SSRG International Journal of Applied Physics
ISSN: 2350-0301/ https://doi.org/10.14445/23500301/IJAP-V11I3P102

Volume 11 Issue 3, 5-13, Sep-Dec 2024

Original Article

A Comparative Analysis of Dumpsite and Surface Soil Samples in Gboko Metropolis

Ayaakaa, D. T.[1*], Akaagerger N. B[1], Shiada S. M.[1], Enape M. O.[1], Nyiyongo E. S.[2], Ikum J. I[1].

[1]*Department of Physics, Benue State University, Makurdi-Nigeria, PMB 102119.*
[2]*Department of Physics, University of Mkar, Mkar-Nigeria, PMB 017 Gboko.*

[*]*Corresponding Author : ayakadalton@gmail.com*

Received: 05 September 2024 Revised: 12 October 2024 Accepted: 30 October 2024 Published: 15 November 2024

Abstract *- Comparative analysis of dumpsite and surface soil samples in Gboko metropolis. This project deploys the method of using a reduction factor to reduce the value of the raw data. The values of 40K range from 2.39 to 2.79 Bq/Kg from Benue Cement Company (Dangote Cement Plant) to Gboko Polytechnic for surface soil samples and dumpsites values of 10.20 to 17.58 Bq/Kg from Adekaa Market to Mechanic Site (New Road) respectively. 238U and 235U values range from 1.57 to 2.49 Bq/Kg and 2.03 to 4.13 Bq/Kg in Gboko East to Akperan Orshi and Mkar to Hausa Quarters, respectively. The values of 232Th are higher in surface soil than dumpsite, ranging from 2.41 to 4.72 Bq/Kg from Benue Cement to Mkar Hill and 1.01 to 1.57 Bq/Kg dumpsites from Rice Mill to Adekaa, respectively. The absorbed dose rate value was 6.96 to 10.29 nGy/h for Gboko East and 15.06 nGy/h to 22.82 nGy/h for Adekaa Market and Mechanical Site for dumpsites, respectively. The annual effective dose ranges from 0.008 to 0.012 mSv/y in Gboko East and Gboko Polytechnic, respectively, for surface soil and 0.018 to 0.027 mSv/y for dumpsites samples. The internal hazard values range from 0.049 to 0.073 from Gboko East to Gboko Polytechnic for surface soil samples with a mean value of 0.061, and dumpsites values range from 0.099 to 0.129 in Adekaa Market to Akaajime respectively and the mean value of 0.123. All the values are lower than the world average value of 370 Bq/Kg, 51 nGy/h, 0.07 mSv/y and 1 for activity concentration, absorbed dose rate, annual effective dose and internal hazard. Despite these small exposures to radiation with continuous accumulation, they pose a health threat to humans.*

Keywords - *Surface soil, Gboko metropolis, New road, United Nations Industrial Development Organization, Soil sample.*

1. Introduction

Humans are constantly exposed to natural radiation arising from within and outside the earth. Exposure to ionizing radiation from natural sources occurs because of the Naturally Occurring Radioactive Materials (NORM) in the soil and rocks, cosmic rays entering the earth's atmosphere from outer space and internal exposure from radioactive elements through food, water and air. The natural terrestrial component is due to the radioactivity of members of the decay series of 238-Uranium (^{238}U) and 232-Thorium (^{232}Th) and non-series 40-Potassium (^{40}K) that are present in the environmental materials such as different types of rocks, soil and the building materials composed of them (Ibikunle, 2013). The major radionuclides of concern are potassium, uranium and thorium and their decay products, some of which, like radium and radon are intensely radioactive but occur in low concentrations. Most of these sources have been decreasing due to radioactive decay since the formation of the Earth (because no significant amount is currently transported to the Earth). Thus, the present activity on earth from uranium-238 is only half as much as it originally was because of its 4.5 billion year half-life and potassium-40 (half-life 1.25 billion years) is only at about 8% of original activity (Mokobia *et al.,* 2006).Industrialization and population increment in most cities in Nigeria result in changing the composition and quality of waste generated, as this can be seen in most cities of developing countries United Nations Industrial Development Organization (UNIDO, 2021). Soil from waste dumpsites may contain significant amounts of heavy metals and naturally occurring radionuclides (Faweya and Babalola, 2010). Hazardous waste can cause and has caused pollution, damage to health and even death. The external radiation exposure pathways to the population have been extensively studied (Ramli, Hussein and Wood, 2005; Jibiri and Adewuyi, 2008). Several studies in Nigeria have measured the activity concentration of natural radionuclides in the soil to ascertain the levels of contamination (Oresegun and Babalola, 1990; Obed, Farai and Jibiri, 2005; Jibiri and Esen, 2011; Ademola and Farai, 2006; Ademola and Obed, 2012). Ayaakaa, Sombo and Utah., (2016) reported that the activity concentrations of some radionuclides in soil samples collected from10 locations in the Gboko local government of Benue State have been determined using the Gamma-ray Spectroscopy (Model No: 3M3/3). The soil activity ranges from 58.88 to 64.49Bq/Kg for

40K, 3.33 to 5.31Bq/Kg for 236U and 4.66 to 8.25Bq/Kg for 232Th, respectively, for the urban areas. In the rural areas, the activity concentration ranges from 55.42 to 66.26Bq/Kg for 40K, 3.77 to 5.55Bq/Kg for 238U and 4.21 to 10.02Bq/Kg for 232Th, respectively. The mean absorbed dose rate in air ranges from 6.78nGy/h in Gboko-East to 9.37nGy/h in Mkar - Hill while the annual effective dose for the same areas varied from 0.01mSv/y in three sites to 0.01mSv/y in Mkar - Hill. The estimated absorbed dose rate in air varied from 6.73nGy/h in BCC to 10.28nGy/h in Gboko Poly with annual absorbed dose of 0.01mSv/y in BCC to 0.03mSv/y in Ape - Inumbu. The results showed that the annual effective dose rate is much lower than the 0.1mSv/y maximum permissible limit recommended for humans by WHO (2009). It is also lower than the safe limit of 0.07mSv/y permitted by UNSCEAR (2009) for individual members of the public.

