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Environmental Radioactivity Monitoring and Radiological Impact Assessment of Agbara Industrial Area, Ogun State, Nigeria

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Abstract

Naturally occurring radionuclides of terrestrial origin exists in every component of the earth. Making humankind to be continuously exposed to ionizing radiation, which is dangerous to human health. Monitoring of environmental radioactivity is very crucial to minimizing exposure above the threshold limit. Consequently, the background radioactivity due to ^{232}Th, ^{238}U, and ^{40}K of some locations in Agbara industrial area of Ogun State was determined using RS125 Gamma Spectrometer (a portable NaI [Tl] detector). The mean activity concentration of the primordial radionuclides were 177.87 $Bqkg^{-1}$, 20.01 $Bqkg^{-1}$ and 52.90 $Bqkg^{-1}$ for ^{40}K, ^{238}U and ^{232}Th respectively. The in-situ measured dose rate (DR) ranges between 12.18 $nGyh^{-1}$ (Access Bank area) and 97.95 $nGyh^{-1}$ (Market area), with an average value of 47.22 $nGyh^{-1}$. The average measured and estimated absorbed dose rates were within the safe limit of 57 $nGyh^{-1}$ provided by UNSCEAR. However, the measured dose rates exceeded the recommended limit in ten locations, while measured activity for thorium exceeded the world average for over half of the study locations. The mean values of all the estimated radiological parameters were within the recommended threshold values. It could be concluded that the risk of exposure to higher level of ionizing radiation is low for all the area in Agbara industrial area of Ogun State, but there is possibility of cancer risk for someone that has stayed in the area for 70 years and above.

Keywords: Radioactivity, Radiation Hazards, Environmental Assessment Impact, Agbara Industrial Estate, Ogun State

1. Introduction

Naturally occurring radionuclides of terrestrial origin are known to exists in every component of the earth, thereby making humankind to be continuously exposed to ionizing radiation. Over exposure to ionizing radiation is very dangerous to human health and it can cause cancer and induced other radiation illnesses (UNSCEAR, 2008). Monitoring of environmental radioactivity is very crucial to minimizing exposure above the threshold limit. The result of the monitoring provides useful information on the radioactivity level and the distribution of the primordial radionuclides (^{234}Th, ^{238}U and their daughter nuclides, as well as the nonseries ^{40}K) in the environment. This result of the environmental radioactivity study can serve as important radiological baseline submission, which is essential for instituting remediation steps and enacting radiation protection laws (Usikalu et al, 2020; Omeje et al, 2021; Omeje et al., 2022; Ajibola et al., 2022). The level of background radioactivity has been reported to be elevated by anthropogenic activities such as mining (Orosun et al., 2022, Orosun et al., 2021), Agricultural activities (Orosun et al., 2017), industrial activities such the ones at Agbara industrial areas (Usikalu et al., 2020) or geogenic processes (Orosun et al., 2020).

In Nigeria, many works have been carried on environmental radioactivity from different areas of the country (Adagunoado et al., 2019; Adagunodo et al., 2018; Ademola et al., 2014; Usikalu et al., 2016; Usikalu et al., 2017; Orosun et al., 2022). This study is intended to supplement and broaden the existing data on radiological impact assessment in the country with specific interest in the Agbara industrial areas, Ogun State. This is necessary because it provides needed baseline information on the level of radiation exposures in the industrial areas as benchmark for future reference on the radiological health impacts on the residents of the study areas. It also address the SDG goal 3 as it relates to the good health and well-being of those in the study area.

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2. Materials and Methods

2.1 Study Area

Agbara Industrial area is one of the largest industrial estates in sub-Saharan Africa. The industrial area is a model integrated Town development on 454.1 hectares of land. It is situated approximately 31 kilometers west of Lagos on the Lagos-Badagry expressway on high ground above the Owo River and derives its name from the neighbouring Agbara village. It center lies at 6°31′0″ North, 3°6′0″ East (www.gomapper.com) and it has an elevation of 37 meters above sea level. The industrial areas are made up of 41.55% (188.289 hectares) of the whole estate. The location and accessibility of Agbara Estate makes the transportation of raw materials and finished goods informed the location as a good industrial area. Figure 1 shows the map of the study area. The geology of Ota is generally made up of sedimentary rocks of the Dahomey Basin (Figure 1). The lithostratigraphy sequences underlying the study area are Abeokuta, Ewekoro, Oshosun, Ilaro, and Benin Formations. Recently, an Alluvium which are of sands and shales are considered as the youngest of all these sequences, while Abeokuta Formation is considered as the oldest (Adagunoado et al., 2019; Adagunodo et al., 2018). As revealed in Figure 1, the study area falls on the Benin Formation, which is known as Coastal Plain Sands. This sequence is of Pliocene age, which is majorly composed of continental sands and intercalations of clay and shale within these sands (Usikalu et al., 2020).

