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Evaluation of background ionizing radiation to estimate effective dose and excess lifetime cancer risk from two major dumpsite in Calabar, Nigeria

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Abstract

By using a chamber radiation survey meter, meter rule to measure distance between data points, and a geographical positioning system (GPS) to measure the coordinate of the study area, the study of background ionizing radiation levels in Calabar the metropolis has been conducted to assess the effective dose to the body's organs and tissues as well as the excess lifetime cancer risk. The elevation level of the chamber survey meters was maintained at 1.0 meters above the ground. The average BIR absorbed dose rate, annual effective dose equivalent, excess lifetime cancer risk, and effective dose to the organs and tissues were among the radiological hazard characteristics that were assessed. From the results of the mean radiological hazard indices from the study are BIR dose rate is 0.03±0.003 (μSv/h), ADR is 33±3.10 nGy/h, AEDE 0.04±0.004 mSv/y, ELCR is 0.14±0.013mSv/y while EDR was 1.4±0.07mSv/y for Udeme dumpsite. In Lemna dumpsite we have the following radiological hazard indices mean values, the BIR dose rate 0.04±0.03, ADR of 29±3.8nGy/h, AEDE 0.0 4± 0.005 mSv/y, ELCR is 0.12±0.016 while EDR is 1.7±0.16 respectively. All the calculated radiological hazard parameters are below the recommended dose limit of 1mSv/y by UNSCEAR, ICRP, IAEA and WHO. Even the ELCR is less than the recommended dose limit of 0.29 mSv/y, except effective dose to the organs and tissues which are relatively above recommended threshold at both dumpsites. The results show that the estimated dose to various body organs and tissues are relatively higher than the recommended 1.0mSv/y. The food nutrient absorption rate within the study area justifies the relatively lower dose consumption for the brain, skin, and bone and the comparatively greater dose for the heart, pancreas, and prostate.

Keywords; Dumpsites; Background ionizing radiation; ELCR; Effective dose

1. Introduction

Background ionizing radiation has an ionizing effect, which is a form of energy generated by atoms with sufficient power to liberate tightly bonded electrons from other atoms to form ions [1]. People encounter it on a regular basis as a result of both natural and man-made events [2]. This procedure is categorized by nature and source of radiation and has the potential for severe damage to living tissues (radiation exposure). Ionizing radiation exposure comes from a variety of sources, including internal, terrestrial, and cosmic radiation. This focuses only on background radiation that occurs naturally. In the environment, ionizing radiation from naturally occurring sources is known as natural background radiation. These sources add to the total amount of radiation to which we are exposed to on a daily basis. Location and other variables, such as altitude, affect the typical dose rate for background radiation. On average, nevertheless, 2.4 millisieverts (mSv) annually are produced [3]. This includes intakes from natural sources including radon gas, terrestrial radiation from the earth, and cosmic radiation.

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Background ionizing radiation (BIR) is constantly emitted from waste dumpsites and naturally occurring radioactive materials (NORM) in the soil. These emissions happen as a result of degradation processes [4]. Other ionizing radiation sources include ^{137}Cs, ^{133}Ba, ^{90}Sr, and ^{222}Rn gas, which are primarily generated and discarded by industries. The total effective radiation dose to living things in a particular environment is made up of all these materials when they are handled or disposed of carelessly according to (UNSCEAR) [5].

Avwiri et al. suggest that radiation exposure and health hazards for both workers and the general public in a given area are directly related [6]. When background ionization radiation above safe occupational and public health thresholds, it may be regarded as a type of environmental contamination. Human activity in the city produces a variety of wastes that, if not effectively handled, can be an aesthetic nuisance, lower the city's socio-economic value, and endanger the public's health. Background radiation exposure, which is found in the atmosphere and all over the planet, can also increase radiation exposure levels that could have adverse effects on residents' health [7].

According to studies, ionizing radiation exposure during pregnancy could result in cancer and mental disability in the unborn child. According to the National Research Council (NRC), high radiation dosages can also result in additional health consequences [8, 9]. According to Ibiri's 1999 assessment, the population faces a number of health issues as a result of rising background ionizing radiation levels from multiple sources. According to Farai and Jibiri, the dose rate of outdoor gamma radiation exposure in eastern Nigeria ranges from 0.025 to 0.08 Gyh^{-1} [11]. The radiation levels in the environment in Ikot-Ekpene, South South Nigeria, were also examined by Akpabio, who found that they are typically low [12]. Echeweozo et al, 2025, evaluated health risks at the major solid waste dumpsite in Ebonyi State as a result of environmental radioactivity and heavy metal contamination and reported that the average ^{40}K, ^{232}Th, and ^{238}U concentration values found across all locations under investigation are below the global average. According to Osimobi et al., who were monitoring some of the solid mineral mining sites in Enugu state, the background ionizing radiation levels were 38.5% higher than usual.

