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Estimation of Radiological Risks in Soils from Selected Oil-Spill Communities in the Niger Delta, Nigeria

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ABSTRACT
The estimation of radiological risks in soils from selected oil-spill communities in the Niger Delta, Nigeria has been carried out using Sodium Iodide detector dopped with Thallium based on gamma spectroscopy, NaI(Tl)Ɣ, followed by mathematical computations The activity concentrations of radionuclides of ^{226}Ra, ^{232}Th, and ^{40}K ranged from 25.23±2.30 to 50.12±4.22 Bq/kg, 42.18 ± 4.01 to 60.01±2.30 Bq/kg, and 150.29±8.31 to 210.00±8.18 Bq/kg respectively. Also, the mean values of the activity concentration of radionuclides of ^{226}Ra, ^{232}Th, and ^{40}K were 37.34, 50.72, and 181.57 Bq/kg respectively. The mean values of the annual gonadal dose equivalent (AGDE), representative gamma index, (Iγ), external hazard index (Hex), internal hazard index (Hin), and radium equivalent activity (Raeq) were 384.42 μSv/y, 1.509, 0.334, 0.435, and 123.90 Bq/kg, respectively. mean of the annual effective doses for infants, children, teenagers, and adults were $32.726x10^{-3}$, $26.086x10^{-3}$,$24.522x10^{-3}$, and $23.135x10^{-3}$mSv/y respectively. the obtained value was all below the recommended safe limit of 1.0 mSv/y. The corresponding mean of lifetime fatality risks were 37.16 $x10^{-6}$, 73.98 $x10^{-6}$, 74.21 $x10^{-6}$, and $68.13x10^{-6}$ for infants, children, teenagers, and adults, respectively. The results indicated that higher estimated risk was recorded within the teenage age group. In general, the results showed that the investigated soil samples do not constitute any significant radiological health hazard under the existing exposure conditions. However, use of high-power germanium detector is recommended for further study.

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Keywords: Activity Concentration, Gamma Spectroscopy, Lifetime Fatality Risk, Oil Spill, Soil Sample.

INTRODUCTION

Natural radionuclides are an inherent Earth's environmental component and it constitutes largest sources of radiation exposure to the public. The naturally occurring radionuclides (NORs), precisely ^{238}U,^{232}Th, and ^{40}K, which are presently in varying concentrations within sediments, water, rocks, soils, air, and other biological materials. These radionuclides within the environment continuous to undergo radioactive decay with the emission of alpha, beta, and gamma radiation which contributes significantly to the terrestrial radiation exposure (UNSCEAR, 2020). The exposure of human to background ionizing radiation emanates from natural and anthropogenic sources. The natural background radiation contributed majorly to the annual radiation exposure received by humans and its environment. Terrestrial radionuclides also contribute substantially alongside with cosmic radiation, radon, and internal radionuclides. The exposure of human and environment to low levels of natural radiation are unavoidable, the rapid increase in radionuclides concentrations resulting from industrial activities or geological conditions may consequently pose some health-related risks to human due to over exposure radiation (UNSCEAR, 2024; UNSCEAR, 2020). Oil exploration, production, transportation, processing of crude oil and natural gas have been on high size and also recognized as industrial activities which are capable of redistributing naturally occurring radioactive materials (NORM). Crude oil spillage has the potential of elevating the NORMs and production activity could also alter the natural ecosystem through, scales, sludges, and drilling muds. Niger Delta region of Nigeria is one of the world's most petroleum productive provinces and with extensive oil exploration and production for many decades (Orisakwe, 2021). Regrettably, there have been repeated oil spills resulting from failures of pipeline, equipment corrosion, pipelines vandalism and illegal refining operation Ukhurebor et al., (2021). for agricultural activities. According to (Avwiri & Agbalagba, 2018; UNSCEAR, 2020), this type of contamination within the environments lead to the accumulation of naturally occurring radionuclides, increasing the potential health risk of residents due to due radiation exposure. The natural radionuclides within the contaminated soils migrate into groundwater, surface water, cultivated crops, aquatic system, and other related sources through environmental erosion, weathering, leaching, and biological uptake. Subsequently, humans are exposed through the ingestion of the contaminated food, drinking water, inhalation of the contaminated dust particles, or through the external gamma radiation emitted from contaminated soils. The prolonged exposure to radionuclides with elevated concentrations level has been associated with increased risks of cancer development, genetic mutations, damage to tissue, and other related health effects (UNSCEAR, 2024; ICRP, 2020). The radiological assessment of radionuclides, therefore plays essential role in the evaluation of the safety of contaminated environments. The measurements of activity concentrations of radionuclides (^{40}K, ^{238}U and ^{232}Th) using the gamma-ray spectrometry which provide significant information for estimating radiological hazard indices such as absorbed dose rate, annual effective dose equivalent (AEDE),

radium equivalent activity (Raeq), external hazard index (Hex), internal hazard index (Hin), annual gonadal dose equivalent (AGDE), representative gamma index (Iγ), and excess lifetime cancer risk (ELCR). These indices are internationally accepted indicators for assessing the potential health risks associated with environmental radioactivity and are widely applied in environmental radiation protection studies (UNSCEAR, 2020). Though, there have been previous studies on oil spill in the Niger Delta but there remains insufficient information regarding the radiological implications of exposure. This study therefore determined the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soils from selected oil-spill communities in the Niger Delta and evaluated their associated radiological exposure and health-risk indices.

Study Area

The research work was conducted within Rivers, Bayelsa and Delta States in the Niger Delta, with the consideration of selected communities across the three states in southern Nigeria Niger Delta. Niger Delta is a complex deltaic environment categorized by wide-ranging river channels, creeks, wetlands, mangrove ecosystems and low-lying terrain, with drainage systems ultimately discharging into Gulf of Guinea. Niger Delta, represents one of Africa's major river-delta environments and has significant ecological and socioeconomic importance (James et al., 2014; Ola et al., 2024). The entire area is made of abandoned beach ridges with many tributaries of river Niger, Anekwe et al, 2023, which has a geographical coverage of approximately from 4°00′N to 5°40′N Latitude and 5°20′E to 8°00′E Longitude, as shown in Figure 1. Sixteen (16) locations were investigated for the purpose of the study and locations covered are; Rumuekpke, Bodo City, Ahoda West, Elemed, Gokana and Iloma in Rivers State; Adibawa North-East 1, Nembe, Ogboinbiri, Ikarama, Tebidaba, Peremabiri, Obololi and Imiringi in Bayelsa State; and Ndokwa East in Delta State. The area landscape is mainly formed by fluvial and marine sediments and with freshwater swamps, mangrove ecosystems, tidal creeks and unified waterways (Ewim et al., 2023; Ola et al., 2024). The major economy activities of communities within the Niger Delta are traditionally associated with fishing, farming, forestry and other natural-resource-dependent with petroleum exploration and production in Nigeria. Therefore, Oil exploration, transportation, spills and other petroleum-related oil activities have contributed greatly to the environmental pressures in the area such as; the contamination of soil and water and degradation of mangrove and swamp ecosystems (Ukpong et al., 2019; Ozigis et al., 2019). The selected oil spill communities and their state are shown on the map in figure 1 below.

