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RADON-222 CONCENTRATION IN AIR: A CASE STUDY OF AYEDUASE TOWNSHIP, KUMASI, GHANA

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ABSTRACT

Objective: Radon levels in structures (interior environment) were measured in many dwellings and hostels in Ayeduase Township, Ashanti Region, Ghana. The purpose of this study was to quantify radon toxicity in the Ayeduase community, which houses approximately half of the students at Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, and to determine the risk levels for individuals (categorized as infants, children, and adults) living in the community's various suburbs.

Materials and Methods: Households in Ayeduase had an average of four people per room. The radon in air concentration was measured with a continuous radon monitor using continuous active sampling approach. Multiple measurements were taken at tight space-time intervals over a period of 24 hours. The Continuous Radon Monitor was installed in dwelling rooms in zones where the monitor could record fresh air entering the room. The yearly effective dose was computed using the Mondal 3 Software.

Results: The continuous sample air radon concentration in Ayeduase Township was found to be in the range of 8.510 0.05607 Bq/m3 to 11.100 0.6379 Bq/m3. The manually computed effective annual dose rate for indoor air radon was 0.3494 mSv/year to 0.4558 mSv/year for babies, 0.0683 mSv/year to 0.0891 mSv/year for children, and 0.0559 mSv/year to 0.0729 mSv/year for adults. The comparative results from the Mondal 3 Software showed that the effective annual dose rate for indoor air ranged from 0.32 mSv/year to 0.37 mSv/year, with an average of 0.36 mSv/year for infants, 0.11 mSv/year to 0.14 mSv/year, with an average of 0.12 mSv/year for children, and 0.084 mSv/year to 0.097 mSv/year, with an average of 0.94 mSv/year for adults.

Conclusion*:* Ayeduase's radon toxicity profile in terms of air showed distinct features. The maximum value of indoor air radon concentration level determined was lower than the global average value of 40 Bq/m^3 of indoor radon concentration level and also lower than the reference level of 100 Bq/m^3. In Ayeduase, the estimated average effective dosage over a year for babies, children, and adults were lower than the 1.2 mSv/year indicated by ICRP Publication 126.

Recommendation: Radon toxicity due to water and soil sources are required to access the total toxicity levels in the township. Reliable evaluation of the potential for human exposure to radon depends in part on the reliability of supporting analytical data from environmental samples and biological specimens is highly recommended, as well as, concentrations of radon in unpolluted atmospheres and in pristine surface waters are typically within the limits of current analytical methods.

Keywords: *Radon, Effective Dose, Annual Effective dose (AED), indoor radon, Air pressure differentials (APD), Human Respiratory Tract Model (HRTM).*

INTRODUCTION

Radon monitoring has grown in popularity over the years as a result of the health dangers it poses. Radon concentrations in air, soil, and water have recently been measured. Radon-226 (radon) is a radioactive noble gas created by the decay of Uranium, which is naturally present in practically all soils and water (UNEP, 2017). Radon has the shortest half-life of an isotope, having a half-life of 3.82 days (91.68 hours). Because of their short half-lives, radon and its progeny pose a health risk. In terms of radiation hygiene, the most significant source of public exposure is radon and its offspring, which account for more than half of the dosage exposure received by the public from natural radiation sources (UNSCEAR, 2000; Bochicchio et al., 1995; NCBI, 2022; Eisenbud M & Gesell T, 2014). Radon emitted by rocks and soils is rapidly dispersed in the atmosphere (ICRP, 1993; Darby et al., 2015; Efstratios and Dimitrios, 2014; Appleton, 2007).

People are exposed to radioactivity that occurs naturally in the land, air, water, and food. Radon concentrations in the open air are typically quite low and do not represent a risk. Radon may enter the home via foundation fractures and gaps in the floors and walls. Radon may reach extremely high concentrations in poorly ventilated buildings, hence the degree of ventilation can influence radon levels in structures. People spend the majority of their time inside – in workplaces, lecture halls, residences, and so on – and are therefore exposed to radon gas that has collected in the space, which may be dangerous depending on the concentration levels (Lubin et al., 2004).

Several variables have been discovered to impact the quantity of radon in homes. This includes the age of the residence, the kind of rock underneath the habitation, the interior and exterior construction materials, the structure's level, seasonal change, and geological considerations (Barros-Dios, 2007; Papaefthvmiou et al., 2003; Khan, 2000; Turk et al., 2012 and Sundal et al., 2004). The amount of radon outdoors and inside varies depending on various contributing variables. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has estimated the worldwide, population-weighted values of these parameters for dwellings to be 25 Bq/m3 , 2.5 Bq/m3 and 40 Bq/m3 , respectively (UNSCEAR, 2000). The ICRP Publication 115 suggested reference level is 100 Bq/m3, but the US EPA standard is 148 Bq/m3 (ICRP, 2010; US EPA, 2016).

