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Measurement of Background Ionizing Radiation in Selected Buildings with Altitude within Delta State, Nigeria

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ABSTRACT

Anthropogenic activities play a crucial role in radiation exposure, resulting in a myriad of adverse health effects. Hence, the need to monitor and maintain exposure levels as low as reasonably achievable, particularly in residential areas. In the present study, the measurement of the background ionization radiation in selected buildings with Altitude within Delta State, Nigeria was carried out using a well calibrated radiation nuclear meter (Digilert 200). The study covers Warri and Asaba, which are the major cities in the state. The exposure rate varied from 0.007 to 0.020 mR/h with an overall mean value of 0.012 ± 0.030 to 0.016 ± 0.003 mR/h. The calculated absorbed doses rates ranged from 60.9 to 174.0 nGy/h with an overall mean of 107.3 ± 22.4 to 139.2 ± 27.51 nGy/h. The calculated annual effective doses equivalent ranged from 0.09 to 0.27 mSv/y with an overall mean of 0.16 ± 0.03 to 0.21 ± 0.04 mSv/y. The excess life cancer risk ranged from 0.32 to 0.93 with an overall mean annual effective dose equivalent was determined to be below the safe world recommended permissible limit of 1.00 mSv/y, while others slightly exceeded their respective global average safe thresholds. Therefore, there may not be any immediate radiological health effect on residents of the areas based on the data obtained.

Keywords:
Altitude,
Cosmic rays,
Digilert 200,
Exposure Rate,
Organ Dose,
Radiation.

INTRODUCTION

Every living thing is affected by ionizing radiation, which comes from cosmic rays, natural materials in the earth, construction materials, the air we breathe, water, food, and even our own bodies. This exposure is constant and uniform for all individuals, including the exposure gotten from potassium-40 found in food. Cosmic radiation is stronger at higher altitudes, and some areas have more uranium and thorium in the soil than others. Additionally, everyday activities can change the amount of radiation encountered. For example, the types of construction materials, building designs, and the setup of ventilation systems all play a role in determining the amount of radon gas we might breathe in (Ramachandran, 2011; Joseph et al., 2018).

Natural background radiation is the main source of radiation exposure for people. Cosmic rays contribute about 13% of the total radiation dose we received at ground level, while cosmic radionuclides add to a small fraction (0.4%) (UNSCEAR, 2008). The higher in altitude, the lower the air available to block radiation, meaning that those at higher elevations get more exposure. Variations in background radiation can happen due to altitude, soil composition, and geographical conditions of different regions (Shahbazi-Gahrouei et al., 2013).

Radiation has been a part of our world since the earth formed, and its intensity varies across different locations and times. Cosmic radiation from the sun adds to the natural background. Factors like altitude and latitude can also affect radiation levels at any given site (Amanjeet et al., 2017). Human activities, such as mining, quarrying, disposing of radioactive waste, and blowing up radioactive substances, can increase the risk of exposure to ionizing radiation (Olabamiji et al., 2023; Tyongiga et al., 2024).

There has been considerable discourse regarding the adverse health effects of radiation resulting from anthropogenic activities. Radiation, which is omnipresent in various forms and intensities in our daily lives, has been recognized as potentially detrimental to human health. Exposure to elevated levels of radiation doses presents significant health hazards. Direct radiation, such as Alpha and Beta particles, and Gamma rays, exhibit strong ionizing and penetrating capabilities, respectively. When these radiations interact with biological cells, they can induce excitation and ionization, leading to structural alterations within the cells (Emelue et al., 2014). Prolonged exposure to background radiation, even at low levels, can increase the risk of cancers, particularly leukemia, lung cancer, and thyroid cancer. The risk accumulates over time, indicating that lifetime exposure substantially elevates the probability of adverse health outcomes. There is also a potential for genetic mutations due to radiation exposure, which could impact future generations, although this is less prevalent than cancer risks. Due to the potentially lethal effects of ionizing radiation, it is standard practice to monitor and maintain exposure levels as low as reasonably achievable—a principle known as ALARA (Ilugo et al., 2021). Estimating background ionizing radiation is a primary concern for regulatory bodies, radiation protection experts, and the public. Understanding background radiation is crucial for identifying potential sources and assessing its impact on human health (Sadiq &Agba, 2011). In Nigeria, various studies have been conducted to determine background radiation levels in different locations. For instance, research by Esi & Okpilike (2023) revealed that the background radiation for individuals residing in Agbarho Kingdom, Delta State, ranged from 0.013 to 0.019 mR/h, which exceeded the safe limit of 0.013 mR/h. Another study in Lafia Metropolis, Nasarawa State, reported a mean background radiation value of 0.021 mR/h, surpassing the recommended safe limit of 0.013 mR/h.

