

Determination of Soil Radioactivity and Radiological Hazard Indices in Nigeria: A Review

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ABSTRACT

Soils are used extensively for agricultural practice and as major mixing materials for building construction. Hence, there's a great need to review the activity and concentrations of natural radionuclide present in the soil in order to accurately assess the radiological health implications to the members of the public utilizing the soil in building constructions and Agricultural activities. It was reported in different literature that, the exposure to radiation emanated from natural radionuclide affect the respiratory track and radon with its decay products in the soils are the reason. Continuous absorption of the radionuclide in the soil imposed high risk health hazard to public such as cancer of the lung, hypokalemia, heart disease, mutation, and others. Therefore, it becomes very important to review and identify the region with high or low level of concentrations of radionuclide in the soil. This work aimed at reviewing the natural radionuclide levels in the soil samples collected from the Mining sites, Normal living, working, and non-living environments by different researchers and Scholars in Nigeria. The highest activity Concentration was reported in Ibadan, Ijoro, Bitsichi, Bakuru, Ropp, Odua and Oguta for ^{238}U , ^{226}Ra , ^{232}Th , and ^{40}K respectively, while the highest radiological hazard indices such as Absorbed Dose Rate, Annual Effective Dose, Radium equivalent and Excess Life Cancer Risk were recorded in Bitsichi, Oguta, Odua, Bitsichi, Oguta and Port Harcourt respectively. Similarly external, internal and gamma index were generally low compare to worldwide average value. Therefore, based on this review, it was figured out that some areas in Nigeria are radiologically unsafe for inhabitants.

Keywords: Radionuclide, Soils and Radiological hazard indices

INTRODUCTION

Natural radionuclide in the soil is essentially the major source of external gamma radiation; these include ^{235}U , ^{238}U , ^{226}Ra , ^{232}Th and ^{40}K . Each of these radionuclide contribute to the world average of the terrestrial gamma dose rate of 60nGy/h (i.e. ^{40}K contribute 13.8%, ^{232}Th contribute 14% and ^{226}Ra contribute 55.8%) (Tibor *et al.*, 2013). Additionally, alpha transformation of radium in the ^{232}Th produced radioactive noble gas such as ^{220}Rn and in ^{238}U chain generates ^{222}Rn . The radioactive species generated, contribute more than half to the effective dose an individual member of the population can receive from natural radioactive sources on the world wide average and they are the second major cause of lung cancer, soon after smoking cigarette (Augustine *et al.*, 2014). For these reasons, natural radioactivity in soil attracts attention of the researchers worldwide and systematic measurements of ^{40}K , ^{232}Th and ^{226}Ra have been performed in a number of countries. Due to the hazard associated with the exposure to these radionuclides and inhalation of the short-lived decay products of radon, international bodies and governmental organization such as International Commission on Radiological Protection and Environmental Protection Agency have adopted strong measures at minimizing such exposure (Augustine *et al.*, 2014). Considering natural radioactivity in Nigeria, a different research in living and working environments has been conducted over the years. As of recent, radionuclide such as, ^{40}K , ^{232}Th , ^{238}U , ^{226}Ra were analyzed in the soil samples from various parts of the country. (Tibor *et al.*, 2013). The literature in Nigeria

showed that studies on radionuclide concentrations in soil of mining sites have been extensively studied. The Mining activities in Nigeria have not been subjected to radiological regulatory control and so there is generally little or no awareness and knowledge of the radiological hazards and exposure levels to natural radionuclide in mining areas of Nigeria (Augustine *et al.*, 2014). The contribution of radiation from soil to human exposure can either be whole body due to external radiation originating directly from primordial radionuclides present in Environmental soil or internal due to inhalation (Isinkay and Emelue, 2015).

Radioactivity is part of the human physical environment. The earth we are living is naturally radioactive and about 90% of radiation exposure arises from natural sources such as cosmic radiation, exposure to radon gas and terrestrial radionuclide. Gamma rays are known to be highly penetrating and are part product of the radioactive materials containing radon gas that may be inhaled (or ingested) into the human body from the soil. Continuous absorption of these radon gas may have imposed high health risk of hazard to man such as, cancer of the lung, hypokalemia, heart disease, mutation, and others hence it becomes very important to investigate the background radiation level in our surface soils (Shittu *et al.*, 2015). No doubts that radionuclide in the soil poses serious contamination hazards. Therefore, assessment of its level in soils media provides useful information on potential unwanted radiation exposure to humans. The analysis is carried out on soil samples in order to assess the effects of natural

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radionuclides in the environment using different radiation detection techniques. This article reviews some of such studies with a view of gathering vital information on the recently used techniques, discusses current situations and gives highlights of recent findings.

MATERIALS AND METHODS

Soil Sample Preparation

The Soil samples collected by Nigerians researchers, scholars and students of different institutions were air dried at room temperature in different laboratories of Nigeria. The soil samples were then crushed and pulverized after which all are sieved by the used of 2mm mesh sizes. The samples were filled into Polyvinylchloride containers (PVC) which were then sealed with the aid of PVC tape to prevent the escape of airborne ²²²Rn and ²²⁰Rn from the samples (Shittu *et al.*, 2015). After the samples were prepared the empty containers were weighed to know the weight of the empty container and then when the sample was sealed into the container it was then weighed again to know the weight of empty container and soil sample, then to get the weight of sample you are to subtract the weight of the empty container from the weight of container plus sample. Radon and its short-lived progenies were allowed to reach secular radioactive equilibrium by storing the samples for certain days at ambient temperature prior to gamma spectroscopy measurements.

