

Radiological Health Risk Assessment of Agricultural Soils Around Selected Quarry Sites in Ondo and Ekiti States, Southwest Nigeria

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ORIGINAL RESEARCH

Abstract

Twenty soil samples in the agricultural farmland surrounding selected quarry sites in Ondo and Ekiti states was assessed to measure the concentration of ²³⁸U, ²³²Th, ⁴⁰K using NaI (TI) detector and estimating radiological parameters in order to determine the possible radiation effects to the farmers and member of the public consuming the farm products. Analysis of the result revealed that the average contents of the measured radioelements were 15.19, 31.92 and 1354.15, 16.55, 38.60 and 1185.44, 24.66, 34.25, 1385.89 and 18.10, 37.66, 1242.67 Bq/kg for Iyin, Ita ogbolu, Aaye and Ikere quarry sites, accordingly. The absorbed dose rate in the soil samples ranges from 64.91 nGy/h in Iyin quarry site to 146.88 nGy/h in Aaye quarry site with the mean value of 86.06 nGy/h for the four study locations. The concentration of ⁴⁰K, the absorbed dose rate, the indoor and outdoor annual effective dose and the excess lifetime cancer risk were higher than the world limit in the study area, predisposing the member of the public in these locations to hazard of radiation exposure. There is the need for constant monitoring of the quarry sites, provision of radiation protective shield for workers mining at the sites, awareness of radiation risks to the farmers and members of the public around the quarry sites.

Keywords— farmers quarry sites, radioelements, radiation risks.

1 INTRODUCTION

Assessment of radioelement contents in soil is essential for environmental fortification against the damaging effect of radiation. Determination of the distribution of radioelements content of soil used in agricultural practice and construction purposes cannot be over-emphasized for human safety (Missimer *et al.*, 2019). Soil does not only serve as a source of mineral resources but also serve as a mean of conducting the minerals element to plants that sustain the ecosystem. Mining of granite and its subsidiary products such as crushed granite, granite dust or fines granite chips, dimension stone off cuts, granite sand are very essential sources of raw materials for construction and industrial use. Quarrying activities hold a potential for raising the radioactivity level of an environment (Cheweezo and Igwesi, 2021; Echeweozo *et al.*, 2024) especially in locations where the inherent geology is rich in radioactive minerals such as ²³⁸U, ²³²Th, ⁴⁰K.

Accumulation of radioelements through soils dust deposition, erosion, perturbation of rock materials makes agricultural soil near quarry sites to be vulnerable to exposure to radioactive elements (Ofomola *et al.*, 2023)

thereby raising the radioactivity level and impacting the health of the members of the public.

Soil samples of Swabi region in Pakistan was assessed with HPGe detector to determine the specific concentration of primordial radioelement, the outcome of the assessment revealed that the concentration of ²³²Th was slightly higher than the world limit and that the concentration of ⁴⁰K was 2.2 times the word average limit (Azeem *et al.*, 2024). The soil and rock samples around quarry sites in Uturu Abia state Nigeria was assessed and the study concluded that there is a possible radiation risks to the workers in the mining site, farmers and the residents of the community (Echeweozo *et al.*, 2024). Regassa *et al* (2023) investigated the Hakin Gura quarry site in Ethiopia and discovered that the concentration of ²³⁸U, ²³²Th, were above the world average limit (Regassa *et al.*, 2023). Quarry operations are very common in southwest Nigeria because of the abundance of granitic and metamorphic rocks in the region. Nonetheless, the radiological health risks connected with this human activity are not yet fully comprehended or regularly monitored. Enrichment of agricultural soils with radioelement contents above the threshold value for a long period of time could pose significant health risks such as cancer and genetic defects to farmers and consumers of food crops from the cultivated farmland around the quarry sites (Odelami *et al.*, 2024). The purpose of this study is to assess the radiation risk connected with the agricultural soils surrounding selected quarry sites in Ondo and Ekiti States Southwest Nigeria that have not been monitored in order to determine the concentration of ²³⁸U, ²³²Th, ⁴⁰K and estimating radiological parameters. The study will

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Section A- AGRICULTURAL ENGINEERING AND RELATED SCIENCES

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provide the needed understandings into the possible environmental and public health impacts of quarry activities in the selected locations and contribute to emerging procedures for safer practices and boost sustainable agricultural use of lands in the affected areas.

