DOI: 10.5281/zenodo.14949202

SESSION THREE: FOCUS ON THE PLANET (SDG 13, 14, and 15)

1. Environmental Pollution and Radiological Hazards Assessment of Quarrying Activities in Southwestern Nigeria

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Abstract

The introduction of pollutants to any environment poses a significant threat to human health and the overall well-being of ecosystems, thus undermining the Sustainable Development Goal (SDG). In 2019, the World Health Organization (WHO) reported that approximately 9 million annual deaths were attributed to air pollution resulting from human activities. The research investigated radiological pollution hazards caused by quarrying-related dust emissions. The assessment includes estimations of internal hazard index (H_{in}), external hazard index (H_{ex}), radium equivalent activity (Ra_{eq}), absorbed gamma dose rate (D), Annual Effective Dose Equivalent (AEDE), and Excess Lifetime Cancer Risk (ELCR). Two-hundred-gram (200g) of each dried dust sample was placed into gas-tight, radon impermeable cylindrical polyethylene containers with a uniform base diameter of 2cm and then sealed for 28 days to achieve secular equilibrium before using NaI(Tl) gamma-ray spectrometer for counting. The highest activity concentrations of 1691.9Bqkg^{-1}, 55.0 Bqkg^{-1}, and 124.8 Bqkg^{-1} were recorded for ^{40}K, ^{226}Ra and ^{232}Th respectively. Radiological hazard indices were computed and compared with the *International Commission on Radiological Protection* (*ICRP*) and it was observed to be slightly higher than the standard limit. The results suggested that more attention is required in monitoring dust from quarrying-related activities in the study areas. It emphasizes the inclusion of proper ventilation in residential structures to mitigate the accumulation of radon. Quarrying dust'spotential impact on the environment, human health, and Sustainable Development Goal (SDG) has been addressed.

Keywords: Quarrying dust, Hazard indices, Health impact, Pollution, Environment

Introduction

A pollutant/contaminant is any physical, chemical, biological or radiological substance or matter that hurts air, water, or soil (Babuji *et al.,* 2023). The presence of pollutants in any environment interferes with human health and welfare, thus limiting proper functioning of the human capacity and the environmental system (Manisalidis *et al.*,2020). Out of thousands of hazardous pollutants, radioactive pollutants are the most toxic (Saleh *et al.,* 2022) because they are all-pervasive, emitting radiation consisting of energetic particles that damage human tissues leading to varioushealth challenges. Natural sources of ionizing radiation have always been part of the human environment; they come from the earth (rocks/ soil) or cosmic (Kormanovskaya *et al*., 2023). Meanwhile, long-lived radioactive elements including uranium, radium, thorium and non-decay series potassium are present in variable quantity in the earth and their concentration depends on the composition of the soil or rocks within that geographic area.

Environmental pollution can trigger physical illness (Olden *et al.,*2011) and activate diseases if not controlled. Humans' health depends greatly on the care given to the control of environmental pollution; the more we understand our environment the healthier we live. Even though quarrying activities has createdjobs opportunity and economic development, the environmental effects and challenges cannot be neglected (Ipeghan *et al*., 2019; Ajibade *et al.,* 2022). Typically, air pollution is a major effect caused by quarrying exhibited by releasing dust particles into the atmosphere, which may be carried long distances by wind or rose into the upper levels of the atmosphere where they can cause major worldwide problems. It is disinteresting to note that many health

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problems are linked to air pollution. World Health Organization (WHO) in 2019 reported that about 9 million deaths per year was because of air pollution from anthropogenic sources (Giuliani *et al.,* 2021). In addition, Manisalidis *et al.*, (2020) established that respiratory and cardiovascular diseases may result from air pollution problems leading to reproductive and central nervous system dysfunctions, and cancer. Notwithstanding the aforementioned, many authors have provided more thoughts as to the environmental implications and health of quarrying, Ipeghan *et al.*, (2019), investigated the effect of rock crushing on Ishiagu environment in Enugu State, Nigeria, the report found that the air around quarry sites could be contaminated by numerous number of potentially toxic heavy metals which may include iron, zinc, copper, lead, cadmium, chromium and nickel.

