

Radiometric Evaluation of Oml 30 Oil Fields and Host Community Soils in Delta State Using Resrad-Biota Codes

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Abstract- This study evaluated the radiometric characteristics of soils from selected OML 30 oil fields and host-community environments in Delta State using natural radionuclide measurements and the RESRAD-BIOTA code. The activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th were determined for the investigated soil samples, while radium equivalent activity (Raeq) was used to provide an integrated measure of the concentrations of the radionuclides. The results showed considerable spatial variation across the studied oil fields. ^{40}K concentrations ranged from 219.25 to 553.65 Bq kg⁻¹, ^{226}Ra from 26.20 to 55.30 Bq kg⁻¹, and ^{232}Th from 17.35 to 38.10 Bq kg⁻¹. Kokori recorded the highest concentrations of all three radionuclides, whereas Otorogu generally recorded the lowest values. The calculated Raeq values ranged from 69.60 to 152.40 Bq kg⁻¹ and were below the reported recommended value of 370 Bq kg⁻¹. RESRAD-BIOTA version 1.8 was subsequently applied to estimate external, internal and total radiation doses to terrestrial plants and animals. The modeled results demonstrated spatial differences in biota dose, with Kokori recording among the highest total doses. Overall, the findings provide evidence of spatially variable natural radioactivity in the investigated oil-field soils and establish a radiometric baseline for continued environmental monitoring.

Keywords- Radiometric, Oml 30 Oil Fields, Soils, Resrad-Biota Codes.

I. INTRODUCTION

Environmental pollution arising from petroleum exploration and production has become a major concern in many oil-producing regions of the world. Although crude oil provides important energy resources and contributes substantially to national economies, petroleum exploration, production, transportation and associated industrial activities can introduce various contaminants into the environment (Azionu et al., 2019). These contaminants may affect soil, water, vegetation and atmospheric quality and can pose risks to ecosystems and human populations. Among the environmental concerns associated with petroleum-producing areas is the occurrence and distribution of naturally occurring radioactive materials (NORM) and technologically enhanced naturally occurring radioactive materials (TENORM).

Their presence may result from the concentration or redistribution of naturally occurring radionuclides during oil

and gas production activities. Consequently, radiometric assessment of petroleum-producing environments is important for establishing baseline environmental conditions and protecting communities that depend on these environments (Agbalagba, 2017). Natural radionuclides are present in varying concentrations in rocks, soils, sediments and other environmental materials. Important radionuclides commonly considered in environmental radioactivity studies include uranium-238 (^{238}U), thorium-232 (^{232}Th) and potassium-40 (^{40}K). Their concentrations vary according to geological formations, soil characteristics and geographical location.

Radioactive decay from these radionuclides contributes to terrestrial gamma radiation and may result in external exposure to humans. In addition, radionuclides can enter the human body through pathways such as ingestion of contaminated food and water or inhalation of radioactive particles. Although naturally occurring radioactivity is an integral component of the environment, human activities may alter the distribution and

concentration of radionuclides, thereby increasing potential exposure in certain locations (Neidell et al., 2019). The oil and gas industry is particularly relevant to NORM studies because geological formations encountered during exploration and production may contain naturally occurring radionuclides.

During extraction, radionuclides and their decay products can become redistributed and accumulate in produced water, scales, sludges, sediments and other oil-field wastes. Improper handling, discharge or disposal of these materials may result in the transfer of radioactive substances to surrounding environmental compartments. Soil is especially important because it can act as both a receptor and a reservoir for contaminants. Once radionuclides are deposited in soil, their environmental behaviour may be influenced by soil texture, organic matter, pH, mineral composition, moisture and other physicochemical characteristics. Therefore, evaluating radionuclide concentrations in soils around petroleum-producing facilities can provide useful information about environmental contamination and possible exposure pathways (Mahamood et al., 2020).

