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MEASUREMENT OF NATURAL RADIOACTIVITY AND EVALUATION OF RADIATION HAZARDS IN SOIL OF ABUA/ODUAL DISTRICTS USING MULTIVARIATE STATISTICAL APPROACH

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ABSTRACT: *The activity concentration of ^{238}U, ^{232}Th and ^{40}K in the soil from Abua/Odua districts of Rivers State have been measured using gamma ray spectrometry. Radiological health parameters were estimated from the activity concentration of these radionuclides in order to assess health implication of exposure of the general public to the studied soil. The average value of ^{238}U, ^{232}Th and ^{40}K measured are 67.40, 507.19 and 8217.77 $Bqkg^{-1}$respectively. The calculated radium equivalent (Raeq), absorbed dose (D), annual effective dose equivalent (AEDE), activity utilization index (RLI),internal and external hazard indices (H_{in}, H_{ex}), excess lifetime cancer risk (ELCR), and annual gonald dose (AGED) were used to access the health implication of exposure to the soil studied. The results were higher than the recommended safe and criterion limits given by UNSCEAR. The statistical method was used to study the relationship between the radionuclides and also the calculated radiation parameters. The results of this study revealed an area of high gamma emitting radionuclides which could lead to significant health hazard to the exposed populace. The result will also serve as a baseline radiometric data for future studies in the area and radiological mapping of the area.*

KEYWORDS: Multivariate, Spectroscopy, Radiological, Gonald dose, Norms, Radionuclides

INTRODUCTION

All living organisms including man are constantly exposed to varying degrees of ionizing radiation from naturally occurring radioactive materials (NORMs) in the environment and radionuclides generated by human activities which is called technologically enhanced naturally occurring radioactive materials (TENORM). Many artificial sources of radiation have been introduced since the discovery of X-rays and radioactivity at the end of the nineteenth century, and particularly since the exploitation of the process of nuclear fission in the middle of the twentieth century (Alan *et al*., 2012). Also radionuclides enter the environment during nuclear weapon testing, nuclear accidents, medical and industrial radiation applications. These artificial sources now add a significant contribution to the total radiation exposure of the population. The naturally occurring radioactive materials (NORMs) are found in various geological formations such as soil, rocks, water, sediments, air and in some building materials (Avwiri *et al*., 2012).

In the oil and gas industries, naturally occurring radium and its daughter products can build up as scale in pipes and vessels. The de-scaling of these results in occupational radiation exposure and in waste streams containing radium. In the smelting of iron ore, high concentrations of lead-210 and polonium-210 occur in dusts and residues. In other metal smelting applications, the use of special mineral sands containing natural uranium and thorium can lead to exposures either directly or from the enhanced concentrations in foundry slag. Another material containing levels of uranium, thorium and potassium that can be of radiological significance is

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phosphate rock. This is often used as an agricultural fertilizer. In addition, gypsum, this arises as a by-product of phosphate processing, is widely used in building materials.

Isinkaye and Emelue (2015) stated that 87% of radiation dose received by humans are from natural radiation sources, which comes from the naturally occurring radioactive isotopes of ^{238}U and ^{232}Th and their progeny as well as ^{40}K. The pathway by which artificial radionuclides reaches man, excluding a massive dose of radiation , may not be the inhalation of dust or vapor but the deposition of nuclides on soils (Qureshi et al., (2014). Radionuclides may be transferred from soils to plants, animals and finally to man. 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 soil or internal due to inhalation (Jibril and Okeyode, 2012). The internal exposure to radiation affecting the respiratory track is due to radon and its decay products which emanate from soil, sediment and building materials (Isinkaye and Emelue , 2015). Some of the radiation health effects due to long term exposure and inhalation of radionuclide are chronic lung disease, acute leucopoenia, anemia and necrosis of the mouth, cataract, chronic lung cancer and leukemia (Qureshi et al., 2014; Sureshgandi et al., 2014). Exposure to Thorium can cause lung, pancreas, hepatic, bone, kidney cancers. It has been stated earlier that 87% of human exposure to radiation comes from naturally occurring radioactive materials in the environment. The study of the distribution of these radionuclide helps in the determination of the radiological health implication of exposure to gamma rays and inhalation of radon and its daughter products.

The aim of this study is to measure the activity concentration of the identified radionuclide in soil samples from seven districts of Abua/Odua local Government Area of Rivers state and from the obtained data, estimate all the radiation hazard indices, absorbed dose, annual effective dose, annual gonadal dose and excess lifetime cancer risk associated with the exposure. There are no radiological data on the natural radioactivity level of soil of Abua/Odua local Government Area of Rivers State. The result of this study will serve as the natural radioactivity level database for this area since there has not been any radiological study of the area and multivariate statistical techniques were used to determine the relationship between those radionuclides and the radiological parameters.

MATERIALS AND METHOD

Study Area

Abua/Odual Local Government Area lies between longitudes 6º 24' - 6°50' and latitudes 4°40'-5º 55'. The area is in Rivers State located at the southern part of Nigeria. This area is within the coastal belt dominated by low lying coastal plain of the sedimentary formation of the Niger Delta. The prevailing activity in this area is fishing and farming. Other activities include timber and lumbering, oil exploration and development.

