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AN ASSESSMENT OF RADIONUCLIDE CONCENTRATION AND ABSORBED DOSE IN RAINWATER FROM SELECTED AREAS IN AKWA IBOM STATE, NIGERIA.

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ABSTRACT:

This study has been carried out mainly for the assessment of naturally occurring radionuclides i.e ^{40}K, ^{238}U and ^{232}Th in rain water samples collected from five LGAs in Akwa Ibom State, Nigeria. The activity concentrations of the naturally occurring radionuclides ^{40}K, ^{238}U and ^{232}Th in the rainwater samples were measured by the means of a gamma-ray spectrometry using a sodium Iodide Thallium doped NaI (TI) detector. The average activity concentration obtained for ^{40}K in all the location was 27.8 $\pm$2.50 $Bq.L^{-1}$ with a range of 9.4 $\pm$ 0.88 to 52.3 $\pm$ 4.26 $Bq.L^{-1}$, while for ^{238}U, the average activity concentration was 5.2 $\pm$ 0.88 $Bq.L^{-1}$ with a range of 1.2 $\pm$ 0.21 to 15.00 $\pm$ 2.92 $Bq.L^{-1}$, for ^{232}Th, the average activity concentration was 6.7 $\pm$ 0.69 $Bq.L^{-1}$ with a range of 0.1 $\pm$ 0.00 to 14.2 $\pm$ 1.41 $Bq.L^{-1}$. The total annual effective dose due to the intake of ^{40}K, ^{238}U and ^{232}Th by all the locations ranged from 0.08 $\pm$ 0.01 $mSv.y^{-1}$ to 1.53 $\pm$ 0.17 $mSv.y^{-1}$ with an average of 0.76 $\pm$ 0.08 $mSv.y^{-1}$ did not show any significant health impact since it is below the recommended public exposure limit of $1mSv.y^{-1}$. Also the calculated values of radium equivalent, absorbed dose rate, external and internal hazard index in all the locations were found to be lesser than the recommended values.

Keywords: Natural radionuclide, dose, gamma spectroscopy, radiation, hazard index, activity concentration and rainwater

1. INTRODUCTION

Water is a very important commodity and the most common solvent in the world without which there is no life. Radionuclides are present in the air that humans breathe and in food and drinking water [1, 2] consumed by man and in the ground from which human settlements are built [3]. Enhanced levels of uranium, thorium and their daughter products might be present in water in area that is rich in natural radioactivity or through human activities. The dumping of large amount of waste materials in site without adequate soil protection measures results in soil as well as, surface and ground water pollution [4] Contaminants from human activities pass into air, soil and water, and, hence into fish crops and other animals. The input of radionuclides such as ^{40}K to the environment is derived from terrestrial soil and atmospheric diffusion [5]. Considering the high radio toxicity of ^{226}Ra and ^{228}Ra, their presence in water and the associated health risks require particular attention.

A radionuclide is an atom with an unstable nucleus which, to become more stable, emits energy in the form of rays or high speed particles which are known as ionizing radiation [6]. Radiation damage to tissue and/or organ depends on the dose of radiation received, or the absorbed dose which is expressed in a unit called the gray [Gy] [7].The potential damage from an absorbed dose depends on the type of radiation and the sensitivity of different tissues and organs. Radionuclides when ingested or inhaled enter the human body and are distributed among body organs according to the metabolism of the element involved. The organs normally exhibit varying sensitivities to the radiation and thus, varying dose and risk result from their consumption and inhalation [8]. Beyond certain thresholds, radiation can impair the functioning of tissues and/or organs and can produce acute effects such as skin redness, hair loss, radiation burns, or acute radiation syndrome [7]. These effects are more severe at higher instance; the dose threshold for acute radiation syndrome is about 1000 mSv. If the dose is low or delivered over a long period of time (low dose rate), there is greater likelihood for damaged cells to successfully repair themselves. However, long term effects may still occur if the cell damage is repaired but incorporates errors, transforming an irradiated cell that still retains its capacity for cell division. This transformation may lead to cancer after years or even decades have passed. Effects of this type will not always occur, but their likelihood is proportional to the radiation dose. This risk is higher for children and adolescents, as they are significantly more sensitive to radiation exposure than adults. Epidemiological studies on populations exposed to radiation (for example atomic bomb survivors or radiotherapy patients) showed a significantly increase of cancer risk at doses about 100 mSv [7]. Prenatal exposure to ionizing radiation may induce brain damage in foetuses following an acute dose exceeding 100 mSv between 8-15 weeks of pregnancy and 200 mSv between 16-25 weeks of pregnancy. Before the 8^{th} week or after the 25^{th} week of pregnancy human studies have not shown radiation risk to fetal brain development. Epidemiological studies indicate that cancer risk after fetal exposure to radiation is similar to the risk after exposure in early childhood.

2. MATERIALS AND METHODS

2.1 Study Area

Akwa Ibom is a state in Nigeria. It is located in the Coastal Southern part of the country, lying between Latitudes $4^{o}32^{o}N$ and $5^{o}33^{o}N$, and Longitudes $7^{o}25^{o}E$ and $8^{o}25^{o}E$. It consists of 31 Local government areas (L.G.A). It covers an area of about $7,081Km^2$ (2,734Sqmi). As at 2005, it estimated population was about 4,805,470. The major cities in the state are Uyo, Eket, Ikot Ekpene, Oron, Abak, Ikot Abasi, Ikono, Etinan, Esit, Eket and Uruan. The major ethnic groups of the state are Ibibio, Annang, Oron, Eket and Obolo.

For this study, five L.G.A of Akwa Ibom State were considered. The Local Government Areas include Uyo, Ikot Ekpene, Essien Udim, Obot Akara and Ikono. The choice for Uyo and Ikot Ekpene L.G.A for this study is based on the fact that this L.G.As has larger population when compare to others and also a lot of economic activities takes place in these areas. While the other L.G.As were choosing based on preference. Uyo is a city and Local Government Area in South-South Nigeria and is the capital of Akwa Ibom State, a major oil producing state. The population of Uyo, according to the 2006 Nigeria census which comprises of Uyo and Itu, is 436,606. While the

urban area, including Uruan, is 554,906. The Area of Uyo and Itu is about 115Km^2 (44Sqmi), while the urban area is 168Km^2 (65Sqmi). Some of the localities under Uyo L.G.A which were considered for this study include Eniong Offot, Obio- Offot, Plaza, Mbribit- Itam, Abiakpo Ikot Essien, Ewet Housing Estate, Itiamu Ikot Ebia, Mbereba Obio, Uniuyo permanent site, Ikot Okubo. Ikot Ekpene is a historical town in the Southern Nigeria in Akwa Ibom State. It has a total area of 200Km^2 (80Sqmi) and its population as at 2005 was 230,000. Some of the localities in Ikot Ekpene considered for this study include Ifuho, Ikot Inyang, Ikot Osurua, Ikot Obong Edong, Ikot Abia Idem, Ikot Enwang and Ikot Uboh.