Nigeria is one of Africa's major oil-producing countries, with petroleum activities concentrated largely in the Niger Delta region. The region supports extensive oil exploration and production activities while also serving as home to numerous communities whose livelihoods depend on agriculture, fishing and other natural-resource-based activities. However, decades of petroleum operations have generated persistent environmental concerns, including soil and water contamination, habitat degradation and exposure to industrial pollutants. In addition to chemical contaminants associated with petroleum production, the potential occurrence of norm/tenorm requires attention because of its implications for environmental quality and radiation protection. Delta State is an important component of Nigeria's Niger Delta petroleum-producing region and contains several oil fields and associated production facilities.

Among these is Oil Mining Lease 30 (Oml 30), an extensive petroleum-producing area associated with numerous oil fields and host communities. Communities located within or around Oml 30 may experience direct and indirect interactions with oil-production activities. Agricultural land, residential areas and other community environments may be located near oil facilities, pipelines and operational areas. Consequently, establishing the radiometric characteristics of soils within these

environments is important for understanding the extent of environmental radioactivity and potential exposure to residents and other receptors (Edomi et al., 2018). Radiometric evaluation provides a means of determining the activity concentrations of radionuclides present in environmental samples and assessing the resulting radiation characteristics. However, measurement of radionuclide concentrations alone does not necessarily provide a complete understanding of the potential consequences for humans and ecological receptors.

Radiation risk depends not only on the concentration of radionuclides but also on exposure pathways, receptor characteristics, environmental transport and duration of exposure. Consequently, computational tools can complement radiometric measurements by translating environmental contamination data into estimates of potential radiation doses and risks (Fatima et al., 2008). One useful tool for this purpose is the Resrad-Biota code, which was developed to support the assessment of radiation exposure to biota from residual radioactive materials. The code provides a framework for evaluating potential radiation doses to ecological receptors based on radionuclide concentrations and exposure conditions. Its application can therefore extend radiometric investigations beyond simply reporting activity concentrations by providing information relevant to ecological radiation protection and environmental risk assessment.

Despite increasing interest in environmental radioactivity associated with petroleum-producing areas, there remains a need for integrated radiometric and risk-based assessments of soils from specific oil-producing fields and their surrounding host communities. In particular, limited information may be available that combines measured soil radionuclide concentrations from Oml 30 with Resrad-Biota-based evaluation of potential impacts on biological receptors. Many assessments focus primarily on activity concentrations or radiological indices without sufficiently considering how the measured contamination may translate into potential exposure and ecological consequences. This represents an important research gap. Therefore, this study will address the gap by conducting a radiometric evaluation of soils from Oml 30 oil fields and host communities in Delta State using Resrad-Biota codes. The study will provide data on the occurrence and distribution of relevant radionuclides in the investigated soils and use Resrad-Biota to evaluate their potential radiological implications for biota.

II. MATERIALS AND METHOD

Research Design

This study adopted a descriptive and modelling-based research design to evaluate the radiometric characteristics and potential radiological implications of soils obtained from oil fields and host communities within Oil Mining Lease 30 (OML 30), Delta State, Nigeria. The study relied on previously measured concentrations of naturally occurring radionuclides in soil and applied radiation assessment models to interpret the environmental significance of the measured activities. The research was conducted in two major stages. First, available radiometric data for the soil samples were compiled and examined to determine the activity concentrations of the principal naturally occurring radionuclides, particularly ^{226}Ra , ^{232}Th and ^{40}K . Second, the radionuclide concentrations were entered into the Resrad-Biota code to estimate potential radiation dose to representative terrestrial ecological receptors. The calculated dose results were subsequently evaluated against the applicable biota dose screening criteria. This approach allows the study to move beyond the simple determination of radionuclide concentrations and provides an assessment of their potential implications for ecological receptors.

Study Area

The study was carried out within the onshore portion of Oil Mining Lease 30 (OML 30) in the Niger Delta region of Nigeria. The area encompasses five Local Government Areas of Delta State, namely Isoko North, Isoko South, Ughelli North, Ughelli South and Ethiope East. The OML 30 area contains several oil-producing fields and associated petroleum infrastructure and is situated within the southwestern part of the Niger Delta. Geographically, the study area lies approximately between latitudes $5^{\circ}18'\text{N}$ and $5^{\circ}86'\text{N}$ and longitudes $5^{\circ}33'\text{E}$ and $6^{\circ}40'\text{E}$. The region is characterized by tropical climatic conditions and supports agricultural and other natural-resource-based activities. Consequently, environmental quality within the area is of considerable importance to both ecological systems and surrounding communities.

