Assessment Of Natural Radionuclides And Geophysical Effects In Hydrocarbon-Producing Communities In Ondo State, Nigeria

Bayode O. P.[†1], Ilori O. A.[2], Alasi T. K[3], Oluwafisoye .P. A[4], Toyeje A. B[5], and Aderanti A[6]

[1,3,5]Department of Physics with Electronics University of Ilesa, Ilesa Nigeria.
[2]Department of Physical Sciences Olusegun Agagu University of Science and Technology, Okitipupa Ondo State.
[4]4Department of Education Training and Inspectorate Nigeria Institute of Science Laboratory Technology Samonda, Ibadan
[6]Department of Science Laboratory Technology (Physics Option) Igbajo Polytechnic, Igbajo Osun State Nigeria.

Corresponding Author: Bayode, O. P E-mail: oladele bayode@unilesa.edu.ng

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Abstract

The assessment of natural radionuclides and geophysical effects in hydrocarbon- producing communities in Ondo State, Nigeria was conducted using gamma spectrom- etry. A calibrated NaI(TI) detector was used to analyze 25 sediment and 25 plants samples collected from different area within the communities.

The radionuclides concentrations of K, Th and U in the sediment samples ranged from 299.48±12.13 to 2795.58± 45.93 Bq/kg 14.88±2.4 to 186±9.38 Bq/kg and 11.51±0.42 to 68.39±2.64 Bq/k respectively. Also, the radionuclides concentration in plant samples ranged from 7.44± 1.07 to 82.26±3.56 Bq/kg 3.24±0.28 to 75.96±1.36 Bq/kg and 7.44 ±1.07 to 82.26 ±3.56Bq/kg respectively.

The absorbed gamma radiation dose rate, excess lifetime cancer risk and external radiation hazard index were calculated. The results showed that all radiological risk

*Keywords and Phrases : hypergroupoid, hypergroup, polygroup, polygroupoid, left-,right-, middle- nucleus, alternativity flexibility

†All correspondence to be addressed to this author.

parameters exceeded the recommended safety levels in sediment samples. However, the radionuclide concentrations in the plant samples were within permissible limits.

This research indicates potential health risks from radiological exposure in the region especially in farmland. These findings contradict one of the Sustainable Devel- opment Goals (SDGs), which aims to substantially reduce the number of deaths and illnesses caused by hazardous chemicals, air pollution, and water and soil contamina- tion. Furthermore, incessant oil-spills and hydrocarbon pollution continue to threaten the livelihoods of the affected communities.

1 Introduction

Oil production releases both induced radionuclides from exploration activities and the ac- companying natural radionuclides. This increases the background radiation levels in the areas that produce oil. The amount of background radiation in areas where oil is produced increases as a result of regular oil spills and the evacuation of oil-producing waters into nearby bodies of water. Many oil spills have occured in Nigeria's Niger Delta. The amount of radiation threat to people and their surroundings is influenced by factors such as the type of radioactive pollutant, contamination level, and extent to which contaminants have spread (Ogundare, F. O; Adekoya .O. I, 2015).

To understand how natural radionuclides migrate through soils and how various plants react to them, one must first understand how they interact with the sediments (Shtangeeva, 2010). Electrical conductivity (EC), cation exchange capacity (CEC), total organic carbon (TOC), nutrition, mineralogy, climate, and (bio)chemical processes including complexion, precipitation, and redox reactions are only a few of the variables that might affect the intake of trace elements by biota (Sohlenius, G., Saetre, P., Nordden, S ., Grolander, S., Sheppard, S., 2013; Gupta, D. J., Chatteriee, S., Datta, S., Veer, V., Walther, C., 2014; Zhao, C. M., Campbelll, P.G., Wilkinson, K. J.,, 2016) These characteristics were not taken into account in around 50% of the TF-focused analyses (Vandenhove, H., Olyssaeger, G., Sanzharova, N., Shubina, O., Reed, E., Shang, Z., Velasco, H .,, 2009), and this restricts our comprehension of the biota's metal intake. Determining radionuclide distributions in the soil-plant system is challenging because of a lack of understanding regarding the rate of radioactive uptake and storage by different plant species (Shtangeeva, 2010). The majority of TF research up to this point has been conducted in temperate regions, which have significantly different weath- ering processes, nutrient cycles, climate conditions, and metal intake, by living things than tropical regions (IAEA, 2010). Few comprehensive studies have been conducted on tropical agricultural soils impacted by coal mining, particularly in Brazil (FAO, 2012; Galhardi, J. A., Garcia-Tenorio, R., Bonotto, D. M., Frances, I . D., Motta, J. G.,, 2017).

