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Radiometric Survey of Granitic Quarry Site of Ebony State, Nigeria

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Authors' contributions

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

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ABSTRACT

Radiometric survey of the granitic quarry site at Ishiagu and its environment was done using two radiation monitors and geographical positioning system (GPS) for GIS mapping. *In-situ* measurement of exposure rate was carried out following the international standard organizational standard between May 2018 and June 2019. The measured average exposure rates ranged from 0.010± 0.002 to 0.038 ± 0.003 mRh^{-1} with mean value of 0.026 ±0.005 mRh^{-1}. The estimated outdoor absorbed dose rate ranged from 87.0 to 330.6 $nGyh^{-1}$ with mean value of 228.38 $nGyh^{-1}$. The equivalent dose rate ranges from 0.84 to 3.20 $mSvy^{-1}$ with mean value of 2.21 $mSvy^{-1}$. The mean annual effective dose equivalent (AEDE) calculated was 0.28 $mSvy^{-1}$ while the mean excess lifetime cancer risk (ELCR) was 0.98 x 10^{-3}. The estimated annual effective dose to different organs showed that the testes have the highest annual effective dose of 0.191 $mSvy^{-1}$ followed by ovaries and kidney of 0.135 and 0.139 $mSvy^{-1}$ respectively while the liver has the lowest annual effective dose of 0.103 $mSvy^{-1}$. The radiation contour map of the area showed the distribution of radiation of high and low areas. The result showed that the radiation exposure rate and its associated

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radiological risk parameters exceeded the safe limits prescribed by ICRP and also the values reported in literatures. However, these values may not constitute acute health risk but long term exposure of residents and workers may be detrimental to their health. Therefore adequate monitoring of this quarry site is necessary to checkmate the exposure rate and provide some protective measures for quarry workers.

Keywords: Granite; quarry; excess lifetime cancer; organ dose; Ishiagu.

1. INTRODUCTION

The natural radioelements uranium, thorium and potassium are lithophile elements widely distributed in crustal rocks being concentrated preferentially in acid igneous rocks compared with intermediate, basic and ultra-basic varieties [1,2]. Potassium is a major element widely distributed in crustal rocks, for instance a calcium rich granites may contain up to 2.5% of potassium. Thorium occurs predominantly as a tetravalent cation and as a trace constituent in phosphates, simple and multiple oxides and silicates as well as in the major rock-forming minerals such as monazites, thorianite (Tho2) and thorite (Thsio4) among others. While Uranium is found in rocks of different mineral species (like apatite, sphene and zircon) as a secondary/ accessory mineral or it can form its own minerals. Uranium distribution in rocks is linked to isomorphous minerals substitution, adsorption or inclusion process [1]. Biotite (black mica) contains between 19% and 22% of the total uranium because it may contain inclusions of minerals rich in this elements such as zircon. Heavy minerals such as zircon, monarzite, apatite, magnetite, ilmenite and riebeckite contain between 61% and 65% of uranium in a rock [3,4,5].

The presence of naturally occurring radionuclides in construction materials originating from quarry products offers radiation exposure both inside and outside the building environments. This is mainly due to gamma radiation of ^{40}K and members of the uranium and thorium decay series. Quarry stones are construction aggregates produced by breaking rocks into desired sizes using a crusher or hammer. Due to their angular surface which makes it easy to roll and key into cement mix, crushed stone are widely used mainly for construction projects [6]. In a study by Ilangovana, et al.[7] the strength of quarry rock dust concrete was reported to be 10-12% more than that of similar mix of conventional concrete.

Quarry stone aggregates are used extensively for building construction in many cities in Nigeria. The rocks being quarried are mainly biotite granite and biotite hornblende granite, all belonging to the younger granite complex. They are known to contain significant amount of ^{238}U, ^{232}Th and ^{40}K and therefore constitute a major source of exposure to radiation to the inhabitants of the area [6]. Quarry products comprises a wide number of different natural rocks with different mineral contents, crushed into various sizes at quarries. This include different geological materials such as gneiss, granite, diorite, granodiorite and other rocks that after an industrial process are suitable for use as building materials and ornamental rocks [8].

