

Article

Radiometric Mapping and Evaluation of Radiation Health Risk Parameters in Imo North Senatorial District, Nigeria

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Abstract: A Radiometric mapping and analysis of Radiation Health Risk Parameters of Imo North Senatorial District, Nigeria (situated between 7°4'48" E and 7°25'48" E, and 5°30'36" N and 5°56'24" N) was carried out through the use of two well Calibrated nuclear radiation meters, Radalert 100 and Digilert 200 and a GPS device, to measure the background Ionizing radiation exposure rate. Golden Software Surfer 20.1.195 and QGIS 3.16.8 were used for plotting radiation contour maps and radiometric map respectively. The average radiation exposure rates from thirty communities in the six local government areas of the district was 0.0128 ± 0.0006 mRh⁻¹. The average absorbed dose rate was 110.86 ± 4.77 nGyh⁻¹. The average annual effective dose equivalent (AEDE) result was 0.1136 ± 0.006 mSvy⁻¹. The excess life time cancer risk (ELCR) average values was $(0.476 \pm 0.02) \times 10^{-3}$. The average radiation exposure rates was below the UNSCEAR 2008 world average of 0.013 mRh⁻¹ while the average of AEDE in this study are within the recommended safety values of 1.00 mSvy⁻¹ for the public as stipulated by the ICRP. The average absorbed dose and ELCR surpassed the world average of 84 nGyh⁻¹ and 0.29×10^{-3} respectively. The values recorded for absorbed dose rate and ELCR may not result in an acute health impact on residents of Imo North Senatorial District, but continuous exposure may likely result in stochastic radiation effects.

Keywords: Background Ionizing Radiation; Outdoor Exposure Rate; Radiometric Map; Radiation Health Risk; Imo North Senatorial District

1. Introduction

Radiation is the emission and transmission of energy in the form of photons and particles. Being energy, radiation is found everywhere throughout the entire universe. There are two primary types of radiation which are ionizing and non-ionizing radiation [1]. In this study the interest lies on ionizing radiation. The need to create awareness about the effects of excessive radiation exposure cannot be overemphasized and this has led to the numerous studies to determine radiation levels in different environments and recommend safety measures.

The ionizing radiation that is continuously present in the environment termed background ionizing radiation (BIR) is the sum of external radiation due to terrestrial naturally occurring radionuclides which are grouped under naturally occurring radioactive materials (NORMs) and technologically enhanced natural occurring materials (TENORMs), radiation from outer space, and radiation that emanate from human activities [2]. Terrestrial radiation varies according to the amount of radioisotopes such as Uranium series, Thorium series, potassium-40, and others found in the soil [3]. Traces of these radioisotopes are found everywhere on earth but background ionizing radiation is very high in places where they are found in abundance. Cosmic radiation is split into the primary radiation which is the direct gamma radiation from outer space and the secondary radiation which is the aftermath of

interaction between radiation from space and atoms on earth to create particles and rays like neutrons, electrons, and many others [4]. The cosmic radiation depends on the latitude and solar activity to an extent but increases with an increase in altitude [5]. Owing to the progressive reduction in atmospheric attenuation, cosmic radiation dose rates increase with altitude, approximately doubling for every 1.5 km rise in elevation [6,7].

There is a large scale effort geared towards protection of the environment, fauna and flora from the harmful effects of radiation. This is evidenced in the numerous agencies both national and international such as International Commission on Radiological Protection (ICRP), International Atomic Energy Agency (IAEA), United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), National Council on Radiation Protection and Measurements (NCRP) and many more [8] that oversee, regulate, and recommend safety measures that can keep the population safe. Obtaining the background ionizing radiation is important in many ways aside from calculating the radiological risk parameters; it is used as a baseline when carrying out any radiation based measurements [9]. Understanding spatial variation in BIR is essential for establishing baseline radiological data, evaluating potential health risks, and informing environmental protection policies. The ICRP recommends an average exposure limit for the general public of approximately 1 mSv^{-1} , corresponding roughly to 0.013 mR^{-1} [10]. The UNSCEAR provides similar guidelines, emphasizing that regional background values should be compared to global which range from 10 to over 200 nGy to assess any deviation due to natural or anthropogenic processes [11,12].

Studies in different parts of the world report varying levels of ionizing radiation. Some places, where levels of background radiation higher than the recommended levels are reported, are caused by anthropogenic activities while others are as a result of natural radiation with typical examples including most of the researches conducted in the Niger Delta regions of Nigeria [13,14] and some of those conducted in parts of Iran [15]. Other studies conducted around the world showed absorbed dose rate of some countries such as North Sinai Coast, Egypt (72.7 nGy^{-1}) [16] and Ireland (37 nGy^{-1}) [17].

There is limited radiometric data available for Imo North Senatorial District. This study aims to measure the background ionizing radiation of Imo North Senatorial District, calculate the associated radiation risk factors as well as provide a radiation map of the district to form a baseline for any radiation study in the district. It is worth noting that the *in situ* method of data collection was used and the data is limited to the area under study. Data collection was done in the month of August alone which corresponds with the Nigeria rainy season, Also the type of radionuclides that give rise to the observed background radiation was not determined in this work.