Evaluation of Radioactivity of Soil Samples

The analysis was done using NaI (TI) and HPGe detector coupled to photomultiplier tube. The detectors are enclosed in a lead shield with usually cadmium and copper sheets in order to minimize the effects of background and scattered radiation. The acquisition of data is done by the use of computer software. Each sample was measured for a certain period of time (Gyuk *et al.*, 2017). The activity concentrations were determined using the equation below:

$$C(\text{Bq/kg}) = \frac{C_n}{\epsilon P_y M_s} \dots \dots \dots (1)$$

Where C is the activity concentration (Bq/kg), C_n is the count under the photo peak, ε is the detection efficiency at the specific γ-ray energy, P_y is the absolute transition probability of the γ-ray and M_s is the mass of the sample (kg) (Ogunremi *et al.*, 2020).

Evaluation of Radiological Hazard Parameters

Absorbed gamma dose rate (D nGyh-1)

This refers to the amount of radiation energy absorbed or deposited per unit mass of substance. The absorbed gamma dose rates due to gamma radiations in air at 1 m above the ground surface for the uniform distribution of the naturally occurring radionuclides (238U, 232Th and 40K) were calculated based on the guidelines provided by united nation. To convert activity concentration to dose the following factors was used such as 0.462, 0.604 and 0.0417 for uranium (or Ra), thorium and potassium respectively (Ononugbo *et al.*, 2016).

$$\text{Absorbed dose (D) (nGyh}^{-1}\text{)} = 0.462C_U + 0.604C_{Th} + 0.0417C_K \dots \dots \dots (2)$$

But in terms of ²²⁶R the formula can be written as

$$\text{Absorbed dose (D) (nGyh}^{-1}\text{)} = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \dots \dots \dots (3)$$

Where C_u, C_{Ra}, C_{Th} and C_k are the activity concentrations of 40K, 238U and 232Th in Bqkg⁻¹ respectively

Annual Effective Dose Equivalent (AEDE)

The annual effective dose rate (AEDR) in mSvy⁻¹ resulting from the absorbed dose values (D) was calculated using the following formula:

$$\text{AEDE (mSvy}^{-1}\text{)} = D (\text{nGyh}^{-1}) \times 8760 \text{ h} \times 0.7 \text{ Sv/Gy} \times 0.2 (4)$$

But in μSv y⁻¹, the AEDE expression can be written as

$$\text{AEDE (mSvy}^{-1}\text{)} = D (\text{nGyh}^{-1}) \times 8760 (\text{h/y}) \times 0.7 \text{ Sv/Gy} \times 0.2 \times 10^{-3} \dots \dots \dots (5)$$

Radiation Hazard Indices

Scientist defined two other indices that represent external and internal radiation hazards. External hazard index Hex and internal hazard index Hin is used to evaluate external exposure to gamma radiation in outdoor air and internal exposure to radon respectively. The external and internal hazard index is obtained from Raeq expression through the supposition that its allowed maximum value (equal to unity) corresponds to the upper limit of Raeq (370 Bq kg⁻¹). The external hazard index (Hex) and internal hazard index (Hin) can then be defined as

$$\text{Hex} = \frac{C_U}{370\text{Bq/kg}} + \frac{C_{Th}}{259\text{Bq/kg}} + \frac{C_K}{4810\text{Bq/kg}} \dots \dots \dots (6)$$

$$\text{Hin} = \frac{C_U}{185\text{Bq/kg}} + \frac{C_{Th}}{259\text{Bq/kg}} + \frac{C_K}{4810\text{Bq/kg}} \dots \dots \dots (7)$$

Where C_k, C_U (C_{Ra}) and C_{Th} are the activity concentrations of 40K, 238U and 232Th in Bq/Kg respectively. The external hazard index (Hex) is widely used to reflect external exposure. It provides a solitary index that expresses the gamma yield from various combinations of 226Ra, 232Th and 40K in the sample. The indices were calculated by the use of activity concentrations of radionuclide available in the literatures.

Gamma Index (Iγ)

Estimation of the level of gamma radioactivity associated with different concentrations of some specific radionuclides is known as the gamma index (Ononugbo *et al.*, 2016), which is given as

$$I_\gamma = \frac{C_U}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \dots \dots \dots (8)$$

Where C_k C_U and C_{Th} are the activity concentrations of ⁴⁰K, ²³⁸U and ²³²Th in Bq/kg respectively Values of Iγ ≤ 1 corresponds to an annual effective dose of less or equal to 1mSv. If Iγ in the locations exceed unity the area is radiologically Unsafe. The radionuclides' activity concentration in the literature was used to calculated gamma index shown in Table 2.

Radium equivalent (Raeq)

The radiological health effect can be determined by evaluating the radium equivalent effect because it is a measure of radiation hazard. This allows for uniformity in terms of radiation exposure and the comparison of the specific activity of materials containing different amounts of 226Ra, 232Th and 40K. Raeq is evaluated on the basis that the gamma dose rate produced by 370 Bqkg⁻¹ of 226Ra, 259 Bqkg⁻¹ of 232Th and 4810 Bqkg⁻¹ of 40K is the same

$$\text{Raeq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \dots \dots \dots (9)$$

Due to the non-uniform distributions of radionuclides in soil, radium equivalent activity has been defined as a single radiological parameter that compares the specific activity of materials containing varying concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K. It is the sum of the weighted activities ²²⁶Ra, ²³²Th and ⁴⁰K based on the estimation that 10 Bq/kg of ²²⁶Ra, 7 Bq/kg of ²³²Th and 130 Bq/kg of ⁴⁰K produced the same gamma dose rate. In terms of the radiological health safety assessment, the maximum permissible limit of $R_{eq} \leq 370$ Bq/kg had been set for materials to be used as component of building construction. The formula used for the calculation is given in Equation 9.

