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Activity Concentration and Radium Equivalent Significance in Soil from Oil and Gas Fields in Nembe Communities, Bayelsa State, Nigeria

N.B. Esendu[1], G.O.Avwiri[2] and C.P.Ononugbo[3]

[1]Institute of Natural Resources, Environment and Sustainable Development (INRES), University of Port-Harcourt, Rivers State, Nigeria

[2,3]Department of Physics, University of Port-Harcourt, Rivers State, Nigeria

bennimifa@yahoo.com[1], gregory.avwiri@uniport.edu.ng[2], onochinyere@yahoo.co.uk[3]

ABSTRACT

The activity concentration and radium equivalent significance in soil from selected Nembe oil and gas fields and host communities, Bayelsa State, Nigeria were determined using gamma-ray spectrometry. The activity concentrations of ^{40}K, ^{238}U and ^{232}Th in soil samples have their minimum values as 127.68±8.31 Bqkg^{-1}, 0.00 Bqkg^{-1} and 6.05±0.62 Bqkg^{-1} and their maximum values as 775.89±42.68 Bqkg^{-1}, 51.89±42.64 Bqkg^{-1} and 109.67±9.75Bqkg^{-1} respectively. The average values of ^{40}K, ^{238}U and ^{232}Th are 439.96±24.87 Bqkg^{-1}, 20.82±6.00 Bqkg^{-1} and 49.66±5.23 Bqkg^{-1} respectively, were recorded for the oil and gas fields. The radium equivalent estimated from activity concentration of ^{40}K, ^{238}U and ^{232}Th in soil samples values ranged from 35.23 Bqkg^{-1} to 235.03 Bqkg^{-1} with an average value of 125.71 Bqkg^{-1} and found to be lower than the world average value of 370 Bkg^{-1} set by the Organization of Economic Cooperation and Development. The obtained average results of soil samples of ^{40}K, ^{238}U and ^{232}Th were compared with UNSCEAR, 2000 standard and are higher above the recommended standard of 400.0 Bqkg^{-1} and 35 Bqkg^{-1} for ^{40}k and ^{232}Th and lower than the recommended standard of 33 Bqkg^{-1} for ^{238}U. Therefore, the use of this soil for industrial and domestic activities will not pose any radiological threat to human health.

Keynotes: Soil; Activity Concentration; Oil and Gas fields, Nembe Communities and Radium Equivalent.

**Corresponding author: E-mail: bennimifa@yahoo.com;*

1. Introduction

The environment we live contains natural occurring radioactive materials (NORMs) which spread widely and exit in geological different formations such as rocks, soil, air and water. Many researchers have revealed the effects of natural radioactivity in the environment. All humans are constantly exposed to a significant fraction of the background radiation. The constant exploitation, exploration, mining and processing of petroleum by the oil and gas companies may have posed serious environmental effects to occupational workers and people living around these facilities. Nembe communities in Niger Delta region is one of the single largest oil and gas producing communities and have greatly contributed to the growth of Nigeria economy. It has attracted foreign and local exchange earnings as well as attracted direct capital investment to the country (Avwiri *et al.*, 2007).

During oil and gas exploration, exploitation and production activities, technically enhanced naturally occurring radioactive materials (TENORM) are brought to the surface environment. The major radionuclides that are largely present in the soil and produce radiation are ^{40}K, ^{238}U and ^{232}Th. The release of these materials may contain radioactive elements like uranium and thorium and their daughter products, ^{226}Ra and ^{228}Ra. These radioactive wastes like produce water, scales, sludge, and used drilled mud are usually discharged into the land of the study location (Chad-Umoren, 2012). It has been reported by various researchers that the obtained average results of activity concentrations of natural radionuclide in soil and water associated with oil and gas fields environment contain radioactive materials like uranium, thorium and their progenies Ra-226 and Ra-228 (Emelue *et al.*, 2014; Eke *et al.*, 2014; Ahijjo *et al.*, 2018 and Avwiri *et al.*, 2017). Oil and gas firms are considered to be the largest users of ionizing radiation source and radiation emitting devices in nuclear well logging, non-destructing testing (NDT) and in process industry for quality control (Emelue *et al.*, 2014).

