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Radioactivity Concentrations in Soil and Plants Farmed Around Crude Oil Producing Areas of Edo State, Nigeria

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Abstract: The exploration and production of crude oil have raised environmental concerns, particularly regarding the accumulation of naturally occurring radioactive materials (NORMs) in soil and crops. This study investigates the concentrations of radioactivity in soil and plants cultivated around crude oil-producing areas of Edo State, Nigeria, to assess potential radiological health risks. The primary objective is to determine the levels of radionuclides in agricultural soil and evaluate their transfer to food crops. A systematic sampling approach was employed, collecting soil and plant samples from selected farmlands within and outside oil-producing zones. Gamma spectrometry was used to analyze the activity concentrations of key radionuclides, including uranium-238, thorium-232, and potassium-40. The measured values were compared with international safety limits recommended by organizations such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Atomic Energy Agency (IAEA). The mean activity concentration levels of potassium (K), uranium (U), and thorium (Th) in plant (soil) samples are 389.62 Bq/kg (2618.06 Bq/kg), 26.10 Bq/kg (87.47 Bq/kg), and 5.50 Bq/kg (21.43 Bq/kg) respectively. The soil-to-plant transfer factors (TF) for ^{40}K, ^{238}U, and ^{232}Th were found to be 0.14882, 0.298287, and 0.256239, respectively, indicating that uranium has the highest mobility and bioavailability, followed by thorium and potassium. The calculated absorbed dose rate, gamma dose rate, radium equivalent, annual effective dose equivalent, and excess lifetime cancer risk for plant (soil) are 31.62 nGy/h (162.5234 nGy/h), 64.13 Bq/kg (320.3806 Bq/kg), 0.173 (0.863414), 0.038782 µSv/y (0.199319 µSv/y) and 0.135735 (0.697615), respectively. The global average annual effective dose from natural background radiation is approximately 2.4 mSv/year below the 1 mSv/year threshold set by international radiation protection guidelines. These values suggest that the soils are safe for general use, with no immediate concerns for radiation-related health effects, and that monitoring these values is more for precaution and continued assessment of environmental conditions.

Keywords: Activity concentration, annual effective dose equivalent, crude oil exploration, and sodium iodide doped thallium detector.

1 Introduction

The exploration and production of crude oil have significant environmental implications, particularly in regions where oil extraction is intensive. One area of concern is the presence of naturally occurring radioactive materials (NORMs) associated with crude oil deposits.

These radionuclides, primarily from the uranium and thorium decay series, can be released into the environment during drilling, refining, and waste disposal processes [1-3].

Over time, such activities may lead to the accumulation of radioactive elements in the soil, which could subsequently be absorbed by plants. This process raises concerns about potential exposure risks for individuals consuming crops cultivated in these areas [4, 5].

The contamination of soil and food crops by radionuclides in oil-producing areas poses a potential health and environmental challenge. While extensive research has been conducted on the chemical pollution associated with crude oil exploration, limited studies have examined the radiological impact, particularly in Nigeria [2, 6- 8]. Since crops grown in contaminated soil can absorb radionuclides, prolonged consumption of such food products may lead to internal exposure, increasing the risk of radiation-related illnesses such as cancer and genetic mutations [4, 7, 8].

In Edo State, oil extraction activities continue to expand,

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raising concerns about the potential increase in background radiation levels in surrounding farmlands. However, there is a lack of comprehensive data on the distribution of radionuclides in soil and food crops from these areas.

Without adequate monitoring and assessment, it is difficult to determine the extent of environmental contamination and its potential risks to public health.

Edo State, located in southern Nigeria, is one of the regions where crude oil is actively extracted. Agricultural activities remain a major source of livelihood for communities in this region, making soil quality an essential factor for food safety. However, the impact of oil exploration on the levels of natural radioactivity in farmlands and food crops has not been extensively studied. Previous research indicates that both natural and human-induced activities contribute to variations in soil radioactivity, with industrial operations playing a significant role in increasing radionuclide concentrations [3, 9-12]. Given the potential health risks associated with long-term exposure to radiation in food and the environment, it is important to assess the levels of radioactive contamination in soil and plants from oil-producing areas of Edo State. This study aims to address this knowledge gap by analyzing the levels of radioactivity in soil and plants farmed around crude oil production sites in Edo State. The findings will provide crucial information for environmental health assessments and contribute to the development of strategies for radiation protection in agricultural communities.

