

Assessment of Outdoor Gamma Radiation Levels and Radiological Health Risks in Selected Oil-Producing Communities of Eastern Obolo, Akwa Ibom State, Nigeria

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ABSTRACT

This study evaluated outdoor gamma radiation levels and the associated radiological health risks in selected oil-producing communities within Eastern Obolo Local Government Area, Akwa Ibom State, Nigeria. A cross-sectional field approach was adopted, with in situ measurements carried out across five communities: Okoroete, Iko, Obianga, Okorombokho, and Elepon, using a portable radiation survey meter. The geographical coordinates of all sampling locations were recorded using a handheld Global Positioning System (GPS) device. The measured absorbed dose rates were used to calculate key radiological risk parameters, including annual effective dose equivalent (AEDE), external and internal hazard indices, representative gamma index, and excess lifetime cancer risk (ELCR), based on standard models. The absorbed dose rates ranged from 55.6 to 91.5 nGy/h, with a mean value of 72.2 nGy/h, exceeding the global average of 59 nGy/h reported by UNSCEAR. The AEDE values varied between 0.082 and 0.094 mSv/y, with an average of 0.089 mSv/y, remaining below the recommended public exposure limit of 1.0 mSv/y. The external hazard index (0.38–0.46), internal hazard index (0.45–0.54), and representative gamma index (0.58–0.69) were all below the permissible limit of unity, indicating no immediate radiological risk, the

Citation: Amuka Johnpaul O, Nnadozie Chukwuemeka F, Ekpe John E, Okpoji Awajiroijana U, Ude Ikenna C, Victor Eze, Egop Egop B, Okadigwe Veraline C, Obunadike Joy C, Obi Justina N, Ohaturuonye Sampson O, Onuchukwu Ejikeme E, Anumaka Collins C, Akpan Nsima A and Nwafor Ernest K (2026). Assessment of Outdoor Gamma Radiation Levels and Radiological Health Risks in Selected Oil-Producing Communities of Eastern Obolo, Akwa Ibom State, Nigeria.

Agriculture Archives: an International Journal.

DOI: <https://doi.org/10.51470/AGRI.2026.5.1.39>

Received on: October 17, 2025

Revised on: November 15, 2025

Accepted on: December 20, 2025

Available Online: January 28, 2026

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ELCR values ranged from 2.87×10^{-4} to 3.29×10^{-4} , with most values slightly higher than the global average of 2.9×10^{-4} , suggesting a marginal increase in long-term cancer risk. The findings indicate moderately elevated background radiation levels compared to global averages, although still within internationally accepted safety limits. Continuous environmental monitoring is therefore recommended to ensure long-term radiological safety in oil-producing communities of the Niger Delta.

Keywords: Gamma radiation; radiological risk; absorbed dose; AEDE; ELCR; oil-producing communities; Eastern Obolo; Niger Delta.

1.0 Introduction

Environmental radiation forms an integral part of the Earth's natural environment and primarily arises from cosmic radiation as well as naturally occurring radionuclides found in rocks, soils, water, and the atmosphere [39,40]. Human exposure to ionising radiation from these natural sources is inevitable, although the level of exposure varies depending on geological characteristics, altitude, soil composition, and anthropogenic influences [11,23,43].

Among the various exposure pathways, background gamma radiation represents a significant source of external radiation dose to humans. While these natural radiation levels are generally low, prolonged exposure to elevated concentrations may increase the risk of biological effects such as cancer and genetic mutations [23,39,43]. In recent years, increasing attention has been directed toward environmental radiation, especially in areas impacted by industrial and extractive activities. Oil and gas exploration and production, in particular, have been identified as processes capable of mobilising and concentrating naturally occurring radioactive materials (NORM) within the environment [20,21,41,42]. Radionuclides including uranium, thorium, radium, and potassium are naturally present in subsurface geological formations associated with petroleum reservoirs and may be brought to the surface during drilling, production, refining, and waste disposal operations [20,21,41]. As a result, oil-producing regions may experience elevated background radiation levels beyond normal terrestrial conditions, posing potential radiological risks to both workers and surrounding populations.

