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Isodose mapping and its radiological implications in Lagos state, Nigeria

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ABSTRACT

Background: The annual effective dose equivalent (AEDE) due to ionizing radiation in a coaster area in Nigerian has been determined using Geiger-Muller counter. ***Materials and Methods***: isolevels in the study area were represented by using the kriging interpolation technique on ArcGIS 10.1 software. Duncan multiple range test was performed using Statistical Package for Social Sciences (SPSS). ***Results:*** The results obtained show that the AEDE ranged from 0.19±0.01 to 0.35±0.02 mSv y^{-1} with a mean of 0.27±0.03 mSv y^{-1}. The excess lifetime cancer risk (ELCR) ranged from 0.0007 to 0.0012, with a mean of 0.0010. The total annual collective effective dose equivalent is 4839.49 person-Sv. ***Conclusion:*** The AEDE in the study area is lower than the maximum permissible limit of 1 mSv y^{-1} recommended by ICRP. The AEDE was higher in areas of high elevations than those of low elevations. It was estimated that about twenty-eight (28) of every one hundred thousand (100,000) persons are at risk of developing radiation-induced diseases per annum in the study area.

Keywords: *Ionizing radiation, Geiger-Muller Counter, Dose, iso-levels, permissible limit.*

INTRODUCTION

Life evolved in an environment filled with radiation. Traces of radionuclides are found in water, air, soil and human bodies. Human inhale and ingest radionuclides every day and radioactive materials have been ubiquitous on earth since its creation. The presence of natural radioactivity in the environment results in both internal and external exposure to humans (1).

Many radioisotopes are naturally occurring and originated during the formation of the solar system and through the interaction of cosmic rays with molecules in the atmosphere. Tritium is an example of a radioisotope formed by cosmic rays' interaction with atmospheric molecules. Some radioisotopes (such as uranium and thorium) that were formed when the solar system was created have half-lives of billions of years and are still present in the environment. Background radiation is the ionizing radiation constantly present in the natural environment (2).

Most of the variation in exposure to natural radiation results from inhalation of radioactive gases that are produced by radioactive minerals found in soil and bedrock (1). The largest source of natural background radiation is airborne radon, a radioactive gas that emanates from the ground. Thoron is a radioactive gas produced by the decay of thorium. Radon and thoron levels vary considerably by location depending on the composition of soil and bedrock (3). Once released into the air, these gases will normally dilute to harmless levels in the atmosphere but sometimes they become trapped and accumulate inside buildings and are inhaled by occupants. Radon gas poses a serious health risk not only to uranium miners, but also to homeowners if it is left to accumulate in the home (2).

The measurement of radioactivity in the environment is important so as to assess the health effects of the resulting radiations on humans. Many researches have worked on natural background radiation evaluation. Ajayi and Ajayi observed relatively low absorbed dose rate and collective effective dose equivalents due to gamma radiation from selected radionuclides in soils from Ondo and Ekiti States, South-western Nigeria (4). Farai and Jibiri observed the same low trend for outdoor gamma radiation exposure dose rates due to radioactivity concentrations of ^{40}K, ^{238}U and ^{232}Th in the soil from eighteen (18) cities across Nigeria (5).

Shahbazi-Gahrouei estimated the natural background radiation dose in the high-altitude region of Iran using portable Geiger Muller and scintillation detectors (6). He obtained a mean annual effective dose equivalent of 0.49 mSv y^{-1} and an overall population –weighted mean outdoor dose rate of 49 nGy h^{-1}, which are higher than the world mean values of 0.11 mSv y^{-1} and 44 nGy/h respectively for low background radiation area, (7). A good correlation between the altitude and the exposure rate was observed, like the higher the altitude, the higher the natural background radiation levels. Arogunjo measured the terrestrial gamma radiation levels and determined the radiological implications in southwestern Nigeria (8). The mean effective dose equivalent obtained for the region was 0.8 mSv y^{-1}, which is less than 1 mSv y^{-1} recommended for normal environment (7). Luevano-Gurrola *et al*. carried out a research on the lifetime effective dose assessment based on background outdoor gamma exposure in Chihuahua City, Mexico. The results indicated that the lifetime effective dose to the inhabitants of Chihuahua City is on average 19.8 mSv, resulting in a lifetime cancer risk of 0.001 (9). It is therefore imperative to constantly evaluate the exposure of human to natural and artificial nuclear radiation in order to estimate the effective risk associated with the exposure and the factors that influence the rate of exposure.

