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ORIGINAL ARTICLE

Indoor External Radiation Risk in Densely Populated Regions of Southern Nigeria

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Abstract

It is known that certain types of building materials contain significant concentrations of natural radionuclides; consequently, exposure to indoor background radiation is from the combined radioactivity from the soil as well as building materials; indoor exposures therefore have higher radiation hazard potentials than outdoor exposures in this regard and hence, need to be monitored. In this paper, an evaluation of background ionizing radiation from different buildings in Lagos and Ibadan, Southwestern Nigeria was carried out to determine the exposure rate of the general public to indoor ionizing radiation. 630 in situ measurements from the different buildings were taken using a Geiger Muller counter (model GQ-320 Plus). The indoor dose rates (i.e., 50–120 nGy/h) were within the world average values while the Annual Effective Dose for most of the buildings were above the world average AED for indoor gamma exposure from building materials. The mean AED for Lagos and Ibadan due to indoor exposures were 0.37 and 0.39 mSv/y with Excess Lifetime Cancer Risk of 0.99E−3 and 1.05E−3, respectively.

Keywords Indoor external radiation · Dose rate · Annual effective dose · Excess lifetime cancer risk

1 Introduction

The main sources of radiation exposure to human beings are natural and artificial radionuclides (UNSCEAR 2008). Natural radioactivity is widely spread in the earth's environment and it exists in various geological formations like soils, rocks, plants, water and air (Nikolaev 1999) and as such, the human body is exposed to radiation from these different sources (Jitka and van Barnet 2002). All building materials are mostly composed of rock and soil and these two raw materials contain natural radioactive isotopes such as ^{232}Th and ^{238}U decay series and ^{40}K (IAEA 2008; El-Taher 2010). The concentrations of the radioisotopes in the earth's crust and in building materials, determine the dose of natural radiation, both outside and inside of building (Ademola 2009). Ambient dose rates of natural radiation could be influenced by soil composition, atmospheric conditions, topography and vegetation (Bossew et al. 2017; Ljiljana and Lidija 2017). Natural radionuclides in building materials may cause both external exposure caused by their direct gamma radiation and also internal exposure from radon gas. The gamma radiation arising from the walls, floors and ceilings, as well as ^{222}Rn and ^{220}Rn and their progeny are the major sources of radiation exposures. More specifically, natural environmental radioactivity due to gamma radiation depends primarily on the geological and geographical conditions, and appears at different levels in the soils of each region in the world (UNSCEAR 2000). External irradiation from radionuclides naturally present in the environment is an important component of the exposure of human populations (Otwoma et al. 2013). As individuals spend more than 80% of their time indoors the internal and external radiation exposure from building materials creates prolonged exposure situations (Senthilkumar et al. 2014). The worldwide average indoor effective dose due to gamma rays from building materials is estimated to be about 0.4 mSv per year (UNSCEAR 2000). ^{222}Rn, a decay product of uranium with a half-life of 3.82 days is of concern for indoor background ionizing radiation and contributes an annual exposure of 1.15 mSv

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to internal exposure. Cases of lung cancer are also linked to radon exposure through inhalation (UNSCEAR 2000) as it penetrates into the lungs when it is inhaled. ^{222}Rn daughters such as ^{218}Po and ^{214}Po are alpha emitters and are also considered to be harmful. The continuous deposition and interaction of high energy alpha particles from ^{222}Rn and its daughters with the lung result to damage and the incidence of lung cancer. ^{222}Rn finds its way indoors through building materials, diffusion and convection and the soil under the building.

Gamma radiation from natural radionuclides in materials used for building construction can lead to significant indoor external dose (Ravisankar et al. 2012; Senthilkumar et al. 2013). Building construction requires large quantities of low cost materials and new products that may be substitutes for the widely used natural products as conventional building materials. By-products and waste products from some industrial, production and manufacturing industries are extensively widely used in building materials; these include: fly ash obtained during smelting processes, phosphogypsum from phosphate industry, uraniferous coal slag, burned alum shale, and residues from mineral processing (IAEA 2008; Marinela et al. 2015; Kim and Rigdon 1998; Thomas et al. 1993). These building materials may also contain significant quantities of naturally or technologically enhanced levels of radioactivity. The gamma activity concentration in natural radionuclides in raw materials and processed building products and consequently, the dose from them vary (Sumithrarachchi et al. 2000). Of all the naturally occurring radionuclides in building materials, ^{226}Ra, ^{232}Th and ^{40}K are considered the most important (Khan et al. 1998). In the ^{238}U decay series, the chain segment starting from ^{226}Ra is radiologically the most important and, consequently, reference is often made to ^{226}Ra instead of ^{238}U (El-Taher 2012). 98.5% of the radiological effects of the uranium series are produced by radium and its daughter products, the contribution from ^{238}U and other ^{226}Ra precursors are normally ignored (UNSCEAR 2000). It is reported that the activity concentration of radionuclides is higher in soils than in some building materials. Man-made radionuclides, mainly ^{137}Cs, could be found in building materials as a result of nuclear fallout deposition on the earth (Nikezic 1989).

