IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

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Measurements of Terrestrial Gamma Dose Rate Distributions along Idiroko Road, Ota, Ogun State, Nigeria: Health Implications on Roadside Dwellers

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Abstract: An extensive study concerning the terrestrial gamma dose rates of the surface soils from Canaanland entrance Road, Ota to Eleha Complex along Idiroko Road, Ota has been carried out to cover the road running across both areas. The In-situ measurements of gamma dose rates and radionuclides were carried out using the Gamma detector (Super Spec RS 125). The result shows that the average outdoor gamma dose rate in the study area is 73.57 $nGyh^{-1}$. The average values of the radionuclides obtained were 32.9 Bq/kg for ^{238}U, 68.4 Bq/kg for ^{232}Th, and 328.7 Bq/kg for ^{40}K. The background dose rate of 113.3 nGy/h was found in station 9 and is twice higher than the recommended permissible limit of 59 nGy/h suggested by UNCSEAR, 2000, and ICRP, 1999, respectively. Results were obtained based on radiological parameters for the outdoor absorbed dose rate (D_{out}) with a mean value of 73.57 $nGyh^{-1}$, the indoor absorbed dose rate (D_{in}) with a mean value of 131.84 $nGyh^{-1}$, the annual effective dose rate (AEDR) with a mean value of 0.74, the radium equivalent (Ra_{eq}) with a mean value of 156.0, the internal hazard index (H_{in}) with a mean value of 0.51, the external hazard index (H_{ex}) with a mean value of 0.42 and the excess lifetime cancer risk (ELCR) with a mean value of 2.57. Similarly, results obtained from estimated radiological parameters show that the station with the highest value for radium equivalent (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}), and annual effective dose rate (AEDR) is Station 9 at 237.91 Bq/Kg, 0.64, 0.72 and 1.13 $mSvy^{-1}$ respectively while the station with the lowest value for radium equivalent (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}) and annual effective dose rate (AEDR) is Station 17 at 85.58 Bq/Kg, 0.23, 0.27 and 0.40 $mSvy^{-1}$ respectively. This study will serve as a guide on assessing the road construction materials on radioactive contents before application to reduce the exposure risks to the populace along the busy roadsides.
Keywords: Radioactivity; Gamma-ray spectrometry; Natural radionuclides; Outdoor gamma dose rate; Gamma detector (Super Spec RS 125), Idiroko Road.

1. Introduction

Radioactivity is a natural and ubiquitous component of the universe. The decay of the radium isotope (^{226}Ra), which produces radon gas (^{222}Rn) and its decay progeny, is the main source of natural radiation to which the human body is exposed [1]. Nuclear reactions and the resulting radioactivity created all matter in our environment. Variations in nuclide stability are responsible for the relative abundance of elements that one can consider stable.

IOP Conf. Series: Earth and Environmental Science 1178 (2023) 012031 doi:10.1088/1755-1315/1178/1/012031

The presence of low-level radiation emanating from soil or rock is due to isotopes of radioactive elements found in rocks and minerals in the Earth's crust. Of more than 5000 known atoms(nuclides), around 95% are radioactive and this is a norm and not an exception [2]. Surveysand maps conducted using the radiometric method of the survey can be applied to many fields of science. This is because they provide researchers with not only geological but also geophysical information inareas like geochemical mapping, mineral prospecting, and structural geology. The information obtainedfrom these surveys and maps enables processes to involve the comparison of geological features presentacross specific regions in the survey area. The application of gamma-ray in mapping method issuccessfully conducted in emergency situations for other fields of science despite its origin in geoscience.Most emergency situations involve creating maps based on contamination due to nuclear fallout andpinpointing the position or specific location for lost radioactive sources. In order to solve large geologicaland environmental problems, an introduction to data processing using modern computers was made thusattaining a higher rate of achieving success in solving geological problems[3].

Many people are unaware that radioactivity is present in this world naturally. It is, in fact, quite common and can be found in the rocks, soil, and air which is virtually everywhere. Natural radioactivity maps may resemble geologic maps in appearance. But because different types of rocks have different levels of uranium and radon, scientists can get a good idea of the levels just by looking at geologic maps [4].

