Estimation of Radiological Hazard Indices Due To Radioactivity in Soils in Ibiono Ibom, Akwa Ibom State, Nigeria

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Abstract- The radiological hazard indices due to the radioactivity in soil samples in Ibiono Ibom Local Government Area of Akwa Ibom State, Nigeria were estimated. Soil samples were randomly collected at the depth of 30 cm in different locations from each of the three studied sites. The radionuclide activity concentrations in the soil samples were measured using gamma spectroscopy method. The mean activity concentration of ^{40}K are 238.10±22.47 Bq/Kg, 73.84±7.15 Bq/Kg and 106.58±8.63 Bq/Kg respectively for the three sites, then for ^{238}U the mean values for the three sites are respectively 8.26±2.06 Bq/Kg, 6.11±1.58 Bq/Kg and 3.16±0.80 Bq/Kg and for ^{232}Th the mean values are 9.13±1.03Bq/Kg, 8.13±0.91Bq/Kg and 5.91±0.66Bq/Kg respectively. The mean radium equivalent for the three areas is 27.222 Bq/kg. The mean absorbed dose rates for the areas were 19.805 $nGyh^{-1}$, 10. 863$nGyh^{-1}$ and 9.787 $nGyh^{-1}$ The mean total annual effective dose equivalent obtained for the areas were 0.101$mSvy^{-1}$, 0.062$mSvy^{-1}$ and 0.060$mSvy^{-1}$ respectively The values for all the hazards indices obtained were found to be below the world limits Therefore the level of exposure at the study areas presently poses no significant health threat, hence, the soils can be used as building material.

Index Terms- Activity concentrations, radionuclides, radiological hazard indices, gamma spectroscopy.

I. Introduction

Soils are natural sources of radioactive materials (NORMs) which are known to be the most prominent means of exposing the public to radiation. Rocks, soils and vegetation are known to contains long half live radionuclide such as Uranium - 238, Thorium-232 and Potassium-40 and the knowledge of these radionuclides distribution in an environment is necessary for the estimation of the effect of radiation exposure due to both terrestrial and extraterrestrial sources (Thabayneh and Jazzar, 2012). It is reported that these NORMs are widely distributed in the rocks, with Potassium as the major element widely present (Gbenu *et al.*, 2016). Environmental problems, such as health threats, associated with these NORMs occur in the process of quarrying, leaching, handling, storage, transportation of quarried products and the use of contaminated equipments without controls. In the process of preparation of these rocks for utilization, these radiations are absorbed by man through food intake and air inhalation. (Innocent *et al*, 2013).

Recently there is increasing demands for quarry products such as rocks, gravels, clays, stone sands, by state governments, non-governmental organizations (NGOs) and individuals as buildings materials and for other developmental purposes in this area under study. Therefore, due to the economic values and high demands for the quarry products, some areas of Ibiono Ibom Local Government Area of Akwa Ibom, Nigeria, which are naturally endowed with these resources in a large quantity, are now witnessing commercial quarries. The quarry activities which involve the digging of the ground soils to certain depth in order to bring the natural resources to the top surfaces also bring the NORMs to the soil surface, thereby increasing the radiation exposure to the workers and environment. Therefore the knowledge of the activity concentration of these NORM and their progenies in these soils samples enable one to assess any possible radiological hazards to occupants of the dwellings where these samples are used as building materials to construct homes. Again, the information could be used to estimate population exposure to these radiation both indoors and outdoors as the populace spends 80 % of their times indoors and 20 % outdoors (Bede *et al*., 2015). However, no adequate evaluation of the radiological effects due to the radioactivity in the soil in the area has been conducted before now. It is on this background that this work was carried out to assess the level of radiological effects due to the soils in Ibiono Ibom Local Government area.