Excess Lifetime Cancer Risk (ELCR)

Excess Life Cancer Risk is the probability of developing cancer over a life time at a given exposure level. A higher value of ELCER implies higher probability induction of cancer of the individual that was exposed. It can be calculated using (Ononugbo *et al.*, 2016).

$$ELCER = AEDE \times DL \times RF \dots \dots \dots (10)$$

AEDE = Annual Effective Dose Equivalent, DL = Duration of Life (estimated to be 70 years) and RF = Risk Factor (Sv^{-1}).

For stochastic effects, ICRP uses RF as 0.05 for the general public. Some ELCR calculated in this review is higher than the world permissible value of 0.29×10^{-3} while others are in agreement with the world average (Ononugbo *et al.*, 2016). Therefore; ELCER was calculated in this review using DL as 70 years with RF as 0.05.

RESULTS AND DISCUSSION

Summary of the results of researches carried out by different research groups in Nigeria are summarized in Table 1, while radiological parameters were calculated from radionuclide activity concentrations in Table 1 and tabulated in Table 2.

Table 1: Showing activities concentrations of ²³⁸U, ²²⁶Ra, ²³²Th, and ⁴⁰K in Soils at different locations of Nigeria.

S/N	Location	²³⁸ U (Bq/kg)	²²⁶ Ra (Bq/kg)	²³² Th (Bq/kg)	⁴⁰ K (Bq/kg)	References
1	Ajaokuta	31	*	36	712	Usikalu <i>et al.</i> , 2017
2	Odua , River	67.4	*	507.19	8 217.8	Ononugbo <i>et al.</i> , 2016
3	Osogbo, Osun	15.39		4.54	223.59	Abiodun <i>et al.</i> , 2019
4	Lokoja	*	41.27	18.9	508.86	Ilemona <i>et al.</i> , 2016
5	Owerri, Imo	*	19.7	18.1	167.2	Nwaka <i>et al.</i> , 2014
6	Ibiono 1 Akwaibom	8.26	*	9.13	238.1	Essienet <i>et al.</i> , 2017
8	Ibiono 2 Akwaibom	6.11	*	8.13	73.84	Essien <i>et al.</i> , 2017
9	Ibiono 3 Akwaibom	3.16	*	5.91	106.58	Essien <i>et al.</i> , 2017
10	Akure Ondo	1.29	*	6.98	278.16	Majolage <i>et al.</i> ,2014
11	Chikun Kaduna	*	62.28	155.36	459.56	Gyuk <i>et al.</i> , 2017
12	Port Harcourt River state	41.96	*	62.61	643.1	Avwiri <i>et al.</i> , 2014
13	Bagega Zamfara	*	18.3	16.86	370.79	Girigisu <i>et al.</i> ,2013
14	GarinAuwal Kebbi	*	23.85	18.8	425.96	Girigisu <i>et al.</i> ,2014
15	Bitsichi	*	163	451	466	Jibiri <i>et al.</i> , 2009
16	Bakuru	*	129	147	1062	Jibiri <i>et al.</i> , 2009
17	Ropp	*	129	147	1062	Jibiri <i>et al.</i> , 2009
18	Abeokut	*	65	184	411	Jibiri <i>et al.</i> , 2009
19	Anka	*	47.06	75.97	216.02	Mbet <i>et al.</i> , 2019
20	Ibadan 1	50.01	*	84.66	261.37	Egunyinka <i>et al.</i> , 2009
21	Benue 1	4.13	*	4.92	46.23	Sombo <i>et al.</i> , 2016
22	Benue 2	4.28	*	5.73	63.32	Sombo <i>et al.</i> , 2016

23	Toro	*	38.78	105.77	491.89	Ibrahima <i>et al.</i> ,2019
24	Ibadan 2	85.67	*	10.77	8.92	Lawal <i>et al.</i> , 2019
25	Nasarawa	*	32.52	56.23	403.963	Ibrahim <i>et al.</i> ,2013
26	Itaganmodi,	55.3		26.4	505.1	Augustine <i>et al.</i> , 2014
27	Ogun	23.4	*	16.5	314.11	Olatunji and Bamidele, 20
28	Oguta,	*	47.89	55.37	1023	Isinkay and Emelue, 2015
29	Ijero	70.57	*	19.56	659.15	Felix <i>et al.</i> , 2016
30	Oshogbo, Osun	15.4	*	4.54	223.59	Abiodun <i>et al.</i> ,2019
31	Ondo	0.03	*	0.004	69.42	Ademila and Ugo, 2018
32	Owerri	*	19.7	18.1	167.2	Nwakaet <i>al.</i> , 2014
33	Kaduna	*	62.28	155.36	459.6	Gyuk <i>et al.</i> , 2017
34	Worldwide average	35	35	30	400	UNSCEAR, 2000

*means data not available

Table 2: Radiological hazard parameters of 238U, 226Ra, 232Th, and 40K in Soils at different locations of Nigeria.