Nigeria is blessed with over forty (40) different minerals, according to the National Bureau of Statistics (NBS); about six per center of Nigeria's gross domestic products (GDP) in 2021 was generated from mining and quarrying sector. Despite this huge contribution to national GDP, there are a number of environmental safety measures guiding the operation of mining and quarrying, unfortunately, these safety measures are not the major concerns of the stakeholders in mining and quarrying sectors rather to generate and maximize revenues (Taiwo and Ogunbode, 2024). No adequate measures have so far been recorded by authors in safeguarding the lives of the nearby dwellers, perhaps the environment where most quarries are sited. From the experience of field sampling, eighty percent of the quarry sites are in rural areas where majority of the inhabitants lack or unaware of the adverse effects of the environmental pollution caused by mining and quarrying. Alausa *et al.,* 2015 reported that gamma rays are predominantly emitted by dust emanating from crushed rocks, primarily from isotopes such as ^{40}K, ^{226}Ra, and ^{232}Th along with their radioactive decay products. Olabamiji *et al.,* (2023) also noted that dust from crushed rocks can also release radon, an inert gas, and its radioactive decay products; this could affect the whole-body,skin and respiratory tract of humans when they are inhaled

This study measured he concentrations of natural radionuclides in some crushed rocks taken from quarry sites, in Southwestern Nigeriausing sodium iodide detector (NaTI), the detector is preferable in the analysis of natural radionuclide in rock samples due to its relatively higher efficiency and it works under room temperature conditions. The primary aim is to determine the natural activity concentration of primordial radionuclide in dust from some selected quarries.

Materials and methods

Geology of the study locations

The Nigerian geological basement complex is located from between Latitude 4°N and 15°N and Longitude 3°E and 14°E between the Pan-African mobile belt in-between the West African and Congo Craton (Jibiri *et al.,* 2016). Furthermore, the basement complex of Southwestern Nigeria lies between latitudes 7°N and 10°N and longitudes 3°E and 6°E. It is a crystalline basement rock comprising amphibolite, migmatite gneisses, granites, pegmatite and some other important rocks including schist comprising biotite schist, quartzite schist, talc-tremolite schist, and the muscovite schist (Usikalu *et al.,* 2015). In terms of lithology, Osun and Oyo States belong to the crystalline basement complex region, while Ogun State belongs to the basement complex (undifferentiated) region post-cretaceous.

Sample collection

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The geological map and features of different types of rocks found in the three states have been carefully studied before the sample collection. Crushed rock dust samples were collected from the site, and quantities of the collected crushed rock dust were packed into polyethylene bags, tied and labeled. The sampling was carried out randomly in five (5) quarry sites in each state. Ten different rocks were collected from each site to make a total of 50 samples for the study. The samples were then taken to the Radiation and Health Physics Research Laboratory at the Department of Physics, Federal University of Agriculture Abeokuta for spectrometry analysis.

Sample preparation for spectrometry analysis

The crushed rock dust samples were pulverized and homogenized. The sample was sieved with a <0.16mm mesh sizebefore drying in an electric temperature-controlled oven at 110^0C temperature for 4 hours to remove moisture (if any). Two hundred (200g) of each of the dried samples was carefully weighed using an electronic balance with a sensitivity of 0.01mg and emptied into a gas-tight radon impermeable, cylindrical polyethylene container of 2cm uniform base diameter and it was then sealed. The container was substantially fit to sit on the 5cm x 5cm NaI(TI) detector that was used for the measurement. The prepared samples were kept for 4 weeks to allow for a state of secular radioactive equilibrium between ^{222}Rn and its short-lived decay products (^{214}Pb and ^{214}Bi).

Determination of activity concentrations

A 5cm × 5cm solid NaI(Tl) gamma-ray spectrometric that was coupled to a Digital-based multi-channel analyzer (MCA) was used to count the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th. The detector has an energy resolution of about 8% at the energy of 0.662 MeV, which was considered adequate to distinguish the gamma energies of interest in the study. However, the activity concentration of ^{214}Bi determined from its 1.76 MeV gamma ray peak was chosen to provide an estimate of ^{226}Ra in samples, while that of the daughter radionuclide ^{208}Tl determined from its 2.61 MeV gamma ray peak was chosen as an indicator of ^{232}Th. The activity concentration of ^{40}K was determined from 1.46 MeV gamma-rays emitted during the decay of ^{40}K. The standard reference sample used for efficiency calibration was from Rocketdyne Laboratories California, USA, traceable to a mixed standard gamma source (Ref No 48722-356) by Analytic Inc., Atlanta, GA, USA.

