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A Gamma Spectrometeric Analysis and Radium Equivalent Activity Index of Water in Abak, Nigeria: A Baseline Survey

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Abstract
This study evaluated the concentration of radionuclides and radiation hazard indices for water with the use of gamma spectrometer in 10 different communities of Abak Local Government Area of Akwa Ibom State, Nigeria to serve as baseline data on the radiological status of the area. The results show that the commonly occurring radionuclides are not uniformly distributed in the water. The mean activity concentration of ^{40}K, ^{238}U and ^{232}Th in the samples were estimated to be 105.46±8.16 Bq/l, 13.02 ± 3.13 Bq/l and 2.44 ± 0.21; Bq/l respectively. These values are well below internationally determined permissible exposure limits. The hazard indices radium equivalent activity, absorbed dose rate, effective dose rate, external and internal hazard indices had mean values of 24.6±4.06 Bq/l, 11.9±1.92 nGy/h, 0.02±0.002mSv/yr, 0.07±0.01 and 0.1±0.02 respectively.The computed hazard indices are all below the recommended standards. Therefore the water at the present time poses no radiological health threat to the populace.
Keywords: Radionuclide concentration, radium equivalent, absorbed dose rate, internal hazard index

Introduction

Ionizing radiation is present in the human environment either through radionuclides occurring naturally in the human environment or those occurring due to man's technological activities. Throughout one's lifetime, human beings are exposed to ionizing radiation emanating from both natural sources and also from anthropogenic sources (Alaamer, 2008). Considering the danger of such radiations, the knowledge of environmental radionuclide distribution and radiation levels in the environment is important to help evaluate the impact of radiation exposure due to both terrestrial and cosmogenic sources. It has been estimated that natural sources of radiation constitute about 80% of the collective radiation exposure of the World's population (UNSCEAR, 2000). The main external source of irradiation of the human body comes from terrestrial background radiation. Also, other important sources of natural external exposure include cosmic rays and gamma ray emitters in soil, building materials, water, food and air (Alaamer, 2008). In areas where there had been nuclear weapon testing or where a nuclear power plant accident had occurred (such as the Chernobyl accident and the Japan nuclear power plant disaster), appreciable quantities of manmade radionuclides such as ^{90}Sr, ^{131}I and ^{137}Cs may also be present in the atmosphere. A further source of radiation is the routine discharge of radionuclides from nuclear installations (Kabir et al., 2009).

A number of environmental radiation studies have been carried out to assess the contribution of various parameters to the radiation profile of various areas. These included the work of Agbalagba et al (2013) which evaluated the radiological impact of oil and gas activities in some oil fields in Delta State, Nigeria; the study done by Ononugbo et al (2011) which examined the effect of gas exploitation on the environmental radioactivity of Ogba/Egbema/Ndoni Area, Nigeria; the work done by Chad-Umoren and Nwali (2013) which assessed the specific activity concentration and percentage contribution of the primordial radionuclides ^{226}Ra, ^{232}Th and ^{40}K to the absorbed dose rate of the Port Harcourt Refinery Company host community.

In our previous investigation (Chad-Umoren and Umoh, 2014), we had studied the radionuclide distribution patterns in the soil and had also calculated the radiation hazard indices for Abak, Nigeria, where we found that the activity concentration in the various soil samples ranged from 14.80±1.16Bqkg^{-1} to 150.20±11.47Bqkg^{-1} with a mean value of 98.709±7.693Bqkg^{-1} for ^{40}K; from 14.52±3.49Bqkg^{-1} to 42.04±8.59Bqkg^{-1} for ^{238}U with a mean of 24.826±5.425Bqkg^{-1} and from 3.05±0.27Bqkg^{-1} to 7.00±0.58Bqkg^{-1} with a mean of 5.172±0.31 Bqkg^{-1} for ^{232}Th. These values are within international regulatory standards. That previous study also showed that the radiation hazard levels for the area gave values of 18.789±3.102nGy.h^{-1} for absorbed dose, 0.3±0.05BqKg^{-1} for representative level index, 39.82±6.65Bqkg^{-1} for radium equivalent, 0.11±0.02 for external hazard index, 0.18±0.032 for internal hazard index and 0.023±0.004mS/yr for effective dose rate. These indices are much lower than the ICRP permissible limits for soil showing that the soil of the study area poses no radiological threats to the public.