Study Area

The study area is located on the reassembled of West African basement complex rock interspersed with sedimentary basins and crystalline rocks as shown in Figure 1. Its geology is based on the Dahomey basins that extended from southern part of Liberia through Ivory-coast, Ghana, Togo, Benin, and ended in Nigeria (Oladapo *et al.*, 2022). The Dahomey basin comprises of five basins: Ivory-coast, Tano, Salt pond, Central and Kete. The study area is bounded by Dahomey basin on the west, Niger-delta basin in the east, Basement rock in the north and Atlantic Ocean in the south. The two major water basins in the Dahomey basins are located in the study area: Benin- Owena, and Ogun- Osun (Joel *et al.*, 2020). The region is characterized with tertiary and cretaceous sediments. The precambrian basement rocks of south- west comprises of migmatites, banded gneiss, and granite gneiss, with low grade metasedimentary, and metavolcanic schists. The pegmatites veins and dykes often intrude the migmatites and gneiss metasediments, while the metasediment and metavolcanic schists are intruded by Pan- Africa age granite and charmockites.

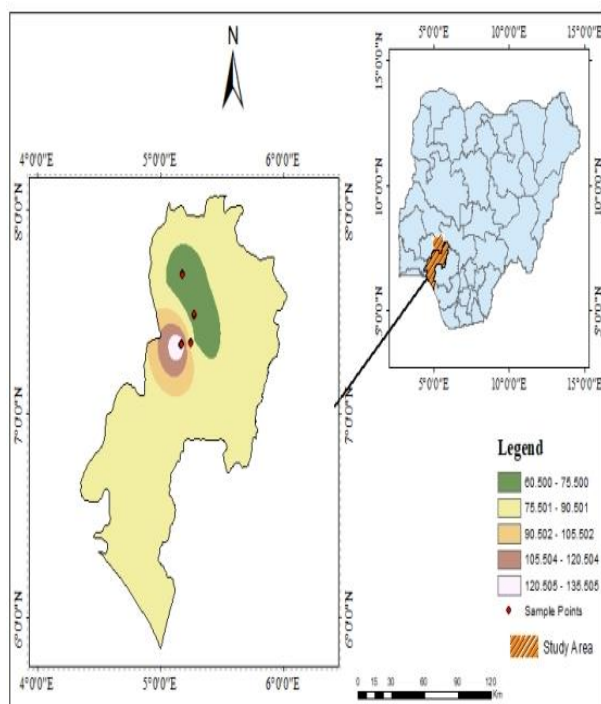


Figure 1: Map showing study locations

2 MATERIALS AND METHOD

Five soil samples each weighing 2 kg, were spatially collected in four different quarry sites in the study locations with the aid of soil auger at 5 cm beneath the

earth's crust, in a labelled polythene bag with the coordinate of each sample marked with geographical positioning system. In the laboratory, the soil samples were sieve to remove stones and debris under room temperature and humidity (Yang & Sun 2022). To completely removed moisture, the soil samples were oven dried at 110 °C until a constant weight was attained, samples were then grinded and pulverized with 3 mm mesh to obtain a homogeneous particle. 250 g of oven dried samples were packed and labelled in an air-tight plastic container and stored in the laboratory for 28 days to attain secular equilibrium (Jafir, 2023) before the radioelements measurement using NaI (TI) detector at Nigeria Institute of Radiation Research, Ibadan.

2.1 The Detector

NaI (TI) detector is a scintillation detector that has a wide application in nuclear medicines and environmental monitoring. It is very efficient in detecting and measuring gamma radiation at room temperature. The radioelement from background radiation interacts with the material medium through three major ways, namely photo electric effect, Compton effect and pair production. The detector consisted of NaI doped with TI that enhances the emission of light from the crystal when in contact with ionizing radiation. The interaction of NaI (TI) crystal with gamma ray resulted in ionization and excitation of the crystal lattice which give rise to the emission of photons with the energy that is proportional to the energy of the incident radiation spectrum. The photo multiplier tube (PMT) enclosed in the light tight proof casing adjacent to NaI (TI) scintillation crystal convert the scintillation light to electrical signal that is amplified by the amplifier.

Evaluation of Radiological Parameters

The radiological parameters of interest were determined to assess the risk of radiation to the populace in the two communities, using the following equation:

Absorbed Dose Rate

$$DE \text{ (nGy/h)} = 0.462A_U + 0.604A_{Th} + 0.0417A_K \quad (1)$$

DE is the absorbed dose rate A_U , A_{Th} , A_K are the concentrations of ^{238}U , ^{232}Th , and ^{40}K , respectively (UNSCEAR 2000, Isinkaye *et al.*, 2023).