Equation (1) shows the usual relationship between activity concentration and the count rate under the photo peak of a given gamma-ray spectrometry detector (Jibiri and Akomolafe, 2016)

$$C = \frac{C_n}{\varepsilon_p I_\gamma m_s} \qquad (1)$$

where C is the activity concentration of the radionuclides (^{40}K, ^{226}Ra and ^{232}Th) in the sample (Bqkg^{-1}), C_n is the count rate under the photo peak, $\varepsilon_p$is the detector efficiency at a specific gamma-ray energy, $I_\gamma$is the absolute transition probability of the specific gamma-ray and m_s is the mass of the sample.

An empty container of the same geometry asthe sample container was counted for the same time to take care of the background radiation count and determination of the radionuclide detection limits. The detection limits (DLs) which describe the operating capability of the detector without the influence of any sample were determined using the Alausa *et al.* (2015) model.

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The detection limits (DLs) obtained in the present study was 0.12, 0.14 and 0.40 Bqkg^{-1} for ^{40}K, ^{226}Ra and ^{232}Th respectively. The activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th less than the corresponding values of the DLs are referred to as below detection limit (BDL). One-half of each DL is considered for calculating the mean activity concentrations of the radionuclides and the radiological parameters (Alausa *et al.,* 2015)

Radiological Assessments

Outdoor absorbed and effective dose rates

The quantity of absorbed dose is the amount of energy per unit mass absorbed by the irradiated object. Absorbed dose is the energy responsible for damage in living organism. The absorbed dose rate (nGyh^{-1}) at 1 m above the ground in air is calculated using the expression given by Olabamiji *et al.,* (2023)

$$D_R = 0.462A_{Ra} + 0.604A_{Ra} + 0.0417A_K \quad (2)$$

where D_R is the absorbed dose rate in nGyh^{-1}, A_{Ra}, A_{Th} and A_K are the respective activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K measured in Bqkg^{-1}. However, an annual effective dose is used to assess potential long-term effects that might occur in future due to ionizing radiation exposure of the public. The annual effective dose E_D (mSvy^{-1}) to the public due to the absorbed dose rate in air can be calculated using UNSCEAR (2016).

$$E_D = D_R \times 8760 \times 0.2 \times 0.7 \quad (3)$$

Where E_D is the effective dose in mSvy^{-1}, D_R (nGyh^{-1}) is the dose rate in air, 8760 is the time in hoursfor one year, 0.2 is the outdoor occupancy factor and 0.7 isthe conversion factor Olabamiji *et al.,* (2023)

Excess lifetime cancer risk

Lifetime cancer risk is defined as an estimate of the risk to a member of a population that is dying from cancer because of exposure to ionizing radiation (IAEA, 2003). The cancer risks due to the external radiation exposure of soils from the dumpsites are determined using a model proposed by the United States Environmental Protection Agency (UNSCEAR, 2016): Lifetime cancer risk assessment (R) was calculated using equation 4

$$R = \sum A_{edr} R_f L_e \quad (4)$$

Where A_{edr} is the annual effective dose equivalent measured in Svy^{-1}, Dl is the duration of life (55.2 years for Nigerians) while R_f (Sv^{-1}) is the risk factor according to ICRP (1996), the risk assessment probability coefficient is given as 7.3×10^{-2} Sv^{-1}. The results of the lifetime cancer risk are presented in Table 2. From the results, the lifetime cancer risk obtained in the present study were not significant when compared with the world recommendation of 8.4×10^{-3} (UNSCEAR 2016) corresponding to 2.4 mSvy^{-1}.

