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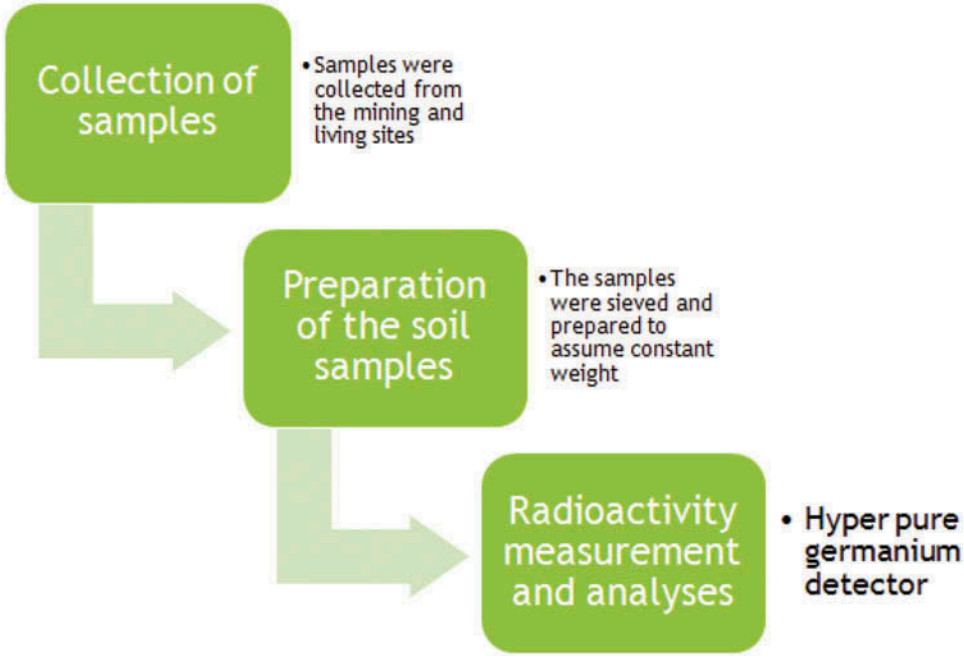

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Radiation dose assessment of soil from Ijero Ekiti, Nigeria

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Abstract: The activity concentration of ^{238}U, ^{232}Th and ^{40}K in the soils of mining and living areas of Ijero Ekiti were determined using hyper pure germanium gamma ray spectrometer. The mean concentrations of ^{238}U, ^{232}Th and ^{40}K were found to be 128.05 $Bqkg^{-1}$, 24.8 $Bqkg^{-1}$ and 455.05 $Bqkg^{-1}$, respectively, for mining areas, while it was found to be 42.02 $Bqkg^{-1}$, 43.27 $Bqkg^{-1}$ and 635.41 $Bqkg^{-1}$, respectively, for the living areas. The mean absorbed dose rate, annual effective dose equivalent, gamma index and the excess lifetime cancer risk evaluated for the locations were 89.70 $nGyh^{-1}$, 0.11 $mSvy^{-1}$ and 1.4 for mining areas; while it was 72.22 $nGyh^{-1}$, 0.089 $mSvy^{-1}$ and 1.14 for living areas, respectively. The absorbed dose rate, annual effective dose equivalent and gamma index estimated for the mining site were higher than the living areas. The mean excess lifetime cancer risk estimated for the mining areas was consecutively higher than the recommended limit of 0.29×10^{-3} for background radiation. It is therefore necessary for government to barn illegal mining activities going on in the town so as to reduce natural radiation burden from their operations in the town.

Subjects: Agriculture & Environmental Sciences; Physics; Nuclear Engineering; Civil, Environmental and Geotechnical Engineering

Keywords: mining; soil; dose assessment; excess lifetime cancer risk; Ijero Ekiti

M. R. Usikalu

ABOUT THE AUTHORS

M. R. Usikalu is a Lecturer and Head Radiation and Health Physics Research Cluster in Department of Physics, Covenant University. She has worked extensively on the measurement of radioactivity in the soil, rock and water for the estimation of the associated radiological risks in various part of the country. Through these researches, she has been able to identify soils and rocks that are not fit for construction purposes due to high radiation burden (cancer incidence, untimely death) associated with them. The research outcome provides useful information for policy makers on setting guidelines for the populace on type of soil that could be used for building and construction purposes and the safety distance to build houses from mining sites.