Annual Effective Dose Rate

Both the indoor and outdoor effective doses were determined using equations (2, 3, and 4) (Isinkaye, *et al.*, 2023)

$$AED \text{ (mSv/y)} = DR \times T \times F \quad (2)$$

$$AED_{in} \text{ (mSv/y)} = DR \times 8760 \times 0.8 \times 0.7 \times 10^{-6} \quad (3)$$

$$AED_{out} \text{ (mSv/y)} = DR \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (4)$$

The symbol has their usual meaning as reported by (Isinkaye, *et al.*, 2023)

Excess Lifetime Cancer Risk

$$ELTCR \text{ (mSv/y)} = DR \times v \times F \quad (5)$$

ELTR is the excess life-time cancer risk, DR is the absorbed dose rate, v is the life expectancy which will be taken as 70 years and F is the conversion factor and taken as 0.05 Sv^{-1} (Usikalu *et al.*, 2023; Eke *et al.*, 2024)

Results and Discussions

The result of measured radioelements content and estimated radiological parameters for soil samples collected in selected quarry sites in the study locations are presented in Table 1 and 2. Figure 2 and 3 presents the comparison of the measured radioelements and estimated radiological parameters with the world limit. Analysis of the result shows that the concentrations of the measured radioelements range from 4.07 to 29.86, 23.19 to 40.78, and 1030.1 to 2024.34 Bq/kg for ²³⁸U, ²³²Th, and ⁴⁰K, in Iyin quarry site, 8.12 to 28.29, 27.26 to 49.16, 1030.1 to 2024.34 Bq/kg in Ita-ogbolu, 11.67 to 43.08, 19.27 to 49.11, 924.46 to 2277.25 Bq/kg in Aaye, 4.4 to 36.53, 26.89 to 40.53, 1002.08 to 1661.00 Bq/kg in Ikere. The average radioelements content for the four quarry sites are 15.19, 31.92 and 1354.15, 16.55, 38.60 and 1185.44, 24.66, 34.25, 1385.89 and 18.10, 37.66, 1242.67 Bq/kg accordingly as illustrated in Figure 2.

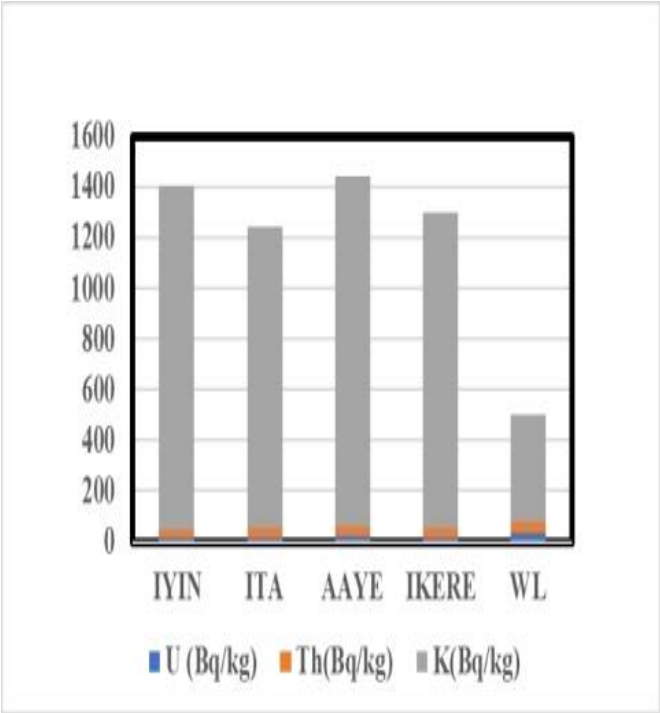


Figure2: Comparison of the measured radioelements with the world limits (WL)

The absorbed dose rate in the soil samples ranges from 64.91 nGy/h in Iyin quarry site to 146.88 nGy/h in Aaye quarry site with the mean value of 86.06 nGy/h for the four study locations. The outdoor and indoor annual effective dose interspersed between 0.080-0.181 mSv/y with the average value of 0.11 mSv/y and 0.319-0.721 mSv/y with the mean of 0.42 mSv/y. The excess lifetime cancer risks range from 0.227 to 0.514 with the mean value of 0.30 mSv/y as depicted in Figure 3.