The study area (Lagos State) is an industrial core of Nigeria with an extremely high population density. It is an important fraction of the country and an ascribed commercial capital of African continent. The effect of ionizing radiation on such population is of great concern to a health physicist. The aim of this work is to assess the health detriment of the ionizing radiation on the populace of the study area and to represent the exposure trend with isodose mapping, which will clearly reveal areas of high exposure rate. The result of the work will guide in formulating radiation safety policy. The specific objectives of the research are to measure the outdoor ambient ionizing radiation dose, determine the radiological hazard resulting from exposure to this radiation and develop a radiation map for the study area.

MATERIALS AND METHODS

Description and geology of the study area

The research was carried out to cover the entire environment of Lagos State, Nigeria. Lagos State is the most congested state with the highest population density in Nigeria. The state is in southwestern geopolitical zone of Nigeria. The State is arguably the most economically important state of the country. On the North and East, it is bordered by Ogun State, in the West it shares boundaries with the Republic of Benin, while on its southern borders lies the Atlantic Ocean (figure 1). Lagos State has an area of about 3,577 km^2. About 22% of it is covered with water and creeks.

Lagos State is underlain by a series of sedimentary rocks, the geological formations of the state include the Benin and Ogwashi formation (Oligocene - Quaternary), Ewekoro formation (Paleocene), Oshosun formation (Eocene), Akinbo formation (Late Paleocene - Early Eocene), Alluvium (Recent) and Basement Complex (Precambrian) (10).

The Benin formation consists of yellow and white sands, pebbly beds and clays with some sandy clay lenses. The Ogwashi formation consists of a variable sequence of clay, sand, and thin lignite seams. The Oshosun formation consists of mudstones and claystones. The Ewekoro formation consists of 10 to12.5 metres of thinly bedded glauconitic and sandy limestone at the base (11).

Sampling and Measurement of Radiation Dose

The outdoor radiation levels of four hundred and thirty four (434) locations were measured in twenty (20) LGAs and thirty-seven (37) LCDAs of Lagos State. The measurements were taken at 1 m above the ground level (gonadal level) using Geiger Muller counter (Kindenoo blue Geiger PG -15). The Geiger Muller counter detects radiations such as alpha, beta and gamma rays. Its measurement range is between 0.05 μSv h^{-1} and 300 μSv h^{-1}. The Geiger-Muller counter consists of two main elements; the Geiger Muller tube which detects the radiation, the processing and display electronics. A Global Positioning System (GPS) was used to determine the coordinates and the elevations of the study area above sea level.

With the use of the Geiger Muller counter, four (4) readings were taken at intervals of two (2) minutes after the first stop mode reading was recorded making a total of five (5) readings at a particular point. The process was repeated in at least seven (7) different points in a particular location of each LGA or LCDA depending on the size of the location. The average readings from different locations in every LGA and LCDA were obtained in order to have a more reliable value. The radiation dose measured by the Geiger Muller counter when the reading was stabilized is the background equivalent dose measured in micro-Sievert per hour (μSv h^{-1}).

Calculation of Radiological Parameters and Analysis of Results

Using the outdoor occupancy factor 0.2 recommended by (1), the equivalent doses in (μSv h^{-1}) were converted to annual effective dose equivalent (AEDE) in milli-Sievert per year (mSv y^{-1}).

$$AEDE(mSV^{-1})=EDm(\mu Sv\ h^{-1})\times 8760\times 0.2\times 10^{3} \quad (1)$$

The excess lifetime cancer risk which deals with the probability of developing cancer over a lifetime at a given exposure level was also calculated. It is presented as a value representing the number of cancers expected in a given number of people on exposure to a carcinogen at a given dose. It is worth noting that an increase in the ELCR causes a proportionate increase in the rate at which an individual can develop cancer of the breast, prostate or even blood. Excess lifetime cancer risk (ELCR) was estimated by using equation 2 (12).

$$ELCR = AEDE \times DL \times RF \times 10^{-3} \qquad (2)$$

Where; AEDE is the annual effective dose equivalent, DL is the average duration of life (estimated to 70 years), and *RF* is the Risk Factor (Sv^{-1}), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP uses *RF* as 0.05 for the public (12).

