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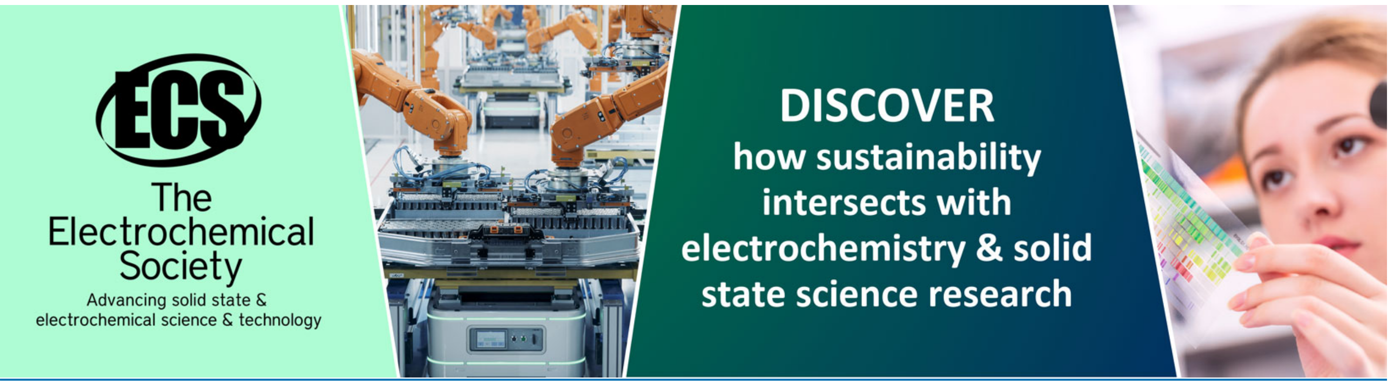

Background gamma radiation and associated health implications for Ifo-Dagbolu-Ajakaye, Ogun state

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Abstract. The need for safe habitat in view of the demands of Sustainable Development Goal 3 - sound health and wellbeing, calls for attention to ascertain the level of exposure of gamma radiation to man and the environment. Keeping the levels of specific activities of naturally occurring radionuclides (NORs) within safety limits will help in attaining the Sustainable Development Goal 3-"Good Health and Well-being". Background gamma dose rates and activity concentrations of NORs: ^{40K}, ^{238}U, and ^{232}Th in an agrarian settlement, Ifo-Dagbolu-Ajakaye, Ogun State, Southwest Nigeria, was surveyed using an Ultra-rugged Super-spec RS-125 gamma spectrometer. The respective mean values of the background gamma dose rates and specific activities of ^{40}K, ^{238}U, and ^{232}Th were 14.96 nGyh^{-1}; 31.60, 16.54 and 12.91 Bqkg^{-1}. The values of the specific activities were used to estimate the associated radiological health parameters and the values obtained were lower when compared with their corresponding United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) permissible limits. Hence the levels of the activity concentrations of the studied NORs do not present health hazards to the dwellers in the examined station.

Keywords: Naturally occurring radionuclides, Background gamma dose, Radiological parameters, Ifo-Dagbolu-Ajakaye

1. Introduction

According to United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 80% of the yearly average effective gamma radiation dose to a person comes from natural sources [1]. In recent times, the level of cancer-induced diseases is on the increase and an urgent attention is needed to ascertain if the possible source could be due to exposure to background gamma radiation [2]. These reasons and the demands of Sustainable Development Goal 3 informed the need for this study [3]. Naturally occurring radionuclides (NORs) abound in the environment and there is a need to be aware of the levels of the background gamma radiation coming from them as they can produce direct and indirect biological effects on the environment and its inhabitants [4]. The major NORs responsible for human exposure are ^{238}U, ^{232}Th, their decay progenies and ^{40}K [5]. Each of these three NORs has a very long half-life and they have been present on the Earth since its formation. As a result of the health hazards associated with exposure to NORs and inhalation of their short-lived decay progenies, international bodies and governmental organizations such as the International Commission on Radiological Protection (ICRP) [6], International Union of Radioecology (IUR) [7], and (UNSCEAR) [1] formulated measures to minimise these threats. The examined agrarian settlement has a long history of excavation of top soil for building purposes and the failure to restore the top soil may lead to the spread of NORs thus polluting the environment and exposing the dwellers to health risk due to radioactivity [8]. In order to ascertain the levels of radioactivity in this location, an in-place survey was done to determine the distribution of ^{40}K, ^{238}U, and ^{232}Th using an Ultra-rugged Super-spec RS-125 gamma spectrometer. With the measured specific activities of the NORs, associated radiological health risk indicators were estimated and statistical analysis done. The data so collected will be available for an awareness of the radioactivity levels in the examined location.