Essien Udim is one of the annang speaking L.G.A in Akwa Ibom State, Nigeria. It was created out of the former Ikot Ekpene division and includes the following clans in Annang land; Ukana, Adiasim, Ikpe, Okon, Nsasak, Ekpenyong Atai and Ukana Ikot Ntuen, Odoro Ikot, Afaha. The localities considered for this study include Ukana West, Ukana East, Uwa, Urua Edet Obo, Nsasak. In Obot – Akara L.G.A, the localities considered are Ikot Mboho, Abiakpo Idiaha, Oruk Osung, Ikot Ikot and Ubon Akwa. The localities considered for this study in Ikono L.G.A of Akwa Ibom State are Oduk, Nung Ukim and Iton Odoro.

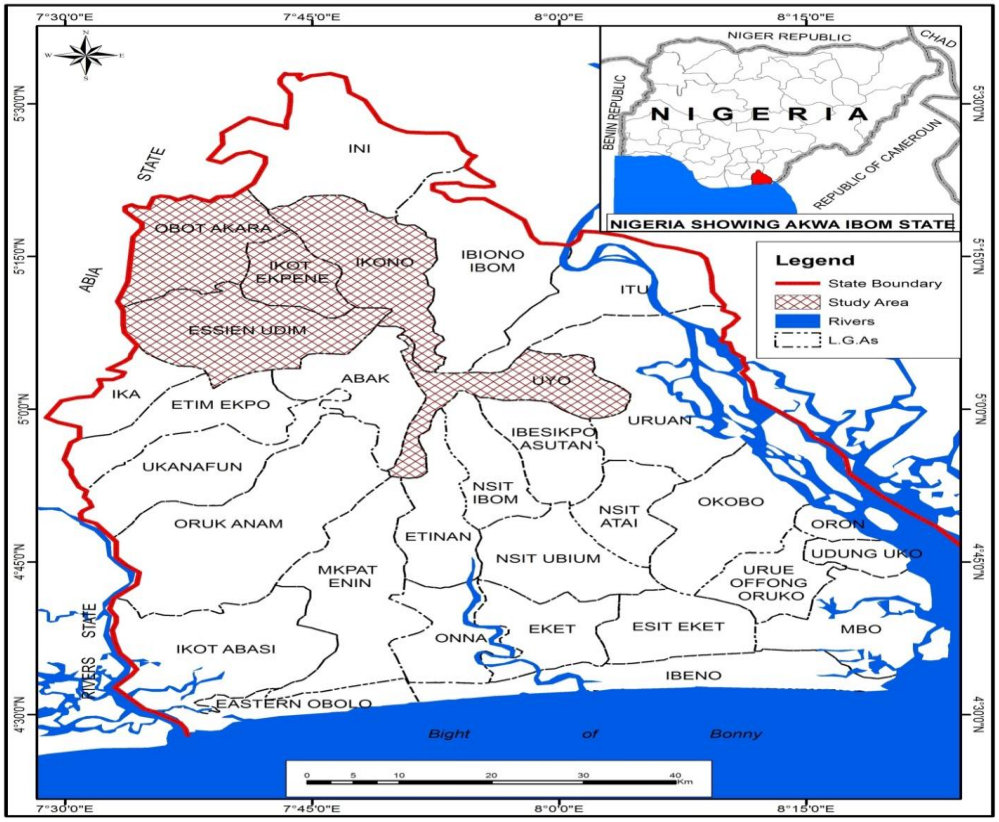

Figure 1: Map of Akwa Ibom State Showing study Areas

2.2 Sample collection and treatment

The rainwater samples were collected directly from the sky i.e free falling rainwater and the container for collecting them was placed on top of a support which was a distance of 1.5m from the ground in other to avoid unwanted particles from entering the samples collected with the aid of a funnel. The rainwater samples were collected from five Local Government Areas in Akwa Ibom States. The L.G.As includes Uyo, Ikot-Ekpene, Essien Udim, Ikono and Obot Akara. In Uyo L.G.A, a sample of rainwater was collected each from ten(10) different localities which includes Eniong Offot, Obio-Offot, Plaza, Mbribit-Itam, Abiakpo Ikot Essien, Ewet Housing Estate, Itiam Ikot

Ebia, Mbereba Obio, Uniuyo permanent site and Ikot Okubo, making a total of ten(10) rainwater samples from Uyo L.G.A. From Ikot Ekpene LGA, samples of rainwater were also collected from seven (7) different localities. In Essien Udim and Obot Akara LGAs, samples of rainwater were collected from five different localities making a total of ten (10) samples from those LGAs. Also three samples of rainwater were collected from three different localities in Ikono LGA. Hence the total number of samples collected from the five (5) LGAs, is thirty (30). At the point of collection, each sample was given a sample code. Also at the specific location were the sample was collected, the Global positioning system (GPS) was used in taking the coordinate of each sample.

Each sample consists of one liter of rainwater and was acidified at the rate of 10mL of 11m H_2S0_4 per liter of rainwater to obtain a PH less than 2 in other to prevent the absorption of the radionuclides into the wall of the container and then sealed in a properly cleaned container for at least one month so as to attain a state of secular radioactive equilibrium before analysis.

2.3 Measurement of Activity Concentration

The method employed for the measurement of the activity concentration in the samples was the gamma ray spectroscopy. The detector used for the radioactivity measurements is a lead-shielded 76 x 76 mm Sodium Iodide Thallium NaI (TI) doped detector crystal (Model No.802 series, Canberra Inc.) coupled to a Canberra series multichannel Analyzer (MCA) (Model N0.1104) through a preamplifier. It has a resolution full width at half maximum (FWHM) of about 8% at energy of 0.662 Mev. The choice of radionuclides to be detected was predicted based on the fact that the NaI (TI) detector has a modest resolution.