The collective annual effective dose equivalent, S_E, to a population, which is a measure of the collective detrimental effects and the percentage of people at risk of incurring radiation-induced diseases was estimated in this work using equation 3 (13):

$$S_E = AEDE \times N \qquad (3)$$

where, S_E is the collective annual effective dose equivalent (person-Sv), AEDE is the annual effective dose equivalent, and N is the number of individuals exposed to radiation. This quantity was estimated for each of the twenty (20) LGAs using the 2006 Lagos State population census figures [14]. The mean values of the effective dose equivalent for the local LGAs and their respective LCDAs were used for the calculation of the collective effective dose equivalent.

The collective health detriment, *G* (Person), due to exposure to gamma radiation in an environment, was estimated using the equation 4 (13).

$$G = RF \times S_E \qquad (4)$$

Where, G is the collective health detriment (person), RF is the risk factor (Sv^{-1}), and S_E is the collective effective dose equivalent (person-Sv). The risk factors for different tissues is given by ICRP (13).

The statistical analysis of the results was conducted using Statistical Package for the Social Science (SPSS) version 21 software. The Duncan Multiple Range test was performed using anova to determine the significant difference in the level of radiation dose varying from one LGA or LCDA to another and to arrange the LGAs and LCDAs in order of highest effective dose equivalent to lowest effective dose equivalent. The geospatial analysis of the results was conducted using the ArcGIS software. The kriging interpolation technique was used to represent the spatial distribution of the effective dose equivalent in the study area. The data were also super imposed on Lagos State map to produce a geospatial and elevation map using ArcGIS software.

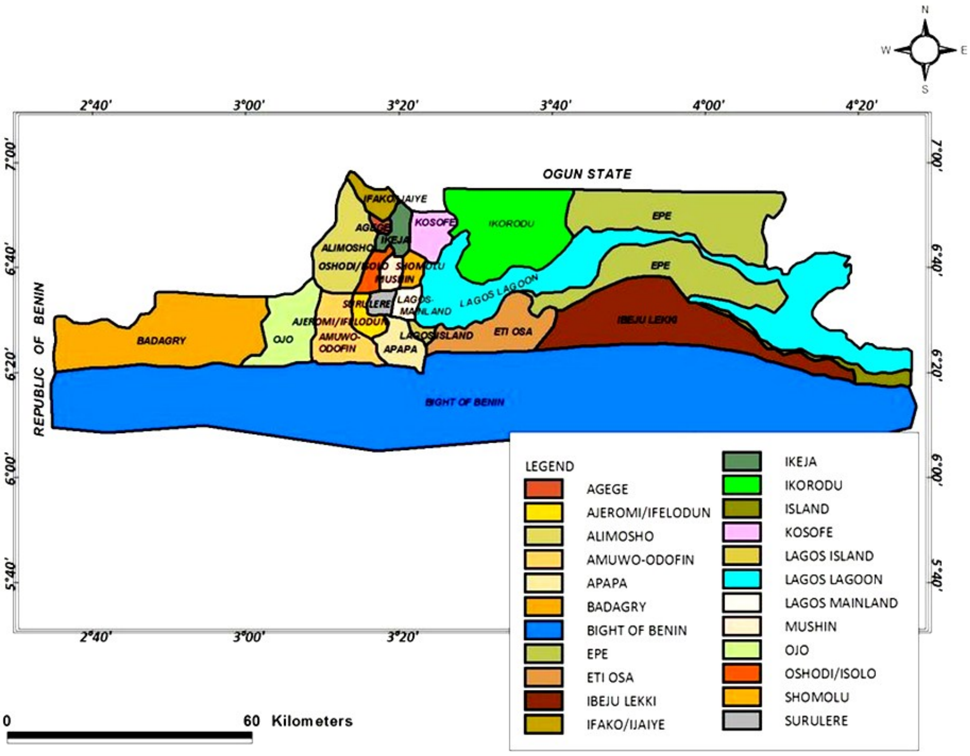

Figure 1. Map of Lagos State Showing the Study Area (Local Government Area) Source: Ministry of Physical Planning, Lagos State.