In this present study, we assess the radionuclide content of the water in the Abak area and also calculate the radium equivalent activity index of the water and other radiation hazard indices to enable us evaluate the suitability of the water for human consumption. This is necessary, because once present in the environment, radionuclides become available for uptake by plants and animals and find their way into the human body through the food chain (Agbalagba et al, 2012).

MATERIALS AND METHOD

Description of the Study Area

The study was carried out in 10 communities at Abak Local Government Area of Akwa Ibom State, Nigeria, $4^0$59'N $7^0$47'E. Abak is located at the south west of Akwa Ibom in the Niger Delta region. It is a semi-urban and hinterland area and known for its importance in agricultural development. It has many agro-based and agro allied industries located within it. It has a land mass of 304 square kilometres. The major economic activity of the people of this area is palm oil produce. The 2006 census determined the total population of Abak to be 139,090. (wiki, 2013).

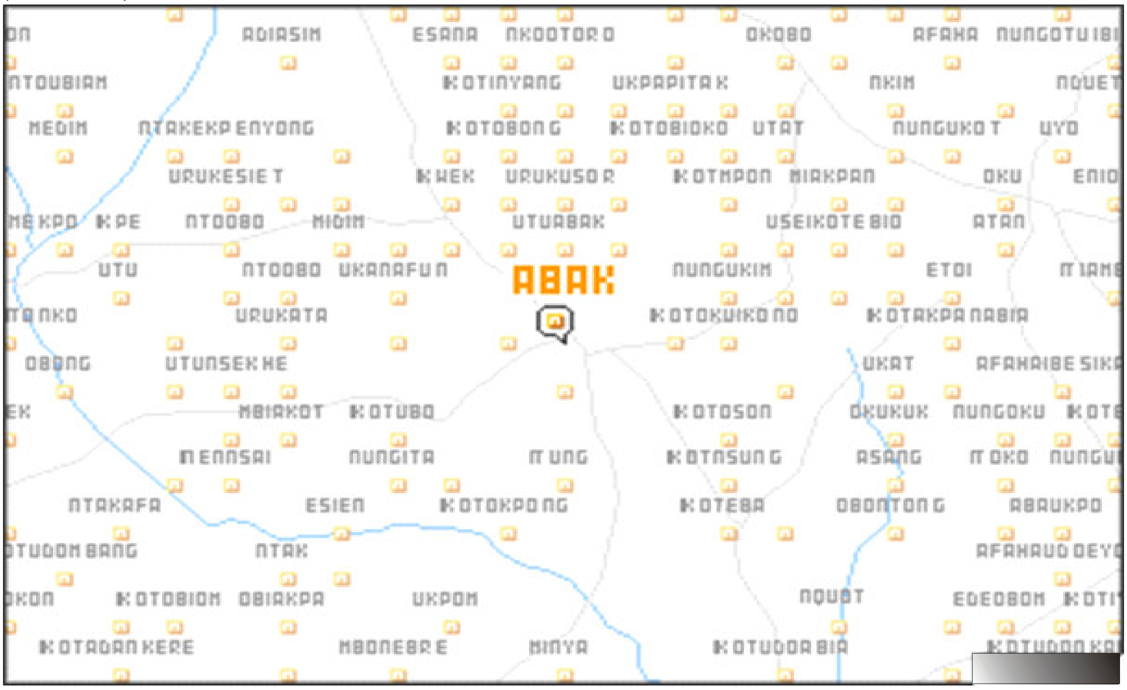

Fig. 1 Map of the study area

Sampling and Sample Preparation

The water samples were collected at ten different communities in the local government. The communities were Ediene Abak, Oku Abak, Manta, Midim Waterside, Utu Abak, Abak Usung Atai, AbakUsungIdim, IkotEkang, Mbarakom and Ibagwa. Water samples were put in 1.5litre containers prior to processing for gamma spectrometer analysis.They were acidified with 11molar concentration of Hydrochloric acid at the rate of 10ml per litre of sample immediately after collection to avoid adsorption of radionuclide onto the walls of the containers (IAEA, 1989)

Radiation Hazard Indices

To assess the radiation hazard associated with the health status of a radiated or irradiated environment the following indices have been defined.

