Assessment of Radiation Hazard Indices Due to Natural Radionuclides in Soil Samples from Imo State University, Owerri, Nigeria

Benedict Chukwudi Eke[1], Idowu Richard Akomolafe[2], Udoka Mathias Ukewuihe[1] and Chibueze Paul Onyenegecha[1]

[1]Department of Physics, School of Physical Sciences, Federal University of Technology, Owerri, Nigeria. [2]Department of Physical Sciences, Faculty of Natural Sciences, Redeemer's University Ede, Nigeria.

ABSTRACT: A total of 30 soil samples from different sampling points at Imo State University (IMSU), Owerri, Nigeria were collected for the study. The activity concentrations of naturally occurring radionuclides (^{238}U, ^{232}Th, and ^{40}K) were measured in the samples by gamma-ray spectrometry using NaI (TI) detector. Absorbed dose rate (D), annual effective dose (AED), radium equivalent activity (Ra_{eq}), and radiological hazard index parameters (activity utilization index [AUI], external hazard index [H_{ex}], internal hazard index [H_{in}], and excess lifetime cancer risk [ELCR]) due to the naturally occurring radionuclides were determined. The mean activity of ^{238}U, ^{232}Th, and ^{40}K were found to be 20.32 ± 3.22, 22.55 ± 0.68, and 91.63 ± 1.54 Bqkg^{-1} which were lower than the world average reference mean values of 33, 45, and 420 Bqkg^{-1} for ^{238}U, ^{232}Th, and ^{40}K, respectively, as reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The average value of D, Ra_{eq}, AUI, ELCR, H_{ex}, and H_{in} in the soil samples was 26.86 ± 1.97 nGyh^{-1}, 59.62 ± 4.14 Bqkg^{-1}, 0.42 ± 0.03, 0.14 ± 0.01 ($\times 10^{-3}$), 0.16 ± 0.01, and 0.22 ± 0.02, respectively. The annual effective dose to the general public was 33.07 ± 2.40 μSvy^{-1}. This value lies well below the average worldwide reference value of 0.7 mSvy^{-1}, as reported by UNSCEAR. Soil samples from IMSU pose no significant radiological health hazards to the university community.

KEYWORDS: Radiation dose, NaI(TI) detector, radionuclides, cancer risk, Owerri

Introduction

Primordial radionuclides with long half-lives have been part of the Earth's crust and they remain significant sources of natural ionizing radiation to the human population.[1-3] Radiation is classified into 2 depending on the sources: natural and artificial.[4] Naturally Occurring radiation comes mainly as terrestrial gamma radiation from naturally occurring radionuclide materials (NORMs) in the Earth's crust[5-7] or as cosmic rays from space.[8] In contrast, artificial radiation arises from medical radiological imaging or nuclear industrial fallouts.[4]

Natural radionuclides in the Earth's crust are significant terrestrial radiation sources. Those predominantly found in the soil include ^{238}U, ^{232}Th, and ^{40}K.[1,9,10] The natural radioactivity from soil comes from ^{238}U, ^{232}Th decay series, and non-decay ^{40}K.[1,11,12] They are often at a low concentration level that might not cause harmful biological effects.[1,10] However, anthropogenic activities in some environments have enhanced the concentration level of the radioactivity in soil,[13,14] which could increase the background radiation in the environment because soil serves as a significant source of background radiation exposure to the human population and also a medium of transferring radionuclides into our environment.[11,15] These suggest that soil is a significant indicator of radioactivity contamination in our environment[4,16] and should be appropriately and regularly investigated.

Due to the natural radionuclides in the soil and man's activity with the Earth, humans have continuously prolonged exposure to natural radiation.[17,18] This natural radiation forms the major component of the total annual exposure to the human population.[4,8,19,20] Prolonged radiation exposure can cause harmful radiological effects, ranging from DNA deformation to other bimolecular and cellular effects.[3,21] Exposure to uranium and thorium nuclides and their progenies can cause health hazards such as lung diseases, muscle necrosis, and generation of cancerous cells even in the bones.[4,8,22,23] The natural radionuclides in the soil samples vary and depend on the lithological and geological nature of the land.[8,24]

The natural radioactivity in soil and terrestrial radiation exposure from the environment depends mainly on geological and geographical parameters. It changes in different soil levels of each region in the earth's crust.[1,25] Some other factors, such as mineralogy, organic concentration, and geochemical composition of the soil, can also affect the activity concentration of the radionuclides in the soil.[12] Considering the non-uniformly distribution of radionuclides in the soil[26] and the fact that most of these radionuclides can cause a harmful effect,[3,21] it is imperative to have a perfect understanding of the soil radioactivity concentration level and determine the radiological risks due to exposure of the human population.
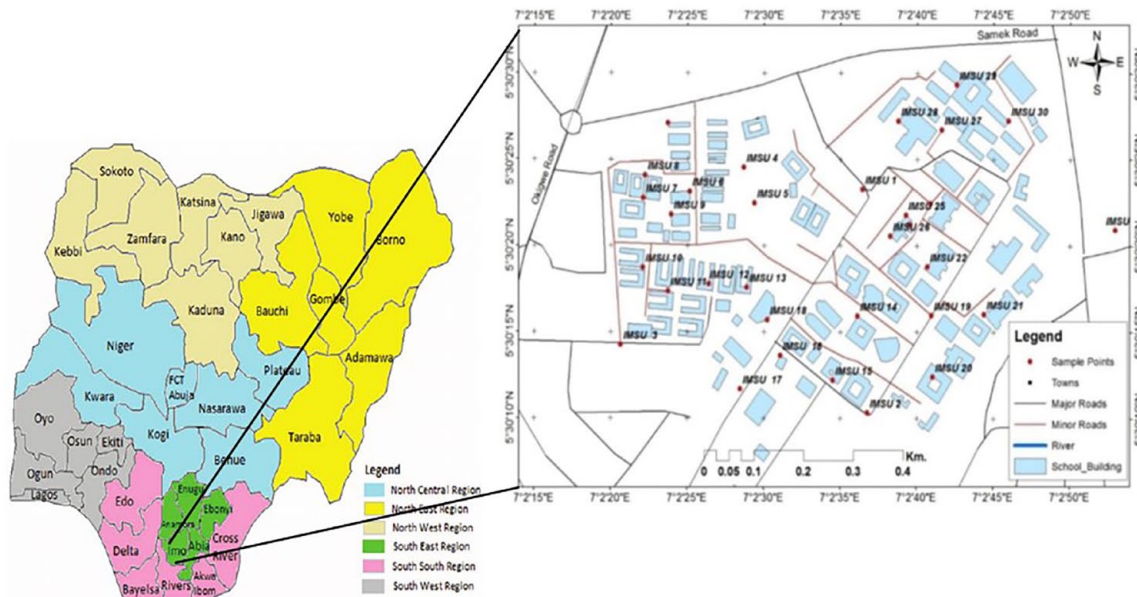
Figure 1. Map of the study location.