Location	D (nGy/h)	AED (mSv/y)	I γ	Hex	Hin	Raeq (μ Sv/y)	ELC (mSv/y) $\times 10^{-3}$	REFERENCES
Ajaokuta	66.20	0.80	1.05	0.14	0.15	137.30	0.28	Usikalu <i>et al.</i> , 2017
Odua	654.20	0.80	10.70	3.74	3.91	1425.50	0.03	Ononugbo <i>et al.</i> , 2016
Osogbo	19.65	0.17	0.30	0.10	0.14	140.77	0.60	Abiodun <i>et al.</i> ,2019
Lokoja	51.70	0.06	0.33	0.10	0.11	107.48	0.21	Ilemona <i>et al.</i> , 2016
Owerri	27.10	0.13	0.12	0.04	0.04	58.50	0.46	Nwaka <i>et al.</i> , 2014
Nig	60.04	0.07	0.74	0.23	0.23	116.80	0.25	Abdullahi <i>et al.</i> , 2013
Ibiono 1	19.81	0.10	0.15	0.04	0.05	27.22	0.35	Essien <i>et al.</i> , 2017
Ibiono 2	10. 90	0.06	0.05	0.02	0.02	23.42	0.21	Essien <i>et al.</i> , 2017
Ibiono 3	9.79	0.06	0.07	0.02	0.022	19.82	0.21	Essien <i>et al.</i> , 2017
AkureOnd	16.89	0.02	0.16	0.05	0.05	32.69	0.07	Majolage <i>et al.</i> ,2014
Chikun	141.77	0.17	0.39	0.12	0.13	319.83	0.06	Gyuk <i>et al.</i> , 2017
Port Harcourt	86.71	0.76	0.43	0.13	0.14	181.01	2.66	Avwiri <i>et al.</i> , 2014
Bagega	27.25	0.03	0.23	0.07	0.08	70.96	0.11	Girigisu <i>et al.</i> ,2013
Awwal	34.26	0.04	0.27	0.07	0.08	83.53	0.14	Girigisu <i>et al.</i> ,2014
Bitsichi	350.00	0.43	0.62	0.19	0.21	843.81	1.51	Jibiri <i>et al.</i> , 2009
Bakuru	196.00	0.24	0.76	0.24	0.25	420.98	0.84	Jibiri <i>et al.</i> , 2009
Ropp	196.00	0.24	0.76	0.24	0.25	420.98	0.84	Jibiri <i>et al.</i> , 2009
Abeokuta	167.00	0.40	0.38	0.12	0.13	359.77	1.40	Jibiri <i>et al.</i> , 2009
Anka	76.64	0.09	0.19	0.47	0.06	172.33	0.32	Mbet <i>et al.</i> , 2019
Ibadan 1	88.92	0.11	0.23	0.07	0.08	191.19	0.39	Egunyinka <i>et al.</i> ,2009
Benue 1	6.48	0.01	0.03	0.01	0.01	14.73	0.04	Sombo <i>et al.</i> , 2016
Benue 2	8.00	0.01	0.04	0.01	0.01	17.35	0.04	Sombo <i>et al.</i> , 2016
Toro	102.24	0.21	0.36	0.11	0.12	227.91	0.74	Ibrahima <i>et al.</i> ,2019
Ibadan 2	3.54	0.0043	0.06	0.02	0.017	6.50	0.02	Lawal <i>et al.</i> , 2019
Nasarawa		0.04	0.28	0.09	0.1	141.56	0.14	Ibrahim <i>et al.</i> ,2013
Itaganmodi,	62.56	0.08	0.34	0.10	0.11	131.94	0.28	Augustine <i>et al.</i> , 2014
Ogun	33.14	0.04	0.20	0.06	0.07	71.18	0.14	Olatunji and Bamidele, 2020
Oguta,	186.80	0.92	1.20	0.56	0.67	205.67	3.21	Isinkay and Emelue,2015
Ijero	70.98	0.44	0.43	0.26	0.18	149.29	1.56	Felix <i>et al.</i> , 2016
Oshogbo, Osun	19.18	0.17	0.14	0.04	0.05	115.13	0.59	Abiodun <i>et al.</i> ,2019
Ondo	2.91	0.01	0.04	0.01	0.02	5.38	0.04	Ademila and Ugo,2018
Owerri	27.01	0.13	0.12	0.03	0.04	58.46	0.46	Nwaka <i>et al.</i> , 2014

Kaduna	141.78	0.17	0.38	0.12	0.13	119.63	0.61	Gyuk <i>et al.</i> , 2017
World Average	84.57	0.48	1.00	1.00	1	370.00	0.29	UNSCEAR, 2000

Discussion on Activity Concentrations of Radionuclide Activity Concentration of ²³⁸U

The mean activity concentration of ²³⁸U ranged between 0.03 to 85.67Bq/kg with the highest activity concentration

in observed in Ibadan region and Ijero village as shown in Figure. 1.