Several studies on the analysis of naturally occurring radionuclides in soil samples from oil and gas fields have been evaluated to determine their activity concentrations using gamma spectroscopy. Agbalagba *et al* (2012**)** carried out analysis of naturally occurring radionuclide in soil samples from oil and gas field environment of Delta State using gamma spectroscopy. He revealed that the activity concentration of the samples ranged from 19.2 ± 5.6 $Bqkg^{-1}$ to 94.2 ± 7.7 $Bqkg^{-1}$ with mean value of 41.0 ± 5.0 $Bqkg^{-1}$ for ^{226}Ra, 17.1 ± 3.0 $Bqkg^{-1}$ to 47.5 ± 5.3 $Bqkg^{-1}$ with mean value of 29.7 ± 4 $Bqkg^{-1}$ for ^{232}Th and 107.0 ± 10.2 $Bqkg^{-1}$ to 712.4 ± 38.9 $Bqkg^{-1}$ with a mean value of 412.5 ± 20.0 $Bqkg^{-1}$ for ^{40}K. These values obtained are well within the world average and values reported elsewhere in other countries, but are little above some countries reported average values and some part of Nigeria.

Muhammed *et al*., (2010) studied the distribution of gamma-emitting radionuclides in soils around the Centre for Energy Research and Training (CERT) Ahmadu Bello University, Zaria, Northern Nigeria and found out that estimated concentrations of ^{232}Th, and ^{238}U were considerably lower when using a germanium detector (HpGe) than from sodium Iodide detector (NaI(Tl)) system in the laboratory. However, the mean activity concentrations were higher for ^{232}Th and ^{40}K but lower for ^{238}U when compared to world average values.

Edomi *et al.,* (2018) studied the radionuclides in soils from selected oil and gas producing communities in Delta Central, Delta State, Nigeria. The results revealed the presence of ^{238}U, ^{232}Th and ^{40}K respectively. The minimum values for these radionuclides' activity concentrations are 83.76+4.10, 4.10+0.12 and 1.92+0.09 Bqkg^{-1} respectively. It was observed that the activities of ^{40}K and ^{232}Th are higher than that of ^{238}U. The specific activities of ^{40}K and ^{232}Th are below the worldwide average while that of the values obtained from ^{238}U is above standard.

2. **Materials and Methods**

2.1 **Study Area**

Nembe is one of the eight local government areas of Bayelsa State in the Niger Delta region and bounded by Brass, Southern Ijaw and Ogbia Local Government Areas. Its headquarters is Nembe in the east of the area, which lies between latitudes 4^{o} 32' 22'' N and longitude 6^{o}24'59''E. Nembe and its environs comprises of fresh water and salt water respectively. The Okoroma/Tereke communities' areas are where fresh waters are found and the soil is made up of clay with raffia and palm trees. There are numerous oil and gas wells spread around the communities. While the salt waters environment comprises Nembe oil and gas and fields and major parts of the areas are submerged. The study covers some areas were oil and gas flow-stations, oil wells, residential and farms of communities which could be termed the hot spot for TENORM. The impact of oil and gas exploration has direct effects on the environment resulting to degradation, pollution and contamination which posed radiological health effect on members of the public and host communities. Figure 1. Map shows the study areas of Nembe oil and gas fields and communities.