Radon is emitted from the water and mixes with the interior air in numerous settings, including bathing, washing clothing, and flushing toilets. As a result, radon from water adds to the overall risk of radon inhalation linked with indoor air (Ishikawa et al., 2009). The principal health consequence of radon is lung cancer, which is caused by inhaling radon in indoor air. Some uranium miner studies have repeatedly shown a link between radon and lung cancer (Carrillo et al., 2015; Lubin et al., 1990; Axelson, 1991; Finkelstein, 1996). When radon decays and is absorbed into the lungs, it emits charged particles with kinetic energy, which may damage the cellular DNA molecule in sensitive lung tissues and may cause cancer. According to the Health Effects of Radon Exposure, radon exposure is responsible for around 14 percent of the 164,100 cancer of lung deaths in the United States each year, which equates to roughly 15,000 to 22,000 cancer of lung fatalities per year. Overexposure to the outside air (mainly mines) has been blamed for 700 of these fatalities (BEIR VI, 1999; ATSDR, 1990). Radon in houses was responsible for around 9% of lung cancer deaths and approximately 2% of total cancer deaths. A 100 Bq/m3 rise in long-term average radon concentration raises the risk of lung cancer by 16% (Darby et al., 2005; ATSDR, 1990; WHO, 2009). Various radiological models may be used to analyze the complete effect of radon gas exposure in the environment. When inside air is warmer than outside air, it rises and leaves via the roof. This air is replaced by radon-containing soil gases. The stack effect draws radon into a residence when the house temperature rises and the outside temperature falls. The largest variables influencing radon levels to grow or decrease inside a residence are air pressure differentials (APD) and the stack effect (Papaefthvmiou et al., 2003; Kyusun et al., 2016; Yousef & Zimami, 2020). Because APDs and thstack effect are greater at night and lower during the day, indoor radon levels are higher at night and lower during the day, a phenomenon known as the diurnal APD/stack effect.The purpose of this study was to quantify radon toxicity in the Ayeduase community, which houses approximately half of the students at Kwame Nkrumah University of Science and Technology, Kumasi, and to determine the risk levels for individuals (categorized as infants, children, and adults) living in the community's various suburbs. This investigation supplied the baseline data for measuring the danger of exposure to this gas by the people in this town, particularly Kwame Nkrumah University of Science and Technology (KNUST) students who are the country's future leaders.

Radiological Model

The Human Respiratory Tract Model (HRTM) allows for the assessment of dosage per unit intake or exposure, as well as the interpretation of bioassay data from persons who inhale gases. Figure 1 (Bailey et al., 2007) depicts a model that takes into account five parts of the respiratory tract: two extrathoracic regions, the bronchial region (BB), the bronchiolar region (BB), and the alveolar-interstitial region (A1), as well as their various radio sensitivities. The anterior nose, or ET1 and the posterior nasal passages, larynx, throat, and mouth are the two extrathoracic regions (ET2) (World Health Organization, 2009; Taylor, 1996).