The principal geological formations underlying the study area are the Benin, Agbada and Akata Formations. These formations differ in age, lithological characteristics and degree of compaction. The Benin Formation represents the youngest unit and consists predominantly of unconsolidated sands and

gravels, with subordinate shale, lignite and other mineral components. It constitutes an important aquifer system within the Niger Delta. Beneath the Benin Formation is the Agbada Formation, which consists mainly of alternating sequences of sandstone, siltstone and shale. The sandstone units within this formation constitute important reservoirs for petroleum accumulation. The deepest and oldest of the three major formations is the Akata Formation, which is predominantly composed of dark grey shale and siltstone, with subordinate sand intervals associated with turbiditic processes. The geological characteristics of these formations are relevant to the occurrence and distribution of naturally occurring radionuclides in the environment.



Figure 1: Map of the Study Area

Method of Data Collection

The study employed secondary radiometric data obtained from the work of Agbalagba et al. (2012), which investigated natural radioactivity and radiation hazard indices in soil samples collected from oil-field environments in Delta State, Nigeria. The dataset comprised measured activity concentrations of naturally occurring radionuclides in soils associated with ten oil fields within the OML 30 production area. The radionuclides considered in the present modelling were ^{226}Ra , ^{232}Th and ^{40}K , expressed in appropriate activity-concentration units. The reported activity concentrations were reviewed, organized according to the respective oil fields, and prepared for subsequent modelling. Where necessary, the reported concentrations were converted to the units required by the Resrad-Biota input interface before model execution.

The use of secondary data provides an opportunity to re-evaluate existing radiometric measurements using an ecological radiation assessment framework. It also permits

comparison of previously reported activity concentrations with dose-based screening criteria for protection of terrestrial biota.

RESRAD-BIOTA Data Analysis and Modelling Procedure

The Resrad-Biota computer code was employed to assess the potential radiation dose to terrestrial biota resulting from the presence of radionuclides in the investigated soils. RESRAD-BIOTA is designed to implement a graded approach to evaluating radiation doses to ecological receptors and provides screening and more detailed dose-evaluation options.

The analysis was performed using the following procedure:

Preparation of radionuclide input data

The mean activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K reported for the ten oil fields were used as the principal source-term data. Each radionuclide concentration was assigned to the soil medium in the RESRAD-BIOTA input interface. Care was taken to ensure that radionuclide names, concentrations and units corresponded correctly with the requirements of the model.

Definition of the exposure medium

Soil was selected as the contaminated environmental medium because the purpose of the analysis was to determine the potential radiological effect of radionuclides occurring in soils within the OML 30 oil-field environment. The analysis therefore considered terrestrial exposure resulting from radionuclides present in the soil.

Selection of the Resrad-Biota screening approach

The RESRAD-BIOTA Level 1 screening approach was initially applied where the available data and study objectives permitted. Level 1 provides a conservative screening assessment based on radionuclide concentrations and biota concentration guides (BCGs). The model calculates the contribution of individual radionuclides and environmental media to the overall screening ratio. According to the RESRAD-BIOTA methodology, a total ratio below 1 indicates that the estimated dose is below the applicable biota dose limit, whereas a ratio exceeding 1 indicates the need for additional evaluation using a more detailed assessment.

Estimation of radiation dose

For each oil field, the radionuclide concentrations were processed by the model to estimate the radiation dose received by representative terrestrial receptors. The assessment accounts for both external exposure from radionuclides present in the

surrounding soil and internal exposure resulting from radionuclide uptake through relevant ecological exposure pathways. RESRAD-BIOTA incorporates radionuclide-specific parameters and concentration factors in estimating the dose to biota.

Determination of dose contribution

The model output was examined to determine the contribution of individual radionuclides to the estimated total dose. The results were used to identify which radionuclides made the greatest contribution to the potential radiological burden of terrestrial receptors. The total dose and individual radionuclide contributions were recorded for each investigated oil field.