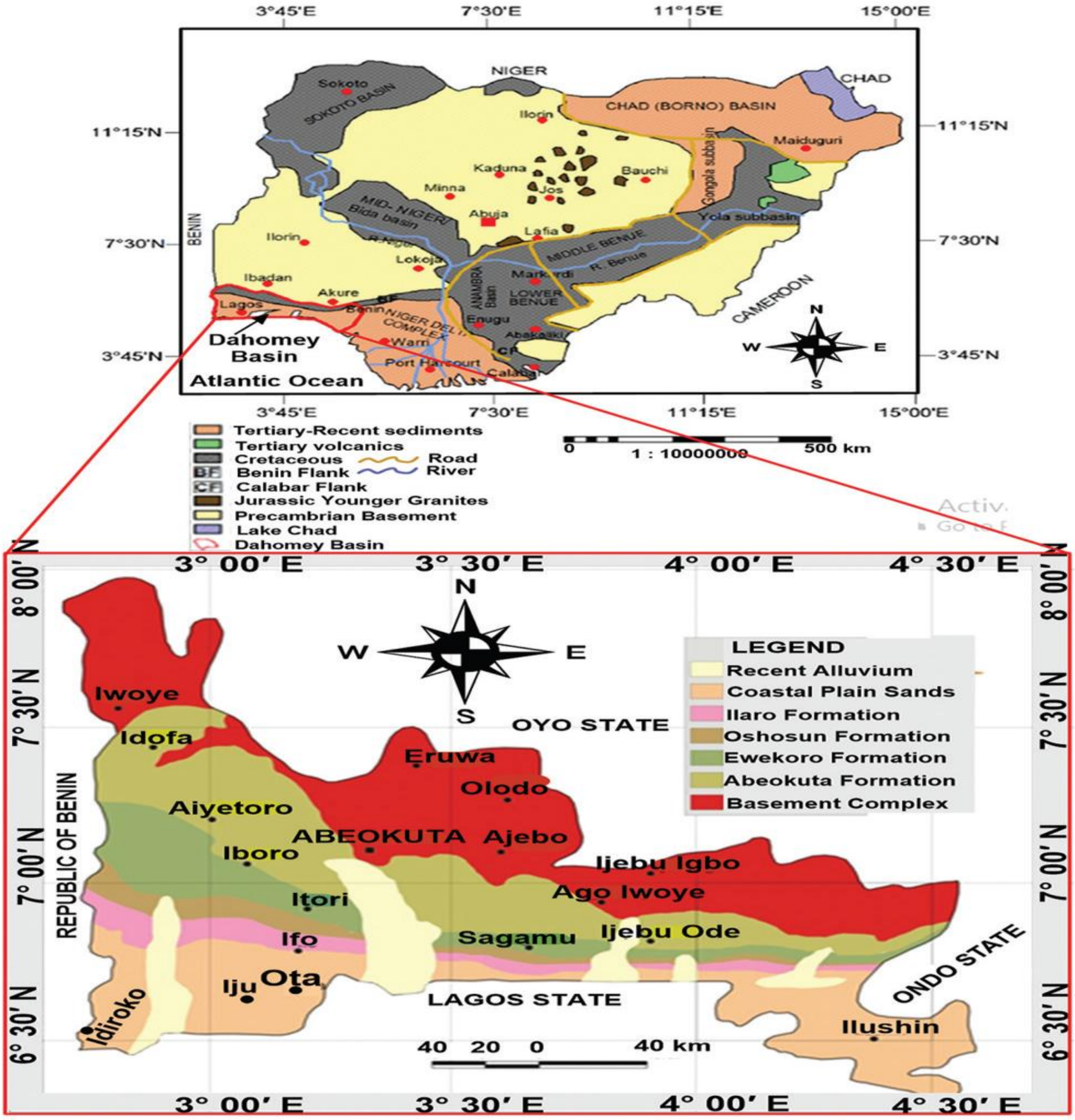

Figure 1: Geological map of Ogun state

Source: (Usikalu et al., 2020)

2.2 In-situ Radioactivity Measurements using Super-Spec RS125 Gamma Spectrometer

Hand- held RS-125 gamma ray spectrometer was used to measure the absorbed dose rate, the activity concentration of ^{40}K, ^{238}U and ^{232}Th and the global positioning system was employed to mark the coordinates of each of the twenty sampled points of the study locations. Super SPEC RS- 125 gamma spectrometer was made in Canadian geophysical institute Canada. The detector is made up of 2.0 × 2.0 NaI crystal. The instrument employs NaI doped with (TI) as activator. It was calibrated on 1×1 m test pads with the use of 5 mins spectral accumulation for Uranium, Thorium and Potassium for 10 mins for terrestrials' pads. It has a wide energy range of 30-3000 keV to detect radiation of terrestrial origin. It has enormous data storage capacity that can take measurement of different readings. Its ruggedness, high precision and its ease of operation, makes it a detector of choice in geophysical assessment. Repeated readings were recorded at each sampling points and the mean values were taken. The activity concentration of the measured radionuclides was taken in part per million (ppm) for ^{238}U, ^{232}Th and percentage (%) for ^{40}K. The measured values were converted to Becquerel per kilograms (Bq/kg) using the conversion factor reported by (IAEA, 1989; Oyeyemi et al., 2017).