Scientists have found that radiation exposure is strongly associated with environmental and human health concerns. These risks are linked to several waste types, including metal scraps, hazardous industrial waste, chemical toxic waste, radiation waste, household waste, and agricultural waste. The radiation dose is determined by the radiation's energy and intensity, type, duration of exposure, exposed area, and depth of energy deposition. The absorbed dose, the effective dose, and the equivalent dose are among the quantities that have been established to specify the dose received and its biological effectiveness [20].

The absorbed dose rate (ADR) indicates the amount of radiation absorbed per unit mass of material. Gray is the S.I. unit. 1Jkg-1 = 1Gy. The absorbed dose rate (ADR), which is measured in Gys^{-1} and $mGyh^{-1}$, is the rate at which a dosage is absorbed. It is important to remember that the biological effect depends on the rate at which the dosage was taken as well as the total amount of exposure to tissue. The equivalent dose rate (EDR) and the absorbed dose do not give a reliable indicator of the damage that radiation can inflict since identical absorbed levels of radiation do not necessarily have the same biological effects. Alpha radiation is more dangerous than beta or gamma radiation when absorbed in doses of 0.1 Gy. It uses the equivalent dose to reflect the harm caused by various forms of radiation to biological systems. Its definition is based on the absorbed dosage, weighted by a radiation-type-dependent component. It is measured in Sieverts (Sv) [20].

Ionizing radiation exposure has a significant risk of indirect chromosomal change, radiation keratogenesis, and cancer induction. The method of reducing one's exposure to ionizing radiation to the lowest level that is practically possible is known as ALARA (as low as reasonably achievable) [19].

In terms of industrialization and socioeconomic activity, Calabar, the capital of Cross River State, is one of the fastest-growing states in Nigeria's south-south geopolitical zone.

As such, all the municipal waste generated finds their way to the major dumpsites in the state. Therefore, the purpose of this study was to gather detailed information on ionizing radiation exposure in Calabar's various waste dumps and determine the potential health risks (cancer risk) for scavengers and local residents. The exposure information gathered for this study will supplement that gathered for previous research [15, 16, 17, 18,19].

2. Theoretical Background

2.1. Evaluation of Absorbed Dose Rate (ADR)

Absorbed dose rate (ADR) with SI unit in $nGyh^{-1}$ for air at 1 meter higher than the ground level was estimated using equation (1)

$$ADR = 0.0417C_K + 0.604C_{Th} + 0.462C_U \quad ………. (1)$$

Since radium and its offspring from uranium's breakdown produce most of the radiation, ^{226}Ra from ^{238}U was used in estimating the absorbed dose rate. The estimated absorbed dose rates in air, which are typically 1m higher than the ground level, are linked with the absorbed dose in humans.

2.2 Evaluation of Annual Effective Dose Equivalent (AEDE).

Annual effective dose (mSvy−1) often refers to the total of the annual absorbed doses from both indoor and outdoor sources. It was calculated using equations (2), (3), and (4).

$$AEDE_{in}\ (mSvy^{-1}) = ADR \times 0.7 \times 0.8 \times 8760 \times 10^{-6} \quad ………... (2)$$

$$AEDE_{out}(mSvy^{-1}) = ADR \times 0.7 \times 0.2 \times 8760 \times 10^{-6}, \quad ………... (3)$$

$$AEDE_{TOTAL} = AEDE_{IN} + AEDE_{OUT} \quad ………... (4)$$

where the total number of hours in a year is 8760, the rate of dose absorption in the air is ADR, the conversion ratio from absorption dose to effective dose is 0.7, and 0.2 and 0.8 are the occupancy factors for exposures in the indoor and outdoor environments, respectively [22].