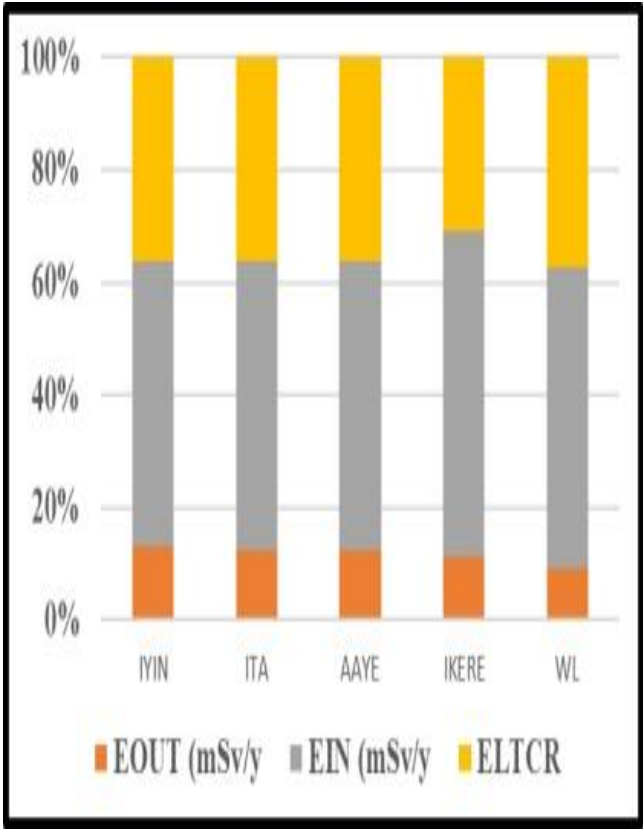


Figure 3: Comparison of the radiological parameters with the world limit (WL)

The concentration of ²³⁸U, ²³²Th in most of the sites were lower than global limit of 35, 45 Bq/kg (Morakinyo *et al.*, 2022) but the average value for the study area was higher than the reported values in Kwara, Osun, Nassarawa, and Lagos states, Nigeria (Kanmi *et al.*, 2024; Esan *et al.*, 2022; Mustapha *et al.*, 2024; Adedokun *et al.*, 2022). Nonetheless the average content of ²³⁸U, ²³²Th in the quarry sites in this study area is lower in comparison to the values reported in Imo state, Nigeria, Iraq, Bangladesh and Pakistan (Jibri and Eke, 2022; Dina *et al.*, 2022; Azeem *et al.*, 2024). The average concentration of ⁴⁰K in Aaye and Iyin quarry sites were more than three times the global limit of 420 (Usikalu *et al.*, 2023) Bq/kg while that of Ikere and Ita-Ogbolu quarry sites were approximately three times the world limit. Findings from the soil samples in the sites reveal a predominant elevation of the concentration of ⁴⁰K which may be associated with the availability of mineral resources such as kaolinite and feldspar. (Kanmi, 2024; Taalab, 2024) and agricultural practices in the study locations (Adedokun, 2022). ⁴⁰K is an essential nutrient in the soil needed for plant growth and production of food for human sustenance (Tiwari, 2024). However, concentration of ⁴⁰K above the norms had been linked to carcinogenesis diseases (Hamed *et al.*, 2024; Amodu *et al.*, 2024).

The mean value for the absorbed dose rate in the quarry sites for the study location was 86.06 nGy/h which was above the global limit of 59 nGy/h (Morakinyo *et al.*, 2025) and higher than the values reported in other locations according to Table 3 with the exception of Bangladesh

that was reported as 110.0 nGy/h. The outdoor annual effective dose was more than the reference limit 0.07 (Mitra *et al.*, 2023) for the member of the public in all the sampling locations while the indoor annual effective dose was higher than 0.41 mSv/y, the global limit (Khyalia *et al.*, 2024) in 45% of the study locations. The excess lifetime cancer risk was higher than the global limits of 0.29 mSv/y (Jafer *et al.*, 2023) in 45% of the study locations, this predispose the dwellers around those locations in a lifetime of 70 years to the risk of developing carcinogenesis diseases (Simon *et al.*, 2022). The external and internal hazard indices were lower than unity, indicating that the danger of radiation injury to both external and internal organ as a result of exposure to the radioelements cannot occur in the study locations (Eke *et al.*, 2024). The values of the annual gonadal index for the study locations were less than unity in all the sampling point except for only one point in Aaye quarry site, which indicate that the workers and farmers around the quarry site might not be in danger of respiratory disorder a result of exposure. It is also worth noting that gamma representative index values were less than unity which make the quarry products of the study locations safe for construction purposes with the exception of a location in Aaye (Oladejo *et al.*, 2025).

Table 1: Concentration of the measured radioelements in quarry sites

Locations	LONG (°N)	LATT (°E)	U (Bq/kg)	Th (Bq/kg)	K (Bq/kg)
IYIN 1	5.179983	7.680881	4.07	29.87	1030.1
IYIN2	5.182695	7.683262	4.37	40.78	1314.28
IYIN3	5.183078	7.684162	15.32	33.07	1306.17
IYIN4	5.181147	7.684123	29.86	23.19	1095.87
IYIN5	5.180543	7.681875	25.91	32.69	2024.34
ITA1	5.248307	7.348243	9.29	33.98	1030.1
ITA2	5.247575	7.346305	28.29	27.26	1314.28
ITA3	5.247348	7.346907	11.5	40.32	1306.17
ITA4	5.246653	7.348315	25.53	42.27	1095.87
ITA5	5.246117	7.348155	8.12	49.16	2024.34
AAYE1	5.170057	7.33147	20.52	19.27	924.46

