Advances in Physics Theories and Applications
ISSN 2224-719X (Paper) ISSN 2225-0638 (Online)
Vol.32, 2014
www.iiste.org

Baseline Radionuclide Distribution Patterns in Soil and Radiation Hazard Indices for Abak, Nigeria

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Abstract

A gamma spectroscopy analysis for the naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K has been carried out for soil samples collected from communities in Abak Local Government Area of Akwa Ibom State to determine the concentration and distribution patterns of these radionuclides in the study area and to assess the possible radiological risks from the soil. The activity concentration of the samples range from 14.80±1.16Bq/kg to 150.20±11.47Bq/kg with a mean value of 98.709±7.693Bq/kg for ^{40}K; from 14.52±3.49Bq/kg to 42.04±8.59Bq/kg for ^{238}U with a mean of 24.826±5.425Bq/kg and from 3.05±0.27Bq/kg to 7.00±0.58Bq/kg with a mean of 5.172±0.31Bq/kg for ^{232}Th. These values are within international regulatory standards. Assessment of the radiation hazard levels for the area gave values of 18.789±3.102nGy/h for absorbed dose, 0.3±0.05Bq/kg for representative level index, 39.82±6.65Bq/kg 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.

Keywords: Radionuclide concentration, radiation hazard index, radium equivalent, internal hazard index

Introduction

Our natural environment is continuously bombarded with ionizing radiations from both natural and man-made sources of ionizing radiation (Ademola, 2008; Chad-Umoren, 2012). The most common radionuclides in soil and groundwater are the radioactive isotopes of the three natural decay series (^{235}U, ^{238}U, and ^{232}Th) and ^{40}K. Natural sources of radiation constitute almost 80% of the collective radiation exposure of the World's population (UNSCEAR, 2000). Human beings are exposed naturally due to sources outside their bodies, mainly cosmic ray and gamma ray emitters in soil, water, food and air, etc (Agbalagba et al, 2012). Some manmade radionuclides are also present in the environment as a result of testing of nuclear weapons, accidents such as the Chernobyl accident and the Japan nuclear power plant disaster, and the routine discharge of radionuclides from nuclear installations. Once they enter into the environment, these radionuclides whether natural or man-made are taken up by plants and animals, as a result, they find their way into the human body through the food chain. Because of natural and artificial processes, radionuclide may accumulate and be concentrated in selected areas of the environment. The natural radioactivity of soil and sediment/sludge depends on their formation and transportation processes that were involved since soil formation; chemical and biochemical interactions influence the distribution patterns of Uranium and Thorium and their progenies (ECNR, 1995).

Agbalaba et al (2012) analysed the natural radioactivity levels and estimated the hazard indices, radium equivalent activities, representative level index, external and internal hazard index, absorbed dose rate and the effective dose rate in soil and sediment of ten oil and gas field in Delta state using gamma-ray spectroscopy. Results shows that the activity levels of the radionuclides showed enhanced activity concentrations across the area under study.The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were found to be 41.0 $\pm$ 5.0, 29.0 $\pm$ 4.0 and 412.5$\pm$20.0 Bq/kg respectively. The values obtained for ^{226}Ra and ^{40}K were slightly higher than the world average.

A study was undertaken to measure the ionizing radiation distribution in Rivers state (Chad-Umoren and Briggs-Kamara, 2010). In the study, Rivers State was divided into three sub environments – an upland college campus environment, a rural riverine environment and an industrial zone environment. The values obtained for the industrial zone were all higher than the CERN recommended value of 1.0mSv/yr for the general population who are not engaged in nuclear radiation related occupations, while the values for the other 2 environments were within CERN standard. This conclusion was attributed to several factors including the higher concentration of oil operations and establishment in the industrial zone.

Sixteen marine sediment cores from selected locations within theeast coast of peninsula Malaysia exclusive economic zone (EEZ) were collected for the determination of NORM concentrations (Mei-Wo, 2011). Thirty locations were identified and sampling was done according to a grid within the EEZ that covers shallow coastal, near-shore and off-shore zones. The concentration of ^{226}Ra ranged between 16 – 46 Bq/kg with mean of 30±6 Bq/kg. The activity of ^{228}Ra varied from 28 – 87 Bq/kg with mean 56±11 Bq/kg and that of ^{40}K from 171 - 690 Bq/kg with mean 420±90 Bq/kg. The radiation hazard indices were also calculated and were all below recommended standards showing that no extra hazards are introduced to the workers though surrounded by these samples daily.