Plants are the primary source of radioactive contamination in the food chain once ra-
dionuclides are released into the atmosphere. TF is a number that is utilized for the ma- jority of significant agricultural products in evaluation studies on the impacts of routine or inadvertent radionuclide releases into the environment. One of the most crucial factors in determining the safety of nuclear reactors for the environment is the soil-to-plant TF. En- vironmental transfer models that estimate radioactive concentrations in crops require this parameter to determine the human dosage (IAEA, 1994).

It is critical to be aware of radiation pollution and absorption processes. Depending on how well they absorb radiation, different foods and plants contain varying levels of radioac- tive contaminants. The diet, dosage, location of preparation, and methods used to prepare food, whether vegetable or animal-based, all have an impact on radionuclide absorption. Public awareness and concern about environmental radioactivity have grown (Theophilus, A., Emmanuel, .O., Frederic, S.,,2017). If the exposure level is sufficiently high, it can harm health. High levels of above-background radiation exposure may cause somatic and radiosen- sitive organs to die, (Awudu, et al. , 2012). In many occupational situations, particularly in phosphate fertilizer manufacturing, oil and gas extraction, and mineral mining and pro- cessing, background radiation levels are greater, because all rocks and soils are naturally radioactive. Because all rocks and soils are naturally radioactive, the same is true for all ores. Fortunately, radioactive concentrations in NORM rarely constitute a serious threat to the environment or to individuals when buried in the ground. It is important to consider this increase in active contamination in the after effect, residue, or waste from factory-made activities because NORM is concentrated as a result of human activities such as coal burning, water treatment waste, and oil and gas production (IAEA, 2006). The natural decay series of uranium and thorium contain the radionuclides necessary for NORM. The assessment of these radionuclides is critical because of their potential impacts on human health and the environment. In Nigeria, several studies have focused on the radiometric analysis of soils, ex- ploring the distribution, concentration, and health implications of these radionuclides across different regions. However, there is still a gap in understanding the specific radiometric char- acteristics of soils in coastal areas, especially those affected by industrial activities such as crude oil exploration and spillage. (Ilori O. I; Ojo .M.F; Karigidi O.K;, 2024). The presence of natural resources, such as crude oil, bitumen, mineral sand, and coal, and their exploration activities have been reported to increase the levels of radionuclides in the environment, with such activities destroying living things in vast lands and waters. These natural resources cause varying levels of environmental pollution, affecting weather conditions, soil fertility, and crop productivity. Elevated levels of radionuclides cause equivalent effects

of radiation on human health. (Ilori Olawale Abiola; Naven Chetty;,2024).

In Nigeria, besides the medical sector, the petroleum industry ranks as the largest importer and consumer of radioactive materials, encompassing both upstream and downstream activities. Human actions, particularly industrial operations such as gas flaring at oil gath- ering sites, crude oil spills at oil and gas facilities, and the release of imported hazardous chemicals and radionuclide materials for geological surveys, x-ray welding, and well logging, contribute to increased background ionizing radiation levels in communities or cities. Monitoring radiation in Nigeria's hydrocarbon regions is essential due to the health risks and environmental consequences associated with ionizing radiation. Numerous surveys of ionizing radiation have been conducted in the Niger Delta to evaluate the effects of industrialization on the region's radiation profile, revealing a significant correlation between heightened industrial activities and increased Background Ionizing Radiation (BIR) levels in certain areas.(Luka. S Yani.; Gregory O. Avwiri.; Chinyere P. Ononugbo, 2022)

Figure 1: Map of Ondo State showing Geographical Location of hydrocarbon producing communities, (Igbokoda) within Ilaje Local Government Area. (Bayode, O.P., Alabi, O.O., Isola, G.A., Morakinyo, R.O., Araka, I.O., Ogunwale, E.I.,, 2024)