2 Materials and Method

2.1 Study Area

Edo State, located in the southern part of Nigeria, is one of the areas affected by oil spills due to its proximity to the Niger Delta region, a hub of extensive oil exploration and production activities. The Niger Delta, including parts of Edo State, is characterized by a network of pipelines, oil wells, and refineries operated by both local and international oil companies. This region has experienced numerous oil spills over the decades, resulting in significant environmental degradation.

Oil spills in Orhionmwon, Edo State have led to the contamination of soil and water bodies, adversely affecting agricultural land, aquatic life, and the health of local communities. The spills often result from pipeline leaks, operational mishaps, and, in some cases, sabotage and oil theft. The agricultural sector, which many residents depend on, has been particularly hard-hit, with polluted soils reducing crop yields and contaminating food sources.

The ecological impacts include the destruction of mangrove forests, which are crucial for maintaining biodiversity and protecting shorelines from erosion. Contaminated rivers and streams have also diminished the availability of clean water for domestic use and fisheries, leading to health issues and economic challenges for the communities.

Fig.1. Map of Nigeria showing the Study area.

Fig. 2. Map of Edo State showing the study area.

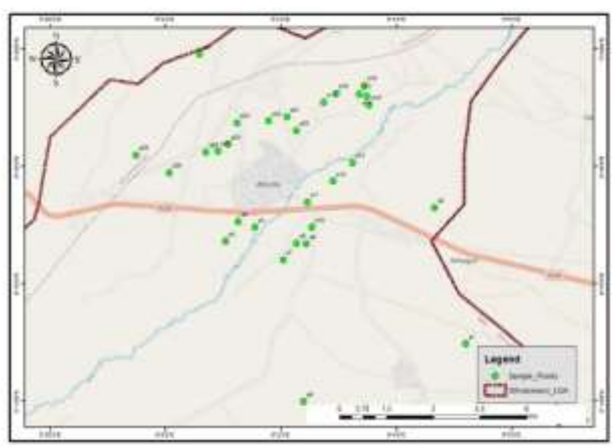

Fig.3. Map of Orhiomwon LGA showing the study locations.

2.2 Population of Samples

The soil and plant samples used in this study were randomly selected from farmland around crude oil exploration sites in Edo State. The population of this study includes all the farmland around crude oil exploration sites in Edo State. Thirty sampling sites were randomly selected in the study area for the collection of soil and plant samples. A total of thirty soil and plants) were collected from the study area and were analyzed for heavy metal concentration analysis and activity concentration analysis. The background exposure levels were determined for all the sampling points.

2.3Method of Soil Sample Collection

A total of thirty (30) soil samples were collected from farms around the crude oil exploration sites in Edo State. These samples were collected randomly from each sampling farm around the oil exploration sites. Soil samples were collected 50 m apart from each farm. The method to be applied in sampling is simple random sampling to achieve statistical sensitivity of sampling. A hand trowel was used to collect soil samples to a depth of about 10 cm. Each composite soil sample collected weighed about 400g of mass and was separately collected and placed in a well-labeled polythene bag and was sealed to avoid cross-contamination of the samples during transportation to the laboratory.

2.4 Method of Plant Sample Collection

A total of thirty (30) plant samples were collected using a systematic random sampling from farms around the study area. Plant samples were collected 50 m apart from each farm same as the soil sample collection. A cutlass was used to collect plant samples which consist of the root, stem, and leaf of the plant. Each composite plant sample collected is expected to weigh about 600g of mass and was separately collected and placed in a well-labeled polythene bag and then sealed to avoid cross-contamination of the samples during transportation to the laboratory [13].

2.5 Method of Soil and Plant Sample Preparation

The soil and plant samples were prepared through a process of open-air drying at room temperature to remove moisture and were oven-dried at a temperature of 500C - 1100C to obtain uniform weight. Stony soil samples and plant samples were ground into powdery form separately and singly using mortar and pestle and sieved with a wired mesh with holes of thickness 0.5 mm to obtain homogeneity of sample size. The samples were kept in well-labeled sealed polythene bags for 28 days to attain secular equilibrium between ^{238}U, ^{232}Th, and ^{40}K and their progeny before being them to the laboratory for NaI(Tl) analysis.