Imo State University (IMSU) is a densely populated institution situated at the center of Owerri City, Nigeria, with many industrial and human activities. In the interest of workers, and students, the measurement of natural radioactivity concentration in soil within such an environment is important.[20,27] In the past few years, there has been an increase in the campaigns all over the world on research on radionuclides and natural radioactivity concentration in soil due to the harmful health effect it might pose on humans as a result of both natural and anthropogenic activities.[18,28-30] As referenced in this study, several works have been done on radionuclide and radioactivity concentrations. Still, there are no available data on the radioactivity concentration level of soils from IMSU, Nigeria. Thus, this study will contribute significant data to the existing literature on the measurement of radioactivity concentration levels in soils of the study area.

The study aimed to assess radiation hazard indices due to natural radionuclides (^{238}U, ^{232}Th, and ^{40}K) in soil samples collected from 30 locations in IMSU, Nigeria. To achieve this aim, the following objectives will be carried out: calculate the radium equivalent value (Ra_{eq}), the total absorbed dose rate (D), the annual effective dose (AED), external hazard indices (H_{ex}), internal hazard indices (H_{in}), activity utilization indices (AUI), and excess lifetime cancer risk (ELCR) due to natural radionuclides from the soil in the university.

Material and Method

Study area

Imo State University is in Owerri Metropolis in Imo State, South-Eastern Nigeria. The map of the study area is presented in Figure 1. The university is on a latitude of 5.5080°N and a longitude of 7.0423°E. The environmental catchment area of the study location is about 104 km², which cuts across Owerri Municipal, Owerri North, and Owerri West. IMSU accommodates an average daily population above 15 000, including students, staff, and visitors, as seen from the daily report at the school entrance gate. It is a famous institution in Owerri due to its location and population density. It is also at the base of the dip slope from Okigwe (the center of mining in Imo State) to Owerri. This suggests that most radionuclides washed off by water floods from the rocks and mining sites from Okigwe might settle in Imo State University and its environs.

The study area is slightly sloped flat land, partly covered with sandy, loamy, stony, and clay soil. It has a moderately dry climate with an average monthly temperature of 24°C to 29°C, with rainfall from March to July and September to October. The dry season is dominated by harmattan breeze and moderate sun intensity from December to February and August.

Sample collection

Soil samples were collected from 30 sampling points in the natural, uncultivated grass-covered level areas within the region, as stipulated by International Atomic Energy Agency (IAEA) recommendations.[31] The samples were collected on a sunny day in March 2022 after clearing each sampling point's surface of stones, pebbles, vegetation, and roots. Each soil sample was collected at a depth of 15 cm beneath the surface and packed in a labeled polythene bag for preparation and gamma spectroscopic analysis.

Sample preparation

All collected soil samples were transported to the laboratory, and all visible unwanted materials were removed using a

wooden tongue. The samples were first air-dried under ambient temperature (30°C) for 1 week and were later subjected to a higher temperature using a drying oven at 105°C to eliminate any moisture. Each sample was crushed using a mechanical potter and sieved with a 2.00 mm mesh to ensure sample homogeneity. About 0.2 kg of each homogeneous sample was weighed into a cylindrical container of negligible mass and correctly labeled with indelible ink for easy identification.[4,32] The cylindrical containers used for the package were washed with borehole water (5 times) and rinsed thoroughly with distilled water. The packaged samples were allowed in the laboratory for at least 4 weeks so natural radionuclides and their progenies could attain secular radioactive equilibrium.[4,8,32] Afterwards, the samples were gathered in a big plastic carrier and transported to the Radiation and Health Physics Research Laboratory, Department of Physics, University of Ibadan, Nigeria, for gamma-ray spectrometry analysis.

Gamma-ray spectrometry analysis

The gamma-ray spectrometry analysis was conducted at the radiation and health physics research laboratory, Department of Physics, University of Ibadan, Nigeria. Each sample was counted for a total of 36 000 seconds. The detector employed for the radioactivity measurements was a 76 mm × 76 mm NaI(Tl) detector crystal (802 Series, Canberra Inc.) coupled to a Canberra series 10 Plus multichannel analyzer (MCA) of model no: 1104 via a preamplifier. The system had an adequate lead shield that reduced the background radiation by 95%. The energy resolution of the NaI(Tl) detector was 8% at 0.662 MeV (^{137}Cs). As this study aimed to determine the activity concentration of ^{238}U, ^{232}Th, and ^{40}K radionuclides in the soil samples, the ^{238}U and ^{232}Th series and ^{40}K activities were considered as the amount of these radionuclides that would enter the air from the soil, so the energy values upon which the measurement was to be based were initially determined. The radionuclides (^{238}U and ^{232}Th) activity concentrations were determined using the gamma energy of their progenies that was noticed during the decay series as 1.760 MeV for ^{226}Ra (^{238}U) and 2.615 MeV for ^{232}Th. The activity concentration of ^{40}K was determined using only its gamma energy of 1.460 MeV. The activity concentrations of radionuclides in the samples were estimated using equation (1).[4]

$$C\left(Bqkg^{-1}\right) = \frac{C_n}{\varepsilon P_\gamma M_s t} \tag{1}$$

where C is the radionuclide activity concentration of soil samples given in Bqkg^{-1}, C_n represents the count rate under the corresponding peak, ε is the detector's efficiency at the specific gamma-ray energy, $P\gamma$ is the absolute transition probability of the specific gamma-ray, M_s is the soil sample mass in kg, and t is the counting time in seconds.

A gamma-ray detector's detection limit (DL) specifies its operational capabilities without the effect of the sample.[33] This calculation was performed using equation (2).

$$DL\left(Bqkg^{-1}\right) = 4.65 \frac{\left(C_b\right)^{1/2}}{t_b} k \tag{2}$$

where t_b in the second represents the background counting time, C_b is the total background count in the corresponding peak, and k is the conversion factor given in equation (1). The present study's measurement system showed that soil samples' detection limits were 16.96, 4.43, and 3.65 Bqkg^{-1} for ^{40}K, ^{232}Th, and ^{238}U, respectively. Any activity concentrations lower than these numbers are considered below the detector's detection limit (BDL).