Radium equivalent

The radium equivalent (Ra_{eq}) is commonly used as an index to compare the specific activity concentrations of radionuclides in different sample matrices. It is the sum of the weighted activity of radionuclides based on the

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estimation that 130 Bq kg^{-1} of ^{40}K, 10 Bqkg^{-1} of ^{226}Ra and 7 Bq kg^{-1} of ^{232}Th will deliver an equivalent gamma dose rate. It was calculated using the expression below by Agnieszka, *et al.,* (2018)

$$Ra_{eq} = 0.077A_K + A_{Ra} + 1.43A_{Th} \quad (4)$$

Where A_K, A_{Ra} and A_{Th} are the activity concentrations (Bqkg^{-1}) of ^{40}K,^{226}Ra and ^{232}Th respectively

External hazard index

The external hazard due to the emitted natural gamma radiation is an important criterion used to assess the radiological suitability of a material for building purposes, and it was calculated using equation 5 (Azeez *et al.*, 2020)

$$H_{ex} = \frac{A_K}{4810} + \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} \quad (5)$$

where A_K, A_{Ra}, A_{Th} are the activity concentrations (Bqkg^{-1}) of ^{40}K,^{226}Ra and ^{232}Th, respectively

Internal hazard index

In addition to the external hazard index, there is also a threat to the human respiratory organs due to ^{222}Rn, the gaseous decay product of ^{226}Ra. Internal exposure to radon and its progeny products is quantified by estimating the internal hazard index using Jibiri (201)

$$H_{in} = \frac{A_K}{4810} + \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} \quad (6)$$

where A_K, A_{Ra}, A_{Th} are the activity concentrations (Bqkg^{-1}) of ^{40}K,^{226}Ra and ^{232}Th, respectively.

Gamma index

The gamma index ($I\gamma$) referred to as the representative index is a hazard parameter used to correlate the annual dose rate due to the excess external gamma radiation caused by any superficial materials. It is used only as a screening tool for identifying materials that might be a threat to human health when used for building construction. The gamma index was calculated using the European Commission proposal Anetai *et al.,* (2022):

$$H_{\gamma} = \frac{A_K}{3000} + \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} \quad (7)$$

where A_K, A_{Ra}, A_{Th} are the activity concentrations (Bqkg^{-1}) of ^{40}K,^{226}Ra and ^{232}Th, respectively.

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RESULTS AND DISCUSSION

Activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in samples from the study area

The resultsof the activity concentration are presented in Table 1. The error observed in each sample is uncertainty from the spectrometry detector while the error attached toeach mean value of the activity concentration is the standard deviation.

From Table 1, the activity concentrations of the natural radionuclides in the rock samples ranged from 213.3 to 1573.4Bqkg^{-1} with a mean value of 781.23±10.1 Bgkg^{-1} for ^{40}K; ^{226}Ra : 4.9 to 55.0 Bqkg^{-1} with a mean of 30.2±6.3 Bqkg^{-1} and ^{232}Th 10.4 to 111.0 Bqkg^{-1} with a mean value of 49.23±0.02 Bqkg^{-1}. Figures 1, 2, 3 illustrates the mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th and the world average values, In addition to the data in Table 1, the values of ^{40}K show a very huge margin compared to the values recorded for ^{226}Ra and ^{232}Th. Several literatures have shown that ^{226}Ra and ^{232}Th usually have lesser values than ^{40}K (Hanfi *et al.,* 2019; Abedin and Khan, 2022; Madzunya *et al.,* 2020). Moreover, an elevated activity concentration of natural radionuclides recorded in rocks from the study may be attributed to the presence of minerals such as zircon, iron oxides, fluorite and other radioactive minerals that could contribute to the distribution of uranium and thorium in the earth's crust (Aita *et al.,* 2024; El Dabe *et al.,* 2022). In addition, the possible cause of high valuesfrom background radiation may be because of rocks being major hostsof naturally occurring radioactive materials (NORMs) (Oviri *et al.,* 2023).