2.6 Method of Data Collection

Soil and plant samples collected were analyzed to determine the radioactivity concentration levels of ^{238}U, ^{232}Th, and ^{40}K using a NaI(T) detector. The Gamma-ray spectroscopy with a well-calibrated NaI (Tl) detector system was used to measure the activity concentration. Global position systems (GPS) were used to track the data record and provide geo-location information. All samples were properly packed and marked for their identification code.

2.7 Method of Data Analysis

The data on radioactivity concentration from soil and plant samples were analyzed. The hazard indices and soil-to-pant transfer factor due to activity concentration level were determined to ascertain the potential risk associated with the samples. MS Excel was used for the data analysis.

2.7.1 Hazard Indices Determination of Activity Concentration Analysis

Transfer Factors (TF) were determined using the equation as expressed by UNSCEAR [13] as:

$$TF = \frac{Activity\ Concentration\ of\ radionuclide\ in\ dry\ weight\ of\ plant\ \left(\frac{Bq}{kg}\right)}{Activity\ Concentration\ of\ radionuclide\ in\ dry\ weight\ of\ soil\ \left(\frac{Bq}{kg}\right)} \quad (3.1)$$

Gamma Absorbed Dose Rate (D) was determined from the activity concentration and by applying the conversion factors of 0.462, 0.604, and 0.0417 for ^{226}Ra, ^{232}Th, and ^{40}K respectively as expressed by UNSCEAR [13] as:

$$D = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (3.2)$$

A_U, A_{Th}, and A_K are the Activity Concentrations for ^{238}U, ^{232}Th, and ^{40}K respectively.

It is assumed that the contribution from other radionuclides, such as 137Cs, 235U, 87Rb, 90Sr, ^{138}La, ^{147}Sm, and ^{176}Lu to the total dose rate is negligible. UNSCEAR reported that the world average absorbed gamma dose rate mean is 55nGyh^{-1}.

Radium Equivalent Activity (Ra_{eq}) was determined using the weighted sum of activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, as expressed as:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (3.3)$$

Where A_{Ra}, $A_{Th,}$ and A_K are the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K in Bqkg^{-1} respectively.

External Hazard Index (Hex) was evaluated to limit the activity concentration (A) of ^{226}Ra, ^{232}Th, and ^{40}K to ensure that a permissible dose rate of less than 1 mSv/y as expressed by UNSCEAR [15] as:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (3.4)$$

Where A_{Ra}, $A_{Th,}$ and A_K are the specific activities of ^{238}U, ^{232}Th, and $^{4}0K$ in Bq/kg respectively.

Annual Effective Dose Rate (AEDR) was evaluated using the absorbed dose rate (D) data obtained and a conversion factor value of 0.7 Sv/Gy of absorbed dose in the air to the effective dose adults receive as expressed by UNSCEAR [15] as:

$$AEDR = D \times 8760 \times 0.2 \times 0.7 \times 10^{-3} \quad (3.5)$$

Where, D(nGy/hr) is the absorbed dose, 8760 h/yr is the working hours per year, 0.2 is the occupancy factor, and 0.7 is the conversion coefficient.

Excess Life Cancer Risk (ELCR) was determined by the product of determined AEDR with Duration of Life (DL), 70 years for children and 50 years for an adult, and low dose background radiation Risk Factor (RF) of 5% for public exposure considered to produce a stochastic effect as expressed in ICRP [9] as :

$$ELCR = AEDR \times RF \times DL \quad (3.6)$$

Where, AEDE is the Annual Effective Dose Equivalent, DL is the Duration of Life which is 70 yrs for children and 50 yrs for adults, and RF is the Risk Factor which is $0.05Sv^{-1}$ (5%) for public exposure considered to produce stochastic effects.

3 Results and Discussion

The results of activity concentration in soil and plant samples collected from the study area are presented in Figure 1 and Figure 2, respectively.

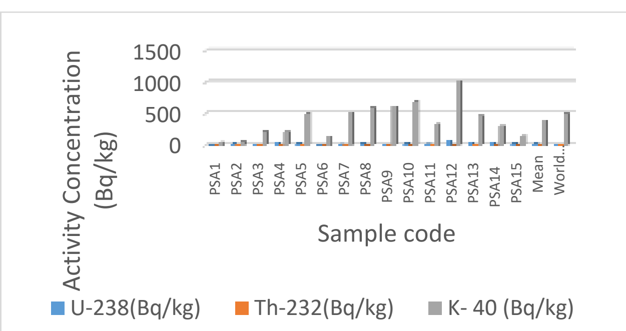

Fig.1. Comparison of activity concentration level in plant samples collected from the study area.