II. Materials and Method

Ibiono Ibom local government area is situated in the South south geopolitical zone of Nigeria and it lies between longitudes $7^0\ 38^1$ and $8^0\ 10^1$ E and latitudes $5^0\ 5^1$ and $5^0\ 30^1$N. It has a large land mass and is highly populated. The area is bounded by rivers from Cross River State also in the south southern part of Nigeria. The villages where soil samples were collected are Ikot Ekwuo Idoro, Ikot Ekoi and Use Ikot Amama. The major economic activities of the people are predominantly quarrying, fishing and farming. Ibiono Ibom local government area is also highly rich in igneous, sedimentary and metamorphic rocks widely used as building materials in construction of dwelling places and construction of roads

A total of 30 soil samples were randomly collected from the selected abandoned quarry sites in different villages that made up the study area. Fourteen (14) soil samples were collected from Ikot Ekwuo Idoro abandoned quarry sites, eight (8) samples from Ikot Ekoi village and seven (7) samples from Use Ikot Amama abandoned quarry sites. At each sampling location, the soil surface was cleared of stones, pebbles, vegetations and roots then the rocks samples collected according to (Chad and Ohwekevwo,

2012) were sealed in a well labeled polythene bags and taken to National Institute of Radiation Protection and Research (NIRPR), Nigerian Nuclear Regulatory agency (NNRA), University of Ibadan, Nigeria for analysis.

The collected soil samples were first dried and then crushed, grounded and passed through a sieve of 1.0mm mesh size. The fine-grained powder of each sample obtained were dried in an oven to about 110^0 C for 2 hours to ensure total removal of moisture and 300g of each dried prepared sample was sealed in a cylindrical plastic container and properly labeled for easy identification. The prepared samples were stored for a period of 30 days to ensure secular radioactivity equilibrium between ^{226}Ra and its short lived progeny (EL-Arabic, 2005). In the laboratory, the activity concentrations of uranium–238, thorium–232 and potassium–40 were determined using gamma spectrometer coupled to NaI(TI) detector. The data acquisition and analysis of gamma spectra were made possible by a computer base multi-channel analyzer maestro program and the radionuclide activity concentration per unit mass (c) was calculated using equation (1) (Essien and Akpan 2016)

$$c = \frac{N}{\xi t \gamma M} \quad 1$$

Where M is the mass of the samples measured in Kg, ξ the detector energy dependent efficiency, t is the counting live time (s), γ is the gamma ray yield per disintegration of the nuclides and N is the net peak area of the nuclide.

111 Radiological hazard indices

The radiological hazard indices considered for this work are radium equivalent activity, radioactivity level index, absorbed dose rate, annual effective dose equivalent, external and internal hazard indices as well as the excess lifetime cancer risk.

Radium Equivalent Activity

The radium equivalent activity, R_{aeq} is used to compare the specific activities of material containing different quantities of ^{238}U, ^{232}Th and ^{40}K. The values of R_{aeq} could be obtained from (Bede *et, al.,* 2015)

$$R_{aeq} \left(BqKg^{-1}\right) = C_u + 1.43C_{Th} + 0.077C_K \quad \text{.....2}$$

where C_u, C_{Th} and C_K are the average activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively. In calculating Ra_{eq} values, the average activity concentration of 370Bq/kg, 259Bq/Kg and 4810Bq/kg used for ^{238}U, ^{232}Th and ^{40}K radionuclide, respectively, were assumed to produce the same gamma dose rate (EL-Taher *et al,* 2004).

Absorbed Dose Rate in Air

The effects of gamma radiation, emanating from radioactive sources in the environment, are usually given in terms of the total gamma radiation absorbed dose rate in air, Dγ and is calculated from the measured activity concentrations of ^{238}U, ^{232}Th and ^{40}K radionuclides as proposed by UNSCEAR (Bede *et, al.*, 2015).

$$D_\gamma (nGyh^{-1}) = 0.427C_u + 0.662C_{Th} + 0.043C_K \quad 3$$

Annual Effective Dose Equivalent

The annual effective dose equivalent (AEDE) received by individuals are generally obtained from the calculated values of Dγ by applying the conversion factor of 0.7SvGy^{-1} and the occupancy factors of 0.2 and 0.8 for outdoors and indoors effective doses, respectively (UNSCEAR, 2000). The annual effective dose outdoor (AEDE outdoor), the annual effective dose indoor , (AEDE indoor) and the total annual effective dose (AEDE total), are obtained using the following relations.