2.3 Excess Lifetime Cancer Risk (ELCR):

Excess lifetime cancer risk refers to the hazard of cancer death that is greater than the "natural" background risk as a result of lifetime exposure to carcinogens. The ELCR is calculated using the equation (Keringa, et al 2020).

$$ELCR = AEDE \times DL \times RF \quad ………... (5)$$

where AEDE is the Annual Effective Dose Equivalent, DL is the average Duration of life (calculated as 70yrs), and RF is the risk factor (that is hazardous cancer risk per Sievert).

3. Materials and Methods

3.1. Materials

Materials used in this research are, Chamber radiation survey meter (model 451P ion), geographical positioning system (GPS), measurement tape and writing materials.

3.2. Methods of sample collections

Uwah and Inyang [19] had previously described the research area, Calabar, which is located between longitude 4.88^0 and 5.12^0 N and latitude 8.25^0 and 8.54^0 E of the Greenwich meridian. The two major dumpsites in the city of Calabar are the Lemna and Udeme avenue dumpsite. The Lemna dumpsite is the biggest dumpsite in the state located at Calabar Municipality Local Government Area while Udeme avenue dumpsite is one of the oldest dumpsites in the state and is located at Calabar South Local Government Area. In each of the dumpsites, twenty (20) measurement was taken. And at each sample point, three (3) data points were collected and average taken. To allow samples to retain their original ambient conditions, an in-situ method of measuring background ionizing radiation was used. According to standard procedure, the radiation monitoring meter's tube was elevated to 1.0 meters above the ground [23,24], the chamber radiation survey meter was placed at a point in the location and the readings were recorded, the geographical positioning system (GPS) was used to take coordinate of the area and the procedure was recorded, the measuring meter was used to take the measurements of one data point to another, in this research a distance of 10m apart was employed. The exposure levels were obtained in $\mu Svhr^{-1}$ (micro sievert per hour) and recorded.

4. Results

4.1. Discussion of Results

4.1.1. Presentation of Data

The results of the evaluation of the background ionizing radiation exposure level from the major dumpsite in Calabar metropolis are shown in Tables 1 and 2. The background exposure rate was measured in (μSv/hr) using a chamber radiation survey meter. To record the dumpsites' locations, a geographical positional system (GPS) was employed. For easy identification, each dumpsite's location was coded.

Table 1 Result of background exposure level of Udeme avenue dumpsite

SN	Sampling code	Average Exposure (BIR) (μSvhr^{-1})	Longitude	Latitude	Elevation
1	A1	3.6	N04^{0}55′16.3″	E008^{0}19′45.1″	10m
2	A2	3.5	N04^{0}55′15.3″	E008^{0}19′45.4″	11m
3	A3	3.2	N04^{0}55′16.4″	E008^{0}19′45.7	9m
4	A4	3.3	N04^{0}55′16.0″	E008^{0}19′46.1″	9m
5	A5	3.6	N04^{0}55′16.3″	E008^{0}19′46.3″	7m
6	A6	3.7	N04^{0}55′16.0″	E008^{0}19′45.3″	8m
7	A7	3.2	N04^{0}55′15.9″	E008^{0}19′45.6″	7m
8	A8	2.8	N04^{0}55′16.8″	E008^{0}19′45.6″	8m
9	A9	2.7	N04^{0}55′16.6″	E008^{0}19′45.2″	7m
10	A10	2.7	N04^{0}55′16.3″	E008^{0}19′45.5″	9m
11	A11	3.1	N04^{0}55′16.0″	E008^{0}19′44.8″	9m
12	A12	3.2	N04^{0}55′15.6″	E008^{0}19′44.6″	9m
13	A13	3.5	N04^{0}55′15.5″	E008^{0}19′44.5″	7m
14	A14	3.5	N04^{0}55′15.4″	E008^{0}19′44.7″	8m
15	A15	3.8	N04^{0}55′15.1″	E008^{0}19′45.1″	9m
16	A16	3.2	N04^{0}55′14.9″	E008^{0}19′45.3″	9m
17	A17	3.4	N04^{0}55′15.6″	E008^{0}19′35.6″	8m
18	A18	3.3	N04^{0}55′15.9″	E008^{0}19′44.4″	7m
19	A19	3.5	N04^{0}55’15.9″	E008^{0}19′44.2″	9m
20	A20	3.5	N04^{0}55′15.6″	E008^{0}19′43.8″	9m