AAYE2	5.169737	7.33217	11.67	32.35	1238.08
AAYE3	5.169997	7.339359	30.06	30.28	1303.43
AAYE4	5.170951	7.340985	17.97	40.22	1186.21
AAYE5	5.171735	7.340065	43.08	49.11	2277.25
IKERE1	5.277,595	7.480943	20.25	26.89	1174.72
IKERE2	5.278813	7.480775	36.53	40.35	1661
IKERE3	5.276282	7,482,633	22.73	40.35	1288.19
IKERE4	5.276243	7.482658	4.4	40.35	1002.08
IKERE5	5.274462	7.485252	6.6	40.35	1087.36

Table 2: Estimated radiological parameter for soil samples in quarry sites

Site	DE (n Gy/h)	E _{OU} (m Sv/y)	E _{IN} (m Sv/y)	H _{EX}	H _{IN}	AG DE (m Sv/y)	Ra (Bq/kg)	I _y	EL TC (m Sv/y)
IYIN 1	64.91	0.08	0.319	0.34	0.35	0.461	119.62	0.50	0.27
IYIN 2	84.24	0.10	0.414	0.44	0.45	0.597	155.61	0.65	0.295
IYIN 3	83.47	0.10	0.410	0.44	0.48	0.596	154.96	0.65	0.292
IYIN 4	74.31	0.09	0.365	0.39	0.47	0.533	140.51	0.58	0.260
IYIN 5	117.94	0.15	0.579	0.61	0.68	0.852	215.79	0.92	0.413
ITA1	68.84	0.09	0.338	0.36	0.39	0.486	128.95	0.53	0.241
ITA2	88.67	0.109	0.435	0.47	0.54	0.638	165.51	0.69	0.310
ITA3	73.55	0.090	0.361	0.39	0.42	0.516	139.45	0.57	0.257
ITA4	94.27	0.12	0.63	0.50	0.57	0.68	178.80	0.73	0.330
ITA5	87.72	0.11	0.431	0.46	0.48	0.615	165.09	0.68	0.270

A	60.	0.0	0.2	0.	0.	0.4	113	0.	0.2
Y	48	7	97	32	37	34	.44	47	12
1				2	8		5	3	
A	78.	0.0	0.3	0.	0.	0.5	145	0.	0.2
Y	56	97	86	41	44	60	.47	61	75
2				4	5		5	3	
A	87.	0.1	0.4	0.	0.	0.6	165	0.	0.3
Y	84	08	31	46	55	29	.52	68	07
3				9	0		6	6	
A	84.	0.1	0.4	0.	0.	0.5	159	0.	0.2
Y	33	04	14	45	49	96	.36	65	95
4				0	9		2	6	
A	146	0.1	0.7	0.	0.	1.0	274	1.	0.5
Y	.88	81	21	77	89	53	.33	14	14
5				9	6		2	8	
I	75.	0.0	0.3	0.	0.	0.5	141	0.	0.2
K	95	93	73	40	45	44	.76	59	66
1				3	8		7	4	
I	112	0.1	0.5	0.	0.	0.8	211	0.	0.3
K	.34	38	52	60	69	03	.68	87	93
2				0	9		0	7	
I	90.	0.1	0.4	0.	0.	0.6	171	0.	0.3
K	75	12	46	48	54	43	.51	70	18
3				5	6		8	7	
I	70.	0.0	0.3	0.	0.	0.4	132	0.	0.2
K	85	87	48	37	38	97	.95	55	48
4				6	8		8	0	
I	75.	0.0	0.3	0.	0.	0.5	141	0.	0.2
K	38	93	70	40	41	30	.18	58	64
5				0	8		8	6	

Table 3: Comparison of the findings from other locations with the present study.

Locations	U (Bq/kg)	Th (Bq/kg)	K (Bq/kg)	DR (nGy/h)	Detector	Reference
Kwara state,	10.64	6.61	711.26	55.56	NaI (TI)	Kanmi <i>et al.</i> , 2024
Osun state,	30.3	2.6	228.1	25.03	CsI (TI)	Esan <i>et al.</i> , 2022
Nassarawa, state	5.66	0.904	277.62	14.74	NaI (TI)	Mustapha <i>et al.</i> , 2024
Imo state,	23.32	38.72	146.03		NaI (TI)	Jibiri & Eke, 2022
Iraq	19.4	36.2	426.6		NaI (TI)	Jafir, 2023
Bangladesh	47.0	64.0	762.0	110.0	HP (Ge)	Dina <i>et al.</i> , 2022