RESULTS

The values of the equivalent dose mean (EDM), the annual effective dose equivalents (AEDE) and excess lifetime cancer risk (ELCR) are presented in table 1.

The equivalent dose mean (EDM) ranged from 0.11±0.01 to 0.20±0.01 µSv h^{-1}. The annual equivalent dose rates ranged from 0.94±0.07 to 1.77±0.13 mSv y^{-1} with a mean value of 1.40±0.13 mSv y^{-1}.

The values of the annual effective dose equivalents ranged from 0.19±0.01 mSv y^{-1} to 0.35±0.02 mSv y^{-1} with a mean value of 0.27±0.03 mSv y^{-1}. This value is lower than the maximum permissible limit of 1 mSv y^{-1} as recommended by (15); but in agreement with Arogunjo,(8). Figures 2 and 3 show the charts of the annual dose rates in the LGAs and LCDAs respectively. The annual effective dose equivalent was highest in Ikeja LGA, and Yaba LCDA, while it was lowest in Lekki LCDA and Olorunda LCDA. Maps of the isolevels of the annual effective dose equivalents and the elevations are shown in figures 4 and 5 respectively. The maps show that most regions with low values of the annual effective dose equivalents are regions of low elevations, while areas with high annual effective dose equivalents correspond to areas of high elevations. Previous studies (6, 16, 17) have shown that altitude has a significant effect on the effective dose equivalent. The effective dose equivalent of a particular region is dependent on the geological and geographical conditions of that region.

Table 1. Equivalent dose mean, annual effective dose equivalent and excess lifetime cancer risk.