In Nigeria, mining activities like in granite quarry sites have been carried out since the beginning of the last century; however, their radiological investigation had started in 1970 by Sanni and 1981 by Babalola with a comprehensive analysis of their radionuclide composition [9]. Mining activity can cause environmental pollution. This is because most of the rocks contains some level of naturally occurring radionuclide and other accessory minerals which may be harmful are released to the environment during mining. The mining of minerals resources also facilitates the release of radioactive materials from the host minerals into the environment [10].

Exposure to radiation can cause several health hazards to man and the environment. Some of radiation related risks ranging from malignancies and damage to genetic materials have been observed from long term epidemiological studies of population exposed to radiation [11]. Radiation doses of different levels, delivered at different rates to different parts of the body can cause different types of health effects at different times [9]. At very high radiation exposure, death will occur within several months or less. At moderate levels exposure to radiation increases the chance of developing cancer, with a time delay of about ten years for most cancers. Similarly when the exposure is low, the cancer risk decreases but the relationship between cancer risk and the level of exposure is uncertain. Among other risks, genetic effects and the exposure of fetus during pregnancy with mental retardation, in terms of frequency of occurrence and severity of effects, cancer is the most serious consequence and receives the greatest attention [12].

The growing number of residents and increased mining activities and non-availability of data on the BIR levels at Ishiagu solid mineral mining areas necessitated this research work. Hence the result of this study will serve as baseline data for the background ionizing radiation levels in this area. In order to evaluate the radiological impact of mining activities on the residents and workers, some hazard indices which will show the likelihood of developing various health effects associated with radiation exposure was evaluated.

2. MATERIALS AND METHODS

2.1 Study Area

Ishiagu quarry site is location at Latitude 5°52′ to 6°00′ and longitude 7°30′ to 7°35′. It is part of the geologic complex called Benue trough a deep linear sediment filled basin which extends to Niger Delta for over 700km toward the North-Eastern part of Eke, Isikwuato by south and Lokpa and Lekwensi by west [13]. Ishiagu area is generally a dominant low lying to gentle undulating shally terrain of 85-100 m above sea level and punctuated by few isolated low hills. The land surface is usually marshy in wet season which prevails from April – October yielding annual rainfall of between 1200-2000 mm [14]. According to Eburue and Eseribe [15], Ishiagu has many mineral deposit, making the inhabitant prominently miners.

2.2 Field Measurement

The *in-situ* measurements of the exposure rate of Ishiagu quarry site of Ebonyi state was done using two calibrated nuclear Radiation monitoring meter (Digilert–200 and Radalert – 100) (S.E. International Incorporation, Summer Town, USA), containing a Geiger-Muller tube capable of detecting alpha, beta, gamma and X-rays were used within the temperature range of - 10ºC to 50ºC to measure radiation exposure rate of the selected quarry sites and a geographical positioning system (GPS) was used to measure the precise location of sampling. The Geiger-muller tube generates a pulse current each time radiation passes through the tube and causes ionization [7]. Each pulse is electronically detected and registered as a count. The radiation meters were calibrated with a 137 Cs source of specific energy and set to measure exposures rate in milli Roentgen per hour ($mRhr^{-1}$). The meter has an accuracy of ±15%.

The tube of the radiation monitoring meter was raised to a standard height of 1.0 m above the ground [8,9], with its window facing the suspected source while the GPS reading was taken at that spot. Measurements were repeated four times at each sampling point during different months within the two seasons to account for any fluctuation in the environmental parameters. Readings were obtained between 1300 and 1600 h because the radiation meter has a maximum response to environmental radiation within these hours according to the NCRP [10].

2.3 Radiological Parameters

2.4 Equivalent Dose Rate

This is used to assess how much biological damage is expected from radiation absorbed dose. The equivalent dose rate is the rate at which an equivalent dose is received. To estimate the equivalent dose rate over a period of one year, we used the National Council on Radiation Protection and Measurement's recommendation [16].

$$1\ mRh^{-1} = \frac{0.96\ x\ 24\ x\ 365}{100}\ mSvy^{-1} \quad (1)$$

The results of the calculated equivalent dose rate are presented in Table 1.