2.3 Evaluation of the in-situ radiological hazard indices

The absorbed dose rate assesses the effects of exposure to ionizing radiation on living cells. This was evaluated using equation (1)

$$D\ (nGyh^{-1}) = 0.462K_U + 0.604K_{Th} + 0.0416K_K \quad (1)$$

D *(nGyh^{-1})* is the dose rate, K_U, K_{Th}, K_K are the activity concentration of ^{238}U, ^{232}Th, and ^{40}K in Bqkg^{-1} respectively (UNSCEAR, 2000).

The Annual effective dose equivalent (AEDE) is the effective dose over a period of a year. This was obtained using equation (2).

$$AEDE = D \times O_F \times C_C \times 8760 \quad (2)$$

D represent the absorbed dose, O_F is the occupancy factor that was taken as 0.2 for outdoor and 0.8 for indoor, C_C represents the conversion coefficient which was be taken as 0.7 (UNSCEAR, 2000).

The excess lifetime cancer risk measures the probability of the risk of cancer disease to the dweller around the market, was obtained using the equation (3)

$$ELCR = AEDE \times DL \times RF \quad (3)$$

AEDE is the annual equivalent dose, *DL* is the average duration of life which was taken as 65 years and *RF* is the risk factor *(Sv^{-1})* was taken as 0.05 (UNSCEAR, 2000).

The external hazard index measure the radiation risk as a result of external exposure in the study area, while the internal hazard index estimates the hazard to the respiratory organs from internal exposure to radon and its progeny. The external hazard index and the internal hazard index were estimated using equations (4 and 5).

$$H_{int} = \frac{K_U}{185} + \frac{K_{Th}}{259} + \frac{K_K}{4810} \quad (4)$$

$$H_{ext} = \frac{K_U}{370} + \frac{K_{Th}}{259} + \frac{K_K}{4810} \quad (5)$$

Radium equivalent activity Raeq (Bq/kg) assesses the gamma output from different mixture of ^{238}U, ^{232}Th, ^{40}K in an environment. It was estimated using equation (6) (UNSCEAR, 2000).

$$Ra_{eq} = K_U + 1.43K_{Th} + 0.077K_k \quad (6)$$

Gamma representative index measure the gamma radiation hazard due to the natural radionuclides in the particular material being assessed. This was calculated using equation (7) (UNSCEAR, 2000).

$$I_Y = \frac{K_U}{150} + \frac{K_{Th}}{100} + \frac{K_K}{1500} \quad (7)$$

3. Results and Discussion

3.1 In-situ Activity concentration using handheld Super-Spec RS125

The mean *in situ* measured activity concentrations of ^{238}U, ^{232}Th, ^{40}K and the gamma dose rate (*DR*) is provided in Table 1. The descriptive statistics for the *in-situ* measured activity concentrations and the gamma dose rate (*DR*) presented by

Table 2 and the spatial distributions for the measured parameters were show in Figures 2 to 5. The results revealed that the activity concentration of ^{238}U and ^{232}Th, were slightly skewed (having almost a symmetric distribution) since most of the measure of the asymmetry of their probability distribution about their means falls outside the range of -1 and +1. While ^{40}K and the gamma dose rate (DR) whose skew values falls within the range of -1 and +1, were normally distributed (Orosun *et al*., 2019).

From Table 2, the lowest mean values of the activity concentration of ^{40}K, ^{238}U, ^{232}Th and the gamma dose-rate are below the detection limit (AG23, Mentos area); (AG31, Access bank area); (AG23, Mentos area) *Bqkg*$^{-1}$ and 12.18 *nGyh*$^{-1}$ (AG31, Access Bank Area) respectively. While their corresponding highest values are 472.14 *Bqkg*$^{-1}$ (Access bank area), 72.88 *Bqkg*$^{-1}$ (AG7, Market area), 148.00 *Bqkg*$^{-1}$ (AG40, Agbara bus stop) and 97.95 *nGyh*$^{-1}$ (Market), respectively. These high and low values of the activity concentration of ^{40}K, ^{238}U, ^{232}Th and the gamma dose-rate were revealed by the spatial distribution map (Figures 2 to 5). The highest values obtained for the concentrations of ^{238}U, ^{232}Th, ^{40}K, and the gamma dose rate (*DR*) exceeds their corresponding global average values in 7 (17.50 %), 23 (57.50 %), 1 (2.50 %) and 10 (25.00 %) of the locations respectively.

The estimated overall mean values for the *in-situ* measured activity concentrations of ^{238}U, ^{232}Th, ^{40}K, and the gamma dose rate (*DR*) are 20.01 *Bqkg*$^{-1}$, 52.90 *Bqkg*$^{-1}$, 177.87 *Bqkg*$^{-1}$, and 47.22 *nGyh*$^{-1}$, respectively. The overall mean values of the activity concentration of the radionuclides are below 32.00, 420.00 *Bqkg*$^{-1}$ and 59.00 *nGyh*$^{-1}$ global average values for exposure to ^{238}U, ^{40}K, and the gamma dose rate (*DR*) respectively, provided by ICRP (1991), IAEA (1996) and UNSCEAR (2000). Only the mean value of ^{232}Th (52.90 *Bqkg*$^{-1}$) exceeds its global average value of 45.00 *Bqkg*$^{-1}$.