This research indicated that the samples' soil may not have been impacted radiologically. Akaagerger, Ikum and Ayaakaa (2023) studied activity concentrations of some radionuclides in dumpsites samples were collected from 8 selected locations in Gboko, selected locations each in Makurdi and Otukpo metropolis respectively of Benue State have been determined using the Gamma-ray Spectroscopy (model T35240K). The soil activity from Gboko ranges from 13.10±0.25 Bq/Kg to 22.56±0.32 Bq/Kg for 40K, 0.35±0.00 Bq/Kg to0.71±0.00 Bq/Kg for 238U and 0.12±0.00 Bq/Kg to 1.20±0.00 Bq/Kg for 232Threspectively with a mean value of 19.15±0.29Bq/Kg for 40K, with the mean value of0.60±0.00 Bq/Kg for 238U, and with the mean value of 0.14±0.00Bq/Kg for 232Threspectively in Gboko. The soil activity from Makurdi ranges from 12.88±0.24Bq/Kg to 22.23±0.32 Bq/Kg for 40K, 0.37±0.00 Bq/Kg to 0.66±0.00 Bq/Kg for 238Uand 0.09±0.00 Bq/Kg to 0.21±0.00 Bq/Kg for 232Th respectively with the mean value of 18.76±0.29Bq/Kg for 40K, mean value of 0.52±0.00 Bq/Kg for238U and with mean value of 0.15±0.00 Bq/Kg for 232Th respectively in Makurdi.

The soil activity from Otukpo ranges from 10.42±0.22 Bq/Kg to 23.59±0.33 Bq/Kg for 40K,0.41±0.00 Bq/Kg to 0.68±0.00 Bq/Kg for 238U and 0.14±0.00 Bq/Kg to 0.20±0.00Bq/Kg for 232Th with the mean value of 17.86±0.36 Bq/Kg for 40K, with the mean value of 0.54±0.00 Bq/Kg for 238U and with the mean value of 0.17±0.00 Bq/Kg for232Th respectively in Otukpo. The mean absorbed dose rate in air from Gboko ranges from 0.91±0.00 nGyhr −1 to 1.35±0.00 nGyhr −1, the mean absorbed dose rate in air from Makurdi ranges from 0.80±0.00 nGyhr −1 to 1.17±0.00nGyhr −1andthe mean absorbed dose rate in air from Otukpo ranges from 0.74±0.00nGyhr −1 to1.28±0.00nGyhr −1while the annual effective dose for Gboko varied from0.0011±0.00 mSvy −1 to 0.0016±0.00 mSvy −1, the annual effective dose for Makurdi varied from 0.0009±0.00 mSvy −1 to 0.0016±0.00 mSvy −1 and for Otukpo varied from 0.0009±0.00mSvy −1 to 0.0015±0.00 mSvy −1. The results showed that the dose rate is lower than the safe limit of 0.07mSv/y permitted by UNSCEAR for individual members of the public. This research indicated that the sample soil may not have been impacted by high radiological risk. Bello, Najib, Umar and Ibrahim (2015) undertook measurement of natural radioactivity concentration at an E-waste dumpsite around the Alaba international market in Lagos, Nigeria, and it was assessed by gamma-ray spectroscopy using a highly shielded Canberra NaI (Tl) detector.

Twenty soil samples from the e-waste dumpsite were analyzed while a total of fifteen soil samples from control sites in Ibadan were equally analyzed. The mean value of 226_R, $232_{Th}$and 40_K concentrations for the soil samples were 84.26 ± 28.08 Bq/kg, 20.70 ± 0.21 Bq/kg, and 13.32 ± 12.86 Bq/kg, respectively. The mean value of 226_R, $232_{Th}$and 40_K concentrations for soil samples from Oritaperin control dumpsite were 488.91 ± 217.24 Bq/kg, 27.93 ± 10.52 Bq/kg, and 44.93 ± 7.24 Bq/kg respectively while that of ring road control dumpsite were 405.89 ± 75.79 Bq/kg, 35.10 ± 10.97 Bq/kg, and 52.46 ± 7.29 Bq/kg respectively.

The mean values of 226_R, $232_{Th}$and 40_K obtained were below that from the control sites and are much lower than the world average values of 400 Bq/kg, 35 Bq/kg and 30 Bq/kg, respectively, as indicated by NSCEAR. The mean Annual Effective Dose Rate obtained for soil samples from e-waste dumpsite, Oritaperin and ring road control dumpsites were respectively 0.03mSv/yr, 0.07mSv/yr, and 0.01mSv/yr. These are all below the limit of unity.

The mean absorbed dose rate of samples from e-waste dumpsite was 21.12nGy/hr, which is lower than the world average of 60nGy/hr. Values for other hazard indices were below the world average. Hence, e-waste does not pose any immediate radiological risk to the people working/living on the dumpsite, the international market and its environments. The objectives: To compare the surface soil and dumpsite samples with UNSCEAR (2000) threshold value 51 nGy/h for activity concentration, to Compare the absorbed dose rates in surface soil and dumpsites, to determine the one with the highest value of emission and to determine internal and external hazard.

2. Materials And Method

2.1. Analytical Method

The activity concentrations of ^{40}K, ^{238}U and ^{232}Th were measured using the gamma-ray spectroscopy method. The measuring system consists of a scintillation detector sealed with a photomultiplier tube and connected through a preamplifier base to a Canberra series 10-plus multi-channel analyzer (MCA). The detector is a 3cmx3cm NaI (TI) (Model NO. 3M3/3). The detector has a resolution of about 8% at 0.662meV of 137Cs. The detection energy calibrations of the system were carried out using a reference standard source prepared by the Radiochemical Centre, Amersham, England.

Table 1. Sampling locations and their coordinates for surface soil samples

S/No	Location	Latitude/ Longitude
1	Akperan-Orshi Coll. Of Agric	N7˚8'16"/E8˚37'46"
2	G. R. A	N7˚48'28"/E9˚54'0"
3	Fidei-poly	N7˚29'54"/E8˚7'24"
4	Mkar Hill	N7˚24'3"/E8˚58'1"
5	Gboko Main Market	N7˚15'27"/E8˚30'43"
6	Gboko East	N7˚23'34"/E8˚51'2"
7	Gboko-poly	N7˚33'18"/E8˚0'49"
8	Gboko Hill	N7˚21'8"/E8˚29'35"
9	Benue Cement Company	N7˚34'13"/E8˚35'47"

Table 2. Locations and their coordinates in Makurdi town dumpsites

S/No	Location	Latitude/Longitude
1	Gboko south	7.3100/9.0073
2	Mkar	7.3213/9.0419
3	Adekaa	7.3446/9.0009
4	GRA	7.3362/8.9985
5	Hausa quarters	7.2040/9.0003
6	New road	7.2954/8.7024
7	Akaajime	7.2532/8.4352
8	Rice mill	7.3089/8.9767

The 1.460MeV photopeak was used for the measurement of ^{40}K, while the 1.120MeV photopeak from ^{214}Bi and the 0.911MeV photopeak from ^{288}Ac were used for the measurement of ^{238}U and ^{232}Th, respectively. Each of the samples was counted for 25200 seconds (Ayaakaa *et al.,* 2016; Ayaakaa *et al.,* 2018; Akaagerger *et al.,* 2023).