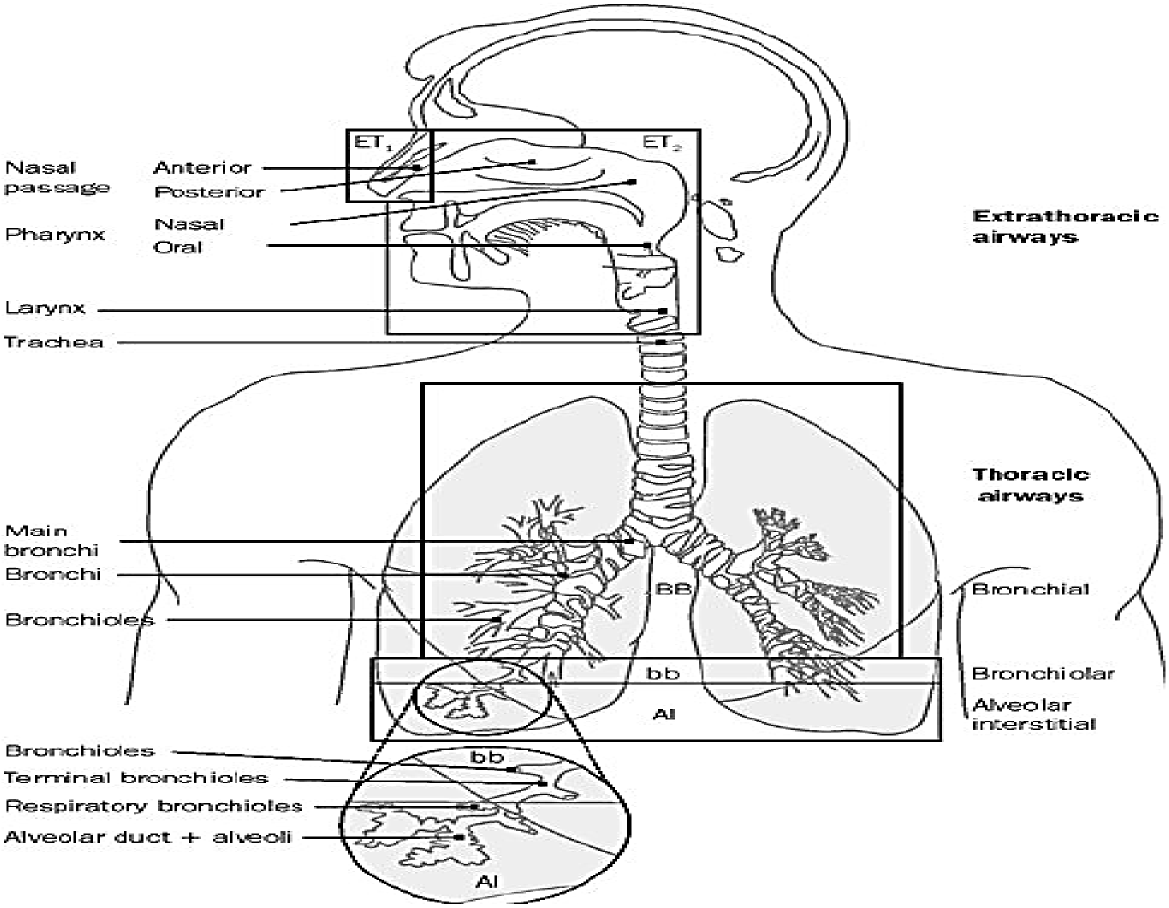

Figure 1: The ICRP Human Respiratory Tract Model (ICRP, 1994)

Default parameter values are recommended for all elements, depending on whether absorption is deemed slow (S), moderate (M), or rapid (F) (F). The original reference values are reported in Publication 66 (ICRP, 1994) and are replicated in Table 1 with the ICRP HRTM updated (Bailey et al., 2007). The compartment model is shown in Figure 2 along with estimates of the inhaled material originally held in each compartment (ICRP, 1994).

Table 1: Material – Specific Absorption Rate

Type F	100 percent absorption in 10 minutes. The material in BB, bb, and AI is rapidly absorbed, while 50% of the material in ET2 is cleared to the GI tract by particle transport.
Type M	10 percent absorbed in 10 minutes, and 90 percent in 140 minutes. About 10% of the deposit in BB and bb and 5% of the deposit in ET2 are absorbed quickly. Approximately 70% of the AI deposit reaches the body's fluids.
Type S	0.1 percent absorbed in 10 minutes and 99.9 percent in 7000 days Only a small percentage of the AI deposit enters bodily fluids by ET, BB, or bb absorption.

Radon monitoring has been widespread concern over the years because of the dangers it poses to human health. In the last several months, radon levels in the air, soil, and water have been measured (Eisenbud M, Gesell T., 1997; UNEP, 2016; Fujiyoshi R. et al, 2002). Researchers in Ayeduase, Nigeria, are investigating radon toxicity and determining the danger levels for people living in the different suburbs of the village (infants, children, and adults).