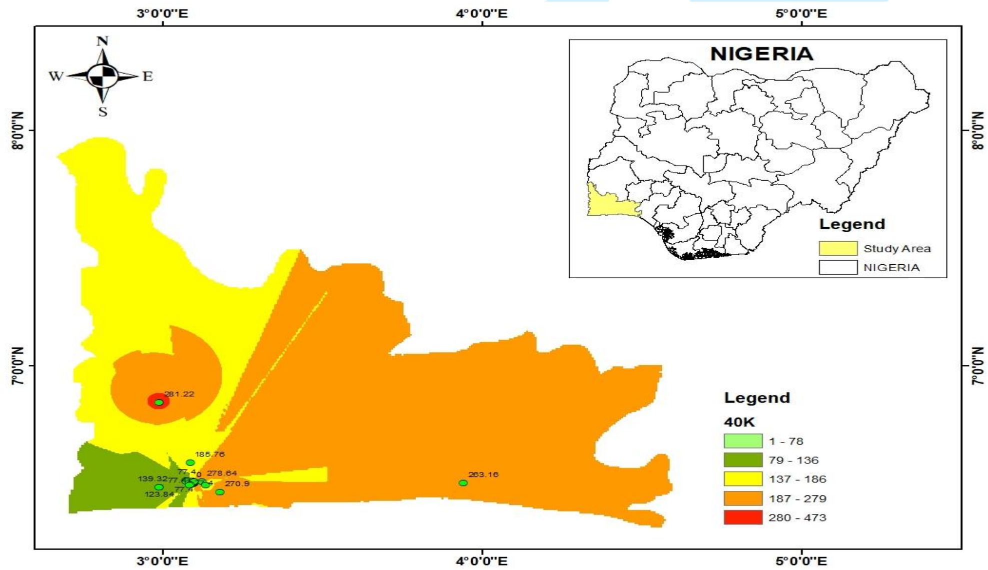

Figure 2: Spatial distribution of the in-situ measured activity concentration of ^{40}K.

Source: *Authors' computations*

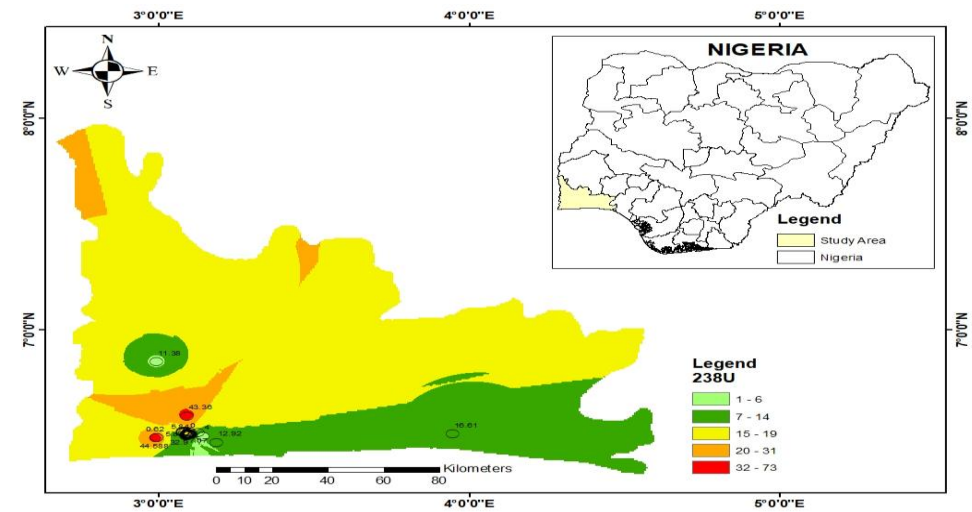

Figure 3: Spatial distribution of the in-situ measured activity concentration of ^{238}U.