2. Study Location

The excavated landscape of Ifo-Dagbolu-Ajakaye stretches to a long distance and the examined portion of it is located within 6.7883 - 6.7886° N and3.2275 - 3.2278° E and at an elevation of about 42 m, Figure 1. It is an agrarian settlement with rivulets that are infested with catfish running on it and even cattle do come from municipal Agege abattoir to graze there apart from those from Ifo abattoir.

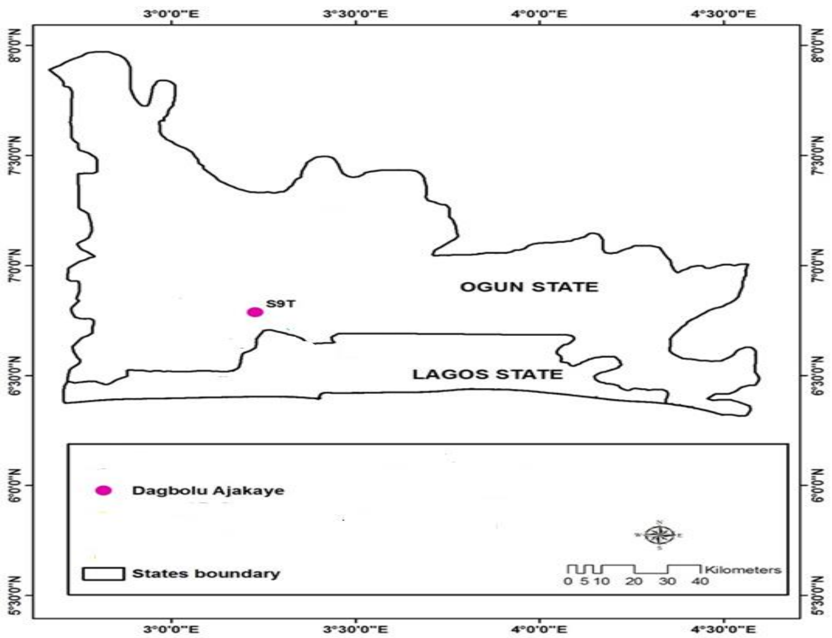

Figure 1: Location map of the study area

3. Materials and Methods

3.1 Assay Measurements

Values of the calculated assay readings of the Ultra-rugged Super Spec RS-125 were taken after it stabilized against the background radiation with a preset time period of 2 minutes between measurements. In order to get a broad picture of NORs distribution and generation of background radiation, a modified form of the "envelope" method was selected [9]. Five readings in each sampling point were collected from the vertices A, B, C, D of a 4-sided area and its center E (Figure 2) and these were averaged. The GPS coordinates and the elevations of the 5 sampling points were also recorded. To take the assay readings of the dose rate and the specific activities of the NORs at a sampling point, the RS-125 spectrometer was always placed on a 1 m pipe that is placed on the surface. At the center of a sampling point, using a 1 m span from this central point to 4 cardinal points, 5 readings were taken at each of the 4 cardinal points and at the center itself, Figure 3. The RS-125's direct evaluation mode gives NORs concentrations analyses with LCD display of readings of ^{40}K, ^{238}U and ^{232}Th in their respective stated units. For data analysis, the assay readings of the RS-125 for ^{40}K, ^{238}U, and ^{232}Th in (%), (ppm) and (ppm) in that order, were converted to their corresponding activity concentrations values in Bqkg^{-1} using the conversion factors according to [10] and are presented in Equations 1 - 3.

For ^{40}K; $1\ \% = 316$ Bqkg^{-1} (1)
For ^{238}U; 1 ppm $= 12.3$ Bqkg^{-1} (2)
For ^{232}Th; 1 ppm $= 4.1$ Bqkg^{-1} (3)

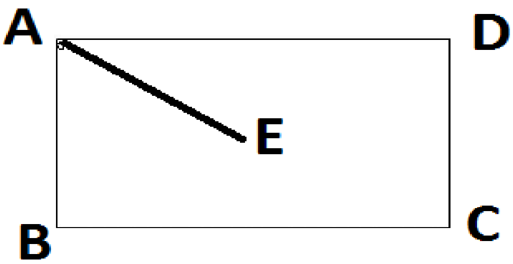

Figure 2: A modified form of the "envelope" method for the measured rectangular area of a station showing 5 station points: A, B, C, D and E [9].

