to be insensitive to X-ray, beta and gamma particles. The result indicated that geographical position and the concentration of radioactive materials could greatly vary from one region to another (Yousef et al., 2019) (Table 6).

Conversely a study on dose rate measurement on bedrocks and soil in quarry sites in Ogun State, South-West Nigeria by Okedeyi et al., show that ADR value ranged from 2.3 to 19.4 $nGy.hr^{-1}$ and AED ranged from 2.6 to 23.81 $mSv.yr^{-1}$ (Okedeyi et al., 2012). Similarly, the maximum ADR and AED from a study by Samuel et al in Benue State, Nigeria from quarry granite site were 18.87 $nGy.hr^{-1}$ and 0.25 $mSv.yr^{-1}$ (Samuel, 2018). In addition, a study by Myatt et al, on granite countertops shows a range of 0.005 to 0.18 $mSv.yr^{-1}$. A possible reason for dose rate reduction may be attributed to the finishing of the granite, which may have interfered with the overall activities (Myatt et al., 2010) (Table 6). The values were lower compared to those obtained in this study. This was also the case in a study by Orosun et al., who determined dose rate from granite mining fields in Asa, North-Central Nigeria. The results (ADR = 59 $nGy.hr^{-1}$; AED = 0.07 $mSv.yr^{-1}$) were below our study and were below the world average values (Orosun et al., 2019).

The excessive lifetime cancer risk (ELCR) for the granite, bitumen and staff residential areas ranged from $(1.0-1.16)\times10^{-3}$, $(0.280.47)\times10^{-3}$ and $(0.421.02)\times10^{-3}$ respectively with the highest in granites. The average value in the granite (with different sizes) was $(1.07)\times10^{-3}$. The average ELCR in this study was lower compared to studies in Korea, Pakistan, Nigeria and India (Kang et al., 2021; Qureshi et al., 2014; Isinkaye and Emelue, 2015; Jeelani et al., 2021) and was higher compared to a study in Egypt (Abdel Gawad et al., 2022) (Table 7). The geographical locations of the samples played a major role in the variation of the data obtained.

The UNSCEAR 2000 report is an average value from country reports which is on the average of 0.29×10^{-3}. The average value from our study was lower compared to the world average but ELCR from the granite was higher. The EPA document has graded risk not according to the world average but according to the hazards it may cause. Our study was found to be graded as "high" and with risk of 0.77×10^{-3} (1 per 1,300), connoting that remedial action is required in the site.

Table 7: Comparison of excessive lifetime cancer risk with other studies.

Study	ELCR ($\times 10^{-6}$)
This study	0.77×10^{-3}
(UNSCEAR, 2000)	0.29×10^{-3}
(Kang et al., 2021)	3.21×10^{-3}
(Qureshi et al., 2014)	3.21×10^{-3}
(Isinkaye and Emelue, 2015)	3.21×10^{-3}
(Jeelani et al., 2021)	3.06×10^{-3}
(Abdel Gawad et al., 2022)	3.35×10^{-3}

4 Conclusions

A study to estimate BIR, ADR, AED and ELCR have been carried out in 4 construction processing/dump site in Aniocha South LGA of Delta State. The average ELCR from this study was below the world average but showed a high risk from the environmental protection agency (EPA) report, suggesting that remedial action be taken in terms of safety. This study will create awareness and improve regulatory compliance in the department environment and mineral resources in Delta State through regular radiation monitoring and awareness programme in construction dump sites.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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