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Evaluation of Radiological Health Risks and Seasonal Variations in Gamma Radiation Exposure at Dumpsites in Cross River State, Nigeria

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Abstract
This study evaluated gamma radiation levels and associated radiological health risks at municipal dumpsites in Cross River State, Nigeria, during the wet and dry seasons. In-situ exposure measurements were taken using a RADEX RD1212-BT Geiger counter, GPS device, measuring tape, and field notebooks. Four dumpsites were assessed, with twenty sampling points at each site. Exposure rates were converted to absorbed dose rate, annual effective dose equivalent (AEDE), effective dose, and excess lifetime cancer risk (ELCR) using standard conversion factors. Mean absorbed dose rates were 56 ± 5.02 nGy/h in the dry season and 41 ± 1.80 nGy/h in the wet season, both within UNSCEAR's global outdoor background range of 20–59 nGy/h. AEDE values ranged from 0.05 to 0.08 mSv/y, though some effective dose values exceeded the ICRP public exposure limit of 1.0 mSv/y. ELCR values in both seasons were above the internationally accepted safety threshold, indicating a potentially elevated long-term cancer risk for individuals living or working near these dumpsites. Overall, radiation levels were within international limits, suggesting no immediate radiological hazard. Nonetheless, improved waste management, routine radiation monitoring, community sensitization, and possible site remediation are recommended to reduce long-term risks.

Keywords: *Gamma radiation, dumpsite, absorbed dose, AEDE, ELCR, dry and wet season.*

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I. Introduction

Background of Study

Public health is becoming more concerned about ionizing radiation pollution of the environment from both natural and man-made sources, especially in developing nations with loosely regulated waste management systems. Gamma radiation from naturally occurring radionuclides, including ^{238}U, ^{232}Th, and ^{40}K, can expose people living close to waste disposal sites both internally and externally (Onwuamaoke, Agomuo, & Ige, 2021). Due to the movement of radionuclides into the soil, water, and atmosphere, open dumpsites, which are common throughout Nigeria, may serve as secondary sources of environmental radiation.

In developing countries like Nigeria, where open dumpsites are prevalent in urban and peri-urban regions, solid waste management continues to be a significant environmental concern. Domestic, industrial, and biological waste that may contain materials enriched with naturally occurring radioactive materials (NORMs) is frequently disposed of at these locations as a last resort. These wastes have the potential to increase ambient background radiation levels, which could endanger the radiological health of waste handlers and adjacent residents (Agbalagba, Avwiri, & Ononugbo, 2013).

According to Avwiri and Ononugbo (2012) (Avwiri & Ononugbo, 2012), anthropogenic activities, including waste disposal and leachate migration, can mobilize naturally occurring radionuclides like uranium-238 (^{238}U), thorium-232 (^{232}Th), and potassium-40 (^{40}K), which are found in soils and rocks. Via processes including leaching, runoff, and soil erosion, seasonal variations, especially between the dry and rainy seasons, might affect the movement, concentration, and distribution of these radionuclides (Itota & Balogun, 2017). Therefore, it is essential to evaluate the seasonal fluctuations in radiation exposure levels at disposal sites in order to comprehend the temporal dynamics of environmental radiological hazards.

Increasing the risk of genetic alterations and cancer are among the possible health consequences of extended exposure to ionizing radiation, contingent on the dose and duration of exposure (ICRP, 1990; UNSCEAR, 2000a). According to earlier research conducted in Nigeria and other African countries, radiation dosage rates in dumpsite soils can occasionally surpass worldwide averages (Agbalagba, Avwiri, & Ononugbo, 2013). Even though the Cross River region is becoming more urbanized and producing more garbage, little is known about seasonal radiological fluctuations and risk assessment.

Additionally, ionizing radiation may be produced by commercial, industrial, or medical operations. Medical X-rays are the most well-known and, across the country, the most significant source of exposure. Natural radiation accounts for over 88% of the population's yearly dosage, with medical procedures accounting for the majority of the remaining 12%, according to recent studies. The majority of artificial radiation and natural radiation are identical in type and impact (UNSCEAR, 2008).

Therefore, this study intends to investigate the associated radiological health concerns at specific dumpsites in Cross River State, Nigeria, as well as the seasonal fluctuations in gamma radiation exposure levels. It is anticipated that the results will yield important information for environmental monitoring, radiation safety policy, and public health management in waste-impacted areas.

II. Materials And Methods

Study Area

The study was conducted at selected dumpsites in Cross River State, Nigeria, located between latitudes 5°30′–6°30′N and longitudes 8°00′–8°45′E. The area experiences two distinct seasons: a dry season from November to March and a wet (rainy) season from April to October in the region's tropical climate. Calabar, Ikom, and Ogoja, which represent the southern, central, and northern regions of the state, respectively, were among the key towns from which dumpsites were chosen.

Radiological Parameters.

Standard equations were used to calculate the excess lifetime cancer risk (ELCR), annual effective dose equivalent (AEDE), and absorbed dose rate (D) (UNSCEAR, effects and Risks of Ionizing Radiation. New York, United Nations, 2008).

Rate of Absorbed Dose (D) (nGy/h):

$$D = 0.0417\, C_K + 0.604\, C_U + 0.604\, C_{Th} \quad (1)$$

where C_K, C_{Th} and C_U are the activity concentrations of ^{40}K, ^{232}Th and ^{238}U.