Area code	LGA/LCDA	EDM (μSv h^{-1})	AEDE (mSv y^{-1})	ELCR
A1	Agege LGA	0.18±0.01	0.31±0.02	0.0011
A2	Orile-Agege LCDA	0.17±0.02	0.29±0.03	0.0010
A3	Ajeromi-Ifelodun LGA.	0.14±0.02	0.24±0.03	0.0008
A4	Ifelodun LCDA	0.13±0.01	0.23±0.02	0.0008
A5	Alimosho LGA	0.17±0.01	0.30±0.01	0.0011
A6	Ayobo-Ipaja LCDA	0.14±0.01	0.26±0.02	0.0009
A7	Ikotun-Igando LCDA	0.16±0.01	0.28±0.02	0.0010
A8	Egbe-Idimu LCDA	0.16±0.01	0.28±0.01	0.0010
A9	Mosan-Okunola LCDA	0.20±0.01	0.35±0.03	0.0012
A10	Agbado-Okeodo LCDA	0.17±0.02	0.30±0.04	0.0011
A11	Amuwo-Odofin LGA	0.15±0.01	0.27±0.01	0.0010
A12	Oriade LCDA	0.14±0.01	0.25±0.02	0.0009
A13	Apapa LGA	0.16±0.02	0.28±0.03	0.0010
A14	Iganmu LCDA	0.16±0.02	0.28±0.03	0.0010
A15	Badagry LGA	0.14±0.02	0.25±0.03	0.0009
A16	Badagry-West LCDA	0.11±0.01	0.20±0.01	0.0007
A17	Olorunda LCDA	0.11±0.01	0.19±0.02	0.0007
A18	Epe LGA	0.16±0.01	0.27±0.01	0.0010
A19	Ikosi-Ejirin LCDA	0.13±0.02	0.24±0.03	0.0008
A20	Eredo LCDA	0.16±0.01	0.27±0.02	0.0010
A21	Eti-osa LGA	0.15±0.02	0.26±0.03	0.0009
A22	Eti-osa-East LCDA	0.16±0.02	0.28±0.03	0.0010
A23	Iru-Victoria Island LCDA	0.19±0.02	0.32±0.03	0.0011
A24	Obalende-Ikoyi LCDA	0.15±0.02	0.25±0.03	0.0009
A25	Ibeju-Lekki LGA	0.12±0.04	0.21±0.06	0.0007
A26	Lekki LCDA	0.11±0.01	0.19±0.01	0.0007
A27	Ifako-Ijaye LGA	0.19±0.01	0.33±0,01	0.0012
A28	Ojukoro LCDA	0.17±0.01	0.30±0.03	0.0011
A29	Ikeja LGA	0.20±0.01	0.35±0.02	0.0012
A30	Onigbongbo LCDA	0.19±0.02	0.33±0.04	0.0012
A31	Ojodu LCDA	0.19±0.02	0.34±0.04	0.0012
A32	Ikorodu LGA	0.19±0.02	0.34±0.04	0.0012
A33	Ikorodu West LCDA	0.15±0.01	0.26±0.02	0.0009
A34	Igbogbo LCDA	0.15±0.01	0.26±0.02	0.0009
A35	Ijede LCDA	0.18±0.02	0.31±0.03	0.0011
A36	Ikorodu North LCDA	0.16±0.01	0.28±0.02	0.0010
A37	Imota LCDA	0.14±0.02	0.25±0.03	0.0009
A38	Kosofe LGA	0.16±0.01	0.29±0.02	0.0010
A39	Agboyi-Ketu LCDA	0.17±0.01	0.30±0.02	0.0011
A40	Ikosi LCDA	0.16±0.02	0.28±0.03	0.0010
A41	Lagos Island East LGA	0.16±0.01	0.28±0.02	0.0010
A42	Lagos Island West LCDA	0.15±0.01	0.26±0.02	0.0009
A43	Mainland LGA	0.18±0.02	0.32±0.03	0.0011
A44	Yaba LCDA	0.20±0.01	0.35±0.01	0.0012
A45	Mushin LGA	0.17±0.02	0.23±0.03	0.0008
A46	Odi-Olowo LCDA	0.18±0.02	0.32±0.03	0.0011
A47	Ojo LGA	0.16±0.02	0.27±0.03	0.0010
A48	Iba LCDA	0.11±0.01	0.19±0.02	0.0007
A49	Oto-Awori LCDA	0.12±0.01	0.21±0.01	0.0007
A50	Oshodi LGA	0.17±0.01	0.29±0.02	0.0010
A51	Isolo LCDA	0.16±0.02	0.28±0.03	0.0010
A52	Ejigbo LCDA	0.17±0.01	0.30±0.02	0.0011
A53	Somolu LGA	0.16±0.02	0.27±0.03	0.0010
A54	Bariga LCDA	0.15±0.02	0.26±0.03	0.0009
A55	Surulere LGA	0.14±0.01	0.25±0.02	0.0009
A56	Itire-Ikate LCDA	0.14±0.01	0.24±0.02	0.0008
A57	Coker-Aguda LCDA	0.16±0.02	0.27±0.03	0.0010
Average		0.16±0.01	0.27±0.03	0.0010

The number before" ±" denotes mean values while the number after denotes standard error.

Terrestrial and cosmogenic radionuclides contribute to the effective dose equivalent. At higher altitudes, the dose due to cosmogenic radionuclides increases. Thus, regions with high elevations have high effective dose equivalents compared to regions of low elevations this is in agreement with the fact that most people receive an average dose from space radiation of about 0.3 mSv each year. This dose depends on where a person lives, that is the latitude and altitude (18, 19).

The distribution of the effective dose equivalents (AEDE) to different organs of the body in different LGAs and LCDAs were calculated taking into account the weighting factor for each organ. As expected, the gonad has the highest effective dose for each LGA and LCDA. This is because gonad has the highest weighting factor, followed by the breast, red bone marrow, lung, thyroid and bone. The excess lifetime cancer risk (ECLR) calculated ranged from 7.0×10^{-4} to 1.2×10^{-3}, with an average value of 1.0×10^{-3}. The average of the excess lifetime cancer risk is higher than the world average of 2.9×10^{-4} (7). This implies that the populace of the study area is at a high risk of developing cancer over a period of time. The collective effective dose equivalent, S_E, to a population, which is a measure of the collective detrimental effects and the percentage of people at risk of incurring radiation-induced diseases was determined.