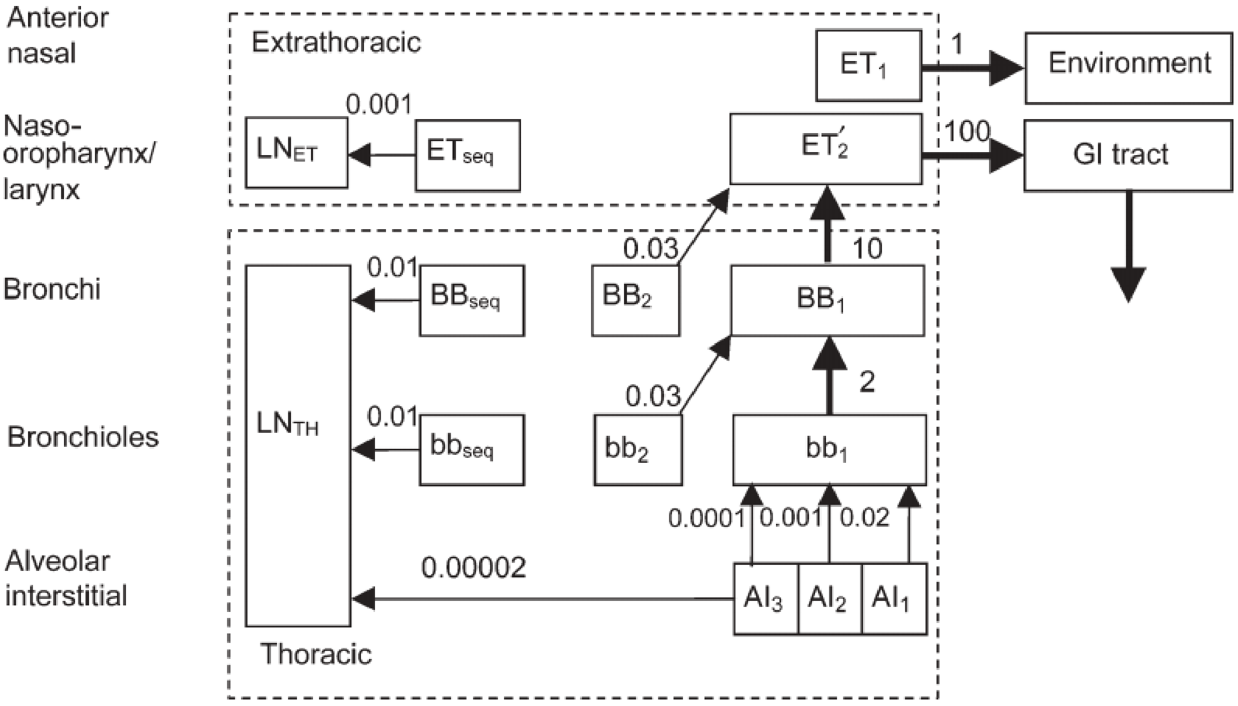

Figure 2: The flow chart of the Compartment model for the Human Respiratory Tract (ICRP, 1994)

MATERIALS AND METHODS

Study Area

Ayeduase Township is a populated location (Class P - populated place) in Ashanti Region, Ghana, inhabited by indigenous people and migrants, the majority of whom are students at Kwame Nkrumah University of Science and Technology (KNUST). Longitude 1.54250W and latitude 6.67450N are approximate coordinates for the location. It has a population of 29,748 people and is situated at an elevation of 246 meters above sea level. It is bordered by Boadi Township to the east, KNUST to the west, Koite to the south, and Kentikrono to the north (figure 3). The location is in the semi-equatorial zone, with two major rainy seasons. The main season lasts from March to June, while the second season lasts from September to the end of November. The city's yearly rainfall averages between 150 and 170 mm. Geologically, the city is located in the Kumasi Basin of the Birimian Supergroup (Figure 3) and is made up of three major lithological units. These are the thin top duricrust layer with a thickness of 0.1–0.3 m covering a saprolite layer with a thickness of 5 to 30 m that averages approximately 28 m in the research region (Wemegah et al., 2017). Ayeduase has a population of 29,748 people and 2,210 residential homes, as well as 55 hostels (Wemegah et al., 2017). 36.2 percent of the hostels had four students per room, 27.6 percent had two students per room, 24.8 percent had three students per room, 6.8 percent had one student per room, and 4.8 percent had more than four residents (Danso and Hammond, 2017). Households in Ayeduase had an average of four people per room. Figure 4 shows the total number of sample locations considered for indoor air concentration measurements.