2.1.1. Absorbed Dose Rate (D_a)

The total absorbed rate in the air (nGy h^{-1}) at 1 m above the ground due to the activity concentration of 238U, 232Th, and 40K was calculated using the formula (UNSCEAR, 2000). We assumed here that the contribution from other naturally occurring radionuclides and cosmic radiation at the locations were insignificant. Where D is the dose rate (nGy h-1) at 1 m above the ground due to 238U, 232Th, and 40K in the soil sample. A_U, A_{Th}, and A_K are the activity concentrations of 232U, 232Th, and 40K in Bqkg^{-1} and reduction factor of 12.3, 15.4 and 18.5 for U, Th and K, respectively (Ayaakaa *et al.*, 2018).

$$D_a = 0.470A_U + 0.572A_{Th} + 0.0421A_K \quad (1)$$

2.1.2. Annual Effective Dose

In estimating the outdoor effective dose equivalent in any environment, we consider two important factors – the conversion factor from Gyh^{-1} to Svh^{-1} and the outdoor occupancy factor. While the first important gives the human dose equivalent (Svh^{-1}) from the absorbed dose rate in the air (Gyh^{-1}), the second gives the fraction of the time that an individual is exposed to outdoor radiation. The occupancy factor depends on the living style of the people, which is not the same in rural and urban areas. Hence, the rural resident spends more time outdoors than urban residents then, with an outdoor occupancy factor of 0.2 for urban and rural dwellers 0.3 (about 8h out of 24h of the day.) for both rural and urban dwellers respectively, with a conversion factor of 0.7Sv Gy^{-1}, then, the annual outdoor effective dose equivalent is given as., (Ajayi and Ibikunle., 2000) and with background reduction factors of 12.3, 15.4 and 18.5 for Uranium-238, Thorium-232 and Potassium, respectively (Avwiri and Ononugbo, 2012).

$$A_e(\text{mSv/y}) = D_a(\text{nGy/h}) \times O_f \times 8760 \times C_f \times 10^{-6} \quad (2)$$

2.1.3. Radium Equivalent Activity and Internal Hazard Index

It is important to assess the gamma radiation hazards to humans associated with the use of the soil from the site for filling or use in construction. Radium equivalent activity (Raeq) was calculated in this study because it gives a single index to describe the gamma output from different mixtures of radium, thorium, and potassium in the samples (Berekta and Mathew, 1985; Yang *et al.*, 2005). Where A_U, A_{Th} and A_K are the activity concentrations in Bqkg-1 of 238U, 232Th, and 40K respectively. The radiation hazard due to internal exposure from radon and its short-lived decay products to the respiratory organs can be estimated using the following formula:

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \quad (3)$$

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (4)$$

With the accepted value of 1

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

Where H_{in} is the inter-hazard index and A_U, A_{Th}, and A_K are the activity concentrations in Bqkg^{-1} of 238U, 232Th, and 40K, respectively

Table 3. Activity concentration of ^{238}U, ^{232}Th and ^{40}K Bqkg^{-1} in Gboko Surface Soil

Sites	40_K	238_U	232_{Th}
Akperan Orshi	2.55	2.49	3.62
GRA	2.48	2.27	2.72
Fidei Poly.	2.70	2.24	4.06
Mkar Hill	2. 49	2.18	4.72
Gboko Mkt	2.57	1.85	2.92
Gboko East	2.72	1.57	2.67
Gboko Poly.	2.79	1.77	5.73
Dangote Cement	2.39	1.91	2.41
Mean	2.59	2.04	3.61
Range	2.39 – 2.79	1.57 – 2.49	2.41 – 4.72

Table 4. The absorbed dose rate, annual effective dose, internal and external index hazard surface soil in Gboko

Sites	Internal hazard index (H_{in})	External hazard index(H_{ex})	$D_a(n\text{Gyhr}^{-1})$	$D_e(m\text{Svy}^{-1})$
Akperan Orshi	0.066	0.051	8.67	0.010
GRA	0.057	0.049	7.47	0.009
Fidei Poly.	0.066	0.054	8.99	0.011
Mkar Hill	0.069	0.057	9.39	0.011
Gboko Mkt	0.054	0.043	7.34	0.009
Gboko East	0.049	0.041	6.96	0.008
Gboko Poly.	0.073	0.063	10.29	0.012
Dangote Cement	0.050	0.039	6.72	0.008
Mean	0.061	0.049	8.23	0.009
Range	0.049 – 0.073	0.039 – 0.063	6.72 – 10.29	0.008 – 0.012

Table 5. Activity Concentration of ^{235}U, ^{232}Th and ^{40}K Bqkg^{-1} in Bqkg^{-1} Gboko Dumpsites

Sites	40_K	235_U	232_{Th}
Gboko South	15.73	3.17	1.12
Mkar	17.14	2.03	1.45
Adekaa	10.20	3.29	1.57
GRA	14.88	3.60	1.23
Hausa quarters	13.58	4.13	1.49
Mechanical Site	17.58	3.86	1.38
Akaajime	15.25	3.86	1.43
Rice mill	14.99	4.05	1.01
Mean	14.92	3.49	1.34
Range	10.20 – 17.58	2.03 – 4.13	1.01 – 1.57

Table 6. The absorbed dose rate, annual effective dose, and internal and external index hazard in Gboko Dumpsites

Sites	Internal hazard index (H_{in})	External hazard index(H_{ex})	$D_a(n\text{Gyhr}^{-1})$	$D_e(m\text{Svy}^{-1})$
Gboko South	0.123	0.103	20.02	0.024
Mkar	0.118	0.106	20.62	0.025
Adekaa	0.099	0.079	15.06	0.018
GRA	0.123	0.103	19.71	0.024
Hausa quarters	0.123	0.101	19.20	0.023
Mechanical Site	0.141	0.188	22.82	0.027
Akaajime	0.129	0.107	20.54	0.025
Rice mill	0.127	0.104	20.05	0.024
Mean	0.123	0.111	19.75	0.024
Range	0.099 – 0.129	0.079 – 0.188	15.06 - 22.82	0.18 – 0.027

3. Discussion of Results

The values of Tables 3 and 5 show that the activity concentration of 40K is 2.39 in Benue Cement Company (Dangote Cement Plant) and higher with the value of 2.79 Bq/Kg in Gboko Polytechnic with a mean value of 2.59 Bq/Kg for surface soil. In contrast, the value of 40K for dumpsites is lower in the Adekaa market with a value of 10.20 Bq/Kg and higher with 17.58 Bq/Kg in Mechanic Site (New Road). This shows that there is more emission in dumpsites than in surface Soils.