PUBLIC INTEREST STATEMENT

Radiation is inevitable as long as we walk on soil, drink water and carry out our day-to-day activities under the sun. This is because soil, water, rock, etc., contain different natural radioactivity concentration in varying proportion. The radiation level in a location depends mainly on the geological makeup of the rock, soil and different activities taking place in the area. In this work we assessed the natural radioactivity concentration in locations where illegal mining are taking place and compare the measured activity to where there are no mining activities. The radioactivity measurement was done using hyper pure germanium detector. This was done to verify whether mining activities has impact on the radiation dose from a location. The results from the research established that mining activities increase the radiation dose and the excess lifetime cancer risk of the study area.

1. Introduction

The radiation exposure from natural primordial radionuclides ^{238}U and ^{232}Th and their progenies constitute the largest source of radiation to man. ^{238}U and ^{232}Th condense in crystalline rocks such as granites and other alkaline magmatic because of their big atom and they often accompany by rare earth elements (UNSCEAR, 2000). The associated health hazards of these radionuclides are as a result of their ability to pile up in human tissues. In reaction, the radionuclides emit gamma rays as well as high-LET charged particles that are capable of damaging the tissues where they are localized and also to some extent nearby organs. Banat, Howari, and Al-Hamad (2005), Akinlua, Ajayi, and Adeleke (2006), Birkefeld, Schulin, and Newack (2006), Nyarko et al. (2006), Adagunodo, Hammed, Usikalu, Ayara, and Ravisankar (2018), Omeje et al. (2018) reported that radionuclides of both uranium and thorium decay series can be found in high concentration in the natural occurring materials in the vicinity where mining activities are going on, which can be considered as technological enhanced naturally radioactive material (TENORM). The digging of huge quantities of sand which is usually piled up to form large volume of tailings is one of the negative implications of mining activities on the environment. These activities usually affect the natural radionuclides in the soil and equally produce change in the ecosystem. UNSCEAR, (2000) and Lipsztein et al. (2001) observed that mining, milling and processing of uranium- and thorium-bearing minerals can lead to increase in radiation exposures not only to the workers but also to the inhabitants of the mining sites. Another issue is the haphazard dumping of the tailings which resulted into forming of huge slopes and this leads to increase in their movement and the risk of transportation to a large extent. ^{238}U and ^{232}Th from the sites find their ways of getting to the ground water potential through percolation, thereby contaminating the water and soil in the area (Usikalu, Anoka, & Balogun, 2011). Therefore, the tailings are a nuisance and source of pollution to the ground water and surrounding soil (Sam & Awad Al-Geed, 2000). The implication of the pollution to man is of great concern since the radionuclides will find their way to the food and inhalation in the air thereby increasing the radiation burden of the inhabitant in the surrounding.

Ijero Ekiti with coordinates 7.8120° N, 5.0677° E is situated in the northwest part of Ekiti State. The Ijero local government has a largely agrarian population producing cash crops such as cocoa, kola nuts, coffee, cashew and timber. Food crops such as yam, cocoyam, cassava, pepper, tomatoes and banana are equally grown in the town. It also has mineral resources such as tourmaline, colombat, vesper, and crystal stone in the northern part of the town called Kusa Mountain. Kusa Mountain in Ijero falls within the basement complex of southwestern Nigeria. It is distinguished by the abundance of pegmatites that contain different minerals like rare earth metals, gem-stones and metallic-ores (Oyawoye, 1972). It is intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is overlain by Cretaceous and younger sediments as shown in Figure 1. The pegmatite comprises of quartz, biotite, albite, microcline, muscovite, tourmaline, hornblende and other minerals in varying quantity.