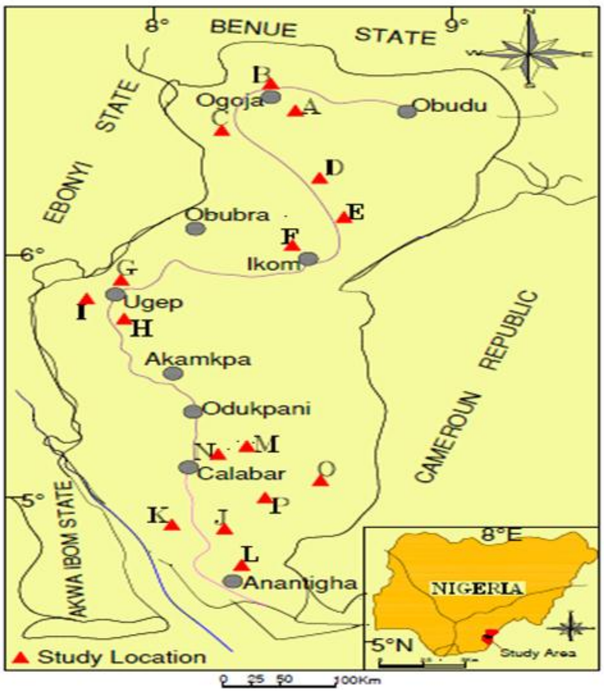

Fig 1: Map of study areas showing data points

Annual Effective Dose Equivalent (AEDE) (µSv/y):

$A E D E = D \times 8760 \times 0.7 \times 0.2 \times 10^{-3}$ (2)

Excess Lifetime Cancer Risk (ELCR):
ELCR=AEDE×DL×RF (3)
where RF is the risk factor (0.05 Sv□¹) and DL is the lifespan or duration of life (70 years).

Materials Used

Materials include a measuring tape, RADEX RD1212-BT (Geiger radiation meter with Bluetooth), a geographical positioning system (GPS), and writing materials.

III. Results And Discussion

Results Presentation

The comprehensive findings on background ionizing radiation for locations A–N, measured during dry and wet seasons, are presented in this chapter. The radiation safe parameters were measured as follows: Exposure Rate (μR/h); the airborne radiation level, dose rate (μSv/h & nGy/h); the rate at which radiation energy is absorbed by tissues (μSv/h) or the atmosphere (nGy/h). The projected total radiation dose that an individual will get in a year is known as the Annual Effective Dose Equivalent (AEDE, mSv/y). Excess Lifetime Cancer Risk (ELCR): The higher lifetime risk of cancer as a result of radiation exposure. The computed dose, known as the "effective dose" (mSv), represents the total danger associated with uneven radiation exposure to various body regions, by comparing them to global averages and previous studies [6]. The location codes are **A** for Ogoja dumpsite, **C** for Ogoja control area, **D** for Ikom dumpsite, **F** for Ikom control area, **J** for Udeme dumpsite, **K** for Udeme control area, **M** for Lemna dumpsite, and **N** for Lemna control area for both dry and wet seasons. The results are presented in tables and graphs as seen below.

Table 1 Mean exposure rate and estimated hazard indices at location A (Ogoja dumpsite), dry season.

Parameter	Mean ± SD
Exposure Rate (μR/h)	5.61 ± 0.50
Dose Rate (μSv/h)	0.06 ± 0.005
Absorbed dose rate	56±5.02
AEDE (mSv/y)	0.07 ± 0.006
ELCR	0.24 ± 0.0022
Effective Dose (mSv/y)	1.5 ± 1.01

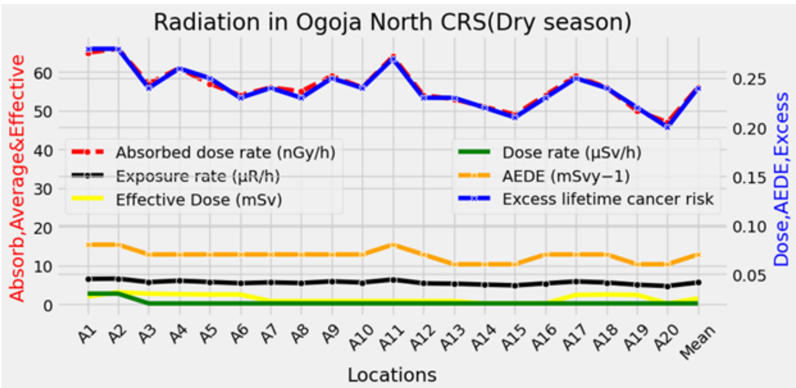

Figure 2: Measured exposure rate and estimated radiological indices at Ogoja dumpsite, during the dry season.

Radiological measurements at Location A demonstrate clear seasonal variation, with consistently higher readings in the dry season. While wet season values fall within or below global benchmarks, dry season levels, though elevated, remain near average for high-background regions. This observed variation is consistent with established UNSCEAR (2000) (UNSCEAR, 2000b) principles, which cite soil moisture, dilution, and atmospheric conditions as key factors reducing gamma exposure during the wet season.

Table 2: Mean exposure rate and estimated hazard indices dry season at Location C (Control area, Ogoja).

Parameters	Mean ± SD
Exposure Rate (μR/h)	4.61 ± 0.55
Dose Rate (μSv/h)	0.05 ± 0.005
Absorbed Dose Rate (nGy/h)	46 ± 5
AEDE (mSv/y)	0.06 ± 0.007
Excess Lifetime Cancer Risk (ELCR)	0.20 ± 0.0024

Effective Dose (mSv/y)	1.2 ± 0.1

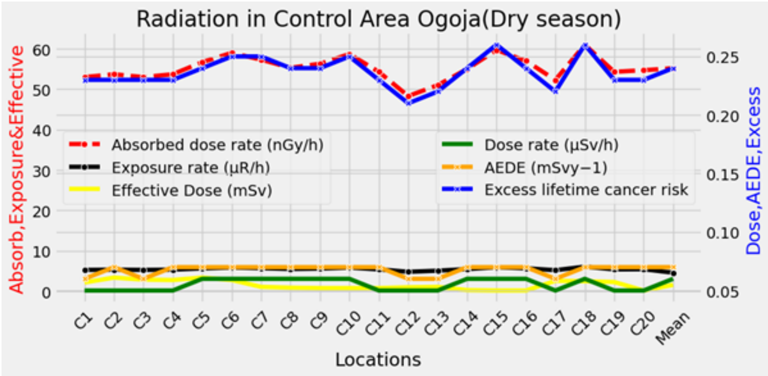

Figure 3. Graph of exposure rate and estimated hazard indices at the control area, location C, Ogoja.