Radium Equivalent Index

Radium equivalent (Ra_{eq}) is an index used to compare the specific activities of materials containing ^{40}K, ^{238}U and ^{232}Th by a single quantity and which takes into account the radiation hazards associated with them (Avwiri et al, 2012). The activity index provides a useful guideline in regulating the safety standard of dwellings. This radium equivalent activity represents a weighted sum of activities of ^{40}K, ^{238}U and ^{232}Th radionuclides and is based on the estimation that 1Bq/kg of 226Ra, 0.7Bq/kg of 232Th, and 13Bq/kg of 40K produce the same radiation dose rates. The radium equivalent activity index is given in the equation below.

$$Ra_{eq} = C_{Ra} + 1.43\, C_{Th} + 0.077\, C_k \qquad (1)$$

Where C_{Ra}, C_{Th} and C_K are the radioactivity concentration in Bq/kg of ^{238}U, ^{232}Th, and ^{40}K.

Absorbed Dose Rate

Absorbed dose measures the energy deposited in a medium by ionizing radiation per unit mass, which may be measured as joules per kilogram when it is represented by the equivalent SI unit, gray (Gy). The absorbed dose from a given level of incident radiation depends on the absorbing medium. Absorbed dose is used to rate the ability of devices to survive such as electronic components in ionizing radiation environments. The larger the absorbed dose the higher the hazard. It is given by:

$$D = 0.462\ C_{Ra} + 0.621C_{Th} + 0.041CA_k \quad (2)$$

Where D is in $nGyh^{-1}$ and C_{Ra}, C_{Th}, and C_k are the activity concentrations of uranium, thorium and potassium.

Representative Level Index

Representative level index, l_γ is used to estimate the gamma- radiation hazard associated with the natural radionuclide in specific investigated samples. It is given as:

$$l_\gamma = C_{Ra}/150 + C_{Th}/100 + C_k/1500 \quad (3)$$

Where C_{Ra}, C_{Th} and C_K are the radioactivity concentration in Bq/kg of ^{238}U, ^{232}Th, and ^{40}K. This gamma index is also used to correlate the annual dose rate due to the excess external gamma radiation caused by superficial materials. It is a screening tool for identifying materials that might be of health concern when used for building construction (Tufail et al., 2007).

Effective dose rate

The annual effective dose rate in mSv/yr is given by the formula.

$$\text{Effective dose rate} = D(nGy/h) \times 8760/yr \times 0.7 \times 103mSv.10^{-9})nGy \times 0.2$$
$$= D \times 1.2264 \times 10^{-3} \quad (4)$$

External Hazard Index

The factors which determine the exposure rate of an individual is the concentration of radionuclides in the soil and the time spent outdoors. External hazard index is an assumption that helps to evaluate the additional radiation hazard of natural gamma radiation. The External Hazard Index is defined as:

$$H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_k/4810 \quad (5)$$

The value of this index must be less than unity for the radiation hazard to be negligible (Avwiri et al, 2012). H_{ex} =1 is a corresponding quantity to the upper limit of Ra_{eq} (370Bq/kg).

Internal Hazard Index

The internal hazard index (H_{in}) is given as

$$H_{in} = C_{Ra}/185 + C_{Th}/259 + C_k/4810 \quad (6)$$

For the radiation hazard to be negligible, $H_{in}<1$.

Results and discussion

Table 1: Specific activity of ^{40}K, ^{238}U and ^{232}Th in the water samples

S/N	Sample Location	K-40 (Bq/l)	U-238 (Bq/l)	Th-232 (Bq/l)
1	Ibagwa	99.47±7.68	15.94±3.74	2.02±0.18
2	Manta	68.24±5.35	6.79±1.61	3.66±0.31
3	Mbarakom	32.86±2.49	10.57±2.60	3.02±0.27
4	Midim waterside	220.96±16.72	4.72±1.24	0.86±0.08
5	Oku Abak	70.04±5.49	13.99±3.42	2.12±0.19
6	EdieneAbak	72.57±5.77	10.98±2.71	2.93±0.26
7	IkotEkang	122.76±9.53	10.80±2.59	3.01±0.27
8	AbakUsungIdim	190.81±14.56	17.06±3.97	3.87±0.32
9	AbakUsungAtai	27.26±2.14	10.63±2.77	1.96±0.17
10	Utu Abak	149.65±11.84	28.69±6.61	0.91±0.08
Min. value		27.26±2.14	4.72±1.24	0.86±0.08
Max. value		220.96±16.72	28.69±6.61	3.87±0.32
Average		105.46±8.16	13.02±3.13	2.44±0.21
Standard		400	35	30