The samples were placed symmetrically on top of the detector and measured for a period of 10 hours. The net area under the corresponding peaks in the energy spectrum was computed by subtracting counts due to Compton scattering of higher peaks. From the net area, the activity concentrations in the samples were obtained using [9, 10].

$$C(Bq.L^{-1}) = KC_n \quad - - - - - - \quad (1)$$

$$\text{Where } K = \frac{1}{\varepsilon P_\gamma V_s} \quad - - - - - - \quad (2)$$

C is the activity concentration of the radionuclides in the samples in $Bq.L^{-1}$, C_n is the count rate under the corresponding peak, ε is the detector efficiency at the specific ϒ-ray energy, P_γ is the absolute transition probability of the specific ϒ-ray energy, and V_s the volume of the sample in litres.

3. RESULTS AND DISCUSSIONS

3.1 Radionuclide Activity concentrations

The values for the activity concentrations of the radionuclide in the rainwater samples for all the locations are shown in table 1 below. The activity concentration for ^{238}U in all the locations ranges from 1.2 ± 0.21 $Bq.L^{-1}$ – 15.0 ± 2.92 $Bq.L^{-1}$ with an average of 5.2 ± 0.88 $Bq.L^{-1}$ and the highest activity concentration for ^{238}U in all the locations was in Mbrit-Itam (15.0 ± 2.92 $Bq.L^{-1}$) in Uyo LGA and the lowest was in Ikot Enwang (1.2 ± 0.21 $Bq.L^{-1}$) in Ikot Ekpene LGA. Also, the activity concentration for ^{232}Th in all the locations ranges from 0.1 ± 0.00 – 14.2 ± 1.41 $Bq.L^{-1}$ with an average of 6.7 ± 0.69 $Bq.L^{-1}$. The highest activity concentration for ^{232}Th in all the locations was in Mbribit-Itam (14.2 ± 1.41 $Bq.L^{-1}$) in Uyo LGA and the lowest was in Iton Odoro (0.1 ± 0.00 $Bq.L^{-1}$) in Ikono LGA.

Figure 2 is a bar chart representation of the mean activity concentration of ^{40}K, ^{238}U and ^{232}Th in rainwater samples. It shows that Ikot Ekpene and Obot Akara LGAs have the highest activity concentrations of ^{40}K while Ikono has the lowest. The largest contribution to the overall activity concentration in the rainwater samples from all the locations came mainly from ^{40}K In fact; this cannot be a surprise because ^{40}K is a naturally occurring radionuclide which abounds in the earth crust and in human body [11]. The activity concentration due to ^{232}Th is relatively low in all the samples investigated when compared to that due to ^{238}U. This is because ^{238}U is more mobile than ^{232}Th [11].

Table 1: Activity concentrations of ^{40}K, ^{238}U and ^{232}Th in rain water samples from all locations

LGA	Samples code	Locations (degrees) North	Locations (degrees) East	Activity concentrations in Bq.L^{-1} ^{40}K	^{238}U	^{232}Th
	Uy 1	5.0283	7.9520	25.4 ± 3.28	9.5 ± 2.01	4.1 ± 0.45
	Uy 2	5.0166	7.8793	30.4 ± 2.71	4.8 ± 0.76	7.2 ± 0.75
	Uy 3	5.0343	7.9277	16.3 ± 1.50	BDL	5.5 ± 0.61
	Uy 4	5.0532	7.8803	48.2 ± 4.06	15.0 ± 2.92	14.2 ± 1.41
	Uy 5	5.0445	5.0445	33.5 ± 3.03	8.8 ± 1.83	9.1 ± 0.99
UYO	Uy 6	5.0138	7.9463	24.6 ± 2.31	11.6 ± 2.01	12.5 ± 1.27
	Uy 7	5.0216	7.9368	28.7 ± 2.62	6.2 ± 1.21	9.8 ± 0.98
	Uy 8	4.9907	7.9037	18.4 ± 1.65	7.5 ± 1.35	3.5 ± 0.38
	Uy 9	5.0306	7.9882	27.4 ± 2.68	1.7 ± 0.32	3.8 ± 0.40
	Uy 10	5.0207	7.8917	31.4 ± 2.92	10.3 ± 2.29	10.9 ± 1.13
			AVERAGE	28.4 ± 2.68	7.5 ± 1.47	8.0 ± 0.84
	IE 11	5.1717	7.6901	9.4 ± 0.88	3.0 ± 0.45	6.8 ± 0.72
	IE 12	5.1630	7.6766	45.8 ± 4.00	3.8 ± 0.78	10.9 ± 1.15
	IE 13	5.1594	7.6665	52.3 ± 4.26	4.1 ± 0.74	14.1 ± 1.44
IKOT	IE 14	5.1802	7.7103	43.9 ± 3.80	BDL	7.0 ± 0.78
EKPENE	IE 15	5.2033	7.6988	29.1 ± 2.53	2.4 ± 0.46	9.0 ± 0.92
	IE 16	5.1615	7.6760	26.7 ± 2.43	1.2 ± 0.21	5.3 ± 0.55
	IE 17	5.1757	7.6584	30.2 ± 2.66	10.5 ± 1.64	11.6 ± 1.18
			AVERAGE	33.9 ± 2.94	4.2 ± 0.61	9.3 ± 0.96
	EU 18	5.1046	7.7101	33.5 ± 3.23	5.9 ± 0.82	4.0 ± 0.45
	EU 19	5.1202	7.6648	24.8 ± 2.20	2.0 ± 0.33	7.0 ± 0.60
ESSIEN	EU 20	5.1564	7.6493	22.5 ± 1.97	3.6 ± 0.54	2.7 ± 0.30
UDIM	EU 21	5.1738	7.6810	21.5 ± 1.84	11.9 ± 1.82	6.0 ± 0.63
	EU 22	5.1538	7.6951	17.6 ± 1.52	BDL	1.8 ± 0.20
			AVERAGE	24.0 ± 2.15	5.8 ± 0.88	4.3 ± 0.44
	OA 23	5.1542	7.5288	40.1 ± 3.26	4.3 ± 0.79	9.4 ± 0.92
	OA 24	5.1710	7.5473	46.9 ± 4.02	10.3 ± 1.68	13.0 ± 1.31
OBOT	OA 25	5.1556	7.6767	45.7 ± 3.93	4.9 ± 0.65	12.4 ± 1.28
AKARA	OA 26	5.1706	7.5118	15.0 ± 1.36	3.1 ± 0.63	5.4 ± 0.61
	OA 27	5.1715	7.6432	22.2 ± 2.12	7.3 ± 1.05	4.1 ± 0.43
			AVERAGE	33.9 ± 3.01	6.0 ± 0.96	8.9 ± 0.91
	IK 28	5.2691	7.7230	13.9 ± 1.19	2.2 ± 0.40	5.1 ± 0.53
IKONO	IK 29	5.2571	7.7231	17.1 ± 1.57	2.8 ± 0.47	3.6 ± 0.41
	IK 30	5.2417	7.7057	25.8 ± 2.30	2.7 ± 0.51	0.1 ± 0.00
			AVERAGE	18.9 ± 1.69	2.6 ± 0.46	2.9 ± 0.31