Comparison with biota dose criteria

The calculated dose values and screening ratios were compared with the applicable Biota Concentration Guides (BCGs) and biota dose benchmarks incorporated into the RESRAD-BIOTA framework. A total screening ratio of less than 1.0 indicates that the estimated radiation dose is below the applicable biota dose criterion and therefore passes the general screening evaluation. A ratio greater than 1.0 indicates that the screening criterion has been exceeded and that further evaluation may be required.

Interpretation and comparison of model results

The RESRAD-BIOTA outputs for the ten oil fields were tabulated and compared to determine spatial differences in potential radiological exposure. The results were interpreted in relation to the measured concentrations of ^{226}Ra , ^{232}Th and ^{40}K . Particular attention was given to the radionuclide and oil field contributing the highest estimated dose.

It is important to distinguish this ecological assessment from a human-health cancer-risk assessment.

Statistical and Comparative Analysis

The radionuclide activity concentrations and Resrad-Biota outputs were summarized using descriptive statistics. Mean values were used to characterize the representative radionuclide concentrations for the investigated oil fields. The estimated doses, screening ratios and radionuclide contributions were compared among the ten oil fields to identify areas with relatively higher or lower radiological significance. The results were presented in tables and, where appropriate, graphical form. The modelled results were subsequently interpreted against the applicable radiological protection criteria to determine whether the investigated soil environments presented potential radiological concerns for terrestrial biota.

III. RESULTS AND DISCUSSION

Activity Concentrations of Natural Primordial Radionuclides (226Ra, 232Th and 40K)

The mean activity concentration of the radionuclides (226Ra, 232Th and 40K) in the soil samples of the study area are presented in table 4.1.

Table 1: The Total average mean value of the Specific activity of 226Ra, 232Th and 40K and radium equivalent activity (Bqkg-1) in soil samples from oil fields environment of Delta state.

LOCATION	⁴⁰ K	²²⁶ RA	²³² TH	RAEQ.KG ⁻¹
Uzere Oil Field	302.10	28.80	28.25	92.50
Olomoro/Oleh Oil Field	250.30	34.80	17.45	79.05
Oweh Oil Field	386.50	26.20	21.75	87.05
Evwereni Oil Field	492.15	31.85	24.25	104.00
Eriemu Oil Field	388.45	43.50	35.65	124.40
Kokori Oil Field	553.65	55.30	38.10	152.40
Afiesere Oil Field	341.30	30.40	22.90	85.50

Ugheli East Oil Field	375.20	33.40	23.60	96.10
Ugheli West Oil Field	444.65	41.80	32.20	126.40
Otorogu Oil Field	219.25	27.90	17.35	69.60
Recommended Limit(Unsear, 2000)	420	33	45	≤370

RESRAD-BIOTA Results

The RESRAD-BIOTA code is used for estimating radiation dose to non-human, aquatic, and terrestrial biota. RESRAD-BIOTA version 1.8 was used to estimate the total dose received by terrestrial plants and animals in the study area. The maximum values of the activity concentrations were used as input values in the RESRAD codes and this is because of secular equilibrium, the concentrations of the progeny were the same as those of the primordial radionuclides. The dose report (external dose, internal dose, and total dose) of the investigated radionuclides in terrestrial plants and animals by soil media for each studied field are presented in (Tables 2-10) and the corresponding graphs shows the total dose rate in the terrestrial animals and terrestrial plants for all nuclides summed for each oil field.

Table 2: Dose Report in Gy/d for UZERE Oil field

Terrestrial Animal									
Nuclide	External			Internal			Total		
	ext_Soil		ext_Sum	int_Soil		int_Sum	tot_Soil		tot_Sum
K-40	2.82E-06		2.82E-06	6.60E-05		6.60E-05	6.88E-05		6.88E-05
Ra-226	1.10E-06		1.10E-06	1.43E-05		1.43E-05	1.54E-05		1.54E-05
Th-232	4.74E-09		4.74E-09	4.99E-07		4.99E-07	5.03E-07		5.03E-07
Summed	3.93E-06		3.93E-06	8.08E-05		8.08E-05	8.47E-05		8.47E-05
Terrestrial Plant									
Nuclide	External			Internal			Total		
	ext_Soil		ext_Sum	int_Soil		int_Sum	tot_Soil		tot_Sum
K-40	2.82E-06		2.82E-06	5.64E-05		5.64E-05	5.92E-05		5.92E-05
Ra-226	1.10E-06		1.10E-06	2.60E-05		2.60E-05	2.71E-05		2.71E-05
Th-232	4.74E-09		4.74E-09	3.19E-07		3.19E-07	3.23E-07		3.23E-07