The Niger Delta region of Nigeria is one of the world's most significant hydrocarbon-producing areas and has served as the hub of petroleum exploration and production for several decades [6,10,14,19]. The region is characterised by extensive sedimentary formations and intensive oilfield activities, including drilling operations, gas flaring, crude oil transportation, and refining processes [6,10,14]. These activities, along with associated industrial wastes and environmental degradation, may disrupt the natural radiation balance of the environment. Evidence suggests that technologically enhanced naturally occurring radioactive materials can accumulate in oilfield by-products such as produced water, drilling mud, sludge, scale deposits, and contaminated soils [12,13,20,21]. This accumulation raises concerns about possible increases in environmental gamma radiation levels and the long-term health implications for residents of such areas.

Numerous studies across Nigeria have investigated background radiation levels and their associated radiological impacts in different environmental settings. Elevated radiation levels have been reported in the Jos Plateau, largely attributed to its granitic geology and history of tin mining activities [2,15,26,32,35,36]. Similar studies conducted in Ogbomoso, Abuja, Port Harcourt, and other locations have revealed spatial variations in radiation exposure influenced by both geological formations and human activities [3,9,17,24,31]. Within the Niger Delta, Emelue et al. [18] documented increased excess lifetime cancer risk in areas surrounding the Warri Refinery and Petrochemical Company, indicating that oil and gas environments may pose radiological concerns even when annual effective doses remain within recommended public safety limits. These findings highlight the importance of continuous environmental radiation monitoring in regions affected by industrial activities.

Eastern Obolo Local Government Area of Akwa Ibom State is a coastal oil-producing region within the Niger Delta that is exposed to petroleum exploration and related operations. These activities have the potential to alter environmental conditions and influence radiological characteristics of the area. In addition to radiation-related concerns, communities in the Niger Delta are already subjected to multiple environmental challenges, including soot pollution, hydrocarbon contamination, water pollution, and ecological degradation [1,16,27,28,29,30,33].

In such a complex environmental setting, evaluating background gamma radiation provides further insight into potential environmental health risks. Despite its environmental and economic significance, there is limited data on outdoor gamma radiation levels and associated radiological hazard indices in many parts of Eastern Obolo.

The assessment of outdoor gamma radiation is essential for establishing baseline environmental radiation levels and evaluating public exposure through key parameters such as absorbed dose rate, annual effective dose equivalent, and excess lifetime cancer risk [8,23,39,40]. The absorbed dose rate represents the intensity of gamma radiation present in the environment, while the annual effective dose equivalent provides an estimate of cumulative radiation exposure over time. Hazard indices, including the external hazard index, internal hazard index, and representative gamma index, are commonly employed to determine whether radiation levels pose potential health risks [3,8,12]. An excess lifetime cancer risk serves as an important indicator for estimating the probability of cancer development due to prolonged exposure to low-level radiation [18,38]. Therefore, this study aims to evaluate outdoor gamma radiation levels in selected oil-producing communities of Eastern Obolo, Akwa Ibom State, Nigeria, and to assess the associated radiological health risks to the exposed population.

2.0 Materials and Methods

2.1 Study Area

The study carried out in the selected oil-producing communities of Eastern Obolo Local Government Area, Akwa Ibom State, Niger Delta, Nigeria. The communities covered were Okoroete, Iko, Obianga, Okorombokho, and Elepon. Eastern Obolo is a coastal area characterised by sedimentary formations, mangrove vegetation, and intense petroleum exploration and production activities. These activities, together with the natural geological setting of the area, may contribute to variations in environmental background radiation levels.