Higher altitude generally means that cosmic rays have higher natural radiation. Sun solar flares and subatomic particles from outer space cause cosmic radiation. These particles react in contact with the elements of the Earth's atmosphere. If one is on an aircraft, one's cosmic radiation is significantly higher than when they are on the ground. There are different natural radioactivity levels for different people and this is based on their different or various geographical locations. Idiroko Road, Ota's geography and topography are diverse and the levelsof radioactivity, both natural and man-made, differ from one region to another, as one might expect. While one shouldn't be affected by this terrestrial radiation, it is advisable to be aware of its concentration.

Idiroko Road in Ota, the state of Ogun, is a poorly maintained road in Nigeria. Despite this, the levels of radioactivity in the various areas that make up this road need to be mapped out. This is because, despite being poorly maintained, Idiroko Road is one of the most populated roads in Ota and is known for its heavy traffic due to heavy trucks that break down the asphalt and granite rocks used for road construction into tiny particles. These rocks used for road construction are known for their extent of radioactive elements such as ^{238}U, ^{232}Th, and ^{40}K, respectively.

In order to establish baseline data, it is necessary to map routes immediately. The measurements on site of the background radiation are performed using a hand-held gamma-ray spectrometer to record the levels of radiation in areas and along the roads of Idiroko, Ota. The base map is created using software known as ArcGIS. In order to estimate the amount of change in the radioactive setting due to the radioactivity propagation during the time it has been carried out, the need to do this study focuses on the radiation effect, which has great importance and interest to health physics.

Soil and asphalt forming Idiroko Road have not yet been tested on different radiation levels, but a map and a guide on the radioactive levels of Idiroko Road from Canaanland entrance Road, Ota to Eleha Complex Idiroko Road, Ota has been created by this study, and a sufficient map provided. The map is derived from radioactivity measurements of the study area using a hand-held gamma-ray spectrometer. Some of the areas showing particularly high or low radiation levels on the map are explained by a series of texts presented by graphs.

IOP Conf. Series: Earth and Environmental Science 1178 (2023) 012031 doi:10.1088/1755-1315/1178/1/012031

2. Materials and methods

2.1 In-situ gamma spectroscopy measurements using super-spec rs-125 gamma spectrometer.
The measurements were all done while using a Super Spec RS-125 and on-site at about 1 meter above the ground. The gamma detector used was a 2.0 cm x 20 cm NaI detector. The gamma detector utilized the obtained activity concentration of the radionuclides (^{40}K, ^{232}Th, and ^{238}U) as well as the background dose rate.

The procedures for these measurements are adopted specifically to detect the radioactivity level of the soil on site. The Super Spec RS-125 obtained from a corporation known as Canadian Geophysical Inc. was used in the measurements to measure the background gamma dose rate around the study area so as to determine the variations of ^{40}K, ^{232}Th, and ^{238}U (Omeje et al. 2020). This SuperSpec RS-125 is considered more suitable for the detection of radionuclides that occur naturally as well as the level of radionuclides exposure (dose exposure). The instrument also has a high level of accuracy with an error level of ± 5 %.

Table 1: The Acquired Raw Field Data of the Dose Rates and Radionuclides Along Idiroko Road

STATION	DOSE RATE	^{40}K (Bq/Kg)	^{238}U (Bq/Kg)	^{232}Th (Bq/Kg)
1	84.6	1.5	3.0	18.0
2	94.1	1.2	3.6	21.6
3	95.4	1.3	4.6	20.1
4	43.3	0.3	2.5	9.7
5	96.5	1.4	3.9	21.3
6	46.0	0.3	3.2	9.2
7	75.3	1.1	2.6	17.3
8	61.1	0.6	2.5	14.5
9	113.2	1.8	2.4	28.4
10	50.2	0.5	1.9	12.3
11	71.7	1.0	3.6	14.6
12	83.7	1.5	3.2	17.4
13	47.5	0.7	1.2	12.1
14	72.4	1.4	1.6	16.9
15	98.7	1.7	1.6	24.9
16	87.2	1.4	2.6	20.6
17	40.5	0.5	1.3	9.9
18	62.9	0.7	2.7	14.5

The Super Spec RS-125 is not only portable but also easy to use, has a design incorporated into it, is highly sensitive, makes direct assay read-out of the values to be shown on the screen, and has a strong data storage point with good weather protection.