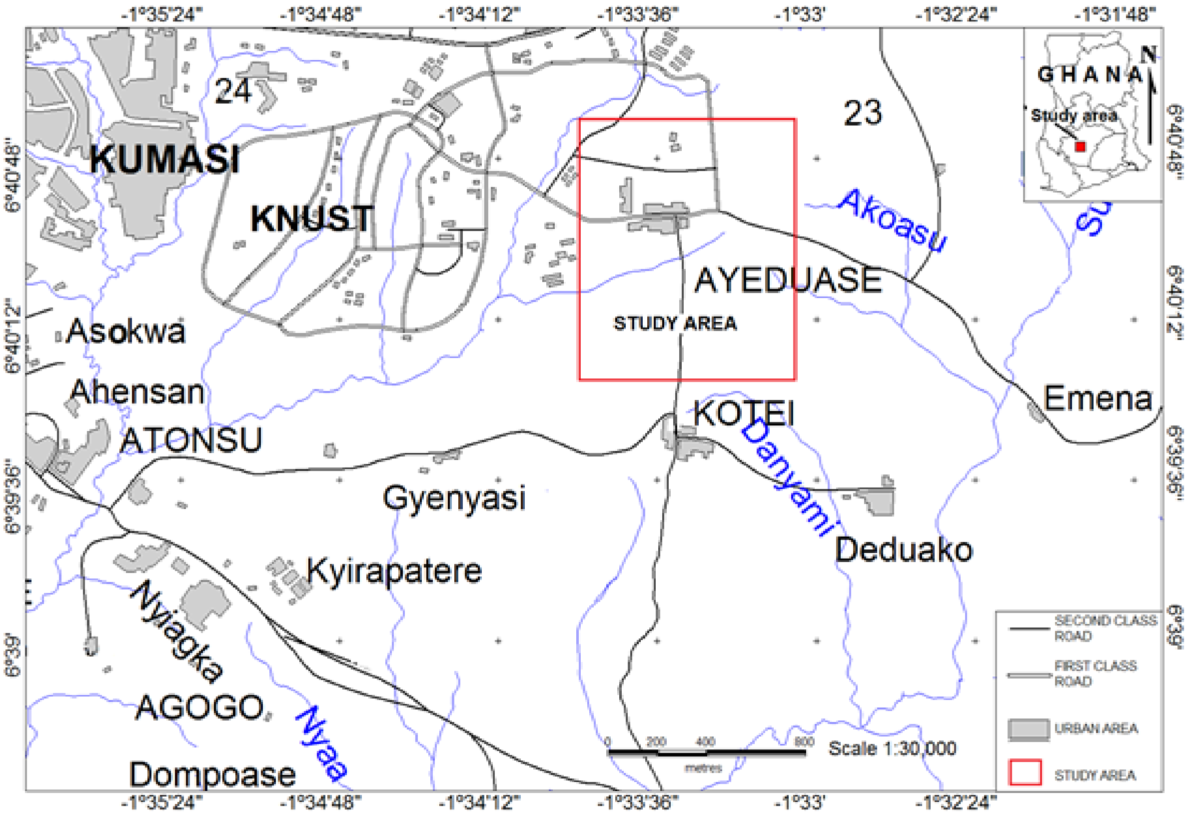

Figure 3: Map of Kumasi showing sample site (Ayeduase).