$$AEDEoutdoor(mSvyr^{-1}) = D_\gamma(nGyh^{-1}) \times 24h \times 365.25days \times 0.2 \times 0.7SvGy^{-1} \times 10^{-6} \quad 4$$

$$AEDEindoor(mSvyr^{-1}) = D_\gamma(nGyh^{-1}) \times 24h \times 365.25days \times 0.8 \times 0.7SvGy^{-1} \times 10^{-6} \quad 5$$

The total annual effective dose equivalent could be obtained from (Gbenu et al 2015)

$$AEDEtotal(mSvyr^{-1}) = 5AEDEoutdoor \quad 6$$

External and internal hazards indices

The external radiation hazard index, H_{ext}, corresponding to ^{238}U, ^{232}Th and ^{40}K natural radionuclides are calculated using the relation below

$$H_{ext} = \frac{C_K}{4810} + \frac{C_{TH}}{259} + \frac{C_U}{370} \quad 7$$

The internal hazard index for ^{238}U, ^{232}Th and ^{40}K are obtained using the equation

$$H_{in} = \frac{C_K}{4810} + \frac{C_{TH}}{259} + \frac{C_U}{185} \quad 8$$

where C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively and the numbers in the numerators of equations 5 and 6 are their respective conversion factors (Bede et al 2015). In comparison to equation 6, we can have equation 9.

$$H_{total} = H_{ext} + H_{in} \quad 9$$

The value for the external and internal hazard indices must be less than unity for the radiation hazard to be considered negligible (Beretka and Mathew, 1985). Similarly for radiological safety the value for H_{total} also must be less than unity

Radioactivity Level Index

The radioactivity level index, Iγ is usually employed to evaluate the hazardous level of radionuclides in the human body when exposed to an amount of external annual effective doses of

gamma-radiations decayed from these radioactive nuclides in soil and values of I_γ can be obtained using relation below

$$I\gamma = \frac{C_K}{1500} + \frac{C_{TH}}{100} + \frac{C_U}{150} \quad (10)$$

where C_u, C_{Th} and C_k are the activity concentrations of uranium, thorium and potassium respectively. The calculated values of Iγ must be less than unity for the soil environment to be free from radiological health hazards.

Excess Lifetime Cancer Risk

The excess lifetime cancer risk (ELCR) values are calculated using the given equation

$$ELCR = AEDEtotal \times D_L \times R_F \quad (11)$$

where D_L is the duration of life (taken approximately as 70 years), R_F is the risk factor (Sv^{-1}), which reflects the fatal cancer risk per Sievert. For stochastic effects, a value of 0.05 for the public is recommended, (Taskin, *et al*, 2009).

III. RESULTS

The activity concentration of the three (^{40}K ^{238}U and ^{232}Th) natural radionuclides in the soils in study areas are presented in Tables 1, 2 and 3

Table 1: Activity concentrations of ^{40}k, ^{238}U and ^{232}Th in the soil at the study sites at Ikot Ekwuo Idoro

Sample Point	K-40 (Bq/Kg)	U-238 (Bq/Kg)	Th-232 (Bq/Kg)
1	108.33±10.36	7.63±1.78	5.29±0.59
2	207.24±19.39	5.29±1.50	7.23±0.88
3	205.36±21.39	8.60±2.29	7.64±0.87
4	171.92±16.60	8.14±1.92	8.46±0.95
5	579.81±49.84	7.93±2.17	13.82±1.64
6	300.03±29.22	12.18±2.87	11.28±1.27
7	219.02±20.40	15.08±3.57	10.88±1.22
8	127.17±12.03	5.53±1.51	9.18±0.99
9	249.64±23.09	BDL	4.05±0.48
10	119.64±11.96	3.13±0.80	8.95±0.97
11	386.70±36.03	14.37±3.46	12.50±1.37
12	211.48±20.11	11.09±2.71	9.27±1.02
13	306.63±28.64	11.30±2.74	10.88±1.21
14	140.36±15.56	5.35±1.49	8.32±0.92
Mean	238.10±22.47	8.26±2.06	9.13±1.03