Radiological hazard indices

Radium equivalent: Radium equivalent activity (Ra$_{eq}$) is one of the most widely used hazard indices in comparing radionuclides (^{238}U, ^{232}Th, and ^{40}K) in any material by a single quantity that considers the hazard associated with them.[18,29,31,34] The radium equivalent is calculated using equation (3).[8,35,36]

$$Ra_{eq}\left(Bqkg^{-1}\right) = C_U + 1.43C_{Th} + 0.077C_K \tag{3}$$

where C_K, C_U, and C_{Th} are the activity concentrations in Bqkg^{-1} of ^{40}K, ^{238}U, and ^{232}Th, respectively.

Absorbed dose rate

The absorbed dose rate in the air from exposure to natural primordial radionuclides was evaluated using the activity concentration of radionuclides. The absorbed dose rate (D [nGyh^{-1}]) in the air helps us quantify the amount of radiation absorbed by a body at 1 m above the ground due to ^{238}U, ^{232}Th, and ^{40}K. The absorbed dose rate in the air was calculated using equation (4) as given in the UNSCEAR 2000 report.[1,8,37]

$$D\left(nGyh^{-1}\right) = 0.0417C_k + 0.462C_U + 0.604C_{Th} \tag{4}$$

where C_K, C_U, and C_{Th} are the activity concentrations in Bqkg^{-1} of ^{40}K, ^{238}U, and ^{232}Th, respectively.

Annual effective dose (μSvy^{-1}): it was calculated from the absorbed dose rate using equation (5)

$$AED\left(outdoor\right) = D(nGyh^{-1}) \times 8760 hy^{-1} \\ \times 0.7SvGy^{-1} \times 0.2 \times 10^{-3} \tag{5}$$

where AED is the annual effective dose equivalent (μSvy^{-1}), and D is the absorbed dose rate in the air, $0.7SvGy^{-1}$ is the conversion coefficient and 0.2 is the outdoor occupancy factor.[1,4,8]

Radiological hazard indices (H_{ex} and H_{in}): The harmful gamma radiation effects caused by radionuclides present in these soil samples were estimated by calculating the different hazard indices. Although the total activity concentrations of the exact indication of total radiation hazards have been assessed, these hazard indices also guide the choice of the right materials for building hurts, bricks, and other materials for human habitation. Two hazard indices were employed: the external hazard index (H_{ex}) and the internal hazard index (H_{in}). Both indices were calculated using equations (6) and (7).[8]

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \qquad (6)$$

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \qquad (7)$$

Where C_U, C_{Th}, and C_K are as described in equation (3). Radiation hazard from soil samples is considered negligible if the value of both indices is less than unity.[1]

Activity utilization index (AUI): This is a significant health index that estimates the excess external and indoor gamma radiation from soil and other building materials.[8]

$$AUI = \frac{C_U}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \qquad (8)$$

Where C_U, C_{Th}, and C_K are as described in equation (3).

Excess lifetime cancer risk (ELCR): The excess lifetime cancer risk is evaluated using the equation (9)

$$ELCR = AED \times LE \times RF \qquad (9)$$

Where AED is the annual effective dose equivalent as contained in equation (5),

LE is the life expectancy (assumed to be 70 years in this study),[34] and RF is the risk factor of fatal cancer per Sievert. According to the International Commission on Radiological Protection (ICRP) 103 report, the value of 0.057 was used for stochastic effect for the public.[38,39]

Statistical analysis

The IBM Statistical Package for Social Science (SPSS-27) computer program was used to analyze data. The present study calculated and reported statistical parameters such as mean, maximum, and minimum. The values obtained were reported as means ± SD (standard deviation), and $P < .05$ was accepted for all comparisons. Pearson correlation was used to evaluate the level of correlation of activity concentrations obtained and absorbed dose, effective dose, and other radiological hazard indices, as presented in Table 5.

Results and Discussion
Activity concentration

The estimated activity concentration of naturally occurring radionuclides [238]U, [232]Th, and [40]K in soil samples were given in

Table 1. The radioactivity concentration obtained from this study ranged from BDL to 31.53 Bqkg⁻¹ for [238]U, from BDL to 37.15 Bqkg⁻¹ for [232]Th and from 20.90 to 127.15 Bqkg⁻¹ for [40]K. The spatial distribution of the primordial radionuclides from the studied location is an indication that the evaluated radionuclides are not concentrated in one location, as the report showed a high value for one radionuclide and a low value for the others but unequally distributed within the campus of the institution. The average radioactivity concentrations of [238]U, [232]Th, and [40]K found in soil samples were (20.32 ± 3.22, 22.55 ± 0.68, and 91.63 ± 1.54) Bqkg⁻¹, respectively. The activity concentration of radionuclides in soil samples from IMSU is within the report of Eke et al[34] on the top soil samples from Imo State Polytechnic. In addition, the mean activity concentration of natural radionuclides in soil samples at the 2 tertiary institutions in Owerri, as reported by Eke et al[34] is comparable. Although the activity concentration of radionuclides in soil samples from IMSU is far higher than the values reported by Popoola et al[40] the average values are lower than the world's mean radioactivity concentration of (35, 45, and 420) Bqkg⁻¹for [238]U, [232]Th, and [40]K, respectively.[1] This is shown in Table 2, which compares the radioactivity concentration calculated in this study with other related studies within Nigeria and globally. The present finding showed that [40]K has the maximum average radioactivity concentration and mark maximum at all sampling points except at 2 points, IMSU 16 (Faculty of Law) and IMSU 22 (Agricultural Science Department). Potash feldspar minerals in the studied area may be responsible for the enhanced [40]K recorded in the present study. Since IMSU is at the base of the dip slope from Okigwe (the center of mining in Imo State) to Owerri. This suggests that migration of weathered radionuclides from the surrounding rocks might have settled in Imo State University and its environs, increasing the activity concentration in radionuclides of the studied area. The activity concentration of [40]K obtained from the present research corroborates the findings of Isinkaye.[41]

Similarly, the results of Egunyinka et al[42] on the activity concentration of [40]K agree with the present study. Also, the soil radionuclides' activity concentrations were comparable to other related studies conducted within and outside Nigeria.[4,43-51] Eke et al[4] and Olagbaju et al[51] obtained lower activity concentrations of [226]Ra ([238]U) compared to the present study. Egunyinka et al[42] and Ugbede et al[47] recorded higher activity concentrations of [226]Ra ([238]U) compared to the present study.