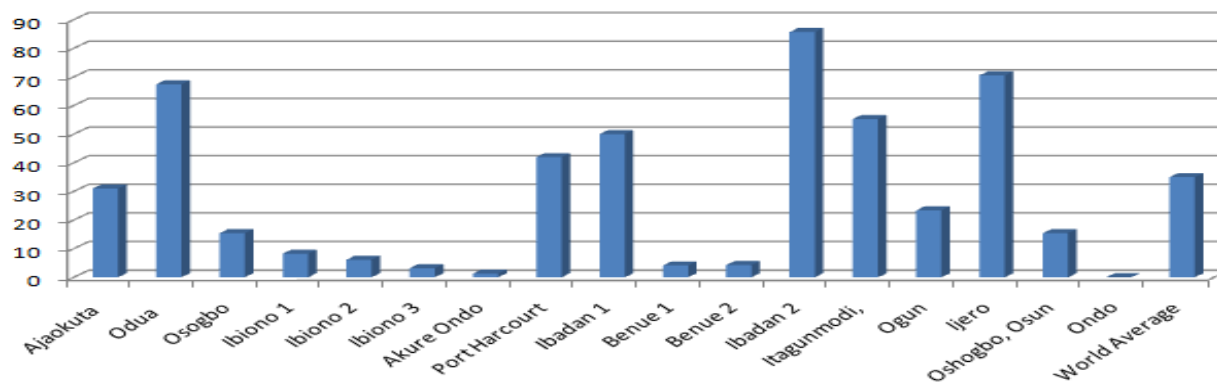


Figure 1: Showing Distribution of ²³⁸U in the soil

Activity Concentration of ²²⁶Ra

The mean activity concentration of ²²⁶Ra as reviewed in this work were ranged from 18.3 Bq/kg to 129 Bq/kg,

while the highest activity concentration was observed from Bitsichi, Bakuru, Ropp, Abeokuta and Kaduna as shown in Fig 2.

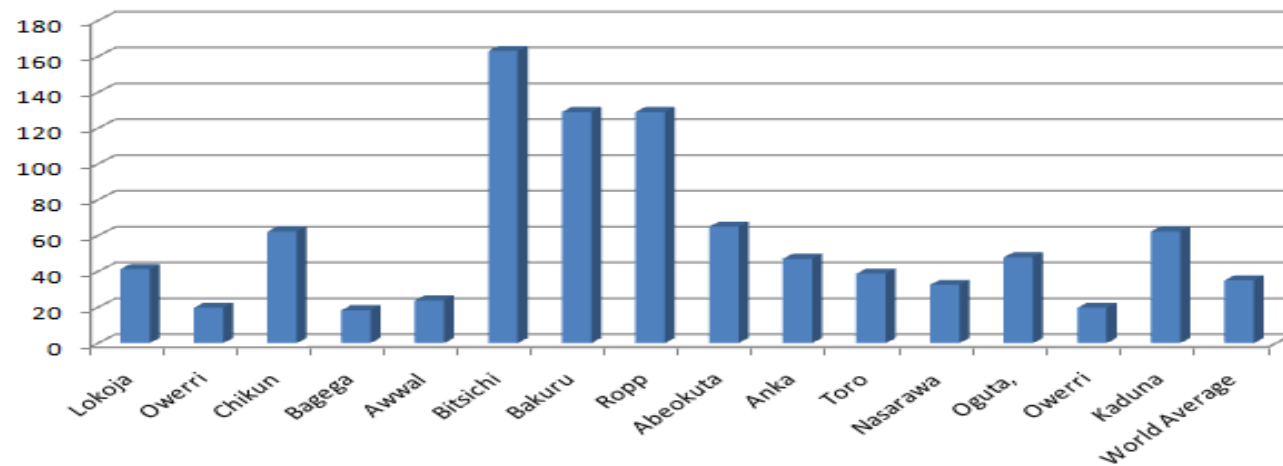


Figure 2: Distribution of ²²⁶Ra in different soil of Nigeria

Activity Concentration of ²²⁶Th

It was observed that ²³²Th activities concentrations in the soil of Bitsichi and Odua have the highest activities concentrations followed by Abeokuta, Kaduna and Chikun as indicated in Figure 3:

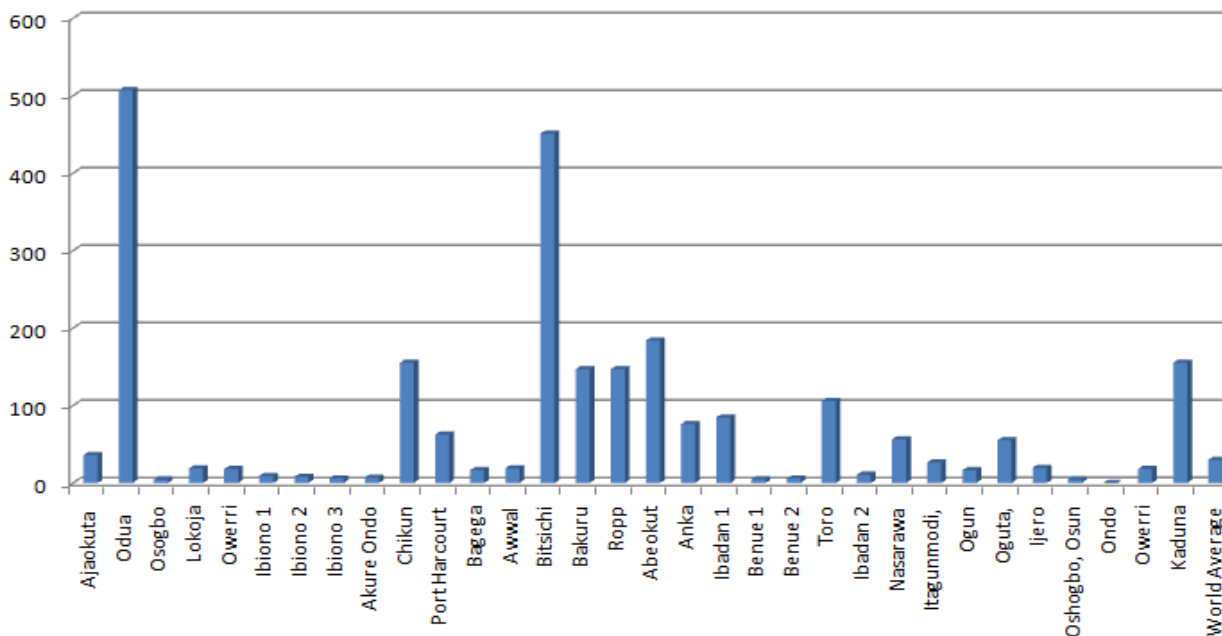


Figure 3: Distribution of ²³²Th different soil at different locations in Nigeria

Activity concentration of 40K

The distribution of 40K in the Soil of some regions of Nigeria was found to be remarkably higher than the world

average in the area like bakuru, Ropp, Oguta, Port Harcourt, Toro and Kaduna while others are in agreement with worldwide average.