Faanu et al (2011) measured the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soils, wastes, rocks and tailings in Tarkwa Gold Mine and its surrounding communities to assess the radiological hazards and risk associated with exposure of the public.Thirty-eight soil/rock samples were collected randomly within some selected areas of the mine. The results of the activity concentrations, absorbed dose rates, annual effective dose, radium equivalent activity and hazard indices were calculated and showed that the average activity concentrations of^{226}Ra,^{232}Th and ^{40}K in this study were lower than the worldwide average values of 32, 45 and 420 Bq/kg, respectively (UNSCEAR, 2000).

Chad-Umoren and Ohwekevwo (2013) carried out a study to investigate the level of impact of oil spillage on the ionizing radiation profile of three communities in the Niger Delta. The study was undertaken to involve an on-site evaluation and laboratory analyses. 15 soil samples (five from each community) were collected from spill sites and analyzed using the Gamma spectrometer and Na(TI) detector. The communities were Ebegoro, Ebocha and Obrikom in Ogba/Egbema/Ndoni Local Government Area (ONELGA) of Rivers state.The radiation profile of the soil samples showed the following for the various communities: for Ebegoro community the radiation level ranged from 1.40±0.12mSv/yr (0.017±0.001mR/hr) to 1.58±0.11mSv/yr (0.019±0.001mR/hr); while it went from 1.23±0.12mSv/yr (0.015±0.001mR/hr) to 1.49±0.15mSv/yr (0.018±0.002mR/hr) at Ebocha. For Obrikom the range was from 1.14±0.07mSv/yr (0.014±0.001mR/hr) to 1.49±0.12mSv/yr (0.018±0.001mR/hr). The highest value was recorded at Ebegoro, while the least was obtained at Obrikom.

A study by Avwiri (2012) was carried out todeterminesome radiological parameters and radiation health hazard for Ogulogu-Olo, in Ezeagu Local Government Area and Amagu-Umuene, in Udi Local Government Area of Enugu State, south-east Nigeria. The three natural radionuclides (^{40}K, ^{226}Ra and ^{232}Th) were found in the two boreholes that were studied. However their concentrations were below the respective world average values (UNSCEAR, 2000) and the hazard indices were less than the permissible value of one (Oregun et al., 2007).

Study Area

The study was carried out in 10 communities of Abak Local Government Area of Akwa Ibom State, Nigeria (Fig. 1). Abak ($4^0$59’N $7^0$47’E) 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 landmass 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).

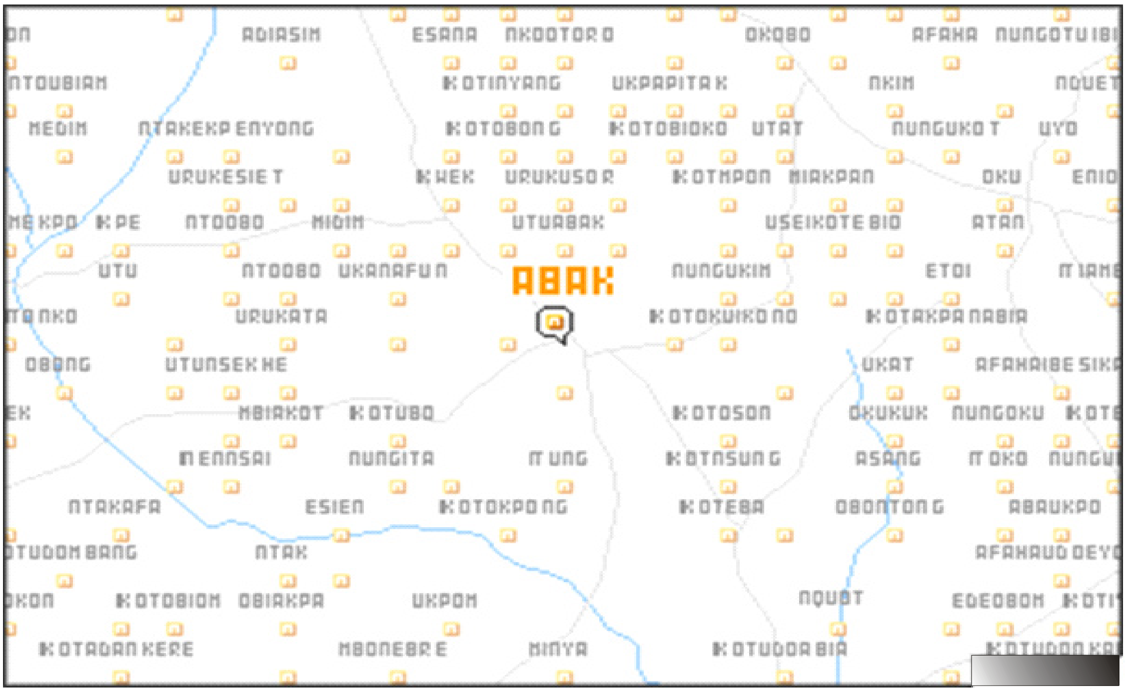

Fig. 1: Map of the study area

Sampling

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, Abak Usung Idim, Ikot Ekang, Mbarakom and Ibagwa. Soil samples were collected with the use of a coring tool at the depth of 25 – 50cm. The soil samples were stored in black polythene bags immediately after collection (Chad and Ohwekevwo, 2012).