2. Materials and Method

2.1. Study Area

The study area is Imo North Senatorial District of Imo State, Nigeria. Geographically, as indicated in **Figure 1**, it is between longitude $7^{\circ}4'48''$ and $7^{\circ}25'48''$, and latitude $5^{\circ}30'36''$ and $5^{\circ}56'24''$ north of the equator. The senatorial district comprises six local government areas namely, Okigwe Local Government, Onuimo Local Government, Isiala Mbano Local Government, Ehime Mbano Local Government, Ihitte Uboma Local Government, and Obowo Local government Area. The district is sometimes casually referred to as Okigwe Zone. Imo North contains the third largest city in Imo State which is Okigwe. The senatorial district is surrounded by Abia Sate in the east and north, Anambra state in the north, Imo West and Imo East Senatorial Districts in the west and south respectively. It has a surface land mass of about 953.3 km^2 [18]. The landscape is mostly hilly and undulating with an average height of about 150 m above sea level. The district is traversed by Imo River and its numerous distributaries. There are several quarry sites scattered in the district where the locals and companies source materials for construction purposes and raw materials respectively. The population is also relatively high with 799,556 people that is projected to be edging towards a million in 2020 [19].

2.2. Materials

Each of the six local government areas sampled was divided into five towns. Four locations were chosen in each town and 3 *in situ* readings recorded. The outdoor ionizing background radiation was measured with two well calibrated nuclear radiation meters, Radalert 100 and Digilert 200 that can detect gamma, alpha, beta, and X-rays. The detectors were held at about 1 m above the ground and turned on. They were allowed to come to a stable value before the readings were taken. The devices were turned off after each reading to allow them to reset before

proceeding to take the second and third readings. Guidelines for taking readings during maximum response to environmental radiation of the detector according to National Council on Radiation Protection and Measurement [20], were strictly adhered to. The detector is calibrated to display in counts per minute (CPM), microsievert per hour ($\mu\text{Sv/h}$) and milliroentgen per hour (mRh^{-1}) but the readings were taken and presented in mRh^{-1} . The coordinates were taken at the same sampling spot using the Garmin 72H GPS receiver.

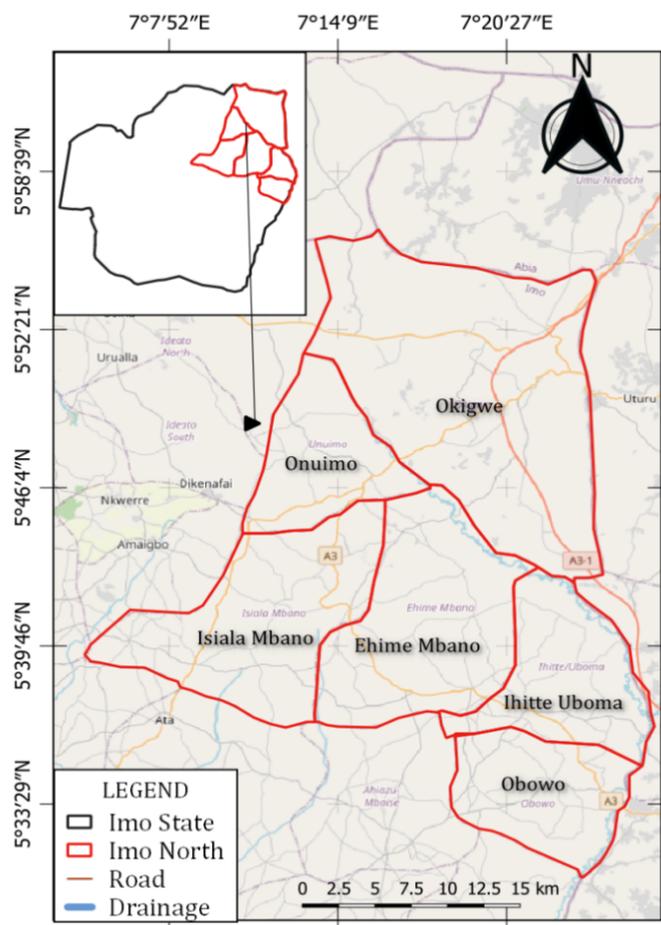


Figure 1. Map of the study area showing all local governments.

2.3. Methods

Four locations were picked from each town and three readings were taken from each location and the average calculated. Five towns were chosen systematically from the six local government areas in the district. In summary, twelve readings were taken from each town, sixty from a local government area and in total 360 readings for the entire senatorial district. Altitude at each sampling location was obtained using Google earth services.

The measured values for the outdoor exposure rate taken from the radiation detection meter were converted to absorbed dose rate (ADR), which is the amount of radiation energy absorbed per unit mass of material. It is expressed in nano Gray per hour employing the relation below [4,5],

$$\text{ADR} = 1\mu\text{R/hr} = 8.7\text{nGy}\text{h}^{-1} \quad (1)$$

The ADR in Equation (1) comprises the terrestrial and cosmic radiation. The contribution to the absorbed dose rate from direct cosmic radiation is calculated using the relations,

$$E1(z) = E1(0)[0.21\exp(-1.649z) + 0.79\exp(0.4528z)] \quad (2a)$$

Dose rate from cosmic neutrons is given as;

$$EN(z) = EN(0)[1.98\exp(0.698z)] \tag{2b}$$

Where,

z is elevation above sea level expressed in kilometers,

El(0) is dose rate at sea level taken as 31 nGyh⁻¹,

EN(0) is dose rate contributed by neutrons at sea level taken as 0.5 nGyh⁻¹ [4].

The mean elevation of the study area is approximately 150 m which indicates from Equation (2) that the cosmic contribution to background ionizing radiation in Imo North Senatorial District is approximately 32 nGyh⁻¹.