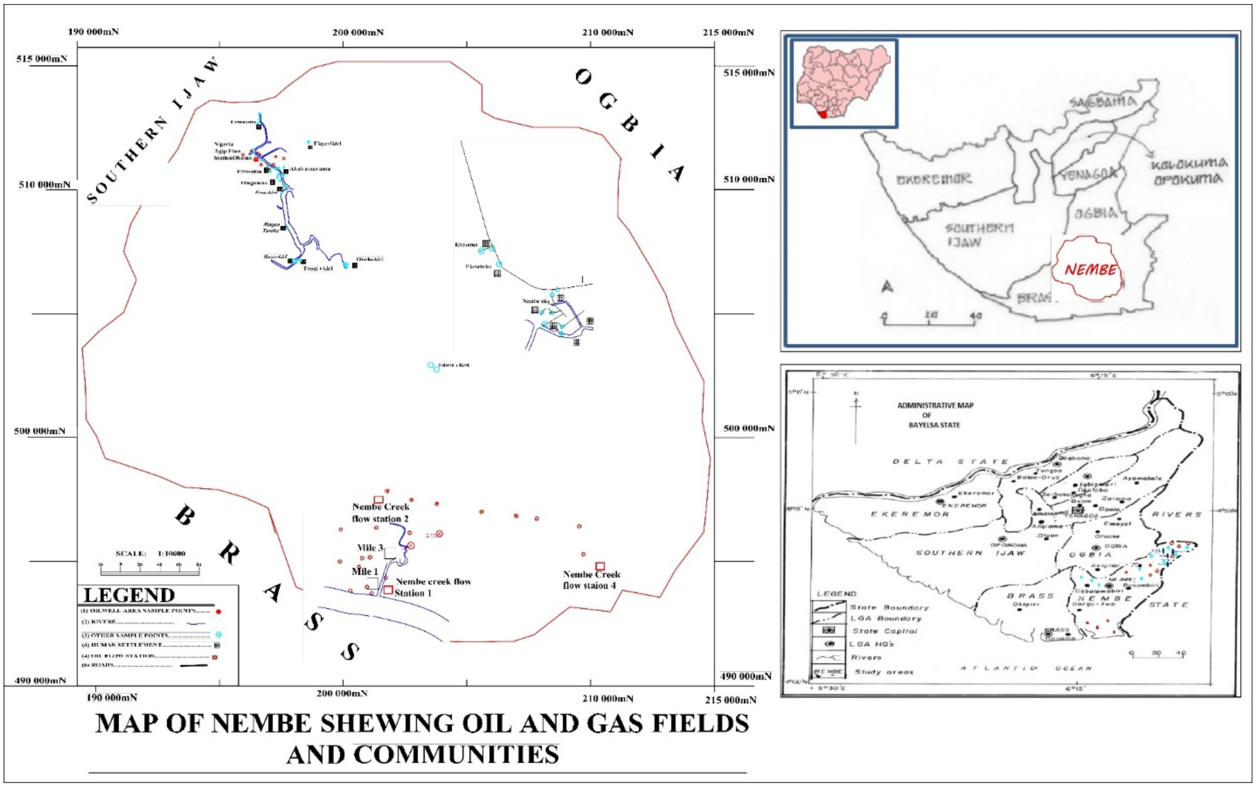

Fig 1: Map of Nembe Oil and Gas fields and Communities

2.2 **Sample Collection and Preparation**

Forty (40) soil samples were collected from selected sites or areas of oil and gas fields in Nembe communities and its environs from a pre-determined depth of 0.5m – 1.0m (Girigisu *et al*., 2013). The soil samples prepared for gamma spectrometry following the standard methods and sealed. The sealed samples were then stored for 28 days according to acceptable practice so that ^{238}U and its progenies will attain secular equilibrium (Eshiemomoh *et al*., 2021).

2.3 **Activity Concentration**

The activity concentration of natural existing radionuclides ^{238}U, ^{232}Th and ^{40}K was determined by using gamma ray spectrometry. Gamma counting was carried out using a Model 802 Sodium Iodide NaI(TI) detector for each of the sample as well as the standard source and background. The assembly has an internal magnetic / light shield, aluminum housing, fourteen (14) pin connectors and a kilovolt external source. The detector was enclosed and shielded with a 6cm lead to ensure that the radiation from the laboratory environment is curtained. The purpose of the background counts is to ensure that appropriate correction in the quantified activities are affected. Also, the standard count allows the quantification of the identified radionuclide using the less error prone absolute method. In order to commence radioactivity counting, energy calibration of the spectrometer was carried out using three gamma standard sources Cs-137, Am-241 and Co-60 were placed into 6cm lead shield of Model 802 Sodium Iodide NaI (TI) detector chamber. The data acquisition software (acquired gamma energies for each sample) used is Genie 2000 from Canberra Nuclear products. Samples were measured for a period of 29000 seconds per one sample and the peak area for each energy in the spectrum was used to calculate the activity concentrations in each sample using the equation below:

$$Ac = \frac{C_{net}}{\gamma\ x\ \varepsilon(E_y) x\ m} \qquad (1.0)$$

Where C_{net} represent peak net counts, γ represent the emission of specific energy, A is the activity in Bq/kg and $\epsilon(E_y)$ is the absolute efficiency of the full energy peak of the detector and m is activity per unit mass. The Data obtained are converted to conventional units using factors to determine the activity concentrations of ^{40}K, ^{232}Th and ^{238}U. (Knoll, 2010, Ghoshal, 2008)