As a result of changes in lifestyle, people spend more time indoors than outdoor. The survey carried out by the World Health Organization (WHO 1987) and the International Commission on Radiological Protection (ICRP 1993) show that residents of temperate climates spend only about 20% of their time outdoors and 80% indoors, e.g., in their homes, offices, schools and other buildings (Chad-Umoren et al. 2006); it can thus be implied that from the survey that probability of exposure to dangerous radiation is higher indoors than outdoors. The report by UNSCEAR (2008) states that information on distribution of indoor exposures derived from direct measurements is not extensive, hence the motivation for this study. Hayumbu et al. (1995) also reported that outdoor background ionizing radiation profile has received much attention than indoor background ionizing radiation. Figures are also not extensively available for Nigeria, hence the need for the survey of indoor background radiation doses in buildings. Indoor background ionizing radiation profiles of buildings are crucial, since they enable us to assess the level of risk of exposure to the regular users of such buildings and the general population. It has been established that chronic exposure, even to a low dose and a low dose rate of nuclear radiations from buildings has the potential to induce harmful chromosomal alterations in people (Mollah et al. 1987). Environmental radioactivity monitoring is believed to have commenced 58 years ago (Olomo 1990). Studies on radioactivity assessment in Nigerian environment include: baseline survey of terrestrial outdoor gamma dose rates levels in Nigeria by Farai and Jibiri (2000), radiation exposure level around industrial area (Mokobia and logun 2003; Funtua and Elegba 2005), etc., and both laboratory and in situ gamma spectroscopy have been employed in many of the studies (Muhammad et al. 2011).

Knowledge of the level of natural radioactivity in building is therefore important to assess the possible radiological hazards to human health especially in the cases where the materials used for the construction of the buildings were not investigated for radiological hazards. The assessment of radiation exposure dose rates from buildings is important in assessing population exposures. According to regulations from the publication of different international radiation regulatory bodies, the general population should not be exposed to more than 1 mSv of radiation from building materials (ICRP 1999; European Commission 1999). In this study, the background ionizing radiation levels from different buildings in Lagos and Ibadan, south western Nigeria are assessed to enable the determination of the level of risk to which people are exposed and compared to international accepted levels.

2 Materials and Methods

2.1 Area of Investigation

Lagos is located in the coastal southwestern region of Nigeria as a large port city and is recognized as one of the most rapidly developing cities in Africa. The state is the most populated of the 36 states in Nigeria with a population above 17 million people, and ranks in the top ten most populous on earth. The relatively small geographical area of the city, i.e., about 3500 km^2, with 22% being lagoons and creeks, gives rise to the high population density in Lagos city. The city welcomes a notable number of tourists especially to mark special events and this serves to strengthen economic activities in the region; as such, Lagos is considered to be the most economically viable state in Nigeria (http://www.latlong.net/place/lagos-nigeria-2286.html). The state is surrounded by: Ogun state in the north and east, Benin republic in the west and the Atlantic Ocean in the south (http://en.wikipedia.org/wiki/Lagos_State).

Ibadan is also located in the southwestern geopolitical zone of Nigeria as the capital of Oyo State and the most populous city in the state with a population of over 3 million people. It is about 130 km northeast of Lagos as shown in maps in Fig. 1 and the third most populous city in Nigeria, after Lagos and Kano; it is, however, the country's largest city by geographical area covering about 3000 km^2. Located at 530 km southwest of Abuja, the federal capital, Ibadan is a prominent transit point between the coastal region and the areas in the hinterland of the country (http://en.wikipedia.org/wiki/Ibadan).