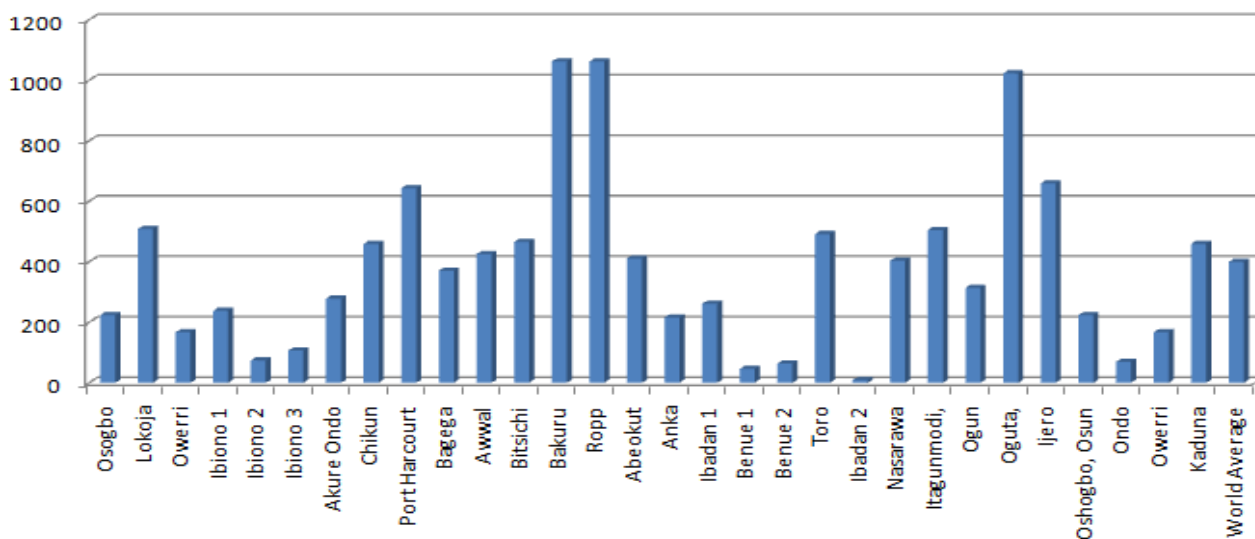


Figure 4: Distributions of ⁴⁰k in the soil

DISCUSSION ON RADDIOLOGICAL PARAMETERS

The radiological hazard indices recorded in Table 2 were presented in Figures 5 in order to compare the regions with the highest/lowest values above/below the world wide average values in the Nigeria’s’ soil..