Source: *Authors' computations*

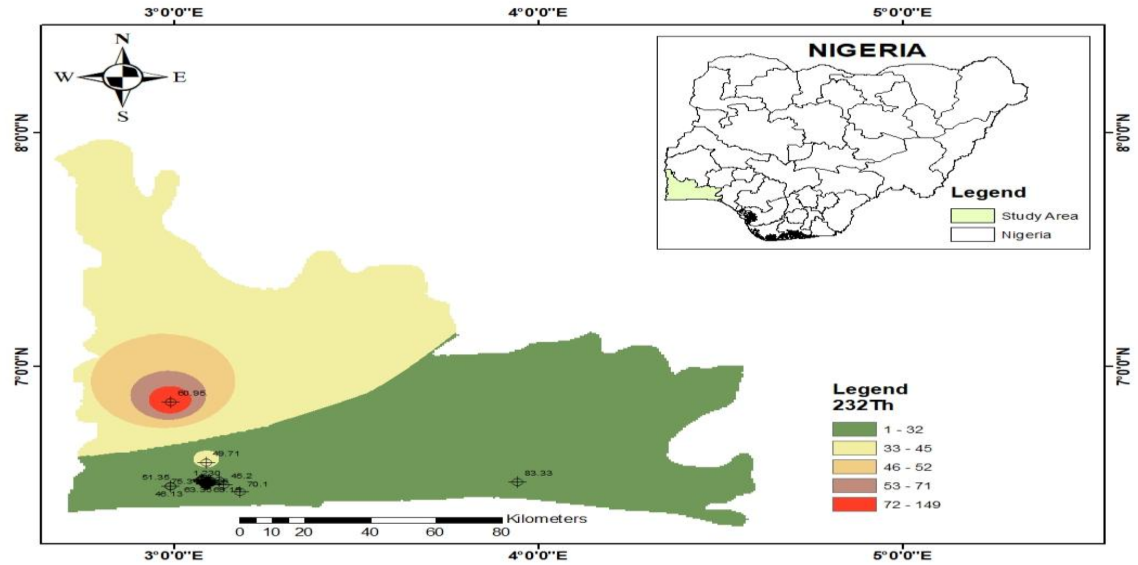

Figure 4: Spatial distribution of the in-situ measured activity concentration of ^{232}Th.

Source: *Authors' computations*

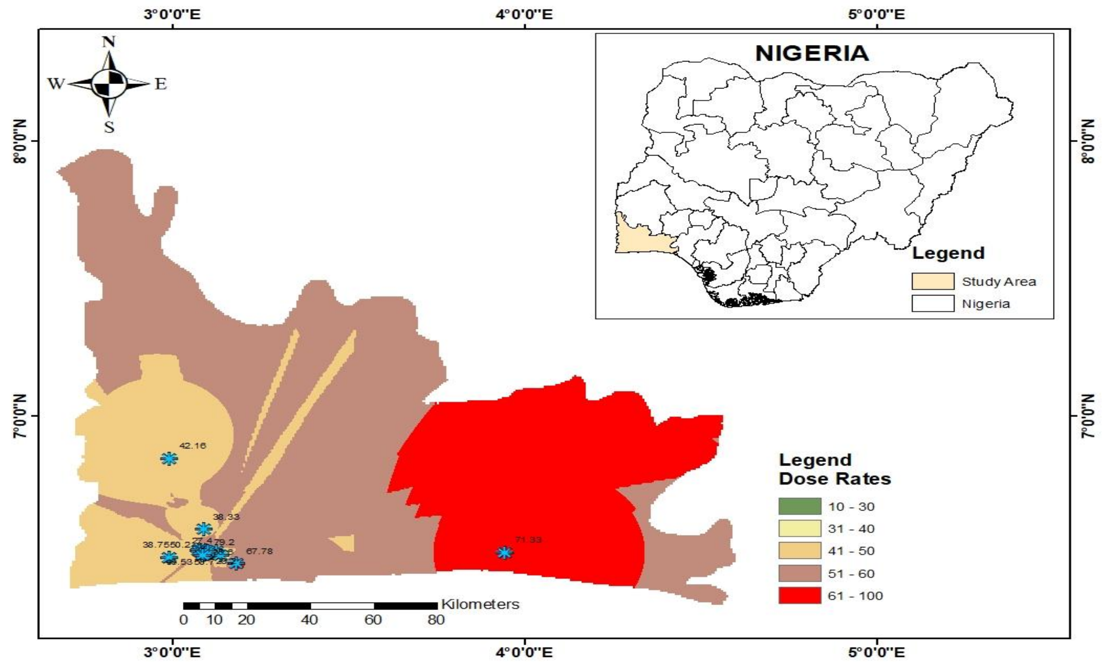

Figure 5: Spatial distribution of the in-situ measured gamma dose rate (DR).

Source: *Authors' computations*

Table 1. Mean in-situ measured Activities of ^{40}K, ^{238}U, ^{232}Th and the gamma dose-rate (DR) in all the locations in Agbara.

S/N	Location	Latitude	Longitude	DR ($nGyh^{-1}$)	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)
1	AG1	6.504708	3.089176	12.85±0.90	0.77±1.55	27.37±2.10	1.23±0.89
2	AG2	6.500614	3.086086	25.80±2.20	47.99±40.88	30.14±20.52	22.65±16.00
3	AG3	6.507735	3.088832	56.33±5.70	143.19±42.63	16.61±12.16	79.64±14.15
4	AG4	6.499700	3.092300	37.10±0.22	77.40±39.97	14.15±1.59	41.31±2.75
5	AG5	6.503389	3.097072	44.75±2.35	296.44±39.03	5.54±1.59	44.49±1.27
6	AG6	6.487200	2.990300	50.20±20.23	123.84±91.14	44.588±16.79	46.13±32.30
7	AG7	6.513678	3.092952	88.73±1.75	290.25±203.56	72.878±23.17	70.93±4.91
8	AG8	6.500350	3.088866	50.18±3.12	317.34±15.48	19.07±7.94	45.92±0.75
9	AG9	6.506515	3.090206	40.58±3.62	77.40±64.45	30.44±7.87	44.18±6.62
10	AG10	6.504600	3.094300	30.75±1.65	301.09±38.78	1.85±1.59	23.58±2.65
11	AG11	6.504021	3.100375	77.78±3.80	402.48±97.90	32.90±4.96	67.86±8.42
12	AG12	6.501131	3.086429	30.08±1.20	77.40±39.97	13.22±6.69	29.21±3.87