The number of count displays of Super-Spec RS-125 in the front side of the panel in cps is at a 1/sec update rate. While the variable rate counts of the SCAN mode are used to store data in the memory of the device through Bluetooth connection to external storage of the hand-held device. The coordinates and location of the Sampling points were all obtained using the Global Positioning System (GPS) which also aided the data stream conducted via Bluetooth connection to the detector. In the area of study, using intervals of 30 m, the measurements were taken while crisscrossing the road. At each station, two different measurements were taken, and the average obtained was used to represent the actual data point for that site. The natural background gamma dose measurements as provided by the assay mode of RS-125 Super Spec and dose rate data are directly acquired in nGy/h. The RS-125 Super Spec comes with utility software that is used to download the statistics record that is stored in memory and further connected to the computer through Bluetooth or USB. The measured data are stored in an excel sheet with proper coordinates processed, georeferenced, and interpolated using ArcGIS (version 10.8) spatial analysis. Below is the data obtained from the site using the assay mode of RS-125 Super Spec to obtain the values of the radionuclides as shown on the detector and the natural background gamma dose measurements presented in Table 1.

3. Result and discussions

3.1 Spatial distribution of gamma dose rate along Idiroko road

The acquired dose rates, longitude, latitude, and elevation of the measured field data are presented in Table 2. Secondly, the acquired field data was used to interpolate the spatial analysis of the gamma dose rate signature measured at each station along the road. The spatial distribution of the gamma dose rate in the study area is presented in Figure 1.

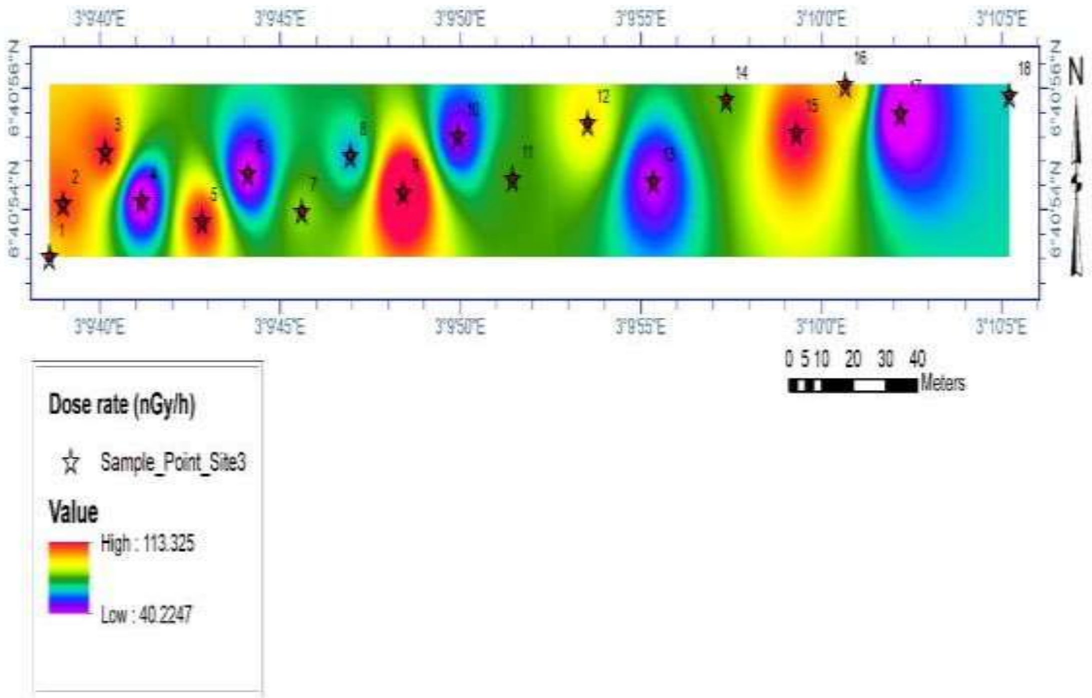
Table 2: The Acquired Field Dose Rate Data Used for GIS Interpolation of the Spatial Distribution Analysis Map

STATION	LATITUDE (Degree)	LONGITUDE (Degree)	DOSE RATE (nGy/h)	ELEVATION (m)
1	6.68145	3.16072	84.6	43
2	6.681695	3.16083	94.1	36
3	6.681933	3.16115	95.4	39
4	6.681708	3.16143	43.3	51
5	6.681613	3.16190	96.5	38
6	6.681832	3.16225	46.0	41
7	6.681658	3.16267	75.3	39
8	6.681912	3.16304	61.1	27
9	6.681745	3.16345	113.2	38
10	6.682002	3.16387	50.2	24
11	6.681808	3.16429	71.7	39
12	6.682062	3.16487	83.7	32
13	6.681797	3.16538	47.5	37
14	6.68217	3.16594	72.4	33
15	6.682018	3.16648	98.7	35
16	6.682237	3.16685	87.2	42
17	6.682105	3.16728	40.5	30
18	6.682188	3.16812	62.9	34