Busphorous Istanbul	11.41	6.87	369.61		HP (Ge)	Isel <i>et al.</i> , 2023
Lagos state	10.99	11.20	19.38	12.50	HP (Ge)	Adedokun <i>et al.</i> , 2022
Turkey	599.40	4.61	29.66		HP (Ge)	Yamcier & Yacer, 2024
Pakistan	35.6	47.0	9.770	81.4	HP (Ge)	Azeem <i>et al.</i> , 2024
Ondo & Ekiti	18.80	35.61	1292.04	86.06	NaI (TI)	Present study

3 CONCLUSION

Twenty soil samples in the agricultural farmland surrounding selected four quarry sites in Ondo and Ekiti state southwest Nigeria was assessed to measure the concentration of ²³⁸U, ²³²Th, ⁴⁰K using NaI (TI) detector and consequently estimated radiological parameters in order to determine the possible radiation effects to the workers at the quarry sites, the farmers and member of the public consuming the farm products. Analysis of the result revealed that among the three primordial radioelements assessed the concentration of ⁴⁰K was elevated above the norms. The estimated mean absorbed dose rate for the study locations was higher than the reference limit but comparable with the values reported from other locations. The indoor and outdoor annual effective dose and the excess lifetime cancer risk were above the world limit predisposing the workers at the mining site, the farmer cultivating around the quarry sites and the members of the public consuming the farm product at the risk of exposure to ionizing radiation above the threshold. There is the need for protective shielded materials for the workers in the quarry sites and awareness of radiation risks to the farmers and members of the public around the quarry sites. Constant monitoring of the quarry sites in the study locations most especially the Aaye quarry site is essential to mitigate the possible exposure to the member of the public.

Author Contribution

RO Morakinyo: Sample collection and preparation, methodology, data analysis, result interpretation, manuscript draft writing; MR Usikalu Conceptualization, methodology, investigation, formal analysis, content review and editing, supervision; TA Adagunodo: Methodology, investigation, content review, co-

supervision; OF Ojo: Methodology, data analysis, result interpretation.

Data Availability: The radiometric data collected for the analysis can be made available upon request from the corresponding author.

Conflict of Interest: The authors declare no conflict of interest.