This study aimed to assess background ionizing radiation exposure levels across different buildings at varying altitudes within selected areas of Delta State. The study also aimed to evaluate the associated radiological health risks of background ionizing radiation levels across the selected buildings, altitudes and areas.

MATERIALS AND METHODS

A well-calibrated Digilert-200 nuclear radiation meter was employed for *in-situ* sampling and measurements, in conjunction with a Global Positioning System (GPS) to ascertain the precise location of sampling. The radiation meter is equipped with a Geiger-Müller detector tube capable of detecting alpha particles down to 2.5 MeV with an 80% detection efficiency and beta particles up to 150 KeV with a 75% detection effectiveness. Within the temperature range of -10°C to 50°C, the Digilert-200 can detect gamma and X-rays down to 10 keV through the window and 40 keV through the case. The effective radiation doses were displayed on the meter's screen in milliRoentgen per hour (mR/hr). Measurements were conducted between 1300 and 1600 hours, as the exposure rate meter demonstrates optimal responsiveness to ambient radiation during this timeframe (Audu et al., 2019).

Study Area

The study sites are located in Delta State, one of Nigeria’s 36 states. The research area is located in the Niger Delta region of Nigeria, between latitudes 5˚18’’N and 5˚86’’N and longitude 5˚33’’E and 6˚40’’E (Audu et al., 2019). The study was carried out in residential buildings, hotels and offices within Asaba, Warri, Ughelli and Kwale with altitude.