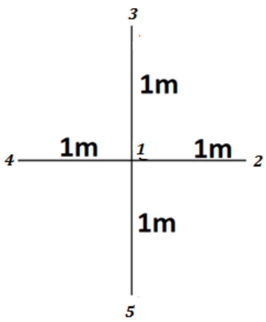

Figure 3: Five sampling points: 1, 2, 3, 4 and 5 for each of the station points: A, B, C, D and of Figure 2

3.2 Evaluation of Mean Radiological Parameters

Radiological health hazards indices are used to quantify the risks posed by the background gamma radiation and those due to NORs to the human anatomy, both presently and in the immediate or far future, even generations born afterwards. There could be direct or indirect biological effects. It is of utmost importance to evaluate the ambient levels of the prevalence of these potential threats via their respective indicators. Eight of such indices were considered in this study. The activities of ^{40}K, ^{238}U and ^{232}Th are not evenly dispersed in soil due to disequilibrium between ^{238}U and its decay progenies [11]. For homogeneity in exposure calculations, the specific activities of NORS are defined in designations of radium equivalent activity (Ra_{eq}) in $Bqkg^{-1}$ as in Equation 4 [11].

$$Ra_{eq}(Bqkg^{-1}) = A_U + 1.43A_{Th} + 0.077A_K \quad (4)$$

A_U, A_{Th} as well as A_K are the specific activities of ^{238}U, ^{232}Th and ^{40}K, in that order.
External and internal hazard indicators (H_{ex} and H_{in}) were estimated with Equations 5 – 6 [11].

$$H_{ex} = \frac{A_U}{370Bqkg^{-1}} + \frac{A_{Th}}{259Bqkg^{-1}} + \frac{A_K}{4810Bqkg^{-1}} \le 1 \quad (5)$$

$$H_{in} = \frac{A_U}{185Bqkg^{-1}} + \frac{A_{Th}}{259Bqkg^{-1}} + \frac{A_K}{4810Bqkg^{-1}} \le 1 \quad (6)$$

A_U, A_{Th} as well as A_K are as declared in Equation 4.

Radiation fallouts are commonly stated in respect of the absorbed dose rate in air. Ingested dose rate in air, D_{out}, 1 m from the surface as a result of NORs ^{238}U, ^{232}Th as well as ^{40}K in soil was evaluated using Equation 7 as described by [12, 13].

$$D_{out} = (0.427)\times A_U + (0.662)\times A_{Th} + (0.0432)\times A_K \quad (7)$$

A_U, A_{Th} along with A_K are as expressed in Equation (3.7).

The indoor gamma dose rate in the indoor environment, D_{in} is derived by radiation from natural radionuclides ^{238}U, ^{232}Th and ^{40}K, and [12] gave the relation between D_{out} in Equation (7) and D_{in} as in Equation 8:

$$D_{in} = (1.4)\times D_{out} \quad (8)$$

The annual effective dose rate received by humans in the environment was evaluated with Equation 9 [5, 11, 14 and 15].

$$AEDR_{out} = D_{out}\times(8766)\times(0.2)\times(0.7)\times(10^{-4}) \quad (9)$$

Where D_{out} was estimated as in Equation 7, 0.7 $SvGy^{-1}$ is a factor of conversion as recommended by [16] and 0.2 is an outdoor occupancy factor noting that people spent averagely 20% of their time outdoors with 8766 hours in a year (365.25 days) [16].

Gamma indicator (I_γ) was employed to evaluate gamma radiation risk accompanying the NORs. Typical I_γ was estimated using Equation 10 [5]. It should be < 1 for the radiation threat to be inconsequential.

$$I_\gamma = \frac{A_U}{300Bqkg^{-1}} + \frac{A_{Th}}{200Bqkg^{-1}} + \frac{A_K}{3000Bqkg^{-1}} \quad (10)$$

A_U, A_{Th} and A_K are as stated in Equation 4.