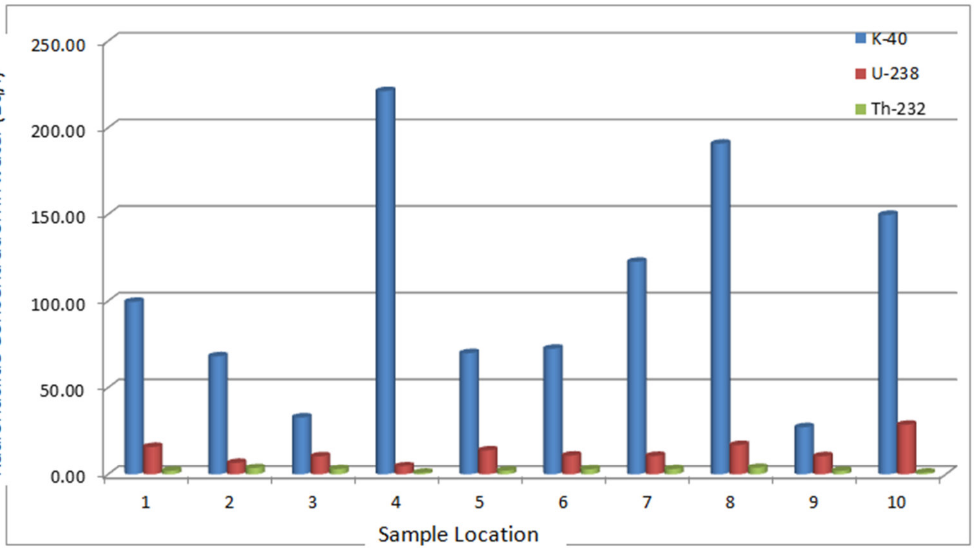

Fig. 2: Radionuclide Concentrations in Water

Radionuclide Concentration in Water

The specific activity concentration obtained for the 10 water samples are shown in Table 1. It ranges between 27.26±2.14 Bql^{-1} (AbakUsungAtai) to 220.96±16.72 Bql^{-1} (Midim Waterside) with a mean value of 105.46±8.16 Bql^{-1} for ^{40}K, between 4.72±1.24 Bql^{-1} (Midim Waterside) and 28.69±6.61 Bql^{-1} (Utu Abak) with a mean value of 13.02±3.13 Bql^{-1} for ^{238}Uand between 0.86±0.08 Bql^{-1} (Midim Waterside) and 3.87±0.32 Bql^{-1} (AbakUsungIdim) with a mean value of 2.44±0.21 for ^{232}Th.Our previous study (Chad-Umoren and Umoh, 2014)of the radioactivity of the soil of this area shows that the mean concentration of ^{40}K is higher in water than in soil (98.71 ± 7.70Bq/kg), while the mean concentrations of ^{238}U and ^{232}Th are lower in water but higher in soil ($24.83 \pm 5.43\ Bq/kg$ and 5.17 ± 0.44Bq/kg respectively). Also, a previous study (Chad-Umoren and Nwali, 2013) around the Port Harcourt refinery host community show lower ^{40}K and ^{238}U (^{226}Ra) concentrations, but higher ^{232}Th concentration compared to this work, These results for the water of the study area are below the standard recommended by ICRP. The maximum concentration of ^{40}K is only 55% of the recommended standard, while it is 82% for ^{238}U and only 13% for ^{232}Th.

Fig. 2 shows the variation of the radionuclide concentration in the water samples. ^{232}Th has the least concentration, while ^{40}K has the highest. Fig. 3 shows the percentage contribution of the radionuclides in the water of the study area. ^{40}K contributes a greater percentage, 87%, ^{238}U 11% and ^{232}Th 2%. This is similar to a previous result obtained around the Port Harcourt Refinery host community (Chad-Umoren and Nwali, 2013).