2.5 Absorbed Dose Rate

The data obtained for the external exposure rate in μRh^{-1} were also converted into absorbed dose rates $nGyh^{-1}$ using the conversion factor [17]:

$$1\ \mu Rh^{-1} = 8.7\ nGyh^{-1} = \frac{8.7\ x\ 10^{-3}}{(\frac{1}{8760y})} = 76.212\ \mu Gyy^{-1} \quad (2)$$

2.6 Annual Effective Dose (AED)

This is the addition of equivalent doses to all organs, each adjusted to account for the sensitivity of the organ to radiation. In calculating AEDE, dose conversion factor of 0.7 Sv/Gy and the occupancy factor for outdoor of 0.25 (6 hours out of 24 hours) was used. The occupancy factor for outdoor was calculated based upon interviews with peoples of the area. People of the study area spend almost 6 hours outdoor due to the nature of their routine. The annual effective dose was estimated using equation 3 [18]:

$$AEDE\ (Outdoor)(mSvy^{-1}) = Absorbed\ dose\ rate\ (nGyh^{-1}) \times 8760h \times \frac{0.7Sv}{Gy} \times 0.25 \quad (3)$$

2.7 Excess Life Cancer Risk (ELCR)

The probabilities of contacting cancer by the mining 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 [19]. The annual effective dose calculated was used to estimate the Excess Lifetime Cancer Risk (ELCR) using equation (4).

$$ELCR = AEDE\ \times Average\ duration\ of\ life \times Risk\ factor\ Rf \quad (4)$$

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 [20,17].