Sample Preparation

The soil samples were separated from each other after collection, spread in a pan and dried under the sun. The soil samples were properly crushed to particle size, weighed, sealed and stored in a laboratory beaker (IAEA, 1989).

Hazard Indices

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

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:

$$D = 0.462\ C_{Ra} + 0.621C_{Th} + 0.041C_K \quad (1)$$

Where D is the dose rate in nGy/h and C_{Ra}, C_{Th}, and C_K are the activity concentrations of uranium, thorium and potassium.

Radium Equivalent Activity

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 ^{226}Ra, 0.7Bq/kg of ^{232}Th, and 13Bq/kg of ^{40}K produce the same radiation dose rates. The radium equivalent activity index is given in eqn (2):

$$Ra_{eq} = C_{Ra} + 1.43\ C_{Th} + 0.077\ C_k \quad (2)$$

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

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

$$I_{yr} = C_{Ra}/150 + C_{Th}/100 + C_k/1500 \qquad (3)$$

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 and construction (Tufail et al., 2007).

Effective Dose Rate
The annual effective dose rate in millisievert per year is given by the formula:

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

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:

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

The value of this index must be less than unity for the radiation hazard to be negligible (Avwiri, 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:

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

For the radiation hazard to be negligible we must have $H_{in}<1$.

Results and Discussion

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

S/N	Sample Location	K-40(Bq/kg)	U-238(Bq/kg)	Th-232(Bq/kg)
1	Ibagwa	120.22±9.35	25.92±5.70	5.26±0.45
2	Manta	94.95±7.18	21.84±4.74	3.52±0.31
3	Mbarakom	109.76±8.36	25.98±5.65	5.54±0.48
4	Midim waterside	14.80±1.16	16.12±3.49	5.83±0.50
5	Oku Abak	140.45±11.53	24.80±5.41	5.04±0.43
6	Ediene Abak	85.57±6.71	14.52±3.56	6.43±0.54
7	Ikot Ekang	150.20±11.47	39.67±8.98	3.05±0.27
8	Abak Usung Idim	69.68±5.40	17.53±3.71	3.57±0.31
9	Abak Usung Atai	79.43±6.19	19.84±4.42	7.00±0.58
10	Utu Abak	122.03±9.58	42.04±8.59	6.48±0.56
Minimum		14.80±1.16	14.52±5.41	3.05±0.43
Maximum		150.20±11.47	42.04±8.59	7.00±0.58
Mean Value		98.71±7.70	24.83±5.43	5.17±0.44
Standard		400	35	30