Table 2 Result of background exposure level of Lemna dumpsite

SN	Sampling code	Average Exposure (BIR) (μSvhr^{-1})	Longitude	Latitude	Elevation
1	B1	3.67	N05^{0}01′59.8″	E008^{0}21′54.5″	25m
2	B2	3.23	N05^{0}02′00.1″	E008^{0}21′54.4″	26m
3	B3	3.5	N05^{0}02′00.5″	E008^{0}21′54.3″	26m
4	B4	2.8	N05^{0}02′00.7″	E008^{0}21′54.2″	29m
5	B5	3.47	N05^{0}02′01.0″	E008^{0}21′53.9″	27m

6	B6	3.07	N05^{0}02′01.2″	E008^{0}21′53.6″	29m
7	B7	2.7	N05^{0}02′01.4″	E008^{0}21′53.4″	31m
8	B8	2.87	N05^{0}02′01.6″	E008^{0}21′53.1″	32m
9	B9	2.67	N05^{0}02′01.9″	E008^{0}21′52.8″	31m
10	B10	3.2	N05^{0}02′02.1″	E008^{0}21′53.0″	33m
11	B11	3.23	N05^{0}02′02.3″	E008^{0}21′53.4″	32m
12	B12	2.83	N05^{0}02′02.1″	E008^{0}21′53.4″	35m
13	B13	2.93	N05^{0}02′01.9″	E008^{0}21′53.9″	33m
14	B14	3.2	N05^{0}02′01.8″	E008^{0}21′54.3″	28m
15	B15	3.37	N05^{0}02′02.1″	E008^{0}21′54.3″	27m
16	B16	3.3	N05^{0}02′02.5″	E008^{0}21′54.3″	28m
17	B17	3.43	N05^{0}02′02.9″	E008^{0}21′54.2″	29m
18	B18	3.4	N05^{0}02′04.3″	E008^{0}21′53.7″	30m
19	B19	3.4	N05^{0}02′04.6″	E008^{0}21′53.5″	32m
20	B20	2.83	N05^{0}02′04.9″	E008^{0}21′53.4″	32m

Data obtained from the research area was examined using radiological hazard factors, including excess lifetime cancer risk (ELCR), annual effective dose equivalent (AEDE), absorbed dose rate (ADR), and effective dose rate.

Table 3 Results of the radiological hazard parameters from Udeme avenue dumpsite

Locations Udeme Avenue Cal. South CRS	**Average BIR (μSv/h)**	**Dose rate (μSv/h)**	**Absorbed dose rate (nGy/h)**	**AEDE (mSv/y)**	**Excess lifetime cancer risk**	**Effective Dose (mSv)**
A1	3.63	0.04	36	0.04	0.16	1.7
A2	3.47	0.03	35	0.04	0.15	2.6
A3	3.17	0.03	32	0.04	0.14	2.5
A4	3.33	0.03	33	0.04	0.14	2.7
A5	3.63	0.04	36	0.04	0.16	2.9
A6	3.73	0.04	37	0.05	0.16	3.0
A7	3.20	0.03	32	0.04	0.14	0.8
A8	2.80	0.03	28	0.03	0.12	0.7
A9	2.70	0.03	27	0.03	0.12	0.8
A10	2.70	0.03	27	0.03	0.12	0.8
A11	3.00	0.03	30	0.04	0.13	0.8
A12	3.17	0.03	32	0.04	0.14	0.8
A13	3.50	0.04	35	0.04	0.15	0.8
A14	3.50	0.04	35	0.04	0.15	0.2
A15	3.77	0.04	38	0.05	0.16	0.2
A16	3.23	0.03	32	0.04	0.14	0.2

A17	3.37	0.03	34	0.04	0.14	2.3
A18	3.33	0.03	33	0.04	0.14	2.2
A19	3.50	0.04	35	0.04	0.15	2.3
A20	3.47	0.03	35	0.04	0.15	0.2
Mean	3.31±0.31	0.03±0.003	33±3.10	0.04±0.004	0.14±0.013	1.4±0.07