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2 Materials and Method

Ondo State is located between latitudes 4°30" and 6° East and longitudes 5°45″ and 8 ◦ 15″ North, situated entirely within the tropical zone. The state shares borders with the Ek- iti/Kogi States to the north, Edo State to the east, Oyo and Ogun States to the west, and the Atlantic Ocean to the south. The oil and gas-producing regions under study are located within the Ilaje Local Government Area (LGA), covering a total area of 1,318 square kilometers (Figure 1). The region experiences an average annual temperature of 25°C and precipitation rate of approximately 3,000 mm. The humidity level in this area is approxi- mately 89%, and its numerous rivers and tributaries make it an essential part of the state's aquatic systems. The local economy is primarily based on agriculture, with crops as maize, oil palm, cocoyam, potato vegetables, bananas, and cassava. Ilaje LGA also contains sig- nificant mineral resources such as crude oil, salt, sand, bitumen, and quartz. The sampling locations for this study included the Araromi Sea Side (offshore), Ogogoro, Omuro, Ojumole, Malu, Eko, Parabe, Minna, Bella, Obe, Esan, Ewa, Opolo, Opuama, and Isekelwu oil fields. From each community, 25 samples of sediments and plant samples were collected from each community.

The sample sediment, was obtained using a hand auger to a depth of roughly 5.5 cm throughout the study locations. The stones and some leaves were removed, and the samples were then dried in an oven at a temperature for 24 h to ensure that as much debris as possible was removed. They were crushed and passed through a 2 mm filter to homogenize them.

The plant (potato) was harvested, spread out in trays (properly segregated to avoid contamination), and allowed to dry outdoors before being ground into a fine powder with a mortar and pestle, integrated, and dehydrated at approximately 50°C to completely remove water without losing radionuclides from the sample (Isola, G. A., Oni, O.M., Akinloye, M. K., Suleman, K.O.,, 2016)

These samples were left for 28 d to establish secular equilibrium between the radionu- clides and their decay products. In preparation for the analysis, the water samples were evaporated to a volume of 50 ml without boiling at a controlled temperature of 60 ◦ *C*. The residue was placed in stainless steel planchets, allowed to equilibrate with ambient tempera- ture, and weighed. Samples were counted for 36,000 s using a gamma spectrometry system equipped with a NaI(TI) scintillation detector, (Princeton Gamma Tech, USA). The detec- tor, measuring 3×3 inches, was enclosed in a lead shield to minimize interference from the background radiation. Calibration for energy and efficiency was performed using a standard

source traceable to the Analytical Quality Control Service (AQCS) in the USA. This stan- dard contained ten radionuclides emitting gamma radiation at energies ranging from 59.54 to 1836 keV.

2.1 The activity concentration

A of the samples was calculated using equation 1.

$$A = \frac{C_{\text{net}}}{M \times \varrho \times P_y \times t} \quad (1)$$

where:A is the activity concentration of the radionuclide,

C_{net} is the peak count,

ϱ is the detector efficiency, and

P_y is the radionuclide emission probability.

2.2 Absorbed Gamma Radiation Dose Rate ($DnGyh^{-1}$)

This term refers to the quantity of radiation absorbed or deposited per unit mass of sub- stance. The uniform distribution of naturally occurring radionuclides (^{238}U,^{232}Th, and ^{40}K) was utilized to calculate the absorbed gamma dose rates from gamma radiation in the air at 1 m above the ground (Abbady, A., El-Arabi, A., Abbady, A., Taba, S.,, 2008)

$$DnGyh^{-1} = 0.427A_U + 0.622A_{Th} + 0.00432A_K \quad (2)$$

Where A_U, A_{Th} and A_K are the activity concentration of ^{238}U,^{232}Th, and ^{40}K respectively

2.3 Determination of Excess Lifetime Cancer Risk:

Excess lifetime risk (ELCR) was calculated by using equation 3

$$ELCR = AEDE \times DL \times RF \quad (3)$$

Where DL is the duration of life (48 years in Nigeria) and RF is a risk factors (Sv^{-1}), and fatal cancer risk per Sievert. For stochastic effects, ICRP 60 uses values of 0.5 for the public (ICRP, 1991)

2.4 External Radiation Hazard Index

The external radiation hazard index, often known as the outdoor radiation hazard index, is caused by the naturally occurring radionuclides ^{226}Ra,^{232}Th, and ^{40}K. To minmize the radiation risk, this index must be lower than one unit. The following formula is used to determine the external hazard index (Beretka, ., Matthew,., 1985)

$$H_e = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentration of ^{226}Ra,^{232}Th, and ^{40}K respec- tively.