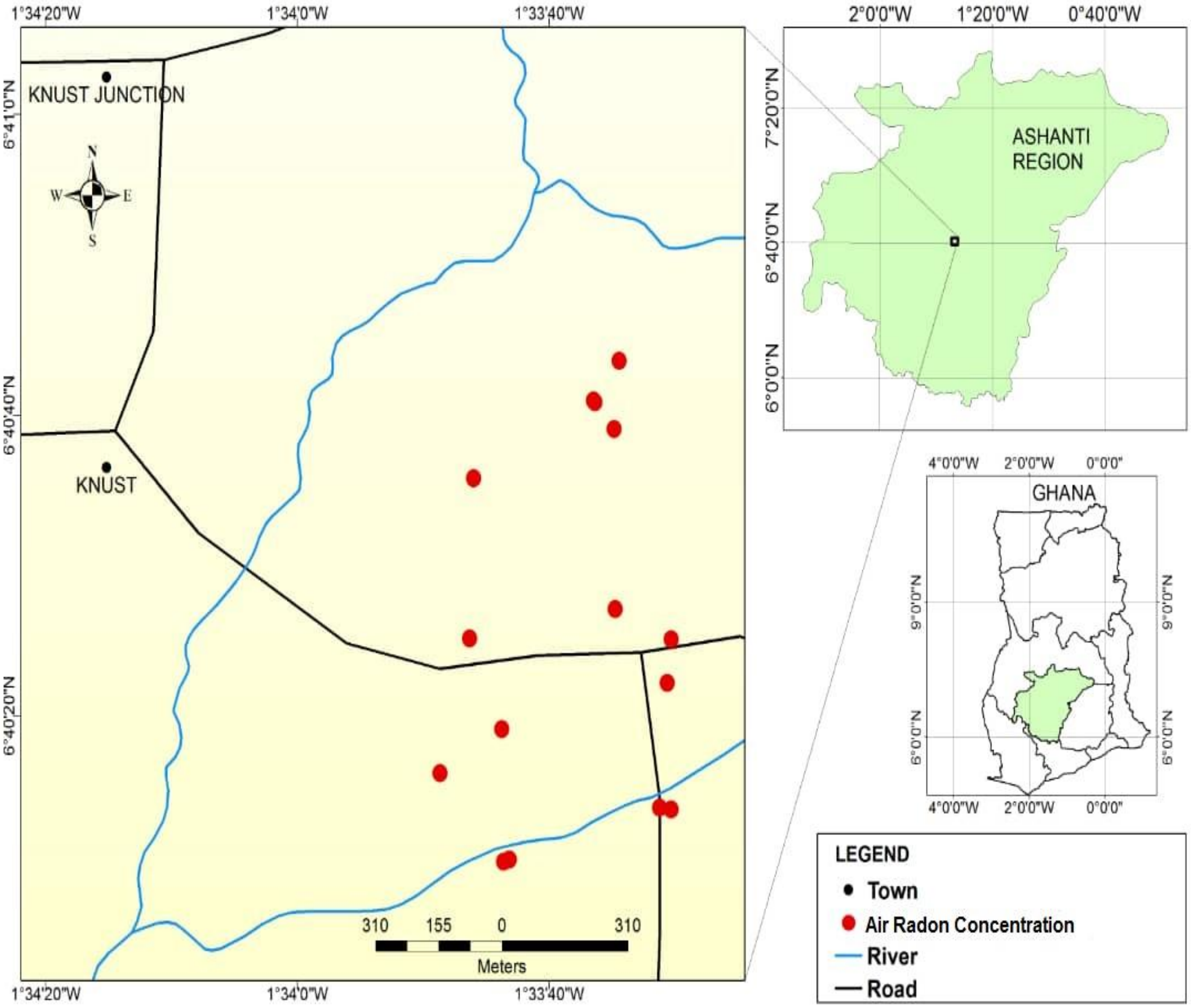

Figure 4: Sampling sites in Ayeduase for indoor radon assessment, overlaid on the basement granitoid rock.

Method

The radon concentration in the air was measured using a continuous active sampling approach. Multiple measurements were taken at tight space-time intervals over a lengthy period. The Continuous Radon Monitor was installed in dwelling rooms in zones where the monitor could record fresh air entering the room. For the specified test duration of 24 hours, readings were obtained at one-hour intervals per measurement location. The data was then examined using the Sun Nuclear 1029 – model software, and the average radon concentration was calculated using the counts. Continuous measurements are useful in investigations of the impacts of various impact factors on indoor radon concentrations, such as ventilation rate or pressure differentials. This type of monitoring is beneficial when radon concentrations fluctuate dramatically or fast over time.

$$RC = \ (Q\ (1 -\ e\hat{}(-\lambda t))/v \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ Eqn\ (1)$$

Where RC = radon concentration at t1 in pCi/L

Q = Source activity in pCi

e = base of the natural logarithm

λ = 0.0001258 per minute

t = time interval between t_o and t_1 (i.e. t_1 - t_o)

v = total volume in litres

The annual effective dose (AED) was calculated using equation 2 (UNSCEAR, 2000). The Mondal 3 software was also used to analyze the effective dose for different age groups.

$$\mathrm{AED\ (mSv/y) = CRn\ \times\ F\ \times\ H\ \times\ T\ \times\ D \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ Eqn\ (2)}$$

Where, F= is the equilibrium factor, F= (0.4)

H = is the occupancy factor, H = (0.8).

T = is the time in one year in hours, T= (8760 h/y).

D = is the dose conversion factor D = (9×10^{-6} (m Sv) / (Bq.h.m^{-3})).

Mondal 3 is a computer based software developed by National Institute of Radiological Sciences (NIRS). Mondal 3 is used to estimate the of radionuclides inhaled or ingested by workers or by members of the public and resulting committed effective dose based on measurement results of individual monitoring such as in vivo counting or bioassay measurement.