Percentage Radionuclide Concentration

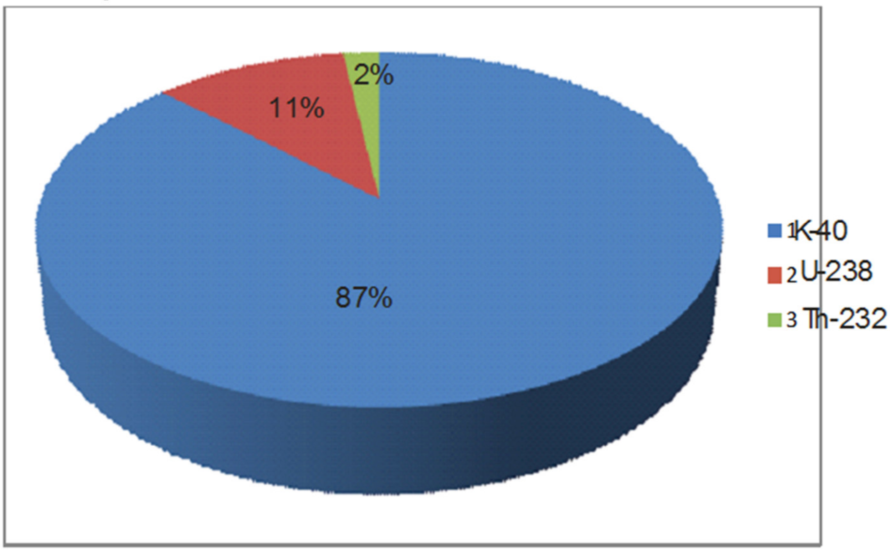

Fig. 3: Percentage Radionuclide Concentrations in Water

Results of Hazard Indices

Table 2: Radium Equivalent Index and Absorbed Dose Rate in water

S/N	Sample Location	Radium equivalent activity index, Ra_{eq} (Bq/l)	Absorbed Dose Rate (nGy/h)
1	Ibagwa	26.5±4.59	12.8±2.16
2	Manta	17.3±2.47	8.3±1.16
3	Mbarakom	17.4±3.18	8.1±1.47
4	Midim waterside	23.0±2.64	11.9±1.32
5	Oku Abak	22.4±4.11	10.7±1.93
6	EdieneAbak	20.8±3.53	9.9±1.65
7	IkotEkang	24.6±3.71	12.0±1.76
8	AbakUsungIdim	37.3±5.55	18.2±2.64
9	AbakUsungAtai	15.5±3.18	7.3±1.47
10	Utu Abak	41.5±7.64	20.1±3.60
Mean value		24.6±4.06	11.9±1.92
Standard		370	60