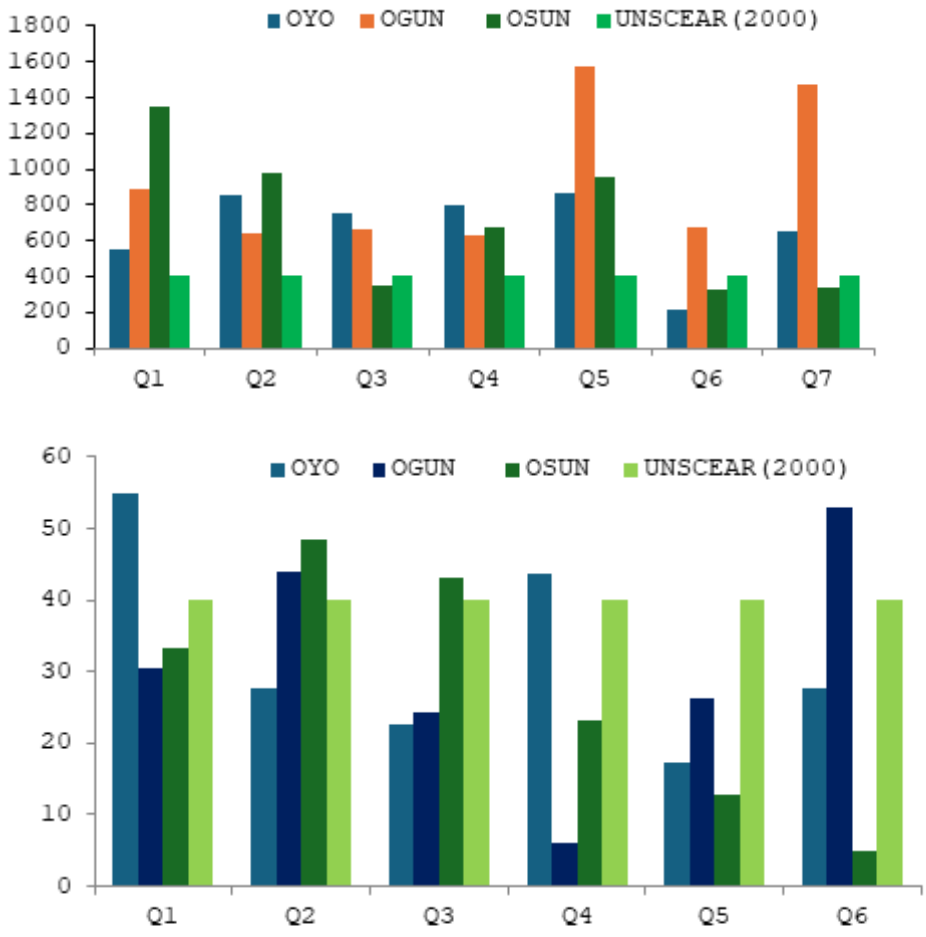

Figure 2: Concentration of ^{226}Ra from Quarry sites

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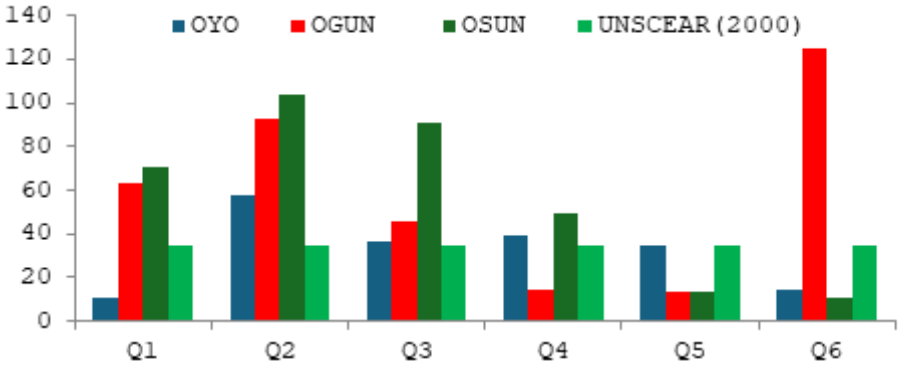

Figure 3: Concentration ^{232}Th from Quarry sites

Table 1: Activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th, in the samples from the study area

