Arab J. Nucl. Sci. Appl., Vol. 57, 4, 1-8 (2024)

ISSN 1110-0451

Arab Journal of Nuclear Sciences and Applications

Web site: ajnsa.journals.ekb.eg

(E S N S A)

Crude Oil Exploration at Akenfa, Bayelsa State, Nigeria: Assessment of Radioactivity in Soil Samples and Health Hazard Implications

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ARTICLE INFO

Article history:

Received: 1st May 2024

Accepted: 18th July 2024

Available online: 15th Aug. 2024

Keywords:

Soil samples;
Natural radioactivity;
Sodium Iodide (Tl) detector;
Activity concentrations;
Hazard parameters.

ABSTRACT

One of the main indicators of radioactive contamination in soil is naturally occurring radioactivity. In this work, twelve (12) soil samples from the vicinity of an oil well in the Akenfa community of Bayelsa state were collected. The activity concentrations of K-40, Ra-226, and Th-232 were determined by analysing the samples using γ-ray spectrometry, which was set up on a sodium iodide, thallium-activated detector. According to the findings, the activity concentration range for *Ra-226* was 0.17 to 11.51*Bq/kg*, *Th-232* was 8.82 to 29.16*Bq/kg*, and *K-40* was 135.43 to 219.19*Bq/kg*. The average values revealed that the absorbed gamma dose rate (D) was 14.45 nGy/y, the radium equivalent activity (RaE) was 30.33 Bq/kg, and the annual effective dose rate (AED) was lower than the global average of 0.7 mSv. The value for the gamma Index (GI) was 0.23, and the calculated values for the internal and external hazards, Hex, and Hin, were below acceptable limits. Based on the results, there was no need for concern for the people in the area as all levels were found to be within the safe ranges.

INTRODUCTION

Natural radioactive materials (NORMs) found in the environment make the entire world intrinsically radioactive. As a result, all life forms on or below the surface of the earth, including plants and animals, are continuously exposed to radiation [1]. Radioactivity is the result of naturally occurring nuclear processes. In most places on Earth, the variation in natural radioactivity from external sources is about a factor of 4, but the variation is greater in places with abnormally high or low concentrations of NORMs in the soil. The contribution from background radioactivity is about 2.4 mSv for an individual's average yearly effective dose [2].

Ninety-six per cent of the radioactivity comes from natural sources, while four per cent comes from manmade sources [3]. Most of the time, trace amounts of primordial nuclides like those in the series of U-238 (half-life: 44.7 x 10^8 years), Th-232 (half-life: 14.1 x 10^8 years) and K-40 (half-life: 12.8 x 10^8 years) are accountable for natural radiation in all ground formations [2].

The earth's crust contains a large quantity of naturally occurring uranium radioisotopes U-238 and U-235, with abundances of 99.28% and 0.72% respectively. The only primordial isotope of thorium, Th-232, is entirely plentiful in Earth's crust. Nuclides that have no series such as K-40, which has an isotopic abundance of 0.012% on Earth, are present almost everywhere [4].

Anaemia, acute leucopenia, oral necrosis, and chronic lung disorders are the few harmful health impacts that can result from long-period inhalation exposure to uranium and radium. Radium is detrimental to human health, causing cancers of the nose, cranium, and bones. Leukaemia, lung, liver, bone, and renal disease, among other ailments, can be brought on by exposure to thorium [5]. Soil is defined as an unconsolidated mixture of organic and mineral materials that are found immediately below the surface of the earth and typically serves as a medium for plant growth and other evolving activities, [6]. The level of exposure to radioactivity is influenced by farming activities, climate, drainage patterns and local geology, which change by location in the globe. Increasing both internal and external exposure to environmental radioactivity from beta radiation and gamma rays significantly increases the risk to human health [7].

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DOI: 10.21608/AJNSA.2024.283216.1812

Determining the activity concentrations of K-40, Th-232 and Ra-226 in soil samples surrounding an oil well at Akenfa community, Bayelsa State is therefore the primary objective of this study with the intent to establish the existence and distribution of naturally occurring radionuclides in the area and to evaluate potential radiological dangers. The results from the analysis and evaluated values were compared with similar reports in the literature.