Considering the distribution pattern in the study as shown in Figure 1, indicates that the regions constitute both high and low background dose rates. It can be observed from the spatial map that the highest value of 113.2 nGy/h was reported in station 9, whereas the lowest value of 43.3 nGy/h was noted in station 4. This highest value indicates the pothole spots along the road, presumably the areas that have been deeply affected by heavy trucks and other users crushing the asphalts used for road construction into tinier particles that could enhance the emanation of radioactivity levels which in turn magnifies the background dose rate exposure in the area. There are other vulnerable zones such as stations 1, 2, 3, 5, and 15, respectively, unlike station 9 which is termed as the hotspot of exposure to the general public along the road. Comparing this highest value of 113.2 nGy/h with the recommended limit of 59 nGy/h according to

UNSCEAR, 2000[5] and ICRP, 1999[6], it can be observed that this current study is twice higher and could pose a stochastic effect on the general public that reside along the roadside.

Figure 1: Spatial Distribution of Background Gamma Dose Rates Along Idiroko Road



3.2 Estimation made concerning radiological hazard

Estimations are made with concern toward the radiological hazards. Below is an explanation of the various estimations.

3.2.1 Absorbed Dose Rate

In this study, the absorbed dose rate refers to the total amount of air absorbed and the dose rate received in the air (open) at 1 m above the ground with respect to the gamma emission from ^{238}U, ^{232}Th and ^{40}K Bq/Kg present in an environment. It is calculated using Equation 1 [5].

$$[nGyh^{-1}] = 0 \cdot 642C_u + 0.604C_{Th} + 0.0417C_k < 80\text{nGyh}^{-1} \quad 1$$

The indoor and outdoor absorbed dose rate ($D_{outdoor}$ and D_{indoor}) in the air due to the activity concentration of the primordial radionuclides ^{40}K, ^{238}U, and ^{232}Th (Bq/kg) along Idiroko Road was estimated using Equations 2 and 3;

$$D_{outdoo}(nGy\, h^{-1}) = 0.462C_u + 0.604C_{Th} + 0.041C_K \quad 2$$

$$D_{indoo}(nGy\, h^{-1}) = 0.92C_u + 1.1C_{Th} + 0.08C_K \quad 3$$

where C_K, C_u, and C_{Th} are the activities of ^{40}K, ^{238}U, and ^{232}Th in the samples respectively [5]
.

3.2.2 The Annual Effective Dose Rate

The indoor annual effective dose equivalent received by humans is estimated from the indoor internal dose rate (D_{in}), occupancy factor which is defined as the level of human occupancy in an area in proximity to a radiation source; is given as 80% of 8760 h in a year, and the conversion factor of 0.7 $SvGy^{-1}$ which is used to convert the absorbed does in the air to effective dose [5]. The annual effectivedose equivalent is estimated using Equation 4;

$$AEDR = (0.49C_u + 0.76C_{Th} + 0.048C_k) \times 8.76 \times 10^{-3} \quad 4$$

where C_u, C_{Th}, and C_K are the radioactivity concentration in Bq kg^{-1} of ^{238}U, ^{232}Th, and ^{40}K.

3.2.3 Radium Equivalent Activity Index (Ra_{eq})

The Ra_{eq} activity of the measured radionuclides is used to compare the activity of each of ^{238}U, ^{232}Th, and ^{40}K contents along Idiroko Road. The radium equivalent (Ra_{eq}) is calculated using Equation 5;

$$Ra_{eq} = C_u + 1.43C_{Th} + 0.077C_K \quad 5$$

where C_u, C_{Th}, C_K are the radioactivity concentration in Bq kg^{-1} of ^{238}U, ^{232}Th and ^{40}K.