2.2 Data Collection and Analysis

Data collection were carried out with a Geiger Muller (GM) Counter (Model GQ GMC-320 Plus) which is capable of measuring beta, gamma radiations and X- radiations of 0.25–3.5, 0.1–1.25, and 0.03–3.0 MeV energy ranges, respectively (GQElectronics 2014). This device suits well for external radiation exposure assessment because it is able to register beta and gamma radiations which are majorly responsible for potential health hazard both for external exposure from the decay of radionuclides in the building materials and unable to register alpha radiation energies that are of significant for internal exposure. In the estimation of Absorbed Dose Rate in air at 1 m above the ground surface (gonadal level) for the uniform distribution of naturally occurring radio nuclides (^{226}Ra, ^{232}Th and ^{40}K) based on the guidelines provided by UNSCEAR (2000) and used in the many studies, e.g., (Senthilkumar et al. 2014), it assumed that the contribution from other naturally occurring radio nuclides, such as: ^{87}Rb, ^{138}La, ^{147}Sm and ^{178}Lu, to actual dose rates are insignificant and as such, the estimated values do not capture the absorbed dose rate from all the gamma-emitting radionuclides; this sets the GM counter used for this study at an advantage to the method mentioned above. An average of thirty measurements was taken at each of the surveyed buildings and the geographical spatial coordinates of the buildings where the measurements were taken was also registered. Counting statistics of the Gaussian distribution model was used to validate the normal functioning of the radiation measuring device using the method described in Knoll (2000).

The Annual Effective Dose (AED) and Excess Lifetime Cancer Risk (ELCR) which are important radiation risk indices were obtained using the methods described in Ajayi (2009) and Taskin et al. (2009) and also employed in the study of Prerna et al. (2014). This method was employed based on the assumption that the most significant contribution to the external exposure are from the gamma-emitting radionuclides present in the building materials (UNSCEAR 2008). The calculation of the Annual Effective Dose (AED) was carried out using the equation shown in Eq. (1) with an indoor Occupancy Factor (OF) of 0.80 and the Dose Conversion Factor (DCF) of

Fig. 1 Location of the study areas in the maps of Africa and Nigeria (http://edition.cnn.com/WORLD/africa/9807/11/nigeria.autopsy.02/map.html)

0.70 $SvGy^{-1}$ (UNSCEAR 2000). T represents the exposure duration per year, i.e., 8760 h of exposure per year:

$$AED = DR \times DCF \times OF \times T. \quad (1)$$

DR represents the indoor absorbed dose rate (nGy/h). To assess the radiological risk, Lifetime Cancer Risks (ELCR) was calculated from the AED values using the Eq. (2):

$$ELCR = AED \times DL \times RF \times T. \quad (2)$$

The DL (duration of life), i.e., 47.6 years, used in this study, was obtained as the average DL for the male and female populations of Nigeria (http://en.worldstat.info/Africa/Nigeria) and RF is the risk factor (Sv^{-1}) which represents the fatal cancer risk per Sievert; for stochastic effects from low dose background radiation. ICRP 103 suggested the RF value of 0.057 for the public exposure (ICRP 2007).

3 Results and Discussion

Figure 2a, b shows the qualitative results of two different frequency and Gaussian distribution curves dose rates of background radiation at two different points in Counts Per Minute (CPM) and Nano Sieverts per hour (nSv/h). These frequency distributions were used to validate the normal functioning of the detector before dose rate measurements were taken in Lagos and Ibadan, respectively. It is observed from the plots that there are more overestimations in the dose rates below the mean values (i.e., peak of the Gaussian curve) and absolute underestimations of dose rates above the mean values within the range of the measured dose rate values compared with the Gaussian model. A further quantitative test to verify the fluctuations in the counting equipment gave a Chi-square result of 0.14 and 0.06, respectively, which are somewhat higher than extremely low probabilities that indicate abnormally large fluctuations. The instrument used is therefore appropriate for this measurement application.

The indoor dose rate for the surveyed buildings in Lagos and Ibadan have ranges of 65.37 ± 1.90–83.00 ± 1.70 and 60.77 ± 1.32–91.25 ± 1.84 nGy/h as well as mean values of 74.68 ± 0.70 and 79.10 ± 0.66 nGy/h, respectively, as shown in Tables 1 and 2. This result is in agreement with the study of Obioha and Okwonkwo (2001) which also revealed that the background gamma radiation in Ibadan (1146.9 ± 20.1 µSv/y) is higher than that of Lagos (943.2 ± 35.9 µSv/y). The highest dose rate value of 120 nGy/h was recorded in Ibadan as compared with 110 nGy/h in Lagos while the minimum value of 50 nGy/h was recorded in both Lagos and Ibadan. The standard deviation dose rate values for Lagos and Ibadan shown in Table 3 reveal that there is a wider spread in the dose rates within the surveyed buildings in Ibadan compared with those of Lagos. Figure 3 shows the distribution of the dose rate values.