The collective effective dose equivalent, S_E as presented in table 2, ranged from 19.91 person-Sv to 603.87 person-Sv. Alimosho LGA has the highest population in Lagos State, with a population of about 2,047,026 people (14). The collective effective dose equivalent in Alimosho LGA is 603.87 person-Sv. This implies that thirty (30) in every one hundred thousand (100000) people in Alimosho LGA are vulnerable to suffer a kind of radiation-induced disease. The collective effective dose equivalent is lowest in Ibeju-Lekki LGA. Ibeju Lekki has an estimated population of about 99,540 people according to the Lagos State Bureau of Statistics (14). The collective effective dose equivalent in Ibeju-Lekki is 19.91 person-Sv, which implies that twenty (20) out of every one hundred thousand (100000) people in the Local Government Area are vulnerable to suffer a kind of radiation-induced disease.

Lagos State has an estimated population of 17,552,942 people. The total collective effective dose equivalent is 4739.29 person-Sv. This implies that twenty-eight (28) in every one hundred thousand (100000) people are at risk of developing a kind of radiation-induced disease in the State. The collective health detriment for the study area is presented in table 3. The total collective health detriment due to the ionizing radiation from radionuclides in the study area is 79.85 person. The statistical analysis results show that Ikeja has the highest effective dose equivalent while Lekki has the lowest.

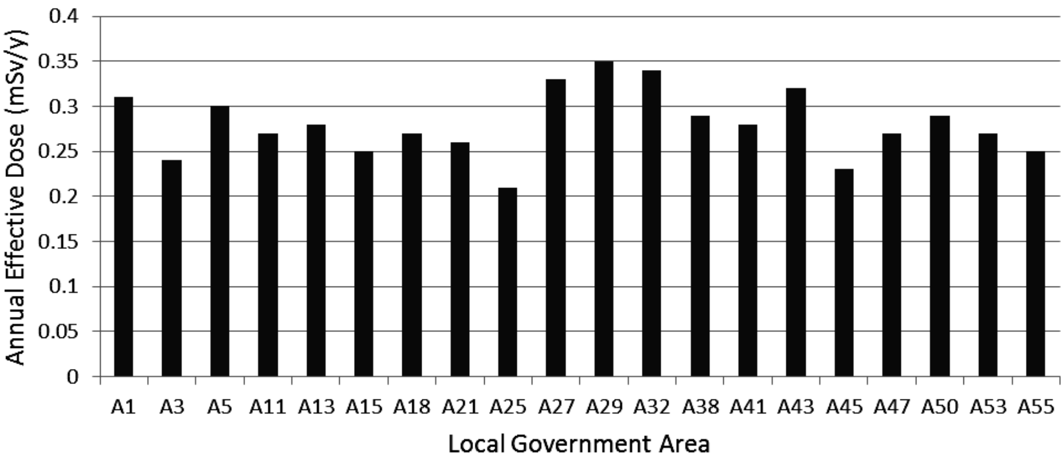

Figure 2. The outdoor annual effective dose equivalents in the 20 Local Government Areas.

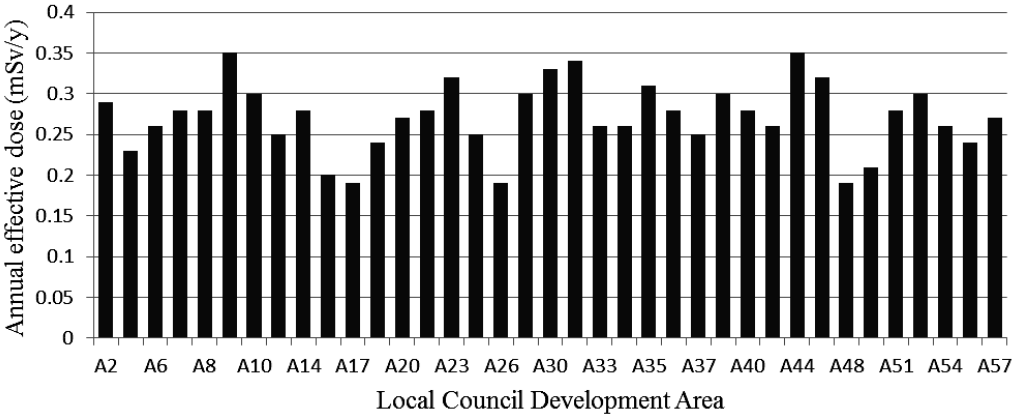

Figure 3. The outdoor annual effective dose equivalents in the 37 Local Council Development Areas.