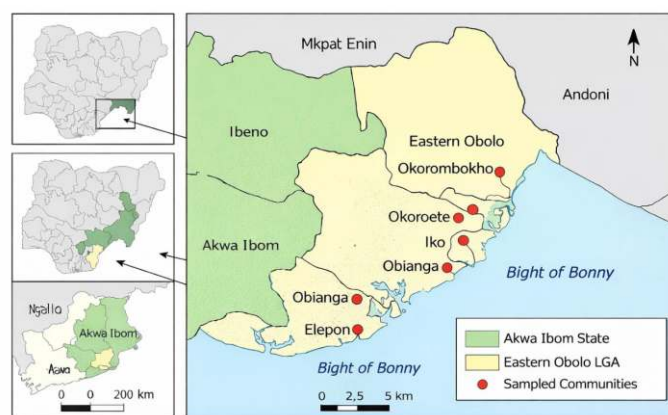


Figure 1: Map of the study area indicating the selected oil-producing communities in Eastern Obolo Local Government Area, Akwa Ibom State, Nigeria.

2.2 Geographical Coordinates of the Study Locations

The geographical coordinates of locations that determined by using handheld Global Positioning System [GPS] receiver. The coordinates were recorded in decimal degrees to ensure accurate identification of the study communities and to aid spatial referencing of the sampling points. The recorded coordinates of the selected communities are presented in Table 2.1.

Table 2.1: GPS Coordinates of Selected Communities in Eastern Obolo, Akwa Ibom State, Nigeria

S/N	Community	Latitude (N)	Longitude (E)
1	Okoroete	4.54077	7.74858
2	Iko	4.53631	7.74710
3	Obianga	4.48068	7.61496
4	Okorombokho	4.53540	7.75301
5	Elepon	4.50887	7.73293

2.3 Research Design

A cross-sectional field survey design was employed for this study. The research involved direct in situ measurements of outdoor gamma radiation levels across the selected communities, followed by the estimation of the annual effective dose equivalent and various radiological hazard indices.

This design was considered suitable because it allowed for the assessment of current environmental radiation conditions across the study area.

2.4 Reconnaissance Survey

A preliminary reconnaissance survey was conducted before the commencement of field measurements. This was done to identify the selected communities, assess accessibility, locate suitable outdoor measurement points, and record the geographical coordinates of the sampling locations. The survey also provided background information on the environmental characteristics and anthropogenic activities within the study area.

2.5 Sampling Procedure

Sampling was carried out in five selected oil-producing communities in Eastern Obolo. In each community, outdoor measurement points were selected to reflect representative environmental conditions. Readings were taken in open spaces away from buildings, walls, trees, metallic structures, and other obstructions that could interfere with radiation measurements. At each point, repeated measurements were obtained and averaged to improve reliability. The resulting data were used to determine the minimum, maximum, mean, and standard deviation of absorbed dose rates for each community.

2.6 Measurement of Outdoor Gamma Radiation

Outdoor gamma radiation dose rates were measured using a portable calibrated radiation survey meter suitable for environmental monitoring. During measurement, the detector was held at approximately 1 m above ground level to simulate the average height of human exposure in the outdoor environment. At each sampling point, the instrument was allowed to stabilise before the readings were recorded. Multiple readings were taken, and the average value was expressed in nanogray per hour (nGy/h). The measured values obtained from the various locations within each community were analyzed to determine descriptive statistics, including the minimum, maximum, mean, and standard deviation.

2.7 Estimation of Annual Effective Dose Equivalent

The annual effective dose equivalent (AEDE) was calculated from the measured absorbed dose rates using the standard conversion model for outdoor exposure. This parameter provides an estimate of the radiation dose received by individuals over a one-year period.