2.4 **Radium Equivalent Activity Ra_{eq})**

For comparative purpose, the radium equivalent activity (Ra_{eq}) is used to assess radiological hazard associated with material or gamma output from different mixtures which contains different concentrations of uranium (radium), thorium and potassium. The measurement unit of radium equivalent is Bq/kg (Becquerel's per kilogram) and can be calculated using equation below:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_k \qquad (2.0)$$

Where A (Ra), A (Th) and A (k) are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/kg). In defining radium equivalent activity, the assumption was made that 370Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K yields the same gamma dose rate. (Diab *et al*. 2008; UNSCEAR, 2000)

3.1. **Results**

The results of the radiological evaluation of soil in selected Nembe oil and gas fields and the host communities in Bayelsa State, Nigeria are presented in Table 1, Figures 2 show radium equivalent values compared with standard.

Table 2: Comparison of natural radioactivity concentration in ($Bqkg^{-1}$) in soil samples with previous study reported from different Countries of the World.

Table 1: Specific Activity Concentration of Radionuclides in soil and corresponding Radium Equivalent in Soil Samples collected from Study Area.

S/n	Sample codes	Sample locations	K-40 (Bq/kg)	U-238 (Bq/kg)	Th-232 (Bq/kg)	Raeq (Bq/kg)
1	NCV001-S	Nembe Creek	480.73±27.07	17.85±4.55	18.57±1.95	81.42
2	NC1 003-S	Well 7	357.57±21.77	14.79±3.66	55.32±30.95	121.43
3	NC1 004-S	Well 27	547.28±30.73	19.61±4.65	54.52±5.24	139.71
4	NC1 007-S	Well 10	442.84±26.92	51.89±42.64	42.64±4.21	146.96
5	NC1 009-S	Well 74/8	495.12±27.92	20.23±5.31	66.02±6.16	152.76
6	NC1 010-S	Well 5	522.25±29.36	19.53±4.98	42.45±4.11	120.45
7	NC2 011-S	Well 34	486.57±27.53	15.39±4.05	57.21±5.33	134.67
8	NC2 014-S	Well 50	598.27±33.55	32.10±7.82	87.47±7.98	203.25
9	NC1 015-S	Well 20	467.87±26.63	24.71±5.86	62.40±5.74	149.97
10	NC4F020-S	NC4FS	326.72±19.24	29.46±7.01	60.21±5.53	140.72
11	NC1F022-S	NC1FS	393.02±22.84	22.25±5.35	88.03±7.88	178.39
12	NCV 023-S	Okokokiri	622.19±34.71	35.18±7.99	61.34±5.84	170.80
13	NCV 024-S	Akakumama	566.10±31.73	32.63±7.35	65.15±6.19	169.38
14	NCV 025-S	Alagoa-tereke	727.80±40.26	22.16±5.69	109.67±9.75	235.03
15	NCV 026-S	Ologoama	546.17±30.77	27.88±6.16	63.71±6.01	161.04
16	NCV 029-S	Ologoama-Farm Area	720.91±39.89	12.58±3.35	99.29±8.63	210.07
17	NCV 030-S	Edwinkiri fishing Port	245.23±15.86	15.64±3.86	33.81±3.54	82.87
18	NCV 031-S	Nembe City water front	233.73±14.09	4.49±1.17	25.51±2.35	58.97
19	NCV 032-S	Etieama 1	168.32±10.17	11.87±2.85	9.48±0.96	38.38
20	NCV 033-S	Etieama 2	528.58±29.82	32.10±6.97	55.52±5.23	152.19
21	NCV 034-S	Ekese-tubo	598.94±33.40	24.27±5.27	58.33±5.41	153.80
22	NCV 035-S	Basanbiri -Nembe	775.89±42.68	39.49±8.89	44.77±4.48	163.25
23	NCV 036-S	Nembe City Market Area	353.73±20.94	29.35±7.41	50.17±4.75	128.33
24	NCV 037-S	Tombi -Nembe	259.38±14.74	6.61±1.54	6.05±0.62	35.23
25	NCV 038-S	Nembe city Center	492.35±27.71	6.16±1.58	20.01±2.08	72.69
26	NCV 039-S	Amasara Polo-Nembe	206.94±12.09	15.43±3.65	11.01±1.11	47.11
27	NCV 040-S	Otatubo- Nembe	197.31±12.36	15.74±4.05	26.63±2.62	69.01