As earlier stated, high percentages of the inhabitants of the town engage in farming activities and food crops such as cocoyam, yam, cereals and vegetables are grown for consumption. Also, the inhabitants leaving around the vicinity see the tailings as source of cheap materials that can be used for building purposes (Usikalu et al., 2011). The radiological impact on the inhabitants and workers are of interest due to the unchecked mining processes going on in the area. In Nigeria, high activities concentrations of natural radionuclides had been reported in foodstuffs obtained from Bisitchi a mining site in Jos Plateau (Jibiri, Farai, & Alausa, 2007). The natural radionucludes in soils from the Kusa Mountain and its radiological implications have not been studied as was done for other mining sites in Nigeria. Hence, there is need to assess the radiological implications of the mining activities in the area. In this research, radiological parameters such as hazard index, radium equivalent, gamma index and excess lifetime cancer risk have been estimated from the activity concentration of ^{238}U, ^{232}Th and ^{40}K. The aim of this study is to assess the health risks associated with the mining activities and develops a baseline of natural background radiation levels for the area.

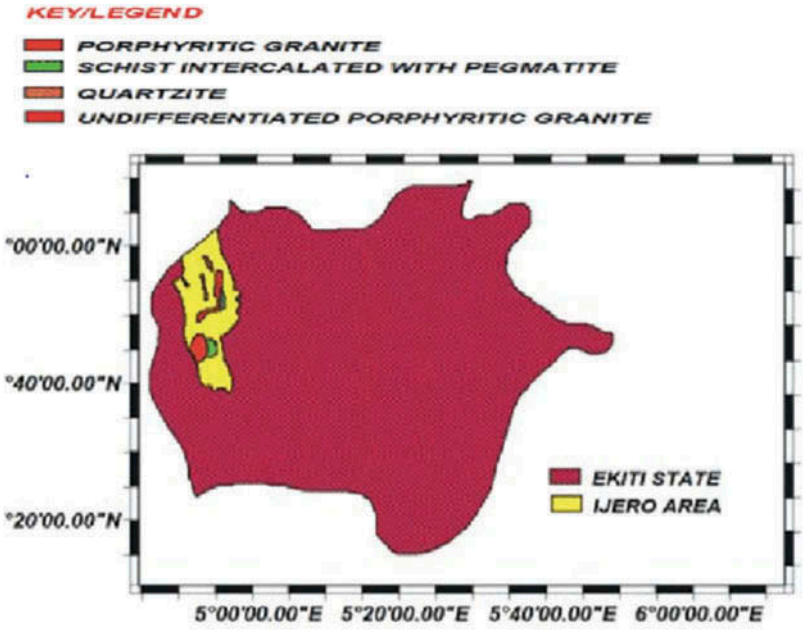

Figure 1. Geological map of Ijero Ekiti (Modified after Ale, Dada, & Adewumi, 2014).

2. Materials and methods

Samples were collected by digging the ground to at least 3 cm so as to take samples free from debris and vegetation. Five soil samples were taken from different points at each location for better sampling. These were kept in Ziploc bags and labeled accordingly making a total of 90 soil samples from all the locations. Forty were from the mining area and fifty from non-mining sites of the town. The samples were oven dried at 110°C to ensure complete removal of moisture and were made to pass through a 2 mm sieve. 100 g of each sample were placed in plastic vessels, 9 cm in diameter with a total capacity of 300 cm^3. The vessels were weighted and sealed for 30 days to allow secular equilibrium in the ^{238}U and ^{232}Th with their respective progeny.

The activity measurement was described fully by Usikalu et al. (2017a). P-type high-purity germanium (HPGe) detector (Canberra model GC4520) coupled to a multichannel analyzer (MCA) with 45 % efficiency was used. It has energy resolution of 2.2 KeV (FWHM) for the 1332.5 KeV gamma-ray transition of ^{60}Co source. The detector was positioned in a 5 cm thick lead to protect the measuring laboratory from external background radiation. The spectra for ^{238}U, ^{232}Th and ^{40}K were obtained using IAEA reference materials RGU-1 (4940 $Bqkg^{-1}$ uranium ore); RGTh-1 (3250 $Bqkg^{-1}$ thorium ore) and potassium chloride (16259 $Bqkg^{-1}$ ^{40}K) from Merck company with 99.5 % purity. Each sample was counted for 36,000 s so as to achieve minimum counting error. The analysis of gamma ray spectrometry used here has been used by other researchers so as to ascertain good quality (Iqbal & Tufail M Amd Mirza, 2000; Kant, Gupta, Kumari Gupta, & Garg, 2015; Usikalu, Maleka, Malik, Oyeyemi, & Adewoyin, 2015). The activity concentrations were calculated using the photo peaks corresponding to each radionuclide. ^{40}K was obtained at photopeak of 1.460 MeV; ^{214}Bi (1238 keV and 1378 keV), ^{214}Pb (295 keV and 351 keV) for ^{238}U and ^{208}Tl (860 keV), ^{228}Ac (338 keV, 911 keV, 969 keV) for ^{232}Th using palmtop MCA software for computation:

$$A_c = \frac{A_{net}}{M_s.t_c.P_\gamma.\varepsilon} \quad (1)$$

where A_{net} is the net area under energy peak (count), P_γ is the gamma emission probability at energy E, t_c is the counting time ε is the absolute efficiency of the detector, and M_s is the mass of the dried sample (kg).

3. Results and discussion

The measured activities concentrations of ^{238}U, ^{232}Th and ^{40}K from Ijero Ekiti soils both in the mining area and Odo-Oye Ijero (control) are presented in Table 1. It was observed that the mean activities of ^{238}U measured in the mining areas (128.05 $Bqkg^{-1}$) is much higher than the area where mining is not going on (42.02 $Bqkg^{-1}$). Meanwhile, the mean activity of ^{232}Th measured in the mining area (24.80 $Bqkg^{-1}$) is lower than the control area (42.02 $Bqkg^{-1}$). The mean activity of ^{40}K measured in the mining area (455.05 $Bqkg^{-1}$) was lower than the control area (635.41 $Bqkg^{-1}$). Figures 2 and 3 display the ratio of the three activity concentrations in the two locations. The ratio of uranium to thorium in the control locations is nearly equal to one while in the mining area uranium is five times higher than thorium concentration. The mining activities might be responsible for the enhanced concentrations of ^{238}U in the mining area. This may be as a result of the mineral contents of the mine deposit or during mining and mineral extraction process due to various physical processes and extraction of the mineral being exploited by chemical processes. Also, there is limited number of in-situ leaching activities since uranium is more soluble than thorium. This may be the reason for the elevated uranium concentration in the mining area. The high-activity concentration level of ^{40}K in both locations as shown in Figures 2 and 3 may have perhaps been from the denudation of the phosphate rocks (Usikalu et al., 2015, 2017b) but most probably from inorganic fertilizer used in agricultural activities in the control area. The continuous application of fertilizers in farms within this region enhances the radioactive levels which in turn increases the radionuclide concentration. Table 2 shows the mean activity measured in different similar areas. Many international organizations have studied and reported average world value for natural background radiations which are taken as recommended limit or permissible level with which radiation of any location can be compared with (UNSCEAR, 2000; IAEA, 1989; ICRP, 1994) as shown in in the last row of Table 2. The results obtained in the present study in the mining area is higher than those obtained in Egypt, Australia and in gold mine Nigeria where high radioactivity had been recorded but compared well with the measured activities in Ijero living area (Ademola et al., 2014; Berekta & Mathew, 1985; El Afifi, Hilal, Khalifa, & Aly, 2006).

Table 1. Measured radioactivity concentration

Activity	*238U*	*232Th*	*40K*
K1	107.42 ± 17.07	31.34 ± 6.76	311.47 ± 3.51
K2	106.99 ± 11.52	23.81 ± 6.76	364.25 ± 3.88
K3	99.38 ± 14.18	36.33 ± 5.01	411.83 ± 3.96
K4	83.64 ± 8.76	17.48 ± 5.66	327.73 ± 3.41
K5	224.96 ± 16.92	14.69 ± 0.35	506.39 ± 4.98
K6	150.06 ± 10.46	21.19 ± 0.20	369.34 ± 3.50
K7	118.85 ± 17.46	44.88 ± 4.05	586.65 ± 5.32
K8	133.12 ± 8.55	8.70 ± 0.23	762.70 ± 6.89
Mean	**128.05 ± 13.12**	**24.80 ± 3.63**	**455.05 ± 4.43**
S1	28.90 ± 7.70	36.43 ± 3.55	539.75 ± 4.88
S2	43.15 ± 7.30	90.76 ± 3.18	495.73 ± 4.46
S3	30.51 ± 2.79	41.18 ± 3.24	517.17 ± 4.66
S4	43.18 ± 6.08	54.03 ± 3.39	606.64 ± 5.44
S5	24.89 ± 3.42	40.28 ± 2.98	338.47 ± 3.12
S6	89.14 ± 4.73	10.88 ± 0.23	1500.67 ± 13.28
S7	29.86 ± 8.78	59.47 ± 3.17	371.28 ± 3.41
S8	33.59 ± 3.85	32.86 ± 2.88	485.05 ± 4.36
S9	64.59 ± 7.20	30.66 ± 4.13	974.41 ± 8.67
S10	32.43 ± 7.52	36.14 ± 3.55	524.89 ± 4.75
Mean	**42.02 ± 5.94**	**43.27 ± 3.03**	**635.41 ± 5.70**