13	AG13	6.487200	2.990300	38.75±5.84	139.32±39.97	0.62±0.71	51.35±6.46
14	AG14	6.516681	3.075786	34.15±2.21	77.40±17.87	25.83±2.46	27.88±3.46
15	AG15	6.510900	3.123900	50.70±8.89	278.64±66.88	13.22±4.75	50.53±13.43
16	AG16	6.514377	3.073164	60.25±1.63	178.02±15.48	11.59±10.97	70.62±11.87
17	AG17	6.847200	2.990300	42.16±9.62	281.22±100.19	11.38±9.60	60.95±14.42
18	AG18	6.512485	3.079906	90.13±6.85	278.64±211.50	61.19±36.41	86.92±17.47
19	AG19	6.464795	3.180979	67.78±3.99	270.90±58.61	12.92±8.37	70.10±9.10
20	AG20	6.501910	3.098582	97.95±3.85	356.04±17.87	22.76±9.29	98.91±8.18
21	AG21	6.589900	3.087100	38.33±19.15	185.76±151.67	43.36±20.32	49.71±5.63
22	AG22	6.512996	3.092952	55.05±5.04	201.24±39.97	20.91±12.58	56.17±6.11
23	AG23	6.504700	3.094300	18.74±1.00	BDL	45.51±1.42	BDL
24	AG24	6.505833	3.095012	40.99±13.43	201.24±156.85	34.13±13.64	34.13±22.93
25	AG25	6.503339	3.094882	32.35±1.44	135.45±14.82	14.76±10.58	32.49±8.87
26	AG26	6.495087	3.136347	37.13±1.38	135.45±34.32	4.00±2.91	45.20±6.08
27	AG27	6.504700	3.094300	29.20±3.34	99.85±16.46	11.22±9.15	31.88±0.39
28	AG28	6.515619	3.076343	25.25±0.21	51.86±14.60	5.04±3.63	29.32±2.38
29	AG29	6.511589	3.076129	46.53±1.52	193.50±92.45	18.76±4.75	46.64±1.08
30	AG30	6.504900	3.943000	71.33±13.94	263.16±96.26	16.61±9.76	83.33±15.94
31	AG31	6.500558	3.092266	12.18±1.66	472.14±108.36	BDL	118.29±13.30
32	AG32	6.503389	3.092266	43.88±1.62	185.76±25.28	17.22±12.42	41.31±5.54
33	AG33	6.504071	3.086086	35.60±2.60	62.69±1.55	17.84±4.20	35.77±4.94
34	AG34	6.501683	3.095356	37.05±4.78	34.83±26.44	21.83±13.19	34.34±3.87
35	AG35	6.503457	3.095993	27.40±1.16	44.89±30.07	13.22±1.18	32.19±1.59
36	AG36	6.496429	3.084797	59.75±1.35	139.32±39.97	5.84±1.18	75.34±3.32
37	AG37	6.504600	3.094300	57.45±0.39	208.21±33.48	0.00±0.00	63.35±1.52
38	AG38	6.511465	3.099994	55.25±2.22	181.89±31.91	28.91±10.56	55.00±2.76
39	AG39	6.498057	3.088499	79.20±9.77	170.28±73.70	7.07±2.54	69.19±4.89
40	AG40	6.496911	3.086679	59.28±3.33	131.58±52.87	5.84±1.18	148.01±6.19
	Global Average (UNSCEAR, 2000)			59.00	450.00	32.00	45.00

BDL means below detection limit

Table 2. Descriptive Statistics of the in-situ measured Activities of ^{40}K, ^{238}U, ^{232}Th and the gamma dose-rate (DR) of all the locations in Agbara

Stat	DR ($nGyh^{-1}$)	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)
Minimum	12.18	0.00	0.00	0.00
Maximum	97.95	472.14	72.88	148.00
Mean	47.22	177.87	20.01	52.90
Standard Error	3.25	17.65	2.57	4.55
Median	43.02	174.15	16.61	46.38
Standard Dev	20.55	111.62	16.27	28.75
Sample Variance	422.27	12460.14	264.71	826.44
Kurtosis	0.12	-0.09	2.19	2.29
Skewness	0.66	0.53	1.37	1.05

Pearson correlation analysis was carried out to further investigate the connection between these measured radionuclides and the in-situ measured outdoor gamma dose rate. The result of the correlation analysis, which is presented in Table 3, were classified according to the correlation coefficient R (Orosun *et al.,* 2019; Orosun *et al*., 2020) i.e.

$0.7 \le |R| \le 1$ indicates a strong correlation;

$0.5 \le |R| \le 0.7$ suggests a significant correlation;

$0.3 \le |R| \le 0.5$ reveals a weak correlation; and

$|R| < 0.3$ indicates an insignificant correlation.