Absorbed dose rate obtained in Equation (1) was then deployed to calculate the annual effective dose equivalent (AEDE) taken by individuals residing in the area under study. AEDE estimates biological risk, and it represents the equivalent dose received by the whole body over a year period, accounting for time, tissue weighting, and radiation type. The recommended conversion factor from ADR in air to effective dose assimilated by adults is 0.7 Sv/Gy according to UNSCEAR 2000 and 2008 reports as well as ICRP 2007 Annals of ICRP Recommendations [10, 11]. Occupancy factor for outdoor exposure in this part of the world was pegged at 0.2 [14].

$$AEDE(\text{mSvy}^{-1}) = D \times T \times Q = D \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \tag{3}$$

Where: D = absorbed dose in nGyh⁻¹,

T = time in hours/year,

Q = quality factor (for gamma radiation, Q = 1),

0.2 = occupancy factor (assumes 20% time spent outdoors. Considering prevailing climatic conditions, socio-economic lifestyles, and typical daily activity patterns that limit prolonged outdoor residence. Another reason is that it has been),

0.7 = dose conversion factor (Sv/Gy for adults).

Excess lifetime cancer risk (ELCR) is the likelihood of having cancer during a life span at a given exposure level [21]. The ELCR was calculated using the equation.

$$ELCR = AEDE \times DL \times RF \tag{4}$$

Where,

AEDE is the Annual Effective Dose Equivalent,

DL indicates the average life span (taken as 70 years average),

RF denotes the Risk Factor (Sv⁻¹). For probability effects, ICRP 106 uses a figure of RF = 0.05 for humans or 5% risk per Sievert [22, 23].

3. Results and Discussion

The results obtained for the ionizing background radiation of Imo North Senatorial District as well as their associated estimated radiological health risk factors are presented in **Tables 1–7**. The tables show the BIR values and their radiological risk factors arranged on the same row to the towns where they were obtained. The radiation risk parameters estimated from the exposure rates are, absorbed dose rate, annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR).

Table 1. Outdoor mean exposure rate and their radiation risk parameters as obtained from Obowo Local Government Area.

S/N	Sampling Town	GPS Coordinate	Mean Exposure Rate (mRh ⁻¹)	Absorbed Dose (nGyh ⁻¹)	AEDE (mSvy ⁻¹)	ELCR × 10 ⁻³
1	Alike	E7.321283 N5.559617	0.0137 ± 0.0014	119.19	0.1460	0.5120
2	Avutu	E7.365236 N5.536347	0.0147 ± 0.0005	127.89	0.1570	0.5490

Table 1. Cont.

S/N	Sampling Town	GPS Coordinate	Mean Exposure Rate (mRh ⁻¹)	Absorbed Dose (nGyh ⁻¹)	AEDE (mSvy ⁻¹)	ELCR × 10 ⁻³
3	Otoko	E7.402183 N5.555933	0.0128 ± 0.0015	111.36	0.1370	0.4780
4	Umuaweke	E7.38945 N5.567400	0.0132 ± 0.0018	114.84	0.1410	0.4930
5	Okwuohia	E7.335983 N5.599317	0.0124 ± 0.0018	107.88	0.1320	0.4630
	Mean		0.0134 ± 0.0009	116.23 ± 7.7500	0.1400 ± 0.0090	0.4990 ± 0.0330
	UNSCEAR (2008) Safe limit		0.0133	84.000	1.0000	0.4860

Table 2. Outdoor mean exposure rate and their radiation risk parameters as obtained from Ihitte Uboma Local Government Area.

S/N	Sampling Town	GPS Coordinate	Mean Exposure Rate (mRh ⁻¹)	Absorbed Dose (nGyh ⁻¹)	AEDE (mSvy ⁻¹)	ELCR × 10 ⁻³
1	Abueke	E7.386933 N5.614483	0.0136 ± 0.0017	118.32	0.145	0.5080
2	Umuihi	E7.352300 N5.636933	0.0142 ± 0.0012	123.54	0.152	0.5300
3	Onicha	E7.352417 N5.702233	0.0128 ± 0.0025	111.36	0.137	0.4780
4	Umuawuchi	E7.385717 N5.651367	0.0107 ± 0.0017	93.09	0.114	0.4000
5	Amakoha	E7.340150 N5.623050	0.0125 ± 0.0006	108.75	0.133	0.4670
	Mean		0.0128 ± 0.0013	111.01 ± 11.580	0.1360 ± 0.0100	0.4760 ± 0.0497
	UNSCEAR (2008) Safe limit		0.0133	84.000	1.0000	0.4860

Table 3. Outdoor mean exposure rate and their radiation risk parameters as obtained from Ehime Mbanjo Local Government Area.

S/N	Sampling Town	GPS Coordinate	Mean Exposure Rate (mRh ⁻¹)	Absorbed Dose (nGyh ⁻¹)	AEDE (mSvy ⁻¹)	ELCR × 10 ⁻³
1	Umueze	E7.239983 N5.622783	0.0127 ± 0.0026	110.49	0.1360	0.4740
2	Umunumu	E7.283067 N5.669450	0.0124 ± 0.0017	107.88	0.1320	0.4630
3	Nsu	E7.316600 N5.635183	0.0132 ± 0.0012	114.84	0.1410	0.4930
4	Umunakanu	E7.270867 N5.665333	0.0124 ± 0.0016	107.88	0.1320	0.4630
5	Umuezeala	E7.278183 N5.633216	0.0141 ± 0.0006	122.67	0.1500	0.5260
	Mean		0.0130 ± 0.0007	112.75 ± 6.2300	0.1400 ± 0.0076	0.4840 ± 0.0270
	UNSCEAR (2008) Safe limit		0.0133	84.000	1.0000	0.4860

Table 4. Outdoor mean exposure rate and their radiation risk parameters as obtained from Isiala Mbanjo Local Government Area.