Twenty one (21) samples of soil at a depth of about 1m were collected from seven districts /Communities of Abua/Odual Local Government Area. Three samples were collected from each district (Kugbo, Adibom, Arghuya, Abua central, Okpeden, Otapha and Emughan) of the study area. The samples were sun dried, grinded using mortar and pestle and are later pass through a mesh size of 150μm to obtain fine powder. The samples were packed and sealed in

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air tight polythene bags and kept for about 28days period to allow radon ^{222}Ra and Thorn ^{220}Ra and their progenies which are short lived to reach radioactive equilibrium.

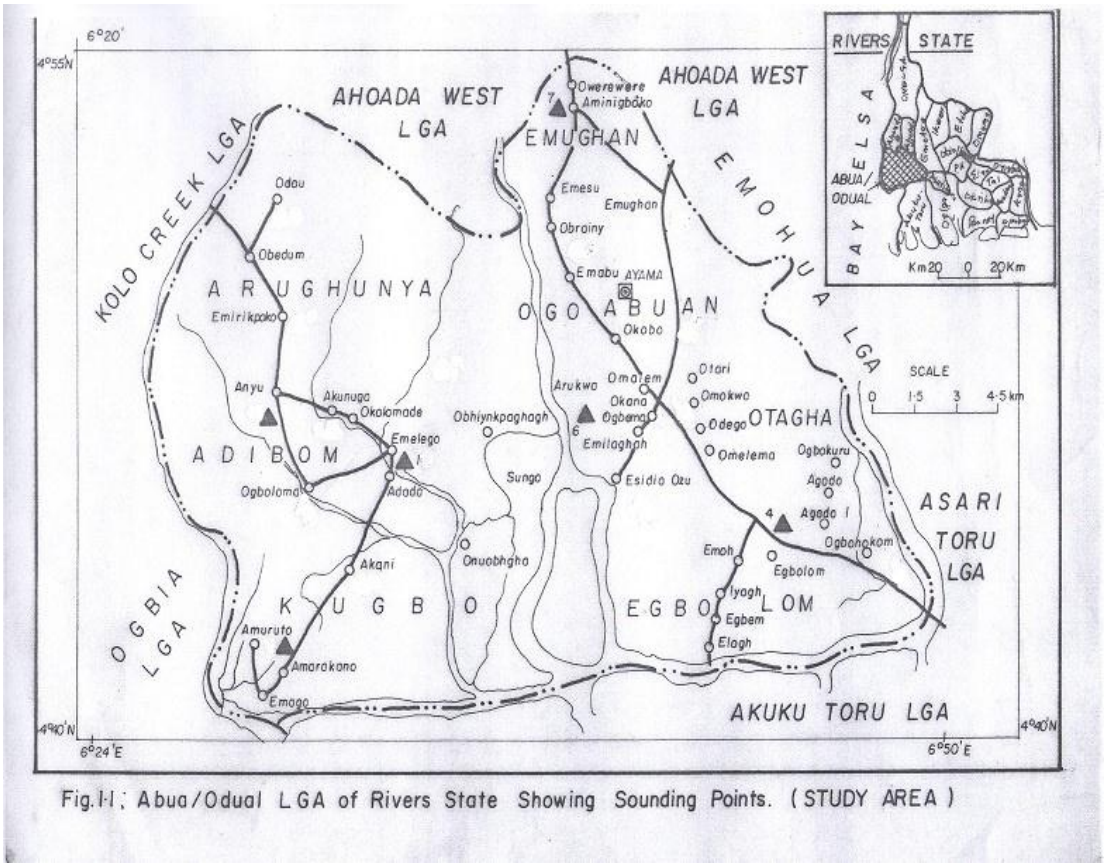

Fig.1: Map of the study Area

Sample preparation and measurements

Three soil samples each were collected from seven districts (Kugbo, Adibom, Arghuya, Abua central, Okpeden, Otapha and Emughan) of the study area making a total of twenty-one soil samples. Soil samples of 3 kg by weight each were collected from a depth of 5cm from the surface using a grab sampler and each sample location covered a surface area of 1 m × 1 m. The collected samples were air dried at room temperature in open air. 3 kg of the sample were packed in a black polyethene bag and transported to the laboratory (National Institute of Radiation Protection and Research (NIRPR) university of Ibadan). The samples were oven dried at temperature of 105ºC for 12 hours, grinded and sieved through 250 µm mesh. The homogenized samples were placed in a 250 g airtight marinelli beaker. The sample containers were then sealed and left for a period of about four weeks. This was done to enable the short lived members of uranium and thorium series reach secular radioactive equilibrium prior to gamma spectroscopy.

Gamma Spectrometric Analysis

Prepared soil samples were analyzed using thallium activated Canberra vertical high purity 3″×3″ Sodium iodide [NaI(TI)] detector connected to ORTEC 456 amplifier. The detector was

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connected to a computer program MAESTRO window that matched gamma energies to a library of possible isotopes. The detector was shielded by 15cm thick lead on all four sides and 10cm thick on top to reduce the effects of the laboratory background radiation by a factor of about 95%. The standard International Atomic Energy Agency (IAEA) sources were used for calibration (IAEA, 2003). To determine the background radioactivity distribution in the environment around the detector, an empty sealed container was counted at the same manner and in the same geometry as the samples (Huang et al., 2014). The background measurements were repeated at regular intervals for quality control. The gamma spectrometry detector was calibrated before it was used for analysis. This was done to ensure that the radiation parameters in the samples could be expressed in physical radiometric units. This calibration was done in two stages. These are energy and efficiency calibrations.