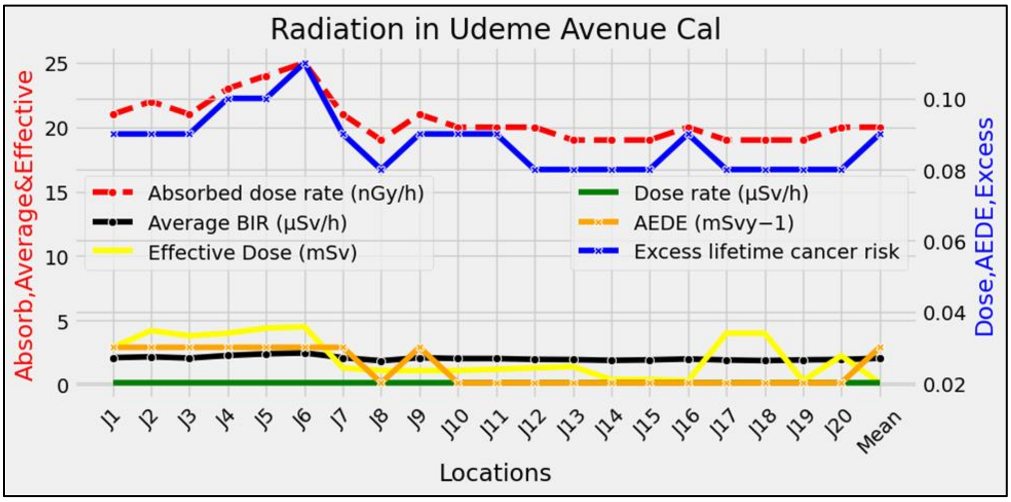

Figure 1 The plot of all the radiological hazard parameters from Udeme Avenue Dumpsite, Calabar South Local Govt

Table 4 Results of the radiological hazard parameters from Lemna dumpsite

Locations Lemna Cal Municipal CRS,	Average BIR (μSv/h)	Dose rate (μSv/h)	Absorbed dose rate (nGy/h)	AEDE (mSvy−1)	Excess lifetime cancer risk	Effective Dose (mSv)
B1	3.67	0.04	37	0.03	0.10	2.2
B2	3.23	0.03	32	0.03	0.10	3.5
B3	3.50	0.04	30	0.03	0.11	4.1
B4	2.80	0.03	35	0.03	0.11	3.9
B5	3.47	0.03	28	0.03	0.11	3.7
B6	3.07	0.03	35	0.03	0.11	3.3
B7	2.70	0.03	31	0.03	0.12	1.0
B8	2.87	0.03	29	0.04	0.12	0.9
B9	2.67	0.03	27	0.03	0.11	1.1
B10	3.20	0.03	32	0.04	0.14	0.9
B11	3.23	0.03	32	0.04	0.14	0.9
B12	2.83	0.03	28	0.03	0.12	0.9
B13	2.93	0.03	29	0.04	0.13	0.9
B14	3.20	0.03	32	0.04	0.14	0.2
B15	3.37	0.03	34	0.04	0.14	0.2

B16	3.30	0.03	33	0.04	0.14	0.2
B17	3.43	0.03	34	0.04	0.15	3.0
B18	3.40	0.03	34	0.04	0.15	2.8
B19	3.40	0.03	34	0.04	0.15	2.8
B20	2.83	0.03	28	0.03	0.12	0.2
Mean	2.91±0.38	0.03±0.004	29±3.8	0.04±0.005	0.12±0.016	1.7±0.16