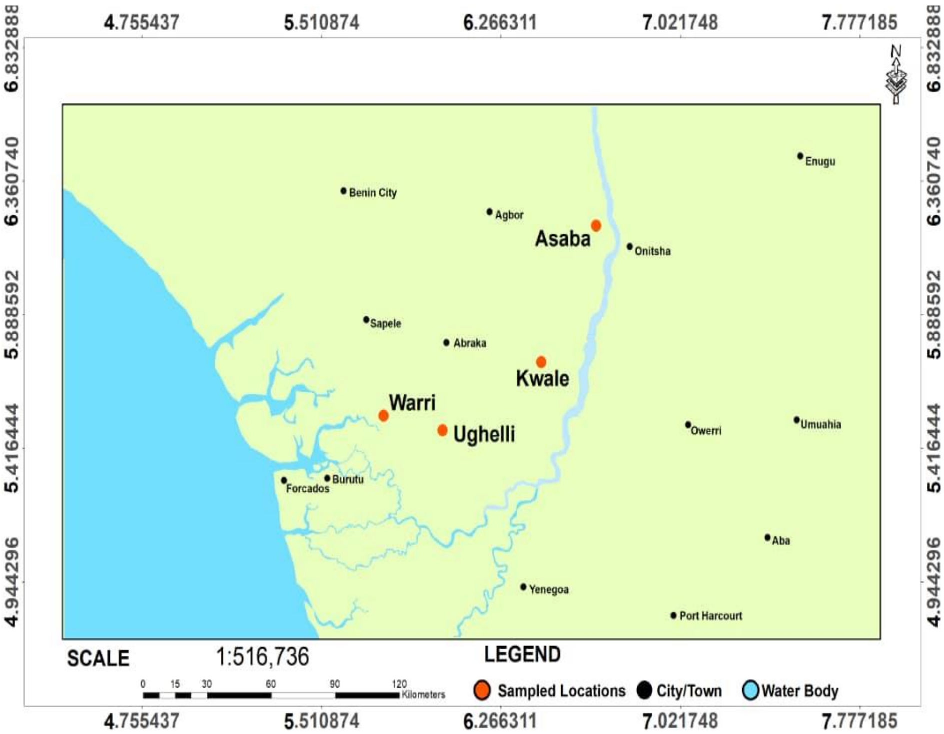

Figure 1: Map of the study area

Method of Data Analysis

Absorbed Dose (AD)

This refers to the measure of the energy (radionuclides) deposited by ionizing radiation in the human body over a certain duration of time (Audu et al., 2019). The data obtained from the external exposure rate in μRh^{-1} was converted into absorbed dose rate using the conversion factor as illustrated in equation 1 (Rafique et al., 2014)

$1\ \mu Rh^{-1} = 8.7\ nGyh^{-1} = 8.7 \times 10^{-3} / (1\ (8760y))$, (1)

$1\ \mu Rh^{-1} = 76.212\ \mu Gyy^{-1}$

Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent (AEDE) received by residents dwelling in the study area was computed for, using the calculated absorbed dose rates. In this calculation of the AEDE, a 0.7 Sv/Gy was used as the dose conversion coefficient recommended by the UNSCEAR for the conversion from absorbed dose in air to effective dose received by adults (Agbalagba et al., 2016). Meanwhile occupancy factor for outdoors of 0.25 (6 hours out of 24 hours) was also used, while 8760 h is the conversion of 1 year to hours. The relationship in equation 2 was used to compute the annual effective dose (Ovuomarie-kevin et al., 2018):

AEDE (outdoor) ($mSvy^{-1}$) = Absorbed dose ($nGyh^{-1}$) ×8760 h × (0.7 Sv/Gy) × 0.25 (2)

Excess Life Cancer Risk (ELCR)

The Excess Lifetime Cancer Risk (ELCR) is employed to assess the likelihood of cancer development among residents of the study area who reside there for their entire lifetime, even in the absence of radioactive components in the environment. According to evidence, the Linear No Threshold (LNT) hypothesis, which extrapolates high-dose effects to low-dose responses, posits that all acute ionizing radiation exposures, down to zero, are detrimental. The harm is directly proportional to the dose and accumulates over a lifetime, irrespective of how low the dose rate is (Arogunjo et al., 2004). This study is grounded in the traditional global radiation protection standards for late (stochastic) effects, which are based on the LNT hypothesis. This implies a probability of cancer development among residents and workers in various communities. The Excess Lifetime Cancer Risk (ELCR) was estimated based on the computed values of AEDE, using equation 3 (Avwiri et al., 2017):

$ELCR = AEDE \times Average\ duration$ of life (DL) $\times Risk\ factor\ (Rf)$ (3)

The annual effective dose equivalent (AEDE) is determined by considering the duration of life (DL), which corresponds to the average human life expectancy of 70 years, alongside the risk factor (RF) for fatal cancer per Sievert (Sv^{-1}). According to the International Commission on Radiological Protection (ICRP) Publication 60, a risk factor (RF) of 0.05 Sv^{-1} is applied for public exposure to low-dose background radiation, which is associated with stochastic effects (Avwiri et al., 2017).

Effective Dose to Different Body Organs (D_{organ})

The calculation of the effective dose rate for various organs and tissues is performed using Equation 4 (Zaid et al., 2010).

D_{organ} ($mSvy^{-1}$) = O x AEDE x F (4)

where AEDE stands for the annual effective dose equivalent, O is the occupancy factor set at 0.8, and F represents the conversion factor for organ dose resulting from ingestion. According to ICRP data (Arogunjo et al., 2004; UNSCEAR, 2000), the conversion factor (F) values for the lungs, ovaries, bone marrow, testes, kidney, liver, and whole body are 0.64, 0.58, 0.69, 0.82, 0.62, 0.46, and 0.68, respectively. Additionally, the F values for the conversion factor of organ dose from air dose for these organs, as reported by ICRP (1996), are identical: 0.64, 0.58, 0.69, 0.82, 0.62, 0.46, and 0.68, respectively.