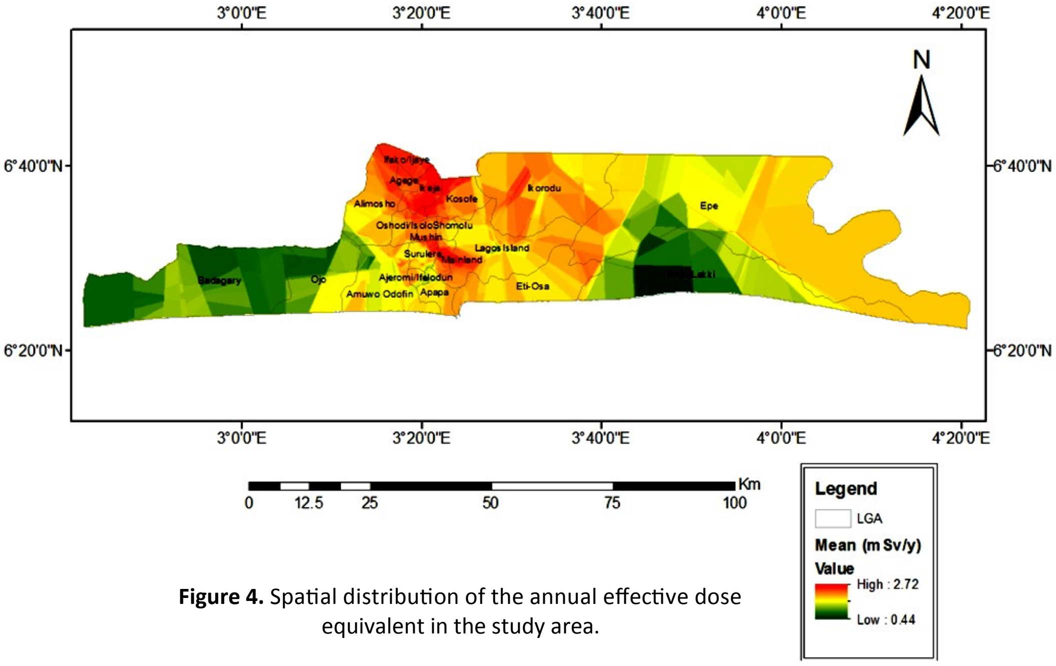

Figure 4. Spatial distribution of the annual effective dose equivalent in the study area.