Table 2: Activity concentrations of ^{40}k, ^{238}U and ^{232}Th in the soil at the study sites at Ikot Ekoi

Sample Point	K-40 (Bq/Kg)	U-238 (Bq/Kg)	Th-232 (Bq/Kg)
1	67.34±6.83	4.19±1.13	10.67±1.22
2	89.96±8.18	9.11±2.11	6.10±0.68
3	78.66±7.77	9.36±2.70	6.63±0.75
4	35.80±3.54	11.09±2.78	10.65±1.20
5	26.85±2.82	6.26±1.32	4.18±0.50
6	68.77±6.38	1.03±0.28	7.24±0.81

7	180.40±18.85	3.31±0.94	10.35±1.12
8	43.33±4.39	4.56±1.40	9.18±0.99
Mean	73.84±7.35	6.11±1.58	8.13±0.91

Table 3: Activity concentrations of ^{40}k, ^{238}U and ^{232}Th in the soil at the study sites at Use Ikot Amama

Sample Point	K-40 (Bq/Kg)	U-238 (Bq/Kg)	Th-232 (Bq/Kg)
1	26.85±2.58	6.68±1.77	4.36±0.50
2	218.55±19.74	3.04±0.80	7.39±0.79
3	113.51±10.72	5.83±1.40	6.64±0.75
4	15.54±1.42	4.67±1.27	5.79±0.64
5	150.72±14.75	BDL	5.31±0.59
6	98.91±0.63	1.91±0.35	4.39±0.50
7	121.99±10.58	BDL	7.67±0.84
Mean	106.58±8.63	3.16±0.80	5.94±0.66

IV. DISCUSSION

Radionuclides activity concentration in the soils samples

Tables 1, 2 and 3 show that activity concentration of ^{40}K are 108.33± 10.36 Bq/Kg to 579.81±49.84 Bq/Kg with mean of 238.10±22.47 Bq/Kg for Ikot Ekwuo Idoro, (26.85±2.82 to 180.40±18.85)Bq/Kg with mean of 73.84±7.15 Bq/Kg for Ikot Ekoi and (15.54±1.42 to 218.55 ±19.74) Bg/Kg with mean of 106.58±8.63 Bq/Kg for Use Ikot Amama respectively, then for ^{238}U the range (mean) for the three sites are respectively BDL-15.08±3.57Bq/Kg (8.26±2.06 Bq/Kg), 1.03±0.28- 11.09±2.78 Bq/Kg(6.11±1.58 Bq/Kg) and BDL-11.10±2.78Bq/Kg (3.16±0.80 Bq/Kg) and for ^{232}Th the values obtained are 4.05±0.48- 13.82±1.66Bq/Kg with mean value of 9.13±1.03Bq/Kg, (4.18±0.50 – 10.67±1.22)Bq/Kg with mean 8.13±0.91Bq/Kg and (4.36±0.50 – 7.67±0.84)Bq/Kg with mean of 5.91±0.66Bq/Kg respectively. These radioactivity concentration values obtained in these quarry sites are below the world average value of 400 Bq/kg for ^{40}k, 35Bq/kg for ^{238}U and 30Bq/kg for ^{232}Th (UNSCEAR, 2000), except in a one sample point at Ikot Ekwuo Idoro that the maximum value for K-40 is higher than the world value.

It could be observed from Fig.1 that the mean activity concentration of ^{40}K is the highest for all the studied sites making ^{40}K the dominant radionuclide in the study areas. This result agrees with the previous study elswhere within the South South zone of Nigeria (Iwetan, *et al* 2015, Bede *et al* 2015). There is a low activity concentration of ^{238}U in soils in all the studied areas while the activity concentration in some areas were below detection limit (BDL).