S/N	Sampling Town	GPS Coordinate	Mean Exposure Rate (mRh ⁻¹)	Absorbed Dose (nGyh ⁻¹)	AEDE (mSvy ⁻¹)	ELCR × 10 ⁻³
1	Anara	E7.168633 N5.704200	0.0133 ± 0.0022	115.71	0.1420	0.4970
2	Umuduru	E7.235733 N5.702667	0.0146 ± 0.0002	127.02	0.1560	0.5450
3	Amaraku	E7.148100 N5.650833	0.0134 ± 0.0010	116.58	0.1430	0.5000
4	Umuelemai	E7.246050 N5.693533	0.0113 ± 0.0034	98.310	0.1220	0.4220
5	Osuachara	E7.207783 N5.726867	0.0114 ± 0.0017	99.180	0.1220	0.4260
	Mean		0.0128 ± 0.00142	111.36 ± 12.350	0.1370 ± 0.0152	0.4780 ± 0.0530
	UNSCEAR (2008) Safe limit		0.0133	84.000	1.0000	0.4860

Table 5. Outdoor mean exposure rate and their radiation risk parameters as obtained from Onuimo Local Government Area.

S/N	Sampling Town	GPS Coordinate	Mean Exposure Rate (mRh ⁻¹)	Absorbed Dose (nGyh ⁻¹)	AEDE (mSvy ⁻¹)	ELCR × 10 ⁻³
1	Okwelle	E7.181733 N5.745233	0.0128 ± 0.0013	111.36	0.1370	0.4780
2	Ezelu	E7.242400 N5.755867	0.0133 ± 0.0022	115.71	0.1420	0.4970
3	Okwe	E7.206983 N5.783483	0.0118 ± 0.0014	102.66	0.1260	0.4410
4	Umuduru	E7.244783 N5.787717	0.0126 ± 0.0025	109.62	0.1340	0.4710
5	Okohia	E7.252667 N5.78183	0.0138 ± 0.0025	120.06	0.1470	0.5150
	Mean		0.0129 ± 0.0026	111.88 ± 6.5600	0.1370 ± 0.0080	0.4800 ± 0.0281
	UNSCEAR (2008) Safe limit		0.0133	84.000	1.0000	0.4860

Table 6. Outdoor mean exposure rate and their radiation risk parameters as obtained from Okigwe Local Government Area.

S/N	Sampling Town	GPS Coordinate	Mean Exposure Rate (mRh ⁻¹)	Absorbed Dose (nGyh ⁻¹)	AEDE (mSvy ⁻¹)	ELCR × 10 ⁻³
1	Amuro	E7.289300 N5.793567	0.012 ± 0.0037	104.40	0.1280	0.4480
2	Ezinachi	E7.332383 N5.767767	0.0106 ± 0.0026	92.220	0.1130	0.3960
3	Okigwe Urban	E7.338300 N5.820867	0.0121 ± 0.0020	105.27	0.1290	0.4520
4	Ihube	E7.367217 N5.870350	0.0113 ± 0.0020	98.310	0.1210	0.4220
5	Umulolo	E7.315950 N5.870750	0.0126 ± 0.0015	109.62	0.1340	0.4710
	Mean		0.0117 ± 0.0008	101.96 ± 6.7800	0.1250 ± 0.0083	0.4380 ± 0.0290
	UNSCEAR (2008) Safe limit		0.0133	84.000	1.0000	0.4860

Table 7. Summary of outdoor mean exposure rate and the radiation risk factors of the sample local governments in the Imo North Senatorial District, Nigeria.

S/N	Sampling Town	GPS Coordinate	Mean Exposure Rate (mRh ⁻¹)	Absorbed Dose (nGyh ⁻¹)	AEDE (mSvy ⁻¹)	ELCR × 10 ⁻³
1	Obowo	E7.365236 N5.536347	0.0134 ± 0.0009	116.23 ± 7.7500	0.1400 ± 0.0090	0.4990 ± 0.0330
2	Ihitte Uboma	E7.340150 N5.623050	0.0128 ± 0.0013	111.01 ± 11.580	0.1360 ± 0.0100	0.4760 ± 0.0500
3	Ehime Mbanda	E7.278183 N5.633216	0.0130 ± 0.0007	112.75 ± 6.2300	0.1400 ± 0.0080	0.4840 ± 0.0270
4	Isiala Mbanda	E7.235733 N5.702667	0.0128 ± 0.0014	111.36 ± 12.350	0.1370 ± 0.0150	0.4780 ± 0.0530
5	Onuimo	E7.206983 N5.783483	0.0129 ± 0.0026	111.88 ± 6.5600	0.1370 ± 0.0080	0.4800 ± 0.0280
6	Okigwe	E7.338300 N5.820867	0.0117 ± 0.0008	101.96 ± 6.7800	0.1250 ± 0.0080	0.4380 ± 0.0290
	Mean		0.0128 ± 0.0006	110.86 ± 4.7700	0.1360 ± 0.0060	0.4760 ± 0.0200
	UNSCEAR (2008) Safe limit		0.0133	84.000	1.0000	0.4860

3.1. Spatial Variation of BIR in Imo North

In the present study, in-situ BIR exposure rate measurements were conducted across six Local Government Areas (LGAs) of Imo North Senatorial District: Obowo, Ihitte Uboma, Ehime Mbanda, Isiala Mbanda, Onuimo, and Okigwe as shown in **Figure 2**. The results indicated no wide variation in the mean exposure rates across the sampled locations, suggesting a relatively uniform distribution of natural radionuclides in the soil and ambient environment.