MATERIALS AND METHODS

Study area

The study area Akenfa is located in Yenegoa Local Government Area (LGA), Bayelsa State. The geographical coordinates of Yenagoa LGA are 4.49^0 N and 5.23^0 N in latitude, and 6.10^0 E and 6.33^0 N in longitude. Akenfa is the third largest village in the kingdom by size and is one of the most prominent cities in the Epie-Atissa kingdom [8, 9]. The Nigerian Niger Delta has the Akenfa Community. The area is made up of several distinct geologic formations made of sediments, which are characteristics of various depositional settings. Geologically speaking, the deposit dates from the Eocene to the more recent Pliocene. The region is made up of a large plain that is periodically flooded as rivers and streams burst their banks. The natural levees on both banks of the rivers and streams are one of their primary characteristics. These levees create vast stretches of back swamps and lagoons, which significantly reduce surface flow [10].

Collection of samples and sample preparation

Twelve samples in all were collected from around the oil well in Bayelsa State's Akenfa Community. The oil well was segmented into four pieces, North, South, East, and West, at distances of 10 metres, 20 metres, and 30 metres from the drilling point. Each sample was obtained at a depth of 10 cm. Soils were gathered and wrapped in unadorned, spotless plastic bags.

To eliminate any remaining organic material and moisture content, the samples were allowed to air dry for a duration of seven days. In the lab, the materials were first crushed using a mortar and pestle and then filtered using a 0.5 mm mesh size. Each soil sample weighing 250g was placed in a uniformly sized cylindrical plastic bottle (70 mm in height and 65 mm in diameter) like the gamma sources used in IAEA standard calibrations for efficiency [11].

Before undergoing gamma spectrometric analysis, the bottles and their contents were closed tightly with caps and cello tape. These bottles were kept undisturbed for about 30 days so that a radiological equilibrium between the natural nuclides and their daughters, namely U-238, Th-232 and their decay offspring can be achieved [12].

Setup for gamma-ray spectrometry

The Multipurpose Physics Laboratory, Federal University of Agriculture, Abeokuta, Nigeria, houses the equipment used in the analysis. It is composed of a 50 mm x 50 mm Sodium Iodide (Tl) (ORTEC) detector that has been carefully calibrated. To help lower radioactivity beyond the shield, a 50 mm thick lead shield surrounds the detector. The sodium iodide (Tl) detector's energy resolution was calculated to be 6.3% at 661700 eV. Next, to gather information and analyse gamma rays, the detector was linked to a computer-based multichannel analyzer (MCA) that ran the MAESTRO (ORTEC) system. A 10800-second counting period was used for each sample, enabling the detector to collect a spectrum with distinct and well-defined peaks of interest. Its gamma energy of 1.460 MeV was sufficient to determine the activity concentration of 40K.

The gamma energies of the radionuclides Ra-226 and Th-232 are 2614.5 KeV (^{208}Tl) and 1764 KeV (^{214}Bi), respectively. We calculated the activity concentrations of Ra-226 and Th-232 by using the energy released by their daughters as they decayed. Equation (1) was used to calculate each sample's concentration per unit mass (M).

$$M = \frac{C}{EI_{\gamma}tb} \qquad (1)$$

Where C represents net counts in the photo-peaks, after determining the background.

E is the measured photo-peak efficiency, Iγ is the intensity of radiation, t is sample counting time,

b is the sample weight

A quadratic method was used to generate error computations for activity concentrations, and the results were shown alongside the estimated results.

Radium equivalent dose (RaE)

A single index representing the gamma production from the mixture of K-40, Th-232, and Ra-226 in the sample was created using the radium equivalent dosage. Its definition is predicated on the following assumptions: the gamma dose rate is produced by 10 Bq/kg of Ra-226, 7 Bq/kg of Th-232, and 130 Bq/kg of K-40 [13]. Equation (2) was used to obtain the RaE activity index.

$$RaE = A_{Ra} + \frac{143}{100}B_{Th} + \frac{77}{1000}C_K \qquad (2)$$

The abbreviations A_{Ra}, B_{Th}, and C_K, respectively, stand for the activity concentrations of K-40, Th-232, and Ra-226 in Bq/kg.

The permissible limit of *RaE* is 370 *Bq/kg* [14].

Absorbed dose (D)

The term "absorbed dose" refers to the amount of energy that ionising radiation deposits in a substance. To determine D in nGy/h, the dose conversion factor for each radionuclide was introduced. This calculation of the absorbed gamma dose rate for uniform dispersion of natural radionuclides in air at one metre above the earth's surface complies with criteria set forth by UNSCEAR [14]. D was computed using Equation (3).

$$D = 0.0417C_k + 0.604B_{Th} + 0.462A_{Ra} \quad \textbf{(3)}$$

Where, C_K, B_{Th} and A_{Ra} are as defined earlier in Eq. (2).