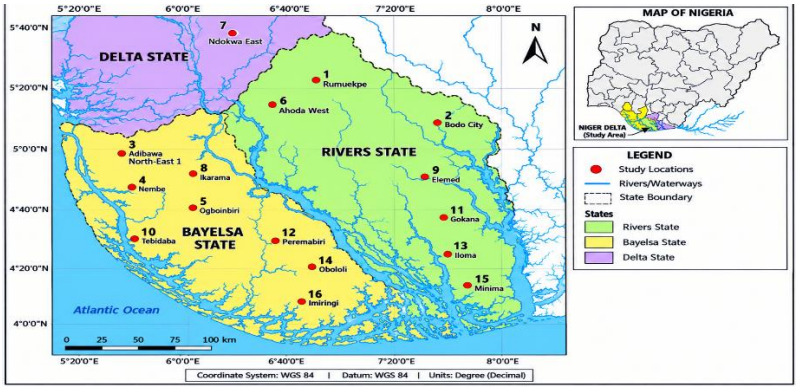


Figure 1: Map of Study Area

MATERIALS AND METHODS

The soil samples were collected from the Selected Communities, each at a depth of 0-15cm using a clean stainless-steel auger to avoid cross contamination and transferred into well label black polythene bags. The soil samples were air dried at a room temperature for seven (7) days to remove moisture content, sieved with a 2mm mesh filter to remove stones, roots and leaves and packed into a new well label black polythene bag. The samples were taken to the laboratory for analysis.

A gamma-ray spectrometry system with Canberra 3×3 model 802 Na(TI) detector was used in analyzing the soil samples in accordance with Jibiri *et al*., 1999. The detector is connected to with an amplifier which are linked to a computer system GENIE 2K software that correlated gamma energies to a number of possible isotopes. The soil samples were kept for thirty (30) days to achieve secular equilibrium. Then the soil sample were placed in a Marinelli beaker and then made to sit on the NaI (Tl) detector. Shielding from environmental background radiation was achieved by counting in Canberra 100 mm thick lead castle. The energy resolution for the detector using Cs137 from International Atomic Energy Agency (IAEA) is 7.5% at 662KeV Cs-137 line. The energy and efficiency calibration of the system was carried out before soil samples analysis using the multinuclide reference standard solution supplied by the International Atomic Energy Agency, IAEA. This was to enable identification and quantification of the activity concentration of the radionuclides in the soil samples. The standard and soil samples were counted for a period of 36,000 seconds to acquire spectral data for a better counting statistics and evaluation. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K were determined after correction for background and inhomogeneity. The calibration of the detector system was made by estimating blended typical sources of known radioisotope with well-defined energies offered through these IAEA Technology. The specific radioactivity intensities of these specimens remained determined using the net region beneath the photo peaks from the energy with efficiency calibration.

$$C(\mathrm{Bq\,kg^{-1}}) = \frac{C_n}{\varepsilon P_\gamma M_s} \quad (1)$$

In the equation above, C is the activity concentration of the sample in BqKg^{-1}, Cn is the count rate under the corresponding peak, P is the supreme change likelihood of the specific gamma ray and Ms is the mass of the Specimen (Nwii et al, 2022). The Peak corresponds to 1460 keV for ^{40}K,

1764.5 KeV for ^{226}Ra and 2614.5 KeV for ^{232}Th remained measured in touching base at the radioactivity levels (Bqkg^{-1}).

Radiological Health Risk Parameters

The following Radiological Health Risk indices were computed.

Annual Effective Dose Due to Soil Ingestion; The annual effective dose due to soil ingestion is an essential radiological parameter used in estimating the internal radiation dose received by individuals through the accidental ingestion of soil contaminated with naturally occurring radionuclides. Soil ingestion occurs unintentionally through hand to mouth activities, consumption of contaminated food, and inhalation. Children are generally more susceptible to soil ingestion than adults because of their frequent hand-to-mouth. (USEPA, 2011).

$$\text{AED} = C_{Soil} \text{ x } IR_{Soil} \text{ x DCF} \quad (2)$$

Where: AED is Annual Effective Dose (Sv y^{-1} or mSv y^{-1}), C is Activity concentration of the radionuclide (Bq kg^{-1}), IR is Ingestion rate of Soil (kg y^{-1}) and DCF Age-dependent ingestion dose conversion factor (SvBq^{-1}). With age specific ingestion dose conversion factor for ^{226}Ra, ^{232}Th and ^{40}K; 4.7x10^{-7}, 3.6x10^{-6},4.2x10^{-8},6.2x10^{-7}, 2.3x10^{-6},4.2.1x10^{-8}, 1.5 x10^{-7},6.2 x10^{-7},4.8 x10^{-8}, 2.8 x10^{-7},2,3 x10^{-7} and 6.2 x10^{-7}, Infant, Children, Teenager and Adult respectively (ICRP 2012 and IAEA 2014).

Lifetime Fatality Risk (LFR): The Lifetime Fatality Risk (LFR) is one of the radiological health risk parameters used in estimating the probability of an individual developing fatal cancer over a lifetime due to consistence exposure to ionizing radiation. It is one of stochastic risk parameter which quantifies, the likelihood of radiation-induced fatal cancer due to prolonged exposure to radionuclides such ^{238}Ra ^{232}Th and ^{40}K. (UNSCEAR, 2020).

$$\text{LFCR} = \text{AED x DL x RF} \quad (3)$$

Where: LFCR= Lifetime Fatal Cancer Risk for age group AED= Annual Effective Dose for age group (Sv y^{-1}), DL = Lifetime duration (commonly 70 years) and RF = Fatal cancer risk coefficient = 0.055 **Sv^{-1}** (Umair et al.,2024).

Severity of Hereditary Effects (SHE): The severity of hereditary effects (SHE) is among the radiological risk parameter utilized for estimating the probability of hereditary disorders that can occur in life of the offspring due to prolong exposure to ionizing radiation. Severity hereditary effect is not like the cancer risk that affects the individual who are exposed to radiation. (ICRP, 2007; UNSCEAR, 2020).

$$SHE = \frac{AED(mSv/y)}{1000} x\ 2.0\ x\ 10^{-3} \quad (4)$$

Estimated Lifetime Hereditary Effect (ELHE): The Estimated Lifetime Hereditary Effect (ELHE) is one of the radiological health risk parameters used for estimating the probability of hereditary that may occur in future generations due to a prolonged exposure to ionizing radiation. Hereditary effects occur when ionizing radiation induces mutations in the germ cells (sperm or ova), which can be subsequently transmitted to the offspring. (ICRP, 2007; UNSCEAR, 2020).

$$\text{ELHE} = \text{AED x } 70 \text{ x } 0.002 \quad (5)$$

Where, AED is Annual Effective Dose (AED), Average lifetime (70 years), and nominal hereditary risk coefficient is 0.002.