RESULTS AND DISCUSSION

The concentration of radon inside is determined by the kind of structure and its ventilation. According to research, the average worldwide outdoor radon level rises between 5 and 15 Bq/m^3 (0.135 and 0.405 pCi/L), although indoor radon levels are greater (BEIR VI, 199; WHO, 2009). Radon concentrations in homes, schools, and workplaces in various nations ranged from 10 Bq/ m^3 to more than 10,000 Bq/m^3 (Efstratios and Dimitrios, 2014; Barros-Dios et al., 2006; Aforlabi et al., 2015; Marcinowski et al., 1994; Swedgemark and Mjönes, 1984; Oikawa et al., 2006; Vaupot The analysis of the data acquired in this research for indoor air revealed that the lowest level of radon indoor concentration was 8.51 Bq/m^3 (0.233 pCi/L) in Area 4 and the maximum level was 11.1 Bq/m^3 (0.301 pCi/L) in Area 3. When compared to the WHO generally acceptable threshold of 100 Bq/m^3 (2.7 pCi/L) (WHO, 2009) and the ICRP permitted range of 200 – 300 Bq/m^3, these values are considerably lower, lowering the risk of getting lung cancer (ICRP, 2010) Radon concentrations in the air were estimated and shown for the five (5) research zones in Ayeduase. The average indoor radon concentration was discovered to be 8.621 0.05589 Bq/m^3, 9.879 0.101264 Bq/m^3, 11.100 0.6379 Bq/m^3, 8.510 0.05607 Bq/m^3, 9.879 0.090782 Bq/m^3 for Zones 1, 2, 3, 4, and 5, as shown in figure. 5. The average radon concentrations measured in the selected region of Ayeduase were lower compared to UNCSEAR (2000) reported average value of 46 Bq/m^3. Again the results obtain in this study were with comparable other studies (Papaefthvmiou et al., 2003; Kyusun et al., 2016; Yousef & Zimami, 2020). Though radon concentration levels measured from the study area were lower than ICRP (2010) recommended levels, ICRP indicated no level of radon is considered harmless.

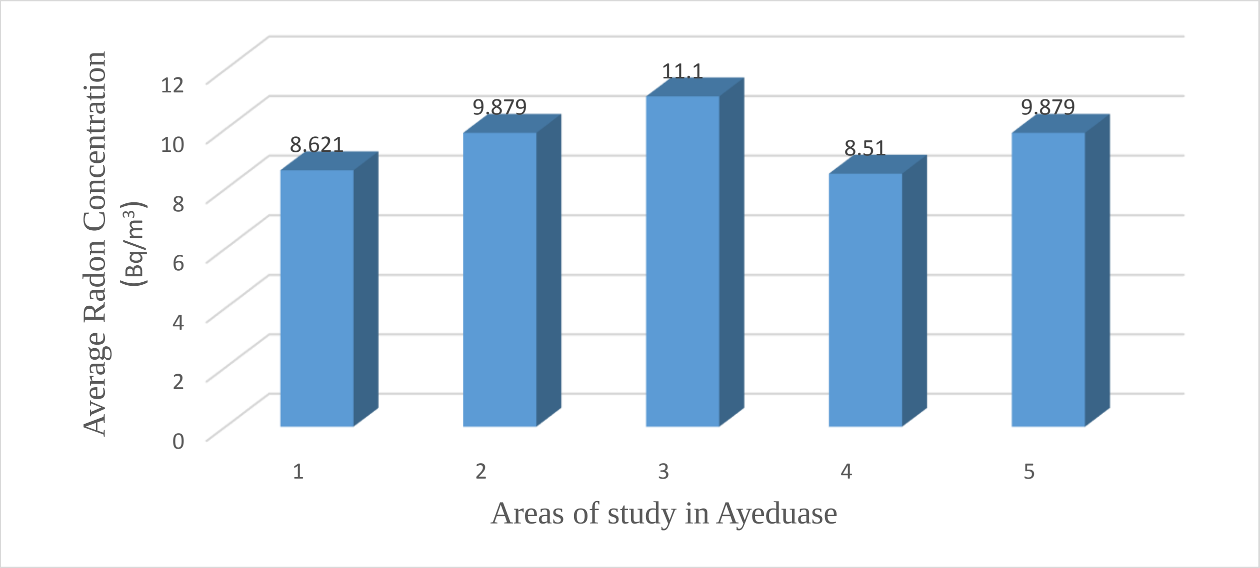

Figure 5: Indoor air average radon concentration levels at various areas in Ayeduase.

When inside air is warmer than outside air, it rises and leaves via the roof. This air is replaced by radon-containing soil gases. The stack effect draws radon into a residence when the house temperature rises and the outside temperature falls. The largest variables influencing radon levels to grow or decrease inside a residence are air pressure differentials (APD) and the stack effect. Because APDs and the stack effect are greater at night and lower during the day, indoor radon levels are higher at night and lower during the day, a phenomenon known as the diurnal APD/stack effect (Tomáš Čechák, Aleš Froňka et al., 2004; Kaiss K Al-Ahmady, David E Hintenlang, 1994).

Data collected was converted into Figure 6, depicting the gridded geographical distribution of radon concentration across the research region. The radon concentration fluctuated widely across the survey, with the northwest and southwest registering the lowest concentrations (blue). A comparable low concentration zone may be found in the area's eastern part. The center point of the region has the greatest levels of radon in the area.