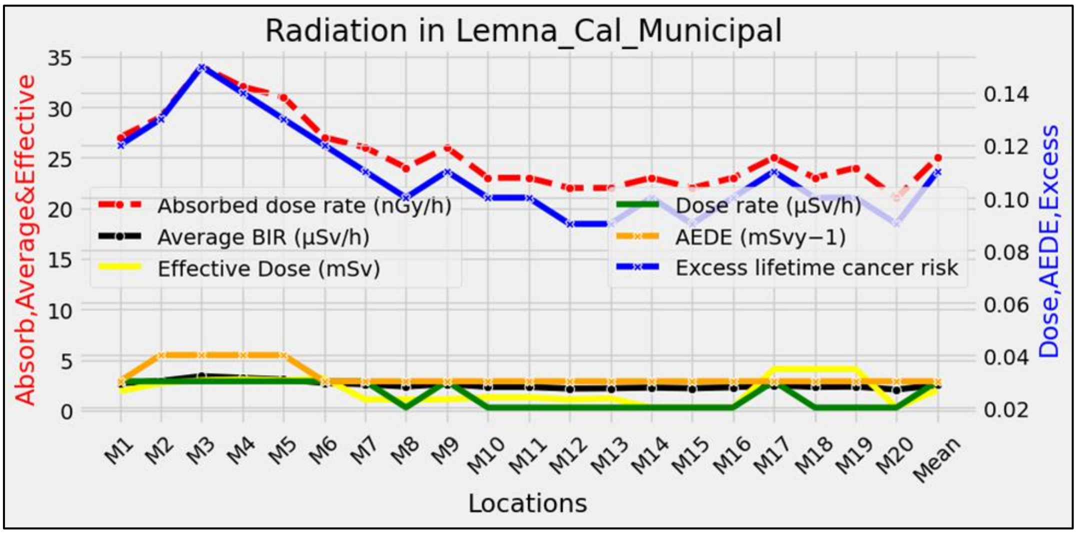

Figure 2 The plot of all the radiological hazard parameters from Lemna dumpsite, Calabar Municipal Local Govt

Table 5 The effective dose to different organs and tissue in the body

S/N	Organs	Organs weighting factor	Absorbed Dose (mGy)	Effective Dose (mSv)
1	Gonads	0.08	23	1.8
2	Bone marrow	0.12	23	2.8
3	Colon	0.12	23	2.8
4	Lung	0.12	27	3.2
5	Stomach	0.12	22	2.6
6	Breasts	0.12	23	2.8
7	Bladder	0.04	23	0.9
8	Kidneys	0.04	25	1.0
9	Testes	0.04	22	0.9
10	Ovaries	0.04	25	1.0
11	Liver	0.04	24	1.0
12	Oesophagus	0.04	25	1.0
13	Thyroid	0.04	25	1.0
14	Skin	0.01	24	0.2
15	Bone Surface	0.01	25	0.3

16	Salivary glands	0.01	26	0.3
17	Heart	0.12	29	3.5
18	Pancreas	0.12	30	3.6
19	Prostrate	0.12	31	3.7
20	Brain	0.01	23	0.2
	Average	0.07	25	1.7
	STDEV	0.05	2.51	1.22

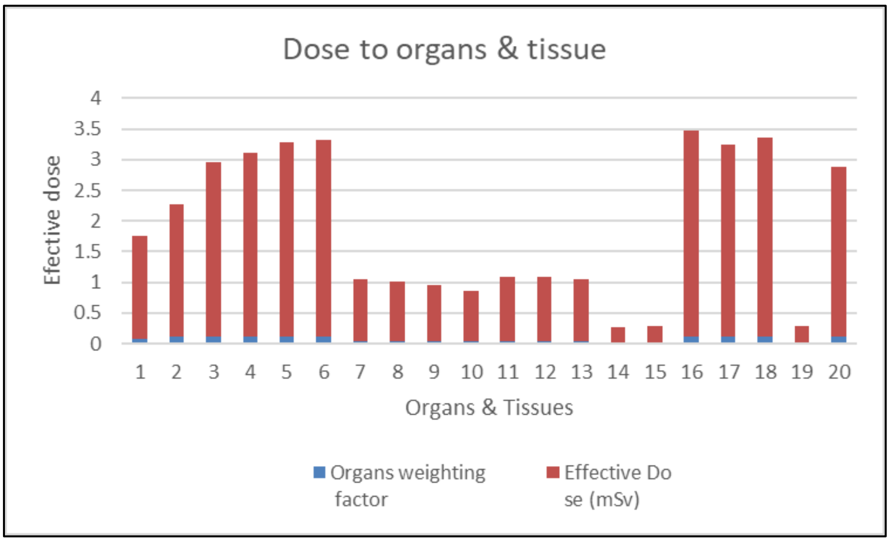

Figure 3 Effective dosage to various human tissues and organs

4.1.2. Background ionizing radiation (BIR)

The outcomes of the background ionizing radiation exposure exposure level evaluated from the study area show that in the Udeme avenue dumpsite, the BIR levels ranged from 3.63(μSv/h) to 3.47(μSv/h) with a mean value of 3.31±0.31 (μSv/h) at Lemna dumpsite the BIR levels ranged from 3.67 (μSv/h) to 2.283(μSv/h) with a mean value of 2.91± 0.38 (μSv/h). The average BIR exposure is less than the 1.0 mSv/y allowable limits for the general public set by the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

4.1.3. Absorbed Dose Rate

The calculated absorbed dose rate ranged from 36nGyh^{-1} to 35nGyh^{-1} with a mean value of 33 ± 3.10nGyh^{-1}, for Udeme avenue dumpsite and 37 nGyh^{-1} to 28 nGyh^{-1n} with a mean value of 29 ±3.8nGyh^{-1}. The average value of the absorbed dose rate seems to be less than the recommended world average rate of 59.00nGh^{-1} [25] and the permissible limits of 84.0 nGyh^{-1} for health workers. These rates show a decrease in radiation pollution of the environment. The local population may not experience any health effects right away, but the cumulative doses of the radiation could pose long-term health hazard.