28	NC1 006-S	Well 13	420.76±23.87	33.86 ± 7.89	37.01 ± 3.57	119.18
29	NC2 013-S	Well 64	325.48±19.22	45.73 ± 9.82	40.82 ± 4.12	129.16
30	NC4 019-S	Well 41	440.63±25.14	31.66 ± 6.89	43.14 ± 4.35	127.28
31	NCV 027-S	Ewoama	445.67±23.94	BDL	21.32 ± 1.77	64.80
32	NC1 005-S	Well 19	495.98±28.10	14.6 ± 3.79	107.72± 9.26	206.83
33	NC4 018-S	Well 28	187.9 ± 10.30	BDL	26.88 ± 2.22	52.91
34	NC2 016-S	Well 49/51/39	572.47±26.00	18.90 ± 5.00	55.83 ± 5.34	142.81
35	NC2 021-S	Well 22	457.47±26.00	29.99 ± 6.98	59.95 ± 5.43	150.94
36	NC1 002-S	Well 16	467.07±25.12	13.54 ± 2.74	58.64 ± 4.77	133.36
37	NC1 008-S	Well 12	490.93±27.79	9.49 ± 2.61	53.39 ± 5.22	123.99
38	NC4 017-S	Well 61	127.68 ± 8.31	7.73 ± 1.86	17.19 ± 1.72	42.14
39	NC2F012-S	NC2FS	282.06±16.64	11.78 ± 3.03	32.32 ± 3.07	79.72
40	NCV 028-S	Well X	522.55±29.47	16.00 ± 3.97	56.64 ± 5.28	137.23
	Mean		**439.96±24.87**	**20.82±6.00**	**49.66±5.23**	**125.71**
	UNSCEAR, 2000		**400**	**35**	**30**	**370**