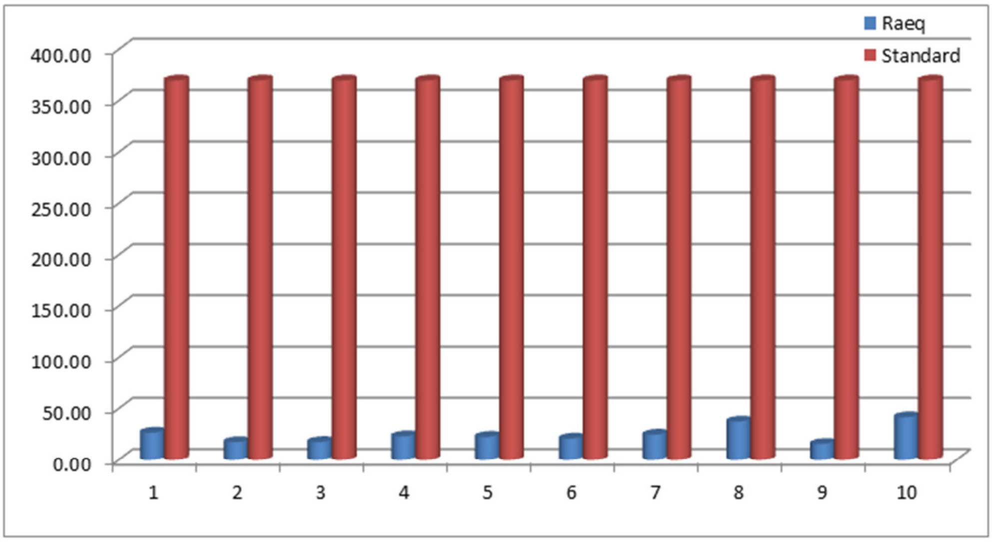

Fig. 4: Comparison of Radium Equivalent index with standard in water

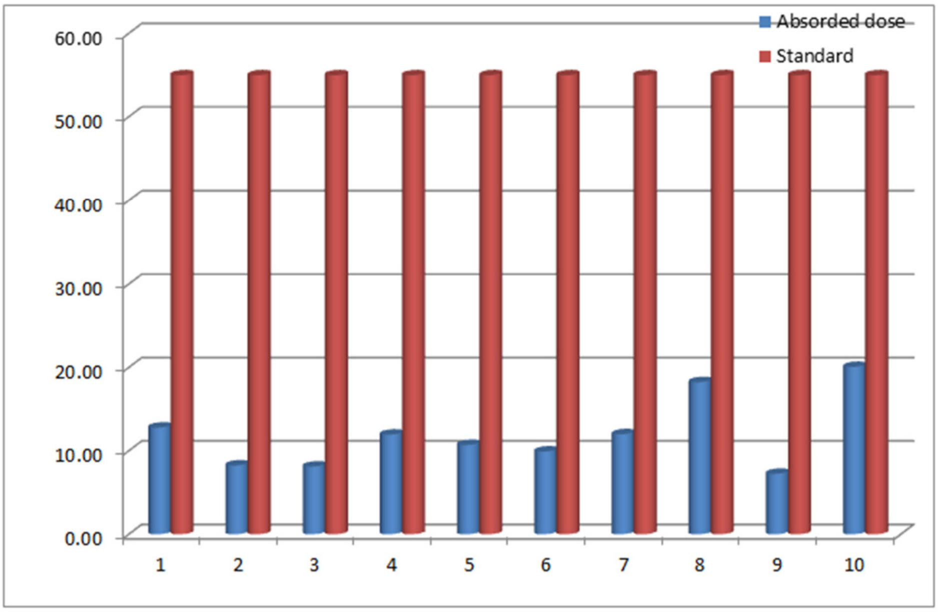

Fig. 5: Comparison of Absorbed dose rate with standard in water

Table 3: Representative Level index and Effective Dose Rate in water samples.

S/N	Sample Location	Representative Level Index (Bq/l)	Effective dose rate (mSv/yr)
1	Ibagwa	0.2±0.032	0.02±0.003
2	Manta	0.1±0.017	0.01±0.001
3	Mbarakom	0.1±0.022	0.01±0.002
4	Midim waterside	0.2±0.020	0.01±0.002
5	Oku Abak	0.2±0.028	0.01±0.002
6	EdieneAbak	0.2±0.025	0.01±0.002
7	IkotEkang	0.2±0.026	0.01±0.002
8	AbakUsungIdim	0.3±0.039	0.02±0.003
9	AbakUsungAtai	0.1±0.022	0.01±0.002
10	Utu Abak	0.3±0.053	0.02±0.004
Mean value		0.2±0.028	0.02±0.002
Standard		1.0	1.0