BDL= BELOW DETECTION LIMIT

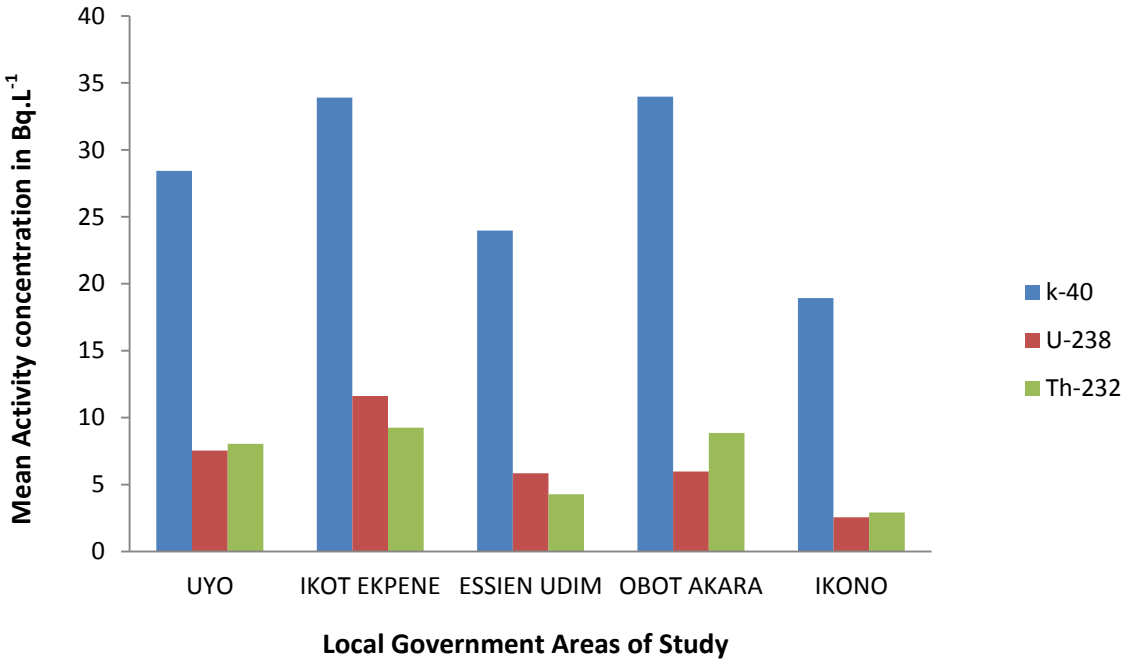

Figure 2: The distribution of the mean activity concentrations for ^{40}K, ^{238}U and ^{232}Th in $Bq.L^{-1}$ for rain water samples from the study areas.

3.2 Contour Maps of the Radionuclides ^{40}K, ^{238}U and ^{232}Th

Global Positioning System receiver Garmin (GPS 12 XL) was used to record the latitude and longitude of each sample point. The coordinates of each were converted to degree decimal unit using CASIO (fx – 991MS) calculator. The World Geodetic System of 1984 was used for definition of the coordinate system and it was used to generate the contour lines. The contour maps of the activity concentration of ^{40}K, ^{238}U and ^{232}Th in the study area are shown in Figures 3 – 5. In Figures 3 – 5, the numbers on the contour lines represent the Activity Concentrations of the radionuclide involved and the intervening spaces are marked with colours to further highlight the concentrations of these radionuclides. The higher the number on the contour line, the higher the concentration of the radionuclide involved. From the contour maps, it is observed that the closer the contour lines the higher the Activity Concentration. This could be used in the prediction of Activity Concentration in the areas outside the study areas.