Radiological dose assessment and radiological hazard indices

The dosimetry parameters, such as radium equivalent activity (Ra_eq), absorbed dose rate (D), and annual effective dose (AED), were recorded in Table 3. The calculated radium equivalent value ranges from 33.62 ± 3.46 to 81.66 ± 3.80 Bqkg⁻¹, with an average value of 59.62 Bqkg⁻¹. The estimated average value of Ra_eq obtained in this study is appreciably lower than the world recommended value of 370 Bqkg⁻¹ [1] and the result

Table 1. The estimated radioactivity concentration of ^{238}U, ^{232}Th and ^{40}K in Bqkg^{-1}.

SAMPLE ID	SAMPLE LOCATION	^{238}U	^{232}TH	^{40}K
IMSU 1	Nursery and Crèche Staff School	18.24 ± 2.09	28.86 ± 0.53	91.45 ± 1.21
IMSU 2	Agricultural / vet nary medicine	20.22 ± 3.45	33.67 ± 0.61	71.19 ± 1.30
IMSU 3	Bookshop entrance	14.30 ± 2.22	19.22 ± 0.67	111.19 ± 1.41
IMSU 4	Old ETF building	12.50 ± 3.10	27.30 ± 0.59	97.10 ± 1.62
IMSU 5	Mass communication department	5.00 ± 4.33	37.15 ± 0.63	105.54 ± 1.58
IMSU 6	Survey and geo-informatics department	27.14 ± 4.10	20.11 ± 0.72	98.11 ± 1.67
IMSU 7	Computer-based test (CBT) centre	21.14 ± 2.48	27.15 ± 0.81	100.24 ± 1.39
IMSU 8	Law library	18.33 ± 3.10	34.10 ± 0.74	97.40 ± 1.43
IMSU 9	Computer science department	10.32 ± 3.58	22.25 ± 0.55	87.11 ± 1.54
IMSU 10	Main Library	20.10 ± 2.57	10.24 ± 0.57	98.44 ± 1.67
IMSU 11	Academic staff office	27.11 ± 3.10	15.13 ± 0.72	115.72 ± 1.58
IMSU 12	Microbiology department	15.78 ± 3.74	18.00 ± 0.84	122.99 ± 1.69
IMSU 13	Theatre arts department	18.93 ± 4.20	16.98 ± 0.73	73.97 ± 1.66
IMSU 14	Public health department	28.47 ± 3.35	BDL	66.90 ± 1.63
IMSU 15	Zoology department	23.10 ± 2.17	20.11 ± 0.69	101.55 ± 1.55
IMSU 16	Faculty of law	28.91 ± 3.37	15.55 ± 0.77	20.90 ± 1.64
IMSU 17	Business administration extension	20.10 ± 4.10	29.33 ± 0.81	84.53 ± 1.59
IMSU 18	New ETF building	16.44 ± 4.65	30.10 ± 0.87	91.30 ± 1.68
IMSU 19	Agric economics extension	22.10 ± 2.55	24.55 ± 0.72	87.10 ± 1.62
IMSU 20	Science Building	12.15 ± 3.10	17.04 ± 0.59	112.23 ± 1.55
IMSU 21	Information management technology	27.85 ± 2.78	32.40 ± 0.64	97.11 ± 1.42
IMSU 22	Agric science department	30.10 ± 3.93	24.44 ± 0.74	25.47 ± 1.46
IMSU 23	Building department	31.53 ± 4.20	28.15 ± 0.82	127.15 ± 1.46
IMSU 24	Food science technology department	28.50 ± 4.15	15.21 ± 0.89	110.12 ± 1.59
IMSU 25	Nutrition and dietetics department	18.50 ± 3.15	18.63 ± 0.73	122.39 ± 1.59
IMSU 26	Faculty of social science	27.40 ± 2.73	14.79 ± 0.57	57.80 ± 1.33
IMSU 27	Faculty of education	16.55 ± 2.43	19.48 ± 0.61	91.12 ± 1.58
IMSU 28	Faculty of engineering	28.90 ± 3.72	25.53 ± 0.75	84.55 ± 1.67
IMSU 29	Economics department	19.77 ± 4.13	27.19 ± 0.61	100.55 ± 1.47
IMSU 30	Fine and applied arts department	BDL	23.94 ± 0.74	97.73 ± 1.46
Minimum estimated value		**BDL**	**BDL**	**20.90 ± 1.64**
Maximum estimated value		**31.53 ± 4.20**	**37.15 ± 0.63**	**127.15 ± 1.46**
Mean estimated value		**20.32 ± 3.22**	**22.55 ± 0.68**	**91.63 ± 1.54**

Table 2. Comparison of average natural radioactivity concentration and radiological parameters evaluated in this study with results from some related studies around the globe.

S/N	LOCATION	^{238}U	^{232}TH	^{40}K	RA$_{EQ}$	D	AUI	AED	H$_{EX}$ AND H$_{IN}$	ELCR × 10^{-3}	REFERENCE
1	Imo State University, Nigeria.	20.32	22.55	91.63	59.62	26.86	0.42	33.07 132.01	0.16 0.22	0.14	Present study
2	World mean value	33.00	45.00	420	370.00	60.00	2.00	70.00 460.00	1.00 1.00	0.29	United Nations Scientific Committee on the Effects of Atomic Radiation[1]
3	Greater Accra Ghana	34.00	30.00	320.00	83.00	39.00	–	47.00	0.20 –	–	Botwe et al[3]
4	FUTO Nigeria	17.88	22.82	90.18	–	25.99	–	31.89	– –	–	Eke et al[4]
5	Richards Bay, South Africa	28.26	31.56	138.07	85.87	38.89	–	290.00	0.23	–	Masok et al[10]
6	East coast of Tamilnadu	3.80	26.23	328.00	–	32.91	0.38	40.00	0.18 0.19	–	Sivakumar et al[12]
7	Rize province Turkey	24.50	51.80	344.99	125.00	56.90	–	69.80	0.34 –	–	Durusoy and Yildirim[15]
8	Ado-Odo/Ota Nigeria	40.44	94.44	134.25	185.82	81.32	1.53	860.00	0.50 –	–	Joel et al[18]
9	Ayranci, Turkey	25.00	50.00	228.00	114.95	52.56	–	51.82	0.64 –	–	Ogar et al[19]
10	Volta Region, Ghana	112.00	14.60	141.00	144.80	66.90	–	90.00	– –	–	Addo et al[20]
11	Rize province Turkey	85.75	51.08	771.57	218.20	110.69	1.60	136.00	0.59 –	0.48	Dizman et al[25]
12	Western Ghats	36.30	107.80	231.90	208.30	91.44	1.47	112.30	0.56 0.66	0.39	Manigandan and Shekar[37]

Abbreviations: AUI, activity utilization index; D, absorbed dose.