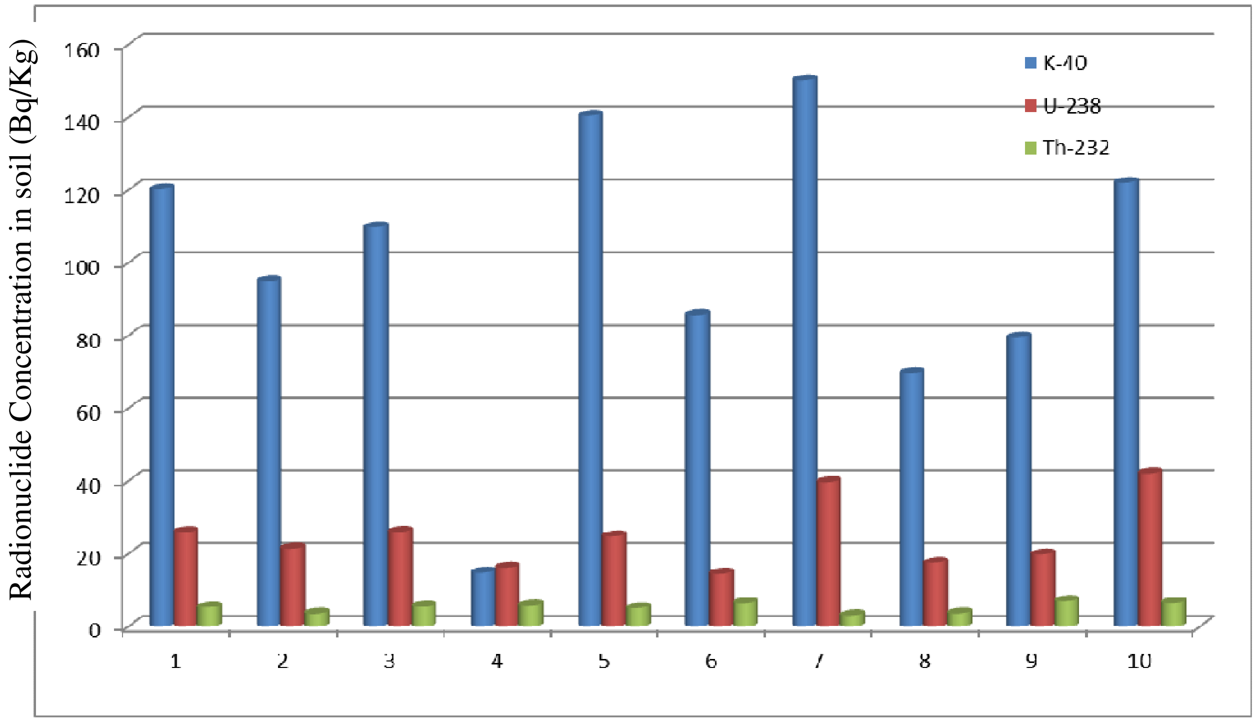

Fig 2: Radionuclide Concentrations in Soil

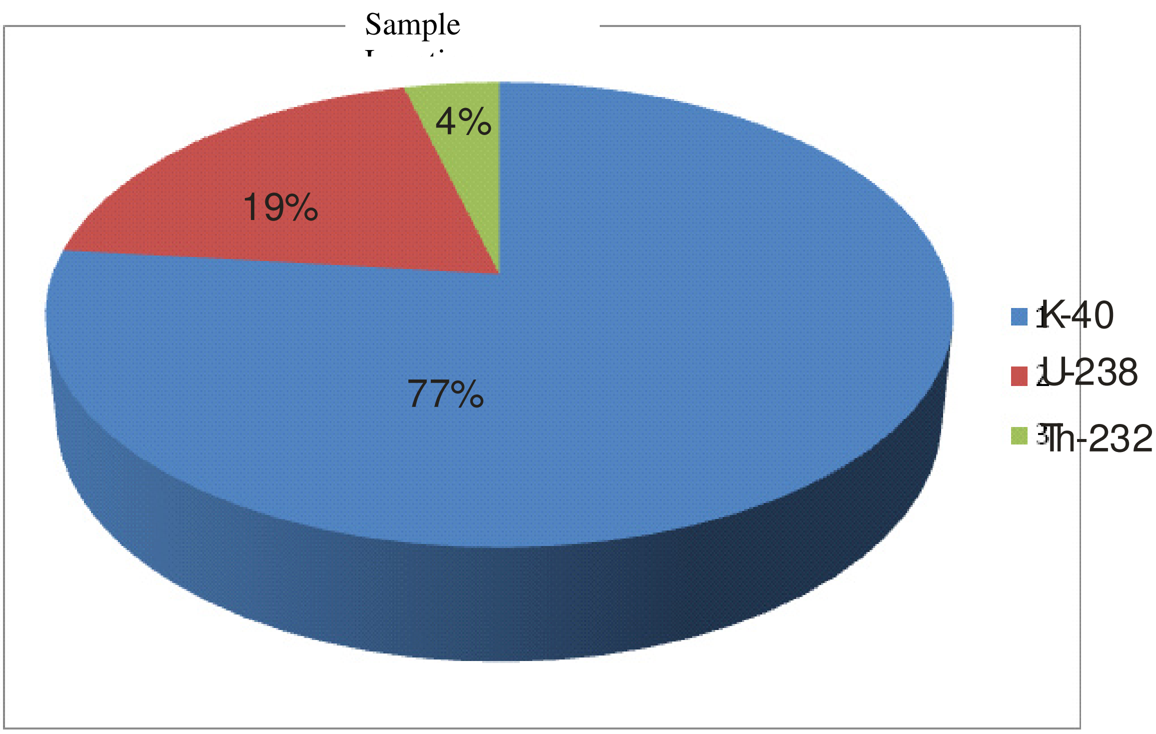

Fig 3: Percentage Radionuclide Concentrations in Soil

Table 2: Calculated Radium Equivalent Activity Index in Bq/kg and Absorbed Dose Rate in nGy/hr in soil samples.