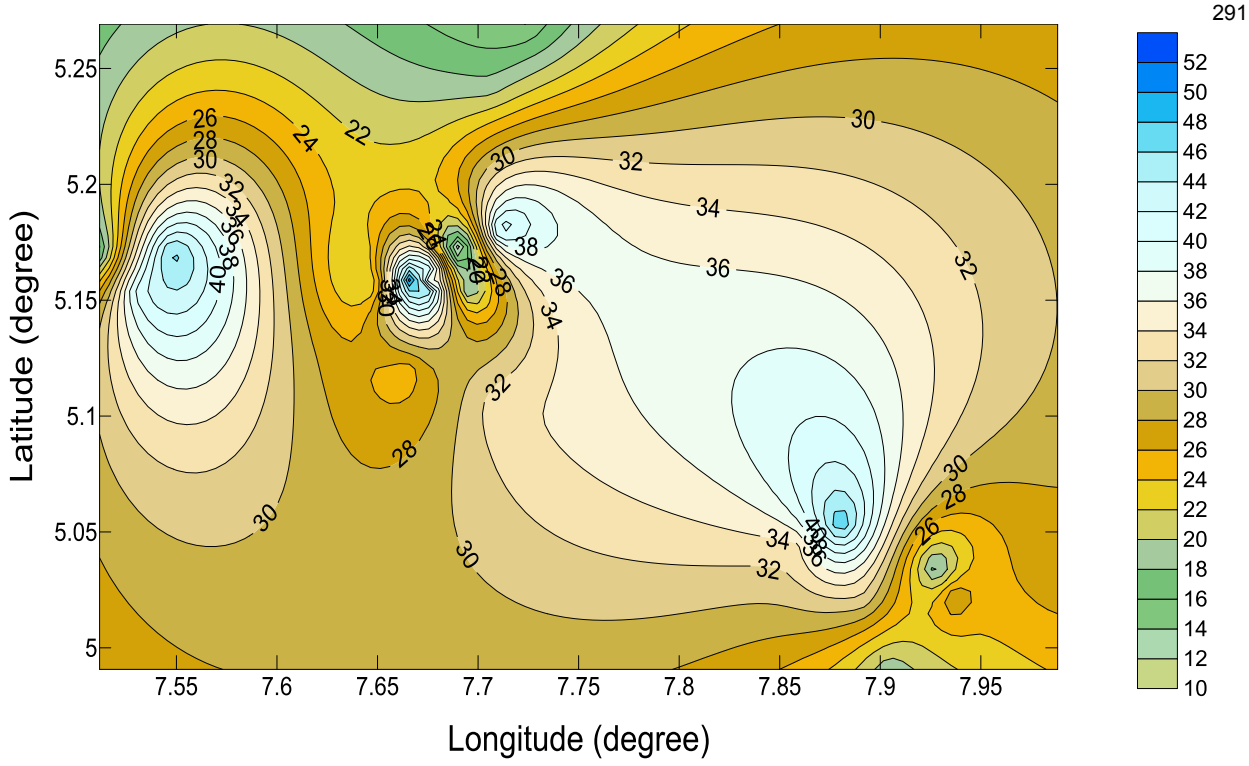

Figure 3: Contour diagram for the activity concentration of ^{40}K in Bq.L^{-1} for the collected samples.

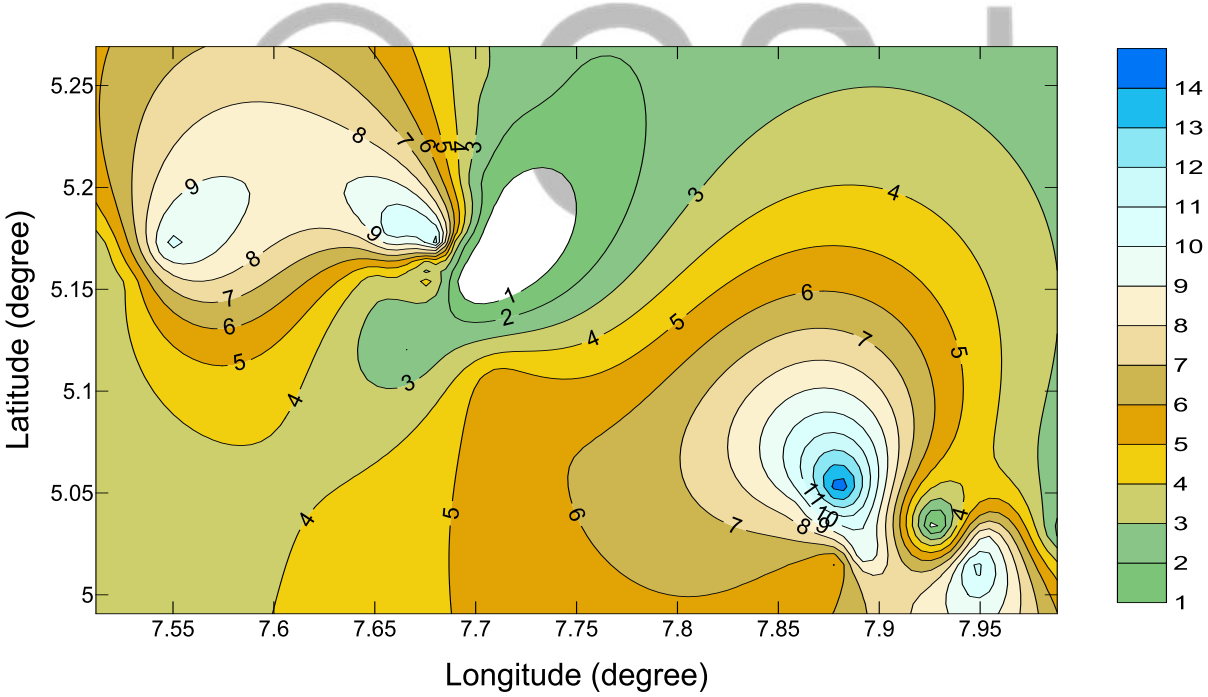

Figure 4: Contour diagram for the activity concentration of ^{238}U in Bq.L^{-1} for the collected samples.

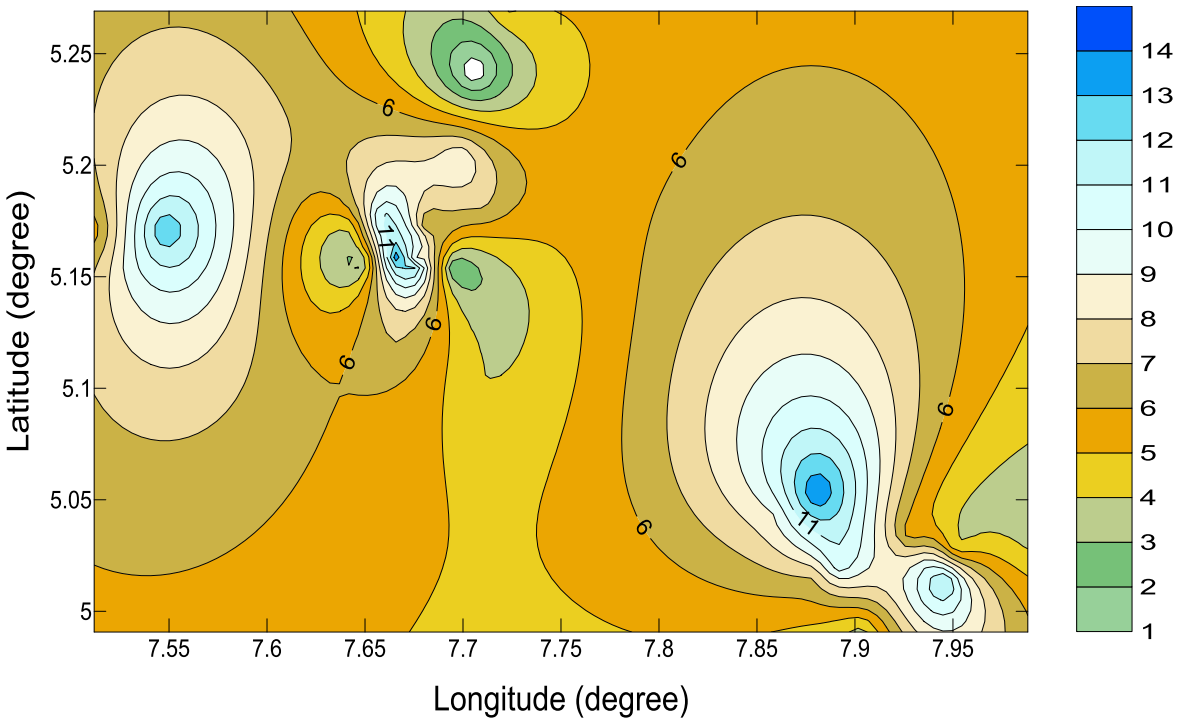

Figure 5: Contour diagram for the activity concentration of ^{232}Th in Bq.L^{-1} for the collected samples.