Figure 1 compares the result of activity concentration levels in plant samples collected from the study area. The mean activity concentration levels of potassium (K), uranium (U), and thorium (Th) in a plant sample, measured at 389.62, 26.10, and 5.50 Bq/kg respectively, reflect the uptake of these radionuclides by plants from the soil. Potassium is an essential nutrient for plants and is readily taken up from the soil. A concentration of 389.62 Bq/kg in plants is typical, as plants absorb potassium from the soil for physiological processes. From a radiological standpoint, the presence of ^{40}K in plants does not pose a significant health risk, as potassium is a common dietary element, and human bodies naturally regulate potassium levels. Uranium at 26.10 Bq/kg in plant samples is somewhat higher than expected for typical environmental levels. Uranium uptake by plants is usually minimal due to its low solubility and limited bioavailability in most soils, though factors like soil pH and uranium speciation can influence its uptake. While uranium itself has relatively low radioactivity compared to some radionuclides, it is chemically toxic, and high concentrations in consumable plants could have implications for renal health and potential radiological risk, though, at these levels, it is relatively low. Thorium is generally low in bioavailability and is less likely to be absorbed by plants, explaining its relatively low concentration at 5.50 Bq/kg. This level suggests minimal uptake from the soil, which is consistent with thorium's behavior as it tends to remain bound to soil particles.

Radiologically, thorium poses minimal risk in plants due to its low concentration and reduced mobility.

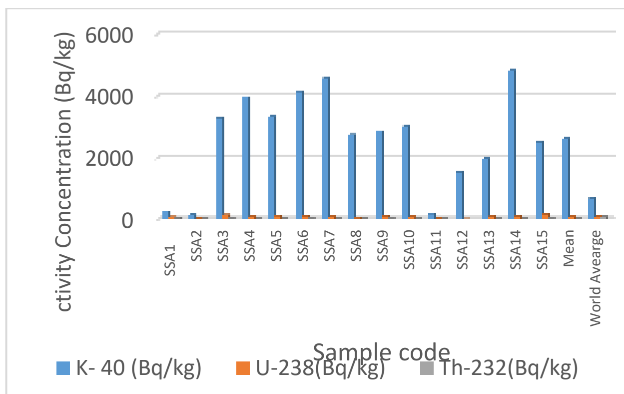

Fig.4.2. Comparison of activity concentration level in soil samples collected from the study area.

Figure 2 presents the result of activity concentration levels in soil samples collected from the study area. The mean activity concentration levels of potassium (K), uranium (U), and thorium (Th) in a soil sample, measured at 2618.06, 87.47, and 21.43 Bq/kg respectively, provide insight into the levels of naturally occurring radionuclides in the soil and their potential radiological impact on the environment and human health. While potassium-40 is naturally occurring, a value of 2618.06 Bq/kg is considerably higher than typical background levels, which are usually in the range of 100–700 Bq/kg in soils worldwide. This concentration of K could increase external gamma radiation, as potassium-40 is a beta and gamma emitter.

The uranium concentration of 87.47 Bq/kg is relatively high compared to average global soil levels, which usually range from about 10 to 50 Bq/kg. Elevated uranium levels in soil could be due to the presence of uranium-bearing minerals, anthropogenic contamination, or specific geological characteristics [17-20].

Elevated uranium levels could also indicate a potential for increased radon gas release, as uranium decays to radon-222, which could affect indoor air quality in buildings constructed on this soil. The thorium concentration of 21.43 Bq/kg is within the expected range for natural soils, as global background levels for thorium usually range between 5 and 50 Bq/kg. Thorium is relatively immobile in soil due to its chemical properties and tends to remain in particulate form, limiting its bioavailability and movement within the environment. Radiologically, thorium-232, the predominant naturally occurring thorium isotope, decays through a long series of alpha and gamma-emitting progeny. While the level here is relatively low, thorium could contribute slightly to the external gamma dose. This thorium level suggests minimal radiological hazard.