According to the European Commission (1999), values of index $He \leq 2$ correspond to a dose rate criterion $0.3 mSvy^{-1}$ whereas $2 \leq He \leq 6$ corresponds $1 mSvy^{-1}$ to which is higher than the recommended level posing danger to the surrounding population.

3 Transfer Factor:

According to (Gaffar, S., Ferdous, M. J., Begum, A., Ullah, S. M., 2014) the transfer coeffi- cient (K_d) is given by:

$$K_d = \frac{A_P}{A_S} \quad (5)$$

Where A_P is the activity concentration in the edible part of the plant (in Bq/kg dry weight) and A_S is the activity concentration in the soil (in Bq/kg and Bq/l dry weight).

It is the ratio of the radionuclide concentration absorbed in a specified solid phase to the radionuclide concentration in a specified liquid phase (Hilton , J; Comans, R.N.J, 2001). The K_d assumes that the radionuclide in the solid phase is in equilibrium with the radionuclide in solution and that exchange between both phases is reversible but does not explicitly take into account the absorption mechanism. Using Equation 5 the sediment-to-plant (potato) transfer coefficient of radionuclides (K-40, U-238, and Th-232) were determined and are presented in Table 8.

4 Results and Discussion

Numerous analyses have been carried out using the concentration measurement and com- putation of the radioactivity intensity, absorbed gamma dose rate, determination of excess lifetime cancer risk external radiation hazard index, and transfer factor. The amounts were determined, and the findings are shown in the tables. A total of 500 sediment and plant (potato) samples were analyzed. The measured activity concentrations of radionuclides across hydrocarbon communities in Ondo State are summarized in Tables 1 and 2. The con-

centrations of ^{238}U,^{232}Th, and ^{40}K in ranged from 2669.68±36.28 to 315.65±13.35 Bq/kg, 82.34±2.04 to 11.51±0.42 Bq/kg, and 186.2±9.38 to 14.88±2.14 Bq/kg respectively. The cor- responding average value were 1597.24±27.41, 49.67±1.55 and 99.79±5.37 Bq/Kg. In Plant (Potato) sample, the radionuclide concentration ranged from 1137.72±14.96 to 126.26±5.34 Bq/Kg, 68.78±1.04 to 7.44±1.07 Bq/Kg and 93.1±4.69 to 3.24±0.28 Bq/Kg. The obtained radionuclide activity concentration in the sediment exceeded the recommended safety level set by the United s Scientific Committee Effect of Atomic Radiation at 400, 35 and 30. This suggests that the sediments in the sampled areas may pose radiological health risks to the population. However, the activity concentration of radionuclides in plant samples for ^{238}U in the Omuro, Malu, Eko, Minna, Bella, Opuama and Isekelwe oil fields was below the global permissible limit for food safety. The ^{232}Th values at Omuro, Malu, Minna, Bella, Opuama and Isekelwe oil fields were below the permissible limit. It was observed that ^{40}K had a

higher activity concentration in sediment than ^{238}U and ^{232}Th,, which may be due to its abundance in the environment. The highest external radiation hazard index in the sediment was registered in Opolo, while Ogogoro registered the highest absorbed gamma dose rate in the sediment. For plants (potato), the highest external radiation index was recorded in Esan and Ojumole recorded the highest absorbed gamma dose rate, which might be attributed to the area's exposure to oil spillage. The radiological parameters for sediment in these communities were found lower Omuro, Malu, Bella also for plants these communities were found lower Omuro, Bella, Malu and Opuama.

Radiological Parameters

The calculated absorbed gamma dose rate D(nGy/h) in the sediment and plant along with the external radiation hazard index (Hex) are presented in Tables 3 and 4. The ab- sorbed gamma dose rate in sediment ranged from 265.98±8.95 to 42.91±3.09 nGy/h with
Opolo registering the highest dose rate. For Plant, dose rates ranged from 141.56±2.99 to 22.32±1.35 nGy/h with Opolo registering the highest dose rate again, meanwhile, the
highest value below acceptance safety limit of 500 (nGy/h).