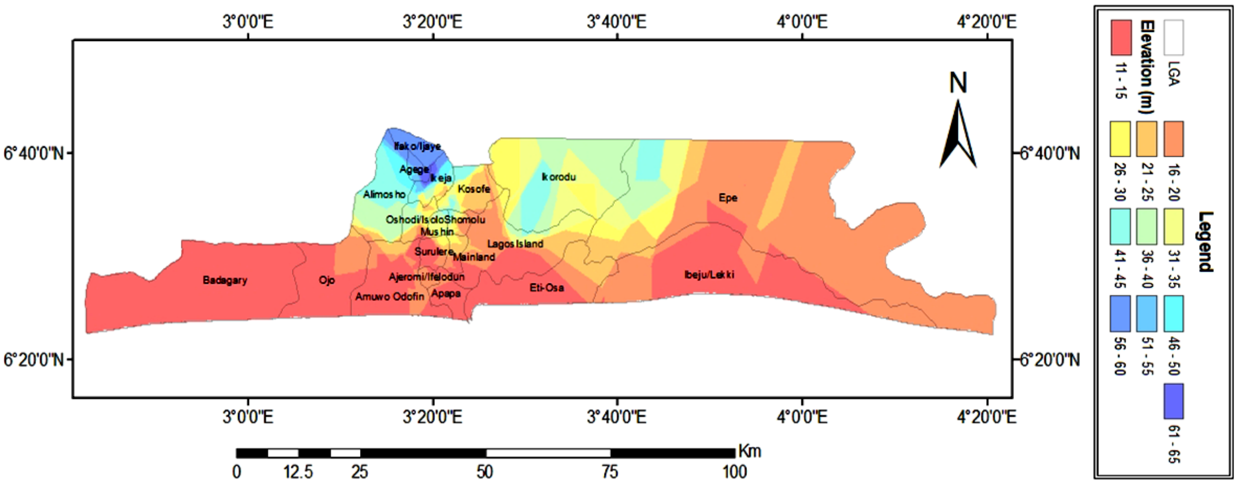

Figure 5. Elevation map of the study area.

Table 2. Collective effective dose equivalent for the twenty Local Government Areas.

S/N	Local Government Area	N (person)	S_E (Person-Sv)
1	Agege LGA	1,033,064	309.92
2	Ajeromi Ifelodun LGA	1,435,295	337.29
3	Alimosho LGA	2,047,026	603.87
4	Amuwo-Odofin LGA	524,971	136.49
5	Apapa LGA	522,384	146.27
6	Badagry LGA	380,420	81.16
7	Epe LGA	323,634	84.15
8	Eti-Osa LGA	983,515	272.93
9	Ibeju-lekki LGA	99,540	19.91
10	Ifako-Ijaye LGA	744,323	234.46
11	Ikeja LGA	648,720	220.57
12	Ikorodu North LGA	689,045	228.53
13	Kosofe LGA	934,614	271.04
14	Lagos Island East LGA	859,849	232.16
15	Mainland LGA	629,469	210.87
16	Mushin LGA	1,321,517	363.42
17	Ojo LGA	941,523	210.27
18	Oshodi LGA	1,134,548	329.02
19	Somolu LGA	1,025,123	276.78
20	Surulere LGA	1,274,362	322.84
	Total	17,552,940	4739.29[a]

[a] Calculated using mean annual effective dose equivalent value of 0.27 mSv y^{-1}.

Table 3. Collective health detriment for the study area.

Organ	Weighting Factor, W_T	Risk Factor (Sv^{-1})	Collective Health Detriment, G (person)
Gonads	0.25	4×10^{-3}	19.36
Breast	0.15	2.5×10^{-3}	12.10
Red Bone Marrow	0.12	2.0×10^{-3}	9.68
Lung	0.12	2.0×10^{-3}	9.68
Thyroid	0.03	0.5×10^{-3}	2.42
Bone	0.03	0.5×10^{-3}	2.42
Others	0.30	5×10^{-3}	24.20
Total	1.00	1.65×10^{-2}	79.85

CONCLUSION

The background ionizing radiation in Lagos State environment has been evaluated with isodose map developed to assess the radiological effect on human. The mean value of the annual effective dose equivalent is 0.27±0.03 mSv y^{-1} which is comparable to the world average value of 0.3 mSv y^{-1} (1), lower than 1 mSv y^{-1} recommendation of ICRP (13) but higher than 0.1 mSv y^{-1} recommendation of WHO (20). Geospatial maps showed that effective dose equivalents increase with elevations and this could be attributed to the cosmogenic radiation effect which is higher in high altitudes. The average space radiation dose makes up about 11 percent of the average total dose of background radiation. Traveling by airplane can expose people to slightly more space radiation because at high altitudes, there is less atmosphere to shield the incoming radiation (21).

The Excess lifetime cancer risk of 1.0×10^{-3} is higher than the world average of 2.9×10^{-4} (7). This implies that the populace of the study area is at a high risk of developing cancer over a period of time due to exposure to ionizing radiation emitted by the radionuclides in the study area. The total collective effective dose equivalent for the entire study area is 4839.49 person-Sv. The significance is that twenty-eight (28) in every one hundred thousand (100000) persons are at risk of developing a kind of radiation-induced disease per annum in the study area.

Conflicts of interest: *Declared none.*

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