Annual Gonadal Dose Equivalent (AGDE): The annual dose equivalents that reproductive organs and other organs of interest specified receive might have a genetic impact on the population that is exposed. Annual gonad dose equivalent (AGDE), which gives the measure of dose delivered to these organs due to specific activities of ^{238}Ra, ^{232}Th, and ^{40}K, was computed using the formula adopted by (Chandrasekaran *et al*., 2015)

$$\text{AGDE} = 3.09A_{Ra} + 4.18A_T + 0.314A_K \quad (6)$$

Activity Utilization Index (AUI): High tendency exists among the locals for the use of sands as aggregates for building materials. Hence, this variable is constructed to enable effective evaluation of dose rates in the air due to varying combinations of radioisotope content in building materials. (Chandrasekaran *et al.*, 2015).

$$\boldsymbol{AUI} = \left(\frac{\boldsymbol{A_{Ra}}}{\boldsymbol{50Bq/Kg}}\right)\boldsymbol{F_u} + \left(\frac{\boldsymbol{A_{Th}}}{\boldsymbol{50Bq/Kg}}\right)\boldsymbol{F_{Th}} + \left(\frac{A_K}{50Bq/Kg}\right)F_K \quad (7)$$

Where A_{Ra}, A_{Th}, and A_K, are the measured specific activities of radioisotopes in Bqkg^{-1}, respectively. F_U, F_{Th} and F_K, with numerical values of 0.461, 0.623, and 0.0414, respectively, represent fractional contributions of radioisotopes to the total gamma dose rate in soils, respectively WNA (2023)

Representative Gamma Index (Iγr): One screening criterion for identifying building materials that can create a radioactive risk is the representative gamma index. It successfully corresponds with the increased annual effective dose rate from surface-level materials. (Guembou *et al*, 2017).

$$I_{yr} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (8)$$

Where A_{Ra}, A_{Th}, and A_K, are the specific activity concentrations of radioisotopes in Bqkg^{-1} respectively.

External and Internal Hazard Indices (Hex and Hin): The Hex, and Hin are radiation criteria used to evaluate the external and internal hazards from gamma radiation due to exposure to radon and decay progeny, respectively (Chandrasekaran *et al.*, 2015).

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (9)$$

Similarly, internal exposure to radon and radioactive decay daughters is controlled by the internal hazard index, (Hin).

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (10)$$

Radium Equivalent Activity (Raeq)*:* The estimation of the activities of ^{226}Ra, ^{232}Th and ^{40}K, an index known as (Raeq) has been presented. This is to enable a single index to define the radiation hazards associated with mixtures of the radionuclides. (Ugbede & Echeweozo 2017).

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (11)$$

here A_{Ra}, A_{Th} and A_K are the activity concentrations of radioisotopes respectively.

RESULTS AND DISCUSSION

The results of the activity concentration, Radiological parameters and some hazard indices are presented in Tables 1 to 14. The comparisons of the measured activity concentrations of (^{226}Ra, ^{232}Th and ^{40}K) with standard are shown in Figures 2 to 4, Figures 5 presents the percentage contributions of the Radionuclides in the study area, while Figures 6, 7 and 8 show the frequency distribution of activity concentration of the Radionuclides of ^{226}Ra, ^{232}Th and ^{40}K respectively.

Table 1: Activity Concentration of Radionuclides (^{226}Ra, ^{232}Th and ^{40}K)

S/N	Locations	Latitude (^{O}N)	Longitude (^{O}E)	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
1	Rumuekpe	5.06300 5º 3’ 46.8’’	6.76800 6º 46’ 4.8’’	30.04±4.22	50.22±4.21	200.56±8.33
2	Bodo City	4.63150 4º 37’ 53.4’’	7.27050 7º 16’ 13.8’’	25.23±2.30	60.01±2.30	198.21±6.56
3	Adibawa Nort-East1	5.08000 5º 4’ 48’’	6.32000 6º 19’ 12’’	37.21±3.29	42.18±4.01	179.34±7.66
4	Nembe	4.39300 4º 23’ 34.8’’	6.42300 6o 25 22.8	40.31±2.32	48.22±4.08	201.42±9.03
5	Ogboinbiri	4.58320 4º 34’ 59.5’’	5.95410 5º 57’ 14.76’’	35.22±3.22	52.33±4.14	189.46±8.32
6	Ahoda West	5.09500 5º 57’ 00.0’’	6.38500 6º 23’ 6’’	50.06±4.22	52.21±3.08	169.78±6.55
7	Ndokwa East	5.650583 5^{0} 39’ 2.09’’	6.5616111 6º 33’ 41.79’’	30.46±3.10	47.33±4.22	210.32±8.18
8	Ikarama	5.14800 5º 8’ 52.8’’	6.31200 6º 18’ 43.2’’	46.02±3.28	53.11±4.01	194.21±9.22
9	Elemed	4.78900 4º 47’ 20.4’’	7.11200 7º 6’ 43.2’’	29.32±2.08	50.32±2.08	163.22±7.16
10	Tebidaba	4.57200 4º 34’ 19.2’’	5.96200 5º 57’ 43.2’’	33.21±4.25	50.21±3.13	169.66±9.45
11	Gokana	4.66850 4º 40’ 6.6’’	7.37420 7º 22’ 27.12’’	42.56±4.35	46.38±4.28	179.82±6.37
12	Peremabiri	4.82100 4o 49 15.6	6.10300 6o 6 10.8	37.06±4.27	48.11±3.24	150.29±8.31
13	Iloma	4.44200 4º 26’ 31.2’’	7.16500 7º 9’ 54’’	38.11±4.22	50.09±2.01	187.39±7.62
14	Obololi	4.82711 4º 49’ 37.59’	6.21131 6º 12’ 40.7’’	42.09±3.10	49.26±1.23	154.35±6.10
15	Minima	4.42000 4º 25’ 12’’	7.19500 7º 11’ 42’’	32.36±4.10	58.22±2.33	176.45±9.23
16	Imiringi			48.29±3.22	53.31±29	180.56±8.12
		Mean		37.34	50.72	181.57
	UNSCEAR	(2020)		35.00	30.00	400.00