Excess lifetime cancer risk (ELCR) is a measure of the likelihood of developing cancer over a lifespan for a given risk level. It is a value showing the number of cancer patients anticipated in a given count of people on subjection to a carcinogen for a given dose. An increase in the ELCR causes a correlative growth in the rate at which an individual can develop prostate, breast, bone, blood and other forms of cancer [2]. ELCR is evaluated as in Equation 11 [17]:

$$ELCR(\times 10^{-3}) = AEDR \times DL \times RF \quad (11)$$

AEDR is the annual effective dose rate, DL is the average duration of life or life expectancy (estimated as 70 years), and RF is the risk factor (Sv^{-1}), that is, fatal cancer risk per Sievert. For stochastic effects, ICRP [6] uses 0.05 Sv^{-1} as RF for public [17] with the ELCR standard being 0.29 x 10^{-3} [16].

4. Results and Discussion

Table 1 presents the background gamma dose rates and the activity concentrations of the natural radionuclides ^{40}K, ^{238}U and ^{232}Th in Ifo-Dagbolu-Ajakaye station together with their statistics summary and the reference level for each of the measured natural radionuclides. The geographical dispersion of the background gamma dose rates is presented in Figure 4. The central station point, IDA3 was identified as the hotspot with topmost background gamma dose rate, 30.18 $nGyh^{-1}$ and this spread radially, decreasing to the four cardinal points with the lowest values at IDA2 and IDA5 respectively. The highest value of 30.18 $nGyh^{-1}$ was lower than the world reference level, 59.00 $nGyh^{-1}$by about 50% [1, 18]. The background gamma dose rates ranged from the minimum value of 9.28 $nGyh^{-1}$ at sampling point IDA2 to the maximum value of 30.18 $nGyh^{-1}$ at sampling point IDA3.

The recorded values of the activity concentrations of the natural radionuclides ^{40}K, ^{238}U and ^{232}Th ranged from their respective minimum values of below detection limit (BDL); 9.10 and 0.49 $Bqkg^{-1}$ at sampling points IDA1, IDA2, IDA4; IDA4 and IDA2 to maximum values of 6.32; 23.12 and 34.28 $Bqkg^{-1}$ at sampling points IDA3, IDA5; IDA1 and IDA3, respectively. The respective averages of the recorded values of the background gamma dose rates and the activity concentrations of the natural radionuclides ^{40}K, ^{238}U and ^{232}Th were 14.96 $nGyh^{-1}$, 31.60, 16.54 and 12.91 $Bqkg^{-1}$ and were all well below the corresponding reference level for each of the parameters [1]. The relationship between all the four parameters are shown in the charts of Figure 5. That the values of the four parameters were relatively low compared with the reference values may be due to long time excavation, for commercial building materials, of the top soil to greater depths leaving behind a stretch of depression that was investigated. The greater concentrations of the NORs might have been carried away during the excavations.

Estimated values of Ra_{eq}, outdoor and indoor dose rates, D_{out} and D_{in},are shown in Figure 6 and their mean values are displayed in Table 2, while the evaluated values of gamma index, I_γ, outdoor and indoor hazard indicators, H_{ex} and H_{in}, annual effective dose rate (outdoor), $AEDR_{out}$ and excess lifetime cancer risk, ELCR, to the dwellers in the examined locations are shown in Figure 7 and their mean values are indicated in Table 2. As shown in Table 2, skewness ranged from 0.25 to 1.92 and the data can be assumed to display normal distribution according to [19]. All the radiological health indices had values of skewness greater than unity similar to that of the specific activity of thorium, while the values for ^{238}U and ^{40}K were both less than unity. This indicate that the level of exposure to background gamma radiation could be attributed majorly to thorium and its decay products. Kurtosis varied from -3.33 to +3.87indicating that the data can be assumed to be closely symmetrically

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distributed [19]. Radiological health risk indicators showed the same positive values of kurtosis similar to that of the specific activity of thorium, while those of ^{238}U and ^{40}K gave negative values. Hence the level of radiological exposure could be strongly associated to that of thorium and its decay progenies. Pearson's correlation coefficients were estimated to demonstrate the degree of interrelationship between the measured specific activities of NORs and the estimated radiological health risk parameters, Table 3. Health risk indices correlated strongly and positively with specific activities of ^{232}Th. This implies that radiological vulnerability in the examined area was majorly due to the level of ^{232}Th and its decay products. Table 3 shows negative but poor interdependence between specific activities of ^{238}U and the health risk indicators. The moderate and positive correlation between ^{40}K and the health risk parameters may not pose any challenge as potassium is homeostatically controlled in man [19].