The values are lower than the permissible values reported by UNSCEAR (2000) of 370 Bq/Kg. The values for surface soil samples are lower than dumpsites' values in all cases and lower than the values reported by (Augustine *et al.,* 2014; Oladapo, 2012). The value of 238 for surface soil samples is lower in Gboko East at 1.57 Bq/Kg and higher in Akperan Orshi with 2.49 Bq/Kg with a mean value of 2.04 Bq/Kg, while the value of 235U values shows Mkar has 2.03 and 4.13 Bq/Kg for Hausa Quarters with the mean value of 3.49 Bq/Kg. The values are all lower than the acceptable value of 33 Bq/kg reported by (Amadi *et al.,* 2012) and UNSCEAR (2000).

The values of 232Th for surface soil samples and dumpsites are found to be lower in Benue Cement Company (Dangote Cement Plant) at 2.41 Bq/Kg and higher I Mkar with 4.72 Bq/Kg with a mean value of 3.61 Bq/Kg. In comparison, activity concentration of 232Th in dumpsites is lower in Rice Mill with 1.01 Bq/Kg and higher in Adekaa Market with a value of 1.57 Bq/Kg with mean value of 1.34 Bq/Kg and lower than world value of 45Bq/kg reported UNSCEAR (2000) and lower than the values reported by (Ajayi *et al*., 2013; Oludosede *et al.,* 2012). The values of surface soil samples are higher than the values for dumpsites reported in Table 4.2. This may be a result of hydrolysis products in the soil (*Harmsen and de Haan*., 1980).