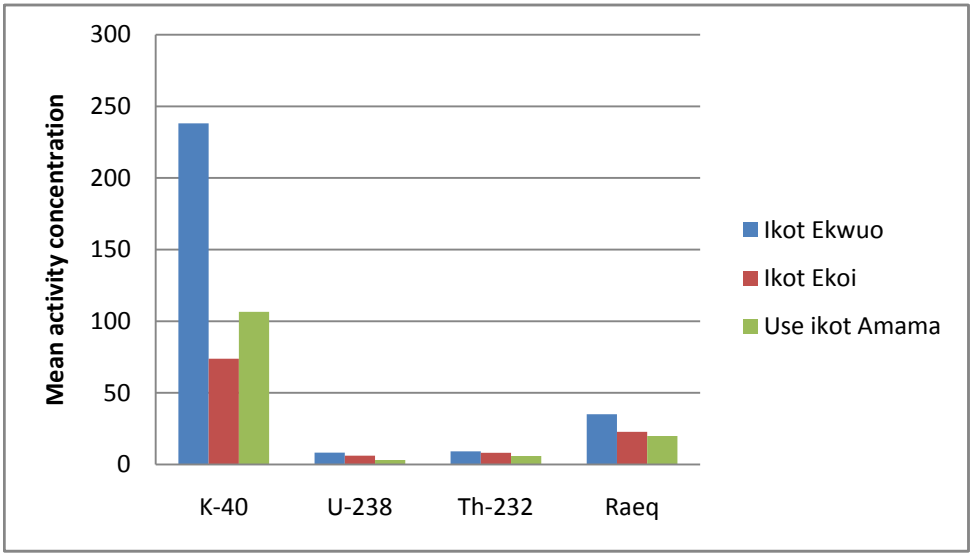

Fig. 1.0. Mean activity concentration of the radionuclides

Radiological Hazard Indices in Soils of the Studied Areas

In Tables 4, 5 and 6 it is observed that the radium equivalent varies from 23.536Bq/kg to 64.673 Bq/kg with a mean of 39.089 Bq/kg for Ikot Ekwuo Idoro, 12.303Bq/kg to 27.554Bq/kg with a mean of 22.750Bq/kg for Ikot Ekoi and 14.982 Bq/Kg to 30.436 Bq/Kg with a mean value of 19.828 Bq/Kg for Use Ikot Amama. These values are below the world standard of 370Bq/kg for radium equivalent.

Table 4 Calculated radiological hazards indices for the soils in Ikot Ekwuo Idoro

Sample Point	Ra_{eq} (Bq/kg)	ADR (nGy/h)	H_{ext}	H_{in}	$I\gamma$	AEDE Total (mSv/yr)	ECLR x 10^{-3}
1	23.536	11.418	0.066	0.084	0.176	0.070	0.049
2	31.586	15.956	0.086	0.099	0.246	0.108	0.070
3	35.338	17.560	0.095	0.119	0.271	0.101	0.077
4	33.476	16.469	0.090	0.112	0.254	0.230	0.070
5	64.673	37.467	0.195	0.217	0.578	0.157	0.161
6	51.413	25.569	0.139	0.172	0.394	0.141	0.109
7	47.443	23.046	0.128	0.169	0.355	0.134	0.098
8	28.449	13.907	0.077	0.092	0.213	0.085	0.060
9	25.014	13.416	0.068	0.068	0.207	0.082	0.060
10	25.141	12.406	0.068	0.076	0.190	0.076	0.053
11	62.021	31.039	0.168	0.206	0.479	0.085	0.133
12	40.630	19.966	0.109	0.140	0.308	0.043	0.088
13	50.469	25.213	0.136	0.167	0.389	0.067	0.109
14	28.055	13.828	0.076	0.090	0.212	0.038	0.060
Mean	39.089	19.805	0.107	0.118	0.305	0.101	0.086

Table 5 Calculated radiological hazards indices for the soils in Ikot Ekoi

Sample Point	Ra_{eq} (Bq/kg)	ADR (nGy/h)	H_{ext}	H_{in}	$I\gamma$	AEDE Total (mSv/yr)	ECLR x 10^{-3}
1	24.633	11.748	0.067	0.078	0.180	0.072	0.049
2	24.760	11.796	0.067	0.092	0.182	0.072	0.053
3	24.898	11.768	0.067	0.093	0.181	0.072	0.049
4	21.598	9.925	0.058	0.084	0.153	0.069	0.042
5	23.557	10.878	0.064	0.081	0.166	0.067	0.046
6	12.303	6.164	0.033	0.036	0.095	0.038	0.028
7	27.554	13.963	0.074	0.083	0.215	0.076	0.060
8	22.697	10.662	0.061	0.074	0.163	0.065	0.046
Mean	22.750	10.863	0.061	0.078	0.167	0.062	0.047