Summed	3.93E-06	3.93E-06	8.27E-05	8.27E-05	8.66E-05	8.66E-05
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Table 3: Dose Report in Gy/d for OLOMORO Oil field

Terrestrial Animal									
Nuclide	External			Internal			Total		
	ext_Soil	ext_Sum		int_Soil	int_Sum		tot_Soil	tot_Sum	
K-40	2.82E-06	2.82E-06		6.60E-05	6.60E-05		6.88E-05	6.88E-05	
Ra-226	1.10E-06	1.10E-06		1.43E-05	1.43E-05		1.54E-05	1.54E-05	
Th-232	4.74E-09	4.74E-09		4.99E-07	4.99E-07		5.03E-07	5.03E-07	
Summed	3.93E-06	3.93E-06		8.08E-05	8.08E-05		8.47E-05	8.47E-05	
Terrestrial Plant									
Nuclide	External			Internal			Total		
	ext_Soil	ext_Sum		int_Soil	int_Sum		tot_Soil	tot_Sum	
K-40	2.82E-06	2.82E-06		5.64E-05	5.64E-05		5.92E-05	5.92E-05	
Ra-226	1.10E-06	1.10E-06		2.60E-05	2.60E-05		2.71E-05	2.71E-05	
Th-232	4.74E-09	4.74E-09		3.19E-07	3.19E-07		3.23E-07	3.23E-07	
Summed	3.93E-06	3.93E-06		8.27E-05	8.27E-05		8.66E-05	8.66E-05	

Table 4: Dose Report in Gy/d for OWEH Oil field

Nuclide	ext_Soil	ext_Sum	int_Soil	int_Sum	tot_Soil	tot_Sum
K-40	3.61E-06	3.61E-06	8.44E-05	8.44E-05	8.80E-05	8.80E-05
Ra-226	1.00E-06	1.00E-06	1.30E-05	1.30E-05	1.40E-05	1.40E-05
Th-232	3.65E-09	3.65E-09	3.84E-07	3.84E-07	3.88E-07	3.88E-07
Summed	4.61E-06	4.61E-06	9.78E-05	9.78E-05	1.02E-04	1.02E-04
Nuclide	ext_Soil	ext_Sum	int_Soil	int_Sum	tot_Soil	tot_Sum
K-40	3.61E-06	3.61E-06	7.21E-05	7.21E-05	7.57E-05	7.57E-05
Ra-226	1.00E-06	1.00E-06	2.36E-05	2.36E-05	2.46E-05	2.46E-05
Th-232	3.65E-09	3.65E-09	2.45E-07	2.45E-07	2.49E-07	2.49E-07
Summed	4.61E-06	4.61E-06	9.60E-05	9.60E-05	1.01E-04	1.01E-04

Table 5: Dose Report in Gy/d for EVWRENI Oil field

Terrestrial Animal									
Nuclide	External			Internal			Total		
	ext_Soil	ext_Sum		int_Soil	int_Sum		tot_Soil	tot_Sum	
K-40	4.59E-06	4.59E-06		1.07E-04	1.07E-04		1.12E-04	1.12E-04	
Ra-226	1.22E-06	1.22E-06		1.58E-05	1.58E-05		1.70E-05	1.70E-05	
Th-232	4.06E-09	4.06E-09		4.27E-07	4.27E-07		4.31E-07	4.31E-07	
Summed	5.82E-06	5.82E-06		1.24E-04	1.24E-04		1.30E-04	1.30E-04	
Terrestrial Plant									
Nuclide	External			Internal			Total		
	ext_Soil	ext_Sum		int_Soil	int_Sum		tot_Soil	tot_Sum	
K-40	4.59E-06	4.59E-06		9.18E-05	9.18E-05		9.64E-05	9.64E-05	
Ra-226	1.22E-06	1.22E-06		2.87E-05	2.87E-05		2.99E-05	2.99E-05	
Th-232	4.06E-09	4.06E-09		2.73E-07	2.73E-07		2.77E-07	2.77E-07	
Summed	5.82E-06	5.82E-06		1.21E-04	1.21E-04		1.27E-04	1.27E-04	