However, its decay products, which include radon-220, could contribute to indoor air radioactivity if disturbed soils are used in construction.

Figure 4.2 compares the soil-to-plant transfer factor from the results of the activity concentration level in the

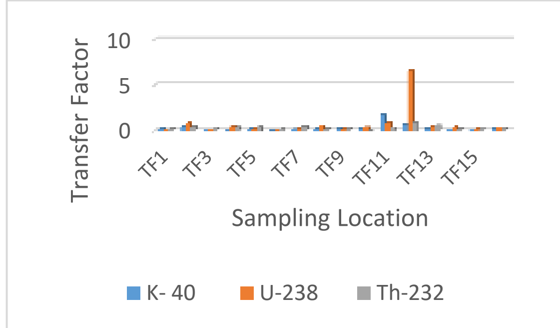

Fig. 4.2: Comparison of soil to plant transfer factor from the study area.

studyarea. The soil-to-plant transfer factors (TF) for ^{40}K, ^{238}U, and ^{232}Th were found to be 0.14882, 0.298287, and 0.256239, respectively, indicating that uranium has the highest mobility and bioavailability, followed by thorium and potassium. These results align with findings from previous studies, such as Ibrahiem et al. [7], who reported higher uranium TF due to its solubility and plant uptake mechanisms, while thorium remained less mobile due to strong soil adsorption.

Similarly, studies by Shahbazi-Gahrouei et al. [11] found that potassium exhibits a lower TF due to biological regulation by plants. The relatively high thorium TF observed in this study suggests that environmental factors such as pH and organic matter may influence radionuclide uptake, consistent with the findings of Prăvălie et al. [4].

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Table 4.9: Result of calculated hazard indices of plant samples collected from the study area.

S/n	Sample Code	D (nGy/h)	Ra_{eq} (Bq/kg)	H_{ex}	AEDE (mSv/y)	ELCR
1	PSA1	7.026105	15.35293	0.041029	0.008617	0.030159
2	PSA2	15.89094	34.74632	0.093239	0.019489	0.06821
3	PSA3	17.92782	37.00057	0.099336	0.021987	0.076953
4	PSA4	30.62305	64.36775	0.173431	0.037556	0.131446
5	PSA5	37.42153	76.11238	0.204569	0.045894	0.160628
6	PSA6	10.17467	20.74314	0.055705	0.012478	0.043674
7	PSA7	32.95542	65.49295	0.176297	0.040417	0.141458
8	PSA8	40.09256	79.35283	0.214106	0.04917	0.172093
9	PSA9	35.13742	68.76221	0.185211	0.043093	0.150824
10	PSA10	41.34736	80.45612	0.217266	0.050708	0.177479
11	PSA11	26.74975	54.78032	0.147224	0.032806	0.114821
12	PSA12	80.04395	160.1916	0.432457	0.098166	0.343581
13	PSA13	45.96955	94.87835	0.255463	0.056377	0.19732

14	PSA14	33.81611	69.65228	0.187918	0.041472	0.145152
15	PSA15	19.15738	40.06021	0.107951	0.023495	0.082231
	Mean	31.62224	64.12999	0.172747	0.038782	0.135735

The calculated hazard indices in plant samples collected from the study area are presented in Tables 2 and 4. The figure shows the plot of calculated annual effective dose equivalent and excess lifetime cancer risk respectively.

Table 1 presents the result of calculated hazard indices of plant samples collected from the study area. The absorbed dose rate in plant samples, with a mean of 31.62 nGy/h and values ranging from 7.03 to 80.04 nGy/h, reflects the gamma radiation emitted by naturally occurring radionuclides taken up by the plants from their environment. Given that natural background gamma dose rates in the environment average around 60 nGy/h worldwide, the mean absorbed dose rate in plants of 31.62 nGy/h is moderate. The radium equivalent activity in these plant samples, with a mean of 64.13 Bq/kg and a range from 15.35 to 160.19 Bq/kg, suggests that the plants contain moderate levels of naturally occurring radionuclides. The values are below regulatory limits, indicating minimal radiological risk from either direct exposure or consumption.

However, routine monitoring might be advisable in areas where higher Ra_{eq} values are observed to ensure safety over time. The external hazard index in plant samples, with a mean of 0.173 and a range from 0.041 to 0.432, demonstrates that these plants pose minimal to no risk in terms of gamma radiation exposure.