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REFERENCE

- Adedokun, M. B., Aweda, M. A., Maleka, P. P., Obed, R. I., & Ibitoye, A. Z. (2022). Evaluation of natural radioelements and associated radiation hazard indices in soil and water from selected vegetable farmlands in Lagos, Nigeria. *Environmental Forensics*, 23(3-4), 301-313. DOI:10.1080/15275922.2020.1850557
- Amodu, F. R., Ben, F., Ben-Festus, B. N., Olawale, O. K., & Edaogbogun, G. O. (2024). Assessing Scalability of Natural Radioelements and Associated Risks in Soils from Gold Mining Areas in Iperindo, Southwestern Nigeria. *Mining, Metallurgy & Exploration*, 41(2), 925-935. doi:10.1007/s42461-024-00946-y
- Azeem, U., Younis, H., Mehboob, K., Ajaz, M., Ali, M., Hidayat, A., & Muhammad, W. (2024). Radioelement concentrations in agricultural soil and lifetime cancer risk due to gamma radioactivity in district Swabi, KPK, Pakistan. *Nuclear Engineering and Technology*, 56(1), 207-215. <https://doi.org/10.1016/j.net.2023.09.026>
- cheweozo, EO; Igwesi, DI. (2021). Investigation of gamma shielding and liquid permeability properties of kaolin for liquid radioactive waste management. *Applied. Radiation. Isotopes*. 176: 109908. <https://doi.org/10.1016/j.apradiso.2021.109908>
- Dina, N. T., Das, S. C., Kabir, M. Z., Rasul, M. G., Deeba, F., Rajib, M., ... & Ali, M. I. (2022). Natural radioactivity and its radiological implications from soils and rocks in Jaintiapur area, North-east Bangladesh. *Journal of Radioanalytical and Nuclear Chemistry*, 331(11), 4457-4468. <https://doi.org/10.1007/s.10967-022-08562-0>
- Echeweozo E. O; Agwu U, K. K; Ogada, J. C; Ike, P. O. (2024). Survey of Natural Radioactivity of Soil and Rock Samples and their Radiological Implications to Human Health in Ugwuele Quarry Mining Site, Uturu, Abia State, Nigeria. *Journal. Applied. Science. Environmental. Management*. 28 (2) 581-587. DOI:10.4314/jasem.U28i2.31
- Eke, B. C., Akomolafe, I. R., Ukewuihe, U. M., & Onyenegecha, C. P. (2024). Assessment of Radiation Hazard Indices Due to Natural Radioelements in Soil Samples from Imo State University, Owerri, Nigeria. *Environmental Health Insights*, 18, . doi:10.1177/11786302231224581
- Esan, D. T., Ajiboye, Y., Obed, R. I., Ojo, J., Adeola, M., & Sridhar, M. K. (2022). Measurement of natural radioactivity and assessment of radiological hazard indices of soil over the lithologic units in ile-Ife area, south-West Nigeria. *Environmental Health Insights*, 16, 11786302221100041.
- Hamed, Y., Ayadi, Y., Hadji, R., Ben Saad, A., Gentilucci, M., & Elaloui, E. (2024). Environmental Radioactivity, Ecotoxicology (238U, 232Th and 40K) and Potentially Toxic Elements in Water and Sediments from North Africa Dams. *Sustainability*, 16(2), 490. doi.org/10.3390/su16020490
- İsel, P., Sahin, L., Hafızoğlu, N., Ganioglu, E., & Mülâyim, A. (2023). Natural and artificial radioactive pollution in sediment and soil samples of the Bosphorus, Istanbul. *Environmental Science and Pollution Research*, 30(27), 70937-70949. <https://doi.org/10.1007/s11356-023-27455-7>
- Isinkaye, M. O., OlaOlorun, O. A., Chandrasekaran, A., Adekeye, A. S., Dada, T. E., Tamilarasi, A., ... & Sulieman, A. (2023). Quantification of radiological hazards associated with natural radionuclides in soil, granite and charnockite rocks at selected fields in Ekiti State, Nigeria. *Heliyon*, 9(11). <https://doi.org/10.1016/j.heliyon.2023e22451>
- Jafir, A. O. (2023). Investigation of radioactivity level in drinking water resources and soil samples collected from the Hawraman villages, Iraq. *Applied Radiation and Isotopes*, 194, 110665 <https://doi.org/10.1016/j.apradiso.2023.110665>
- Jibiri, N. N., & Eke, B. C. (2022). Radionuclide contents in soil, sediments and food samples, and incidences of cancer in oil producing localities in Imo State south-east Nigeria. *Journal of Radiation Research and Applied Sciences*, 15(2), 90-97. <https://doi.org/10.1016/j.jrras.2022.05.002>
- Joel, E. S., Olasehinde, P. I., Adagunodo, T. A., Omeje, M., Oha, I., Akinyemi, M. L., & Olawole, O. C. (2020). Geo-investigation on groundwater control in some parts of Ogun state using data from Shuttle Radar Topography Mission and vertical electrical soundings. *Heliyon*, 6(1). <https://doi.org/10.1016/j.heliyon.2020.e03327>
- Kanmi, A. S., Ibrahim, U., Goki, N. G., Rilwan, U., Sayyed, M. I., Maghrbi, Y., ... & Wais, T. Y. (2024). Assessment of natural radioactivity and its radiological risks in the soil of local government areas (Asa, Ilorin East, Ilorin South, Irepodun, Moro, and Oyun) in Kwara State, Nigeria. *Case Studies in Chemical and Environmental Engineering*, 101040. <https://doi.org/10.1016/j.cscee.2024.101040>
- Khyalia, B., Yadav, J., Kumar, N., Singh, B., Kaintura, S. S., Gautam, P. & Dalal, R. (2024). Estimation of radioelements in the soil samples from the uranium mining zone of Sikar, Rajasthan, India. *Journal of Radioanalytical and Nuclear Chemistry*, 1-12. <https://doi.org/10.1007/s10967-024-09386-w>
- Missimer TM, Teaf C, Maliva RG, Danley-Thomson A, Covert D, Hegy M. Natural Radiation in the Rocks, Soils, and Groundwater of Southern Florida with a Discussion on Potential Health Impacts. *Int J Environ Res Public Health*. 2019 May 21;16(10):1793. doi: 10.3390/ijerph16101793. PMID: 31117171; PMCID: PMC6572226.
- Mitra, P., Mishra, M. K., Reddy, G. P., Srivastava, S., Salunkhe, S. S., Kumari, A., ... & Kumar, A. V. (2023). Countrywide monitoring of absorbed dose rate in air due to outdoor natural gamma radiation in India. *Radiation Protection Dosimetry*, 199(12), 1336-1350.
- Morakinyo, R. O., Usikal, M. R., & Orosun, M. M. (2022, March). Evaluation of background radiation of Maryland School complex, Lagos, Nigeria. In *IOP Conference Series: Earth and Environmental Science* (Vol. 993, No. 1, p. 012015). Doi 10.1088/1755-1315/993/1/012015
- Morakinyo, R. O., Usikal, M. R., Adagunodo, T. A., Ojo, O. F., & Babarimisa, I. O. (2025, April). Qualitative Analysis of Background Radiation from 238U, 232Th and 40K in Selected Locations in Ekiti State using Aeroradiometry Data. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1492, No. 1, p. 012043). DOI 10.1088/1755-1315/1492/1/012043
- Mustapha, I. M., Aliyu, S. M., Okara, O. G., Mohammad, I. A., Adamu, U., Aisha, A. A., & Halimatu, A. S. (2024). Radioactivity Concentration Level of 238U, 232Th, and 40K in Soil Samples of some Abandon Mining Sites in Nasarawa, Nasarawa State, Nigeria. *Journal of Radiation and Nuclear. Applications*, 9, 59-68. <https://dx.doi.org/10.18576/jma/090110>
- Odelami, K. A., Oladipo, M. O. A., Onoja, M. A., Musa, Y., & Aremu, S. O. (2024). Assessment of radiological contamination due to