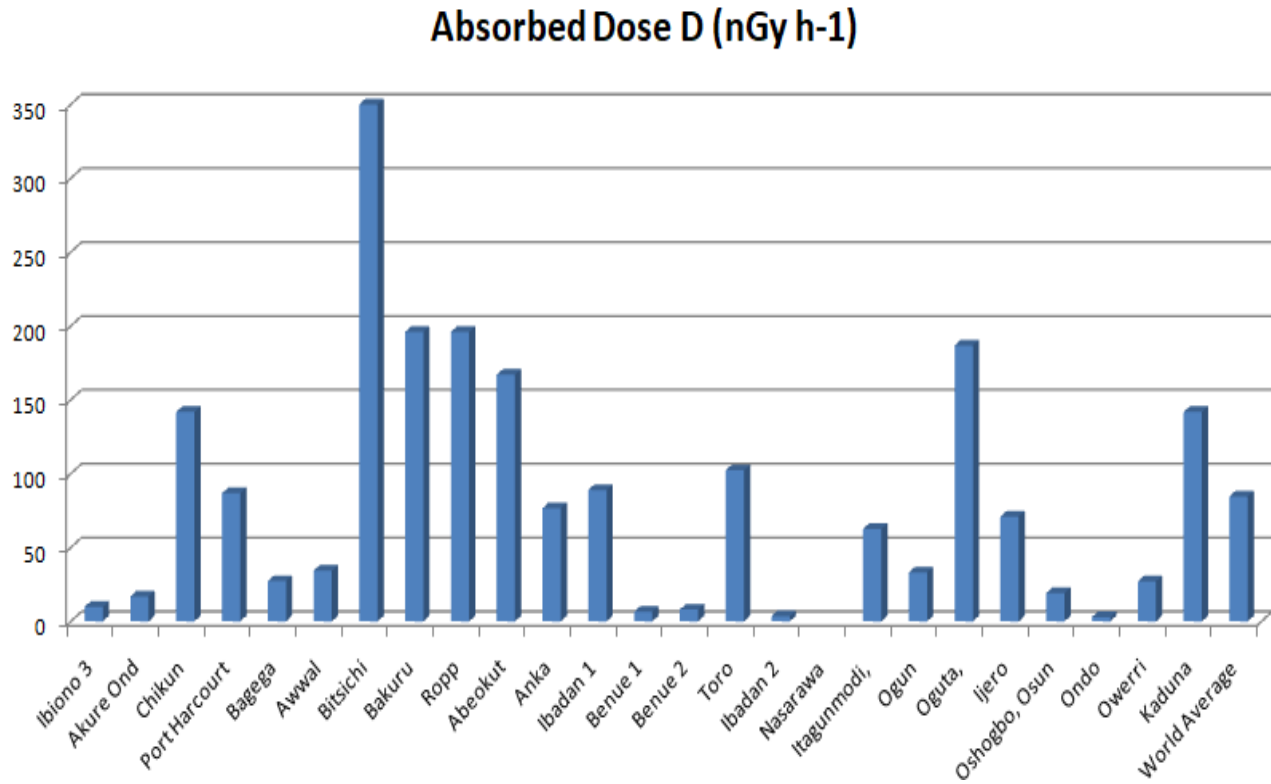


Figure 5: Showing Absorbed Dose Rate (nGy/h)

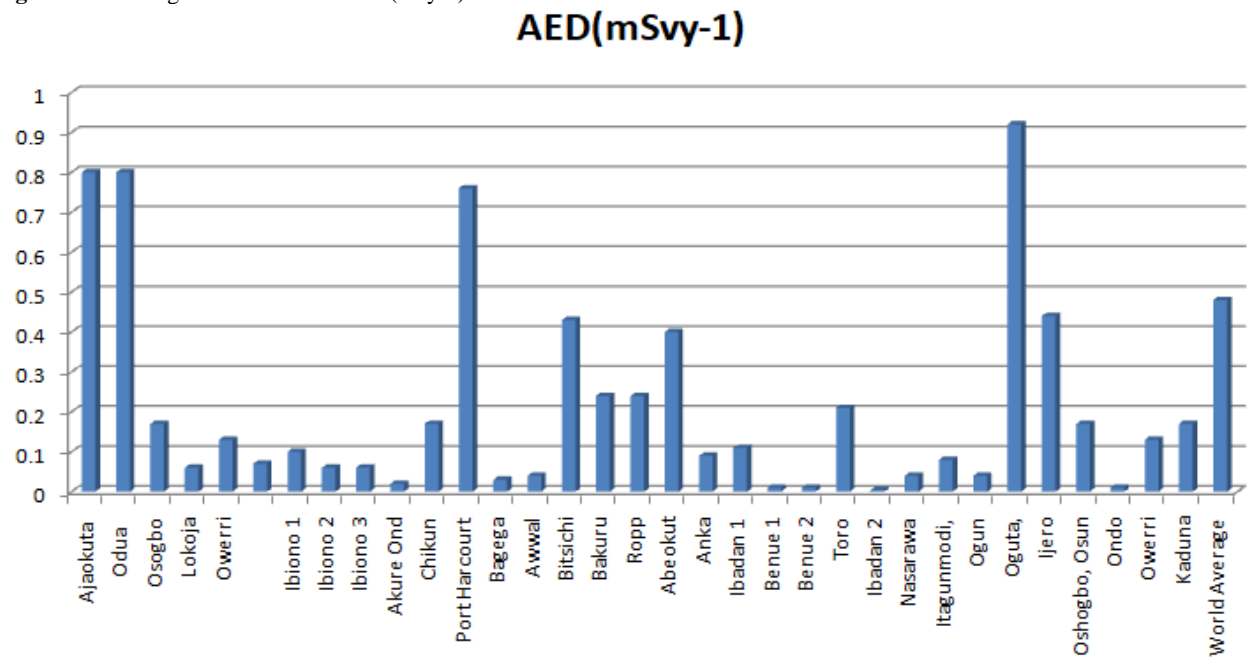


Figure 6: Annual Effective Dose (mSv/y) of radionuclide present in the soil

Raeq (μSvy^{-1})