A significant correlation exists between DR and ^{232}Th (R = 0.60) as well as between DR and ^{40}K (R = 0.50) and between ^{40}K and ^{232}Th (R = 0.57). A weak correlation was found to exist between DR and ^{238}U (R = 0.30). However, a negative but insignificant correlation was observed between ^{40}K and ^{238}U (R = -0.02), between ^{238}U and ^{232}Th (R = -0.12). The correlation results confirm that the enhanced outdoor dose rates at the locations was caused largely by ^{232}Th, followed by ^{40}K and then ^{238}U as shown in Table 3.

Table 3. Pearson correlation for the primordial radionuclides (^{40}K, ^{238}U, ^{232}Th and the gamma dose-rate (DR)).

	DR (nGyh^{-1})	*^{40}K (Bqkg^{-1})*	*^{238}U (Bqkg^{-1})*	*^{232}Th (Bqkg^{-1})*
DR (nGyh^{-1})	1.00			
^{40}K (Bqkg^{-1})	0.50	1.00		
^{238}U (Bqkg^{-1})	0.30	-0.02	1.00	
^{232}Th (Bqkg^{-1})	0.60	0.57	-0.12	1.00

3.2 Evaluation of the in-situ radiological hazard indices for the selected locations.

The radiological hazard indices were estimated in order to evaluate the radiological risks for the locations. The hazards parameters calculated are presented in Table 4 and their corresponding descriptive statistics are provided in Table 5. While the outdoor absorbed dose (D_{out}) rate was obtained using equation 1, the *in-situ* measured outdoor dose rate was used to evaluate the annual effective dose equivalent (AEDE) using equation 2. The ensuing AEDE was eventually used for the evaluation of the excess lifetime cancer risk (ELCR) using equation 3.

The maximum and minimum values of the evaluated outdoor absorbed dose rate are 97.56 and 13.42 nGyh^{-1}, with an overall mean of 48.59 nGyh^{-1}. The maximum and minimum values of the AEDE were observed in the Agbara Bustop (AG40) with 0.12 mSvy^{-1} and Milo area (AG1) with 0.02 mSvy^{-1}, respectively. Expectedly, this AG40 corresponds to the location of high activity concentration of value of ^{232}Th (i.e. 148.01±6.19 Bqkg^{-1}) and the gamma dose-rate (i.e. 97.56 nGyh^{-1}). This means that the risk associated with exposure to ionizing radiation is high for this location. The mean values of the AEDE is 0.06 mSvy^{-1}, which is within the recommended threshold value of 0.07 mSvy^{-1} provided by UNSCEAR (UNSCEAR, 2000). The estimated radium equivalent (Ra_{eq}), H_{ext}, H_{in} and the representative level index (I_γ) follow similar trends with maximum values observed around AG40 as well and minimum values recorded at AG1 respectively. The estimated values for the *ELCR* corroborated our earlier findings with Agbara Bustop 2 and Milo areas recording the maximum and minimum values respectively. The mean values estimated for all the hazard indices are within their corresponding recommended values except for seven locations with values above the average limited given by UNSCEAR (UNSCEAR, 2000). The observed high values at the this location indicates evidence of elevated level of the activity concentrations, which may be attributed to anthropogenic activities going on these areas, and therefore calls for concern. Considerable increase in the concentration of the radionuclides will results in an increase in the level of the background radiation that can lead to exposure to elevated ionization radiation levels. It follows that the Agbara bus stop poses more radiological risks than all the other locations.

Table 4. *In-situ Radiological hazard indices for the selected locations.*

S/N	Location	Ra_{eq} (Bqkg^{-1})	H_{ex}	H_{in}	D_{out} (nGyh^{-1})	AEDE (mSvy^{-1})	Iγ	ECLR (x 10^{-3})
1	AG1	29.19	0.08	0.15	13.42	0.02	0.10	0.06
2	AG2	66.22	0.18	0.26	29.60	0.04	0.23	0.13
3	AG3	141.52	0.38	0.43	61.73	0.08	0.50	0.27
4	AG4	79.18	0.21	0.25	34.71	0.04	0.28	0.15
5	AG5	91.99	0.25	0.26	41.76	0.05	0.34	0.18
6	AG6	120.09	0.32	0.44	53.61	0.07	0.42	0.23
7	AG7	196.66	0.53	0.73	88.59	0.11	0.69	0.38
8	AG8	109.17	0.29	0.35	49.75	0.06	0.40	0.21
9	AG9	99.58	0.27	0.35	43.97	0.05	0.35	0.19
10	AG10	58.75	0.16	0.16	27.62	0.03	0.22	0.12
11	AG11	160.93	0.43	0.52	72.93	0.09	0.58	0.31