The Hex values for the sediment samples were below the recommended safety limit of 1 except for the Araromi Sea Side, Ogogoro, Esan, Ojumole and Opolo. This indicates that these affected communities with prolonged consumption of plants in those areas could increase the risk of radiation exposure to the population. In the Plant samples, the Hex values for all communities were below the global acceptable safety limit, suggesting that there is little or no health risk from potato consumption in these areas.

Excess Lifetime Cancer Risk (ELCR)

The ELCR values calculated for the sediment and plant samples (Table 5) showed that the risk of developing cancer over a lifetime due to radionuclides was higher than the world average in many communities. The highest ECLR values were observed at Opolo, Esan, Ojumole, Ogogoro and Araromi Sea Side with values of 7.8, 7.7, 7.1, 6.7 respectively and
6.7 4.2, 4.2, 3.8, 3.5, and 3.4 for Potato, highlighting the significant health risks posed by radionuclide communities in these areas. The elevated ECLR values indicate long-term ex- posure to radionuclides in both sediments. Both sediment and plant can potentially increase the incidence of cancer in these communities.

Transfer Coefficient

The K_d assumes that the radionuclides in the solid phase are in equilibrium with the radionuclide in solution and the exchange between both phases is reversible but does not explicitly take into account the absorption mechanism. Using Equation 5, the sediment-to- plant (potato) transfer coefficient of radionuclides (K-40, U-238 and Th-232) were determined are presented in Table 8. The average transfer coefficient obtained in the research was 0.39±0.39, 0.78±1.73, 0.40±0.20 for K-40, U-238 and Th-232 respectively. The value of K_d
for K-40 across communities was the same at 0.4±0.40 expect Opuama that was 0.18±0.3 while for U-238. Minima recorded the highest value of 1.02 ±1.97 also Opolo recorded 0.5±0.5 for Th-232, and Opuama the least value of 0.19±0.29 for U-238 and 0.12±024 for
Th-232.

5 Discussion

The findings of this study indicate that the environment is threatened by pollution created by several oil- and gas- related installations, including flow stations, oil well heads, loading terminals and tank farms. The detected levels of U-238, Th-232 and K-40 in the sediment samples were significantly higher than the global average, especially in locations close to oil exploration sites. These elevated concentrations pose a radiological health hazard to the local population, a means of living and other daily uses.

Meanwhile, Plant samples indicated lower concentrations of radionuclides compared to sediment, and the calculated Hex, D (nGy/h) and ELCR values for several communities sug- gest potential long-term health risks for consuming contaminated plants (potatoes). Com- munities such as the Araomi Sea Side, Ogogoro, Ojumole, Eko, Parabe, Obe, Esan, and Opolo appear to be particularly vulnerable because their proximity to oil exploration sites. This research underscores the importance of ongoing environmental monitoring and the implementation of remediation measures in hydrocarbon communities. Contaminated sedi- ment sources pose a significant threat to public health in contrast to the sustainable Devel- opment Goals (SDG) 2 and3, which aim to achieve food security and promote sustainable agriculture, they emphasizes improving access to nutritious food and ensuring a sustainable food production system. Moreover, access to nutritious food from sustainable agriculture is crucial for improving health and well-being, particularly for vulnerable population. Address-

ing this issue is essential to protect both human and terrestrial ecosystems in the region.

6 Conclusion

The research assessed The concentration of U-238, Th-232, and K-40 radionuclides in sed- iment and plant (potato)samples were collected from hydrocarbon communities in Ondo State, Nigeria. The analysis carried out using gamma spectrometry, revealed that the ac- tivity concentrations of these radionuclides in sediment samples significantly exceeded the recommended safety limits set by international bodies such as the United Nation Scientific Committee on Effe ct of Atomic Radiation (UNSCEAR). Although the radionuclide concen- tration in plant samples was grossly below the global permissible limit certain communities showed elevated levels that could still pose long-term health risks.