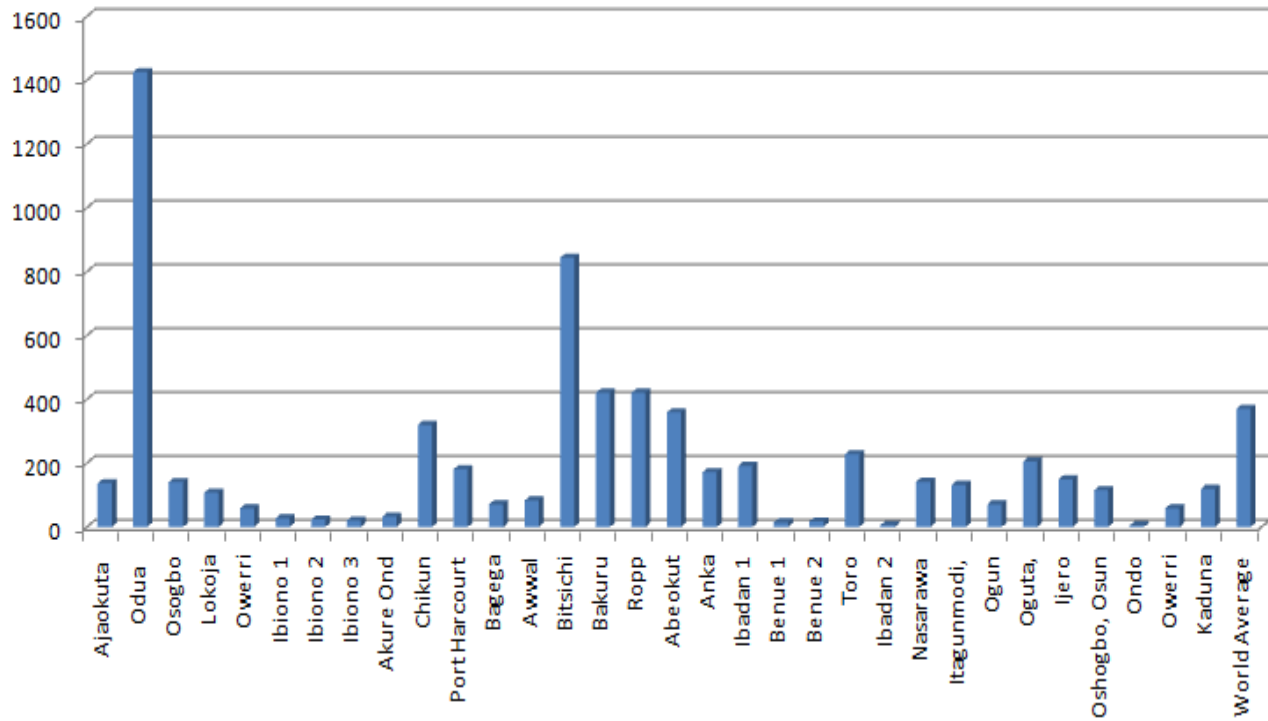


Figure 7: Radiumequivalents (Raeq) in the soil

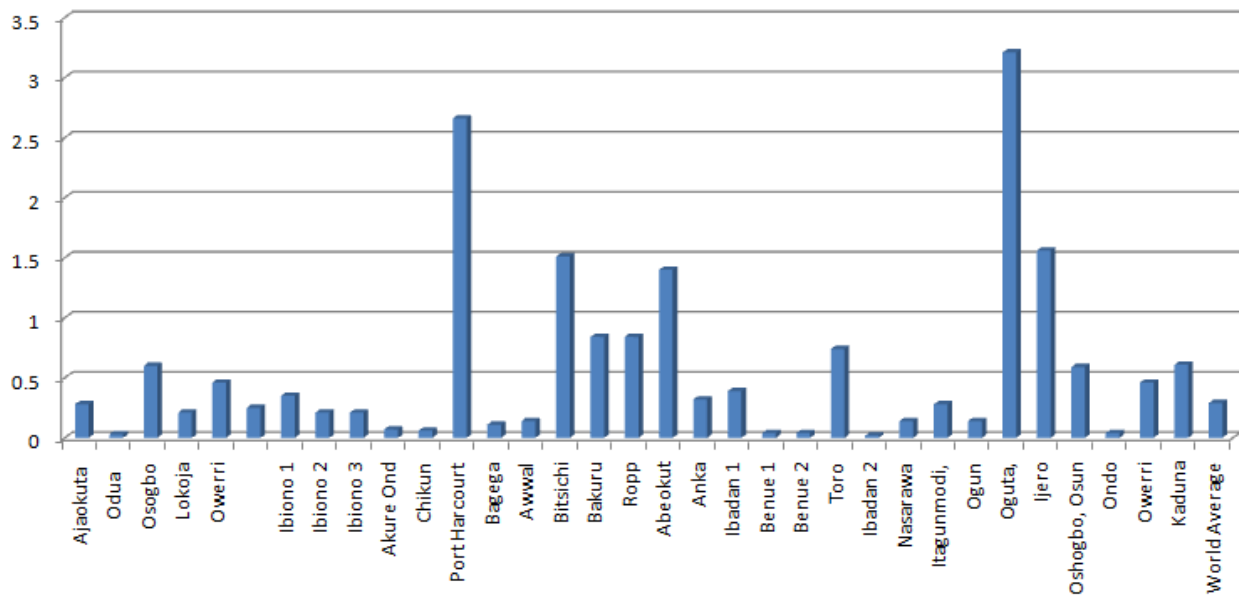


Figure 8: Excess Life Cancer Risk from the Soil

The absorbed dose rate in soil is remarkably high in an area of Bitsichi, Bakuru, Ropp, Abeokuta, Oguta, Chikum and Kaduna as shown in Figure 5. Annual Effective Dose found to be highest in the Oguta, Ajaokuta, Port Harcourt and Odua while others are in agreement with the worldwide values as indicated in Figure 6. The radium equivalent in the two areas (such as Bitsichi and Odua) is higher than the

worldwide average as indicated in the Figure 7, while the Excess Life Cancer Risk was found to be highest in Oguta, Port Harcourt, Ijero, Bitsichi, Abeokuta, Bakuru, Ropp, Owerri, Kaduna and Oshogbo (Osun) as shown in the Figure 8, while others are below and in agreement with the Standard values.

CONCLUSION

From the foregoing, it was observed that the highest activity concentration of ^{238}U , ^{226}Ra , ^{232}Th , and ^{40}K was found in (Ibadan and Ijero), (Bitsichi, Bakuru and Ropp), (Odua and Bitsichi), (Bakuru, Ropp and Oguta) respectively. The results obtained in these areas showed that soils contain the highest level of natural radioactivity. The highest radiological hazard indices were observed in Bitsichi (Absorbed Dose Rate), Oguta (Annual Effective Dose), Odua and Bitsichi (Radium equivalent), and Oguta and Port Harcourt (Excess Life Cancer Risk) respectively. This review work shown that the health burden due to natural background radiation emitted by radionuclide from soils on the inhabitant of some areas is generally high and carried significant radiation hazard. Therefore, based on this review, it was observed that some areas in Nigeria are radiologically Unsafe for dwellers.

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