Table 3. Calculated dosimetry quantities (radium equivalent (Bqkg^{-1}), absorbed dose ($\mathbf{nGy}\textit{\textbf{h}}^{-1}$) and annual effective dose (μSvy^{-1})).

SAMPLE ID	RA$_{EQ}$	ABSORBED DOSE	AED OUTDOOR
IMSU 1	66.55 ± 2.94	29.70 ± 1.34	36.42 ± 1.64
IMSU 2	73.85 ± 4.42	32.67 ± 2.02	40.07 ± 2.48
IMSU 3	50.34 ± 3.29	22.88 ± 1.49	28.06 ± 1.83
IMSU 4	59.02 ± 4.07	26.34 ± 1.86	32.30 ± 2.28
IMSU 5	66.25 ± 5.33	29.18 ± 2.45	35.79 ± 3.00
IMSU 6	63.45 ± 5.26	28.81 ± 2.40	35.33 ± 2.94
IMSU 7	67.68 ± 3.75	30.37 ± 1.69	37.25 ± 2.07
IMSU 8	74.59 ± 4.27	33.16 ± 1.94	40.67 ± 2.38
IMSU 9	48.87 ± 4.50	21.87 ± 2.05	26.82 ± 2.51
IMSU 10	42.32 ± 3.51	19.61 ± 1.62	24.05 ± 1.99
IMSU 11	57.66 ± 4.25	26.52 ± 1.93	32.52 ± 2.37
IMSU 12	50.99 ± 5.07	23.33 ± 2.31	28.61 ± 2.83
IMSU 13	48.91 ± 5.37	22.11 ± 2.45	27.12 ± 3.00
IMSU 14	33.62 ± 3.46	15.96 ± 1.62	19.57 ± 1.99
IMSU 15	59.68 ± 3.28	27.08 ± 1.11	33.21 ± 1.36
IMSU 16	52.76 ± 4.60	23.63 ± 2.09	28.98 ± 2.56
IMSU 17	68.55 ± 5.38	30.55 ± 2.45	37.47 ± 3.00
IMSU 18	66.51 ± 6.02	29.61 ± 2.74	36.31 ± 3.36
IMSU 19	63.91 ± 3.70	28.70 ± 1.68	35.20 ± 2.06
IMSU 20	45.16 ± 4.06	20.62 ± 1.85	25.29 ± 2.27
IMSU 21	81.66 ± 3.80	36.51 ± 1.73	44.78 ± 2.12
IMSU 22	67.01 ± 5.12	29.74 ± 2.92	36.47 ± 3.58
IMSU 23	81.58 ± 5.49	36.91 ± 2.50	45.27 ± 3.07
IMSU 24	58.73 ± 5.55	26.97 ± 2.52	33.08 ± 3.09
IMSU 25	54.56 ± 4.32	24.94 ± 1.96	30.58 ± 2.40
IMSU 26	53.00 ± 3.65	24.02 ± 1.66	29.46 ± 2.40
IMSU 27	51.42 ± 3.42	23.24 ± 1.56	28.50 ± 1.91
IMSU 28	71.92 ± 4.92	32.32 ± 2.24	39.64 ± 2.84
IMSU 29	66.39 ± 5.19	29.78 ± 2.39	37.71 ± 2.93
IMSU 30	41.76 ± 1.18	18.56 ± 0.51	23.50 ± 0.63
Min value	**33.62**	**15.56**	**19.57**
Max value	**81.66**	**36.91**	**45.27**
Mean value	**59.62**	**26.86**	**33.07**

Abbreviations: AED, annual effective dose; Ra$_{eq}$, radium equivalent activity.

from other related studies, as shown in Table 2. The absorbed dose values in Table 3 were found in the range of 15.96 ± 1.62 to $36.91 \pm 2.50\,nGyh^{-1}$ with an average of $26.86\,nGyh^{-1}$. The absorbed dose obtained in this study is lower than the world's recommended value of $59\,nGyh^{-1}$ and within the range of other related studies, as shown in Table 2. The calculated AED value was shown in Table 3, the value ranged from 19.57 ± 1.99 to $45.27 \pm 3.07\,\mu Svy^{-1}$. The average value for outdoor estimated was $33.07\,\mu Svy^{-1}$. The calculated AED was lower than the world's recommended values of $480\,\mu Svy^{-1}$ $(0.48\,mSvy^{-1})$,[1] as presented in Table 3. Also, the annual effective dose of soil samples from the present research is less than $1.0\,mSvy^{-1}$, the

ICRP 2007 recommended value for the members of the public.[39,52]

The estimated radiological index parameters such as H_{ex}, H_{in}, AUI, and ELCR were recorded in Table 4. The values of the external hazard index (H_{ex}) and internal hazard index (H_{in}) ranged from 0.09 ± 0.01 to 0.22 ± 0.01 and 0.11 ± 0.00 to 0.31 ± 0.03, respectively, with associated average values of 0.16 and 0.22. The H_{ex} and H_{in} values estimated in this study were in line with the world's recommended value of <1 (less than unity), as shown in Table 3. The activity utilization index shown in Table 4 has a value ranging from 0.23 ± 0.02 to 0.58 ± 0.04 with an average value of 0.42, which is in line with the results