The mean dose rate from the surveyed buildings in Lagos and Ibadan are lower than those from Ramli et al. (2014) in as well as the study of Sadiq and Agba (2012) in Akwang and Keffi, Nasarawa states with mean dose rates of 148.0 ± 20.0 and 176.0 ± 20.0 nGy/h, respectively, and are also lower than those of Papaefthymiou and Gouseti (2008) in Peloponnese, Greece with mean DR of 70 nGy/h. The Indoor DR in the study areas are comparable with the values recorded in some other areas of the world as shown in Table 4 and mean DR for both Lagos and Ibadan are slightly below the world average mean indoor gamma dose

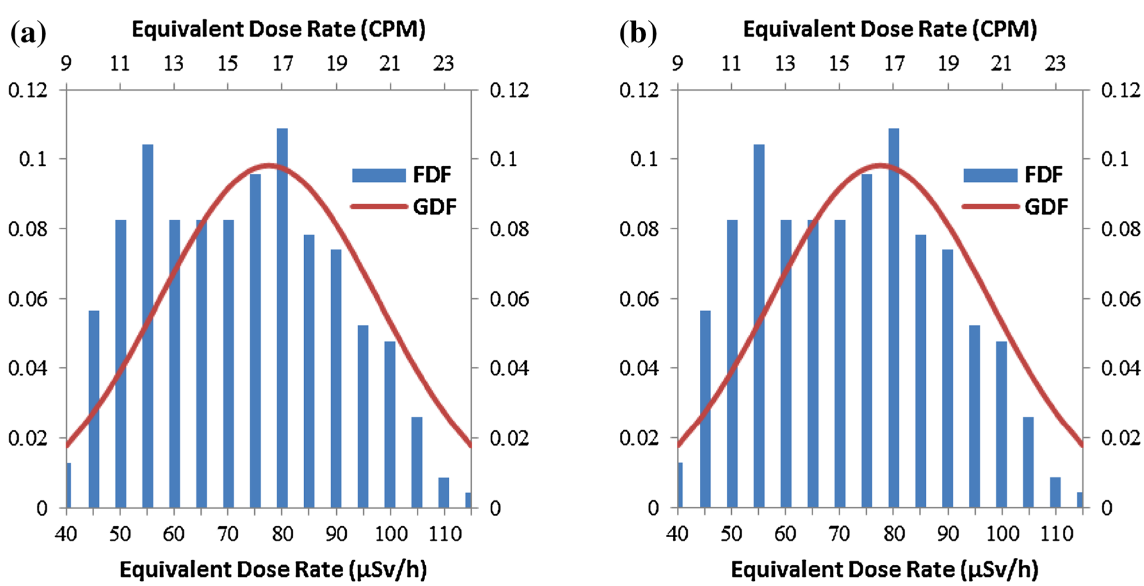

Fig. 2 Frequency distribution function (FDF) and Gaussian Distribution Function (GDF) of dose rates for **a** Lagos and **b** Ibadan, respectively

Table 1 Indoor Gamma dose rate, AED and ELCR for buildings in Lagos

Location	Latitude (°N)	Longitude (°E)	Maximum DR (nGy/h)	Minimum DR (nGy/h)	Mean DR (nGy/h)	AED (mSv/y)	ELCR
L1	6.610555	3.255833	100	60	81.14 ± 1.80	0.40 ± 0.01	1.08E−03
L2	6.610555	3.255833	100	70	83.00 ± 1.70	0.32 ± 0.01	1.10E−03
L3	6.614434	3.264358	80	50	65.37 ± 1.90	0.45 ± 0.01	0.87E−04
L4	6.609676	3.275292	110	50	80.73 ± 2.70	0.40 ± 0.01	1.07E−03
L5	6.612122	3.275758	110	40	67.07 ± 2.30	0.33 ± 0.01	0.89E−04
L6	6.517238	3.255833	100	50	69.44 ± 2.10	0.34 ± 0.01	0.92E−04
L7	6.517238	3.318969	90	50	69.20 ± 2.30	0.34 ± 0.01	0.92E−04
L8	6.548524	3.266768	100	50	76.59 ± 2.10	0.38 ± 0.01	1.02E−03
L9	6.548524	3.266768	100	50	80.82 ± 1.80	0.40 ± 0.01	1.08E−03
L10	6.489166	3.357777	100	50	73.48 ± 2.00	0.36 ± 0.01	0.98E−03