RESULTS AND DISCUSSION

The spatial distribution of exposure rates concerning altitude, indicating areas of low and high concentration, is presented in Table 1. The measured BIR exposure rates ranged from 0.012 ± 0.003 mR/hr to 0.016 ± 0.003 mR/hr. Locations 3 and 4 exhibited the highest exposure rate values of 0.015 mR/hr and 0.016 mR/hr, respectively, which exceeded the recommended permissible limit of 0.013 mR/hr (ICRP, 2007; Osimobi et al., 2015; Agbalagba et al., 2016). Given that altitude is a significant factor influencing the measured dose rate, the findings of this study showed that the region's altitude substantially affected the level of background radiation. Some areas demonstrated low background radiation despite their high altitude, and this is attributable to low concentrations of radionuclides. However, a more detailed analysis of individual measurements revealed a correlation between altitude and exposure rate. Results also indicated that higher altitude regions possess elevated natural background radiation levels, potentially due to buildings being constructed on uranium-rich soil or bedrock, which may increase radon gas seepage, particularly if ventilation is inadequate. At lower altitudes, the Earth's atmosphere provides enhanced shielding against cosmic rays, thereby reducing their contribution to background ionizing radiation. Buildings constructed with low-radiation materials (such as wood, glass, or carefully selected concrete) may exhibit lower radiation levels. Nevertheless, the mean exposure level of 0.016 ± 0.003 mR/hr recorded in Location 4 is lower than the range of 0.011 to 0.090 mR/hr, with an average of 0.021 mR/hr reported by Idris et al. (2021) in their study on Outdoor Background Radiation Level and Radiological Hazards Assessment in Lafia Metropolis, Nasarawa State, Nigeria, but were within the values measured by Esi & Okpilike (2023) in their Radiometric Survey of Background Ionizing Radiation and Assessment of Radiological Health Risk on the Residents of Agbarho Kingdom, Delta State, Nigeria, which ranged from 0.013 to 0.019 mR/hr. A comparison of the background exposure rates is depicted in Figure 2. The calculated absorbed dose rate for high-rise buildings ranged from 60.9 to174 ηGy/hr, with an observed mean value of 98.60 ± 28.94 ηGy/hr. These dose rates, resulting from BIR exposure in the studied locations, significantly exceeded the recorded world weighted average of 59.00 ηGy/hr (Agbalagba, 2017; Monica et al., 2016) and the recommended safe limit of 84.0 ηGy/hr (UNSCEAR, 2008; Ononugbo & Mgbemere, 2016) for outdoor exposure. These dose rates indicate a radiation-contaminated environment. Although the dose rate at these levels may not pose immediate health hazards to the local residents, there is potential for long-term health risks with prolonged exposure. The mean dose rate for BIR recoreded in our study was within the range of 87 to 121.8 ηGy/hr reported by Ijabor et al. (2022) in their study of indoor and outdoor radiation dose levels in Delta State Polytechnic, Ogwashi Uku, Delta State, Nigeria, and was lower than the range of 95.7 to 156.6 ηGy/hr reported in sections of Niger Delta University campus, Bayelsa State, Nigeria by Peter et al. (2024). Results obtained from the absorbed dose rate were used to calculate the Annual Effective Dose Equivalents (AEDE), in the sampling locations. The calculated values of AEDE ranged from 0.09 to 0.27 mSv/y with mean value of 0.24 ± 0.02 mSv/y. The mean Annual Effective Dose Equivalents (AEDE) values were similar to the value reported by Omogunloye & Oyedokun (2022) in their assessment of indoor and outdoor background radiation levels in Olusegun Agagu University of Science and Technology, Okitipupa Ondo State, Nigeria (0.07 mSv/y & 0.02 mSv/y). These mean annual effective doses were higher than theworld average value of 0.07 $mSvy^{-1}$ (ICRP, 2007; UNSCEAR, 2008; Agbalagba, 2017) however, the values were within ICRP and UNSCEAR recommended permissible limits of 1.00 $mSvy^{-1}$ for the general public (ICRP, 2007; UNSCEAR, 2008). Our results revealed the radiological contamination due to the anthropogenic activities taking place in the area. However, the pollution did not pose any immediate radiological health effect on the people living in the area.