Radiological measurements at the control area (Location C) during the dry season were consistently lower than those at the dumpsite (Location A). Key parameters included a mean exposure rate of 4.61 ± 0.55 µR/h and an annual effective dose of 1.2 ± 0.1 mSv/y, confirming a relatively lower radiological hazard at the control location.

Table 3: Wet seasons mean value for Ogoja dumpsite location A

Parameters	Mean value
Exposure Rate (µR/h)	4.09 µR/h
Dose Rate (µSv/h)	0.04 µSv/h
Absorbed Dose Rate (nGy/h)	40.9 nGy/h
AEDE (mSv/y)	0.05 mSv/y
Excess Lifetime Cancer Risk (ELCR)	0.17
Effective Dose (mSv/y)	1.6 mSv

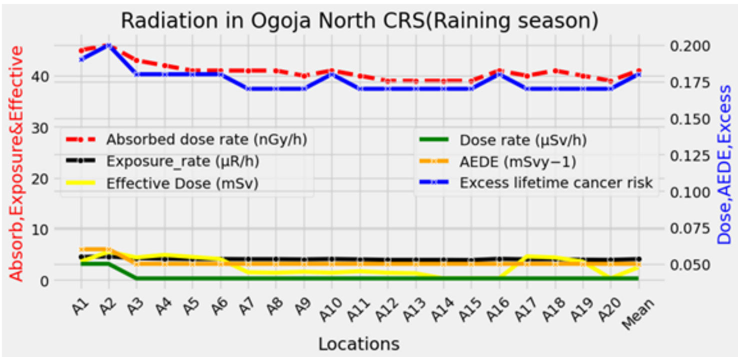

Figure 4: Wet season exposure rate and calculated hazard indices at location A, Ogoja.

Figure 4 illustrates the wet-season ionizing radiation background at the Ogoja dumpsite based on measurements from twenty sampling points (A1–A20). The exposure rate and corresponding annual effective dose equivalent (AEDE) provide insight into radiological safety during periods of high soil moisture.

Table 4: Wet season location B, control site means value.

Parameters	Mean ± SD
Exposure Rate (µR/h)	3.79 ± 0.16
Dose Rate (µSv/h)	0.04 ± 0.002
Absorbed Dose Rate (nGy/h)	38 ± 1.62
AEDE (mSv/y)	0.05 ± 0.002
Excess Lifetime Cancer Risk (ELCR)	0.16 ± 0.007
Effective Dose (mSv/y)	1.7 ± 0.17

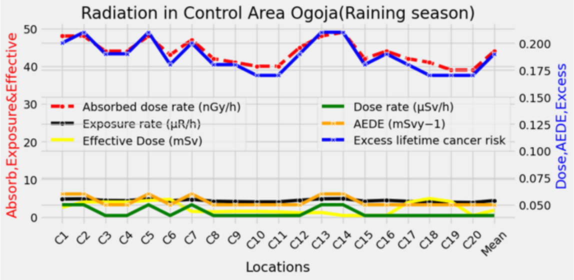

Figure 5. Wet season control area at location C, Ogoja

During the wet season, radiological levels at the control area (Location C) were slightly lower than during the dry season, with a mean exposure rate of 3.79 ± 0.16 μR/h. This seasonal decrease, reflected across all measured parameters including the Annual Effective Dose (1.7 ± 0.17 mSv/y), is consistent with the known effect of rainfall in attenuating gamma radiation.

Table 5: Presents a comparison of radiological parameters from location A at the Ogoja dumpsite, showing measurements taken during both the dry and wet seasons.

Parameter	**Dry Season Mean**	**Wet Season Mean**
Exposure Rate (μR/h)	5.61 ± 0.50	4.09 ± 0.18
Dose Rate (μSv/h)	0.06 ± 0.005	0.04 ± 0.002
Absorbed dose rate (nGy/h)	56±5.02	41 ± 1.8
AEDE (mSv/y)	0.07 ± 0.006	0.05 ± 0.002
ELCR	0.24 ± 0.0022	0.18 ± 0.008
Effective Dose (mSv/y)	1.5 ± 1.01	2.5 ± 0.23

Table 6**:** Radiological data for location D in Ikom during the dry season.

Parameters	**Mean ± SD**
Exposure Rate (μR/h)	4.84 ± 0.51
Dose Rate (μSv/h)	0.05 ± 0.005
Absorbed Dose Rate (nGy/h)	48 ± 5.11
AEDE (mSv/y)	0.06 ± 0.006
Excess Lifetime Cancer Risk (ELCR)	0.21 ± 0.022
Effective Dose (mSv/y)	1.7 ± 0.14

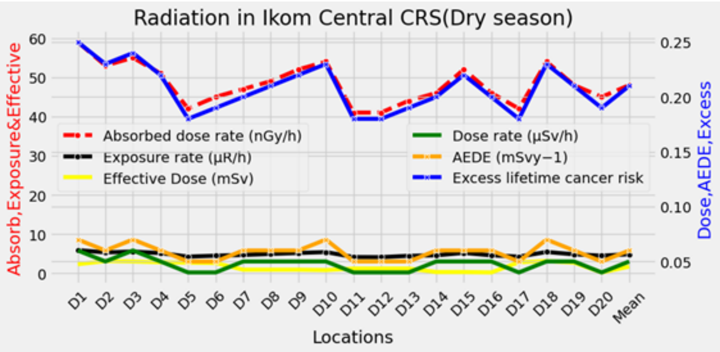

Figure 6: Radiological data for location D in Ikom during the dry season.

Figure 6 shows dry season measurements at the Ikom dumpsite (Location D) confirmed elevated radiological levels, with a mean exposure rate of 4.84 ± 0.51 μR/h. All calculated risk parameters, including an effective dose of up to 1.5 mSv/y, were consistently higher than those recorded at the control site (Location F), underscoring the site's elevated radiological signature.

Table 7**:** Dry season radiological data from the control site (Location F, Ikom).