**Table 4.** Radiological hazard parameters (H_{ex}, H_{in}, AUI, and ELCR).

SAMPLE ID	H_{EX}	H_{IN}	AUI	ELCR $\times 10^{-3}$ (ESTIMATED WITH OUTDOOR AED ONLY)
IMSU 1	0.18 ± 0.01	0.23 ± 0.01	0.47 ± 0.02	0.15 ± 0.01
IMSU 2	0.20 ± 0.01	0.25 ± 0.02	0.52 ± 0.03	0.16 ± 0.01
IMSU 3	0.14 ± 0.01	0.17 ± 0.01	0.36 ± 0.02	0.11 ± 0.01
IMSU 4	0.16 ± 0.01	0.19 ± 0.02	0.42 ± 0.03	0.13 ± 0.01
IMSU 5	0.18 ± 0.01	0.19 ± 0.03	0.48 ± 0.04	0.15 ± 0.01
IMSU 6	0.17 ± 0.01	0.24 ± 0.03	0.45 ± 0.04	0.14 ± 0.01
IMSU 7	0.18 ± 0.01	0.24 ± 0.02	0.48 ± 0.03	0.14 ± 0.01
IMSU 8	0.20 ± 0.01	0.25 ± 0.02	0.53 ± 0.03	0.16 ± 0.01
IMSU 9	0.13 ± 0.01	0.16 ± 0.02	0.35 ± 0.03	0.10 ± 0.01
IMSU 10	0.11 ± 0.01	0.17 ± 0.02	0.30 ± 0.02	0.09 ± 0.01
IMSU 11	0.16 ± 0.01	0.23 ± 0.02	0.41 ± 0.03	0.12 ± 0.01
IMSU 12	0.14 ± 0.01	0.18 ± 0.02	0.37 ± 0.03	0.11 ± 0.01
IMSU 13	0.13 ± 0.01	0.18 ± 0.03	0.35 ± 0.04	0.10 ± 0.01
IMSU 14	0.09 ± 0.01	0.17 ± 0.02	0.23 ± 0.02	0.08 ± 0.01
IMSU 15	0.16 ± 0.01	0.22 ± 0.01	0.42 ± 0.02	0.14 ± 0.00
IMSU 16	0.14 ± 0.01	0.22 ± 0.02	0.36 ± 0.03	0.11 ± 0.01
IMSU 17	0.19 ± 0.01	0.24 ± 0.03	0.48 ± 0.04	0.15 ± 0.01
IMSU 18	0.18 ± 0.02	0.22 ± 0.03	0.47 ± 0.04	0.15 ± 0.01
IMSU 19	0.17 ± 0.01	0.23 ± 0.02	0.45 ± 0.03	0.14 ± 0.01
IMSU 20	0.12 ± 0.01	0.15 ± 0.02	0.33 ± 0.03	0.10 ± 0.01
IMSU 21	0.22 ± 0.01	0.30 ± 0.02	0.57 ± 0.03	0.18 ± 0.01
IMSU 22	0.18 ± 0.01	0.26 ± 0.02	0.46 ± 0.03	0.14 ± 0.01
IMSU 23	0.22 ± 0.01	0.31 ± 0.03	0.58 ± 0.04	0.18 ± 0.01

(Continued)

Table 4. (Continued)

SAMPLE ID	H_{EX}	H_{IN}	AUI	ELCR × 10⁻³ (ESTIMATED WITH OUTDOOR AED ONLY)
IMSU 24	0.16 ± 0.01	0.24 ± 0.03	0.42 ± 0.04	0.14 ± 0.01
IMSU 25	0.15 ± 0.01	0.20 ± 0.02	0.39 ± 0.03	0.13 ± 0.01
IMSU 26	0.14 ± 0.01	0.22 ± 0.02	0.37 ± 0.02	0.11 ± 0.01
IMSU 27	0.14 ± 0.01	0.18 ± 0.02	0.37 ± 0.02	0.11 ± 0.01
IMSU 28	0.19 ± 0.01	0.27 ± 0.02	0.50 ± 0.02	0.16 ± 0.01
IMSU 29	0.18 ± 0.01	0.23 ± 0.03	0.47 ± 0.04	0.15 ± 0.01
IMSU 30	0.13 ± 0.00	0.11 ± 0.00	0.30 ± 0.01	0.09 ± 0.00
Min value	**0.09**	**0.11**	**0.23**	**0.08**
Max value	**0.22**	**0.31**	**0.58**	**0.18**
Mean value	**0.16**	**0.22**	**0.42**	**0.14**

Abbreviatios: AUI, activity utilization index; H_{ex}, external hazard index; H_{in}, internal hazard index.
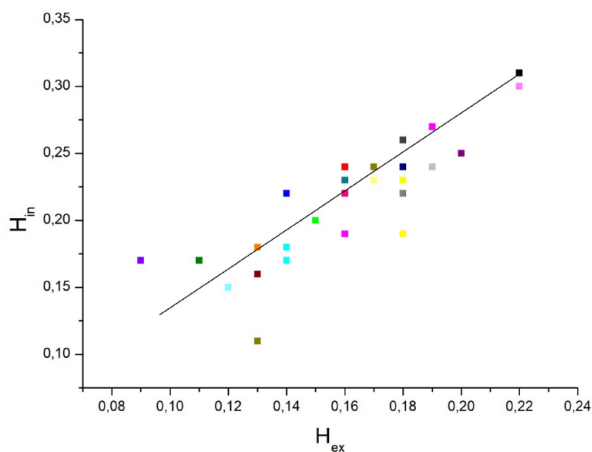
Figure 2. Correlation between the internal hazard index and external hazard index.

from other related studies and also less than the world recommended value of 2 as shown in Table 2. Figure 2 shows a strong relationship between the internal hazard index (H_{in}) and the external hazard index (H_{ex}). The excess lifetime cancer risk (ELCR) was calculated with estimated outdoor values of AED, recorded in Table 4. The range of ELCR recorded is 0.08 ± 0.01 ($\times 10^{-3}$) to 0.18 ± 0.01 ($\times 10^{-3}$), with the corresponding average value of 0.14×10^{-3}. The ELCR value is lower than the world mean value of 0.29×10^{-3}, as shown in Table 2. This implies that the radiation level measured in this study area may not pose serious radiological health hazards, and several research works have also confirmed that the health risk of exposure to low natural radiation doses may be insignificant.[53-56]

Pearson's correlation analysis

Table 5 presents the result of the correlation analysis. Pearson correlation analysis of activity concentrations of radionuclides,

absorbed dose, effective dose, and the radiological parameters revealed strong relationships among these parameters. The findings revealed a significant correlation between the activity concentrations ²³²Th and all the radiological parameters. This implies that an increase in the activity concentrations of ²³²Th radionuclide in the soil sample of IMSU could result in exposure to the community. Similarly, there was a strong correlation between the activity concentrations ²³⁸U and the radiological parameters except for radium equivalent (Ra$_{eq}$) and activity utilization index (AUI). The results of the present study agreed with the findings of Mbonu and Ben[57] who reported the radiation hazard indices due to natural radioactivity in soil samples from Orlu, Imo State, Nigeria. The authors revealed that the activity concentrations of radionuclides in soil samples from the studied locations were below the safe limit. Even though the mean activity concentration of ⁴⁰K was more than ²³²Th and ²³⁸U, there was no significant correlation between it and the radiological parameters.

Conclusion

All the activity concentrations of the radionuclides ²³⁸U, ²³²Th, and ⁴⁰K measured in this study were below the average world values of $33 \, Bqkg^{-1}$, $45 \, Bqkg^{-1}$, and $420 \, Bqkg^{-1}$, respectively.[1] The average radium equivalent of $59.62 \, Bqkg^{-1}$ obtained from the present study was lower than the $370 \, Bqkg^{-1}$ recommended by the International Commission on Radiation Protection (ICRP). Moreover, the absorbed dose, the annual effective dose, the activity utilization index, the external hazard index, and the internal hazard index were lower than the global recommended mean value. The ELCR average value estimated was lower than the global recommended value. From the results of this study, all the radiological parameters estimated were below the permissible limits set by international professional bodies, including UNSCEAR and ICRP. These results indicate that the soil

Table 5. Correlation analysis between activity concentrations of radionuclides and their radiological parameters.