State	^{40}K (Bqkg^{-1})		^{226}Ra (Bqkg^{-1})		^{232}Th (Bqkg^{-1})	
Oyo	Range	Mean	Range	Mean	Range	Mean
Q1	446.4 - 660.6	553.6	53.8.56.7	55	109-115	11.1
Q2	1113.2 – 2289.1	859.1	BDL-30.1	27.8	BDL-60.4	57.5
Q3	1103 - 1189.9	756.4	BDL-29.4	22.7	BDL-46.2	36.6
Q4	790.5 - 820.2	797.1	BDL-50.5	43.6	BDL-47.2	39.3
Q5	1489.8 – 1686.2	864.7	16.0-20.4	17.2	31.7-38.0	34.6
Q6	2126.7 - 2140.4	213.3	BDL-28.4	27.7	BDL-15.4	14.1
Q6	1389.1 - 1501.8	650.4	3.9-5.0	4.9	8.9-11.9	10.4
OGUN						
Q7	677.8 - 1101.7	886.5	BDL-31.2	30.4	BDL-70.3	62.9
Q8	298.2 – 965.	643.9	17.9-79.3	44	37.7-167.2	92.8
Q9	630.3 - 679.3	658.8	19.8-31.6	24.4	43.4-48.3	45.6
Q10	620.6 - 650.3	634.3	4.2-8.2	6	8.9-21.1	14.1
Q11	1445.3 - 1681.2	1573.4	BDL-30.3	26.4	BDL-15.2	13.7
Q12	500.4 - 812.4	669.8	43.6-59.8	52.9	110.4-140.0	124.8
OSUN						
Q13	1302.2 - 1400.9	1351.4	28.9-36.2	33.2	65.4-77.4	71
Q14	890.8 - 1021.4	975.2	46.7-50.3	48.4	100.3-109.4	103.6
Q15	1159.5 - 1160.5	349.5	39.6-47.7	43.2	83.7-100.2	91
Q16	660.6 - 701.2	675.3	21.4-25.6	23.1	44.4-53.4	49.4
Q17	931.3 - 989.1	950.6	10.8-16.4	12.8	24.5-28.7	13.8

BDL- Below Detection Limit

DOI: 10.5281/zenodo.14949202

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Outdoor absorbed and effective dose rates in rocks from the study area

Equation 2 was used to determine the absorbed dose rate ($nGyh^{-1}$) due to radiation exposure in the air at 1 m above ground level and the results are presented in Table 2. The minimum absorbed dose rate was $140.53nGyh^{-1}$ while the highest value was $987.64nGyh^{-1}$ and the mean was $459.59nGyh^{-1}$. The mean absorbed dose rate in the present study washigher than the recommended world average limit of $55nGyh^{-1}$ (UNSCEAR 2016). Moreover, the effective dose rate was calculated using equation 3 and presented in Table2, the mean value of the effective 563 $mSvy^{-1}$ and this value is $0.103mSvy^{-1}$ greater than the world recommended value of $0.460mSvy^{-1}$from terrestrial radionuclide in a normal background area (UNSCEAR, 2016).

Radiological hazard indices in rocks from the study area

The result of radium is equivalent (Table 2). The maximum radium equivalent in the study was 282.94 $Bqkg^{-1}$ while the minimum value was 64.29 $Bqkg^{-1}$ and the mean value was 144.69 $Bqkg^{-1}$ which is about 39.1% of the world recommended average value of 370 $Bqkg^{-1}$ (UNSCEAR, 2016).According to Han *et al*., (2023), the radium equivalent activity was 33.25 $Bqkg^{-1}$from fine dust samples collected in Jeju, Korea, this result is lower than the value from this present work.

The results of the internal, external and gamma hazard indices are also presented in Table 2. The criterion demands that each of the three indices must be less than or equal to one ($H_{in} \leq 1$; $H_{ex} \leq 1$ and $I_{\gamma} \leq 1$) for radiological safety precautions in the use of rocks or any material for the construction of dwellings. However, all the values obtained for the three indices are lower than one.

Lifetime Cancer Risk Assessment (R)

The results of lifetime cancer risk obtained in the present study (table 2)varied when compared with the world recommendation value of 8.4×10^{-3} (UNSCEAR, 2016) corresponding to 2.4 $mSvy^{-1}$. The highest in the present study was 4.88 which are two times lower than the safe limit value. The result indicated that there may be stochasticeffects of radiationon human who are exposed to dust resulting from quarrying from the study areas. Figure shows the graph of excess life cancer risk alongside with other radiation hazard indices to evaluate our present results.