Parameters	**Mean ± SD**
Exposure Rate (μR/h)	4.77 ± 0.46
Dose Rate (μSv/h)	0.05 ± 0.005
Absorbed Dose Rate (nGy/h)	46 ± 4.65
AEDE (mSv/y)	0.06 ± 0.006
Excess Lifetime Cancer Risk (ELCR)	0.20 ± 0.020
Effective Dose (mSv/y)	1.5 ± 0.16

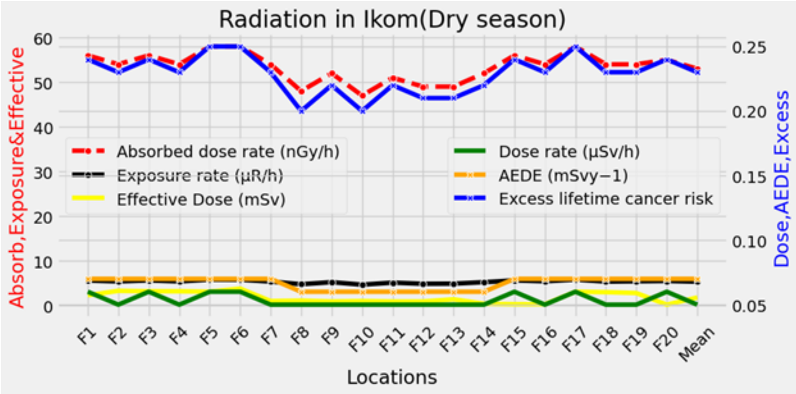

Figure 7: Dry season control site at Ikom.

Table 8: Shows the wet season data for location D in Ikom.

Parameters	Mean ± SD
Exposure Rate (µR/h)	4.63 ± 0.36
Dose Rate (µSv/h)	0.05 ± 0.005
Absorbed Dose Rate (nGy/h)	48 ± 5.11
AEDE (mSv/y)	0.06 ± 0.004
Excess Lifetime Cancer Risk (ELCR)	0.21 ± 0.022
Effective Dose (mSv/y)	1.3 ± 0.18

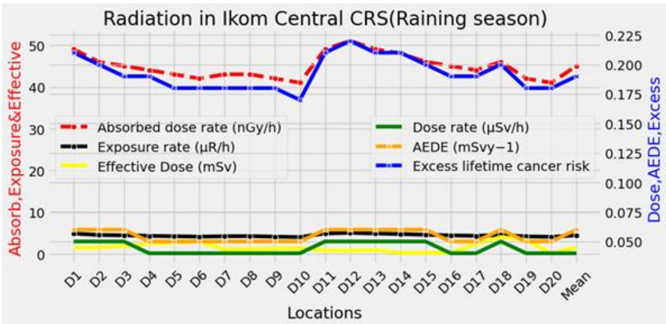

Figure 8: Wet season radiological data at Ikom dumpsite, location D.

Figure 8 shows the wet season, radiological levels at the Ikom dumpsite (Location D) were moderately lower than during the dry season, with a mean exposure rate of 4.49 ± 0.30 µR/h. This seasonal decrease, consistent with the attenuating effect of rainfall, was observed across all parameters, including the effective dose, which ranged from 0.2 to 1.5 mSv/y.

Table 9: Shows the wet season data for the location F control site in Ikom.

Parameters	Mean ± SD
Exposure Rate (µR/h)	4.49 ± 0.30
Dose Rate (µSv/h)	0.04 ± 0.003
Absorbed Dose Rate (nGy/h)	45 ± 3.03
AEDE (mSv/y)	0.06 ± 0.004
Excess Lifetime Cancer Risk (ELCR)	0.19 ± 0.013
Effective Dose (mSv/y)	1.6 ± 0.29

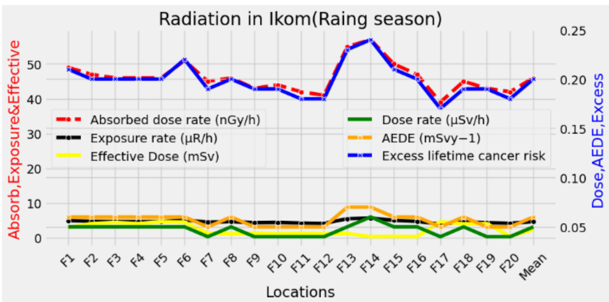

Figure 9. Wet season control site at location F, Ikom.

The Ikom control area (Location F) demonstrated consistent radiological levels across seasons. Wet season measurements, including a mean exposure rate of 4.63 ± 0.36 μR/h, were found to be comparable to dry season data. This stability across all risk parameters confirms the characteristic steadiness of background radiation at this uncontaminated site.

Table 10: Presents a comparative analysis of the radiological parameters measured at location D in Ikom, highlighting the differences between the dry and wet seasons.

Parameters	Dry season	Wet season
Exposure Rate (μR/h)	4.63 ± 0.36	4.49 ± 0.30
Dose Rate (μSv/h)	0.05 ± 0.005	0.04 ± 0.003
Absorbed Dose Rate (nGy/h)	48 ± 5.11	45 ± 3.03
AEDE (mSv/y)	0.06 ± 0.006	0.06 ± 0.004
ELCR	0.21 ± 0.022	0.19 ± 0.013
Effective Dose (mSv/y)	1.8 ± 0.18	1.6 ± 0.29

Table 11: Shows the dry season data for location J at the Udeme Avenue dumpsite.

Parameters	Mean ± SD
Exposure Rate (μR/h)	5.31 ± 0.31
Dose Rate (μSv/h)	0.05 ± 0.003
Absorbed Dose Rate (nGy/h)	53 ± 3.09
AEDE (mSv/y)	0.07 ± 0.004
Excess Lifetime Cancer Risk (ELCR)	0.23 ± 0.013
Effective Dose (mSv/y)	1.4 ± 0.07

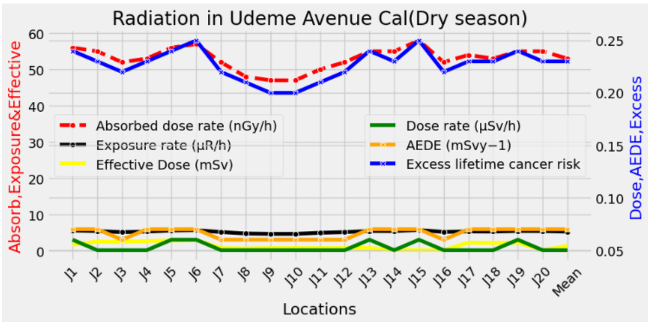

Figure 10: Dry season plot of radiological indices at Udeme Avenue, location J.