ACTIVITY CONC.	ABSORBED DOSE	AED OUTDOOR	H_{EX}	H_{IN}	RA_{EQ}	AUI
K-40						
P. Correlation	.049	.052	.049	−.119	.016	.081
Sig. (2-tailed)	.804	.795	.805	.546	.936	.681
Th-232						
P. Correlation	.779**	.779**	.814**	.466*	.809**	.826**
Sig. (2-tailed)	.000	.000	.000	.012	.000	.000
U-238						
P. Correlation	.397*	.394*	.342	.743**	.364	.315
Sig. (2-tailed)	.036	.038	.075	.000	.057	.102

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

samples from the investigated area pose no serious radiological health hazards to the human population.

REFERENCES

1. United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and Effects of Ionising Radiation.* Vol. 1. United Nations Scientific Committee on the Effects of Atomic Radiation; United Nations Publications; 2000.
2. Kam E, Bozkurt A. Environmental radioactivity measurements in Kastamonu region of northern Turkey. *Appl Radiat Isot.* 2007;65:440-444.
3. Botwe BO, Schirone A, Delbono I, et al. Radioactivity concentrations and their radiological significance in sediments of the Tema Harbour (Greater Accra, Ghana). *J Radiat Res Appl Sci.* 2017;10:63-71.
4. Eke BC, Jibiri NN, Anusionwu BC, Orji CE, Emelue HU. Baseline measurements of natural radioactivity in soil samples from the Federal University of Technology, Owerri, South-East, Nigeria. *Br J Appl Sci Technol.* 2015;5:142-149.
5. Saleh MA, Ramli AT, Alajerami Y, et al. Assessment of radiological health implication from ambient environment in the Muar district, Johor, Malaysia. *Radiat Phys Chem.* 2014;103:243-252.
6. Korkmaz ME, Ağar O, Uzun E. Assessment of natural radioactivity levels for Karadağ Mountain, Turkey. *Int J Radiat Res.* 2017;15:399-406.
7. Ali AH, Tafash HT, Al Shawi AF, Farhan TM. Measurement of radiation activity at Fallujah university in anbar governorate, Iraq. *J Phys Conf Ser.* 2019;1178:012009.
8. Zubair M. Measurement of natural radioactivity in several sandy-loamy soil samples from Sijua, Dhanbad, India. *Heliyon.* 2020;6:e03430.
9. Sharma P, Meher PK, Mishra KP. Terrestrial gamma radiation dose measurement and health hazard along river Alaknanda and Ganges in India. *J Radiat Res Appl Sci.* 2014;7:595-600.
10. Masok FB, Masiteng PL, Mavunda RD, Maleka PP, Winkler H. Measurement of radioactivity concentration in soil samples around phosphate rock storage facility in Richards Bay, South Africa. *J Radiat Res Appl Sci.* 2018;11:29-36.
11. Harb S, Salahel Din K, Abbady A, Moustafa M. Activity Concentration for Surface Soil Samples Collected from Arrant, Qena, Egypt. Proceedings of the 4th environmental physics conference Hurghada, Egypt. 2010:49-57.
12. Sivakumar S, Chandrasekaran A, Ravisankar R, et al. Measurement of natural radioactivity and evaluation of radiation hazards in coastal sediments of east coast of Tamilnadu using statistical approach. *J Taibah Univ Sci.* 2014;8:375-384.
13. Boukhenfouf W, Boucenna A. The radioactivity measurements in soils and fertilizers using gamma spectrometry technique. *J Environ Radioact.* 2011;102:336-339.
14. Ahmad N, Jaafar M, Alsaffar M. Natural radioactivity in virgin and agricultural soil and its environmental implications in Sungai Petani, Kedah, Malaysia. *Pollution.* 2015;1:305-313.
15. Durusoy A, Yildirim M. Determination of radioactivity concentrations in soil samples and dose assessment for Rize Province, Turkey. *J Radiat Res Appl Sci.* 2017;10:348-352.
16. Al-Hamarneh IF, Awadallah MI. Soil radioactivity levels and radiation hazard assessment in the highlands of northern Jordan. *Radiat Meas.* 2009;44:102-110.
17. Alzubaidi G, Hamid F, Abdul Rahman I. Assessment of natural radioactivity levels and radiation hazards in agricultural and virgin soil in the state of Kedah, North of Malaysia. *Sci World J.* 2016;2016:1-9.
18. Joel ES, Maxwell O, Adewoyin OO, et al. Investigation of natural environmental radioactivity concentration in soil of coastaline area of Ado-Odo/Ota Nigeria and its radiological implications. *Sci Rep.* 2019;9:4219.
19. Agar O, Eke C, Boztosun I, Korkmaz ME. Determination of naturally occurring radionuclides in soil samples of Ayranci, Turkey. *J Phys Conf Ser.* 2015;590:012042.
20. Addo MA, Lomotey JS, Osei B, Appiah K. Measurement of natural radioactivity in soil dust samples along roadways in high commercial areas of the Ketu South District of the Volta Region, Ghana. *Radiat Prot Environ.* 2020;43:6-12.
21. Ravanat JL, Breton J, Douki T, et al. Radiation-mediated formation of complex damage to DNA: a chemical aspect overview. *Br J Radiol.* 2014;87:20130715.
22. Keith S, Wholers DW. *Addendum to the Toxicological Profile for Thorium.* 2015:30333. Accessed January 17, 2024. https://www.atsdr.cdc.gov/toxprofiles/thorium_addendum.pdf
23. Findeiβ M, Schaffer A. Fate and environmental impact of thorium residues during rare earth processing. *J Sust Met.* 2017;3:179-189.
24. Dhawal SJ, Phadatare MR, Kulkarni GS, Pawar SH. Gamma radiation levels in the villages of South Konkan, Maharashtra, India. *Environ Earth Sci.* 2014;72:511-523.
25. Dizman S, Görür FK, Keser R. Determination of radioactivity levels of soil samples and the excess of lifetime cancer risk in Rize province, Turkey. *Int J Radiat Res.* 2016;14:237.
26. Rahman S, Matiullah Malik F, et al. Measurement of naturally occurring/fallout radioactive elements and assessment of annual effective dose in soil samples collected from four districts of the Punjab Province, Pakistan. *J Radioanal Nucl Chem.* 2011;287:647-655.
27. Omeje M, Adagunodo TA, Akinwumi SA, et al. Investigation of Driller's exposure to natural radioactivity and its radiological risks in low latitude region using neutron activation analysis. *Int J Mech Eng Technol.* 2019;10:1897-1920.
28. United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and effects of ionising radiation.* United Nations Scientific Committee on the Effects of Atomic Radiation; United Nations Publications; 2012.
29. Joel ES, Maxwell O, Adewoyin OO, Ehi-Eromosele CO, Saeed MA. Comparative analysis of natural radioactivity content in tiles made in Nigeria and imported tiles from China. *Sci Rep.* 2018;8:1842.
30. Omeje M, Adewoyin OO, Joel ES, et al. Natural radioactivity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in commercial building materials and their lifetime cancer risk assessment in Dwellers. *Hum Ecol Risk Assess.* 2018;24:2036-2053.
31. International Atomic Energy Agency. Measurement of radionuclides in food and environmental samples. *IAEA technical report series 295*; 1989.
32. Jibiri NN, Akomolafe IR. Radiological assessment and geochemical characterization of the sediments of Awba Dam, University of Ibadan, Nigeria. *Radiat Prot Environ.* 2016;39:222-232.
33. Jibiri NN, Emelue HU. Soil radionuclide concentrations and radiological assessment in and around a refining and petrochemical company in Warri, Niger Delta, Nigeria. *J Radiol Prot.* 2008;28:361.