Table 6 Calculated radiological hazards indices for the soils in Use Ikot Amama

Sample Point	Ra_{eq} (Bq/kg)	ADR (nGy/h)	H_{ext}	H_{in}	$I\gamma$	AEDE Total (mSv/yr)	ECLR x 10^{-3}
1	14.982	6.895	0.041	0.059	0.106	0.042	0.032
2	30.436	15.588	0.082	0.090	0.240	0.096	0.067
3	20.848	10.277	0.056	0.072	0.158	0.063	0.046
4	15.162	6.965	0.041	0.054	0.107	0.043	0.032
5	19.885	10.314	0.054	0.054	0.158	0.063	0.046
6	17.119	8.584	0.046	0.051	0.132	0.053	0.039
7	20.361	10.201	0.055	0.055	0.158	0.063	0.046
Mean	19.828	9.787	0.054	0.062	0.151	0.060	0.044

Tables 4, 5 and 6 show the results of the calculated radiological hazard indices for each of the studied area. Absorbed dose rates vary from 11.418 $nGyh^{-1}$ to 37.467$nGyh^{-1}$ with a mean of 19.805 $nGyh^{-1}$ Ikot Ekwuo Idoro and 6.164 $nGyh^{-1}$ to 13.963 $nGyh^{-1}$ with a mean of 10. 863$nGyh^{-1}$ for Ikot Ekoi, 6.895 $nGyh^{-1}$ to 15.588 Gyh^{-1} with mean value 9.787 $nGyh^{-1}$ for Use Ikot Amama. These values are below the world standard of 55.0$nGyh^{-1}$. The mean total annual effective dose equivalent obtained was 0.101$mSvy^{-1}$ for Ikot Ekwuo Idoro, 0.062$mSvy^{-1}$ for Ikot Ekoi and 0.060$mSvy^{-1}$ for Use Ikot Amama. However, these values are within the 0.3 -1.0 $mSvy^{-1}$ range proposed by United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) for safety. The calculated radioactivity level index values reported in Tables 4 - 6 are below the world standard value of unity hence the materials from these quarry site can be used as buidling materials for housing construction without posing a health threat to the inhabitants (Tufail et. al, 2007). The calculated H_{ext}, H_{in} has a value range less than unity respectively and Tables 4, 5 and 6 show the values of H_{Toatl} also less than unity. This indicates that interaction with the soils in Ibiono Ibom Local government area will not lead to respiratory diseases such as asthma and cancer and external diseases such as erythema, skin cancer and cataracts (Avwiri et al., 2012). The range mean excess lifetime cancer risk calculated for the studied area is between 0.044 x 10^{-3} – 0.086 x 10^{-3}. These values are below the world standard of 0.29x10^{-3} implying that the probability of people in the quarry sites developing cancer cases is small (Taskin et al., 2009).

V. Conclusion

The evaluation of radiological hazard indices and excess lifetime cancer risk in quarry sites in Ibiono Ibom Local Government Area of Akwa Ibom State, Nigerian have been conducted. This work saves as baseline for future radiological study of the study as the government has many development programmes for these areas. The activity concentrations of ^{40}K, ^{238}U,and ^{232}Th in soil samples of Ibiono Ibom were below their respective world recommended safety limit.The radionuclides are randomly distributed in the soil with ^{40}K being the dorminant radionuclide .The calculated radiological hazard indices for the Ibionno Ibom are all below their respective world standards.Therefore quarry activities and the obtained building materials do not pose any significant health threat to the environment and it's residents. However, regular radiation monitoring and evaluation is recommended to notice any possible rise in radiation level due to the quarry activities in these areas

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