- gold mining in soil and food crops of Babban Tsauni, Gwagwalada, Nigeria. *Radiation Protection Dosimetry*, 200(20), 1961-1970. <https://doi.org/10.1093/rpd/ncae207>
- Ofomola, O. M., Ugbede, F. O., & Anomohanran, O. (2023). Environmental risk assessment of background radiation, natural radioactivity and toxic elements in rocks and soils of Nkalagu quarry, Southeastern Nigeria. *Journal of Hazardous Materials Advances*, 10, 100288. <https://doi.org/10.1016/j.hazadv.2023.100288>
- Oladapo, O. O., Adagunodo, T. A., Aremu, A. A., Oni, O. M., & Adewoye, A. O. (2022). Evaluation of soil-gas radon concentrations from different geological units with varying strata in a crystalline basement complex of southwestern Nigeria. *Environmental Monitoring and Assessment*, 194(7), 486. <https://doi.org/10.1007/s10661-022-10173-x>
- Oladejo, O. F., Olukotun, S. F., Rufai, A. B., & Mathuthu, M. (2025). Assessment of radiation hazards from natural radionuclide activity in quarry sites and surrounding soils in Osun State, Southwest Nigeria. *Scientific Reports*, 15(1), 1-13. <https://doi.org/10.1038/s41598-025-02239-w>
- Regassa, T. N., Raba, G. A., Chekol, B. M., & Kpeglo, D. O. (2023). Assessment of natural radioactivity and associated radiological risks from soils of Hakim Gara quarry sites in Ethiopia. *Heliyon*, 9(9). <https://doi.org/10.1016/j.heliyon.2023.e19476>
- Simon, S. L., Kendall, G. M., Bouffler, S. D., & Little, M. P. (2022). The evidence for excess risk of cancer and non-cancer disease at low doses and dose rates. *Radiation research*, 198(6), 615- 624. <https://doi.org/10.1667/RADE-22-00132.1>
- Taalab, S. A., Hanfi, M. Y., Ahmed, M. S., Saadawi, D. A., Sakr, A. K., Khandaker, M. U., & Khattab, M. R. (2024). Geochemical evaluation and hazard indices due to radioactive minerals associated with granitic areas. *Nuclear Engineering and Technology*, 56(11), 4921-4928. <https://doi.org/10.1016/j.net.2024.08.027>
- Tiwari, S. N., Raj, S. S., Kumar, D., & Gocher, A. K. (2024). Assessment of Radionuclide Transfer in Terrestrial Ecosystem. In *Handbook on Radiation Environment, Volume 1: Sources, Applications and Policies* (pp. 121-159). Singapore: Springer Nature Singapore doi.org/10.1007/978-981-97-2795-7
- United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR, 2000) Sources and Effects of Ionizing Radiation. Report Vol 1 to the General Assembly Annex B, (2000): *United Nations Sales Publications United Nations*, New York.
- Usikalu, M. R., Morakinyo, R. O., Orosun, M. M., & Achuka, J. A. (2023). Assessment of background radiation in Ojota chemical market, Lagos, Nigeria. *Journal of Hazardous, Toxic, and Radioactive Waste*, 27(1), 04022041. Doi 10.1061(ASCE)HZ.2153-5515.0000732
- Yamçıçer, S., & Yaşar, D. (2024). Determination of natural and artificial radioactivity levels and radiation hazard indices for soil samples in Kırşehir. *Radiochimica Acta*, 112(1), 53-61. <https://doi.org/10.1515/ract-2023-0215>
- Yang, J., & Sun, Y. (2022). Natural radioactivity and dose assessment in surface soil from Guangdong, a high background radiation province in China. *Journal of Radiation Research and Applied Sciences*, 15(1), 145-151. <https://doi.org/10.1016/j.jrras.2022.01.019>