The calculated mean value for the ELCR ranged from 0.58×10^{-3} in Location 13 to 0.76×10^{-3} in Location 4. The mean values were greater than the global average value of 0.29×10^{-3} which implies that there exists a chance of cancer development for residents who intend to spend their entire lifetime in the area. The ELCR values reported in our study were within the range reported by Anekwe & Onoja (2020) in the assessment of environmental radioactivity level and its health implication in Imiringi Community Bayelsa State, Nigeria but were lower than those reported by Chiegwu

et al., (2022) in industrial buildings in Nnewi, Anambra State, Nigeria.
The estimated average D_{organ} values for the lungs, ovaries, bone marrow, testes, kidney, liver and whole body due to radiation exposure and inhalation in the study environment were 0.139, 0.126, 0.150, 0.178, 0.134, 0.100, 0.147mSv/yr. These results all fell below the international tolerable limits of 1.0 mSv annually (Agbalagba, 2017) which further indicates that the radiation levels of the study locations do not constitute any immediate health effect on residents of the area. Based on our findings, testies and whole body can be inferred to be the most and least sensitive to radiation exposure. Similar conclusion was made by Darwish et al. (2015) and Agbalagba (2017).

Table 1: Spatial distribution of rates of exposure to altitude in the study location

	Height (m)	Exposure Rate (mR/h)	Annual Absorbed Dose Rate (nGy/y)	Annual Effective Dose Equivalent (mSv/y)	ELCRx10^{-3}
Location 1					
A	3.00	0.018	156.6	0.24	0.84
B	5.75	0.011	95.7	0.15	0.51
C	8.50	0.017	147.9	0.23	0.80
D	11.25	0.009	78.3	0.12	0.42
E	14.00	0.015	130.5	0.20	0.75
F	16.75	0.010	87.0	0.13	0.47
G	20.25	0.011	95.7	0.15	0.51
	Mean	0.013 ± 0.004	116 ± 33.31	0.18 ± 0.05	0.63 ± 0.19
Location 2					
A	2.70	0.011	95.7	0.15	0.51
B	5.60	0.013	113.1	0.17	0.61
C	8.30	0.014	121.8	0.19	0.65
D	11.00	0.010	87.0	0.13	0.47
E	13.70	0.020	174.0	0.27	0.93
F	16.40	0.009	78.3	0.12	0.42
H	19.55	0.014	121.8	0.19	0.65
	Mean	0.013 ± 0.004	111.7 ± 34.54	0.17 ± 0.05	0.60 ± 0.18
Location 3					
A	2.50	0.011	95.7	0.15	0.51
B	4.75	0.014	121.8	0.19	0.65
C	7.00	0.016	139.2	0.21	0.75
D	9.25	0.017	147.9	0.23	0.80
E	11.50	0.019	165.3	0.25	0.89
F	13.75	0.020	174.0	0.27	0.93
	Mean	0.015 ± 0.03	133.98 ± 26.53	0.21 ± 0.04	0.72 ± 0.15
Location 4					
A	2.60	0.012	104.4	0.16	0.56
B	5.00	0.013	113.1	0.17	0.61
C	7.40	0.015	130.5	0.20	0.75
D	9.80	0.018	156.6	0.24	0.84
E	12.20	0.018	156.6	0.24	0.84
F	14.90	0.020	174.0	0.27	0.93
	Mean	0.016 ± 0.003	139.2 ± 27.51	0.21 ± 0.04	0.76 ± 0.14
Location 5					
A	2.55	0.010	87.0	0.13	0.47
B	4.85	0.011	95.7	0.15	0.51
C	7.15	0.013	113.1	0.17	0.61
D	9.45	0.014	121.8	0.19	0.65
E	11.75	0.011	95.7	0.15	0.51
F	14.51	0.018	156.6	0.24	0.84
	Mean	0.013 ± 0.003	111.65 ± 25.46	0.17 ± 0.04	0.60 ± 0.14