Table 1: Background gamma dose rates and activity concentrations of radionuclides in Ifo-Dagbolu-Ajakaye

Sampling Point	**LAT. (^{0}N)**	**LONG. (^{0}E)**	**D_R (nGyh^{-1})**	**^{40}K (Bqkg^{-1})**	**^{238}U (Bqkg^{-1})**	**^{232}Th (Bqkg^{-1})**
IDA1	6.7886	3.2275	10.94	*BDL	23.12	2.87
IDA2	6.7886	3.2276	9.28	BDL	19.93	1.23
IDA3	6.7884	3.2278	30.18	31.60	16.48	34.28
IDA4	6.7883	3.2277	13.84	BDL	11.38	17.06
IDA5	6.7884	3.2277	10.56	31.60	11.81	9.12
UNSCEAR [1]			**59.00**	**420.00**	**33.00**	**45.00**
Statistics Summary						
Mean			**14.96**	**31.60**	**16.54**	**12.91**
Minimum			9.28	BDL	11.38	1.23
Maximum			30.18	31.60	23.12	34.28

*BDL = below detection limit

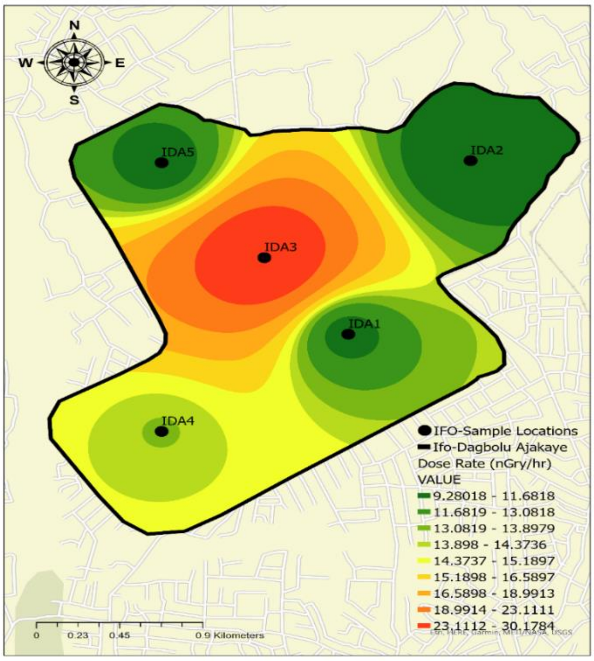

Figure 4: Spatial distribution of the background gamma dose rates in Ifo-Dagbolu-Ajakaye (IDA)

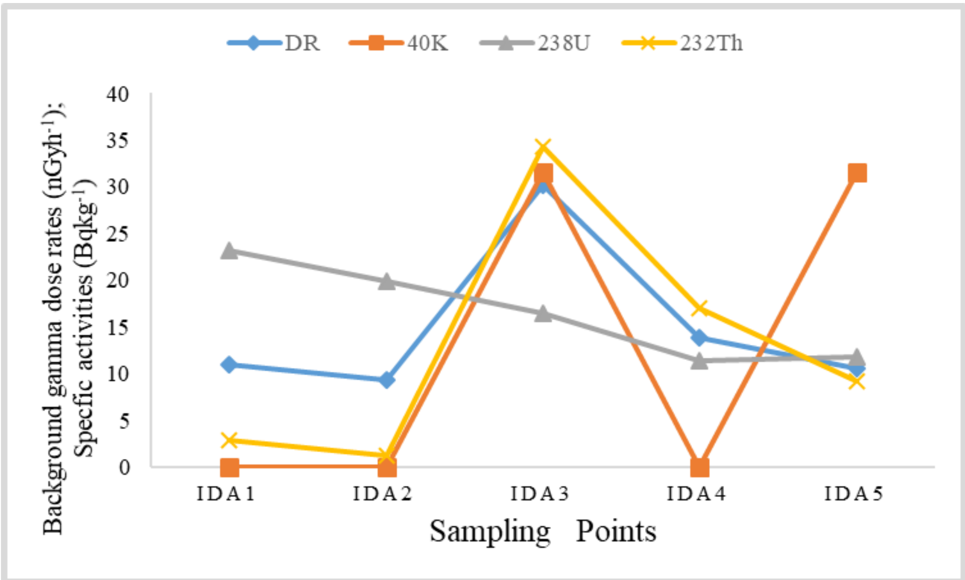

Figure 5: Background gamma dose rates and specific activities of NORs in Ifo-Dagbolu-Ajakaye