In Obowo LGA, mean values from the sampled towns ranged from 0.0124 ± 0.0018 mRh⁻¹ in Okwuhia to 0.0147 ± 0.0005 mRh⁻¹ in Avutu, with an average of 0.0134 ± 0.0009 mRh⁻¹. In Ihitte Uboma LGA, BIR varied from 0.0107 ± 0.0017 mRh⁻¹ in Umuawuchi to 0.0142 ± 0.0012 mRh⁻¹ in Umuihi, yielding a mean of 0.0128 ± 0.0013

mRh^{-1} . The estimated mean exposure rates for Ehime Mbano, Isiala Mbano, Onuimo, and Okigwe LGAs were $0.0130 \pm 0.0007 \text{ mRh}^{-1}$, $0.0128 \pm 0.0014 \text{ mRh}^{-1}$, $0.0129 \pm 0.0026 \text{ mRh}^{-1}$, and $0.0117 \pm 0.0008 \text{ mRh}^{-1}$, respectively.

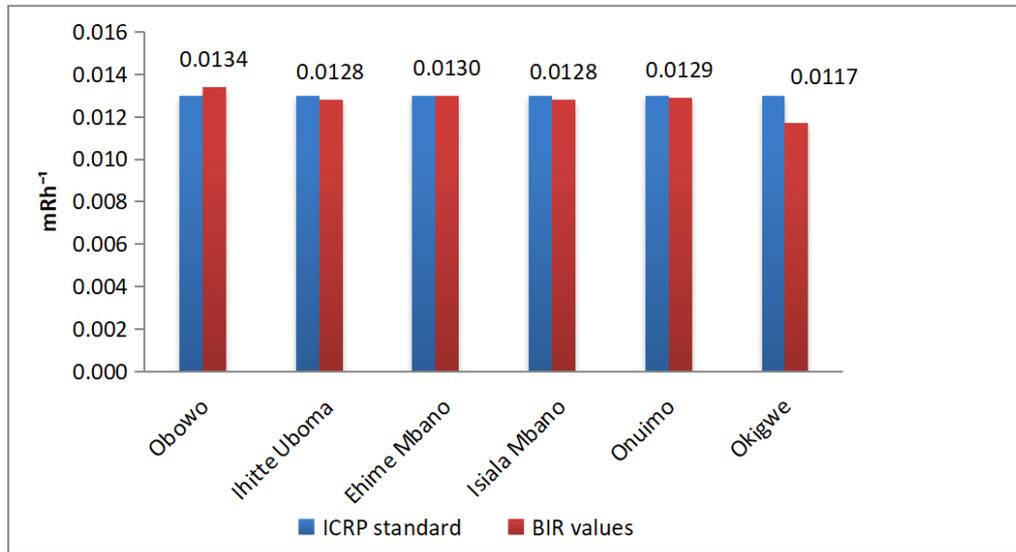


Figure 2. Comparison of outdoor BIR values with ICRP standard in Imo North Senatorial District.

The lowest BIR values of approximately 0.008 mRh^{-1} were recorded in Ezinachi Town (Okigwe LGA) and Umuelemai Town (Isiala Mbano LGA). These towns are relatively rural with limited anthropogenic or industrial activities, which likely explains the low exposure levels. By contrast, the highest values— $0.0147 \pm 0.0005 \text{ mRh}^{-1}$, were observed in Obowo LGA, particularly near Avutu, consistent with the presence of quarrying activities that disturb subsurface materials, potentially exposing naturally radioactive elements such as Uranium—238 and Thorium—232 series isotopes.

The mean BIR level for the entire senatorial district was calculated as $0.0128 \pm 0.0006 \text{ mRh}^{-1}$, which is within the global average range of natural background radiation as reported by UNSCEAR and ICRP [10,11]. This implies that the region's radiation environment poses no acute radiological health concern to the population.

3.1.1. Spatial Visualization Using Geographic Information System (GIS)

To elucidate spatial distribution patterns, a GIS contour map was generated (Figure 3). The contour map depicts the gradation of exposure rates across the senatorial district, highlighting areas of slightly elevated BIR (e.g., Obowo) and lower radiation zones (e.g., Okigwe). Similarly, a radiological map (Figure 4) was constructed to show the geographical locations of the sampled towns and their corresponding BIR levels at a glance.

GIS-based radiation mapping is a robust analytical tool in environmental radiological assessment, as it integrates spatial coordinates, exposure values, and topographical features to visualize distribution trends [9]. This spatial analysis aids in identifying potential hotspots and understanding correlations between geology, land use, and radiation intensity.

3.1.2. Comparative Assessment with Previous Studies

The exposure rate values recorded in Imo North are comparable to those obtained by Ononugbo et al. [14] from the vicinity of Aba River, where background exposure ranged from $0.01\text{--}0.018 \text{ mRh}^{-1}$. Given that Aba River is a tributary of the river system traversing Imo North, the similarity suggests comparable soil mineralogy and sediment characteristics.

The slightly lower exposure rates in Imo North are attributable to reduced population density and limited industrial activities, factors that directly correlate with lesser anthropogenic radiation sources. By contrast, regions such as the Niger Delta exhibit higher values due to oil and gas exploration, refining, and waste disposal practices, which mobilize naturally occurring radioactive materials (NORMs) [13,24,25].