3.3 Correlation Studies

Figures 6 - 8 below shows the correlation between the activity concentrations of ^{40}K and ^{238}U (A_k and A_u), ^{40}K and ^{232}Th (A_k and A_u), ^{232}Th and ^{238}U (A_{Th} and A_u) respectively for all the locations. Fig 9 also shows the correlation between H_{ex} and H_{in} . To establish a correlation between the concentrations of the radionuclides and between the external and internal hazard indices, a linear correlation coefficient was used. For correlation between A_k and A_u, the correlation coefficient was R = 0.494 with intercept=24.80 and slope =1.44. Similarly, for correlation between A_k and A_{Th} , the correlation coefficient was R= 0.970 with intercept=13.90 and slope=2.18. For correlation between A_{Th} and A_u , the correlation coefficient was R=0.541 with intercept=4.80 and slope=0.70. For correlation between H_{ex} and H_{in} , the correlation coefficient was R=0.935 with intercept=0.012 and slope=0.62.

For the correlation between A_k and A_{Th} and also between H_{ex} and H_{in} , the values of their correlation coefficient shows that they are linearly related and as a result the value of one is very much influenced by the value of the other [12]. For the correlation between A_k and A_u and also between A_{Th} and A_u , the values of their correlation coefficient shows that although they are linearly related, but the values of one is not very much influenced by the other [13].

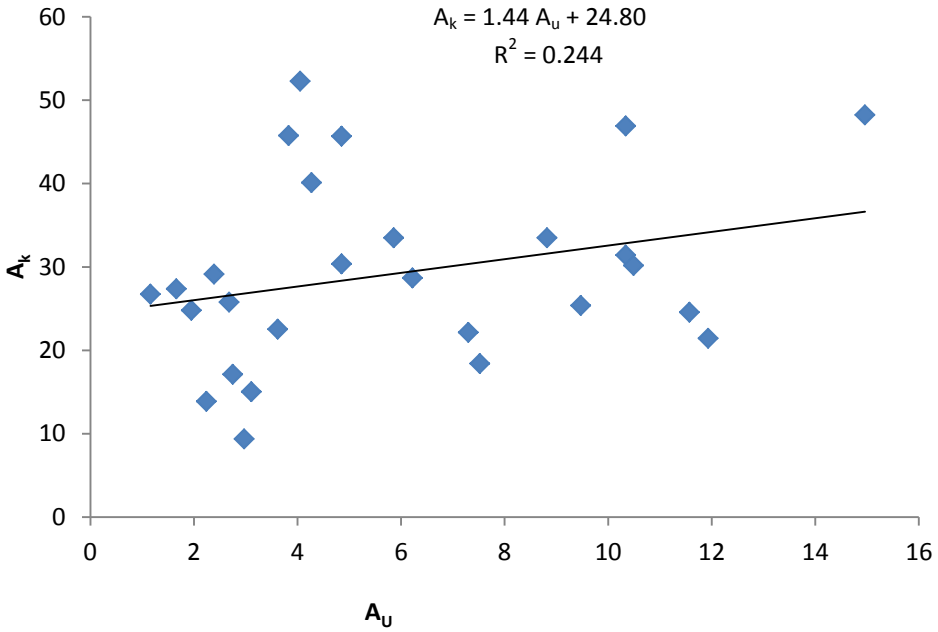

Figure 6: Correlation between the activity concentrations of ^{40}K (A_K) and ^{238}U (A_U) for rain water samples from the study locations.

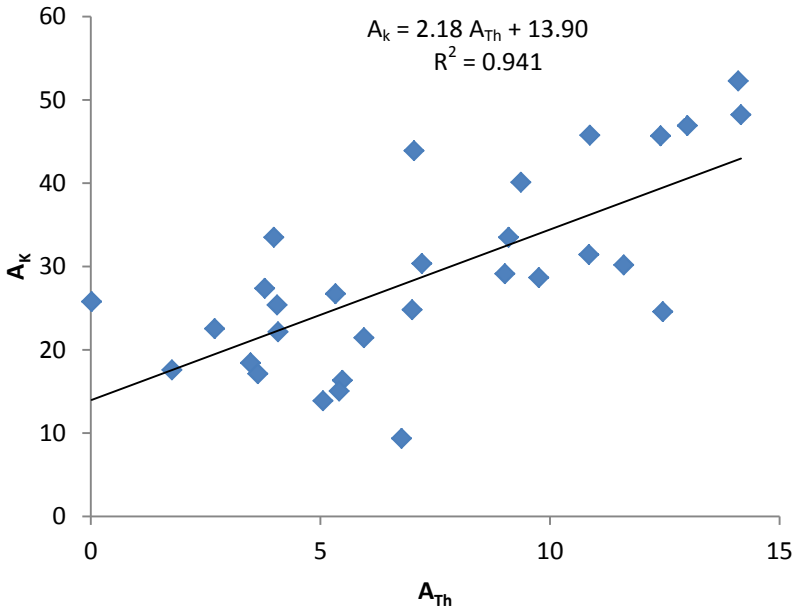

Figure 7: Correlation between the activity concentrations of ^{40}K (A_K) and ^{232}Th (A_{Th}) for rain water samples from the study locations.