The AEDE was determined using the following equation:

$$AEDE = D \times T \times OF \times CC \times 10^{-6}$$

Where:

AEDE = Annual effective dose equivalent (mSv/y)

D = Absorbed dose rate (nGy/h)

T = Total time in hours per year (8760 h)

OF = Outdoor occupancy factor (0.2)

CC = Conversion coefficient from absorbed dose in air to effective dose (0.7 Sv/Gy)

An outdoor occupancy factor of 0.2 was adopted, based on the assumption that individuals spend approximately 20% of their time outdoors. This factor is commonly used in radiological assessments to estimate realistic exposure conditions.

2.8 Estimation of Radiological Hazard Indices

To evaluate the potential radiological effects of outdoor gamma radiation exposure in the study area, selected hazard indices were determined. These included the external hazard index (H_{ex}), internal hazard index (H_{in}), and representative gamma index ($I_{\gamma r}$). These indices provide a useful framework for assessing both external and internal radiation risks to the exposed population.

The external hazard index (H_{ex}) was used to assess the risk associated with direct external exposure to gamma radiation, while the internal hazard index (H_{in}) was applied to evaluate potential internal exposure risks arising from inhalation of radionuclides and related pathways. In addition, the representative gamma index ($I_{\gamma r}$) served as a screening parameter for determining the overall radiological significance of the measured gamma radiation levels. For all indices, values less than unity (≤ 1) were considered to be within acceptable safety limits, indicating that the radiation exposure does not pose significant health risks to the population.

2.9 Estimation of Excess Lifetime Cancer Risk

The excess lifetime cancer risk (ELCR) was estimated to determine the probability of cancer occurrence over a lifetime due to prolonged exposure to background gamma radiation in the study area. This parameter provides an indication of long-term health effects associated with low-level radiation exposure.

The ELCR was calculated using the following expression:

$$ELCR = AEDE \times DL \times RF$$

Where:

ELCR = Excess lifetime cancer risk

AEDE = Annual effective dose equivalent (mSv/y)

DL = Average duration of life expectancy (70 years)

RF = Risk factor for stochastic effects due to low-dose ionizing radiation (0.05 Sv^{-1})

This model is widely used in radiological assessments to estimate the long-term cancer risk associated with environmental radiation exposure.

2.10 Data Analysis

The data obtained from field measurements were organized and analyzed using descriptive statistical methods. Key statistical parameters, including minimum, maximum, mean, and standard deviation of the absorbed dose rates, were calculated for each community. The mean absorbed dose values were subsequently used to estimate the annual effective dose equivalent, radiological hazard indices, and excess lifetime cancer risk. The computed results were compared with internationally recommended reference values and safety limits

to assess the radiological status of the study area and determine any potential health implications.

2.11 Quality Control and Assurance

To ensure the accuracy and reliability of the radiation measurements, the survey meter used for the study was calibrated before field deployment. Measurements were taken under stable environmental conditions, and repeated readings were obtained at each sampling point to minimise random error. Extra care was also taken to maintain uniform detector height and measurement procedure across all locations.

3.0 Results

Table 3.1 presents the measured outdoor gamma radiation dose rates across selected oil-producing communities in Eastern Obolo, Niger Delta, Nigeria. The absorbed dose rates varied across the study locations, with minimum and maximum values ranging from 55.6 nGy/h in Obianga to 91.5 nGy/h in Okorombokho. Among the communities, Okorombokho recorded the highest mean absorbed dose rate (76.3 ± 8.5 nGy/h), followed by Iko (74.8 ± 8.1 nGy/h), Elepon (72.4 ± 7.8 nGy/h), and Okoroete (70.5 ± 7.4 nGy/h), while Obianga recorded the lowest mean value (67.2 ± 6.9 nGy/h). The mean absorbed dose rate for the study area was 72.2 nGy/h. This value is slightly higher than the world average outdoor terrestrial gamma radiation level of 59 nGy/h reported by UNSCEAR, suggesting a mild elevation in environmental radiation levels within the study area, possibly influenced by local geology and oil exploration activities.