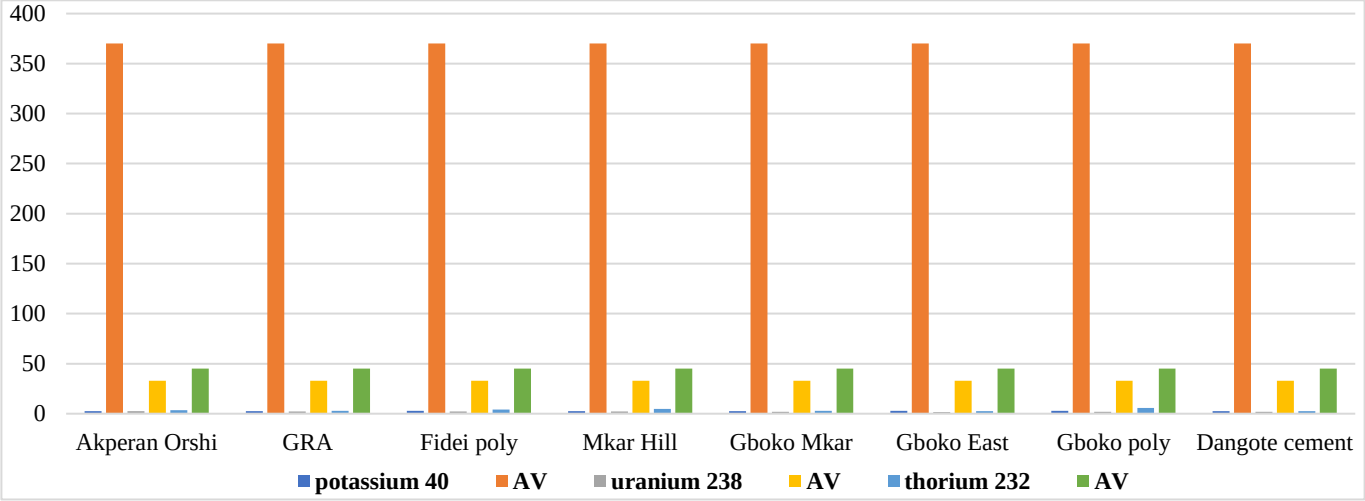

Fig. 1 Activity concentration for surface soil

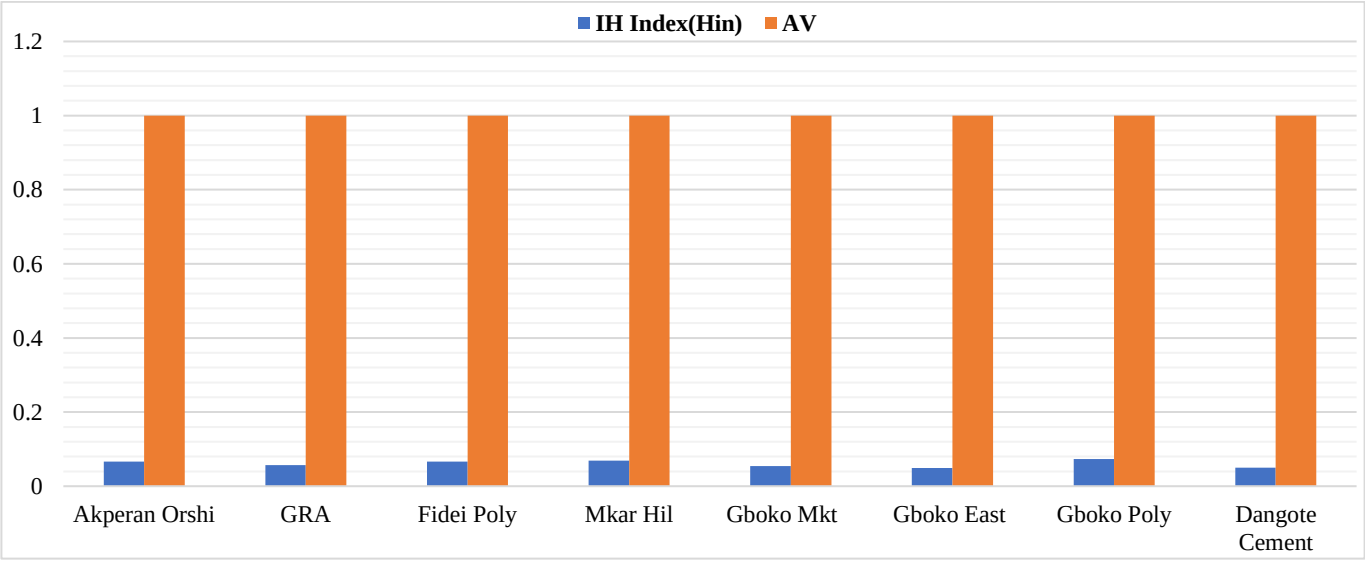

Fig. 2 Internal hazard index for surface soil

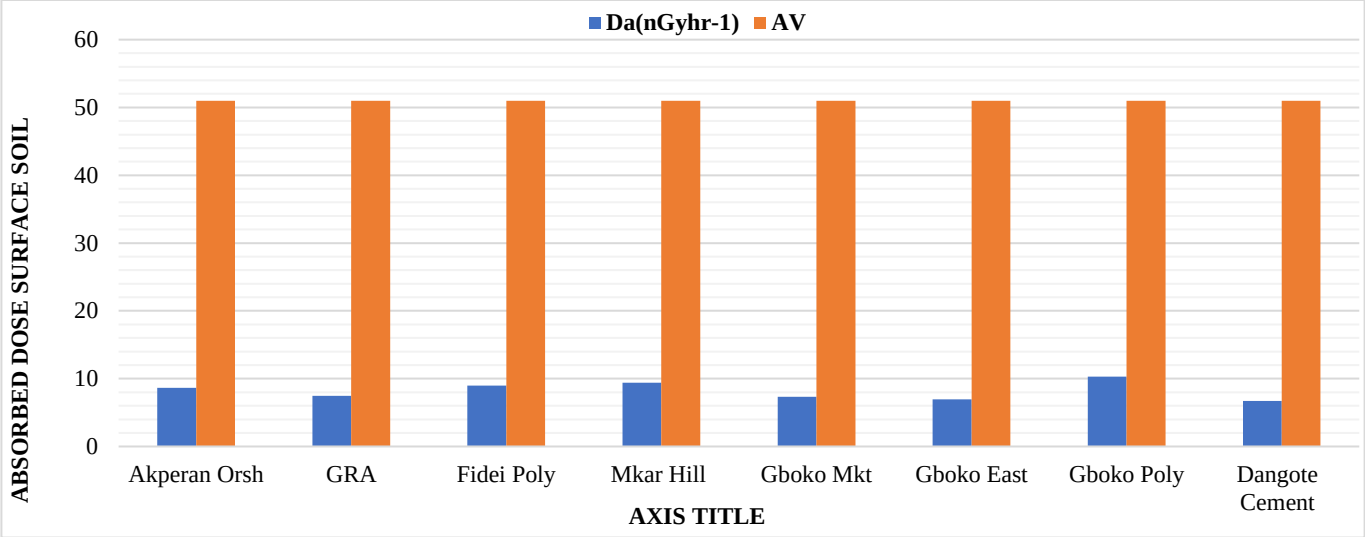

Fig. 3 Absorbed dose rate for surface soil

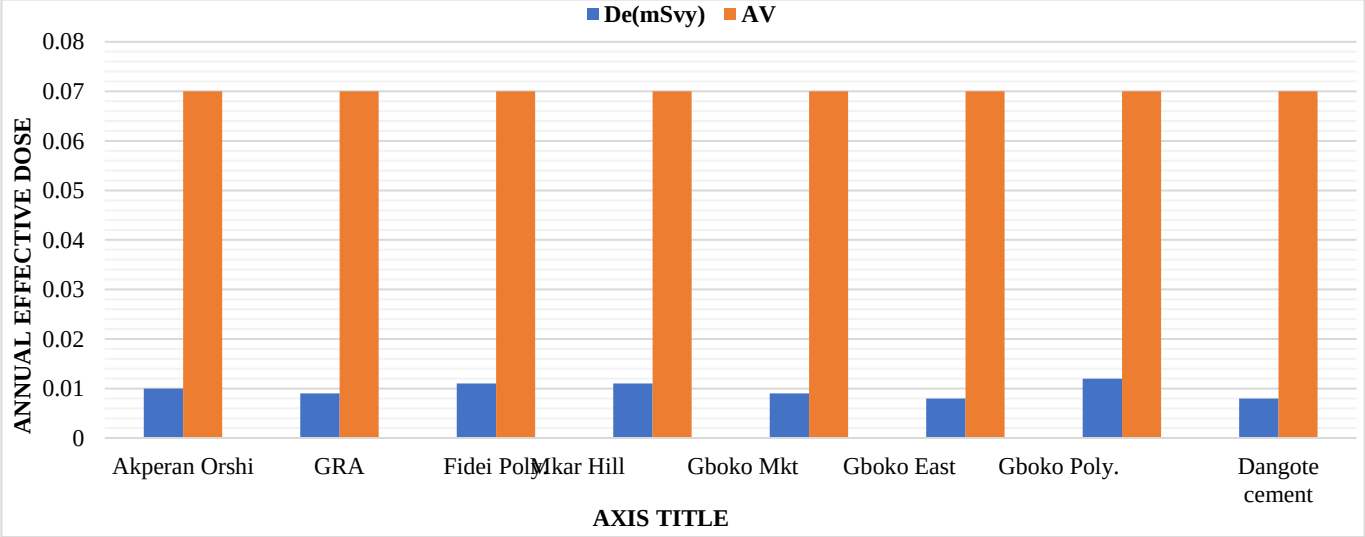

Fig. 4 Annual effective dose rate for surface soil

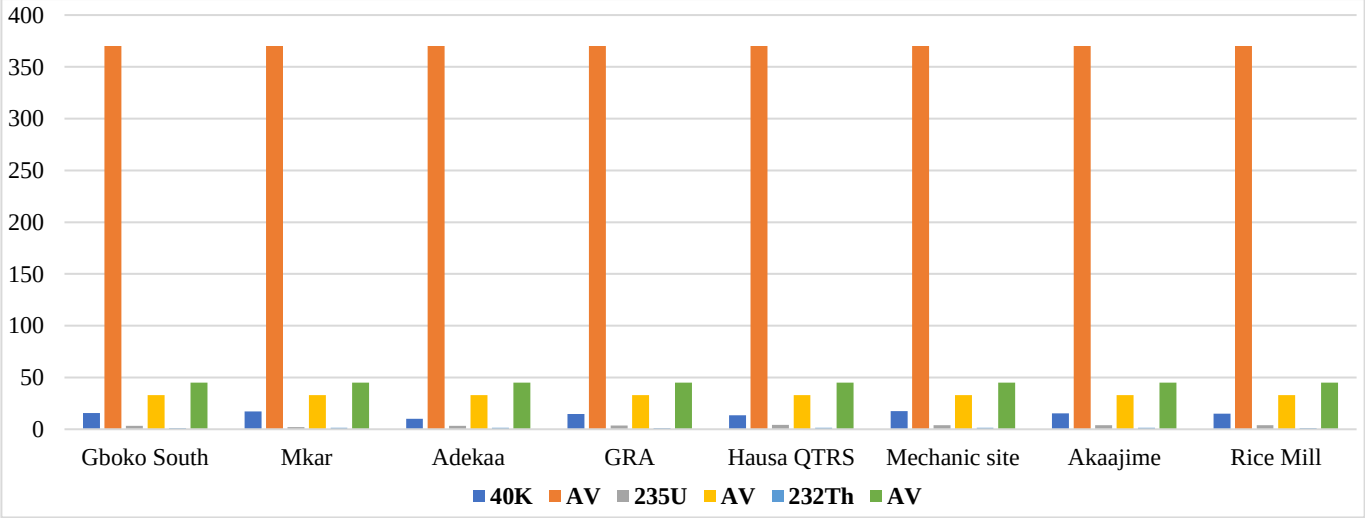

Fig. 5 Activity concentration for dumpsite

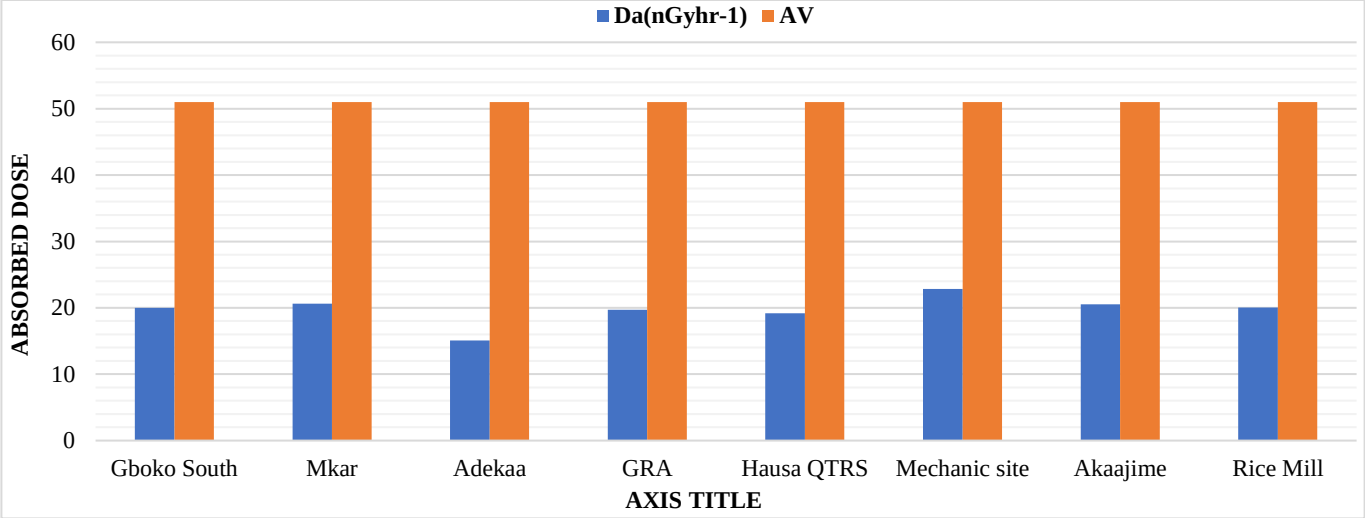

Fig. 6 Absorbed dose rate for dumpsite

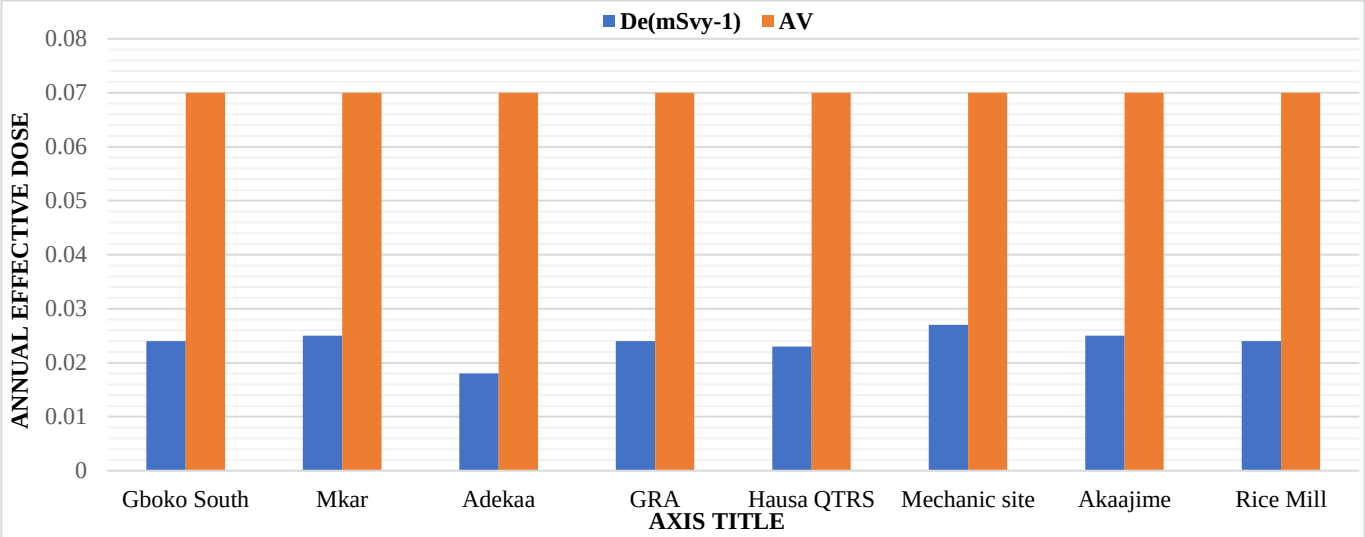

Fig. 7 Annual effective dose rate for dumpsite

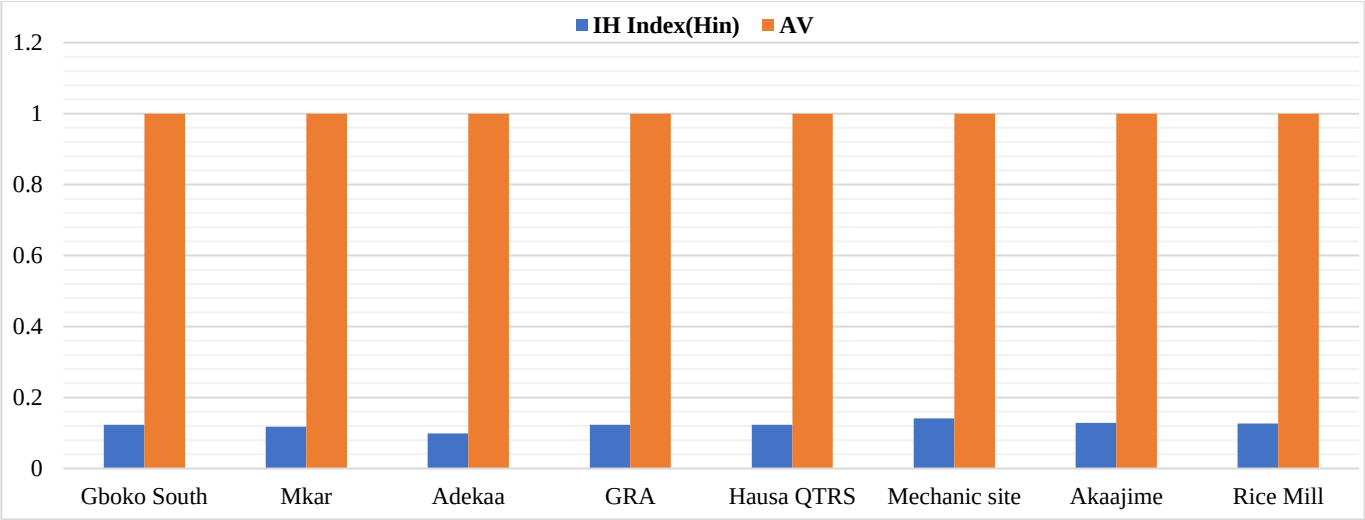

Fig. 8 Internal hazard index for dumpsite

3.1. Absorb Dose Rates in Air (D_a)

The absorb dose value of 6.96 nGy/h in Gboko East was found to be lower and 10.29 nGy/h in Gboko Polytechnic higher with a mean value of 8.23 nGy/h for surface soil, while the dumpsites soil samples values ranged from 15.06 nGy/h in Adekaa Market lower and higher in Mechanic Site (New Road) 22.82 nGy/h with mean value of 19.75 nGy/h which are higher than the values reported in Table 4.2 for surface soil samples but lower than the average value of 51 nGy/h reported by UNSCEAR (2000) for 1 m and lower than the value reported by (Augustine *et al.,* 2014)