Figure 10 shows the dry season measurements at Location J (Udeme Avenue dumpsite). It shows characteristically elevated radiation levels, consistent with reduced environmental attenuation. The consequent rise in AEDE and ELCR reflects a localized increase in gamma radiation. Furthermore, the significant range in the effective dose (0.2–1.8 mSv/y) underscores spatial heterogeneity and identifies specific areas with concentrated activity, or hotspots. According to research on municipal solid waste sites (UNSCEAR, 2000; Chukwuma, 2020), this shows an additional radiation contribution from waste material.

Table 12**:** Mean radiological values for the dry season at Location L (Udeme avenue), control site

Parameters	Mean ± SD
Exposure Rate (μR/h)	5.14 ± 0.22
Dose Rate (μSv/h)	0.05 ± 0.002
Absorbed Dose Rate (nGy/h)	51 ± 8.0
AEDE (mSv/y)	0.06 ± 0.010
Excess Lifetime Cancer Risk (ELCR)	0.22 ± 0.036
Effective Dose (mSv/y)	1.3 ± 0.13

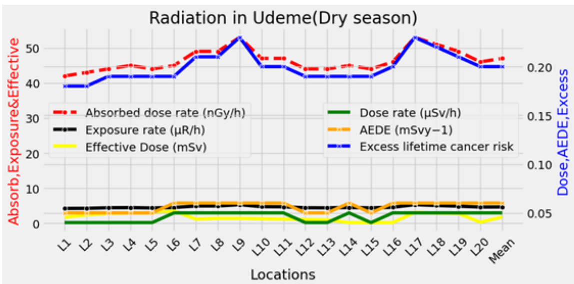

Figure 11: Plot of dry season control area at Udeme avenue, location L

A comparative analysis reveals a pronounced seasonal decline in radiological levels at Location L. The control site is characterized by reduced exposure rates, a lower Annual Effective Dose (AEDE), and a substantially decreased effective dose. Consequently, the associated health risk, quantified by an Excess Lifetime Cancer Risk (ELCR) of 0.17 ± 0.007, is also lower, aligning with the established phenomenon of baseline attenuation of gamma radiation.

Table 13: Shows the wet season data for location J at the Udeme Avenue dumpsite

Parameters	Mean ± SD
Exposure Rate (µR/h)	5.31 ± 0.31
Dose Rate (µSv/h)	0.05 ± 0.003
Absorbed Dose Rate (nGy/h)	53 ± 3.09
AEDE (mSv/y)	0.07 ± 0.004
Excess Lifetime Cancer Risk (ELCR)	0.23 ± 0.013
Effective Dose (mSv/y)	1.4 ± 0.07

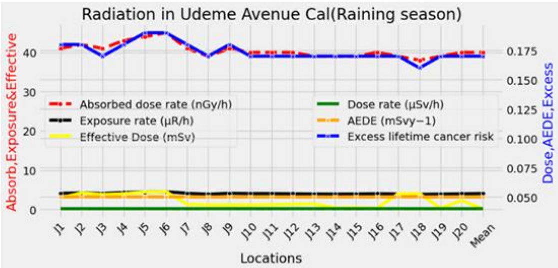

Figure 12: Plot of radiological parameters at Udeme avenue dumpsite location J, during the wet season.

A comparative analysis reveals a pronounced seasonal decline in radiological levels at Location J. The wet season is characterized by reduced exposure rates, a lower Annual Effective Dose (AEDE), and a substantially decreased effective dose. Consequently, the associated health risk, quantified by an Excess Lifetime Cancer Risk (ELCR) of 0.17 ± 0.007, is also lower, aligning with the established phenomenon of rainfall-induced attenuation of gamma radiation.

Table 14: Baseline radiological parameters at the Udeme control site (Location L) during the wet season.

Parameters	Mean ± SD
Exposure Rate (µR/h)	4.05 ± 0.165
Dose Rate (µSv/h)	0.04 ± 0.002
Absorbed Dose Rate (nGy/h)	40 ± 1.65
AEDE (mSv/y)	0.05 ± 0.002
ELCR	0.17 ± 0.007
Effective Dose (mSv/y)	0.14 ± 0.014

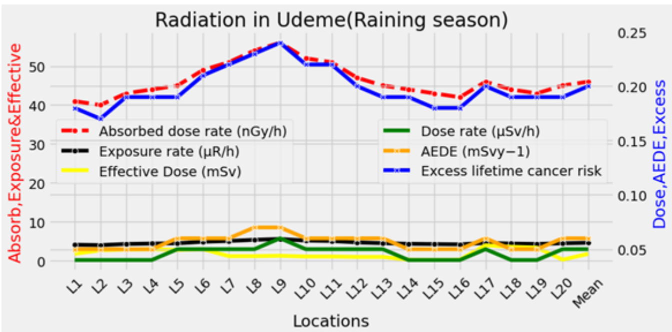

Figure 13: Plot of wet season control area at location L, Udeme Avenue.

Table 15: Presents a comparative analysis of the radiological parameters measured at Location J on Udeme Avenue, highlighting the differences between the dry and wet seasons.

Parameters	Dry season	Wet season
Exposure Rate (µR/h)	5.31 ± 0.31	4.05 ± 0.165
Dose Rate (µSv/h)	0.05 ± 0.003	0.04 ± 0.002
Absorbed Dose Rate (nGy/h)	53 ± 3.09	40 ± 1.65
AEDE (mSv/y)	0.07 ± 0.004	0.05 ± 0.002
ELCR	0.23 ± 0.013	0.17 ± 0.007
Effective Dose (mSv/y)	1.4 ± 0.07	0.14 ± 0.014

Table 16: Presents the mean values for the dry season data at Location M, Lemna dumpsite.