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Table 1: Activity concentration of sediment

LOCATION	K-40	U-238	Th-232
Araromi Sea Side (Offshore)	2605.05 ± 37.45	73.1 ± 1.98	146.48 ± 7.04
Ogogoro	2437 ± 39.13	79.69 ± 2.24	159.3 ± 7.92
Omuro	376.58 ± 14.60	21.9 ± 0.93	41.5 ± 3.84
Ojumole	2669.68 ± 36.23	82.34 ± 2.04	164.52 ± 7.12
Malu	315.65 ± 13.35	20.025 ± 0.87	164.52 ± 7.12
Eko	945.75 ± 21.58	39.36 ± 1.40	79.7 ± 4.96
Parabe	1547.5 ± 27.60	46.4 ± 1.53	93.6 ± 5.38
Minna	573.45 ± 16.80	25.72 ± 1.01	51.44 ± 3.98
Bella	1214.13 ± 7.68	11.51 ± 0.42	14.88 ± 2.14
Obe	1794.15 ± 29.70	44.55 ± 1.38	77.38 ± 4.88
Esan	2844.3 ± 37.40	92.1 ± 2.16	184.72 ± 7.04
Ewa	1570.83 ± 36.98	55.46 ± 2.00	108.36 ± 7.70
Opolo	2795.58 ± 45.93	82.89 ± 2.64	186.2 ± 9.38
Opuama	1489.3 ± 27.08	40.61 ± 1.53	99.64 ± 5.54
Isekelwu Oil fields	779.58 ± 19.58	29.3625 ± 1.14	55.86 ± 4.16

Table 2: Activity concentration of potato

LOCATION	K-40	U-238	Th-232
Araromi Sea Side (offshore)	1042.02±14.98	56.24±3.52	64.94±1.32
Ogogoro	974.83± 15.63	58.6± 3.96	71.56± 1.49
Omuro	150.63±5.84	20.75±1.92	13.91±0.62
Ojumole	1067.87±14.49	54.26±3.56	75.96±1.36
Malu	126.26±5.34	16.66±1.72	11.78±0.58
Eko	378.3 ±8.63	32.85±2.48	35.08±0.93
Parabe	619.00±11.04	41.8±2.69	43.03±1.02
Minna	229.38±6.72	25.2±1.99	22.01±0.73
Bella	485.65±5.84	7.44±1.07	3.24±0.28
Obe	717.66±11.88	38.69±2.44	34.7±0.92
Esan	1137.72±14.96	56.36±3.77	84.69±1.44
Ewa	628.33 ±14.79	54.18±3.85	41.19±1.33
Opolo	1118.23±18.37	68.78±1.04	93.1±4.69
Opuama	264.79±7.22	7.76 ±0.44	12.17±1.37
Isekelwu Oil fields	311.83±7.83	27.93±2.08	23.95±0.76

Table 3: Radiological parameters of sediment

LOCATION	H_{ex}	$D(nGy/h)$	$AEDE(mSv/y)$
Araromi Sea Side (offshore)	1.259±0.044	227.60±6.84	2.792
Ogogoro	1.280±0.045	229.42±7.57	2.814
Omuro	0.298±0.007	51.43±3.42	0.631
Ojumole	1.337±0.041	240.86±6.86	2.943
Malu	0.248±0.019	42.91±3.09	0.526
Eko	0.592±0.028	104.25±4.62	1.278
Parabe	0.795±0.031	142.75±5.19	1.751
Minna	0.386±0.022	67.53±3.64	0.828
Bella	0.341±0.011	66.62±1.84	0.817
Obe	0.792±0.029	144.66±3.12	1.774
Esan	1.456±0.041	261.72±6.92	3.210
Ewa	0.895±0.043	158.94±7.24	1.949
Opolo	1.486±0.053	265.98±8.95	3.262
Opuama	0.804±0.031	143.65±5.27	1.762
Isekelwu Oil fields	0.457±0.023	80.96±3.92	0.993