34. Eke BC, Ukewuihe UM, Akomolafe IR. Evaluation of activity concentration of natural radionuclides and lifetime cancer risk in soil samples at two tertiary institutions in Owerri, Imo State, Nigeria. *Int J Radiat Res*. 2022;20:671-678.

35. Raghu Y, Ravisankar R, Chandrasekaran A, Vijayagopal P, Venkatraman B. Assessment of natural radioactivity and radiological hazards in building materials used in the Tiruvannamalai District, Tamilnadu, India, using a statistical approach. *J Taibah Univ Sci*. 2017;11:523-533.

36. Beretka J, Mathew PJ. Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health Phys*. 1985;48:87-95.

37. Manigandan PK, Shekar BC. Evaluation of radionuclides in the terrestrial environment of Western Ghats. *J Radiat Res Appl Sci*. 2014;7:310-316.

38. Sharma N, Singh J, Esakki SC, Tripathi RM. A study of the natural radioactivity and radon exhalation rate in some cements used in India and its radiological significance. *J Radiat Res Appl Sci*. 2016;9:47-56.

39. ICRP. The 2007 recommendations of the international commission on radiological protection. *Ann ICRP*. 2007;37:1-332.

40. Popoola FA, Fakeye OD, Basiru QB, Adesina DA, Sulola MA. Assessment of radionuclide concentration in surface soil and human health risk associated with exposure in two higher institutions of Esan land, Edo State, Nigeria. *J Appl Sci Environ Manage*. 2019;23:22679-22684.

41. Isinkaye MO. Natural radioactivity levels and the radiological health implications of tailing enriched soil and sediment samples around two mining sites in Southwest Nigeria. *Radiat Prot Environ*. 2013;36:122-127.

42. Egunyinka OA, Olowookere CJ, Jibiri NN, Babalola IA, Obed RI. An evaluation of 238U, 40K, and 232Th concentrations in the top soil of the University of Ibadan (UI), southwestern Nigeria. *Pac J Sci Technol*. 2009;10:742-750.

43. Abba HT, Hassan WM, Saleh MA, Aliyu AS, Ramli AT. Terrestrial gamma radiation dose (TGRD) levels in northern zone of Jos Plateau, Nigeria: statistical relationship between dose rates and geological formations. *Radiat Phys Chem*. 2017;140:167-72.

44. Garba NN, Odoh CM, Nasiru R, Saleh MA. Investigation of potential environmental radiation risks associated with artisanal gold mining in Zamfara State, Nigeria. *Environ Earth Sci*. 2021;80:1-9.

45. Bello S, Zakari YI, Muhammad BG, Chiromawa NL, Saribu AY. Environmental radioactivity assessment of Dana steel limited dump site, Katsina State, Nigeria. *J Nat Appl Sci*. 2016;5:159-166.

46. Olarinoye IO, Sharifat I, Baba-Kutigi A, Kolo MT, Aladeniyi K. Measurement of Background gamma radiation levels at two Tertiary Institutions in Minna, Nigeria. *J Appl Sci Environ Manage*. 2010;14(1):59-62.

47. Ugbede FO, Okoye ON, Akpolile AF, Oladele BB. Baseline radioactivity in the soil of evangel take-off campus, Evangel University, Nigeria, and its associated health risks. *Chem Afr*. 2021;4:703-713.

48. Akpan AE, Paul ND, Uwah EJ. Ground radiometric investigation of natural radiation levels and their radiological effects in Akpabuyo, Nigeria. *J Afr Earth Sci*. 2016;123:185-192.

49. Taqi AH, Shaker AM, Battawy AA. Natural radioactivity assessment in soil samples from Kirkuk city of Iraq using HPGe detector. *Int J Radiat Res*. 2018;16:455-463.

50. Ali MM, Zhao H, Rawashdeh A, Mohammed YA, Al Hassan M. Assessment of radiation hazard indices for sand samples from Ma'rib in Yemen. *Int J Radiat Res*. 2021;19:615-623.

51. Olagbaju PO, Okeyode IC, Alatise OO, Bada BS. Background radiation level measurement using hand held dosimeter and gamma spectrometry in Ijebu-Ife, Ogun State Nigeria. *Int J Radiat Res*. 2021;19:591-598.

52. Aközcan S. Annual effective dose of naturally occurring radionuclides in soil and sediment. *Toxicol Environ Chem*. 2014;96:379-386.

53. Cuttler JM. Commentary on Fukushima and beneficial effects of low radiation. *Dose-Response*. 2013;11:432-443.

54. Morgan WF, Bair WJ. Issues in low dose radiation biology: the controversy continues. A perspective. *Radiat Res*. 2013;179:501-510.

55. Calabrese EJ, Dhawan G. The role of x-rays in the treatment of gas gangrene: a historical assessment. *Dose-Response*. 2012;10:626-643.

56. Feinendegen LE, Pollycove M, Neumann RD. Low-dose cancer risk modeling must recognize up-regulation of protection. *Dose-Response*. 2010;8:227-252.

57. Mbonu CC, Ben UC. Assessment of radiation hazard indices due to natural radioactivity in soil samples from Orlu, Imo State, Nigeria. *Heliyon*. 2021;7:e07812.