Annual effective dose equivalent (AED)

The coefficient derived from the absorbed dose in air and outdoor occupancy factors was utilized in assessing the annual effective dose equivalents. Considering the absorbed dose in the air and the effective dose received by adults, a conversion coefficient of 0.7Sv/Gy was employed. On the other hand, the outside occupancy factor had a value of 0.2 and the indoor occupancy factor of 0.8 [14]. Using Eq. (4 and 5), the AED for outdoor and indoor were determined.

$$AED_{outdoor} = D(nGy.h^{-1}) \text{ x365x24}h.y^{-1} \text{ x } 0.14\ SvGy^{-1}.\phi \quad \textbf{(4)}$$

$$AED_{indoor} = D(nGy.h^{-1}) \text{ x365x24h}.y^{-1}.0.56\ SvGy^{-1}.\ \phi \quad \textbf{(5)}$$

where $\phi = 10^{-6}$ was used to convert nano - Sievert to milli - Sievert.

External hazard index (Hex)

To guarantee that the radiation exposure resulting from the building materials (grains, such as sand) if utilised in construction is contained within acceptable limits, the external hazard index was calculated. If a building is to be built utilising these materials, the measured activities in the materials are crucial for estimating the radiation dosage that may be expected from them. Direct gamma radiation causes exterior exposure, whereas short-lived decay products of thorium (^{220}Rn) and radon (^{222}Rn) may produce internal exposure [15].

Eq. (6) provides the Hex, a relation that measures the exposure factor and assesses the danger posed by natural radioactivity [16].

$$Hex = \frac{C_K}{4810} + \frac{B_{Th}}{258} + \frac{A_{Ra}}{370} \quad \textbf{(6)}$$

Where, C_K, B_{Th} and A_{Ra} are as defined earlier in Eq. (2).

Internal Hazard Index (Hin)

Radon and its short-lived compounds damage the respiratory system in addition to the external hazard rating. The internal hazard index (Hin) measures internal exposure to radon and its daughter products [17]. Hin is computed using Eq. (7).

$$Hin = \frac{C_K}{4810} + \frac{B_{Th}}{258} + \frac{A_{Ra}}{185} \quad \textbf{(7)}$$

Where, C_K, B_{Th} and A_{Ra} are as defined earlier in Eq. (2). An internal Hazard Index value of less than one indicates that a material is safe to use in a home building.

Gamma index (GI)

The amount of gamma radiation risk related to naturally occurring gamma emitters in the soil is estimated using the soil gamma index. The upper limit of GI is equivalent to the allowable limit of 370 BqKg-1 for RaE [17]. Using Eq. (8), the level index was determined.

$$GI = 1.5x10^{-3}C_K + 10^{-2}B_{Th} + 1.5x10^{-2}A_{Ra} \quad \textbf{(8)}$$

Where C_K, B_{Th} and A_{Ra} are as defined in Eq. (2).

RESULTS AND DISCUSSION

Activity concentration

Table 1 displays the activity concentrations of the radionuclides Th-232, K-40, and Ra-226, expressed in Bq/kg, that were identified in soil samples from the Akenfa Community in Bayelsa State.

Within the range of 0.17 ± 0.06 to 11.51 ± 1.59 with a mean value of 3.32 ± 0.54 for Ra-226; 8.82 ± 1.36 to 29.16 ± 1.45 with an average value of 10.04 ± 1.23 for Th-232; and 135.43 ± 0.51 to 219.19 ± 10.47 with an average value of 164.28 ± 18.25 for K-40, the specific activity concentrations (Bq/kg) in the samples varied. The results obtained for Ra-226, Th-232 and K-40, respectively, are within the global average activity concentration of 33, 45, and 420 Bq/kg, as published by UNSCEAR [14]. The principal contributor to the overall activity for all samples is the activity resulting from K-40. The presence of stones and plant residues in the local soils may be the cause of the variation in the activity values of the naturally occurring K-40 radionuclide. Additionally, it's possible that the soil samples were fertilised with synthetic fertilisers containing leftovers from animal carcasses, which could also have an impact on the activity values of the samples [18].

Table 2 compares the average activity concentrations of radionuclides in soil samples from various regions of the world. The world's soil radioactivity concentrations vary depending on some factors, including the geological state of the area and the rate at which fertiliser is applied to the soil [19].