Table 2: Radiological Health Risk Parameter

Locations	^{40}K	^{226}Ra	^{232}Th	AGDE	AUI	Iyr	Hex	Hin	Raeq
Rumuekpe	200.56	30.04	50.22	365.72	19709.62	1.439	0.317	0.398	117.297
Bodo City	198.21	25.23	60.01	391.04	19509.35	1.585	0.341	0.409	126.306
Adibawa North W	179.34	37.21	42.18	347.60	17663.75	1.335	0.300	0.401	111.336
Nembe	201.42	40.31	48.22	389.36	19835.19	1.502	0.337	0.446	124.774
Ogboinbiri	189.46	35.22	52.33	387.10	18679.56	1.525	0.337	0.432	124.640
Ahoda West	169.78	50.06	52.21	426.23	16862.59	1.658	0.372	0.507	137.793
Ndokwa East	210.32	30.46	47.33	358.00	20635.74	1.391	0.309	0.391	114.337
Ikarama	194.21	46.02	53.11	425.18	19196.5	1.652	0.370	0.494	136.922
Elemed	163.22	29.32	50.32	352.19	16114.3	1.408	0.307	0.387	113.846
Tebidaba	169.66	33.21	50.21	365.77	16753.41	1.449	0.319	0.409	118.074
Gokana	179.82	42.56	46.38	381.84	17759.39	1.473	0.331	0.447	122.729
Peremabiri	150.29	37.06	48.11	362.81	14899.08	1.433	0.317	0.417	117.429
Iloma	187.39	38.11	50.09	385.98	18483.79	1.508	0.335	0.438	124.168
Obololi	154.35	42.09	49.26	384.43	15321.66	1.509	0.336	0.450	124.417
Minima	176.45	32.36	58.22	398.76	17443.69	1.606	0.349	0.436	129.201
Imiringi	180.56	48.29	53.31	428.75	17896.16	1.669	0.374	0.504	138.426
Mean	181.56	37.35	50.72	384.42	17922.74	1.509	0.334	0.435	123.855

Table 3: Annual Effective Dosage from Potassium (^{40}K) for Different Age Groups

S/N	Sampling Locations	Annual Effective Dose for Different Age Group for ^{40}K				
		^{40}K (Bq/Kg)	Infant ≤1Yr x10^{-3}	Children (1-12Yrs) x10^{-3}	Teenager (12-17Yr) x10^{-3}	Adult ≥17Yrs x10^{-3}
1	Rumuekpe	200.56	6.217	12.435	12.435	12.435
2	Bodo City	198.21	6.145	12.289	12.289	12.289
3	Adibawa North	179.34	5.56	11.119	11.119	11.119
4	Nembe	201.42	6.244	12.488	12.488	12.488
5	Ogboinbiri	189.46	5.873	11.747	11.747	11.747
6	Ahoda West	169.78	5.263	10.526	10.526	10.526
7	Ndokwa East	210.32	6.52	13.040	13.04	13.04
8	Ikarama	194.21	6.021	12.041	12.041	12.041
9	Elemed	163.22	5.06	10.120	10.12	10.12
10	Tebidaba	169.66	5.259	10.519	10.519	10.519
11	Gokana	179.82	5.574	11.149	11.149	11.149
12	Peremabiri	150.29	4.659	9.3180	9.318	9.318
13	Iloma	187.39	.8.09	11.618	11.618	11.618
14	Oboloili	154.35	4.785	9.570	9.57	9.57
15	Minima	176.45	5.47	10.94	10.94	10.94
16	Imiringi	180.56	5.597	11.19	11.195	11.195
	Mean	**181.56**	**5.629**	**11.257**	**11.26**	**11.26**
	UNSCEAR (2000)	400	**12.4**	**24.8**	**24.8**	**24.8**

Table 4: Annual Effective Dosage from Radium (^{226}Ra) for Different Age Groups

S/N	Sampling Locations	Annual Effective Dose for Different Age Group for ^{226}Ra				
		^{226}Ra (Bq /Kg)	Infant ≤1Yr x10^{-3}	Children (1-12Yrs) x10^{-3}	Teenager (12-17Y) X10^{-3}	Adult ≥17Yrs 10^{-3}
1	Rumuekpe	30.04	7.06	10.21	8.712	8.41
2	Bodo City	25.23	5.93	8.58	7.32	7.06
3	Adibawa North	37.21	7.44	12.65	10.79	10.42
4	Nembe	40.31	9.47	13.72	11.69	11.29
5	Ogboinbiri	35.22	8.28	11.98	10.21	9.86
6	Ahoda West	50.06	11.76	17.02	14.52	14.02
7	Ndokwa East	30.46	7.16	10.36	8.833	8.53
8	Ikarama	46.02	10.82	15.65	13.35	12.89
9	Elemed	29.32	6.89	9.969	8.503	8.21
10	Tebidaba	33.21	7.80	11.29	9.631	9.299
11	Gokana	42.56	10.0	14.47	12.34	11.92
12	Peremabiri	37.06	8.71	12.60	10.75	10.38
13	Iloma	38.11	8.96	12.96	11.05	10.67
14	Oboloili	42.09	9.89	14.31	12.21	11.79
15	Minima	32.36	7.61	11.00	9.384	9.06
16	Imiringi	48.29	11.35	16.42	14.00	13.52
	Mean	37.35	8.67	12.55	10.70	10.33
	ICRP 2007	35.0	0.30	0.30	0.30	1.00

Table 5: Annual Effective Dosage from Thorium (^{232}Th) for Different Age Groups

S/N	Sampling Locations	Annual Effective Dose for Different Age Group for ^{232}Th				
		^{232}Th (Bq /Kg)	**Infant ≤1Yr x10^{-3}**	**Children (1-12Yrs) x10^{-3}**	**Teenager (12-17Y) X10^{-3}**	**Adult ≥17Yrs 10^{-3}**
1	Rumuekpe	50.22	18.079	2.109	2.411	1.406
2	Bodo City	60.01	21.604	2.52	2.88	1.68
3	Adibawa North	42.18	15.185	1.772	2.025	1.181
4	Nembe	48.22	17.359	2.025	2.315	1.35
5	Ogboinbiri	52.33	18.839	2.198	2.512	1.465
6	Ahoda West	52.21	18.796	2.193	2.506	1.462
7	Ndokwa East	47.33	17.039	1.988	2.272	1.325
8	Ikarama	53.11	19.12	2.231	2.549	1.487