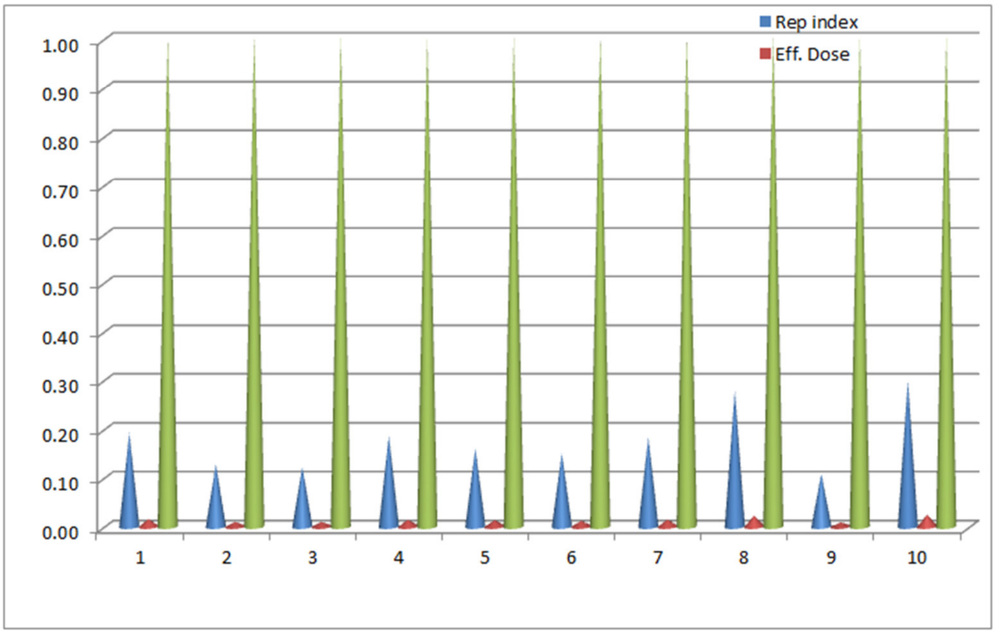

Fig. 6: Comparison of Representative Level index and Effective Dose Rate with standard in the water samples

Table 4: External Hazard Index and Internal Hazard Index in water samples

S/N	Sample Location	External Hazard Index	Internal Hazard Index
1	Ibagwa	0.072±0.012	0.115±0.023
2	Manta	0.047±0.007	0.065±0.011
3	Mbarakom	0.047±0.009	0.076±0.016
4	Midim waterside	0.062±0.007	0.075±0.010
5	Oku Abak	0.061±0.011	0.098±0.020
6	EdieneAbak	0.056±0.010	0.086±0.017
7	IkotEkang	0.066±0.010	0.096±0.017
8	AbakUsungIdim	0.101±0.015	0.147±0.026
9	AbakUsungAtai	0.042±0.009	0.071±0.016
10	Utu Abak	0.112±0.021	0.190±0.039
Mean value		0.067±0.011	0.102±0.019
Standard		1.0	1.0

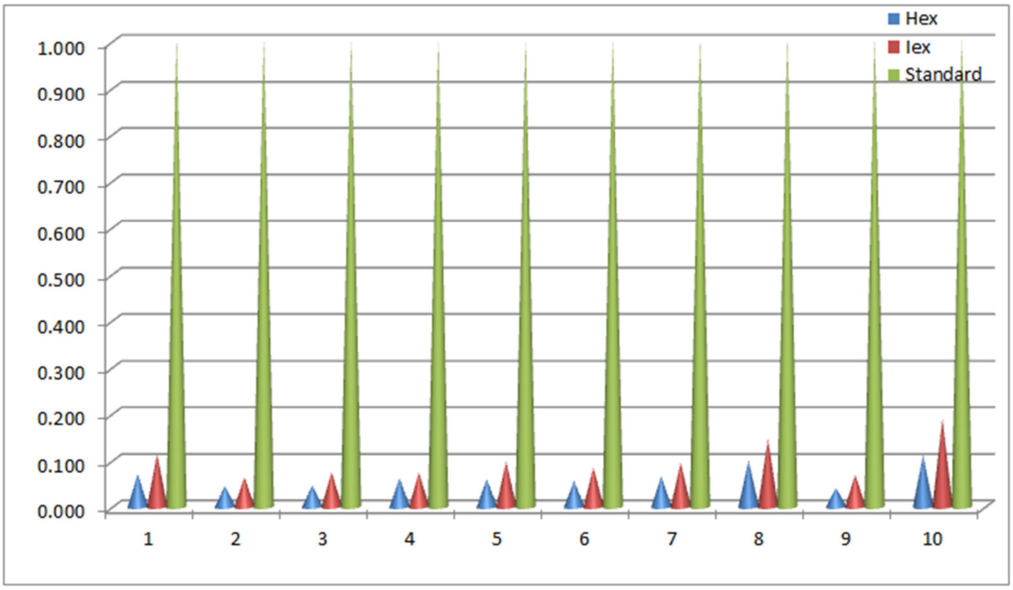

Fig. 7: Comparison of External Hazard Index and Internal Hazard Index with standard in the water samples