Table (1): Activity concentrations of natural radionuclides in soil samples (Bq/kg) from the study area

S/N	Location	Activity Concentration in Bq.kg^{-1}		
		K-40	Ra-226	Th-232
1	East - 10m	135.43±0.51	BDL	11.08±1.72
2	East-- 20m	150.57±0.91	1.59±0.53	20.12±5.42
3	East -- 30m	151.58±29.96	BDL	29.16±1.45
4	North- 10m	146.53±33.51	0.17±0.06	11.08±2.34
5	North- 20m	162.68±5.62	2.30±0.68	BDL
6	North- 30m	201.03±10.45	4.07±0.41	BDL
7	West- 10m	154.61±28.70	4.07±0.91	8.82±1.36
8	West- 20m	145.52±34.13	8.68±0.87	21.25±1.63
9	West- 30m	148.55±0.58	11.51±1.59	BDL
10	South- 10m	219.19±10.47	3.01±0.25	BDL
11	South - 20m	216.17±24.82	BDL	BDL
12	South - 30m	139.47±29.33	4.42±1.17	18.99±1.62
Total	12	1971.33±218.99	39.82±6.47	120.5±15.54
Min		135.43±0.51	0.17±0.06	8.82±1.36
Max		219.19±10.47	11.51±1.59	29.16±1.45
Mean		164.28±18.25	3.32±0.54	10.04±1.23
Worldwide Average		420	35	45

BDL=BELOW DETECTION LIMIT

Table (2): Comparison of average activity concentration (Bq/kg) of radionuclides in soil samples for the present study with previous studies from different places of the world.

Country	Mean Activity Concentration (Bq/kg)			References
	^{226}Ra	^{232}Th	^{40}K	
Upper Egypt	24±9	55±11	549±141	[20]
Jordan	57.7± 5.4	18.1 ± 1.4	138.1 ± 40.8	[21]
Iraqi Kurdistan	25.61	20.15	326.64	[22]
Saudi Arabia	16.73	10.40	419.99	[23]
India	32.4	48.2	312.5	[24]
Malaysia	102.08± 3.96	133.96± 2.92	325.87 ± 9.83	[25]
China	22.1	39.0	859.1	[26]
Burkina Faso	26.06 ± 1.50	33.27± 1.97	133.11± 13.69	[27]
Nigeria	3.32±0.54	10.04±1.23	164.28±18.25	Present Study
World Average	45	35	420	[14]

Radiological hazard indices

The levels of activity of Ra-226, Th-232 and K-40, respectively, have been used to determine the radium equivalent activity (RaE), absorbed dose, annual effective dose equivalent, external hazard index (Hex), internal hazard (Hin), and gamma index (GI). The results are displayed in Table 3.

RaE has an average value of 30.33 Bq/kg and ranges from 14.83 to 53.37 Bq/kg in soil samples from the study area. Radium equivalent activity has a maximum allowable value of 370 Bq/kg [14]. This indicates that building occupants would not be at risk from radioactivity if soil from the study location is utilised to make building materials.

Table 3 shows the estimated absorbed dose rates in the air for the sites under study. The average absorbed dose in nGy/h was 14.45, with a range of 7.85 to 23.93. The average value is less than the 55 nGy/h international recommendation [14]. The gamma index ranges from 0.12 to 0.39 with a mean value of 0.23. The value of Hex ranged from 0.04 to 0.14 with an average of 0.08 while the values of Hin ranged from 0.04 to 0.16 with an average of 0.09. Since all of these values are less than one, it is possible that the population in the study area will not be harmed by these radiation risks.

The graphical representation of the Annual Effective Dose Equivalent is shown in Figure 1.

Table (3): Radium equivalent activity (RaE), Absorbed Dose, external hazard index (Hex) and internal hazard (H_{in}) of ^{40}K, ^{226}Ra and ^{232}Th in soil samples from Akenfa, Bayelsa State.

Location	RaE ($Bq\text{-}kg^{-1}$)	D ($nGy.h^{-1}$)	External hazard index (Hex)	Internal hazard index (Hin)	G_I
E_1	26.27	12.34	0.07	0.07	0.20
E_2	41.96	19.17	0.11	0.12	0.31
E_3	53.37	23.93	0.14	0.14	0.39
N_1	27.30	12.88	0.07	0.07	0.21
N_2	14.83	7.85	0.04	0.05	0.12
N_3	19.55	10.26	0.05	0.06	0.16
W_1	28.59	13.65	0.08	0.09	0.22
W_2	50.27	22.91	0.14	0.16	0.37
W_3	22.95	11.51	0.06	0.09	0.18
S_1	19.89	10.53	0.05	0.06	0.17
S_2	16.65	9.01	0.04	0.04	0.14
S_3	42.31	19.33	0.11	0.13	0.31
Total	363.93	173.38	0.98	1.09	2.78
Min.	14.83	7.85	0.04	0.04	0.12
Max.	53.37	23.93	0.14	0.16	0.39
Mean	30.33	14.45	0.08	0.09	0.23
World Average	<370	55	<1	<1	<1