K1–K8 mining sites and S1–S10 living area.

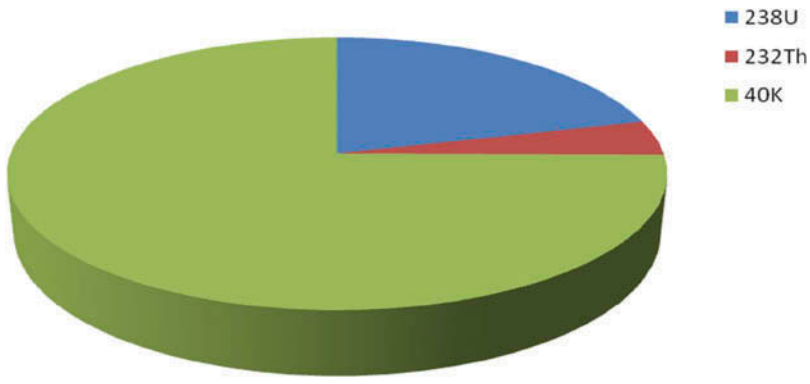

Figure 2. Mean activities in mining area.

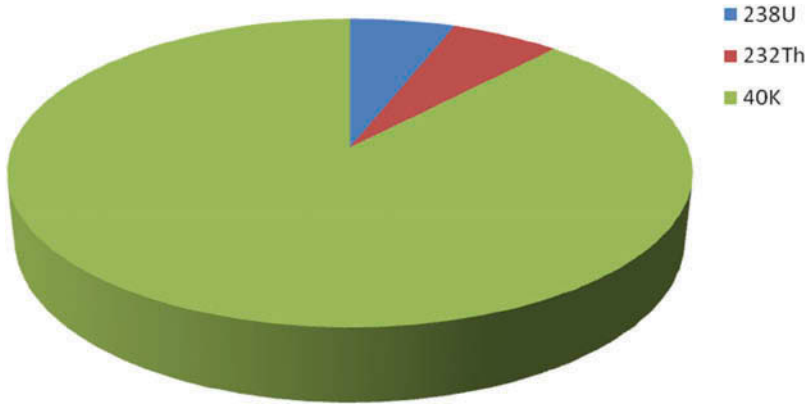

Figure 3. Mean activities in living area.

Table 2. Comparison of the measured activities with other similar studies

^{238}U (Bqkg^{-1})	^{232}Th(Bqkg^{-1})	^{40}K(Bqkg^{-1})	Country	Reference
128.05	24.8	455.05	Nigeria (Ijero Mining Area)	Present study
42.02	43.27	635.41	Nigeria (Ijero Town)	Present study
13.6	24.2	162.1	Ghana	Faanu, Darko, and Ephraim (2011)
51.5	48.1	114.7	Australia	Berekta and Mathew (1985)
78	33	337	Egypt	El Afifi et al. (2006)
41	27	422	Algeria	Amrani and Tahtat (2001)
55.3	26.4	505.5	Nigeria	Ademola et al. (2014)
12.1	60.1	426.5	Nigeria	Innocent, Onimisi, and Jonah (2013)
35	**30**	**420**	**World average**	UNSCEAR (2000)