3.2. Annual Effective Dose (D_e)

The values here from Benue Cement Company and Gboko East are lower with a value of 0.008 mSv/y and higher in Gboko Polytechnic at 0.012 mSv/y with a mean value of 0.009 mSv/y for surface soil samples while the dumpsites values range from 0.018 in Adekaa Market to be 0.027 mSv/y in Mechanical Site. The dumpsites values are higher than the surface soil samples but lower than the world average value of 0.07 mSv/y reported by UNSCEAR (2000), and the values are lower than the values reported by (Augustine *et al.,* 2014; Ajayi *et al*., 2013).

3.3. Internal Hazard (H_{In})

The values of internal hazard in surface soil samples are lower in Gboko East, with a value of 0.049 lower and higher in Gboko Polytechnic, with 0.073 with a mean value of 0.061, while the dumpsites values are higher, ranging from 0.099 Adekaa Market to Akaajime with a value of 0.129 and mean value of 0.123. Although the values are lower than the world acceptable value of 1 by UNSCEAR (2000) and are also lower than the values reported by (Murthy and Karunakara, 2008; Augustine *et al.,* 2014

4. Conclusion

Comparative analysis of dumpsite and surface soil plays an important role in determining the highest value of emission from both soil samples. In this research, an experimental approach was used to determine the level of emission, the Absorbed Dose rate (D_a), the Annual Effective Dose, Radium Equivalent activity and the internal hazard index of the soils. Eight dumpsites' soils and eight surface soil samples were used for the comparison. The values in Tables 3 and 5 reveal that there is more emission in dumpsite than in surface soil. The values of surface soil samples are higher than the values for dumpsites reported in Table 4. This may be a result of hydrolysis products in the soil. Despite small radiation exposure, continuous accumulation poses a health threat to humans. Therefore, soil samples should be analyzed before building houses or cultivating them to avoid consuming them. The government should discourage the use of dumpsites that are close to dwellers, and continuous sanitation should be employed.

Contributions

All authors read and approved the manuscript. Experiment conducted. ADT, IJI and ANB; methodology, ADT, EMO, and SSM; analyzing, ADT, EMO, and ANB; investigation, ADT, ANB; resources, ANB, ADT, EMO, and NES; data collection, ADT, IJI; writing—original draft preparation, ADT, EMO; writing—review and editing, ADT, and ANB; supervision, ANB All authors have read and approved of the published version of the manuscript.