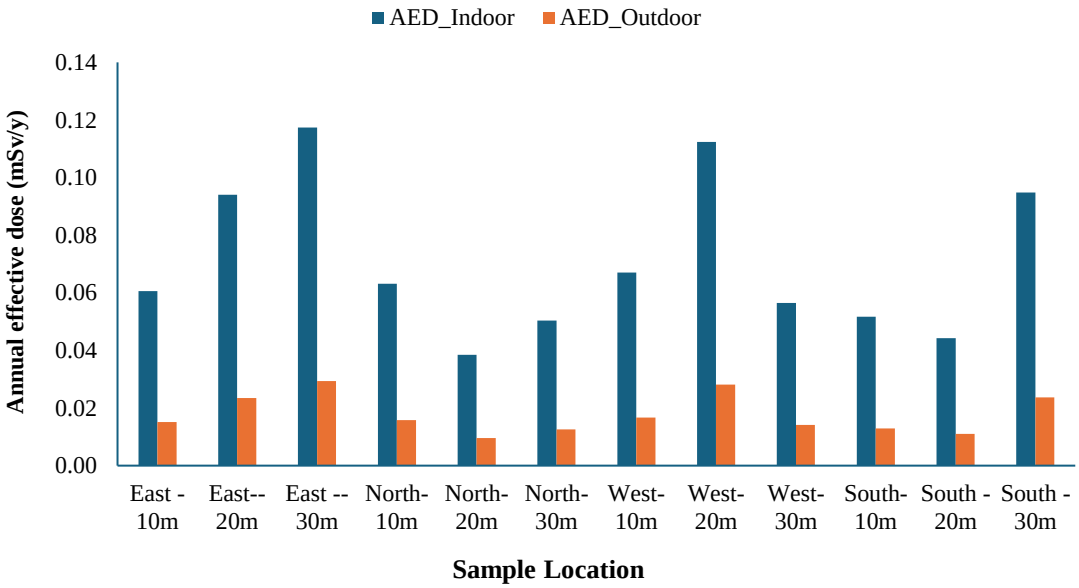

Fig. (1): Graphical representation of the AED

With mean values of 0.56 and 0.19, the indoor and outdoor AED ranged from 0.04 to 0.12 and 0.01 to 0.03 in mSv/y respectively. For outdoor exposure, the global average effective dose equivalent (AED) is 0.7mSv/y [14]. The values obtained in this study are below the global average.

CONCLUSION

The activity concentrations of Ra-226, Th-232 and K-40 in twelve (12) samples of soil from around the oil well from the study area have been determined using a Sodium Iodide (Tl) detector. The values (Bq/kg) ranged from 0.17 ± 0.06 to 11.51 ± 1.59, with an average value of 3.32 ± 0.54 for Ra-226; 8.82 ± 1.36 to 29.16 ± 1.45, with an average value of 10.04 ± 1.23 for Th-232, and 135.43 ± 0.51 to 219.19 ± 10.47 with an average value of 164.28 ± 18.25 for K-40. The mean activity (Bq/kg) was less than the global value of 420, 35 and 45 for K-40, Th-232 and Ra-226 respectively.

For each soil sample, the radiological hazard parameters were evaluated and was found that all the values obtained were not above the allowable limit, indicating that the soil does not pose any significant radiation risks. Although the radiation level in the study area is within safe limits, further industrial activities may increase the activity concentration. Therefore, constant monitoring for possible radioactivity pollution in the future is recommended.

ACKNOWLEDGEMENTS

The authors appreciate the assistance of Mr German Oyinkuro of the Department of Science Laboratory Technology, Delta State Polytechnic, Ozoro for his assistance in the preparation of the samples before analysis. We also thank the Physics Department, Federal University of Agriculture, Abeokuta for lending their laboratory for the analysis of the samples.

Author Contributions: Rita A. Daniel-Umeri came up with the idea, created the layout, and wrote the article. Kugbere Emumejaye carried out the experiments and did the data analysis. Peter E. Biere helped with the data analysis and the paper's proofreading.

Conflicts of Interest: The authors declare that this study report is free of conflict of interest.

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