3.1. Evaluation of radiological parameters

The absorbed dose rates in air at 1 m above the ground level were evaluated using Equation (2). The measured activity of ^{238}U, ^{232}Th and ^{40}K were converted into dose ($nGyh^{-1}$) by applying the conversion factors 0.462, 0.604, and 0.0417 for uranium, thorium and potassium, respectively,

$$\text{Absorbed Dose } (D_R) = C_U + 1.43C_{Th} + 0.077C_K \quad (2)$$

C_U, C_{Th}, and C_K are the concentrations of uranium, thorium and potassium in the soil samples ($Bqkg^{-1}$). The average absorbed dose rates calculated ranged from 50.28 to 126.98 $nGyh^{-1}$ with a mean value of 89.70 $nGyh^{-1}$ for the mining area and 72.22 $nGyh^{-1}$ for the control area. The mean absorbed dose rates estimated for the two locations exceeded the world average recommended limit 60 $nGyh^{-1}$ may be because the soils originated from mineral bearing igneous rocks. The annual outdoor effective dose equivalent (AEDE) received by a member was calculated using Equation (3) with a conversion factor of 0.7 $SvGy^{-1}$ applied to convert the absorbed rate to annual effective dose with an outdoor occupancy of 20%. Table 3, column 3, shows the outdoor annual effective doses. It was found to vary from 0.06 $mSvy^{-1}$ to 0.16 $mSvy^{-1}$ with mean from 0.09 $mSvy^{-1}$ for the control and 0.11 $mSvy^{-1}$ for the mining areas. The estimated values for both locations exceeded the world average (0.07 $mSvy^{-1}$) for outdoor effective. This may be associated with the soils being rich in minerals:

$$\text{Outdoor annual effective dose } \left(\text{AEDEmSvy}^{-1}\right) = (D_R) \times 8760 \times 0.2 \times 0.7 \tag{3}$$

Figures 4 and 5 show the correlation of absorbed doses with the radium equivalent activity within the study areas. Regression analysis technique was used in drawing a trend line between the points. The regression correlation was positive, linear and high but higher in the control area than the mining area.

The internal hazard index was evaluated using Equation (4). The aim of radiation protection is to limit the index to a value less than unity. The H_{in} in one location in mining area is higher than unity but the mean H_{in} for both mining area is less than unity (0.88) and control area (0.53) was less

Table 3. Estimated radiological parameters

Location	D_R	*AEDE*	H_{in}	I_γ	*ELCR*
K1	78.79	0.10	0.77	1.24	0.34
K2	76.18	0.09	0.75	1.19	0.33
K3	82.78	0.10	0.76	1.30	0.36
K4	60.70	0.07	0.591	0.95	0.26
K5	126.98	0.16	1.38	1.98	0.54
K6	93.16	0.11	0.97	1.46	0.40
K7	103.94	0.13	0.94	1.63	0.45
K8	95.06	0.12	0.91	1.48	0.41
Mean	89.70	0.11	0.88	1.41	0.38
Living area					
S1	58.25	0.07	0.41	0.92	0.25
S2	96.29	0.12	0.69	1.53	0.41
S3	60.92	0.07	0.43	0.96	0.26
S4	78.18	0.10	0.57	1.23	0.34
S5	50.28	0.06	0.36	0.79	0.22
S6	109.37	0.13	0.84	1.70	0.47
S7	65.77	0.08	0.47	1.04	0.28
S8	55.67	0.07	0.41	0.88	0.24
S9	88.58	0.11	0.67	1.39	0.38
S10	58.93	0.072	0.42	0.93	0.25
Mean	72.22	0.089	0.53	1.14	0.31

D_R, absorbed dose rate; *AEDE*, annual effective dose equivalent; H_{in}, internal hazard index; I_γ, gamma representative index; *ELCR*, excess lifetime cancer risk.