4.1.4. Annual Effective Dose Equivalent (AEDE)

Annual effective dose equivalent (AEDE) that residents of the study area received was determined using the computed absorbed dose rates. We used the dose conversion factor of 0.7 Sv/Gyh^{-1} recommended by UNSCEAR for the conversion coefficient from the absorbed dose in air to the effective dose received by adults and an occupancy factor of 0.2 for outdoor exposure to calculate the AEDE as stated in equations (2), (3) and (4) [26].

Mean values of the calculated annual effective dose equivalents show that the Udeme has a mean value of 0.04 ±0.004 and the Lemna dumpsite has a mean value of 0.04±0.005. this annual effective dose equivalent is similar to the value reported in Keffi, Nasarawa State, Nigeria [20] but, lower than the value reported by Ezekiel [27].

4.1.5. Excess Lifetime Cancer Risk

Excess lifetime cancer risk (ELCR) was calculated using equation (5). The mean value of ELCR obtain in this study are 0.14±0.013 for Udeme dumpsite and 0.12±0.016 from Lemna dumpsite. The average value of ELCR obtained in the study area is less than the recommended value of 0.29 x 10^{-3}mSv/y [28]. This ELCR value shows that residents of the study area who will live in the city their entire lives have a relatively low risk of developing cancer due to BIR exposure.

4.1.6. The Effective dose

The effective dose rate (D_{organs}) in mSv/y to different organs and tissues in the body can be calculated using the equation

$$D_{organ} = O \times AEDE \times F \quad \ldots\ldots\ldots (6)$$

where F is the organ's conversion factor from the dose consumed, AEDE is the annual effective dose equivalent, and O is the occupancy factor, which is given as 0.8. The computed effective dose rate delivered to the various organs and tissues are shown in Table 5 and the plot is shown in Figure 3. The F values for the various organs and tissues are shown in column 3 of Table 5, as reported by ICRP [29]. The quantity of radiation that a person absorbs and that builds up in different body organs and tissues is estimated by the model of the annual effective dose to organs. Twenty (20) organs and tissues were examined and the results indicate that the prostrate, pancreas and the heart received the highest dose of 3.7mSv/y, 3.6mSv/y and 3.5mSv/y respectively while the dose to the brain, skin and bone were found to be 0.2mSv/y, 0.2mSv/y and 0.3mSv/y respectively with the yearly average effective dose to the organs and tissues were found to be 1.7mSv/y. The results show that the calculated dose to different body organs and tissues are relatively higher than the recommended 1.0mSv/y.

These results show that the inhabitants around the study area have been exposed to higher BIR dose to these organs and tissues in adults. The food nutrient absorption rate within the study area justifies the relatively lower dose consumption for the brain, skin, and bone and the comparatively greater dose for the heart, pancreas, and prostate [30,31].

5. Conclusions

The study concludes by assessing the background ionizing radiation levels around the main Calabar, Nigeria, dumpsite. The mean values of all the radiological hazard parameters, including the dose rate, absorbed dose rate, annual effective dose equivalent, and excess lifetime cancer risk, were below the 1 mSv limit recommended by the World Health Organization (WHO), the International Atomic Energy Agency (IAEA), and the International Commission on Radiological Protection (ICRP).

limit of 1mSv, the world health organization (WHO) recommended limit of 1mSv, international atomic energy agency (IAEA) recommended limit of 1mSv, and Nigeria nuclear regulatory authority (NNRA) recommended limit of 1mSvy^{-1} for outdoor exposure to BIR. However, no radiation level is too low for it to accumulate and become hazardous at a long-term exposure. The excess lifetime cancer risk is also lower than the above international recommended limit of 0.29 x 10^{-3} mSv/y, while the effective dose is relatively above the international recommended limit of 1mSv/y for public exposure to background ionizing radiation.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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