All values are significantly below the safety threshold of 1, indicating that the samples are radiologically safe for human handling and environmental use. Analyzing the Annual Effective Dose Equivalent (AEDE) values for plant samples with a mean concentration of 0.038782 μSv/y and a range from 0.0086170 to 0.098166 μSv/year suggests relatively low radiation levels, particularly given that AEDE values are typically evaluated against natural background radiation standards and public safety limits.

The Excess Lifetime Cancer Risk (ELCR) values in plant samples, with a mean of 0.135735 and a range from 0.030159 to 10.343581, provide insights into potential long-term health risks associated with radiation exposure from these plants if they were to be consumed over a lifetime. ELCR values around 0.1 or higher can prompt consideration in terms of cumulative exposure over time, as these are relatively high in comparison to natural background exposure but generally remain within acceptable ranges for minor incremental risk. The Radium Equivalent Activity (Ra_{eq}) in soil samples, with a mean value of 320.3806 Bq/kg and a range from 61.78479 to 520.8014 Bq/kg, provides a consolidated measure of radiation hazards.

Table 2: Result of calculated hazard indices of soil samples collected from the study area.

S/n	**Sample Code**	**D (nGy/h)**	**R_{eq} (Bq/kg)**	**H_{ex}**	**AEDE (mSv/y)**	**ELCR**
1	SSA1	69.77059	153.3368	0.410974	0.085567	0.299483
2	SSA2	28.3205	61.78479	0.165424	0.034732	0.121563
3	SSA3	218.4557	433.3424	1.168202	0.267914	0.937699
4	SSA4	217.6527	421.1374	1.135968	0.266929	0.934252
5	SSA5	213.2593	422.2416	1.137779	0.261541	0.915394
6	SSA6	232.6227	452.0196	1.218865	0.285288	0.99851
7	SSA7	241.4118	464.277	1.252541	0.296067	1.036236
8	SSA8	150.9405	293.1479	0.790184	0.185113	0.647897
9	SSA9	176.2997	347.2437	0.935922	0.216214	0.756749
10	SSA10	178.2272	349.9281	0.942764	0.218578	0.765022
11	SSA11	33.09862	73.32008	0.19568	0.040592	0.142073
12	SSA12	71.74144	135.4193	0.365359	0.087984	0.307943
13	SSA13	137.4491	274.1587	0.739015	0.168568	0.589986
14	SSA14	268.5755	520.8014	1.404608	0.329381	1.152833
15	SSA15	200.0254	403.5504	1.087916	0.245311	0.858589
	Mean	162.5234	320.3806	0.863414	0.199319	0.697615

from multiple radionuclides, particularly radium-226, thorium-232, and potassium-40**.** A mean Ra_{eq} value of 320.3806 Bq/kg is above the safe limit of 370 Bq/kg set by the Organization for Economic Cooperation and Development (OECD) for building materials, indicating that the soil, on average, poses a moderate radiological hazard. This level suggests that while the average radiation exposure from these soils is not extreme, there could be a significant cumulative radiation dose if the soil is used in construction or if individuals are frequently exposed to it in agricultural or residential settings.

Table 2 shows the result of calculated hazard indices of soil samples collected from the study area. The Absorbed Dose Rate in soil samples, with a mean concentration of 162.5234 nGy/h and a range from 28.3205 to 268.5755 nGy/h, reflects varying levels of environmental radiation in the soil. A mean absorbed dose rate of 162.5234 nGy/h is above the world average, which typically falls around 60 nGy/h. While this value alone does not imply immediate health risks, prolonged exposure to higher absorbed dose rates could increase overall radiation exposure for individuals frequently in contact with these soils. The External Hazard Index (H_{ex}) in soil samples, with a mean value of 0.863414 and a range from 0.165424 to 1.40460, provides an estimate of the potential radiological hazard due to external gamma radiation exposure from naturally occurring radionuclides in the soil. A mean $\mathbf{H_{ex}}$ value of 0.863414 is slightly below the threshold of **1.0,** which is considered the safe limit for building materials as per international guidelines (such as those provided by the OECD and UNSCEAR**)**. This suggests that, on average, the radiological hazard from these soils is moderate and within acceptable limits for normal use. A mean AEDE of 0.199319 mSv/y is relatively low when compared to typical safety standards. The global average annual effective dose from natural background radiation is approximately 2.4 mSv/year. Even at the upper limit of 0.329381 mSv/y, the exposure remains below the 1 mSv/year threshold set by international radiation protection guidelines. These values suggest that the soils are safe for general use, with no immediate concerns for radiation-related health effects, and that monitoring these values is more for precaution and continued assessment of environmental conditions [21-22].