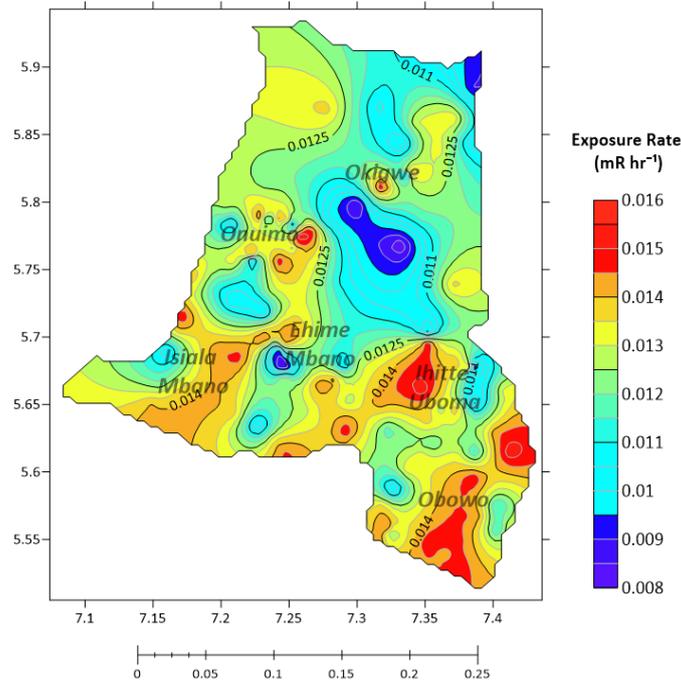


Figure 3. GIS contour map of Imo North Senatorial District depicting BIR exposure rate.

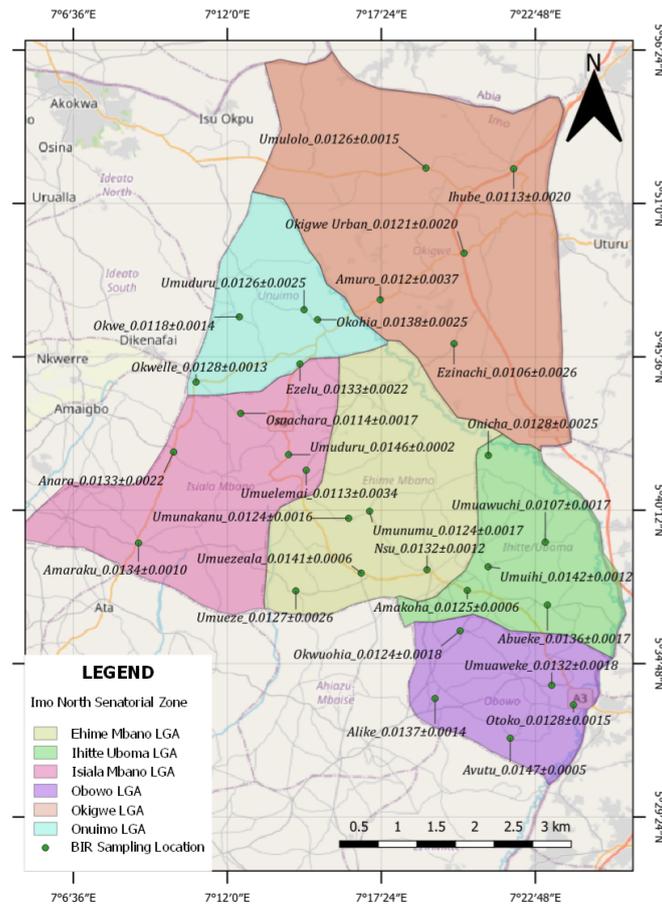


Figure 4. Mean background Ionizing Radiation Map of Imo North Senatorial District, Imo State, Nigeria.

Specifically, Agbalagba and Anekwe reported values of $0.018 \pm 0.003 \text{ mRh}^{-1}$ in Agbor and $0.023 \pm 0.009 \text{ mRh}^{-1}$ in Asaba [9], indicating that the BIR levels in Imo North are lower by comparison. The differences underscore the influence of industrialization and geology—particularly the presence of hydrocarbon-bearing formations—on terrestrial radiation levels.

When compared with international datasets, the mean BIR level in Imo North (0.0128 mRh^{-1}) aligns closely with global averages. The results are lower than those reported in Iran [26] and Pakistan [4], where geological formations are rich in uranium and thorium minerals. Conversely, the values are higher than those from North Sinai, Egypt [16], possibly due to the arid environment with less accumulation of radionuclides in soil. The Imo North values are also comparable to those obtained in India [27], indicating that natural background levels in Imo North Senatorial District fall within the global natural radiation background spectrum ($0.01\text{--}0.02 \text{ mRh}^{-1}$). This trend is also true for the absorbed dose rate as shown in **Figure 5**.