S/N	Sampling Locations	Annual Effective Dose for Different Age Group for ^{232}Th				
		^{232}Th (Bq /Kg)	Infant ≤1Yr x10^{-3}	Children (1-12Yrs) x10^{-3}	Teenager (12-17Y) X10^{-3}	Adult ≥17Yrs 10^{-3}
9	Elemed	50.32	18.115	2.113	2.415	1.409
10	Tebidaba	50.21	18.076	2.109	2.41	1.406
11	Gokana	46.38	16.697	1.948	2.226	1.299
12	Peremabiri	48.11	17.32	2.021	2.309	1.347
13	Iloma	50.09	18.032	2.104	2.404	1.403
14	Oboloili	49.26	17.734	2.069	2.364	1.379
15	Minima	58.22	20.959	2.445	2.795	1.63
16	Imiringi	53.31	19.192	2.239	2.559	1.493
	Mean	50.72	18.26	2.13	2.43	1.17
	ICRP 2007	30.0	0.30	0.30	0.30	1.00

Tale 6: Total Annual Effective Dosage for the Different Age Groups

S/N	Total Annual Effective Dose for Different Age Group				
	Sampling Locations	Infant ≤1Yr x10^{-3}	Children (1-12Y) x10^{-3}	Teenager(12-17Y) X10^{-3}	Adult ≥17Y 10^{-3}
1	Rumuekpe	31.356	24.754	23.558	22.251
2	Bodo City	33.679	23.389	22.489	21.029
3	Adibawa North	28.185	25.541	23.934	22.72
4	Nembe	33.073	28.233	26.493	25.128
5	Ogboinbiri	32.992	25.925	24.469	23.072
6	Ahoda West	35.819	29.739	27.552	26.008
7	Ndokwa East	30.719	25.388	24.145	22.895
8	Ikarama	35.961	29.922	27.94	26.418
9	Elemed	30.065	22.202	21.038	19.739
10	Tebidaba	31.135	23.918	22.56	21.224
11	Gokana	32.271	27.567	25.715	24.368
12	Peremabiri	30.689	23.939	22.377	21.045
13	Iloma	35.082	26.682	25.072	23.691
14	Oboloili	32.409	25.949	24.144	22.739
15	Minima	34.039	24.385	23.119	21.63
16	Imiringi	36.139	29.849	27.754	26.208
	Mean	32.726	26.086	24.522	23.135
	ICRP 2007	1.0	1.0	1.0	1.0

Table 7: Lifetime Fatality Risk (LFR) of (^{40}K) for Different Age Groups

S/N	Sampling Locations	Lifetime Fatality Risk for Different Age Group				
		^{40}K(Bq /Kg)	Infan ≤1Yr x10^{-6}	Children (1-12Yrs) x10^{-6}	Teenager (12-17Y) x10^{-6}	Adult ≥17Yr x10^{-6}
1	Rumuekpe	200.56	0.1754	3.553	3.003	36.729
2	Bodo City	198.21	0.2096	4.246	3.589	43.890
3	Adibawa North	179.34	0.1474	2.987	2.525	30.839
4	Nembe	201.42	0.1683	3.416	2.888	35.266
5	Ogboinbiri	189.46	0.1826	3.702	3.135	38.269
6	Ahoda West	169.78	0.1821	3.696	3.127	38.192
7	Ndokwa East	210.32	0.1650	3.350	2.830	34.612
8	Ikarama	194.21	0.1854	3.762	3.176	38.885
9	Elemed	163.22	0.1755	3.564	3.011	36.806
10	Tebidaba	169.66	0.1755	3.553	3.003	36.729
11	Gokana	179.82	0.1617	3.284	2.772	33.919
12	Peremabiri	150.29	0.1678	3.405	2.879	35.189
13	Iloma	187.39	0.1749	3.548	2.995	36.652
14	Oboloili	154.35	0.1722	3.487	2.945	36.036
15	Minima	176.45	0.2035	4.120	3.482	42.735
16	Imiringi	180.56	0.1859	3.773	3.193	38.885
	Mean	181.56	0.177	3.590	3.034	37.102
	ICRP 2007	400	0.010	0.010	0.010	0.010

Table 8: Lifetime Fatality Risk (LFR) of (^{226}Ra) for Different Age Groups

S/N	Sampling Locations	^{226}Ra (Bq /Kg)	Lifetime Fatality Risk for Different Age Group: Infant ≤1Yr x10^{-6}	Children (1-12Yrs) x10^{-6}	Teenager (12-17Y) X10^{-6}	Adult ≥17Yrs 10^{-6}
1	Rumuekpe	30.04	9.78	26.18	31.22	11.82
2	Bodo City	25.23	8.20	21.98	26.22	9.93
3	Adibawa North	37.21	12.13	32.42	38.50	14.63
4	Nembe	40.31	13.13	35.11	41.97	15.86
5	Ogboinbiri	35.22	11.47	30.68	36.61	13.86
6	Ahoda West	50.06	16.32	43.51	51.98	19.71
7	Ndokwa East	30.46	9.933	26.53	31.65	11.97
8	Ikarama	46.02	14.98	40.04	47.74	18.10
9	Elemed	29.32	9.548	25.56	30.49	11.55
10	Tebidaba	33.21	10.82	28.95	34.53	13.05
11	Gokana	42.56	13.86	37.08	44.28	16.75
12	Peremabiri	37.06	12.09	32.30	38.50	14.59
13	Iloma	38.11	12.40	33.19	39.66	14.98
14	Obololi	42.09	13.71	36.65	43.89	16.56
15	Minima	32.36	10.55	28.18	33.65	12.74
16	Imiringi	48.29	15.75	41.97	50.05	19.02
	Mean	37.35	12.17	32.52	38.81	14.70
	ICRP 2007	35.0	0.010	0.010	0.010	0.010

Table 9: Lifetime Fatality Risk (LFR) of (^{232}Th) for Different Age Groups

S/N	Sampling Locations	^{232}Th (Bq /Kg)	**Lifetime Fatality Risk** for **Different Age Group**: Infant ≤1Yr x10^{-6}	Children (1-12Yrs) x10^{-6}	Teenager (12-17Y) X10^{-6}	Adult ≥17Yrs 10^{-6}
1	Rumuekpe	30.04	12.51	16.24	21.56	16.25
2	Bodo City	25.23	14.98	19.40	25.80	19.40
3	Adibawa North	37.21	10.51	13.63	18.13	13.63
4	Nembe	40.31	12.01	15.59	20.71	15.59
5	Ogboinbiri	35.22	13.05	16.90	22.48	16.90
6	Ahoda West	50.06	13.01	16.86	22.45	16.86
7	Ndokwa East	30.46	11.82	15.28	20.33	15.28
8	Ikarama	46.02	13.24	17.17	22.83	17.17
9	Elemed	29.32	12.55	16.25	21.64	16.25
10	Tebidaba	33.21	12.51	16.25	21.56	16.25
11	Gokana	42.56	11.59	14.98	19.94	14.90
12	Peremabiri	37.06	12.01	15.55	20.67	15.54
13	Iloma	38.11	12.51	16.21	21.52	16.21
14	Obololi	42.09	12.28	15.94	21.18	15.94
15	Minima	32.36	14.51	18.83	25.03	18.83
16	Imiringi	48.29	12.51	16.25	21.56	16.25
	Mean	37.35	12.6	16.33	21.71	16.33
	ICRP 2007	30.0	0.010	0.010	0.010	0.010