Table 3.1: Measured Outdoor Gamma Radiation Dose Rate in Selected Communities of Eastern Obolo (nGy/h, Mean \pm SD)

Community	Minimum	Maximum	Mean \pm SD	World Average (UNSCEAR)
Okoroete	58.4	82.6	70.5 \pm 7.4	59
Iko	61.2	88.9	74.8 \pm 8.1	59
Obianga	55.6	79.3	67.2 \pm 6.9	59
Okorombokho	63.4	91.5	76.3 \pm 8.5	59
Elepon	59.7	85.1	72.4 \pm 7.8	59

Table 3.2 presents the estimated annual effective dose equivalent (AEDE) calculated from the measured absorbed dose rates. The computed AEDE values ranged from 0.082 mSv/y in Obianga to 0.094 mSv/y in Okorombokho. Similarly, Iko recorded a relatively elevated value of 0.092 mSv/y, while Okoroete and Elepon showed values of 0.086 mSv/y and 0.089 mSv/y, respectively. The overall mean annual effective dose for the study area was approximately 0.089 mSv/y. This average value is slightly higher than the global mean of 0.07 mSv/y, it remains well below the recommended public exposure limit of 1.0 mSv/y. This suggests that the current level of radiation exposure in the study area does not pose a significant risk to public health.

Table 3.2: Absorbed Dose Rate and Annual Effective Dose Equivalent

Community	Absorbed Dose Rate (nGy/h)	Annual Effective Dose (mSv/y)	Recommended Limit (mSv/y)
Okoroete	70.5 \pm 7.4	0.086	1.0
Iko	74.8 \pm 8.1	0.092	1.0
Obianga	67.2 \pm 6.9	0.082	1.0
Okorombokho	76.3 \pm 8.5	0.094	1.0
Elepon	72.4 \pm 7.8	0.089	1.0

Table 3.3 presents the calculated radiological hazard indices for the studied communities, including the external hazard index (Hex), internal hazard index (Hin), and representative gamma index (Iyr). The external hazard index ranged from 0.38 in Obianga to 0.46 in Okorombokho.

Similarly, the internal hazard index varied from 0.45 in Obianga to 0.54 in Okorombokho, while the representative gamma index ranged from 0.58 to 0.69. Okorombokho consistently recorded the highest values for all hazard indices, whereas Obianga recorded the lowest. Importantly, all the calculated values remained below the recommended safety threshold of unity (1.0), indicating that the natural radioactivity levels in these communities are within acceptable limits and are unlikely to pose substantial radiological hazards to inhabitants.

Table 3.3: Calculated Radiological Hazard Indices

Community	External Hazard Index (Hex)	Internal Hazard Index (Hin)	Representative Gamma Index (Iyr)
Okoroete	0.41	0.48	0.62
Iko	0.44	0.52	0.66
Obianga	0.38	0.45	0.58
Okorombokho	0.46	0.54	0.69
Elepon	0.43	0.50	0.64

Table 3.4 shows the excess lifetime cancer risk (ELCR) estimated for residents of the selected communities due to prolonged exposure to background gamma radiation. The ELCR values ranged from 2.87×10^{-4} in Obianga to 3.29×10^{-4} in Okorombokho. Okoroete, Iko, and Elepon recorded ELCR values of 3.01×10^{-4} , 3.22×10^{-4} , and 3.12×10^{-4} , respectively. The observed trend reflects the distribution of annual effective dose values across the communities, with higher dose levels corresponding to higher lifetime cancer risk estimates. Although the ELCR values are generally low, most of the communities recorded values slightly above the world average of 2.9×10^{-4} , suggesting a marginal increase in long-term radiological risk in the study area.