Table 4: Radiological parameters of potato

LOCATION	H_{ex}	$D(nGy/h)$	$AEDE(mSv/y)$
Araromi Sea Side (offshore)	0.665±0.02	116.68±2.97	1.431
Ogogoro	0.694±0.02	120.61±3.29	1.479
Omuro	0.165±0.01	24.0.2±1.92	0.295
Ojumole	0.738±0.02	128.50±2.99	1.576
Malu	0.117±0.01	19.90± 1.31	0.244
Eko	0.322±0.01	39.88±2.01	0.489
Parabe	0,421±0.14	73.40±2.28	0.900
Minna	0.202±0.01	34.58±1.63	0.424
Bella	0.134±0.01	26.17±0.88	0.321
Obe	0.388±0.01	69.11±2.12	0.848
Esan	0.813±0.02	141.26±3.14	1.732
Ewa	0.436±0.02	75.90±3.11	0.931
Opolo	0.503±0.01	141.56±4.16	1.734
Opuama	0.123±0.01	22.32±1.35	0.274
Isekelwu Oil fields	0.238±0.01	41.15±1.74	0.505

Table 5: Excess Lifetime Cancer Risk for Water and Fish

LOCATION	ELCR Sediment	ELCR Potato
Araromi Sea Side (offshore)	6.7×10^{-1}	3.4×10^{-1}
Ogogoro	6.7×10^{-1}	3.5×10^{-1}
Omuro	1.51×10^{-1}	0.7×10^{-1}
Ojumole	7.1×10^{-1}	3.8×10^{-1}
Malu	1.3×10^{-1}	0.6×10^{-1}
Eko	3.1×10^{-1}	1.2×10^{-1}
Parabe	4.2×10^{-1}	2.2×10^{-1}
Minna	2.0×10^{-1}	1.0×10^{-1}
Bella	2.0×10^{-1}	0.8×10^{-1}
Obe	4.2×10^{-1}	2.0×10^{-1}
Esan	7.7×10^{-1}	4.2×10^{-1}
Ewa	4.7×10^{-1}	2.2×10^{-1}
Opolo	7.8×10^{-1}	4.2×10^{-1}
Opuama	4.2×10^{-1}	0.7×10^{-1}
Isekelwu Oil fields	2.4×10^{-1}	1.2×10^{-1}

Table 6: World Average and Maximum Acceptable Safety Health Limit of These Radiological Parameters

	Ra_{eq} (Bq/kg)	H_e	H_{in}	ELCR Sediment	ELCR Potato
World Average	89	1	1	59	0.07
Acceptable Safety Limit	370	6	6	1500	1

Table 7: Annual Effective Dose Equivalent of Various Studies

Reference	Year	Area	AEDE
(Ononugbo, et al., 2017)	2017	Port-Harcourt, Nigeria	15.89
(Olalekan and Adebiyi, 2019)	2019	Ile-Ife, Nigeria	33.15± 4.90
(Aishahri, 2016)	2016	Dammam, Saudi Arabia	0.04
(Ghazwa, et al., 2016)	2016	Malaysia	0.073-0.254
(Isola, et al., 2018)	2018	Ogbomoso, Nigeria	12.24±1.62 – 40.40±3.25
(UNSCEAR, 2000)	2000	World average	70

Table 8: Annual Effective Dose Equivalent of Various Studies

LOCATION			
Araromi Sea Side (offshore)	0.4±0.4	0.76±1.78	0.44 ±0.17
Ogogoro	0.4± 0.4	0.74 ±1.77	0.45 ± 0.19
Omuro	0.4±0.4	0.95± 2.06	0.34 ± 0.16
Ojumole	0.4±0.4	0.66± 1.75	0.46± 0.19
Malu	0.4 ±0.4	0.83±1.98	0.35 ±0.17
Eko	0.4±0.4	0.83±1.77	0.44±0.19
Parabe	0.4±0.4	0.90±1.76	0.46±0.19
Minna	0.4±0.4	1.02±1.97	0.43±0.18
Bella	0.4±0.4	0.65±2.55	0.22±0.13
Obe	0.4±0.4	0.87±1.77	0.45±0.19
Esan	0.4±0.4	0.61±1.76	0.48±0.20
Ewa	0.4±0.4	0.98±1.93	0.38±0.17
Opolo	0.4±0.4	0.83±0.4	0.5±0.5
Opuama	0.18±0.3	0.19±0.29	0.12±0.24
Isekelwu Oil fields	0.4±0.4	0.95±1.82	0.43±0.18