Table 10: Lifetime Fatality Risk (LFR) for the Different Age Groups

S/N	Sampling Locations	**Total Lifetime Fatality Risk for Different Age Group**: Infant ≤1Y x10^{-6}	Children (1-12Y) x10^{-6}	Teenager (12-17Y) x10^{-6}	Adult ≥17Y x10^{-6}
1	Rumuekpe	34.57	67.29	66.79	64.8
2	Bodo City	37.85	71.1	68.77	73.22
3	Adibawa North	32.96	66.96	68.41	59.1
4	Nembe	36.92	74.61	76.16	66.72
5	Ogboinbiri	37.3	73.49	73.72	69.03
6	Ahoda West	42.07	86.24	89.02	74.76
7	Ndokwa East	33.30	65.25	65.19	61.86
8	Ikarama	41.19	83.54	85.39	74.16
9	Elemed	34.38	66.76	66.18	64.61

S/N	Sampling Locations	Total Lifetime Fatality Risk for Different Age Group			
		Infant ≤1Y $x10^{-6}$	Children (1-12Y) $x10^{-6}$	Teenager (12-17Y) $x10^{-6}$	Adult ≥17Y $x10^{-6}$
10	Tebidaba	35.61	70.07	70.1	66.03
11	Gokana	36.77	75.04	77.16	65.57
12	Peremabiri	35.84	71.68	72.61	65.32
13	Iloma	37.15	74.23	75.16	67.84
14	Obololi	38.04	77	78.81	68.54
15	Minima	39.31	75.85	74.93	74.31
16	Imiringi	41.27	84.63	86.51	74.16
	Mean	37.16	73.98	74.68	68.13
	ICRP 2007	0.01	0.01	0.01	0.01

Table 11: Estimated Lifetime Hereditary Effect (ELHE) from Potassium (^{40}K)

S/N	Sampling Locations	Estimated Lifetime Hereditary Effect for Different Age Group for ^{40}K				
		^{40}K (Bq /Kg)	Infant ≤1Yr $x10^{-3}$	Children (1-12Yrs) $x10^{-3}$	Teenager (12-17Y) $x10^{-3}$	Adult ≥17Yrs $x10^{-3}$
1	Rumuekpe	200.56	280.78	4.47	5.09	13.36
2	Bodo City	198.21	277.49	5.33	6.09	15.96
3	Adibawa North	179.34	251.08	3.75	4.28	11.21
4	Nembe	201.42	281.99	4.28	4.90	12.82
5	Ogboinbiri	189.46	265.24	4.65	5.32	13.92
6	Ahoda West	169.78	237.69	4.63	5.31	13.89
7	Ndokwa East	210.32	294.44	4.20	4.80	12.59
8	Ikarama	194.21	271.89	4.72	5.39	14.14
9	Elemed	163.22	228.51	4.46	5.11	13.38
10	Tebidaba	169.66	237.52	4.47	5.09	13.36
11	Gokana	179.82	251.75	4.12	4.70	12.34
12	Peremabiri	150.29	210.41	4.27	4.89	12.80
13	Iloma	187.39	262.35	4.45	5.08	13.33
14	Obololi	154.35	216.09	4.38	4.99	13.10
15	Minima	176.45	247.03	5.18	5.91	15.54
16	Imiringi	180.56	252.78	4.73	5.42	14.14
	Mean	181.56	254.19	4.51	5.15	13.49

Table 12: Estimated Lifetime Hereditary Effect (ELHE) from Radium (^{226}Ra)

S/N	Sampling Locations	Estimated Lifetime Hereditary Effect for Different Age Group for ^{226}Ra				
		^{226}Ra (Bq /Kg)	Infant ≤1Yr $x10^{-3}$	Children (1-12Yrs) $x10^{-3}$	Teenager (12-17Y) $x10^{-3}$	Adult ≥17Yrs 10^{-3}
1	Rumuekpe	30.04	42.06	4.47	5.09	13.36
2	Bodo City	25.23	35.32	5.33	6.09	15.96
3	Adibawa North	37.21	52.09	3.75	4.28	11.21
4	Nembe	40.31	56.43	4.28	4.90	12.82
5	Ogboinbiri	35.22	49.31	4.65	5.32	13.92
6	Ahoda West	50.06	70.08	4.63	5.30	13.89
7	Ndokwa East	30.46	42.64	4.20	4.80	12.59
8	Ikarama	46.02	64.43	4.72	5.39	14.14
9	Elemed	29.32	41.05	4.47	5.11	13.38
10	Tebidaba	33.21	46.49	4.47	5.10	13.36
11	Gokana	42.56	59.58	4.12	4.70	12.33
12	Peremabiri	37.06	51.88	4.27	4.89	12.80
13	Iloma	38.11	53.35	4.45	5.08	13.33
14	Obololi	42.09	58.93	4.38	4.99	13.10
15	Minima	32.36	45.30	5.18	5.91	15.54
16	Imiringi	48.29	67.61	4.73	5.42	14.14
	Mean	37.35	52.29	4.51	5.15	13.49

Table 13: Estimated Lifetime Hereditary Effect (ELHE) from Thorium (^{232}Th)

S/N	Sampling Locations	^{232}Th (Bq /Kg)	Estimated Lifetime Hereditary Effect for Different Age Group for ^{232}Th			
			Infant ≤1Yr x10^{-3}	Children (1-12Yrs) x10^{-3}	Teenager (12-17Y) X10^{-3}	Adult ≥17Yrs 10^{-3}
1	Rumuekpe	50.22	3.25	4.22	5.6	4.22
2	Bodo City	60.01	3.89	5.04	6.7	5.04
3	Adibawa North	42.18	2.73	3.54	4.71	3.54
4	Nembe	48.22	3.12	4.05	5.38	4.05
5	Ogboinbiri	52.33	3.39	4.39	5.84	4.39
6	Ahoda West	52.21	3.38	4.38	5.83	4.38
7	Ndokwa East	47.33	3.07	3.97	5.28	3.97
8	Ikarama	53.11	3.44	4.46	5.93	4.46
9	Elemed	50.32	3.26	4.22	5.62	4.22
10	Tebidaba	50.21	3.25	4.22	5.60	4.22
11	Gokana	46.38	3.01	3.89	5.18	3.87
12	Peremabiri	48.11	3.12	4.04	5.37	4.04
13	Iloma	50.09	3.25	4.21	5.59	4.21
14	Obololi	49.26	3.19	4.14	5.50	4.14
15	Minima	58.22	3.77	4.89	6.50	4.89
16	Imiringi	53.31	3.25	4.22	5.60	4.22
	Mean	**50.72**	**3.29**	**4.26**	**5.66**	**4.26**