	Height (m)	Exposure Rate (mR/h)	Annual Absorbed Dose Rate (nGy/y)	Annual Effective Dose Equivalent (mSv/y)	ELCRx10^{-3}
Location 6					
A	2.70	0.007	60.9	0.09	0.32
B	5.28	0.010	87.0	0.13	0.46
C	7.86	0.012	104.4	0.16	0.56
D	10.44	0.015	130.5	0.20	0.70
E	13.30	0.016	139.2	0.21	0.75
	Mean	0.013 ± 0.004	110.2 ± 31.93	0.17 ± 0.05	0.59 ± 0.18
Location 7					
A	2.70	0.009	78.3	2.20	0.08
B	5.18	0.010	87.0	2.20	0.08
C	7.66	0.013	113.1	1.90	0.07
D	10.14	0.007	60.9	0.09	0.32
E	12.62	0.015	130.5	0.20	0.70
F	15.10	0.016	139.2	1.30	0.05
	Mean	0.014 ± 0.004	117.45 ± 30.51	0.18 ± 0.05	0.63 ± 0.61
Location 8					
A	2.93	0.014	121.8	0.19	0.65
B	5.63	0.011	95.7	0.15	0.51
C	8.33	0.013	113.1	0.17	0.61
D	11.03	0.015	130.5	0.20	0.70
E	13.73	0.012	104.4	0.16	0.56
F	16.43	0.019	165.3	0.25	0.89
G	19.58	0.019	165.3	0.25	0.89
	Mean	0.014 ± 0.003	121.8 ± 24.61	0.19 ± 0.04	0.61 ± 0.13
Location 9					
A	2.55	0.007	60.9	0.09	0.32
B	5.31	0.009	78.3	0.12	0.42
C	7.86	0.010	87.0	0.13	0.46
D	10.41	0.012	104.4	0.16	0.56
E	12.96	0.014	121.8	0.19	0.65
F	15.51	0.016	139.2	0.21	0.75
G	18.49	0.018	156.6	0.24	0.84
	Mean	0.014 ± 0.003	121.80 ± 28.94	0.19 ± 0.05	0.65 ± 0.15
Location 10					
A	2.80	0.009	78.3	0.12	0.42
B	5.30	0.011	95.7	0.15	0.51
C	7.80	0.013	113.1	0.17	0.61
D	10.30	0.014	121.8	0.19	0.65
E	12.80	0.016	139.2	0.21	0.75
F	15.80	0.016	139.2	0.21	0.75
	Mean	0.013 ± 0.003	114.55 ± 24.25	0.18 ± 0.04	0.62 ± 0.13
Location 11					
A	2.93	0.010	87.0	0.13	0.47
B	5.43	0.011	95.7	0.15	0.51
C	7.93	0.013	113.1	0.17	0.61
D	10.43	0.015	130.5	0.20	0.70
E	12.93	0.017	147.9	0.24	0.80
F	15.86	0.018	156.6	0.23	0.84
	Mean	0.014 ± 0.003	121.8 ± 28.06	0.19 ± 0.04	0.65 ± 0.15
Location 12					
A	2.85	0.009	78.3	0.12	0.42
B	5.45	0.011	95.7	0.15	0.51
C	8.05	0.013	113.1	0.17	0.61
D	10.65	0.010	87.0	0.13	0.47
E	13.25	0.016	139.2	0.21	0.75
F	16.35	0.018	156.6	0.23	0.84
	Mean	0.013 ± 0.004	111.65 ± 30.84	0.16 ± 0.04	0.60 ± 0.17