The energy resolution of 2.0 kev and relative efficiency of 33% at 1.33Mev was achieved in the system with the counting time of 10000 seconds. The standard International Atomic Energy Agency (IAEA) sources were used for calibration (IAEA, 2003). From the counting spectra, the activity concentrations of ^{238}U, ^{232}Th and ^{40}K was determined using computer program. The peak corresponds to 1460 keV (^{40}K) for ^{40}K, 1764.5 KeV (Bi-214) for ^{238}U and 2614.5 kev (Ti-208) for ^{232}Th were considered in arriving at the activity levels ($Bqkg^{-1}$). The detection limit of NaI(TI) detector system for ^{238}U , ^{232}Th and ^{40}K are 2.21,2.11 and 8.5 Bqkg-1 respectively for a counting time of 10000 s .The activity concentration (C) of the radionuclide was calculated after subtracting decay correction using the following expression (Arogunjo, et al., 2005):

$$C\ (Bqkg^{-1}) = KC_n \quad \text{---------- (1)}$$

Where Ci is the activity concentration of the radionuclide i in the soil samples expressed in $Bqkg^{-1}$., C_n is the count rate under the corresponding photo peak, $K = 1/\epsilon P_y M_s$, ϵ is detector efficiency at specific gamma-ray and M_s is the mass of of each sample in kg. P_y is the absolute transition probability of the specific gamma ray in kg.

RESULTS AND DISCUSSION

Activity Concentration of ^{238}U, ^{232}Th and ^{40}K in soil samples

The activity concentration of ^{238}U, ^{232}Th and ^{40}K in soil samples are given in Table 1. The activities range and mean values (in brackets) for ^{238}U, ^{232}Th and ^{40}K are ≤ 14.24 – 184.90 (67.40), ≤ BDL –979.89 (507.19) and 1547 - 21103.64 (8217.77) $Bqkg^{-1}$ respectively. The minimum activity concentration of ^{238}U and ^{232}Th was recorded at $Emelego_2$ of Adibom district while the maximum value was recorded at $Emego_3$ of Kugbo district for ^{238}U and ^{40}K while ^{232}Th was recorded at Anyu3 of Arughuya district. The wide variations in the activity concentration values of these radionuclides are mainly due to their accumulation in soil component of the area. The results show that the mean activity concentration of ^{238}U, ^{232}Th and ^{40}K are higher when compared with Worldwide average values (35 $Bqkg^{-1}$ for ^{238}U, 30 $Bqkg^{-1}$ for ^{232}Th and 400 $Bqkg^{-1}$ for ^{40}K) of this radionuclide in the soil (UNSCEAR, 2000).

Radium Equivalent Activity (Raeq)

The radium equivalent activity (Raeq) was calculated using equation 2. The radium equivalent activity represents a weighted sum of activities of ^{238}U, ^{232}Th and ^{40}K. It is based on the fact that 370 $Bqkg^{-1}$ of ^{238}U, 259 $Bqkg^{-1}$ of ^{232}Th, and 4810 $Bqkg^{-1}$ of ^{40}K produce the same gamma

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radiation dose rate (Farai and Ademola 2005). Raeq is related to the external γ-dose and internal dose due to radon and its daughters.

$$Raeq = A_U + 1.43A_{Th} + 0.077A_K \quad \text{---------- (2)}$$

Where A_k, A_U and A_{Th} are the activity concentrations of ^{40}K, ^{238}U and ^{232}Th in Bq/Kg respectively. As can be seen in Table 1, the radium equivalent values for the soil samples varied from 414.3 Bqkg-1 to 2376.6 $Bqkg^{-1}$ with an average value of 1380.74$Bqkg^{-1}$. It is noteworthy that all the Raeq values exceeded the maximum permissible limit of 370 $Bqkg^{-1}$ (Grupta *et al*., 2010).

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 (^{238}U, ^{232Th} and^{40}K) were calculated based on the guidelines provided by UNSCEAR, 2000.

$$D\ (nGy/h) = 0.462A_u + 0.604A_{Th} + 0.041A_k \text{ ----------} \quad (3)$$

Where A_k, A_U and A_{Th} are the activity concentrations of ^{40}K, ^{238}U and ^{232}Th in $Bqkg^{-1}$ respectively.

The absorbed dose rate values (Table 2) range between 309.5 and 1266.5 $nGyh^{-1}$ with a mean value of 654.2 nGy h^{-1}. The estimated mean value of *D* ($nGyh^{-1}$) in the studied samples is 77% higher than the world average (populated-weighted) absorbed gamma dose rate of 84 nGy $h^{-1.}$

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 (UNSCEAR, 2000; Ravisankar et al., 2012):

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

The annual effective dose (Table 3), ranged between 0.38 and 1.55 $mSvy^{-1}$ with mean value of 0.80 $mSvy^{-1}$. In normal background areas, the average annual outdoor effective dose from terrestrial radionuclides is 0.48 $mSvy^{-1}$ (UNSCEAR,1993). However, the mean annual effective dose calculated in this study is higher than the permissible value of 0.48 $mSvy^{-1}$.