Parameters	Mean ± SD
Exposure Rate (µR/h)	5.16 ± 0.29
Dose Rate (µSv/h)	0.05 ± 0.003
Absorbed Dose Rate (nGy/h)	52 ± 2.91
AEDE (mSv/y)	0.06 ± 0.004
Excess Lifetime Cancer Risk (ELCR)	0.22 ± 0.013
Effective Dose (mSv/y)	1.7 ± 0.16

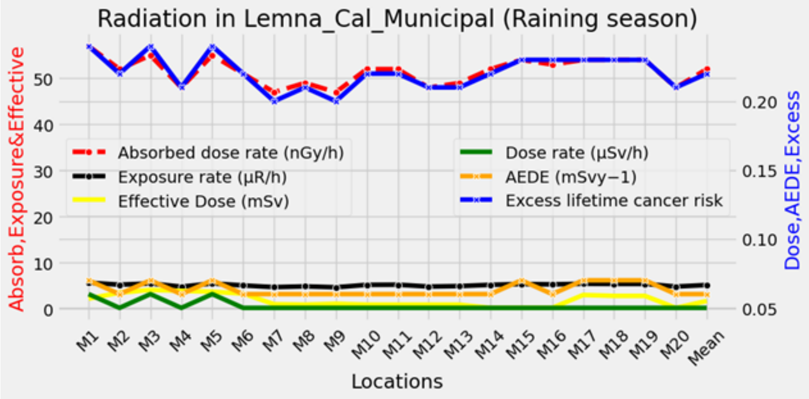

Figure 14: Plot of radiological parameters at Lemna dumpsite location M during the dry season.

Radiological assessment of the Lemna dumpsite (Location M) during the dry season confirmed elevated radiation levels, as evidenced by a mean exposure rate of 5.16 ± 0.29 µR/h. The calculated health risk parameters and the variability in the effective dose (0.2–1.7 mSv/y) demonstrate not only an overall increase in gamma radiation but also distinct spatial heterogeneity across the site. Due to soil cover and moisture attenuating gamma rays, recorded radiation levels are lower during the wet season (IAEA, 2010).

Table 17**:** Baseline radiological parameters at the Lemna control site (Location N) during the dry season.

Parameters	Mean ± SD
Exposure Rate (µR/h)	4.60 ± 0.30
Dose Rate (µSv/h)	0.05 ± 0.003
Absorbed Dose Rate (nGy/h)	46 ± 2.98
AEDE (mSv/y)	0.06 ± 0.004
Excess Lifetime Cancer Risk (ELCR)	0.20 ± 0.013
Effective Dose (mSv/y)	1.4 ± 0.19

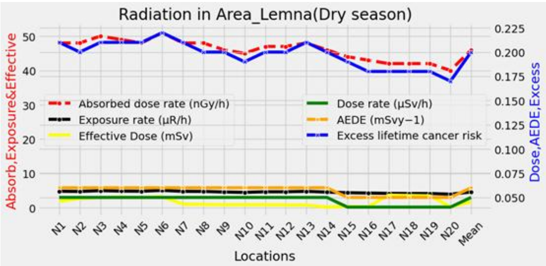

Figure 15: Plot of control area at Lemna location N during the dry season.

Radiological assessment of the Lemna control area (Location N) during the dry season confirmed its characteristic as a reference site. The measured parameters, including a mean exposure rate of 4.60 ± 0.30 µR/h and a calculated ELCR of 0.20 ± 0.013, demonstrate stable background levels. The observed range in effective dose (0.2–1.5 mSv/y) reflects natural, minor spatial variations in ambient radiation.

Table 18**:** Wet season radiological data for Location M, Lemna dumpsite.

Parameters	Mean ± SD
Exposure Rate (µR/h)	4.54 ± 0.36
Dose Rate (µSv/h)	0.06 ± 0.005
Absorbed Dose Rate (nGy/h)	45 ± 3.64
AEDE (mSv/y)	0.06 ± 0.004
Excess Lifetime Cancer Risk (ELCR)	0.19 ± 0.016
Effective Dose (mSv/y)	1.3 ± 0.2

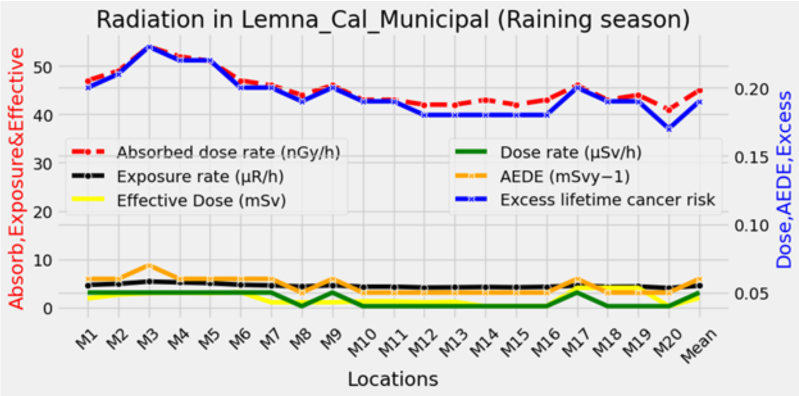

Figure 16: Wet season plot of radiological data at Lemna dumpsite location M.

The Lemna dumpsite (Location M) exhibits a characteristic wet-season reduction in mean radiological parameters, as demonstrated by a lower mean exposure rate. Despite this overall trend, the site displays significant spatial heterogeneity. However, the significant range in the effective dose (0.3–4.1 mSv/y) indicates that localized radioactive hotspots persist despite the general attenuating effect of seasonal rainfall.

Table 19: Wet season radiological data for the control site (Location N, Lemna).