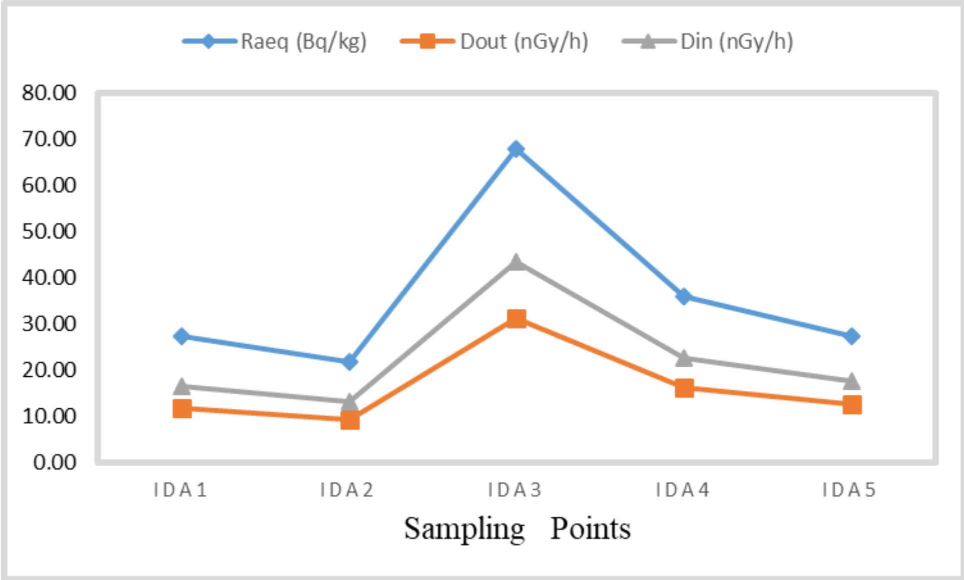

Figure 6: Specific activity of radium equivalent (Ra_{eq}), absorbed dose rates: outside (D_{out}) and inside (D_{in}) in Ifo-Dagbolu-Ajakaye.

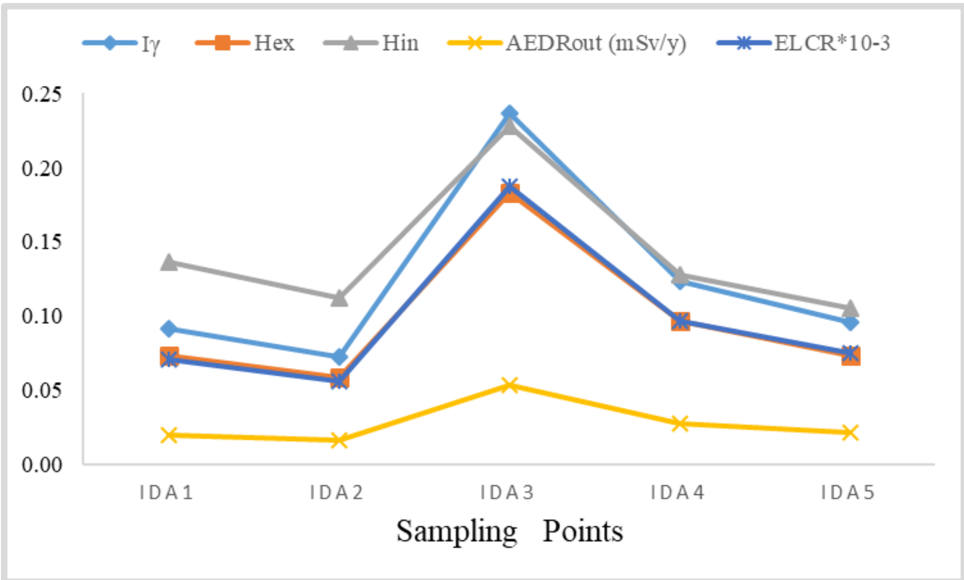

Figure 7: Health hazard indices: gamma index (I_{γ}), external (H_{ex}) and internal (H_{in}) outdoor and indoor hazard indicators, annual effective dose rate, outdoor ($AEDR_{out}$) and excess lifetime cancer risk (ELCR) in Ifo-Dagbolu-Ajakaye.