Table 14: Total Estimated Lifetime Hereditary Effect for Different Age Group

S/N	Sampling Locations	Estimated Lifetime Hereditary Effect			
		Infant ≤1Yr x10^{-6}	Children (1-12Y) x10^{-6}	Teenager (12-17Y) x10^{-7}	Adult ≥17Y x10^{-7}
1	Rumuekpe	326.09	13.16	15.78	30.94
2	Bodo City	316.7	15.7	18.88	36.96
3	AdibawaNorth	305.9	11.04	13.27	25.96
4	Nembe	341.54	12.61	15.18	29.69
5	Ogboinbiri	317.94	13.69	16.48	32.23
6	Ahoda West	311.15	13.64	16.44	32.16
7	Ndokwa East	340.15	12.37	14.88	29.15
8	Ikarama	339.76	13.9	16.71	32.74
9	Elemed	272.82	13.15	15.84	30.98
10	Tebidaba	287.26	13.16	15.79	30.94
11	Gokana	314.34	12.13	14.58	28.54
12	Peremabiri	265.41	12.58	15.15	29.64
13	Iloma	318.95	13.11	15.75	30.87
14	Obololi	278.21	12.9	15.48	30.34
15	Minima	296.1	15.25	18.32	35.97
16	Imiringi	323.64	13.68	16.44	32.50
	Mean	309.75	13.25	15.94	31.23