Table 2 Indoor Gamma dose rate, AED AND ELCR for buildings in Ibadan

Location	Latitude (°N)	Longitude (°E)	Maximum DR (nGy/h)	Minimum DR (nGy/h)	Mean DR (nGy/h)	AED (mSv/y)	ELCR
I1	7.39824	3.92067	70	50	60.77 ± 1.32	0.30 ± 0.01	0.81E−03
I2	7.40059	3.92426	120	50	70.00 ± 4.44	0.37 ± 0.02	1.01E−03
I3	7.39807	3.91357	110	70	91.25 ± 1.84	0.45 ± 0.01	1.21E−04
I4	7.39807	3.91189	120	50	82.31 ± 2.37	0.40 ± 0.01	1.09E−03
I5	7.29952	3.91818	110	50	81.07 ± 3.83	0.40 ± 0.02	1.07E−04
I6	7.46125	3.90815	110	80	96.19 ± 1.76	0.47 ± 0.01	1.28E−04
I7	7.39726	3.91107	90	50	69.41 ± 2.70	0.34 ± 0.01	0.92E − 04
I8	7.39832	3.92648	90	50	72.00 ± 2.68	0.35 ± 0.01	0.96E−03
I9	7.39223	3.91367	90	70	82.94 ± 1.66	0.40 ± 0.01	1.10E−03

Table 3 Statistics of Indoor dose rate for the surveyed buildings in Lagos and Ibadan

Location	Maximum DR (nGy/h)	Minimum DR (nGy/h)	Mean DR (nGy/h)	Standard deviation (nGy/h)	Mean AED (mSv/y)
Lagos	110	50	74.68 ± 0.70	6.60 ± 55.66	0.37 ± 0.01
Ibadan	120	50	79.10 ± 0.66	10.96 ± 77.12	0.39 ± 0.01

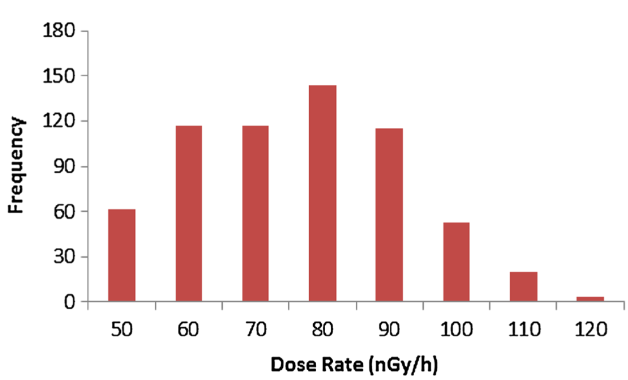

Fig. 3 Distribution of indoor ambient gamma dose rates from buildings in all the surveyed buildings

rate is about 84 nGy/h according to UNSCEAR (2000, 2008) reports.

The variation in the indoor exposures would be as a result of the dependence of the dose rates on radionuclide concentrations in outdoor soils and building materials; the relative contribution from each being highly dependent on the type of house and building material (UNSCEAR 2008). Ibadan covers a wider geographical land mass than Lagos and as such a higher variation of the indoor absorbed dose rate in Ibadan may be as shown in the results may be expected. In terms of dose, the principal primordial radionuclides are ^{40}K, ^{232}Th and ^{238}U. Both ^{232}Th and ^{238}U head series of radionuclides that produce significant human exposure (UNSCEAR, 2000). This study does not reveal the contribution the relevant decay series to the measured dose as many

Table 4 Comparison of Indoor dose rates (DR) in Lagos and Ibadan with other areas in the world