Table 3.4: Excess Lifetime Cancer Risk (ELCR)

Community	Annual Effective Dose (mSv/y)	ELCR
Okoroete	0.086	3.01×10^{-4}
Iko	0.092	3.22×10^{-4}
Obianga	0.082	2.87×10^{-4}
Okorombokho	0.094	3.29×10^{-4}
Elepon	0.089	3.12×10^{-4}

Table 3.5 provides a comparative summary of the measured radiation parameters in the study area against internationally recommended safety standards. The absorbed dose rate ranged from 55.6 to 91.5 nGy/h, with a mean value of 72.2 nGy/h, which is slightly higher than the global average of 59 nGy/h. The annual effective dose equivalent varied between 0.082 and 0.094 mSv/y, with an average of 0.089 mSv/y, also exceeding the global mean value of 0.07 mSv/y. The external hazard index ranged from 0.38 to 0.46, with a mean value of 0.42, remaining well below the recommended safety limit of unity (1.0). Similarly, the excess lifetime cancer risk ranged from 2.87×10^{-4} to 3.29×10^{-4} , with an average value of 3.10×10^{-4} , which is only slightly higher than the global reference value, these results suggest that although radiation levels in the study area are moderately elevated compared to global averages, they remain within internationally acceptable safety limits and do not pose any immediate radiological health risk to the population.

Table 3.5: Comparison of Measured Radiation Levels with International Standards

Parameter	Measured Range	Mean Value	Global Average / Standard
Absorbed Dose Rate (nGy/h)	55.6 – 91.5	72.2	59
Annual Effective Dose (mSv/y)	0.082 – 0.094	0.089	0.07
External Hazard Index	0.38 – 0.46	0.42	< 1
Excess Lifetime Cancer Risk	2.87×10^{-4} – 3.29×10^{-4}	3.10×10^{-4}	2.9×10^{-4}

4.0 Discussion

This study evaluated outdoor gamma radiation levels and corresponding radiological risk parameters in selected oil-producing communities of Eastern Obolo, Akwa Ibom State, Nigeria. The mean absorbed dose rate obtained (72.2 nGy/h) exceeded the global outdoor average value of 59 nGy/h reported by UNSCEAR [39,40], indicating a slight elevation in background radiation within the study area. This increase can be attributed to both natural and anthropogenic factors. In particular, petroleum exploration and production activities are known to mobilise and redistribute naturally occurring radioactive materials (NORM), thereby enhancing environmental radiation levels in oil-producing regions [20,21,41,42]. Additionally, the sedimentary geology of the Niger Delta Basin, which is associated with hydrocarbon deposits, may further influence the observed radiation pattern [6,10,14]. The observed differences in absorbed dose rates among the sampled communities reflect spatial variability in environmental radiation distribution. Okorombokho recorded the highest values, whereas Obianga showed the lowest levels. Such variation may be linked to differences in geological composition, proximity to oil-related operations, and local environmental conditions. Comparable spatial heterogeneity in background radiation has been reported in other parts of Nigeria. For example, Bulus and Abashi [9] documented variations in radiation levels across structures in the Jos-Bukuru area, while Isa et al. [24] reported location-dependent differences in background radiation within the Federal Capital Territory. Similarly, studies conducted in the Jos Plateau region have emphasised the strong influence of geological formations on radiation variability [2,26,35,36]. Although the absorbed dose rate in this study was higher than the global average, the estimated annual effective dose equivalent (AEDE) ranged from 0.082 to 0.094 mSv/y, with a mean of 0.089 mSv/y. These values remain well below the recommended public exposure limit of 1.0 mSv/y set by the International Commission on Radiological Protection [23]. This suggests that current outdoor radiation exposure in the study area does not pose an immediate health risk to the population. Similar findings have been reported in previous Nigerian studies, where elevated absorbed dose rates did not translate into excessive annual effective doses [9,12,24,25,31,37,38]. This indicates that slightly elevated environmental radiation levels may still fall within safe exposure thresholds when evaluated in terms of annual dose. The calculated radiological hazard indices—including the external hazard index (Hex), internal hazard index (Hin), and representative gamma index (I_{γr})—were all below the critical value of unity across the study area. This confirms that the radiation levels are within acceptable safety limits. The Hex values suggest minimal risk from external gamma exposure, while the Hin values indicate a low likelihood of internal exposure hazards under existing environmental conditions. The I_{γr} values further support the conclusion that the study area is radiologically safe. These findings are consistent with earlier studies in Nigeria, where hazard indices below unity have been interpreted as indicative of acceptable radiological conditions [3,8,12,37,38]. The application of these indices as screening tools for environmental radiation assessment has been widely validated [8]. The generally low hazard indices and acceptable AEDE values, the estimated excess lifetime cancer risk (ELCR) ranged from 2.87×10^{-4} to 3.29×10^{-4} , with most values slightly exceeding the global average of 2.9×10^{-4} [39,40].