3.2.4 Evaluation of external hazard index (Hex)

The gamma-ray radiation hazards index due to the specified radionuclides was assessed by external radiation hazard and was calculated using Equation 7 according to UNSCEAR (2000).

$$H_{ex} = (C_u/370) + (C_{Th}/259) + (C_k/4810) \quad 6$$

where C_u, C_{Th}, and C_K are the radioactivity concentration in Bq kg^{-1} of ^{238}U, $^{2,32}Th$ and ^{40}K respectively.

3.2.5 Determination of Internal Hazard Index

The hazard which is defined in relation to internal hazard is represented by H_{in} and can be determined using Equation 7;

$$H_{in} = (C_u/185) + (C_{Th}/259) + (C_k/4810) \quad 7$$

where C_u, C_{Th}, and C_K are the radioactivity concentration in Bq kg^{-1} of ^{238}U, ^{232}Th, and ^{40}K respectively.
Note: H_{in} should be less than unity for the radiation hazard to be negligible.

3.2.6 Excess Lifetime Cancer Risk (ELCR)

The Excess Lifetime Cancer Risk (ELCR) is calculated using Equation 8;

$$ELCR = AEDR \times DL \times RF \quad 8$$

where AEDR is the Annual Effective Dose Rate, DL is the average life duration (assuming 70 years) and RF is the fatal cancer risk per Sievert assumed to be 0.05 for stochastic effects for the populace [5]. The recommended limit for the ELCR is 3.75×10^{-3}.

3.2.7 Evaluation of the Gamma Index

Gamma index is used to evaluate the γ-radiation hazard related to the natural radionuclide in the particular samples under investigation. Its equation is given as Equation 10;

$$I_\gamma = C_u/300(Bq/Kg) + C_{Th}/200(Bq/Kg) + C_k/3000(Bq/Kg) \quad 9$$

where C_u, C_{Th}, and C_K are the radioactivity concentration in Bq kg^{-1} of ^{238}U, ^{232}Th, and ^{40}K respectively. The gamma activity index is used to identify whether a dose criterion is met. The gamma activity index accounts for the ways and amounts in which the materials used in building, with limit value of their indices not exceeding the recommended value and depending on the dose criterion.

3.2.8 Evaluation of Alpha Index

The assessment of the alpha index is another important aspect of hazard assessment that deals with the estimation of that excess alpha radiation due to radon inhalation originating from building materials. The alpha index is calculated using Equation 10;

$$I_\alpha = C_u/200(Bq/Kg) \quad 10$$

where C_u, C_{Th}, and C_K are the radioactivity concentration in Bq kg^{-1} of ^{238}U, ^{232}Th, and ^{40}K respectively.

Table 3: The Radiological risk Parameters associated with the primordial radionuclides

STATION	D_{in} ($nGyh^{-1}$)	D_{out} ($nGyh^{-1}$)	AED_{out} ($mSvy^{-1}$)	AED_{in} ($mSvy^{-1}$)	Ra_{eq} ($Bqkg^{-1}$)	H_{ext}	H_{int}	RLI	ELCR	AGED ($mSvy^{-1}$)
1	152.03	80.51	0.10	0.75	177.71	0.48	0.58	1.29	2.61	0.57
2	167.42	88.91	0.11	0.82	198.79	0.54	0.66	1.43	2.87	0.62
3	174.58	92.22	0.11	0.86	204.84	0.56	0.71	1.47	3.00	0.64
4	79.24	41.90	0.05	0.39	94.42	0.26	0.34	0.66	1.36	0.29
5	174.49	92.45	0.11	0.86	205.57	0.56	0.69	1.48	3.00	0.65
6	84.96	44.67	0.05	0.42	100.16	0.27	0.38	0.70	1.46	0.31
7	134.35	71.37	0.09	0.66	159.06	0.43	0.52	1.15	2.31	0.50
8	108.19	57.52	0.07	0.53	129.52	0.35	0.44	0.92	1.86	0.40
9	199.18	106.44	0.13	0.98	237.91	0.65	0.73	1.73	3.42	0.75
10	89.04	47.42	0.06	0.44	106.93	0.29	0.35	0.76	1.53	0.33
11	131.15	69.18	0.08	0.64	153.33	0.42	0.54	1.10	2.25	0.48
12	151.63	80.18	0.10	0.74	176.69	0.48	0.59	1.29	2.60	0.56
13	85.20	45.50	0.06	0.42	101.94	0.28	0.32	0.74	1.46	0.32
14	128.71	68.54	0.08	0.63	151.62	0.41	0.47	1.11	2.21	0.49
15	171.95	92.01	0.11	0.84	205.30	0.56	0.61	1.50	2.95	0.65
16	156.60	83.32	0.10	0.77	185.45	0.50	0.59	1.35	2.69	0.59
17	71.50	38.11	0.05	0.35	85.58	0.23	0.28	0.61	1.23	0.27
18	112.96	59.95	0.07	0.55	134.40	0.37	0.46	0.96	1.94	0.42
Min	71.50	38.11	0.05	0.35	85.58	0.23	0.28	0.61	1.23	0.27
Max	199.18	106.44	0.13	0.98	237.91	0.65	0.73	1.73	3.42	0.75
Mean	131.84	70.01	0.09	0.65	156.07	0.42	0.51	1.12	2.26	0.49