S/N	Sample Location	Radium equivalent activity index (Bq/kg)	Absorbed Dose Rate (nGy/h)
1	Ibagwa	42.7±7.06	20.3±3.30
2	Manta	34.2±5.74	16.2±2.68
3	Mbarakom	42.4±6.98	20.0±3.26
4	Midim waterside	25.6±4.29	11.7±1.97
5	Oku Abak	42.8±6.91	20.4±3.25
6	Ediene Abak	30.3±4.85	14.3±2.26
7	Ikot Ekang	55.6±10.25	26.5±4.79
8	Abak Usung Idim	28.0±4.57	13.2±2.13
9	Abak Usung Atai	36.0±5.73	16.8±2.66
10	Utu Abak	60.7±10.13	28.5±4.72
Mean value		39.8±6.65	18.8±3.10
Standard		370	60

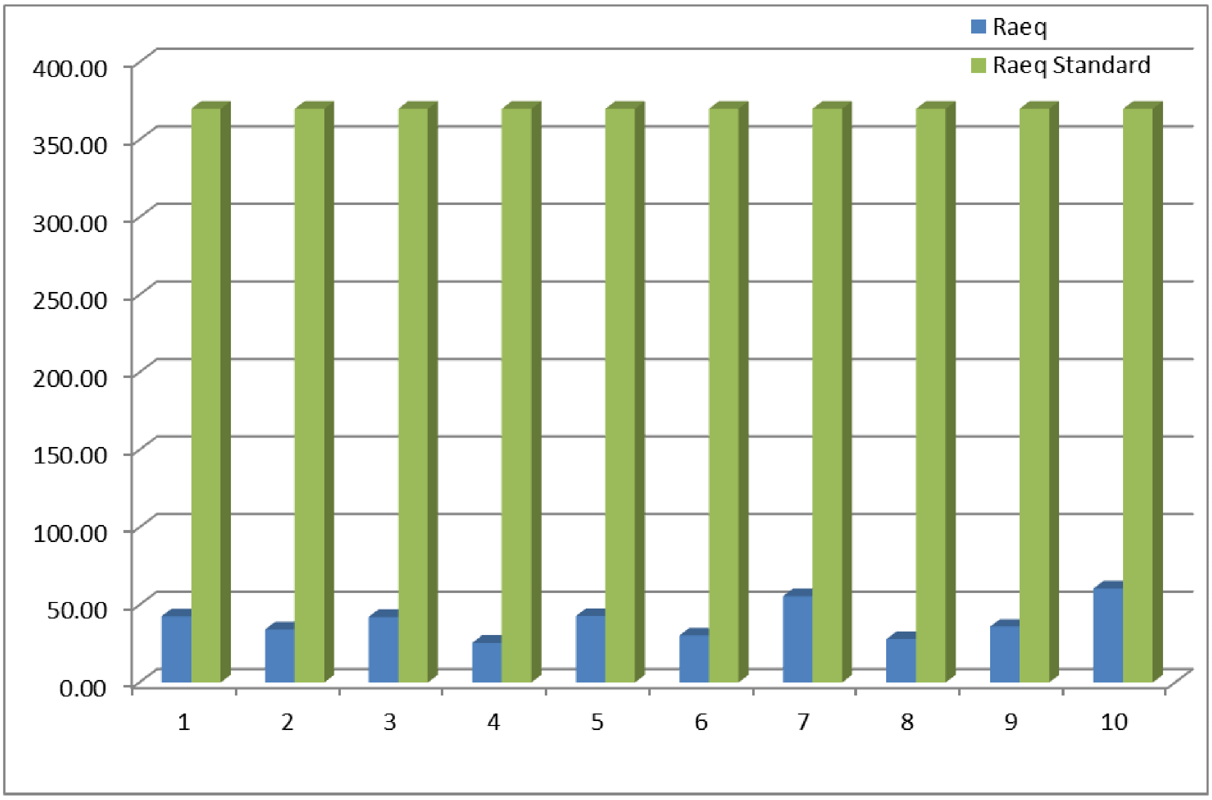

Fig 4: Comparison of Radium Equivalent activity index with standard in soil.