Radiation Hazard Indices

Beretka and Mathew (1985) defined two other indices that represent external and internal radiation hazards. External hazard index H_{ex} and internal hazard index H_{in} 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 (H_{ex}) and internal hazard index (H_{in}) can then be defined as

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$$H_{ex} = \left(\frac{AU}{370Bqkg^{-1}}\right) + \left(\frac{ATh}{259Bqkg^{-1}}\right) + \left(\frac{AK}{4810Bqkg^{-1}}\right) \text{----------(5)}$$

$$H_{in} = \left(\frac{AU}{185Bqkg^{-1}}\right) + \left(\frac{ATh}{259Bqkg^{-1}}\right) + \left(\frac{AK}{4810Bqkg^{-1}}\right) \text{---------- (6)}$$

Where A_k, A_U and A_{Th} are the activity concentrations of ^{40}K, ^{238}U and ^{232}Th in Bq/Kg respectively.

These indices must be less than unity (1) for the radiation hazard to be insignificant. The calculated H_{ex} varies from 1.80 to 6.90 (Table 3). The mean value of Hex (3.74) is higher than unity. Also the calculated internal hazard index H_{in} varies from 1.89 to 7.20 with mean value of 3.91 which is higher than the unity. Therefore, these areas may pose significant radiological health risk to the inhabitants due to exposure to ionizing radiation from the natural radionuclides in the soil.

Gamma radiation representative level index (RLI)

Estimation of the level of gamma radioactivity associated with different concentrations of some specific radionuclides is known as the representative level index (Shanti et al., 2010), which is given as

$$RLI = \left(\frac{AU}{150}\right) + \left(\frac{ATh}{100}\right) + \left(\frac{AK}{1500}\right) \text{---------- (7)}$$

Where A_k, A_U and A_{Th} are the activity concentrations of ^{40}K, ^{238}U and ^{232}Th in Bq/Kg respectively. RLI calculated varies from 5.0 to 20.4 with mean value of 10.7. Values of RLI ≤ 1 corresponds to an annual effective dose of less or equal to 1mSv. RLI in all the locations studied exceeded unity therefore the area is radiologically hazardous.

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 (Taskin *et al*., 2009)

$$ELCER = AEDE \times DL \times RF \quad \text{---------- (8)}$$

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. ELCR calculated varies from 13.3×10^{-3} to 54.3×10^{-3} with an average value of 27.9×10^{-3}. ELCR is higher than the world permissible value of 0.29×10^{-3} (Taskin et al., 2009).

Annual Gonad Equivalent Dose (AGED)

The gonads, the bone marrow and the bone surface cells are considered as organs of interest by UNSCEAR (2000) because of their sensitivity to radiation. An increase in AGED has been known to affect the bone marrow, causing destruction of the red blood cells that are then replaced by white blood cells. This situation results in a blood cancer called leukemia which is fatal. It is calculated using the equation (Avwiri et al., 2014).

$$AGED\ (mSv/yr) = 3.09A_U + 4.18A_{Th} + 0.314A_K \quad \text{---------- (9)}$$

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Where A_k, A_U and A_{Th} are the activity concentrations of ^{40}K, ^{238}U and ^{232}Th in Bq/Kg respectively. AGED varies from 2207.6 to 9259.5 with mean value of 4775.1. This mean value is higher than the world acceptable value of 300, therefore might pose a threat to the bone marrow and the bone surface of the residents of the area.

Table 1 Specific activity of ^{40}K, ^{238}U and ^{232}Th in soil samples and their radium equivalent value

S/N	District	Sample	^{40}k (Bq/Kg)	^{238}u (Bq/Kg)	^{232}Th (Bq/Kg)	Raeq (Bq/Kg)
1	Kugbo	Emago 1	8 875.32±445.49	78.70±18.46	855.51±147.17	1 985.5
2		Emago 2	21064.15±1143.41	64.51±16.44	955.56±56.46	2 548.8
3		Emago 3	21103.64±1150.67	184.90±39.63	928.69±83.79	3 137.9
4	Adibom	Emelego 1	4 773.32±250.48	34.72±8.76	357.69±62.59	913.8
5		Emelego 2	5 196.58±265.40	14.24±3.70	BDL	414.3
6		Emelego 3	12 833.21±709.61	33.23±8.31	495.46±47.31	1 729.9
7	Arughuya	Anyu 1	20164.04±1095.01	165.94±35.01	460.14±44.09	2 376.6
8		Anyu 2	18 017,71±983.32	119.63±25.26	490.59±46.59	2 208.5
9		Anyu 3	21513.16±1174.34	26.58±7.01	979.89±88.20	3 084.3
10	Abua central	Ogbema 1	4 023.45±271.37	20.38±5.15	232.01±22.95	661.9
11		Ogbema 2	3 525.58±219.45	31.49±7.75	285.15±27.52	710.7
12		Ogbema 3	897.05±63.20	52.88±12.83	355.33±61.96	630.1
13	Okpeden	Egbolom 1	2 541.451±164.09	32.47±7.51	486.06±45.96	923.2
14		Egbolom 2	4 052.56±254.17	17.65±4.77	405.37±39.22	909.4
15		Egbolom 3	2 926.90±190.42	17.54±4.36	452.36±41.99	889.8
16	Otapha	Agada 1	4 689.70±294.16	137.07±29.47	756.31±69.41	1 579.7
17		Agada 2	2 765.00±176.85	101.98±22.46	466.29±43.82	880.7
18		Agada 3	5 604.36±348.24	59.27±13.75	546.01±51.23	1 271.6
19	Emughan	Aminigboko 1	1 547.36±93.81	79.94±19.10	507.27±88.19	924.5
20		Aminigboko 2	3 807.26±235.38	23.86±6.31	353.85±34.03	796.4
21		Aminigboko 3	2 651.47±166.60	27.57±6.65	130.26±13.26	418.0
		Mean	**8 217.77**	**67.40**	**507.19**	**1 380.74**
		Standard	**400**	**35**	**30**	**370**