The radiological risk parameters shown in Table 3 were computed to appraise the radiological hazards associated with the primordial radionuclides in the locations under study. The estimated hazards indices are obtainable using equation 6 and 7 while the outdoor absorbed dose rate (D_{out}) whose equivalent values can be obtained using equation 2, was acquired *in-situ* using the RS-125 gamma spectrometer, the indoor absorbed dose rate (D_{in}) was estimated using equation 3 and the resulting values were used to evaluate the annual effective doses using equation 4.

The mean values of the outdoor and indoor absorbed dose rates are 70.01 and 131.84 $nGyh^{-1}$. The values recorded exceeds the recommended limit of 59 $nGyh^{-1}$. Similarly, the estimated mean values of the outdoor and indoor annual effective doses which are 0.09 and 0.65 $mSvy^{-1}$ expectedly exceeded the recommended limit of 0.07 and 0.41 $mSvy^{-1}$ provided by UNSCEAR. The graph is presented in Figure 4.5.

In Table 3, the station with the highest value for Radium Equivalent (Ra_{eq}), External Hazard Index (H_{ex}), Internal Hazard Index (H_{in}) and Annual Effective Dose Rate (AEDR) is shown as Station 9 at 237.91 Bq/Kg, 0.64, 0.72 and 1.13 $mSvy^{-1}$ respectively while the station with the lowest value for Radium Equivalent (Ra_{eq}), External Hazard Index (H_{ex}), Internal Hazard Index (H_{in}) and Annual Effective Dose Rate (AEDR) is Station 17 at 85.58 Bq/Kg, 0.23, 0.27 and 0.40 $mSvy^{-1}$ respectively. This shows that radiologically, that along Idiroko Road between Eleha Complex and in front of Canaanland Entrance Road presents a lot of threat. Also, it can be observed that the representative level index (RLI) exceeds the recommended limits of 1 along Idiroko Road. The estimated values for the Excess Lifetime Cancer Risk (ELCR) and Annual Gamma Effective Dose (AGED) corroborated our earlier findings Idiroko road presenting a lot of radiological threat.

4. Conclusions

The distribution of gamma dose rates and activity concentrations of radionuclides along the busy road of Idiroko Road has been assessed. The study revealed the zones with higher background dose rates (hotspots) from the spatial distribution analysis map. The high background dose rate of 113.2 nGy/h was found in station 9, which is twice higher than the recommended permissible limit of 59 nGy/h suggested by UNCSEAR, 2000, and ICRP, 1999, respectively. This indicates that the region along the study area poses health risks to the general public that resides along the road. Considering the radioactivity and radiological parameters, all the mean values are higher than the permissible limit suggested by UNCSEAR, 2000, and ICRP, 1999, respectively. This busy road has called for urgent attention from the Authorities in order to ensure the safety of the public from pending danger resulting from exposure to radiation. This study has set a baseline on radiological implications posed by road construction materials such as asphalt and crushed granites (quarry) to the general public**.** Also, the mean values of the outdoor and indoor absorbed dose rates for the three locations are 70.01 and131.84 $nGyh^{-1}$. The values recorded exceed the recommended limits. Similarly, the estimated mean values of the outdoor and indoor annual effective doses which are 0.09 and 0.65 $mSvy^{-1}$ expectedly exceeded the recommended limit of 0.07 and 0.41 $mSvy^{-1}$ provided by UNSCEAR. These high observed values at station 9 calls for serious concern since the considerable increase in the concentration of the radionuclides causes an increase in the level of the background radiation that can lead to exposure toelevated ionization radiation levels.

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