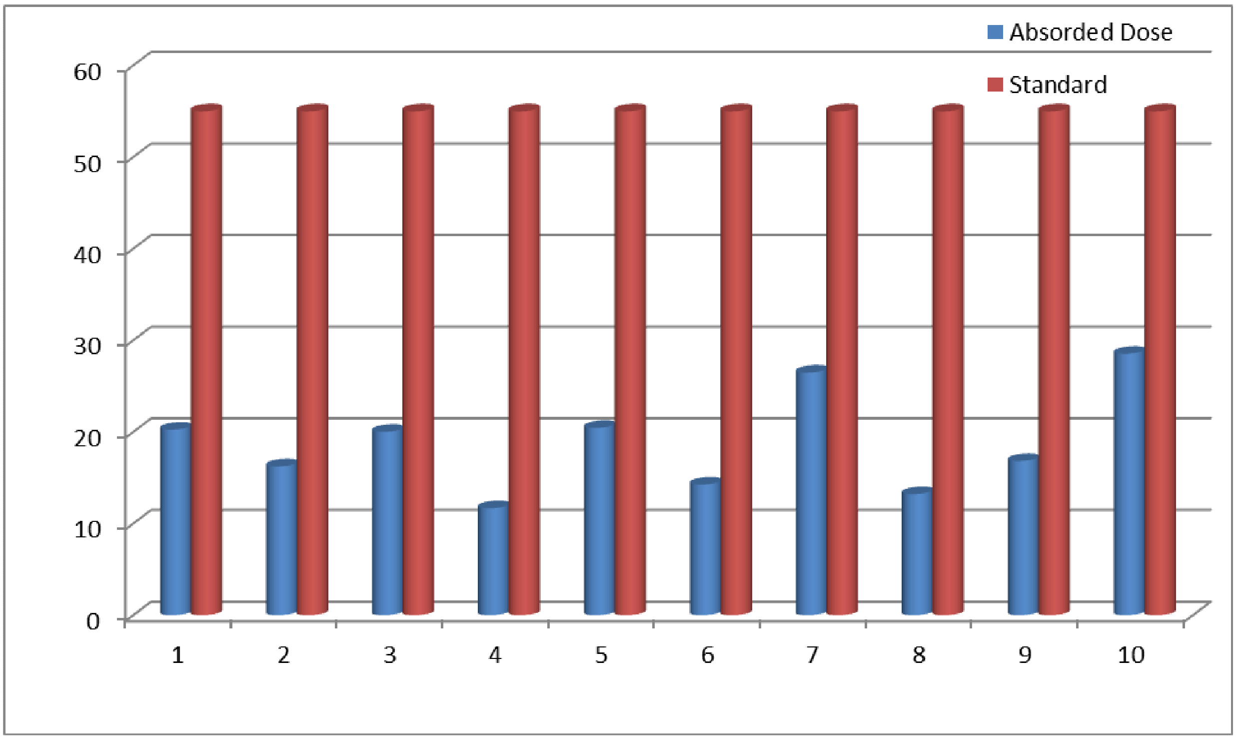

Fig 5: Comparison of absorbed dose rate with standard in soil.

Table 3: Calculated Representative LevelIndex (I_y)and Effective Dose Rate in soil samples.

S/N	Sample Location	Representative Level Index (Bq/kg)	Effective Dose Rate (mSv/yr)
1	Ibagwa	0.3±0.05	0.03±0.004
2	Manta	0.2±0.04	0.02±0.003
3	Mbarakom	0.3±0.05	0.03±0.004
4	Midim waterside	0.2±0.03	0.01±0.002
5	Oku Abak	0.3±0.05	0.03±0.004
6	Ediene Abak	0.2±0.03	0.02±0.003
7	Ikot Ekang	0.4±0.07	0.03±0.006
8	Abak UsungIdim	0.2±0.03	0.02±0.003
9	Abak UsungAtai	0.3±0.04	0.02±0.003
10	Utu Abak	0.4±0.07	0.04±0.006
Mean value		0.3±0.05	0.02±0.004
Standard		1.0	1.0

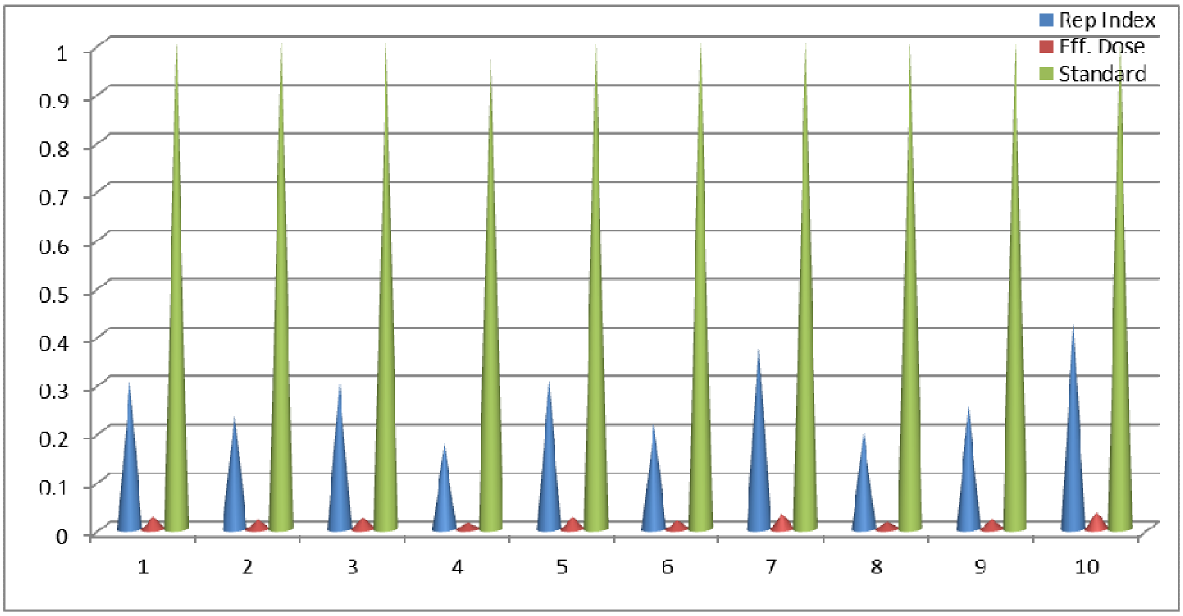

Fig 6: Comparison of Representative Level index and Effective Dose Rate with standards in soil.