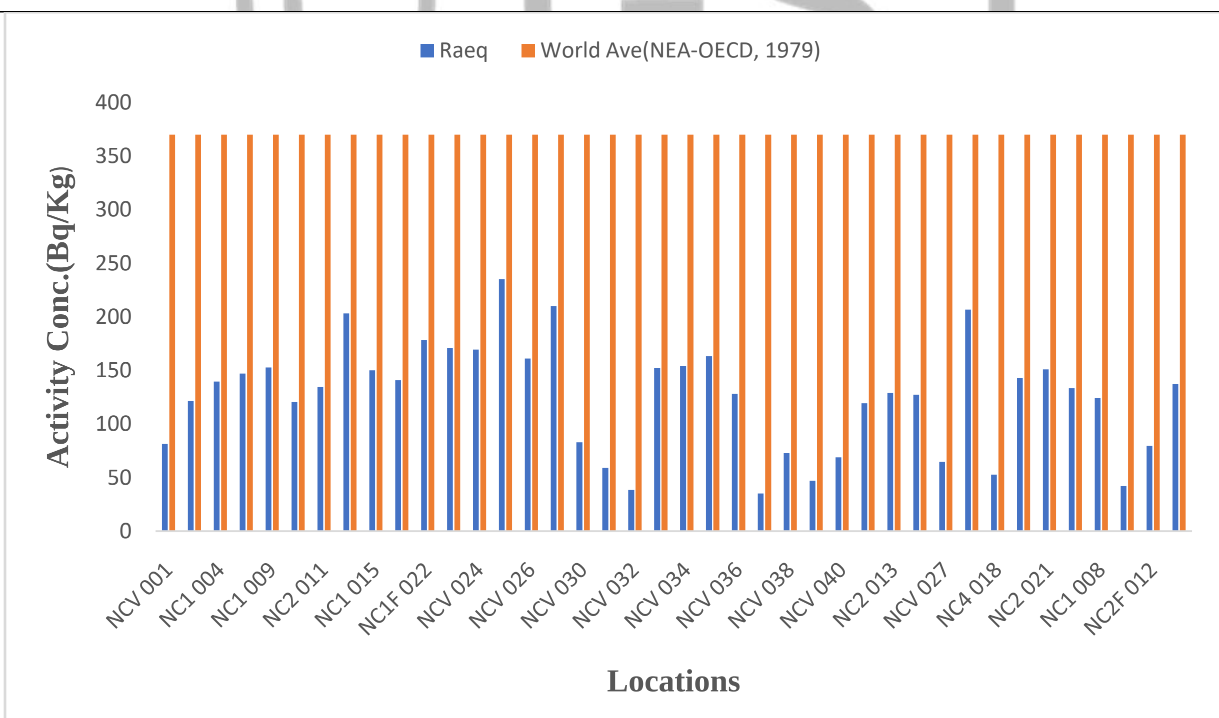

Fig 2: Comparison of activity concentration of Raeq in soil samples with NEA-OECD, 1979 Standard across the study area.

Table 2: Comparison of Natural radioactivity concentration in ($Bqkg^{-1}$) in soil samples with previous study reported from different Countries of the World (Eshiemomoh, 2021)

S/N	Countries	Mean Activity Concentration ($Bqkg^{-1}$) ^{238}U	^{232}Th	^{40}K	^{226}Ra	Reference
1	Saudi Arabia	-	12.3	535.0	9.5	El-Tahor and Al-Zahram (2014)
2	Iran	-	43.4	555.1	38.8	Asgharizadeh et al., (2013)
3	Bangladesh	30.93	61.65	467.8	-	Rahman et al., (2012)
4	Jordan	57.7	18.1	138.40	44.9	Saleh and Abu (2014)
5	Yemen	-	36.26	358.12	30.41	Harb et al., (2014)
6	Baghdad-Iraq	-	21.74	434.67	25.81	Adel Mehdi et al.,(2014)
7	Northern -India	56.02	91.56	340.78	63.85	Rohit and Manmohan (2012)
8	Najaf-Iraq	77.33	9.36	426.31	-	Al-Gazaly et al (2014)
9	Turkey	55.42	22.86	131.8	32	Akozcan et al.,(2014)
10	**Nigeria**	**20.8**	**49.7**	**439.9**	**125.7**	**This Present study**
	World Average	33	35	400	30	UNSCEAR, 2008

3.2 **Discussion**

The results of mean activity concentration of naturally occurring radionuclide of ^{40}K, ^{238}U and ^{232}Th and the radium equivalent measured in selected Nembe oil and gas fields and host communities of Nembe local government area, Bayelsa State, Nigeria were shown in Table 1. The mean activity concentrations of ^{40}K in soil samples have its lowest value as 127.68±8.31 $Bqkg^{-1}$ at NC4017-S and its highest value as 775.89±42.68 $Bqkg^{-1}$ at NCV035-S with an average value of 439.96±24.87 $Bqkg^{-1}$. The mean activity concentration of ^{238}U in soil samples have its lowest value as 0.00 $Bqkg^{-1}$ at NCV027-S and NC4018-S and its highest value as 51.89±42.64 $Bqkg^{-1}$ at NC1007-S with an average value of 20.82±6.00 $Bqkg^{-1}$ .Lastly, the specific activity concentration of ^{232}Th in soil samples have its lowest value as 6.05±0.62 $Bqkg^{-1}$ at NCV037-S and its highest value as 109.67±9.75$Bqkg^{-1}$ at NCV025-S Community with an average value of 49.66±5.23 $Bqkg^{-1}$.In comparing the obtained average results of soil samples of ^{40}K, ^{238}U and ^{232}Th with UNSCEAR, 2000 standard, it was deduced that the obtained average results of ^{40}K and