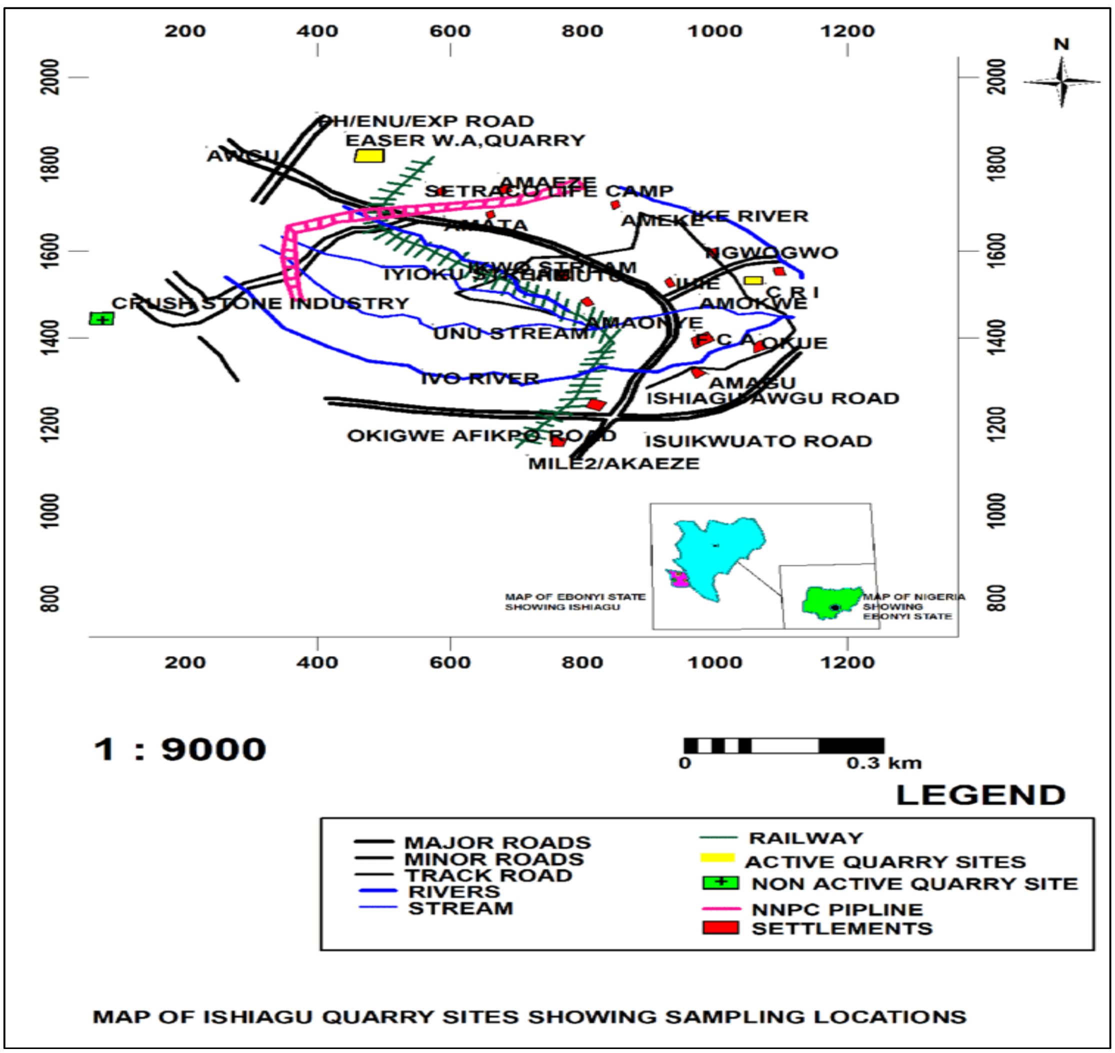

Fig. 1. Map of the study area (source: Osuocha, et al. 2016)

Table1. Exposure rate measured with their radiation parameters at Ishiagu

S/N	Location	GPS	Av. Exposure Rate (mRh^{-1})	Equivalent Dose (mSvy^{-1})	Absorbed dose (nGyh^{-1})	AEDE (mSvy^{-1})	ELCR x10^{-3}
1	ISHAG$_1$	N05^{0}57′015″ E007°34′432″	0.021	1.766	182.7	0.224	0.784
2	ISHAG$_2$	N05°57′031″ E007°34′751″	0.032	2.691	278.4	0.341	1.195
3	ISHAG$_3$	N05^0 57′023″ E007^0 34′ 700″	0.024	2.018	208.8	0.256	0.896
4	ISHAG$_4$	N05^{0}57′009″ E007^{0}34′025″	0.023	1.934	200.1	0.245	0.859
5	ISHAG$_5$	N05^0 57′96.3″ E007^0 3466.6	0.031	2.610	269.7	0.331	1.158
6	ISHAG$_6$	N05^0 57037 E007^0 3475.1	0.038	3.196	330.6	0.405	1.419
7	ISHAG$_7$	N05^0 5795.9 E007^0 3474.6	0.034	2.859	295.8	0.363	1.27
8	ISHAG$_8$	N05^0 5796.6 E007^0 3474.6	0.036	3.027	313.2	0.384	1.344
9	ISHAG$_9$	N05^0 5795.0 E007^0 3458.0	0.027	2.271	234.9	0.288	1.008
10	ISHAG$_{10}$	N05^0 57′07.4″ E007^0 34 54.2″	0.022	1.850	191.4	0.235	0.822
11	ISHAG$_{11}$	N05^0 5706.8 E007^0 3456.1	0.026	2.186	226.2	0.277	0.971
12	ISHAG$_{12}$	N05^0 5706.3 E007^0 3457.3″	0.028	2.355	243.6	0.299	1.046
13	ISHAG$_{13}$	N05^0 5707.6 E007^0 3458.2″	0.018	1.514	156.6	0.192	0.672
14	ISHAG$_{14}$	N05^0 57′99.3″ E007^0 3472.0	0.019	1.597	165.3	0.203	0.71
15	ISHAG$_{15}$	N05^0 5799.1 E007^0 3461.0	0.025	2.102	217.5	0.267	0.934
16	ISHAG$_{16}$	N05^0 5700.8 E007^0 3434.0″	0.023	1.934	200.1	0.245	0.859
17	ISHAG$_{17}$	N05^0 5703.7 E007^0 3475.1	0.014	1.177	121.8	0.149	0.523
18	ISHAG$_{18}$	N05^0 5709.0 E007^0 3452.1	0.032	2.691	278.4	0.341	1.195
19	ISHAG$_{19}$	N05^0 57005 E007^0 3423.8″	0.028	2.355	243.6	0.299	1.046
20	ISHAG$_{20}$	N05^0 5799.3 E007^0 3472.0	0.026	2.186	226.2	0.277	0.971
21	ISHAG$_{21}$	N05^0 5700.8 E007^0 3434.2″	0.037	3.112	321.9	0.395	1.382
22	ISHAG$_{22}$	N05^0 5796.1 E007^0 3472.2	0.031	2.607	269.7	0.331	1.158
23	ISHAG$_{23}$	N05^0 5795.6 E007^0 3461.0	0.025	2.102	217.5	0.267	0.934
24	ISHAG$_{24}$	N05^0 5795.0 E007^0 3458.0	0.010	0.841	87	0.107	0.373
	Mean		0.026	2.21	225.656	0.277	0.784