Table 4: Calculated External Hazard Index and Internal Hazard Index in soil samples

S/N	Sample Location	External Hazard Index	Internal Hazard Index
1	Ibagwa	0.12±0.019	0.19±0.035
2	Manta	0.09±0.016	0.15±0.028
3	Mbarakom	0.11±0.019	0.18±0.034
4	Midim waterside	0.07±0.012	0.11±0.021
5	Oku Abak	0.12±0.019	0.18±0.033
6	Ediene Abak	0.08±0.013	0.12±0.023
7	Ikot Ekang	0.15±0.028	0.26±0.052
8	Abak Usung Idim	0.08±0.012	0.12±0.022
9	Abak Usung Atai	0.10±0.016	0.15±0.027
10	Utu Abak	0.16±0.0274	0.28±0.051
Mean value		0.11±0.018	0.17±0.033
Standard		1.0	1.0

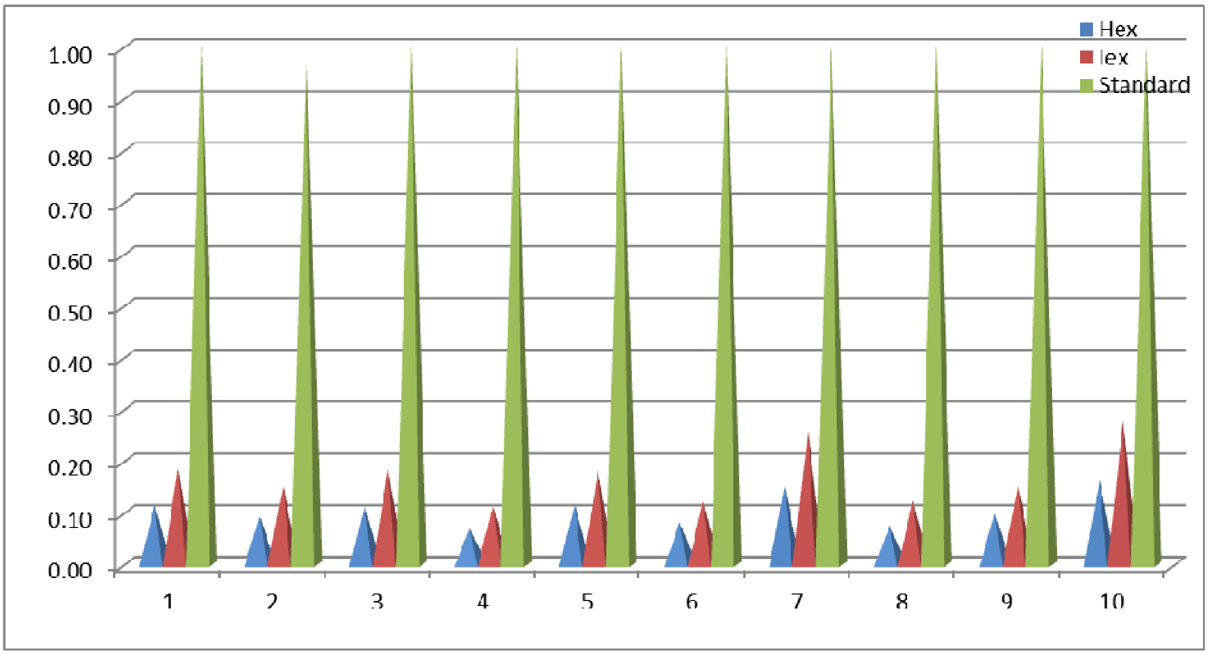

Fig 7: Comparison of External Hazard Index and Internal Hazard Index with standard in soil.

Radionuclide Concentration in Soil

Three naturally occurring radionuclides were detected in all the soil samples. These are ^{40}K, ^{238}U and ^{232}Th.

Table 1 shows the specific activity concentration values obtained for the soil samples. The average activity concentration of ^{40}K is 98.71±7.69 Bq/kg with a range of 14.80±1.16Bq/kg (sample collected at Midim Waterside) to 150.20±11.47 Bq/kg (sample collected at Ikot Ekang). The average activity concentration of ^{238}U is 24.83±5.43 Bq/kg with a range of 14.52±3.49 Bq/kg (sample taken at Ediene) to 42.04±8.59 Bq/kg (sample taken at Utu Abak). The average activity concentration of ^{232}Th is 5.17±0.44 Bq/kg with a range of 3.05±0.27 Bq/kg (sample collected at Ikot Ekang) to 7.00±0.58 Bq/kg (sample taken at Abak Usung Atai).