The combined gamma dose from U, Th, and K activity levels are within safety limits for outdoor soil, given that these radionuclides are typically present at comparable levels in natural soils. If these values are compared to national or international guidelines, they are generally within permissible limits for naturally occurring radioactive materials (NORM). No significant health risk is expected from these concentrations, but routine monitoring could be useful to confirm long-term stability, especially if the soil is disturbed for agricultural or construction activities.

For edible plants, these levels generally suggest a low risk of radiological exposure from K, U, and Th, particularly as uranium and thorium levels remain low. However, the uranium level here could prompt further monitoring if such plants are part of a local diet, to ensure there is no cumulative exposure. Elevated uranium in plants might indicate areas of increased uranium presence in the soil, which could affect other ecological processes if it leaches into water systems or accumulates in animal tissue through the food chain. Comparing these levels to permissible limits for radioactivity in foodstuffs (set by organizations such as the WHO or IAEA) could be advisable, though the potassium level is generally acceptable, and the uranium and thorium levels appear below concern thresholds for human health.

4 Conclusion

This study reports the radiological impact of soil and plant samples collected from farmland around crude oil exploration sites in Edo State. The result indicates minimal uptake from the soil, which is consistent with thorium's behavior as it tends to remain bound to soil particles.

Radiologically, thorium poses minimal risk in plants due to its low concentration and reduced mobility. The absorbed dose rate in the analyzed plant samples is moderate compared to the global average background gamma dose rate. The measured radium equivalent activity further supports the presence of naturally occurring radionuclides at moderate levels. These results suggest that while plants absorb and retain gamma-emitting radionuclides from their environment, the radiation exposure from these sources remains within expected natural variations.

However, the dose rate in the soil samples is significantly higher than the global average, suggesting elevated levels of natural radioactivity in the studied area. While the measured values do not necessarily pose an immediate health risk, prolonged exposure to higher absorbed dose rates could contribute to increased radiation exposure for individuals frequently in contact with these soils. While plants generally uptake minimal uranium, elevated soil levels increase the possibility of bioaccumulation in specific plant species. [23-24].

References

[1] International Atomic Energy Agency (IAEA). (2019). Naturally Occurring Radioactive Material (NORM VIII): Proceedings of an International Symposium. Vienna: IAEA.

[2] Faanu, A., Ephraim, J. H., & Darko, E. O. (2016). Assessment of natural and anthropogenic radioactivity levels in soils and food crops in a gold mining area in Ghana. Radiation Protection Dosimetry., **171(2)**, 213-222.

[3] Jibiri, N. N., & Amakom, C. M. (2020). Radiological impact assessment of oil and gas facilities in the Niger Delta region of Nigeria. Journal of Environmental Radioactivity., **218**, 106252.

[4] Prăvălie, R., Patriche, C. V., & Bandoc, G. (2019). Implications of soil and climate conditions on the transfer of natural radionuclides to plants. Science of the Total Environment., **695**, 133856.

[5] El-Taher, WM Badawy, AEM Khater, HA Madkour., Distribution patterns of natural radionuclides and rare earth elements in marine sediments from the Red Sea, Egypt. Applied Radiation and Isotopes., **151**, 171-181. (2019).

[6] Saba D. I., Samson D. Y., Ibrahim U., and Idris M. M. Determination of Activity Concentration and Radiotoxicity of Some Radionuclides in Gold Mining Area of Galadima Kogo in Niger State, Nigeria. J. Rad. Nucl. Appl.**9(3)**, 213-219. (2024).

[7] Jibiri, N. N., & Emelue, H. U. Soil-to-crop transfer factors of natural radionuclides for some common food crops in a high background radiation area of Nigeria. Environmental Processes.,**4(1)**,185-197. (2017).

[8] Ibrahiem, N. M., Abdel Ghaffar, A., & El Gazar, H. A. Transfer of uranium and thorium from soil to plant in different locations. Journal of Environmental Radioactivity., **101(3)**, 237-243. (2010).