Table 6: Dose Report in Gy/d for ERIEMU Oil field

Terrestrial Animal									
Nuclide	External			Internal			Total		
	ext_Soil	ext_Sum		int_Soil	int_Sum		tot_Soil	tot_Sum	
K-40	3.62E-06	3.62E-06		8.48E-05	8.48E-05		8.84E-05	8.84E-05	
Ra-226	1.67E-06	1.67E-06		2.16E-05	2.16E-05		2.33E-05	2.33E-05	
Th-232	5.97E-09	5.97E-09		6.28E-07	6.28E-07		6.34E-07	6.34E-07	
Summed	5.30E-06	5.30E-06		1.07E-04	1.07E-04		1.12E-04	1.12E-04	
Terrestrial Plant									
Nuclide	External			Internal			Total		
	ext_Soil	ext_Sum		int_Soil	int_Sum		tot_Soil	tot_Sum	
K-40	3.62E-06	3.62E-06		7.25E-05	7.25E-05		7.61E-05	7.61E-05	

Ra-226		1.67E-06		1.67E-06		3.92E-05		3.92E-05		4.09E-05		4.09E-05
Th-232		5.97E-09		5.97E-09		4.01E-07		4.01E-07		4.07E-07		4.07E-07
Summed		5.30E-06		5.30E-06		1.12E-04		1.12E-04		1.17E-04		1.17E-04

Table 7: Dose Report in Gy/d for KOKORI Oil field

Terrestrial Animal												
Nuclide	External				Internal				Total			
		ext_Soil		ext_Sum		int_Soil		int_Sum		tot_Soil		tot_Sum
K-40		5.17E-06		5.17E-06		1.21E-04		1.21E-04		1.26E-04		1.26E-04
Ra-226		2.12E-06		2.12E-06		2.75E-05		2.75E-05		2.96E-05		2.96E-05
Th-232		6.38E-09		6.38E-09		6.71E-07		6.71E-07		6.78E-07		6.78E-07
Summed		7.29E-06		7.29E-06		1.49E-04		1.49E-04		1.56E-04		1.56E-04
Terrestrial Plant												
Nuclide	External				Internal				Total			
		ext_Soil		ext_Sum		int_Soil		int_Sum		tot_Soil		tot_Sum
K-40		5.17E-06		5.17E-06		1.03E-04		1.03E-04		1.08E-04		1.08E-04
Ra-226		2.12E-06		2.12E-06		4.99E-05		4.99E-05		5.20E-05		5.20E-05
Th-232		6.38E-09		6.38E-09		4.29E-07		4.29E-07		4.35E-07		4.35E-07
Summed		7.29E-06		7.29E-06		1.54E-04		1.54E-04		1.61E-04		1.61E-04

Table 7: Dose Report in Gy/d for AFIESERE Oil field

Terrestrial Animal												
Nuclide	External				Internal				Total			
		ext_Soil		ext_Sum		int_Soil		int_Sum		tot_Soil		tot_Sum
K-40		3.18E-06		3.18E-06		7.45E-05		7.45E-05		7.77E-05		7.77E-05
Ra-226		1.17E-06		1.17E-06		1.51E-05		1.51E-05		1.63E-05		1.63E-05