Parameters	Mean ± SD
Exposure Rate (µR/h)	4.54 ± 0.44
Dose Rate (µSv/h)	0.05 ± 0.004
Absorbed Dose Rate (nGy/h)	44 ± 4.39
AEDE (mSv/y)	0.05 ± 0.005
Excess Lifetime Cancer Risk (ELCR)	0.18 ± 0.016
Effective Dose (mSv/y)	1.5 ± 0.14

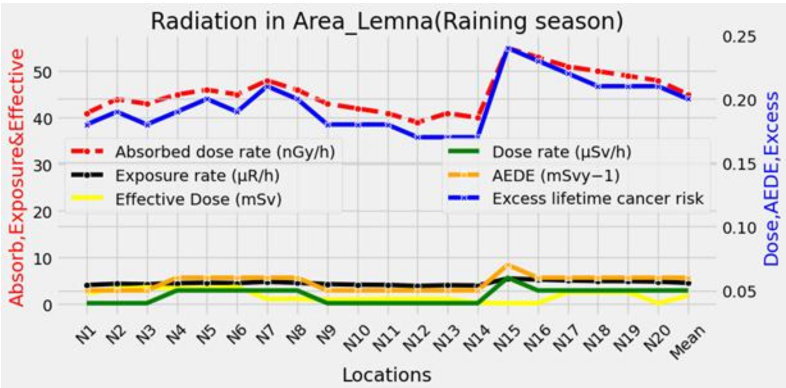

Figure 17: Wet season control site at Location N, Lemna.

The Lemna control area (Location N) demonstrates characteristic stability during the wet season, as evidenced by consistent mean radiological parameters. The recorded mean exposure rate of 4.54 ± 0.44 µR/h and associated risk values confirm this profile. However, the range in effective doses suggests the presence of minor, localized heterogeneity, likely resulting from natural variations in soil composition and other environmental factors rather than anthropogenic contamination.

Table 20: Seasonal variation in radiological parameters at Location M (Lemna): Dry Season vs. Wet Season.

Parameters	Dry season	Wet season
Exposure Rate (µR/h)	5.16 ± 0.29	4.54 ± 0.36
Dose Rate (µSv/h)	0.05 ± 0.003	0.06 ± 0.005
Absorbed Dose Rate (nGy/h)	52 ± 2.91	45 ± 3.64
AEDE (mSv/y)	0.06 ± 0.004	0.06 ± 0.004
ELCR	0.22 ± 0.013	0.19 ± 0.016
Effective Dose (mSv/y)	1.7 ± 0.16	1.3 ± 0.2

Comparison of all radiological measurements across both seasonal periods

The figures below display every measurable radiological parameter for both seasons. Seasonal variations of the dry and wet seasons are shown in the bar chart.

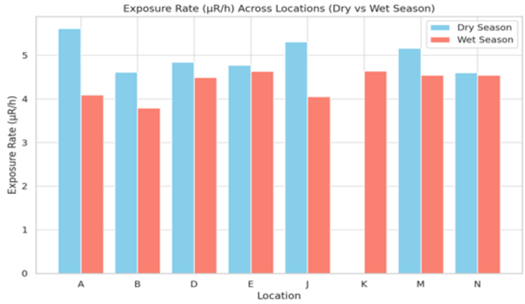

Figure 18: Exposure rate (μR/h) for all locations (dry and wet season)

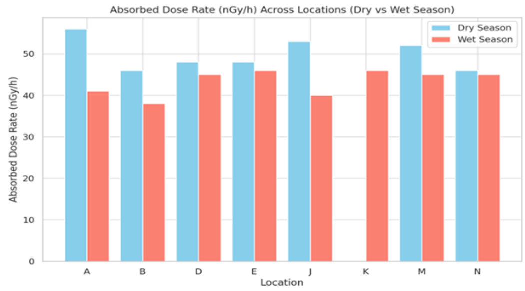

Figure 19: Absorbed dose (nGy/h) for all locations (dry and wet season)

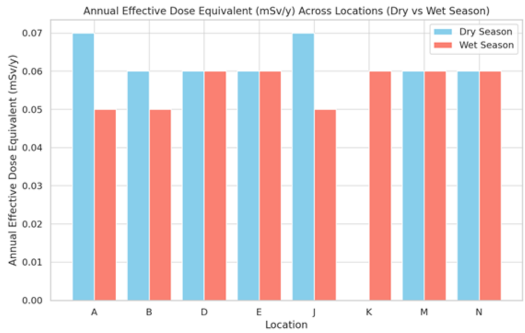

Figure 20: Annual effective dose equivalent (mSv/y) for all locations (dry and wet season)

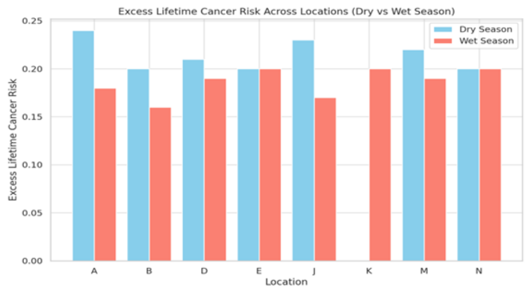

Figure 21: Excess lifetime cancer risk (ELCR) for all locations (dry and wet season).

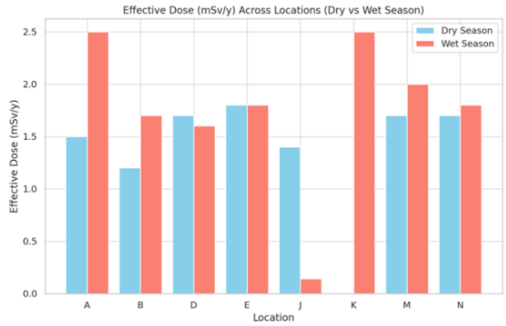

Figure 22: Effective dose (mSv/y) for all locations (dry and wet season).

Exposure rate (µR/h): Exposure rates were consistently higher during the dry season than the wet season. Values recorded at the dumpsites were substantially higher than those at the control (background) sites.

Absorbed Dose Rate (nGy/h): This follows the same pattern as the exposure rate: lower during the rainy season and significantly higher at dumpsites than in control areas.

Annual Equivalent Dose Received (AEDE, mSv/y): People near dumpsites receive a slightly higher annual radiation dose, with the highest values recorded during the dry season.