2.8 Effective Dose Rate D_{organ} in $mSvy^{-1}$ to Different Organs/ Tissues

The effective dose rate to a particular organ can be calculated using the relations:

$$D_{organ}\,(mSvy^{-1}) = O \times AEDE \times F \quad (5)$$

Where AEDE is annual effective dose, O is the occupancy factor 0.8 and F is the conversion factor for organ dose from ingestion. The calculated effective dose rates delivered to the different organs are presented in Fig. 2, with the F values for lungs, ovaries, bone marrow, testes, kidneys, liver and whole body being 0.64, 0.58, 0.69, 0.82, 0.62, 0.46 and 0.68 respectively as obtained from ICRP [21]. The model of the annual effective dose to organs estimates the amount of radiation intake by a person that enters and accumulates in various body organs and tissues [22].

3. RESULTS AND DISCUSSION

The results obtained from the measurements represents the external background radiation levels of Ishiagu quarry site. The average reading of the two monitors for each measurement location are taken and presented in Table 1. The average exposure rate of the quarry site ranged from 0.01 to 0.038 mRh^{-1} with mean value of 0.026 mRh^{-1}. All the sampling points recorded higher exposure rate except for location 24. The mean value of the exposure rate exceeded the ICRP recommended value of 0.013 mRh^{-1} and also the equivalent dose value of 2.21 $mSvy^{-1}$ obtained in this study is higher than the equivalent dose value of 1.49 ±0.04 $mSvy^{-1}$ obtained by Nwankwo, et al. [23] in quarry sites in Ilorin.

According to the international commission on radiological protection (ICRP) [24], dose limits are intended to serve as a boundary condition that will prevent deterministic effect and limit the probability of stochastic effects. Stochastic effects are cancer inducing or heritable effects involving the development of cancer and may occur in either mature somatic cells or through mutation of germ (reproductive) cells while deterministic effects which are often of an acute nature are mostly the result of death or malformation of somatic cells following radiation exposure and only appear if the radiation dose exceeds a threshold value [23]. Consequently the limit for occupational workers are 20 $mSvy^{-1}$ averaged over a period of five years. The ICRP and other regulatory bodies also estimated that dose rising above 1.0 $mSvy^{-1}$ justify the introduction of protection actions for members of the public [25,24].

The total worldwide average dose from natural radiation is approximately 2.4 $mSvy^{-1}$, which varies between 1 and 10 $mSvy^{-1}$ depending on the geology and altitude where people lives. However it was reported that there is no evidence of increased cancers or other health problems arising from these average global natural levels [26]. Fig. 3 is the radiation contour map of the study area. The relative spacing of the contour lines indicates the relative slope of the surface and the distribution of radiation exposure rates of high values.