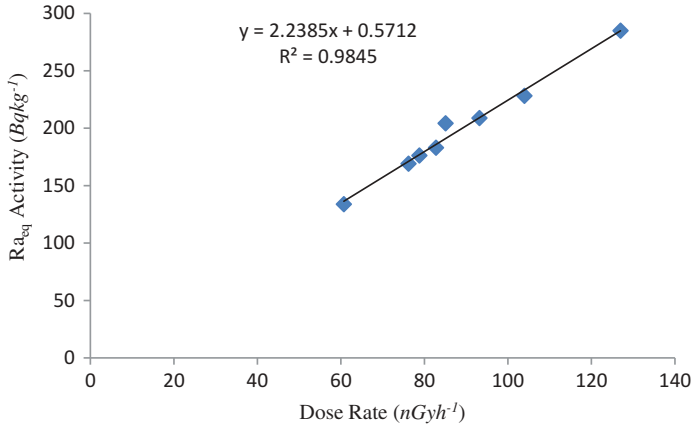

Figure 4. Correlation of radium equivalent with dose rate in mining area.

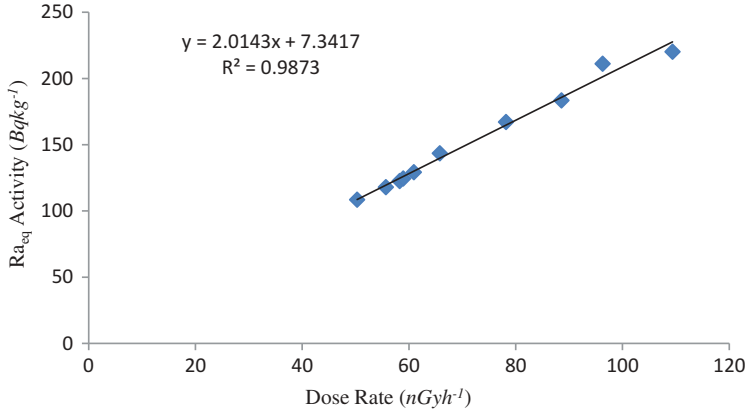

Figure 5. Correlation of radium equivalent with dose rate in living area.

than recommended limit of unity. The gamma representative index (I_γ) was estimated using Equation (5). This was done in order to examine how the soil materials from these locations are suitable for construction purposes. The calculated I_γ is greater than unity in the samples collected from the mining site except in one location with mean value of 1.4. While, it was found to be greater than unity in half of the control locations with a mean value of 1.13. The evaluated mean I_γ obtained for both locations were higher than the recommended permissible limit of unity which suggest that the materials may not be suitable for construction purposes from radiation protection point of view:

$$H_{in} = {}^{C_U}/_{185} + {}^{C_{Th}}/_{259} + {}^{C_K}/_{4810} \tag{4}$$

$$I_\gamma = {}^{C_U}/_{150} + {}^{C_{Th}}/_{100} + {}^{C_K}/_{1500} \tag{5}$$

where C_U, C_{Th}, and C_K are the concentrations of uranium, thorium and potassium in the soil samples ($Bqkg^{-1}$).

Excess Life time Cancer risk (*ELCR*), the additional or extra risk of developing cancer due to exposure to a toxic substance incurred over the life time of an individual as a result of exposure to a toxic substance accumulated over a period of lifetime (Average 70 years) was calculated as follows:

$$ELCR = AEDE \times LT \times FR \tag{6}$$

where *AEDE* had been obtained from Equation (3), *LT* is the average life span (70 years) and *FR* is the risk factor. The calculated *ELCR* was found to be higher than the permissible limit of 0.29×10^{-3}

(UNSCEAR, 2000) in all the samples collected from the mining site except in one location and the mean *ELCR* value of 0.38×10^{-3} was obtained for the mining sites. The increase was found to be 76% above the recommended value (UNSCEAR, 2000). This suggests that dwellers and workers in the vicinity are likely to be exposed to elevated level of natural radioactivity and they may be prone to the development of cancer within their lifetime.

4. Conclusions

- The natural radioactivity contents of soils from Ijero mining and living areas had been measured using hyper pure germanium detector.
- It was revealed that the mining area had the highest activities concentrations of ^{238}U (128.05 Bqkg^{-1}) which exceeded the recommended permissible limit.
- Highest mean absorbed dose rate, annual effective dose equivalent, gamma index and the excess lifetime cancer risk were consistently obtained from the mining sites.
- The high radioactivity measured in the town may be connected with the mining activities going on in the town.
- The study therefore concludes that the soils in most of the studied locations are not suitable for building purpose.
- The research also recommended that government should see to it that illegal mining be stopped in the town so as not to expose the inhabitants to high radiation burden.

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