12	AG12	60.95	0.16	0.20	26.97	0.03	0.22	0.12
13	AG13	84.78	0.23	0.23	37.10	0.05	0.31	0.16
14	AG14	71.66	0.19	0.26	31.99	0.04	0.25	0.14
15	AG15	106.93	0.29	0.32	48.22	0.06	0.39	0.21
16	AG16	126.28	0.34	0.37	55.41	0.07	0.45	0.24
17	AG17	120.19	0.32	0.36	53.77	0.07	0.44	0.23
18	AG18	206.94	0.56	0.72	92.36	0.11	0.73	0.40
19	AG19	134.02	0.36	0.40	59.58	0.07	0.48	0.26
20	AG20	191.62	0.52	0.58	85.07	0.10	0.69	0.37
21	AG21	128.75	0.35	0.46	57.78	0.07	0.46	0.25
22	AG22	116.73	0.32	0.37	51.96	0.06	0.42	0.22
23	AG23	45.51	0.12	0.25	21.03	0.03	0.15	0.09
24	AG24	98.43	0.27	0.36	44.75	0.05	0.35	0.19
25	AG25	71.65	0.19	0.23	32.08	0.04	0.26	0.14
26	AG26	79.07	0.21	0.22	34.78	0.04	0.28	0.15
27	AG27	64.50	0.17	0.20	28.59	0.04	0.23	0.12
28	AG28	50.96	0.14	0.15	22.20	0.03	0.18	0.10
29	AG29	100.35	0.27	0.32	44.89	0.06	0.36	0.19
30	AG30	156.04	0.42	0.47	68.95	0.08	0.56	0.30
31	AG31	205.38	0.55	0.55	91.03	0.11	0.75	0.39
32	AG32	90.60	0.24	0.29	40.63	0.05	0.33	0.17
33	AG33	73.82	0.20	0.25	32.46	0.04	0.26	0.14
34	AG34	73.62	0.20	0.26	32.28	0.04	0.26	0.14
35	AG35	62.71	0.17	0.21	27.42	0.03	0.22	0.12
36	AG36	124.30	0.34	0.35	54.00	0.07	0.44	0.23
37	AG37	106.62	0.29	0.29	46.92	0.06	0.39	0.20
38	AG38	121.57	0.33	0.41	54.14	0.07	0.43	0.23
39	AG39	119.12	0.32	0.34	52.14	0.06	0.43	0.22
40	AG40	227.61	0.61	0.63	97.56	0.12	0.80	0.42
	LIMITS (INSCEAR, 2000)	370.00	≤ 1	≤ 1	59.00	0.07	≤ 1	0.29

Table 5. Descriptive Statistics of the in-situ radiological hazard indices for the selected locations

Stat	Ra_{eq} ($Bqkg^{-1}$)	H_{ex}	H_{in}	D_{out} ($nGyh^{-1}$)	AEDE ($mSvy^{-1}$)	Iγ	ECLR ($x 10^{-3}$)
Minimum	29.19	0.08	0.15	13.42	0.02	0.10	0.06
Maximum	227.61	0.61	0.73	97.56	0.12	0.80	0.42
Mean	109.35	0.30	0.35	48.59	0.06	0.39	0.21
Standard Error	7.54	0.02	0.02	3.32	0.00	0.03	0.01
Median	103.49	0.28	0.33	45.91	0.06	0.37	0.20
Standard Deviation	47.68	0.13	0.15	20.99	0.03	0.17	0.09
Sample Variance	2273.32	0.02	0.02	440.44	0.00	0.03	0.01
Kurtosis	0.18	0.18	0.70	0.06	0.06	0.11	0.06
Skewness	0.80	0.80	1.03	0.78	0.78	0.76	0.78

4. Conclusion

Monitoring of environmental radioactivity due to naturally occurring radionuclides ^{40}K, ^{238}U, and ^{232}Th around Agbara Industrial Area in Ogun, Nigeria, was carried out using RS125 Gamma Spectrometer (a portable NaI [Tl] detector) to detect the level of radiation risks in the areas due to intense anthropogenic activities in the areas. The mean activity concentration of the primordial radionuclides were 177.87 $Bqkg^{-1}$, 20.01 $Bqkg^{-1}$ and 52.90 $Bqkg^{-1}$ for ^{40}K, ^{238}U and ^{232}Th

respectively. The in-situ measured dose rate (DR) ranges between 12.18 $nGyh^{-1}$ (Access Bank area) and 97.95 $nGyh^{-1}$ (Market area), with an average value of 47.22 $nGyh^{-1}$. The study revealed that the study locations are rich in thorium as over 50% of study area have ^{232}Th concentration above the world average. Some locations have absorbed dose higher than the recommended limit but the mean measured and estimated absorbed dose rates were within the safe limit of 57 $nGyh^{-1}$ provided by UNSCEAR. The mean values of all the estimated radiological parameters were within the recommended threshold values. It could be concluded that the risk of exposure to higher level of ionizing radiation is low for some locations in Agbara industrial area of Ogun State, but there is possibility of cancer risk for someone that has stayed in the area for 70 years and above.

Declarations

- **Consent for publication:** All the authors consented and approve the publication of the manuscript.
- **Consent to Participate:** All the authors consented to participate.
- **Availability of data and materials:** All the data and materials are available.
- **Competing interests:** The authors declare that they have no conflict of interest.
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- **Authors' contributions:** M.R.U designed the research work and edited the final manuscript, A.A, I.O.B, T.E.A. collected samples and data, M.M.O and U.M.A plotted the maps and compiled the work.
- **Ethics approval and consent to participate:** Not applicable (No human or animal specimens are involved)

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