	Height (m)	Exposure Rate (mR/h)	Annual Absorbed Dose Rate (nGy/y)	Annual Effective Dose Equivalent (mSv/y)	ELCRx10^{-3}
Location 13					
A	3.23	0.009	78.3	0.12	0.42
B	5.86	0.010	87.0	0.13	0.47
C	8.49	0.012	104.4	0.16	0.56
D	11.12	0.014	121.8	0.19	0.65
E	13.75	0.016	139.2	0.21	0.75
F	16.98	0.013	113.1	0.17	0.61
	Mean	0.012 ± 0.003	107.30 ± 22.46	0.16 ± 0.03	0.58 ± 0.12
Location 14					
A	2.76	0.009	78.3	0.12	0.42
B	5.31	0.010	87.0	0.13	0.47
C	7.86	0.013	113.1	0.17	0.61
D	10.41	0.015	130.5	0.20	0.70
E	12.96	0.017	147.9	0.23	0.80
F	15.93	0.019	165.3	0.25	0.89
	Mean	0.014 ± 0.004	120.35 ± 34.10	0.18 ± 0.05	0.64 ± 0.18
Location 15					
A	0.009	0.009	78.3	0.12	0.42
B	0.011	0.011	95.7	0.15	0.51
C	0.013	0.013	113.1	0.17	0.61
D	0.015	0.015	130.5	0.20	0.70
E	0.016	0.016	139.2	0.21	0.75
F	0.018	0.018	156.6	0.24	0.84
	Mean	0.014 ± 0.003	118.9 ± 28.94	0.18 ± 0.04	0.64 ± 0.16

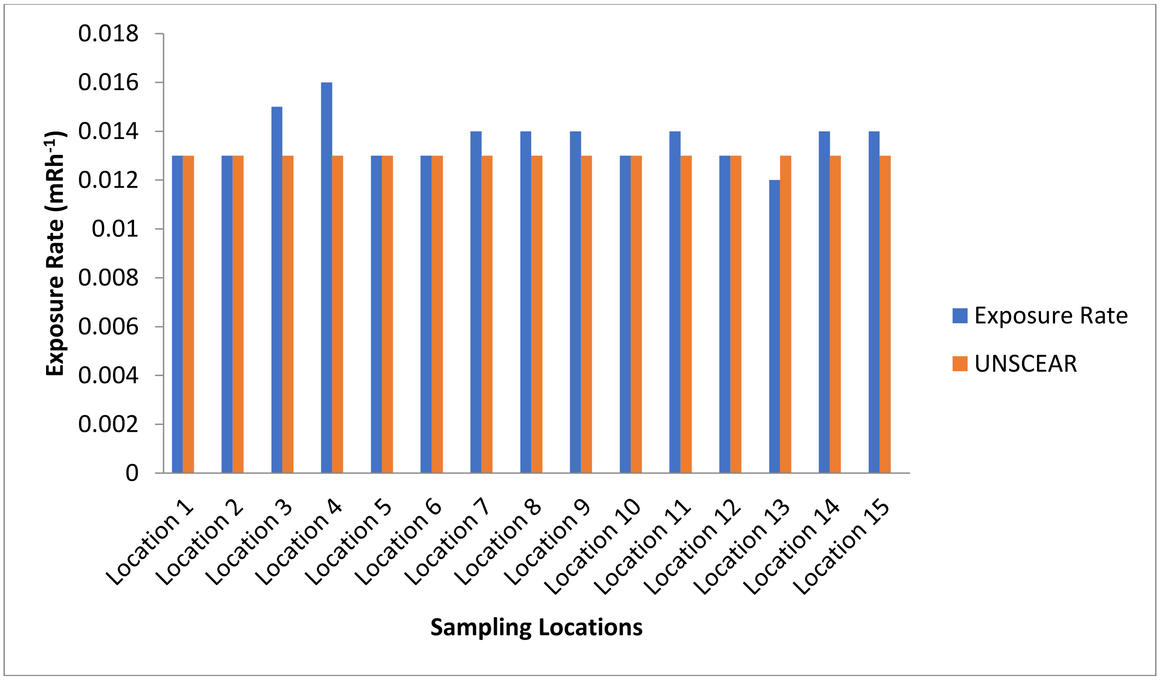

Figure 2: Comparison of radiation exposure rate within selected buildings with altitude in Delta State with world safe limit value