^{232}Th are higher above the recommended standard of 400.0 Bqkg^{-1} and 35 Bqkg^{-1} while ^{238}U is lower than the recommended standard of 33 Bqkg^{-1}. The anomalous high value of activity concentration of ^{40}K and ^{232}Th could be attributed to the oil and gas exploration, oil spill sabotage and drilling activities that took place across the entire study area (Avwiri *et al*., 2017; Ovuomarie *et al.*, 2018). The activity concentration of ^{40}K, ^{238}U, ^{232}Th and ^{226}Ra in soil samples from the studied areas have been compared with similar works investigated in other countries and summary results are presented in Table 2. The ^{238}U values result was lower than reported values for soil of Turkey (55.42 Bqkg^{-1}), Jordan (57.7 Bqkg^{-1}), Bangladesh (30.93 Bqkg^{-1}), Najaf-Iraq (77.33 Bqkg^{-1}) and Northern India (56.02 Bqkg^{-1}). It was also found that the mean value of the activity concentration of ^{232}Th was higher than reported values for soil of Turkey (22.86 Bqkg^{-1}), Najaf-Iraq (9.36 Bqkg^{-1}), Baghdad-Iraq(21.74 Bqkg^{-1}), Yemen (36.26 Bqkg^{-1}), Jordan (18.1 Bqkg^{-1}), Iran (43.4 Bqkg^{-1}) and Saudi-Arabia (12.3 Bqkg^{-1}) while the activity concentration of ^{40}K in soil samples of the present study was lower than reported values for soil of Saudi-Arabia (535.0 Bqkg^{-1}), Iran (555.1 Bqkg^{-1}) and Bangladesh (467.8 Bqkg^{-1}), but higher than the rest countries as stated in Table 2. Finally, the activity concentration of ^{226}Ra in soil samples in the current study was higher than reported values for soil of all countries (Table 2). The discrepancies in the activity concentration of the radioactivity levels in the soil of various locations of the world depend on the geographical and geology conditions of the area and the agricultural lands were fertilizer was used in large extent (Alharbi, 2013).

The result obtained from the current study was compared with similar work done in Nigerian environment. The activity concentration of ^{226}Ra in soil is higher than that reported in selected solid mineral mining Sites and crude oil spilled communities of Niger Delta region (Eshiemomoh *et al.,* 2021; Audu *et al*., 2021; Ovuomarie *et al.*, 2018 and Avwiri and Ononugbo, (2012). This could be attributed to the quantity of spilled oil and duration of oil and gas activities in the area (Agbalagba *et al*., 2012). The mean radium equivalent calculated from activity concentration of ^{40}K, ^{238}U and ^{232}Th in soil samples are presented in Table 1 and figure 2. The values ranged from 35.23 Bqkg^{-1} to 235.03 Bqkg^{-1} with an average value of 125.71 Bqkg^{-1}. It was observed that each of the oil and gas fields and host communities were lower than the world average value of 370 Bkg^{-1} set by the organization of Economic cooperation and development (NEA-OECD, 1979). Therefore, the use of this soil for domestic and industrial application will not pose any radiological threat to human health since radium equivalent activity is widely used to assess the radiation hazards associated with materials that contain ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}.

4. **Conclusion**

The Radiological evaluation of soil samples in selected Nembe oil and gas fields and the host communities have been carried out. We hereby conclude as follows:

1) The study revealed that the average results of ^{40}K and ^{232}Th are higher above the recommended standard of 400.0 Bqkg^{-1} and 35 Bqkg^{-1} while ^{238}U is lower than the recommended standard of 33 Bqkg^{-1}.
2) The radium equivalent (Raeq) in each of the selected Nembe oil and gas fields and host communities investigated were lower than the world average value of 370 Bkg^{-1}.
3) Therefore, the use of this soil for domestic and industrial application will not pose any radiological threat to human health and the environment.

Competing Interests

The Authors declared that no competing interest exist and are grateful to the Institute of Radiation Protection and Research, Ibadan constituted by Nigerian Nuclear Regulatory Authority (NNRA) where the gamma spectrometry was carried out.

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