The absorbed dose rate in the air due to gamma rays 1 m above the ground from the quarries was calculated by converting the external exposure rate using appropriate conversion factor as stated above. The result obtained showed values ranging from 87.0 $nGyh^{-1}$ to 330.6 $nGyh^{-1}$ with mean value of 228.38 $nGyh^{-1}$ as presented in Table 1. The results compare well with the results of 149.85 to 264.35 $nGyh^{-1}$ obtained in similar environment by Abiye, et al.[6]. The mean absorbed dose obtained in this study is far higher than the values of 12.3, 17.27 and 18.87 $nGyh^{-1}$ obtained in Anmuda, Awulema and Ikpayongo quarry sites obtained by Ode Samuel [9]. All the values are higher than the world reference value of 60.0 $nGyh^{-1}$.

The whole body equivalent dose obtained in this work varies from 0.84 to 3.20 $mSvy^{-1}$ with mean value of 2.21 $mSvy^{-1}$. The calculated equivalent dose rates obtained for all the sampling points are above the recommended permissible limit of 1.0 $mSvy^{-1}$ for the public, while for the industrial zone, the values obtained are lower than the recommended occupational permissible limit of 20 $mSvy^{-1}$[24]. The annual effective dose estimated varied from 0.11 to 0.41 $mSvy^{-1}$ with mean value of 0.28 $mSvy^{-1}$. The annual effective dose values are similar to the values reported in Benue state quarry site [9]. The worldwide average annual effective dose is 0.41 mSv, of which 0.07 $mSvy^{-1}$ is from outdoor exposure and 0.34 $mSvy^{-1}$ is from indoor exposure [22,27]. The values obtained in this study are higher than the world average annual effective dose level for outdoor and indoor environment.

The excess lifetime cancer risk calculated from annual effective dose varied from 0.37 $\times 10^{-3}$ to 1.42 $\times 10^{-3}$ with mean value of 0.98 $\times 10^{-3}$. The average value of ELCR is higher than the world average of 0.29 x 10^{-3} [28]. This ELCR value indicates that the probability of contracting cancer by residents and workers of the quarry site who spend all their lives in the quarry area is significant. The estimated effective dose delivered to different organs are presented in Fig. 2. Seven organs and tissues were examined and the result showed that the testes received the highest effective dose with average value of 0.191 $mSvy^{-1}$, while the effective dose was found to be lowest in the liver, with average value of 0.103 $mSvy^{-1}$.