Table 2: Activity concentrations of NORs and radiological hazard indices in Ifo-Dagbolu-Ajakaye

Sampling point	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	Ra_{eq} (Bqkg^{-1})	D_{out} (nGyh^{-1})	D_{in} (nGyh^{-1})	I_{γ}	H_{ex}	H_{in}	$AEDR_{out}$ (mSvy^{-1})	ELCR (10^{-3})
IDA1	0.00	23.12	2.87	27.22	11.77	16.48	0.09	0.07	0.14	0.02	0.07
IDA2	0.00	19.93	1.23	21.69	9.32	13.05	0.07	0.06	0.11	0.02	0.06
IDA3	31.60	16.48	34.28	67.93	31.10	43.53	0.24	0.18	0.23	0.05	0.19
IDA4	0.00	11.38	17.06	35.78	16.15	22.61	0.12	0.10	0.13	0.03	0.10
IDA5	31.60	11.81	9.12	27.28	12.45	17.42	0.10	0.07	0.11	0.02	0.07
UNSCEAR [1]	**420**	**33**	**45**	**370**	**59**	**84**	**1.00**	**1.00**	**1.00**	**1.00**	**0.29**
Statistics summary											
Average	**12.64**	**16.54**	**12.91**	**35.98**	**16.16**	**22.62**	**0.12**	**0.10**	**0.14**	**0.03**	**0.10**
Skewness	**0.61**	**0.25**	**1.22**	**1.85**	**1.82**	**1.82**	**1.84**	**1.85**	**1.92**	**1.82**	**1.82**
Kurtosis	**-3.33**	**-2.03**	**1.04**	**3.55**	**3.45**	**3.45**	**3.51**	**3.55**	**3.87**	**3.45**	**3.45**
Minimum	0.00	11.38	1.23	21.69	9.32	13.05	0.07	0.06	0.11	0.02	0.06
Maximum	31.60	23.12	34.28	67.93	31.10	43.53	0.24	0.18	0.23	0.05	0.19

Table 3: Pearson's correlation matrix between specific activities of NORs and health risk indices

	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	Ra_{eq} (Bqkg^{-1})	D_{out} (nGyh^{-1})	D_{in} (nGyh^{-1})	I_{γ}	H_{ex}	H_{in}	$AEDR_{out}$ (mSvy^{-1})	ELCR (x10^{-3})
^{40}K (Bqkg^{-1})	1										
^{238}U (Bqkg^{-1})	-0.43	1									
^{232}Th (Bqkg^{-1})	0.60	-0.40	1								
Ra_{eq} (Bqkg^{-1})	0.57	-0.17	0.97	1							
D_{out}(nGyh^{-1})	0.59	-0.20	0.98	1.00	1						
D_{in}(nGyh^{-1})	0.59	-0.20	0.98	1.00	1.00	1					
I_{γ}	0.59	-0.19	0.97	1.00	1.00	1.00	1				
H_{ex}	0.57	-0.17	0.97	1.00	1.00	1.00	1.00	1			
H_{in}	0.46	0.10	0.87	0.96	0.95	0.95	0.96	0.96	1		
$AEDR_{out}$ (mSvy^{-1})	0.59	-0.20	0.98	1.00	1.00	1.00	1.00	1.00	0.95	1	
ELCR (x10^{-3})	0.59	-0.20	0.98	1.00	1.00	1.00	1.00	1.00	0.95	1.00	1

5. Conclusion and Recommendation

The background gamma dose rates and specific activities of NORs in Ifo-Dagbolu-Ajakaye were assessed using an Ultra-rugged Super-spec RS-125 gamma spectrometer. Respective means of the recorded values of the background gamma dose rates and activity concentrations of natural radionuclides ^{40}K, ^{238}U and ^{232}Th were 14.96 nGyh^{-1}, 31.60, 16.54 and 12.91 Bqkg^{-1} respectively. The measured values were all below the corresponding reference level for each of the parameters. The estimated means of radiological health hazard indices were also found to be below the threshold limits. All these measured and estimated values being below the threshold limits could be due to the long time excavation, for commercial purposes, of the top soil to great depths. Pearson's correlation analysis applied to all studied parameters show strong positive interrelationship between thorium activity concentrations and radiological health hazard parameters indicating that the major contributor to background gamma radiation exposure was thorium and its decay products. It can be concluded that the level of radioactivity in the examined location poses no threat to the inhabitants of Ifo-Dagbolu-Ajakaye.

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