Table 2 Specific activity of ^{40}K, ^{238}U and ^{232}Th in soil samples and their radium equivalent value

S/N	**District**	**Sample**	**^{40}K (Bq/Kg)**	**^{238}U (Bq/Kg)**	**^{232}Th (Bq/Kg)**	**Raeq (Bq/Kg**
1	Kugbo	Emago	17014.37±913.2	109.37±24.8	913.25±95.81	2557.4
2	Adibom	Emelego	7601.04±408.50	27.22±6.92	284.38±36.63	1019.3
3	Arughunya	Anyu	19898.30±1084	104.05±22.4	643.54±59.63	2556.5
4	Abua centr	Ogbema	2815.36±184.67	69.50±8.58	290.83±37.47	667.6
5	Okpeden	Egbolom	3173.64±202.90	22.54±5.54	447.93±42.39	907.5
6	Otapha	Agada 2	4353.02±273.08	99.44±21.89	589.53±54.82	1244.0
7	Emughan	Aminigboko	2668.67±165.26	43.79±13.05	330.56±45.16	713.0
	Mean		**8217.77**	**67.40**	**507.19**	**1380.7**
	Standard		**400**	**35**	**30**	**370**

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Table 3 Radiation Hazard Parameters for Soil Samples

S/N	DISTRICT	VILLAGE SAMPLING SITE	D $nGyh^{-1}$	H_{ex}	H_{in}	RLI	AEDE $mSvy^{-1}$	ELCR $\times10^{-3}$	AGED
1	Kugbo	Emago	1174.7	6.90	7.20	20.0	1.440	50.4	9006.6
2	Adibom	Emelego	501.4	2.75	2.83	8.1	0.614	21.5	3660.3
3	Arughunya	Anyu	1266.5	6.90	7.19	20.4	1.553	54.3	9259.5
4	Abua Central	Ogbema	309.5	1.80	1.89	5.0	0.379	13.3	2207.6
5	Okpeden	Egbolom	413.3	2.45	2.51	6.8	0.506	17.7	2738.5
6	Otapha	Agada 2	583.6	3.45	3.67	9.4	0.715	24.4	4138.4
7	Emughan	Aminigboko	993.3	1.95	2.07	5.4	0.406	14.2	2354.6
		Mean	**654.2**	**3.74**	**3.91**	**10.7**	**0.802**	**27.9**	**4795.1**

Multivariate Statistical Analysis

Statistical tools were used to describe the statistical characteristics of radionuclides analyzed in soil samples. Conventional and multivariate statistical procedures for data treatment and histograms were performed using the commercial statistics software package SPSS version16.0 for Windows. Cluster analysis and Pearson correlation were carried out in order to clarify the relationship among the variables, especially the influence of soil parameters on the distribution of natural radionuclides. Cluster analysis is a useful statistical method which presents visually the degree of association among variables. The distance axis displays the degree of association between groups of variables, ie, the lower the value on the axis, the more significant the correlation (SureshGandhi et al., 2014).

Basic Statistics

The results of the statistical behaviour of the measured radionuclides are presented in Table 4. The basics statistics show that the arithmetic mean of the activity concentration of ^{238}U, ^{232}Th and ^{40}K are different from each other but are close within the standard deviation. In industrial areas rain water is usually acidic due to the presence of So_2 in the atmosphere and this acidic rain mobilizes some radionuclides in soil especially ^{238}U (Sheppard and Sheppard,1988). In probability theory and statistics according to Sivakumar et al., (2014)," Skewness is a measure of the asymmetry of the probability distribution of a real valued random variable." There are many advantages of carrying out skewness analysis of data. Many models assume normal distribution, ie data are symmetric about the mean. The normal distribution has skewness of zero which is not possible in reality because experimental data points may not be perfectly symmetric. Therefore an understanding of Skewness of a data set indicates whether deviations from the mean are going to be positive or negative. Skewness characterizes the degree of asymmetry of a distribution around its mean (Groeneveid and Meeden, 1984).