Figure 2: Comparison of the Activity Concentration ^{226}Ra with Standard

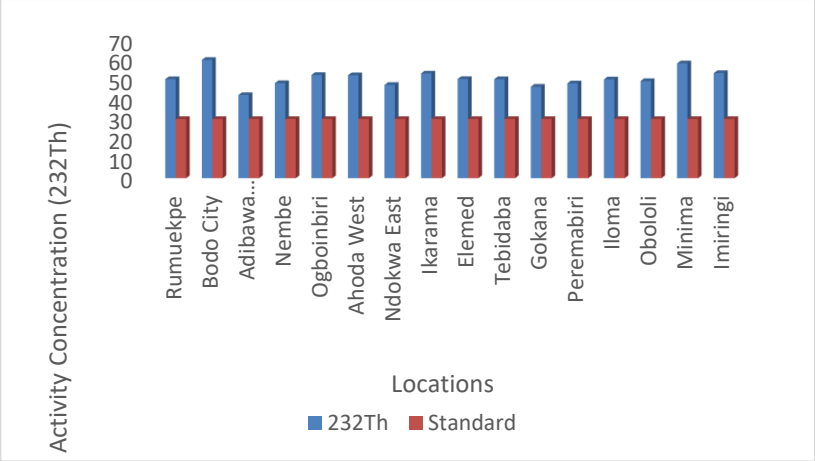


Figure 3: Comparison of the Activity Concentration ^{232}Th with Standard

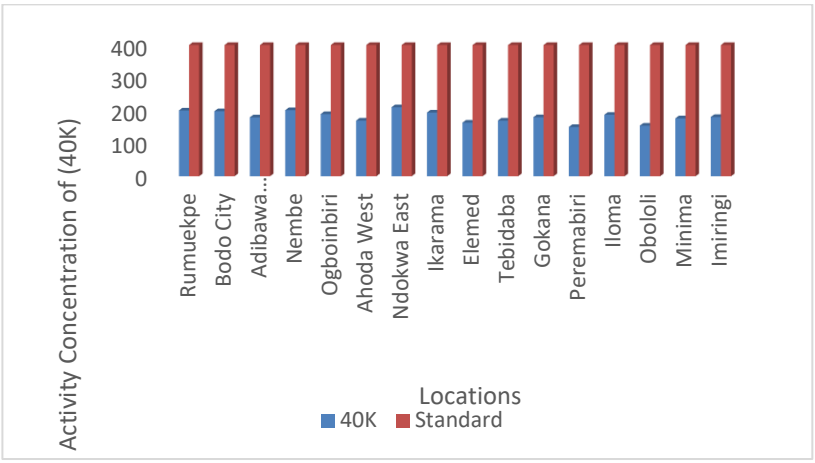


Figure 4: Comparison of the Activity Concentration ^{40}K with Standard

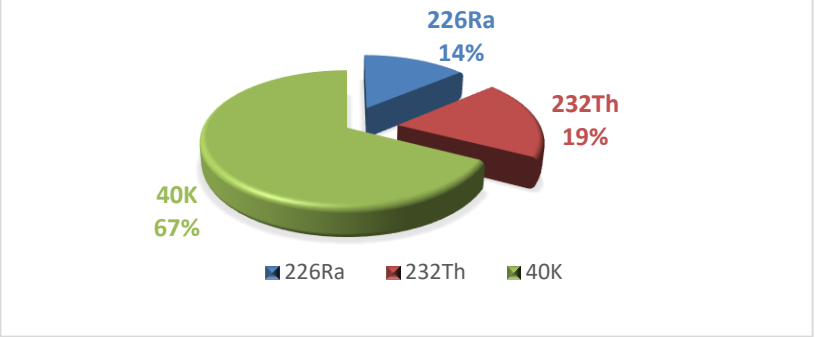


Figure 5: Percentage of Radionuclide with the Study Area

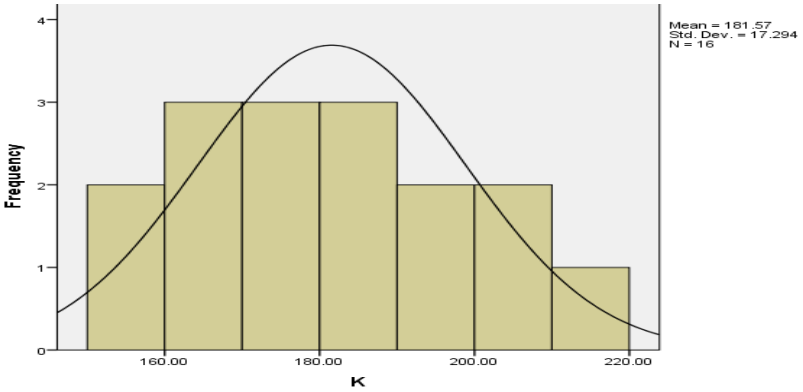


Figure 6: Frequency Distribution of Activity Concentration of ^{40}K for Soil

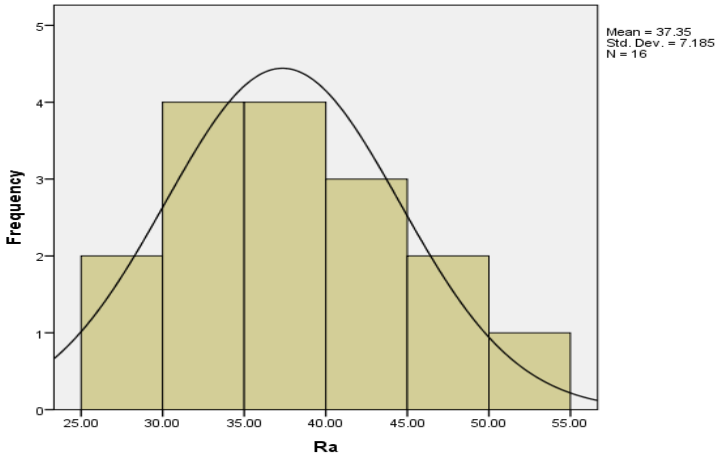


Figure 7: Frequency Distribution of Activity Concentration of ^{226}Ra for Soil

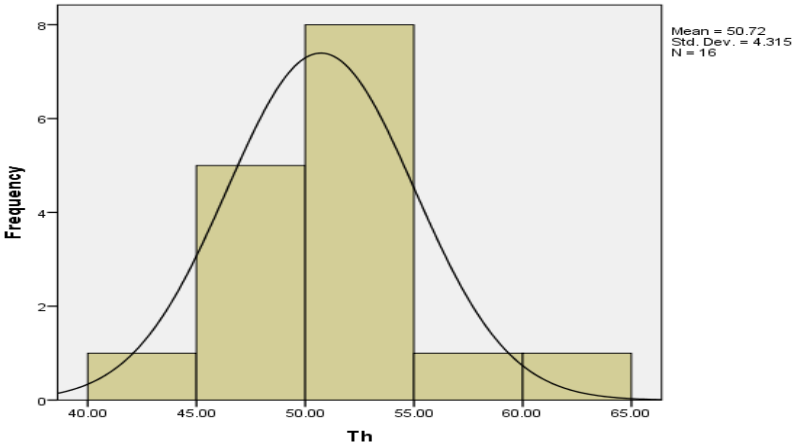


Figure 8: Frequency Distribution of Activity Concentration of ^{232}Th for Soil

DISCUSSION

The results of the activity concentrations of selected soil samples from sixteen locations within the study area ranged from 25.23±2.30-50.12 ±4.22 Bq/kg, 42.18±4.01-60.01±2.30 Bq/kg, and 150.29±8.31-210±8.18 Bq/kg with mean values of 37.34, 50.72 and 181.57 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K respectively. Though high concentration of ^{226}Ra was recorded at Ahoda West, Imiringi, whereas Bodo City had the lowest value which are higher than the UNSCEAR stipulated standard value, while ^{226}Ra was within the recommended safe limit. The obtained mean values are lower than the range reported by Avwiri et al (2021). Figure 5 shows the percentage distribution of radionuclides within the environment.

The results of the radiological parameters have a mean of 384.42, 1.509, 0.334, 0.435 and 123.6 for AGDE, IɣR, Hex, Hin and Raeq respectively. The obtained mean of AGDE exceeded the recommended safe limit of 300μSv/y as stipulated by UNSCEAR 2000. The mean value of AGDE and, external indices (Hex) were higher than the reported work of Avwiri et al (2021). The value of Raeq, Hin and Hex are within the safe limit while the excess life cancer risk was higher than the recommended world average of $0.29x10^{-3}$ indicating slight elevation of lifetime cancer risk within the study area. The obtained result indicates that the radionuclide concentration in the selected soils sample may not pose any significant radiological hazards being in consonance with world average. This also agrees with the work of Agbalagba, et al (2012). Figures 6–8 show the frequency distributions of radionuclides and also demonstrate variability in radionuclide activity concentrations within the selected locations. The predominance of value ^{40}K agrees with reported work of Muhammad and Abbasi (2025). The frequency distributions of ^{40}K, ^{226}Ra and ^{232}Th show variations in the activity concentrations of the selected soil samples with differences in distribution. The predominance of ^{40}K indicates that potassium is an important contributor within potassium-bearing minerals, while similarities between the distributions of ^{226}Ra and ^{232}Th may reflect common geological controls. The result of the total annual effective dose for different age group, showed an age-dependent pattern, with mean values of 32.726×10^{-3}, 26.086×10^{-3}, 24.522×10^{-3} and 23.135×10^{-3} mSv y^{-1} for infants, children, teenagers and adults, respectively. Infants received the highest estimated dose, whereas adults had the lowest. This age-related variation is important because dose coefficients and exposure characteristics differ among age groups. Nevertheless, all estimated doses were well below the recommended safe limit of 1.0 mSv y^{-1} as stipulated by USCEAR (2008) and below the reported range of Igbudu et al. (2025) for the difference age group.

The mean values of the lifetime fatality risk results for the different Age group are 37.16×10^{-6} 73.98×10^{-6}, 74.68×10^{-6} and 68.13×10^{-6} for infants, children for teenagers and adults respectively. The Teenagers have the highest risk because ^{226}Ra and ^{232}Th have higher risk coefficient for growing tissues and the obtained mean value are all higher than the recommended safe limit of $0.01x10^{-6}$. The result provides a

quantitative indication of the potential long-term radiological health risk due to over exposure to the natural radionuclides within the environment.

The mean values of the estimated total annual effective dose show an age-dependent pattern, with mean values of 32.726 $\times 10^{-3}$ mSv y^{-1}, 26.086 $\times 10^{-3}$ mSv y^{-1}, 24.522 $\times 10^{-3}$ mSv y^{-1} for and 23.135 $\times 10^{-3}$ mSv y^{-1} for infants, children, teenagers and adults respectively. The higher estimated was obtained for infants because they are more sensitive to ^{226}Ra and ^{40}K while Teenagers are more sensitive to ^{232}Th than in adults, reflecting the age dependence of the dose coefficients used in the assessment.

CONCLUSION

The result of the study showed that the activity concentrations of radionuclides of ^{226}Ra, ^{232}Th and ^{40}K in the soil from the selected oil-spill communities showed slight elevations in the area. The Raeq, external and internal hazard indices were generally within acceptable limits although the mean AGDE exceeded the recommended safe limit. The annual effective doses showed an age-dependent pattern, with infants receiving the highest estimated dose and adults the lowest. However, all estimated doses were well below the recommended 1.0 m**Sv y^{-1}** public exposure permissible limit. The lifetime fatality risk was highest among teenagers, but the overall radiological risk from the investigated soils remains relatively low. Generally, the results of the study did not suggest any short-term radiological effect, however the use of High-power Germanium detector is recommended.

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