Region/country	DR (mean) (nGy/h)	DR (range) (nGy/h)	References
Cuba	30	10–76	Tomas Zerquera et al. (2001, 2002)
Kazakhstan	–	150–280	UNSCEAR (2008)
Islamic republic of Iran	115	70–165	UNSCEAR (2008)
Kuwait	90	–	UNSCEAR (2008)
Finland	73	24–181	Arvela et al. (1995), Arvela (2002)
Iceland	23	14–32	Ennow and Magnusson (1982)
Lithuania	81	34–224	Lebedyte et al. (1999)
Belgium	60	32–180	Gillard et al. (1988)
Germany	80	20–700	UNSCEAR (2008)
Italy	105	0–690	Bochicchio et al. (1996), Cardinale et al. 1972
Greece (Peloponnese)	70	–	Papaefthymiou and Gouseti (2008)
Bulgaria	75	57–93	UNSCEAR (2008)
Slovenia	75	40–250	Andjelov et al. (1995)
Nigeria (Akwanga, Nasarawa)	148	–	Sadiq and Agba (2012)
Nigeria (Keffi, Nasarawa)	176	–	Sadiq and Agba (2012)
Nigeria (Lagos)	≈ 75	50–110	Present study
Nigeria (Ibadan)	≈ 79	50–120	Present study
World average	84	–	Senthilkumar et al. (2014)

past studies that determined the activity concentration of naturally occurring radionuclides in some natural samples of soil and water with relatively higher concentration of ^{40}K than any other naturally occurring radionuclides. For example, the study of Muhammad et al. (2011) revealed that the ^{40}K series had the highest mean contribution of 57.3%, followed by ^{232}Th and ^{238}U with mean contributions of 39.3 and 7.3%, to the absorbed gamma dose rate in air. Potassium in its natural form contains 0.012% of ^{40}K which decays with a half-life of about 1 billion. It is characterized by gamma ray energies of 1.314 and 1.46 MeV in 89 and 11% of its beta decay, respectively. These gamma ray energies are within the registered beta and gamma radiation energy for the measuring device used in this study.

The mean AED for Lagos and Ibadan due to indoor exposures were 0.37 and 0.39 mSv/y (as shown in Fig. 4) with ELCR of 0.99E−3 and 1.05E−3, respectively. The calculated mean AED are slightly lower than the 0.4 mSv/y world average indoor effective dose (UNSCEAR 2000) but well below the dose limit of 1.0 mSv/y by International Commission on Radiological Protection (ICRP) 60 recommendations for detrimental effects to the general public. However, 40 and 66.67% of the investigated buildings in Lagos and Ibadan, respectively (i.e., over 50% of all the investigated buildings), had AED above the 0.4 mSv world average. The AED from this study are also higher than the value reported from a nationwide study of the terrestrial radiation in Nigeria with mean annual effective dose equivalent is 0.27 mSv/y (Farai and Jibri 2000). The

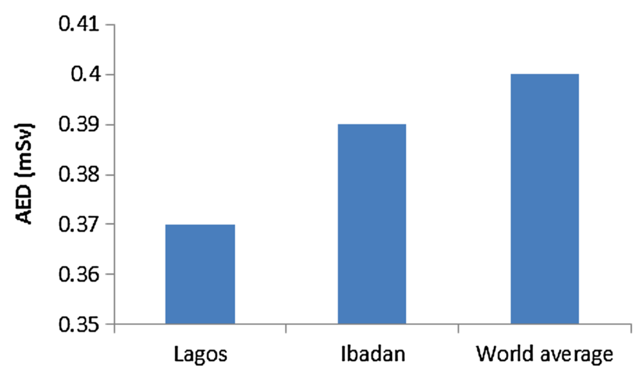

Fig. 4 Comparison of AED in Lagos and Ibadan with the world average value

higher values of the indoor AED from Lagos and Ibadan compared to the AED from the nationwide study could be as a result of the contribution from the building materials. The AED from this study are, however, lower than the value reported in the study by Chad-Umoren et al. (2006) in the evaluation of indoor background ionizing radiation profile of a Physics laboratory in Port Harcourt Nigeria revealing a higher indoor background AED of 0.871 ± 0.03 mSv/y. All the ELCR values as shown in Tables 1 and 2 ranged from 0.87E−03 to 1.08E−03 for Lagos and 0.81E−03–1.28E−03 for Ibadan. These values are higher than the world average ELCR of 0.29×10^{-3} (Taskin et al. 2009).

4 Conclusion

This study revealed that the indoor background radiation within buildings in Lagos State were generally higher than those of Ibadan. The dose rate values in both locations are comparable with those reported in many other areas around the world. The observed variations could be ascribed to the differences in activity concentration of radionuclides in the outdoor soil as well as sand and stones used in the construction of buildings. The mean dose rate values from the buildings in both Lagos and Ibadan are generally lower than the world values average values. However, The Annual Effective Dose from many of the buildings is above the world average values for indoor gamma exposure of 0.4 mSv.

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