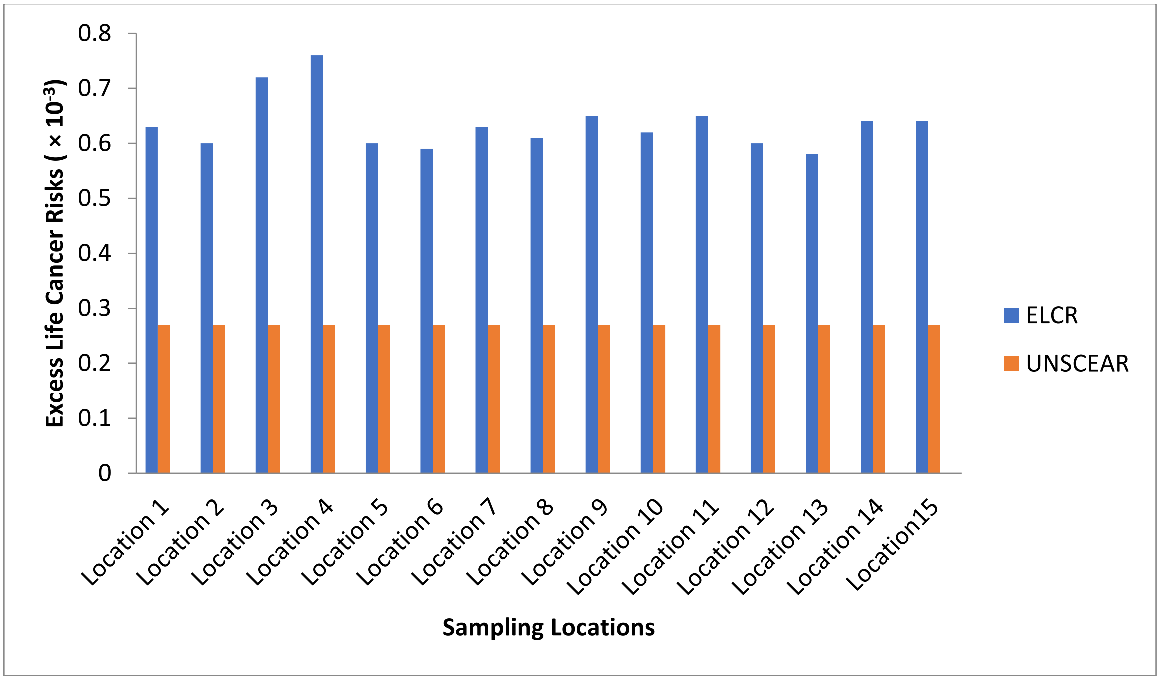

Figure 3: Comparison of average ELCR within selected buildings with altitude in Delta State with world safe limit value

CONCLUSION

Background ionizing radiation in buildings with altitude arises from natural and artificial sources, including cosmic rays, radon gas, and construction materials. The intensity of exposure is influenced by factors such as altitude, ventilation efficiency, and the radiological properties of building materials. Higher elevations generally result in increased cosmic radiation, while adequate ventilation can help mitigate radon accumulation. To minimize radiation exposure, it is essential to use construction materials with low radioactive content, ensure proper airflow to reduce radon levels, and implement shielding measures where necessary. Although radiation levels in most buildings remain within permissible limits, continuous monitoring and adherence to safety regulations are crucial for mitigating potential long-term health risks.

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