Radium Equivalent Index and Absorbed Dose Rate in Water

The radium equivalent index, Raeq and absorbed dose rate, D in the water were computedusingeqns 1 and 2, respectively and are shown in Table 2. The radium equivalent has a range of $15.50 \pm 3.18\ Bq/l$ to $41.50 \pm 7.64\ Bq/l$ with a mean value of 24.6±4.06nGy/h for the water while the absorbed dose has a range of 7.30 ± 1.47nGy/h to 20.10 ± 3.60 nGy/h with a mean value of 11.90±1.92nGy/h.These values are within the UNSCEAR recommended permissible limit of 370 Bq/l for radium equivalent index (Fig. 4) and 60nGy/h for absorbed dose rate(Fig. 5). The maximum value of the radium equivalent index is only 11.2% of the standard value, while the maximum value of the absorbed dose rate is 33.5% of the recommended standard of radiological safety.The study therefore indicates no radiological hazard on the environment and the inhabitants of the community.

Representative Level Index and Effective Dose

The representative level index, l_γ and effective dosefor the samples were calculated using eqns 3 and 4 and are shown in Table 3. The representative level index ranges between 0.1±0.02Bq/l to 0.30±0.05Bq/l with a mean value of 0.2±0.03Bq/l. The effective dose ranges between 0.009±0.002mSv/y and 0.02±0.004mSv/y with a mean value of 0.02±0.002mSv/y.These values are much lower than those obtained by Agbalagba et al (2012)for an environment exposed to the activities of the hydrocarbon industry.Fig.6shows that the representative level index and effective dose rate are lower than the standards and therefore, there is no radiological risk in the study area.

External and Internal hazard Indices

Table4 shows the external and internal hazard indices computed from Eqns5 and 6 for the water. The external hazard index ranges between 0.04±0.009mSv/yr to 0.11±0.021mSv/yr with a mean value of 0.07±0.011mSv/yr for the water, while the internal hazard index ranges between 0.07±0.011 mSv/yr to 0.19±0.04 mSv/yr with a mean value of 0.10±0.02 mSv/yr. A comparison of this result with Mei-Wo et al (2011) shows that this mean value is lower than that of Mei-Wo et al (2011) given as 0.39±0.07 but in the same range as that reported by Avwiri et al (2012). Fig. 7compares the present study with ICRP standard and it shows a lower concentration for public health and safety.

Conclusion

This study evaluated the concentration of radionuclides and hazard indices for water with the use of gamma spectrometer in 10 different communities of Abak Local Government Area of AkwaIbom State, Nigeria to serve as baseline data. The overall result indicates that the distribution of theprimordial radionuclides in the water in the community is not homogeneous. The average activity concentration of ^{40}K, ^{238}U and ^{232}Thin the samples were estimated to be 105.46 ± 8.16Bq/l, 13.02 ± 3.13Bq/l and 2.44 ± 0.21; Bq/l respectively. Comparison of the present study with our previous study of the radioactivity of the soil of the area (Chad-Umoren and Umoh, 2014) shows that^{40}K contributes the most to the radionuclide contentof both soil and water, while^{232}Th contributes the least in the both cases. This implies that those using the water from these communities are more exposed to ^{40}K than the other radionuclides. However, a comparison with international standards shows that the total radionuclide content of both soil and water is within acceptable limits.

The average radium equivalent activity in the samples was 24.6±4.06 Bq/l, while the absorbed dose rate due to the radionuclides in the samples was calculated to have a mean value of 11.9±1.92 nGy/h. The corresponding effective dose rate was estimated to be 0.02±0.002mSv/yr. The external and internal hazard indices in all the samples were less than unity with average values of 0.07±0.01 and0.1±0.02respectively.Again, comparison of the current study with our previous study of the radioactivity of the soil of the area (Chad-Umoren and Umoh, 2014) indicates that the soil of the study area have higher hazard indices than the water except for the effective dose rate where both soil and water have the same value. However, the computed values of the hazard indices are all below the recommended standards for such an environment indicating that there is no significant health threat to the populace from both the soil and the water and that the environment is radiologically safe.

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