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Table 4: Descriptive statistics of the Radionuclides

Variables	*40K*	*238U*	*232Th*	*Raeq*
Mean	6751.672	61.09	431.1283	1184.65
Standard Error	2734.207	14.51388	63.72461	287.4858
Median	3763.33	56.645	389.245	963.4
Standard Deviation	6697.411	35.5516	156.0928	704.1934
Sample Variance	44855311	1263.916	24364.96	495888.4
Kurtosis	4.391626	-2.22383	-1.98287	4.195508
Skewness	2.081253	0.233411	0.522508	1.987136
Range	17229.63	81.51	359.16	1888.9
Minimum	2668.67	22.54	284.38	667.6
Maximum	19898.3	104.05	643.54	2556.5
Sum	40510.03	366.54	2586.77	7107.9
Count	6	6	6	6
Confidence Level(95.0%)	7028.502	37.30912	163.8093	739.0057

positive skewness shows a distribution with an asymmetric tail extending towards values that are more positive. Negative skewness shows a distribution with an asymmetric tail extending towards values that are more negative. Lower skewness value form generally normal distributions. All the radionuclides have positive skewness values (Table 4) which indicate the asymmetric nature.

Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. That is , data sets with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly and have heavy tails. It characterizes the relative peakedness or flatness of a distribution compared with the normal distribution. Higher kurtosis means more of the variance is a result of infrequent extreme deviations, as opposed to frequent modestly sized deviations. In this study, ^{40}K has positive kurtosi showing a peaked distribution while ^{238}U and ^{232}Th have negative kurtosis showing a flat distribution.

Histograms

The frequency distributions of all radionuclides were analyzed and the histograms are given in figures 2-4. The histograms shows that ^{238}U, ^{232}Th and ^{40}K exhibited some degree of multi-modality. This multi-model feature of the radio-elements demonstrates the complexity of minerals in soil samples.

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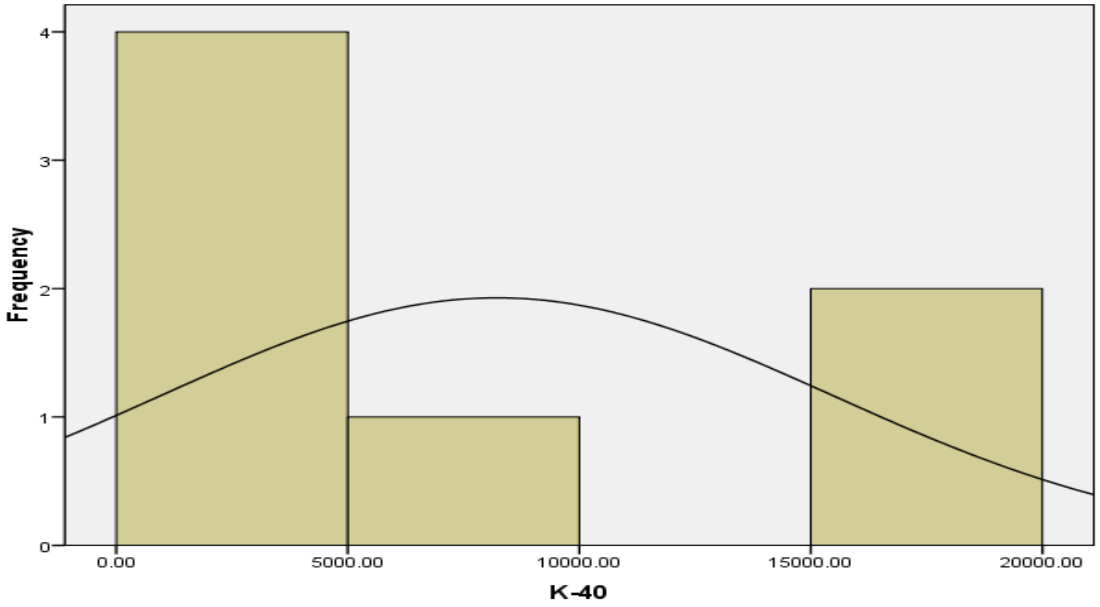