Excess Lifetime Cancer Risk (ELCR): The excess lifetime cancer risk was higher at the dumpsites than at control sites, with the highest values observed during the dry season. The risk was partially reduced during the wet season.

Effective Dose (mSv/y): Clear seasonal and location-based differences are observed. Lemna and Ikom follow similar trends, while the effective dose in Udeme (J/K) is noticeably lower during the wet season.

Discussion

The study's findings demonstrate that, in comparison to other study sites, the Ogoja dumpsite has detectable levels of gamma radiation above typical natural background levels. The dry season's mean absorbed dose rate (56 ± 5.02 nGy/h) exceeded the global average range of 20–50 nGy/h stated by UNSCEAR (2000), suggesting that waste products containing radionuclides contributed to the environmental radiation field. These results are consistent with data from comparable high-radiation disposal locations in the Jos Plateau region, Delta State, and Port Harcourt (Jwanbot, Izam, & Nyam, 2011). Similar increased levels have also been observed in some other Nigerian dumpsites, where poor disposal of battery residues, metal scraps, and electronic components raises the radiological load (Avwiri, Ononugbo, & Nwokeoji, 2016) Results from locations A–N during the dry season showed that the exposure rate varied between 5.03 and 6.60 µR/h, with a mean of roughly 5–6 µR/h. Due to decreased moisture, which typically attenuates terrestrial gamma radiation, this is higher than wet-season values (Essien, Umoren, & Etuk, 2018). According to Avwiri & Chad-Umoren (2019) (Avwiri, Ekpo, & Chad-Umoren, 2019) soil desiccation dramatically raises exposure levels. During the dry season, absorbed dose rates ranged from 40 to 56 nGy/h, with an overall mean of 52 nGy/h. These values are comparable to the UNSCEAR (2000) global outdoor average of 59 nGy/h and remain within the typical natural background range. The corresponding annual effective dose equivalent (AEDE) ranged from 0.06 to 0.08 mSv/y (mean ≈ 0.07 mSv/y), consistent with the worldwide average of 0.07 mSv/y reported by UNSCEAR and well below the ICRP recommended public exposure limit of 1 mSv/y. The dry-season ELCR varied between 0.20 and 0.30 × 10^{-3}, with a few outliers in Location A, exceeding 2–3 × 10^{-3}. The concentration of radionuclides in various materials, such as metal scrap, plastics, ash, and ceramics, may be the cause of these higher readings. Although the slightly raised ELCR suggests potential long-term health hazards, radiation levels in all locations from A to N during the dry-season stay within safety standards. This is in line with Ononugbo et al. (2020) (Ononugbo & Anekwe, 2020) and reflects decomposing garbage, heavy metals, and geological variables.

Wet Season Results from Locations A–N exposure Rate: The computed mean of the wet-season exposure rates was around 4.09 µR/h, with a range of 3.80–4.60 µR/h. Higher air humidity, lower surface radionuclide emission, and soil moisture absorbing gamma rays are all responsible for the overall decline. The mean absorbed dose value was 41 ± 1.8 nGy/h, with a range of 39–46 nGy/h. This confirms safety because it is less than UNSCEAR's 59 nGy/h. The wet-season AEDE was in the low-dose worldwide range, averaging between 0.03 and 0.05 mSv/y. During the rainy season, the average ELCR was 0.18 ×10^{-3}, however, some sites had significantly higher values (A17 = 4.6, for example). These anomalous peaks may be indicative of concentrations of anthropogenic waste, metal pollution, and localized radioactive hotspots. Due to a few peaks, wet-season effective dose values varied greatly (1.4–2.6 mSv). Further soil study is necessary since these increases indicate occasional contamination. According to the study, radiation levels at dumpsites are regularly slightly higher than in control areas, although they are still within international safety limits, while the dry season is higher than the wet season due to soil moisture.

All radiological parameters measured in this study comply fully with international safety guidelines. Absorbed dose rates (mean 41–56 nGy/h) were lower than the global average of 59 nGy/h reported by UNSCEAR. The annual effective dose equivalent (0.05–0.07 mSv/y) was considerably below the ICRP public limit of 1 mSv/y, and the excess lifetime cancer risk (ELCR) fell within the permissible range, in agreement with background levels documented elsewhere Obed et al., 2013 (Obed, Farai, & Jwanbot, 2013) and Eze et al, (2025) (Eze, Ushie, Abong, Ezema, & Aisida, 2025).

IV. Conclusion

Radiation exposure at dumpsites at Locations A–N during the dry and wet seasons was evaluated in this study. Key conclusions include that, since there was less moisture during the dry season, radiation readings were greater. Values during the wet season were much lower, in line with global trends. The UNSCEAR safe range was met with absorbed dose rates (41–56 nGy/h). AEDE readings (0.05–0.07 mSv/y) stayed well below the 1 mSv/y ICRP guideline. Some dumpsites had somewhat higher ELCR readings, although they were still within the WHO's permissible range. Localized hotspots were shown by the sporadic rises in effective dosages. The radiation levels found at all sites are typically within permissible international standards, suggesting that there is no immediate radiological risk at the dumpsites. However, prolonged exposure may increase the risk of cancer, particularly in susceptible groups including youngsters, pregnant women, and scavengers. The seasonal variations validate the influence of soil moisture, waste composition, and climate on radiation behavior. Preventive care and ongoing observation are necessary for the few hotspots that were discovered.

Conflict of interest

The authors declare no conflict of interest

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Authors' contribution

Benson E. Eze: Conceptualization, Original draft preparation, Methodology, Data curation, Software, Reviewing and Editing. **Christian Nwabunwanne:** Conceptualization, Visualization and Data curation. **Samson O. Aisida**: Conceptualization, Data curation, Writing, Methodology, Original draft preparation. **Ushie, P.O:** Writing, Methodology, Data curation. **Kelly B. Ndifon**: Visualization, Data curation, **Fabian I. Ezema:** Conceptualization, Visualization and Data curation.

Data Availability

Data will be made available upon request

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