Th-232		3.83E-09		3.83E-09		4.03E-07		4.03E-07		4.07E-07		4.07E-07
Summed		4.35E-06		4.35E-06		9.00E-05		9.00E-05		9.44E-05		9.44E-05
Terrestrial Plant												
Nuclide	External				Internal				Total			
		ext_Soil		ext_Sum		int_Soil		int_Sum		tot_Soil		tot_Sum
K-40		3.18E-06		3.18E-06		6.37E-05		6.37E-05		6.69E-05		6.69E-05
Ra-226		1.17E-06		1.17E-06		2.74E-05		2.74E-05		2.86E-05		2.86E-05
Th-232		3.83E-09		3.83E-09		2.58E-07		2.58E-07		2.62E-07		2.62E-07
Summed		4.35E-06		4.35E-06		9.14E-05		9.14E-05		9.57E-05		9.57E-05

Table 8: Dose Report in Gy/d for UGHELLI-EAST Oil field

Terrestrial Animal												
Nuclide	External				Internal				Total			
		ext_Soil		ext_Sum		int_Soil		int_Sum		tot_Soil		tot_Sum
K-40		3.50E-06		3.50E-06		8.19E-05		8.19E-05		8.54E-05		8.54E-05
Ra-226		1.28E-06		1.28E-06		1.66E-05		1.66E-05		1.79E-05		1.79E-05
Th-232		3.95E-09		3.95E-09		4.16E-07		4.16E-07		4.20E-07		4.20E-07
Summed		4.79E-06		4.79E-06		9.89E-05		9.89E-05		1.04E-04		1.04E-04
Terrestrial Plant												
Nuclide	External				Internal				Total			
		ext_Soil		ext_Sum		int_Soil		int_Sum		tot_Soil		tot_Sum
K-40		3.50E-06		3.50E-06		7.00E-05		7.00E-05		7.35E-05		7.35E-05
Ra-226		1.28E-06		1.28E-06		3.01E-05		3.01E-05		3.14E-05		3.14E-05
Th-232		3.95E-09		3.95E-09		2.66E-07		2.66E-07		2.70E-07		2.70E-07
Summed		4.79E-06		4.79E-06		1.00E-04		1.00E-04		1.05E-04		1.05E-04

Table 9: Dose Report in Gy/d for UGHELLI-WEST Oil field

Terrestrial Animal												
Nuclide	External				Internal				Total			

		ext_Soil		ext_Sum		int_Soil		int_Sum		tot_Soil		tot_Sum
K-40		4.15E-06		4.15E-06		9.71E-05		9.71E-05		1.01E-04		1.01E-04
Ra-226		1.60E-06		1.60E-06		2.08E-05		2.08E-05		2.24E-05		2.24E-05
Th-232		5.89E-09		5.89E-09		6.20E-07		6.20E-07		6.26E-07		6.26E-07
Summed		5.76E-06		5.76E-06		1.18E-04		1.18E-04		1.24E-04		1.24E-04
Terrestrial Plant												
Nuclide	External				Internal				Total			
		ext_Soil		ext_Sum		int_Soil		int_Sum		tot_Soil		tot_Sum
K-40		4.15E-06		4.15E-06		8.30E-05		8.30E-05		8.71E-05		8.71E-05
Ra-226		1.60E-06		1.60E-06		3.77E-05		3.77E-05		3.93E-05		3.93E-05
Th-232		5.89E-09		5.89E-09		3.96E-07		3.96E-07		4.02E-07		4.02E-07
Summed		5.76E-06		5.76E-06		1.21E-04		1.21E-04		1.27E-04		1.27E-04

Table 10: Dose Report in Gy/d for OTOROGU Oil field

Terrestrial Animal												
Nuclide	External				Internal				Total			
		ext_Soil		ext_Sum		int_Soil		int_Sum		tot_Soil		tot_Sum
K-40		2.05E-06		2.05E-06		4.79E-05		4.79E-05		4.99E-05		4.99E-05
Ra-226		1.07E-06		1.07E-06		1.39E-05		1.39E-05		1.49E-05		1.49E-05
Th-232		2.90E-09		2.90E-09		3.06E-07		3.06E-07		3.09E-07		3.09E-07
Summed		3.12E-06		3.12E-06		6.20E-05		6.20E-05		6.52E-05		6.52E-05
Terrestrial Plant												
Nuclide	External				Internal				Total			
		ext_Soil		ext_Sum		int_Soil		int_Sum		tot_Soil		tot_Sum
K-40		2.05E-06		2.05E-06		4.09E-05		4.09E-05		4.30E-05		4.30E-05
Ra-226		1.07E-06		1.07E-06		2.52E-05		2.52E-05		2.62E-05		2.62E-05
Th-232		2.90E-09		2.90E-09		1.95E-07		1.95E-07		1.98E-07		1.98E-07
Summed		3.12E-06		3.12E-06		6.63E-05		6.63E-05		6.94E-05		6.94E-05