Fig. 2. The Frequency Distribution of the activity Concentration of ^{40}K

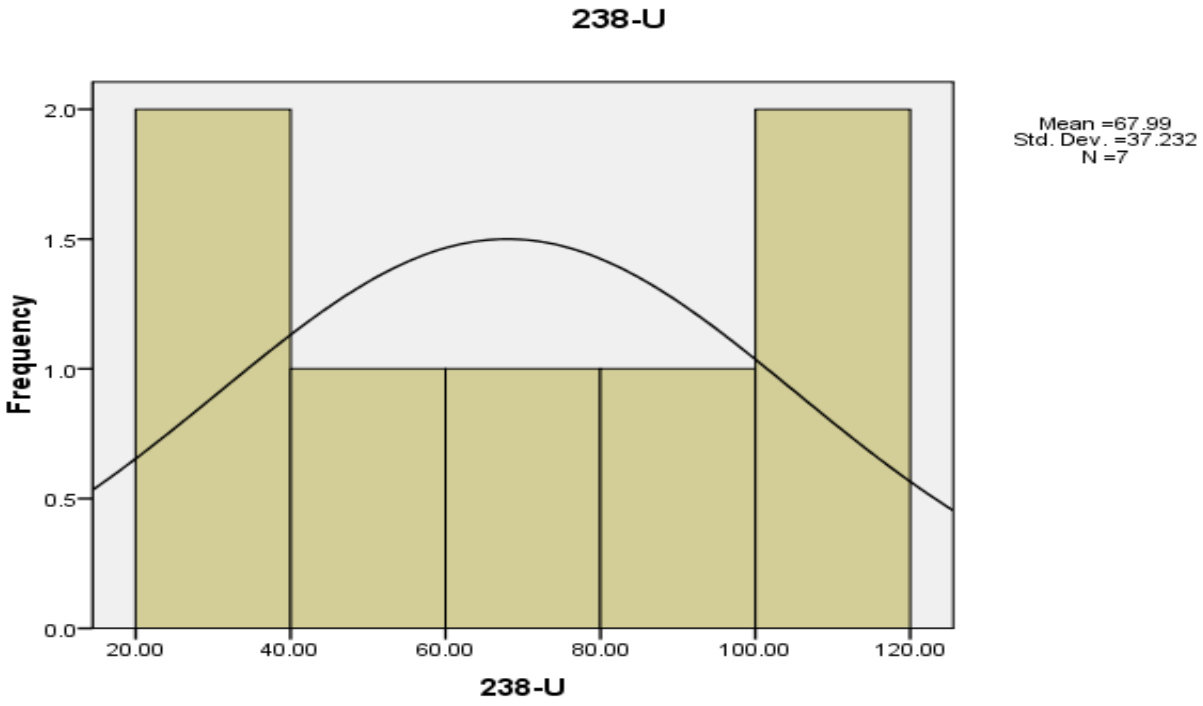

Fig. 3. The Frequency Distribution of the activity concentration of ^{238}U

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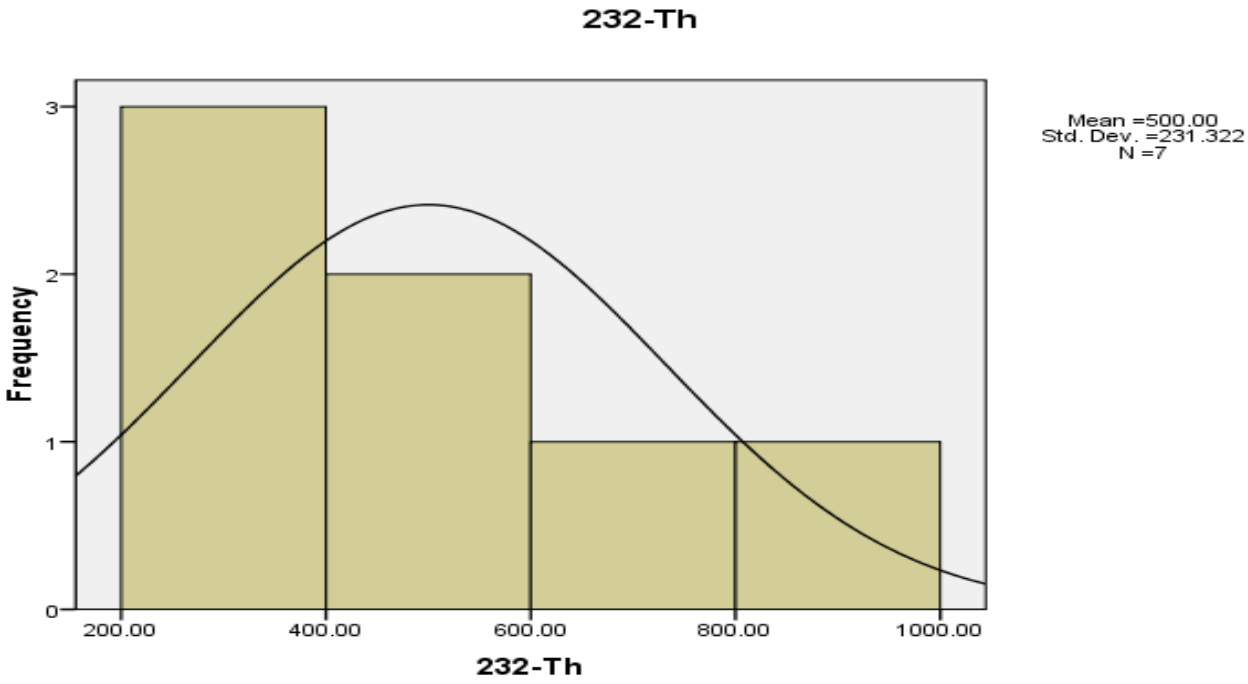

Fig. 4. The Frequency Distribution of the activity concentration of ^{232}Th

Pearson's Correlation Coefficient Analysis

Table 5 Pearson correlation coefficient between radioactive variables in soil samples

	40K	*238U*	*232Th*	*Raeq*	*D*	*AEDE*	*AGED*	*Hex*	*Hin*	*RLI*
40K	1									
238U	0.645556	1								
232Th	0.739517	0.774709	1							
Raeq	0.969126	0.748398	0.878847	1						
D	0.788658	0.575148	0.662568	0.795907	1					
AEDE	0.978801	0.739059	0.846722	0.997419	0.798414	1				
AGED	0.979668	0.744794	0.853849	0.998327	0.80298	0.998588	1			
Hex	0.966438	0.754853	0.88237	0.99988	0.796289	0.997224	0.99796	1		
Hin	0.963649	0.764821	0.885623	0.999501	0.799403	0.996654	0.997506	0.999845	1	
RLI	0.975743	0.738918	0.864702	0.999566	0.799004	0.998707	0.999382	0.999219	0.998602	1

Correlation analysis was carried out as a bivariation statistics in order to determine the mutual relationships and strength of association between the radionuclide and the estimated radiological parameters as shown in Table 5. There was a very good correlation between ^{238}U and ^{232}Th which could be as a result of their origin, radium and thorium decay series occurs

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together in nature (Sivakumar et al., 2014). The positive correlation coefficient was observed between ^{238}U, ^{232}Th and ^{40}K with all the radiological parameters. This implies that very strong relationship between the radionuclides in soil and radiological parameters. Hence this strong relationship shows the all three radionuclides contribute the emission of gamma radiation in all the districts.