[9] MM Idris., R T Sadiq., M. Musa., M A Kana., S H Isah., A. Bello, A. & S AUmar Outdoor Background Radiation Level and Radiological Hazards Assessment in Lafia Metropolis, Nasarawa State, Nigeria. ASEANA Journal of Science and Education., **1(1)**, 27 – 35. (2021).

[10] ICRP recommendation of the International Commission on Radiological Protection. Oxford: Pergamon Press. ICRP publication 60, Annal of the ICRP., 210-3. (1991).

[11] A.J. Innocent., M.Y Onimisi & S.A Jonah Evaluation of naturally occurring radionuclide materials in soil samples collected from some mining sites in Zamfara State, Nigeria. British Journal of Applied Science and Technology., **3(4)**, 684-692. (2013).

[12] Shahbazi-Gahrouei, D., Abdollahi, H., & Gholami, M. Assessment of soil-to-plant transfer factor of natural radionuclides in Iran. Radiation Protection Dosimetry., **157(4)**, 613-620. (2013).

[13] A.K Ademola, & R.I Obed, Gamma radioactivity levels and their corresponding external exposure of soil samples from Tantalite mining areas in Oke-Ogun, South-Western Nigeria. Journal of Radioprotection., **47(1)**, 243-252. (2012).

[14] El-Taher, MAK Abdelhalim., Elemental analysis of phosphate fertilizer consumed in Saudi Arabia. Life Science Journal., **10 (4)**, 701-708. (2013).

[15] El-Taher, A., Abojassim, AA., Najam, LA., HAAB Mraity., Assessment of annual effective dose for different age groups based on radon concentrations in the groundwater of Qassim, Saudi Arabia. Iranian Journal of Medical Physics., **17(1)**, 15-20. (2020).

[16] Elsaman, R., Omer, MAA., Seleem, EMM., El-Taher, A.., Natural radioactivity levels and radiological hazards in soil samples around Abu Karqas Sugar Factory. Journal of Environmental Science and Technology, 2018., **11(1)**, 28-38 ref. 41. (2018).

[17] El-Taher, A., Althoyaib, S.S.., Natural Radioactivity Levels and Heavy Metals in Chemical and Organic Fertilizer Used in Kingdom of Saudi Arabia. Journal of Applied. Radiation and Isotopes., **70**, 290-295. (2012).

[18] El-Taher, A., Analytical Methodology for the Determination of concentration of pollutants and radioactive elements in Phosphate Fertilizer used in Saudi Arabia. Indian Journal Environmental Science ., **8(2),** 71-78. (2013)

[19] El-Taher, R. Garcia-Tenorio, and Ashraf E.M. Khater., Ecological impacts of Al-Jalamid phosphate mining, Saudi Arabia: Soil elemental characterization and spatial distribution with INAA. Applied Radiation and Isotopes., **107**, 382–390. (2016).

[20] El-Taher, A and Ashraf E.M. Khater., Elemental characterization of Hazm El-Jalamid phosphorite by instrumental neutron activation analysis. Applied Radiation and Isotopes., **114**, 121-127. (2016).

[21] Al Mugren, K.S and El-Taher, A.., Risk Assessment of Some Radioactive and Elemental Content from Cement and Phosphate Fertilizer Consumer in Saudi Arabia. Journal of Environmental Science and Technology., **9(4)**, 323-328, (2016).

[22] Saleh Alashrah and Atef El-Taher and Howaida Mansour., Environmental study to assess radiological parameters and elemental contents in soil samples from Harrat Al Madinah, Saudi Arabia. MethodsX., **5**, 485–494. (2018).

[23] SAK Arafin, A. El-Taher, AKMF Hoque, MA Hoque, J Ferdous, MJ Abedin., 2020 Natural gamma radiation level detection in agriculture soil after Aila disaster and comparison with deep soil gamma activity in a specific area of Sundarban region, Satkhira …International Journal of Radiation Research.,**18(3)**, 397-404 (2020).

[24] Mostafa, A., Salman, SA., Seleem, EM., Elnazer, AA., Al-Gamal, AGA., El-Taher, A.., Howaida Mansour Howaida Mansour., Quality assessment of River Nile sediment between Qena and Sohag cities, Egypt.Journal of Environmental Science and Technology., **12(3)**, 117-124 (2019).