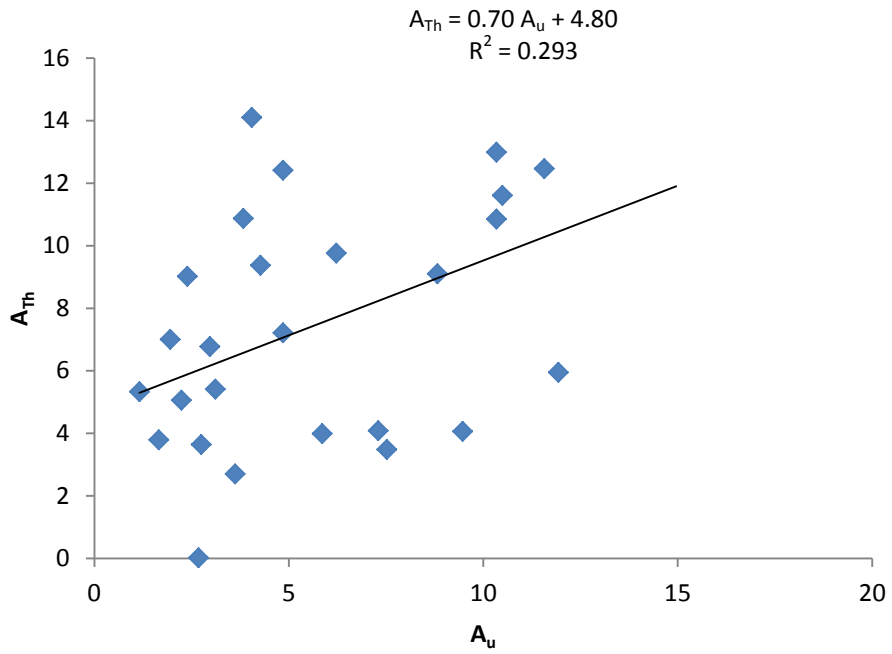

Figure 7: Correlation between the activity concentrations of ^{232}Th (A_{Th}) and ^{238}U (A_u) for rain water samples from the study locations.

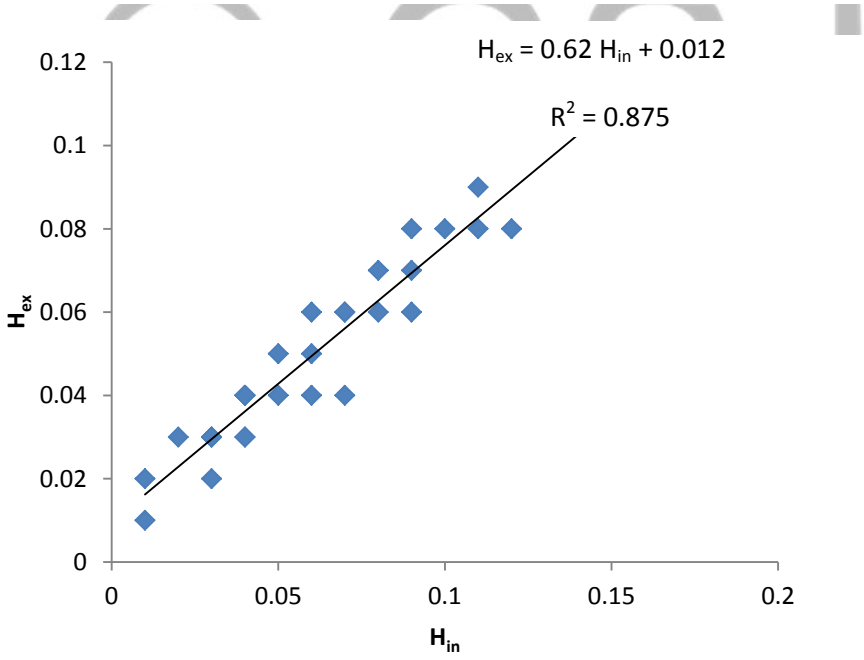

Figure 8: Correlation between external hazard index (H_{ex}) and internal hazard index (H_{in}).

3.4 Radiological Detriments of ^{40}K, ^{238}U AND ^{232}Th in Rainwater Samples

In other to quantify the radiation detriments to members of the public as a result of the activity concentration in the rainwater samples, the annual effective dose and total annual effective dose, radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}) and internal hazard index (H_{in}), were used as radiological indicators to estimate the radiological implications due to the intake of the radionuclides present in the rainwater. The results are shown in Table 2 below.

3.4.1 Annual Effective Dose (AED) and Total Annual Effective Dose

When analyzing the annual effective dose and the total annual effective dose to the human population from natural sources, the dose received by ingestion of long – lived natural radionuclide must be considered [14]. Effective doses resulting from intake of ^{40}K, ^{238}U and ^{232}Th may be determined directly from the rainwater since it can be ingested directly by man. Assuming the volume of the daily intake of a drinking water for adult male to be $1L.d^{-1}$ [15], the annual effective dose was calculated with the intake of individual radionuclide and ingestion doses co-efficient ($Sv.Bq^{-1}$) reported by the International Commission on Radiological Protection [14]. The equation for calculating the annual effective dose (AED) per person for a given radionuclide is given below;

$$AED = I_i \times 365 \times D_i \quad - - - - - \quad (3)$$

While the total Annual Effective Dose (AED) due to all the radionuclides is given by

$$\text{Total } AED = \sum I_i \times 365 \times D_i \quad - - - - - - \quad (4)$$

Where I_i is the daily intake of radionuclide i ($Bq.d^{-1}$) as shown in table 2 below; D_i is the ingestion dose co-efficient ($Sv.Bq^{-1}$). According to the ICRP 1994, the ingestion dose co-efficient for ^{40}K, ^{238}U, and ^{232}Th in public exposure are 6.2×10^{-9} $Sv.Bq^{-1}$, 4.5×10^{-8} $Sv.Bq^{-1}$ and 2.3×10^{-7} $Sv.Bq^{-1}$ respectively. From table 2 below, the total annual effective dose received by all the locations due to the intake of all the radionuclide ranges from 0.08 ± 0.01 $msv.y^{-1}$ to 1.53 ± 0.17 $mSv.y^{-1}$ with an average of 0.76 ± 0.08 $mSv.y^{-1}$ which is less than the $1mSv.y^{-1}$ recommended by ICRP for public exposure [22]. Also from figure 9 below, Obot Akara LGA has the highest total AED while Ikono LGA has the lowest.