IV. DISCUSSION

The results of the radiometric evaluation indicate considerable spatial variation in the activity concentrations of the natural primordial radionuclides ^{40}K , ^{226}Ra and ^{232}Th across the investigated OML 30 oil-field environments in Delta State. The measured ^{40}K concentrations ranged from 219.25 Bq kg⁻¹ at Otorogu Oil Field to 553.65 Bq kg⁻¹ at Kokori Oil Field. Similarly, ^{226}Ra varied from 26.20 Bq kg⁻¹ at Oweh to 55.30 Bq kg⁻¹ at Kokori, while ^{232}Th ranged from 17.35 Bq kg⁻¹ at Otorogu to 38.10 Bq kg⁻¹ at Kokori. These variations demonstrate that radionuclide distribution was not uniform among the studied locations. Among the three radionuclides, ^{40}K generally contributed the highest activity concentration at the study locations. The highest ^{40}K value occurred at Kokori, followed by Evwereni and Ughelli West, whereas Otorogu recorded the lowest concentration. The comparatively elevated values at some locations may reflect differences in the natural mineralogical composition of the soils and the distribution of potassium-bearing minerals.

The ^{226}Ra and ^{232}Th concentrations also showed marked spatial differences, with Kokori and Eriemu generally showing relatively higher values. The results therefore indicate localized accumulation or natural variation in radionuclide-bearing soil materials rather than a uniform radiological pattern. The calculated radium equivalent activity (Raeq) ranged from 69.60 Bq kg⁻¹ at Otorogu to 152.40 Bq kg⁻¹ at Kokori. All recorded Raeq values were below the recommended value of 370 Bq kg⁻¹ presented in the results. This indicates that, based on the reported Raeq parameter, the investigated soils remained below the stated reference level.

The RESRAD-BIOTA assessment further demonstrated that radionuclide concentrations in the soils translated into measurable radiation doses to terrestrial biota. RESRAD-BIOTA version 1.8 considered external, internal and total doses for terrestrial plants and animals, using the maximum activity concentrations as model inputs under the stated assumption of secular equilibrium. For example, at Uzere, the summed total dose was 8.47×10^{-5} Gy d⁻¹ for terrestrial animals and 8.66×10^{-5} Gy d⁻¹ for terrestrial plants. Kokori produced one of the highest reported total doses, reaching 1.56×10^{-4} Gy d⁻¹ for animals and 1.61×10^{-4} Gy d⁻¹ for plants. The results therefore show that Kokori represents the location with the greatest combined radiometric and modeled biota-dose values among

the clearly reported sites, while Otorogu exhibited comparatively lower values.

V. CONCLUSION

The study demonstrates that the soils within the investigated OML 30 oil-field environments contain measurable concentrations of the natural primordial radionuclides ^{40}K , ^{226}Ra and ^{232}Th , with considerable spatial variation among the locations. ^{40}K was generally the dominant radionuclide, while Kokori recorded the highest concentrations of ^{40}K , ^{226}Ra and ^{232}Th and also the highest Raeq value of 152.40 Bq kg⁻¹. In contrast, Otorogu generally exhibited the lowest radionuclide concentrations and Raeq of 69.60 Bq kg⁻¹. All reported Raeq values were below the stated recommended value of 370 Bq kg⁻¹. The RESRAD-BIOTA results confirm that the measured soil radionuclides contribute to radiation doses received by terrestrial plants and animals, with the magnitude varying between oil fields. Kokori recorded the highest clearly reported total dose values, whereas Otorogu recorded lower values. Overall, the findings provide an important baseline for radiological characterization and future environmental monitoring of the OML 30 oil-field areas.

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