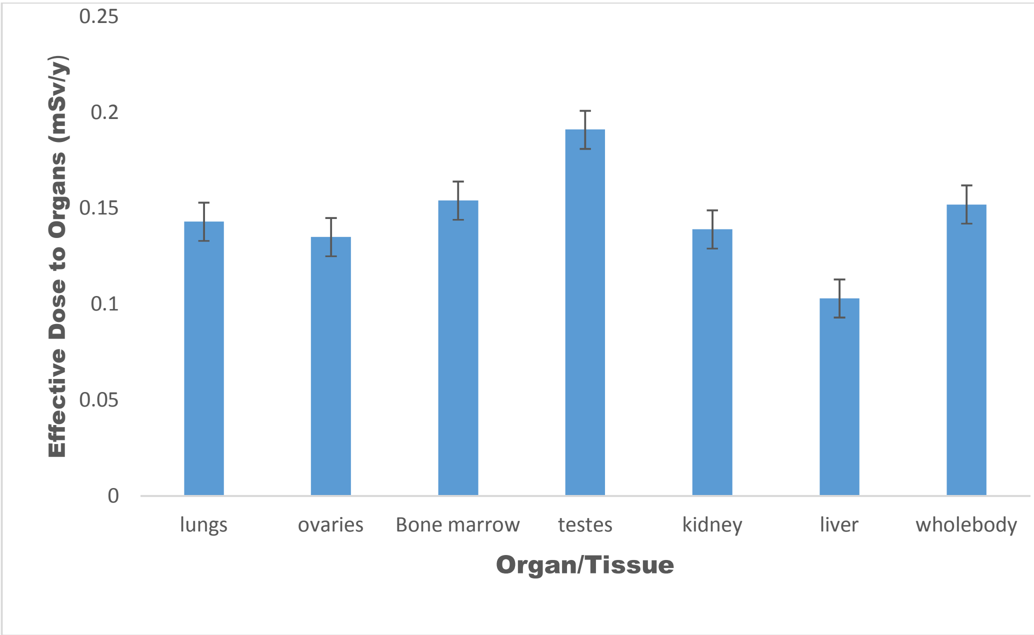

Fig. 2. Effective dose rate to different organs/ tissues

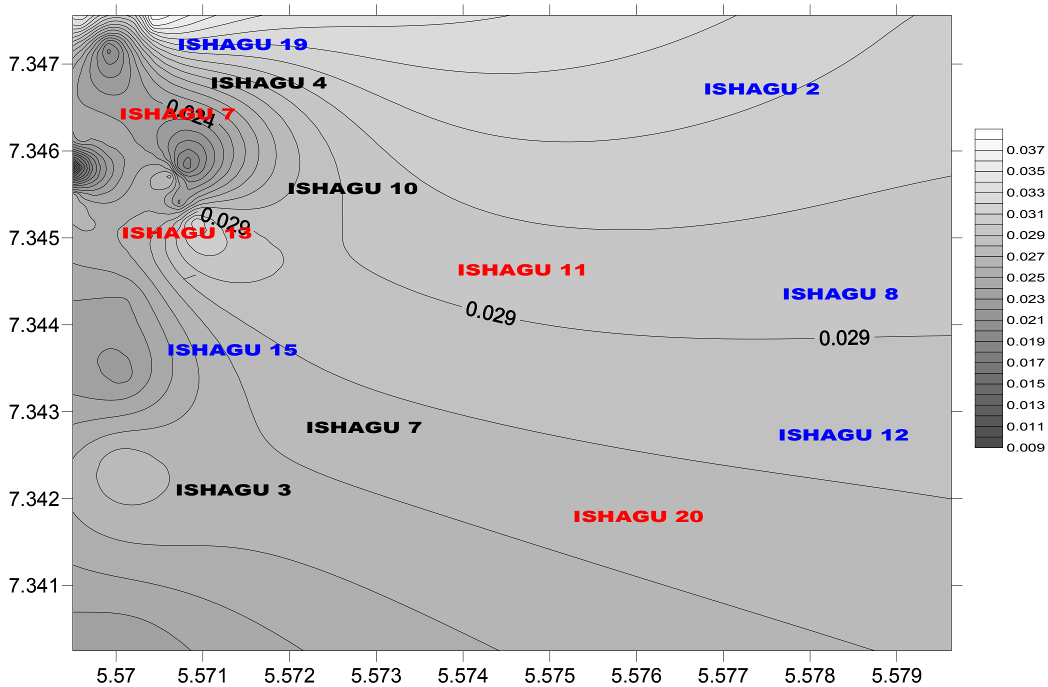

Fig. 3. Radiation contour of the study area

4. CONCLUSION

The radiometric survey of Ishiagu quarry sites in Ebonyi state was carried out using two radiation monitors in order to quantify the radiological risks due to exposure to gamma radiation. The following conclusion were drawn from the study:

1. The study revealed that the exposure rate in all the sampling locations exceeded the recommended level of 0.013 mRh^{-1} and so Ishiagu quarry site have been impacted by mining and quarrying activities.
2. The equivalent dose rate , absorbed dose, annual effective dose and excess lifetime cancer risk estimated exceeded their radiation safety limits respectively. The values are also higher than values in the literature for other countries but similar to results obtained here in Nigeria.
3. These elevated health risk values may not constitute any immediate health risk to the residents and workers but long term exposure might be detrimental to their health.
4. Quarrying and mining activities in the area of study has enhanced the background radiation level of the place. Hence constant monitoring of the area is necessary to help reduce exposure level as low as reasonably practicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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