3.4.2 Radium Equivalent Activity (Ra_{eq})

The distribution of ^{238}U, ^{232}Th and ^{40}K in rainwater is not uniform. Uniformity with respect to exposure to radiation has been defined in terms of radium equivalent (Ra_{eq}) in $Bq.L^{-1}$ to compare the specific activity of samples containing different amount of ^{40}K, ^{238}U and ^{232}Th. It is a weighted sum of activities of ^{40}K, ^{238}U and ^{232}Th; and it is based on the assumption that 370 $Bq.L^{-1}$ of ^{238}U, 259 $Bq.L^{-1}$ of ^{232}Th and 4810 $Bq.L^{-1}$ of ^{40}K produce the same gamma radiation dose rate[16]. To minimize radiation hazards, samples whose Ra_{eq} are greater than 370 $Bq.L^{-1}$ should not be ingested into the body. The radium equivalent activity Ra_{eq} for each sample was calculated by using the formula below [8].

$$Ra_{eq} = C_U + 1.43C_{Th} + 0.77C_K \quad - - - - - \quad (5)$$

Where C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in $Bq.L^{-1}$ in the rainwater samples respectively. Using equation 5 above, the results from table 2 below, show that the estimated Ra_{eq} for all the samples in all the locations ranged from 3.88 $Bq.L^{-1}$ to 38.92 $Bq.L^{-1}$ with an average of 18.06 $Bq.L^{-1}$. These values are smaller than the suggested maximal admissible value of 370 $Bq.L^{-1}$ [17] therefore the samples will not present any significant radiological hazard when ingested.

3.4.3 Gamma Absorbed Dose Rate (D)

The external terrestrial gamma absorbed dose rate in air is calculated by using the equation below; [18].

$$D\ (nGy.y^{-1}) = (R_K \times Q_K) + (R_U \times Q_U) + (R_{Th} \times Q_{Th}) \quad - - - \quad (6)$$

Were R_K (0.0414), R_U (0.462) and R_{Th} (0.604) are the conversion factors for ^{40}K, ^{238}U and ^{232}Th respectively. Q_K, Q_U and Q_{Th} are the activity concentrations of ^{40}K, ^{238}U and ^{232}Th respectively in $Bq.L^{-1}$. From table 2 below, which was

obtained by using equation 6 above, the absorbed dose rate for the rainwater samples for all the locations ranges from 1.80 nGy.y^{-1} to 17.46 nGy.y^{-1} with an average of 8.10 nGy.y^{-1} which is lesser than the world average value of 55 nGy.y^{-1} [19].

3.4.4 External and Internal Hazard Indices

The External Hazard Index (H_{ex}) and Internal Hazard Index (H_{in}) values was calculated using the equations below [20]. These are hazard indicators that predict the external and internal detriment of natural radiation from ^{40}K, ^{238}U and ^{232}Th.

$$H_{ex} = 0.0027C_U + 0.00386C_{Th} + 0.000208C_K \quad - \quad - \quad - \quad - \quad (7)$$

$$H_{in} = 0.0054C_U + 0.00386C_{Th} + 0.000208C_K \quad - \quad - \quad - \quad - \quad (8)$$

Where C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq.L^{-1} respectively.

From table 2 below, whose values were obtained by using equation 7 above, the external hazard index for the rainwater samples from all the locations ranged from 0.01 to 0.11 with an average of 0.05. Since these values are lower than unity which is the recommended value, therefore, according to the radiation protection 112 report [21] the rain water from these locations is safe without posing any significant radiological threat to the locations. Also, from table 2 below, whose values were obtained by using equation 8 above, the internal hazard index for the rainwater samples for all the locations ranged from 0.01 to 0.15 with an average of 0.06 which is also less than the recommended value of 1[21].

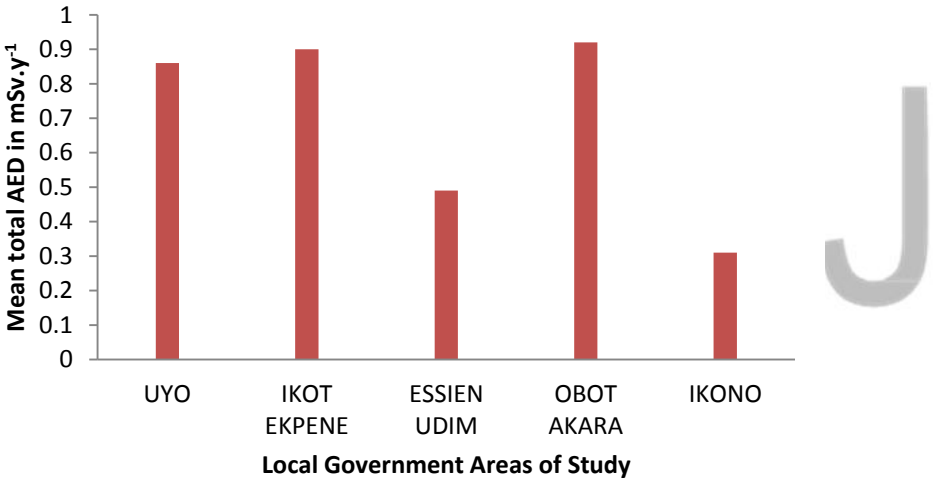

Figure 9: Distribution of the mean total AED due to ^{40}K, ^{238}U and ^{232}Th in mSv.y^{-1} for rain water samples from the study areas.

Table 2: Estimated mean Radium equivalent (Ra_{eq}) in $Bq.L^{-1}$, Gamma absorbed dose rate (D) in $nGy.y^{-1}$, External Hazard Index (H_{ex}) and Internal Hazard Index (H_{in}) and the Total Annual Effective Dose (Total AED) in $mSv.y^{-1}$ for ^{40}K, ^{238}U, and ^{232}Th in all the locations.

LGA	Ra_{eq}	D	H_{ex}	H_{in}	Total AED
UYO	21.20	9.52	0.05	0.08	0.86 ± 0.10
IKOT EKPENE	19.39	8.63	0.05	0.06	0.90 ± 0.09
ESSIEN UDIM	12.64	5.78	0.04	0.04	0.49 ± 0.05
OBOT AKARA	21.25	9.51	0.06	0.07	0.92 ± 0.09
IKONO	8.17	3.72	0.03	0.03	0.31 ± 0.03

4. CONCLUSION

This work is aimed at assessing the concentration of naturally occurring radionuclide in rain water samples from some selected Areas in Akwa Ibom State, Nigeria. The total annual effective dose, radium equivalent, gamma absorbed dose rate and the radiological indices received by all the locations did not show any significant health impact since it is below the ICRP recommended public exposure limit of $1mSv.y^{-1}$ [22].

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