This suggests that although immediate exposure risks are minimal, prolonged exposure to low-level radiation may contribute marginally to long-term stochastic health effects such as cancer. This observation aligns with findings by Emelue et al. [18], who reported elevated ELCR values in areas surrounding the Warri Refinery and Petrochemical Company. Similar trends have also been observed in other Nigerian studies where AEDE values were within permissible limits but ELCR values were slightly elevated [12,24,37]. These results emphasise the importance of considering long-term risk indicators alongside direct dose measurements in environmental radiation assessments.

The relatively higher radiation levels recorded in communities such as Okorombokho and Iko may be associated with more intense oil exploration activities and environmental disturbances. Industrial processes are known to contribute to environmental radioactivity through the concentration and redistribution of radionuclides in soils and aquatic systems [7,21]. In oil-producing environments, materials such as produced water, drilling mud, scale deposits, and sludge can serve as sources of localised radiation enhancement [5,20,21,41,42]. This explanation is particularly relevant for Eastern Obolo, given its location within the oil-rich Niger Delta.

The results indicate that outdoor gamma radiation levels in the study area are moderately elevated compared to global averages but remain within internationally accepted safety limits when assessed using AEDE and hazard indices, the slightly elevated ELCR values highlight the need for continued environmental monitoring, particularly in areas with higher dose rates. Sustained surveillance is essential in oil-producing regions, where cumulative environmental impacts from petroleum activities may gradually increase radiation levels over time [18,20,21,41]. Furthermore, the World Health Organization has noted that prolonged exposure to even low levels of ionising radiation may have health implications depending on duration and cumulative exposure [43].

The findings of this study are consistent with previous radiological assessments conducted in Nigeria, especially in industrially impacted and environmentally sensitive areas [9,18,24,25,31,35,37,38]. This study therefore provides important baseline data for Eastern Obolo and underscores the need for regular radiological monitoring in oil-producing communities of the Niger Delta to safeguard public health and inform environmental management strategies.

Conclusion

The results of this study indicate that outdoor gamma radiation levels in the investigated oil-producing communities of Eastern Obolo are slightly higher than the global average reported by UNSCEAR. Among the sampled locations, Okorombokho exhibited the highest absorbed dose rate and associated radiological indices, whereas Obianga recorded the lowest values. Despite this elevation, the estimated annual effective dose equivalent for all communities remained significantly below the recommended public exposure limit of 1.0 mSv/y. The calculated external hazard index, internal hazard index, and representative gamma index were all below unity, indicating that the current radiological conditions are within acceptable safety limits, the excess lifetime cancer risk values obtained were marginally higher than the global average in most communities, suggesting that prolonged exposure to low-level radiation may contribute slightly to long-term health risks. Although the present radiation levels do not pose an immediate

threat, the influence of ongoing petroleum exploration and environmental disturbances necessitates continuous monitoring. This study provides valuable baseline radiological data for Eastern Obolo and highlights the importance of periodic environmental radiation assessment in oil-producing regions. It is recommended that routine monitoring programmes be implemented, alongside detailed investigations of radionuclide concentrations in environmental media such as soil, water, and sediments, to ensure comprehensive evaluation of radiological risks and protection of public health.

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