Cluster Analysis

The purpose of cluster analysis (CA) is the identification and classification of groups with similar characters in a new group of observations or object. Each observation or object within each cluster is same but the cluster is dissimilar from each other. Similarity is a measure of distance between clusters relative to the largest distance between any two individual variables. The 100% similarity means that the clusters were zero distance apart in their sample measurements whereas 0% means the cluster areas are separated from each other. Cluster analysis was carried out through axes to identify similar characteristics among natural radioisotopes and radiological parameters in the soil.

The average linkage method along with correlation coefficient distance was applied and the derived dendrogram was shown in Figure 5. In this dendrogram, all the parameters were grouped into four statistically significant clusters. Cluster 1 was AEDE, ELCR, RLI and AGED while cluster 4 was D, ^{238}U and ^{232}Th which consisted of natural radionuclides and all radiological parameters distribution, which appear in the same cluster. All of the natural radioisotopes were represented as one group with similar characteristics as they originated from ^{232}Th and ^{238}U series. ^{40}K was identified in another cluster. The close relation between ^{238}U and ^{232}Th series members but not with ^{40}K was in accordance with the result (Chen et al., 2001). Cluster analysis proved to be useful semi-quantitative technique for analyzing the data and determining the linkages between soil samples from various locations.

Dendrogram using Average Linkage (Between Groups)

Rescaled Distance Cluster Combine

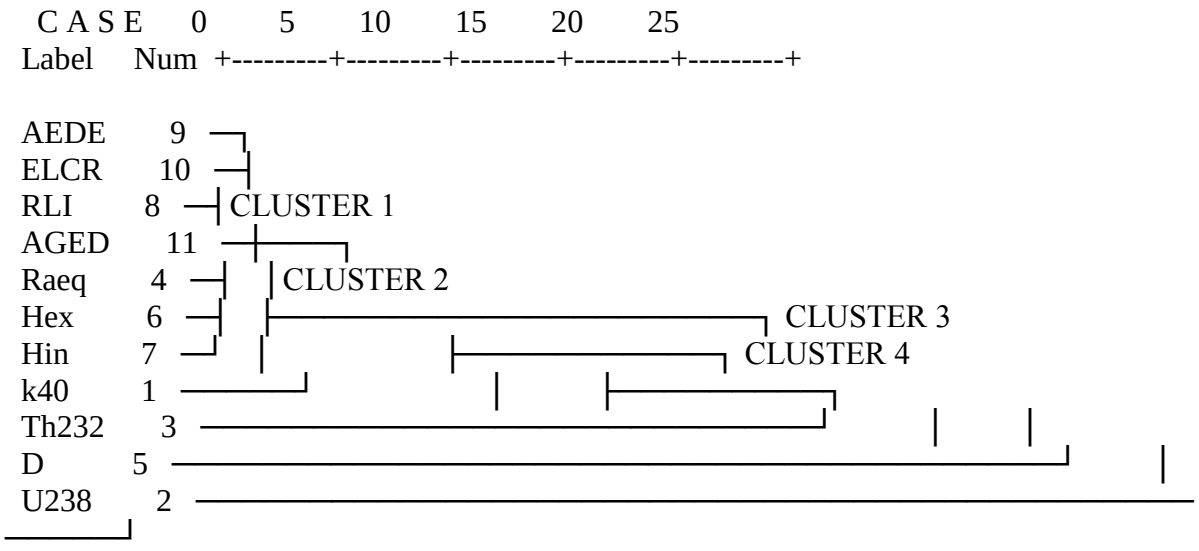

Fig. 5: Dendrogram shows the clustering of radionuclides

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CONCLUSION

The specific activity concentration of ^{238}U, ^{232}Th and ^{40}K in soils collected from seven districts of Abua/Odua Local Government Areas of Rivers State had been determined using gamma spectroscopy method. The activity concentrations of these radionuclides were higher than the safe limit stipulated by UNSCEAR (2000). There was a very good correlation between ^{238}U and ^{232}Th which could be as a result of their origin. The positive correlation coefficient was observed between ^{238}U, ^{232}Th and ^{40}K with all the radiological parameters evaluated. The result indicates that average value of the each radiological hazard parameters calculated are higher than the world average value reported in UNSCEAR. It implies therefore that potential radiological health hazard may directly be associated with the soil from the seven districts of Abua/Odua Local Government area.

The statistical method employed also revealed that the study area posses significant gamma emitting radionuclides which may be detrimental to the health of the general populace in the area. It is therefore recommended that further study be carried out extensively on other environmental media in the seven districts studied in order to determine the sources of this high concentration of ^{238}U, ^{232}Th and ^{40}K found in the soil. The result of this study could be helpful in radiological mapping of the area and as a baseline data for future studies.

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