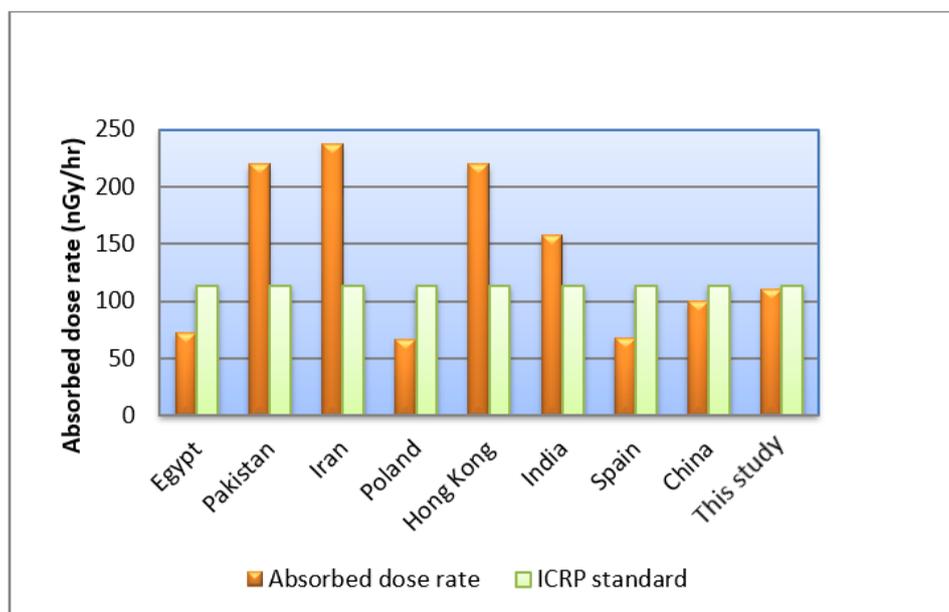


Figure 5. Comparison of outdoor absorbed dose rates of this study with some countries around the world.

3.1.3. Interpretation of Low and High BIR Zones

The relatively low BIR values in Ezinachi and Umuelemai can be theoretically explained by low soil permeability, vegetation cover, and absence of anthropogenic activities that disturb subsurface radionuclides. According to UNSCEAR (2008), areas with clay-rich or water-logged soils often exhibit reduced gamma emissions because of attenuation by moisture and mineral composition.

On the other hand, higher BIR values observed in Obowo are consistent with the “radon progeny hypothesis” and radiation diffusion theory, which state that mechanical disturbances, such as mining or quarrying expose uranium- and thorium-bearing minerals, increasing local gamma flux density. Moreover, quarry sites often contain granitic or metamorphic rocks with elevated natural radioactivity levels [28]. The slightly elevated values, though within safe limits, demonstrate how geological processes influence environmental radiation distribution.

3.2. Absorbed Dose Rate

However, in this study, the absorbed dose rate was determined from *in situ* measurements using a portable gamma-ray detector, and subsequently corrected for altitude and cosmic contribution.

Given the average altitude of 150 m for the Imo North Senatorial District, the cosmic ray contribution was estimated to be 32.33 nGyh^{-1} , while the terrestrial radiation component accounted for 78.53 nGyh^{-1} . This decomposition reflects the global understanding that cosmic rays contribute approximately $25\text{--}35 \text{ nGyh}^{-1}$ at sea level and increase with altitude due to the thinning atmosphere [10]. The total absorbed dose rate thus combines both

contributions, yielding a regional mean of $110.86 \pm 4.77 \text{ nGyh}^{-1}$ for the district.

When comparing local government areas, only Obowo LGA exhibited an absorbed dose rate ($116.2 \pm 7.75 \text{ nGyh}^{-1}$) that slightly exceeded the International Commission on Radiological Protection reference value of 113.1 nGyh^{-1} [29]. The elevated dose rate in Obowo can be attributed to the presence of several quarry sites and the consequent exposure of subsurface materials containing uranium and thorium series radionuclides. Such geological activities enhance the release of radionuclides into the surrounding environment, thereby increasing the terrestrial gamma component [9].

The mean absorbed dose rate across Imo North Senatorial District aligns closely with values recorded in Ishielu Local Government Area, Ebonyi State [30], suggesting similar lithological and soil characteristics. However, it is significantly lower than dose rates reported for southeastern Iran, where elevated natural radioactivity has been linked to granite-rich terrains and volcanic formations [31]. These findings indicate that the Imo North region is characterized by relatively low to moderate terrestrial background radiation, consistent with sedimentary geological formations and limited mineralization activities.

Comparatively, Seddeek et al. observed analogous absorbed dose rate values along the North Sinai Coast of Egypt, a low-lying region [16] similar in altitude and geomorphology to Imo North. This agreement underscores the influence of altitude and lithology on background radiation levels. Globally, the United Nations Scientific Committee on the Effects of Atomic Radiation [11] reports that the worldwide average outdoor absorbed dose rate from terrestrial gamma radiation is about 59 nGyh^{-1} [12], while the total including cosmic radiation is around 84 nGyh^{-1} . Therefore, the elevated value in the present study (110.86 nGyh^{-1}) may reflect local variations in soil radionuclide concentrations.

3.3. Annual Effective Dose Equivalent (AEDE)

Using the average absorbed dose rate of 110.86 nGyh^{-1} , the AEDE for Imo North was calculated as $0.136 \pm 0.006 \text{ mSvy}^{-1}$. This value is below the worldwide average outdoor exposure level of 1.0 mSvy^{-1} recommended by UNSCEAR report and ICRP Publication 103 [10,11]. It also falls below the annual dose limit for the general public of 1.0 mSvy^{-1} , indicating minimal radiological health risk.

The calculated AEDE is lower than the values obtained around the Aba River [14], and those from the oil spill regions of Gokana, Rivers State [13], where intense anthropogenic and industrial activities have contributed to elevated radionuclide concentrations. Conversely, it is higher than values reported for Taiwan [32], likely due to differences in soil composition and cosmic ray intensity at higher latitudes.

The observed AEDE implies that the residents of Imo North Senatorial District receive radiation doses within the safe range for natural background exposure. However, prolonged exposure to even low-level radiation over decades contributes cumulatively to the overall lifetime dose and potential stochastic health effects such as cancer [10,11]. These dose assessments are therefore essential for establishing baseline radiological maps for future environmental and public health monitoring.