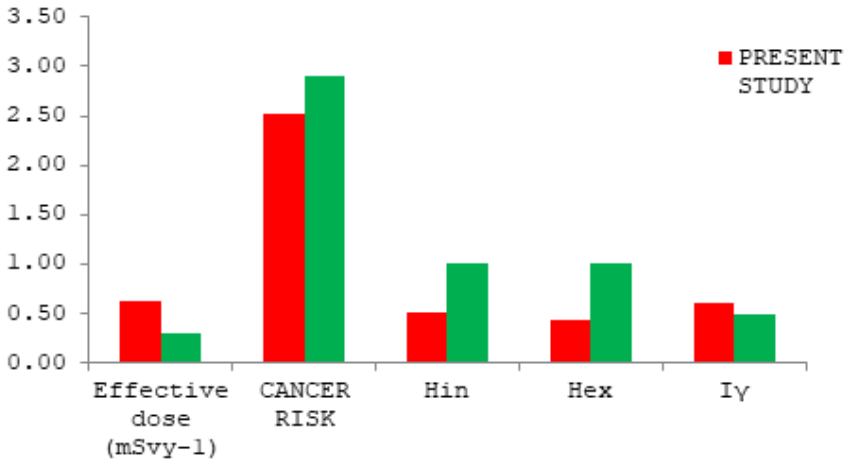

Table 4: effective dose, cancer risk, internal hazard index, external hazard index and gamma index in the present study and world standard

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Table 2: Assessed radiological parameters of the samples from the study areas

Absorbed dose(nGy/hr)	Effective dose ($mSvy^{-1}$)	CANCER RISK	H_{in}	H_{ex}	Ra_{eq} ($Bqkg^{-1}$)	I_γ
352.29	0.43	1.74	0.46	0.31	113.50	0.42
562.88	0.69	2.78	0.55	0.48	176.18	0.67
489.05	0.60	2.42	0.42	0.36	133.28	0.51
516.52	0.63	2.55	0.55	0.44	161.18	0.61
555.37	0.68	2.74	0.41	0.36	133.26	0.52
140.53	0.17	0.69	0.25	0.17	64.29	0.23
410.20	0.50	2.03	0.20	0.19	69.85	0.29
582.54	0.71	2.88	0.59	0.51	188.61	0.71
445.75	0.55	2.20	0.73	0.61	226.28	0.83
432.46	0.53	2.14	0.44	0.38	140.34	0.53
401.92	0.49	1.99	0.22	0.20	75.00	0.30
987.64	1.21	4.88	0.52	0.45	167.14	0.68
477.01	0.59	2.36	0.91	0.76	282.94	1.02
875.78	1.07	4.33	0.73	0.64	238.76	0.92
657.31	0.81	3.25	0.86	0.73	271.64	1.00
261.48	0.32	1.29	0.66	0.54	200.24	0.72
444.44	0.55	2.20	0.46	0.39	145.74	0.55
598.74	0.73	2.96	0.32	0.29	105.68	0.43

H_{in}= Internal hazard index, H_{ex} = external hazard index, Ra_{eq} = radium equivalent, I_γ = gammadose

Conclusion

The activity concentration in rock was determined and from the result, the value obtained for ^{40}K, ^{226}Ra and ^{232}Th are comparably higher than the world recommended except for ^{226}Ra. The mean value of absorbed dose and effective dose are slightly higherthan the world average values. In addition, all three indices that are used to determine radiological safe material for building construction are within the criteria limit (≤ 1). The results from this present study showed that radiation hazard associated with dust has serious health impacts on humans, also, there is a radiological protection concerns for the workers in the quarry who are exposed directly to the dust and spend long working hours within the vicinity, a long terms effects may be suspected. Furthermore, long-term radiation exposure is detrimental to human health,necessitating the need to discourage sitting of residential settlements near quarrying sites to minimize the long-term effects of ionizing radiation. To actualize the Sustainable Development Goal (SDG), appropriate monitoring of environmental pollution particularly from dust must be ensured.

DOI: 10.5281/zenodo.14949202

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