Fig 2 is a bar chart showing the activity concentration of ^{40}K, ^{238}U and ^{232}Thin the soil. It is seen from Fig. 3 that the percentage concentration of ^{40}K is 77%, making ^{40}K the dominant radionuclide in the soil. A previous study by Chad-Umoren and Nwali (2013) which investigated the radiological impact of effluents from the Port Harcourt Refinery Company on its host community also showed that ^{40}K was the dominant radionuclide in the soil. Comparing the present results with those obtained from the measurement of natural radiation in soil at the Federal Capital Territory (Umar et al, 2012) and in parts of Enugu (Avwiri et al, 2012), the concentrations of the radionuclides in the present study are lower than the activity concentration of 539.6±7.0Bq/kg obtained for ^{40}K, 21.6±1.9Bq/kg for ^{238}Uand 85.7±2.4 for ^{232}Thin the FCT, but higher than the values obtained by Avwiri et al (2012). Furthermore, the activity concentrations of the radionuclides in this work are lower than the ICRP standards of 400Bq/kg for ^{40}K; 35Bq/kg for ^{238}Uand 30Bq/kg for ^{232}Th.

Hazard Indices in Soil

The absorbed dose rate and radium equivalent in soil were computed from eqs (1) and (2) respectively and are shown in Table 2. The mean value of the radium equivalent is 39.8±6.65Bq/kg while the mean value of absorbed dose is 18.8±3.10Bq/kg. The results of this study are lower than those obtained by Aviwiri et al (2012) for Udi and Ezeagu Local Government Areas of Enugu State which gave Ra_{eq} as 34.19Bq/kg and absorbed dose as 15.20Bq/kg. However, the present survey indicates no radiological hazard as the values are within the UNSCEAR recommended permissible limits for absorbed dose rate and for radium equivalent in soil (Figures 4 and 5).

The representative level index calculated from eq. (3) ranges between 0.2±0.03Bq/kg to 0.4±0.06Bq/kg with a mean value of 0.3±0.05Bq/kg for soil (Table 3), while the effective dose obtained using eq. (4) ranges between 0.01±0.002mSv/y to 0.04±0.006mSv/y with a mean value of 0.02±0.004mSv/y and are also shown in Table 3.

This study can be compared with a previous study in south western Nigeria which gave that the representative level index ranged between 0.19±0.06 to 6.84±0.29Bq/kg (Ajayi, 2009). Fig.6 shows that the representative level index and effective dose rate for the soil samples of the study area are lower than the recommended standards.

The external hazard index and the internal hazard index were computed using eqs. (5) and (6) respectively. The external hazard index ranges between 0.1±0.01mSv/yr to 0.2±0.63 with mean value 0.1±0.02mSv/yr for the soil, while the internal hazard index ranges between 0.1±0.02mSv/yr to 0.3±0.05mSv/yr with mean value of 0.2±0.03mSv/yr (Table 4). A comparison of this result with the work of Mei-Wo (2011) shows that this mean value is lower than that of Mei-Wo given as 0.39±0.07 but is in the same range as that reported by Avwiri et al (2012). Fig. 7 compares the calculated external and internal hazard indices of this work with the ICRP standard and shows lower concentrations with regards to public health and safety.

Conclusion

The study used gamma spectrometer to investigate the concentration of radionuclides and also determined hazard indices for soil using samples collected from10 different communities of Abak Local Government Area of Akwa Ibom State, Nigeria. This work serves as baseline for future radiological study of the area.

The overall result indicates that the commonly occurring radionuclides are not uniformly distributed in the soil. The average activity concentrations of ^{40}K, ^{238}U and ^{232}Th in the samples were estimated to be 98.7Bg/kg, 24.8Bq/kg and 5.2Bq/kg respectively. The average radium equivalent activity in the samples was 39.8Bq/kg (soil). The absorbed dose rate due to the radionuclides in the samples was calculated to be in a range of 11.7 – 28.5nGy/h with an average value of 18.8nGy/h. The corresponding effective dose rate was calculated to be 0.02mSv/yr. The external and internal hazard indices in all the samples were less than unity with average values of 0.1 and 0.2.

The percentage contribution of the radionuclide in soil shows a higher percentage of K-40, U-238 and Th-232. Comparison with international standards shows that the presence of these radionuclides in the soil is within acceptable limits. Also, the computed hazard indices are all below the recommended standards for such environment and as such exposure to the inhabitant pose no significant health threat and the environment is radiologically safe.

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