3.4. Excess Lifetime Cancer Risk (ELCR)

Substituting the obtained AEDE values yields ELCR values ranging from $(0.438 \pm 0.029) \times 10^{-3}$ in Okigwe LGA to $(0.499 \pm 0.033) \times 10^{-3}$ in Obowo LGA, with an overall mean of $(0.476 \pm 0.020) \times 10^{-3}$. These results are within the recommended global average of 0.486×10^{-3} [5]. This indicates that the population in Imo North experiences normal background cancer risk levels comparable to those in similar low-radiation environments worldwide.

While these figures suggest a negligible radiological hazard, continuous environmental monitoring remains vital since cumulative exposure, even at background levels, can contribute to long-term biological effects. It is imperative to note that no population has been conclusively shown to develop cancer solely from background ionizing radiation exposure [2]. Nonetheless, understanding ELCR trends helps policymakers set local radiation protection guidelines and informs health risk communication.

4. Summary

The present study, therefore, reports a general assessment of the levels of background ionizing radiation in the six Local Government Areas that make up Imo North Senatorial District, southeastern Nigeria. Accordingly, the

variation of the exposure rates was within a narrow range, from 0.0107 to 0.0147 mRh⁻¹, with an overall mean of 0.0128 ± 0.0006 mRh⁻¹. This mean value is within the worldwide natural background limit and also within the limits recommended by the International Commission on Radiological Protection and the United Nations Scientific Committee on the Effects of Atomic Radiation for public exposures [10,11]. The results, therefore, show that residents within the district are not exposed to such radiation levels that exceed internationally accepted safety thresholds.

The spatial distribution of background ionizing radiation across the study area showed a modest variability, largely influenced by geology, soil radionuclide composition, land-use type, and anthropogenic activities. For example, high readings obtained over Obowo Local Government Area were related to quarrying activities and soil disturbance, which expose naturally occurring radioactive materials such as uranium-238, thorium-232, and potassium-40. In contrast, low BIR values in non-industrialized areas like Ezinachi and Umuelemai reflected minimal human interference and less mobilization of soil radionuclides. Such relationships underscore the role of lithological and environmental parameters on background radiation distribution.

The generation of GIS-based contour and radiological maps for the district has provided an essential visual presentation of the regional radiation field. These maps not only delineate areas of relatively higher or lower intensities of radiation but also form very useful baseline data to be used for further monitoring and land-use planning purposes. Spatial mapping techniques applied in radiological studies enhance the capacity for environmental decision-making, especially in the identification of hotspots that might require closer investigation.

These observed results are further validated by a comparative analysis with similar studies from within and outside the country. This mean value of BIR for Imo North is lower compared to those obtained in the Niger Delta region, an area characterized by intense oil and gas exploration activities [9,13], but comparable to levels recorded in other low-lying sedimentary environments such as the North Sinai, Egypt [16]. When juxtaposed with findings from countries like Iran [26], Pakistan [4], and India [27], the BIR in Imo North falls within the lower to moderate global range, underlining the relatively benign radiological landscape of the region.

Further evidence comes from the integrated assessment of the absorbed dose rate, AEDE, and ELCR, all of which confirm that the natural radiation environment in the district is radiologically safe. The average absorbed dose rate of 110.86 ± 4.77 nGyh⁻¹ and the corresponding AEDE of 0.136 ± 0.006 mSv yr⁻¹ are below the international dose limit of 1 mSv yr⁻¹ to the public, hence confirming that there is negligible health risk to the local population. In addition, the mean ELCR of (0.476 ± 0.020) × 10⁻³ falls within the global average [11], hence implying that the probability of radiation-induced cancer within the population lies within the normal background expectation.

5. Conclusions

The result from this study has a number of policy and scientific implications from an environmental and public health perspective. They establish a credible baseline database for regional and national radiation monitoring programs. Such baseline data is very important for the purposes of monitoring changes in environmental radioactivity arising from further urbanization, industrial expansion, or resource extraction. The results contribute to Nigeria's compliance with global radiation safety frameworks put forward by UNSCEAR and ICRP, hence promoting evidence-based environmental protection policies. Moreover, the relatively low dose estimates may guide land-use planners and public health agencies in identifying areas without radiological concerns that are appropriate for residential or agricultural development. However, the study also enumerates the necessity for ongoing monitoring and longitudinal assessments. Change in land-use patterns, quarrying, infrastructural development, and possible intensification of agriculture might disturb the natural background levels of radionuclides in soil and atmosphere, leading to further fluctuations in BIR in future. Hence, sustained surveillance with GIS-based radiological mapping will be necessary to ensure that background radiation remains within safe limits during the development process of the region. In summary, the natural radiation environment of Imo North Senatorial District can be regarded as radiologically safe, as all the parameters measured are within internationally recommended threshold limits. The field measurement and spatial analysis supplement a comparative evaluation of the district's radiological profile. In this way, the study enriches Nigeria's repository of environmental radiation data and supports current global efforts to quantify and manage exposure to natural background radiation. Periodic monitoring and integration of radiological data within the existing framework of environmental management will ensure that the region maintains its present low-risk status in a manner that is protective of socio-economic development, consistent with ICRP and UNSCEAR

radiation protection principles.

Author Contributions

The Research was conceptualized by U.N., G.O.A., and C.P.O.; investigation, data curation, analysis, methodology, software, and original draft preparation were done by U.N., while validation, supervision, and reviews were done by G.O.A. and C.P.O. All authors have read and agreed to the published version of the manuscript.

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Generated data is already presented in the work.

Conflicts of Interest

The authors declare no conflict of interest.

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