References

[1] A.K. Ademola, and R.I. Obed, "Gamma Radioactivity Levels and their Corresponding External Exposure of Soil Samples from Tantalite Mining Areas in Oke-Ogun, South-Western Nigeria," *Radioprotection,* vol. 47, no. 2, pp. 243-252, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[2] J.A. Ademola, and I.P. Farai, "Gamma Activity and Radiation Dose in Concrete Building Blocks Used for Construction of Dwellings in Jos, Nigeria," *Radiation Protection Dosimetry,* vol. 121, no. 4, pp. 395-398, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[3] O.S. Ajayi, and S.B. Ibikunle, "Radioactivity of Surface Soils from Oyo State, Southwestern Nigeria," *International Journal of* Radiation Research, vol. 11, no. 4, pp. 271-278, 2013. [Google Scholar] [Publisher Link]

[4] O.S. Ajayi, "Environmental Gamma Radiation Indoors at Akure, Southwestern Nigeria," Journal of Environmental Radioactivity, vol. 50, no. 3, pp. 263-266, 2000. [CrossRef] [Google Scholar] [Publisher Link]

[5] N.B. Akaagerger, I.J. Ikum, and D.T. Ayaakaa, "Evaluation of Natural Radionuclides in Selected Dumpsites in Gboko, Makurdi and Otukpo Towns of Benue State North Central Nigeria," *Nigerian Journal of Physics,* vol. 32, no. 4, pp. 130-138, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[6] M.K. Akintoye, and J.B. Olomo, "The Radioactivity in Some Grasses in the Environment of Nuclear Research Facilities Located within the Oau Ile-Ife, Nigeria," *Nigerian Journal of Physics,* vol. 17, no. 2, pp. 219-225, 2007. [Google Scholar] [Publisher Link]

[7] A.N. Amadi et al., "A Comparative Study on the Impact of Avu and Ihie Dumpsites on Soil Quality in Nigeria," *American Journal of Chemistry,* vol. 2, no. 1, pp. 17-23, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[8] Augustine Kolapo Ademola et al., "Assessments of Natural Radioactivity and Determination of Heavy Metals in Soil Around Industrial Dumpsites in Sango-Ota, Ogun State, Nigeria," *Journal of Medical Physics,* vol. 39, no. 2, pp. 106-111, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[9] G.O. Avwiri, and C.P. Ononugbo, "Natural Radioactivity Levels in Surface Soil of Ogba/Egbema/ndoni Oil and Gas Fields Energy Science and Technology," *Energy Science and Technology,* vol. 4, no. 2, pp. 92-101, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[10] J. Berekta, and P.J. Mathew, "Natural Radioactivity in Australian Building Materials, Industrial Waste and by-Products," *Health Physics*, vol. 48, no. 1, pp. 87-95, 1985. [CrossRef] [Google Scholar] [Publisher Link]

[11] I.A. Bello et al., "Measurement of Natural Radioactivity Concentration at E-waste Dumpsite Around Alaba International Market Lagos, Nigeria," *Advances in Applied Science Research*, vol. 6 no. 6, pp. 55-64, 2015. [Google Scholar] [Publisher Link]

[12] E.B. Faweya, and I.A. Babalola, "Radiological Safety Assessment and Occurrence of Heavy Metals in Soil from Designated Waste Dumpsites used for Building and Compositing in Southwestern Nigeria," *Arabian Journal for Science and Engineering*, vol. 35, no. 2, pp. 219-225, 2010. [Google Scholar] [Publisher Link]

[13] K. Harmsen, and F.A.M. De Haan, "Occurance and Behaviour of Uranium and Thorium in Soil and Water," *Netherlands Journal of Agricultural Science*, vol. 28, no. 1, pp. 40-62, 1980. [CrossRef] [Google Scholar] [Publisher Link]

[14] N.N. Jibiri, and N.U. Esen, "Radionuclide Contents and Radiological Risk to the Population Due to Raw Materials and Soil Samples From the Mining Sites of Quality Ceramic and Pottery Industries in Akwa Ibom, Nigeria," *Radioprotection*, vol. 46, no. 1, pp. 75-87, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[15] N.N. Jibiri, and G.O. Adewuyi, "Radionuclide Contents and Physico-Chemical Characterization of Solid Waste and Effluent Samples of Some Selected Industries in the City of Lagos, Nigeria," *Radioprotection*, vol. 43, no. 2, pp. 203-212, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[16] C.E. Mokobia et al., "Radioessay of Prominent Nigerian Fossil Fuels Using Gamma and TXRF Spectroscopy," *Fuel*, vol. 85, no. 12-13, pp. 1811-1814, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[17] V.R.K. Murty, and N. Karunakara, "Natural Radioactivity in the Soil Samples of Botswana," *Radiation Measurement*, vol. 43, no. 9-10, pp. 1541-1545, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[18] R.I. Obed, I.P. Farai, and N.N. Jibiri, "Population Dose Distribution Due to Soil Radioactivity Concentration Levels in 18 Cities across in Nigeria," *Journal of Radiological Protection*, vol. 25, no. 3, pp. 305-312, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[19] O.O. Oladapo et al., "Assessment of Natural Radionuclide Level in Wasteland Soil Around Olusosun Dumpsite Lagos, Nigeria," *IOSR Journal of Applied Physics*, vol. 2, no. 3, pp. 38-43, 2012. [Google Scholar] [Publisher Link]

[20] O. Olubosede, O.B. Akinnagbe, and O. Adekoya, "Assessment of Radiation Emission from Waste Dumpsites in Lagos State of Nigeria," *International Journal of Computational Engineering Research*, vol. 2 no. 3, pp. 806-811, 2012. [Google Scholar] [Publisher Link]

[21] M.O. Oresegun, and A.I. Babalola, "Occupational Radiation Exposure Associated with Milling of Th-U-Rich Sn ore in Nigeria," *Health Physics*, vol. 58, no. 2, pp. 213-215, 1990. [Google Scholar] [Publisher Link]

[22] A. Termizi Ramli, A. Wahab M.A. Hussein, and A. Khalik Wood, "Environmental ^{238}U and ^{232}Th Concentration Measurements in an Area of High-Level Natural Background Radiation at Palong, Johor, Malaysia," *Journal of Environmental Radioactivity*, vol. 80, no. 3, pp. 287-304, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[23] "*Sources and Effects of Ionizing Radiation*," United Nations Scientific Committee on the Effect of Atomic Radiation, pp. 1-659, 2000. [Google Scholar] [Publisher Link]

[24] "Industrial Environmental Policy and Strategy for Ethiopia," *United Nations Industrial Development Organization* (UNIDO, 2001), pp. 1-57, 2019. [Publisher Link]

[25] Ya-xin Yang et al., "Radioactivity Concentration in Soil of the Xinzhuang Granite Area, China," *Applied Radiation and Isotopes*, vol. 63, no. 2, pp. 255-259, 2005. [CrossRef] [Google Scholar] [Publisher Link]