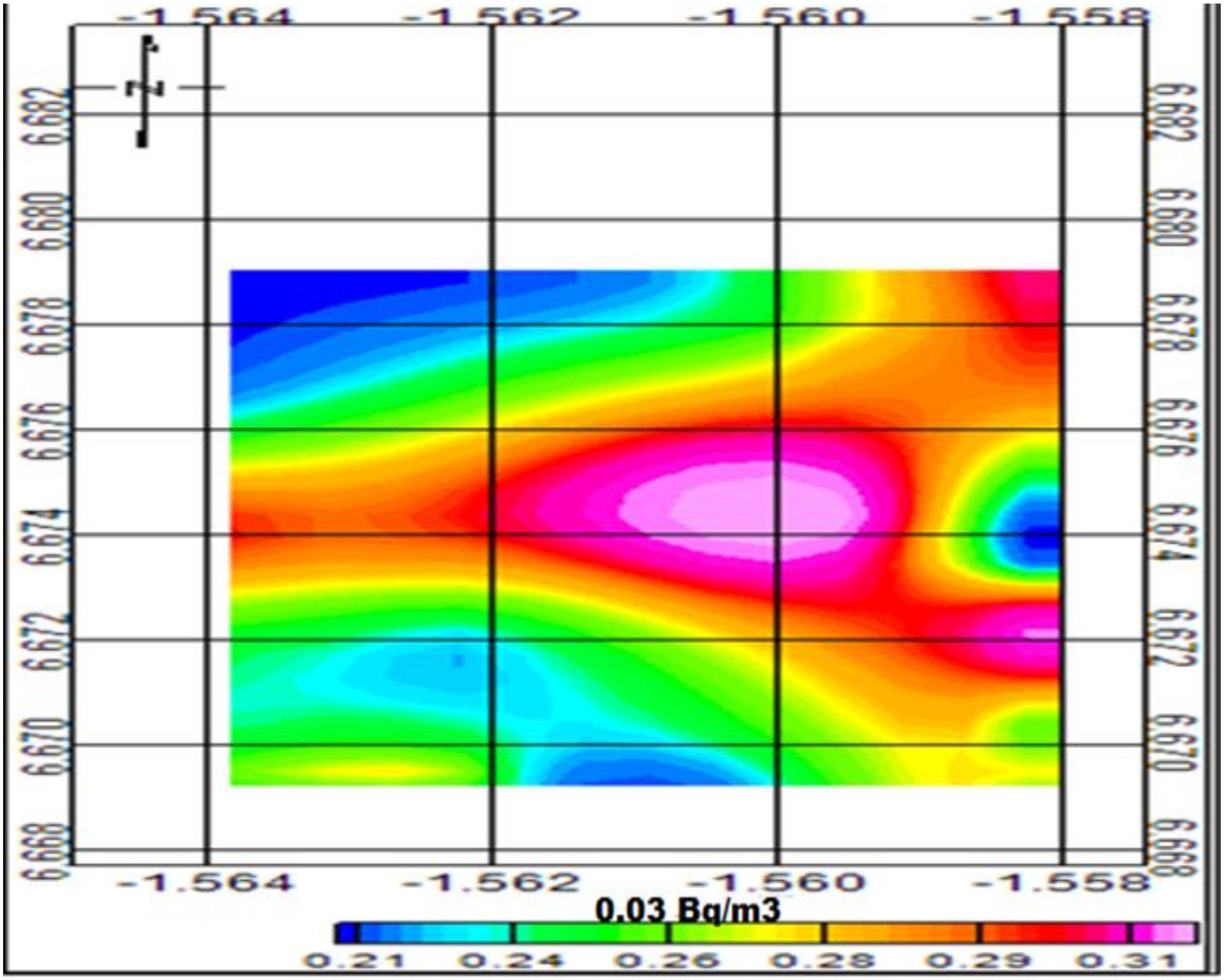

Figure 6: Gridded image showing the spatial distribution of radon concentration in the study area.

The yearly effective dosage for the study regions, figure 7, was estimated and found to be in the range of 0.22 to 0.28 mSv/y with an average value of 0.25 mSv/y. the results were found to be within the tolerable limits of 3 -10 mSv/y indicated by International Commission on Radiological Protection (ICRP) publication 65. (ICRP, 1993). Also the average yearly effective dose was lower than ICRP (2010) global average of 1.15 mSv/yr indicating that dose levels from the study area do not pose a risk.

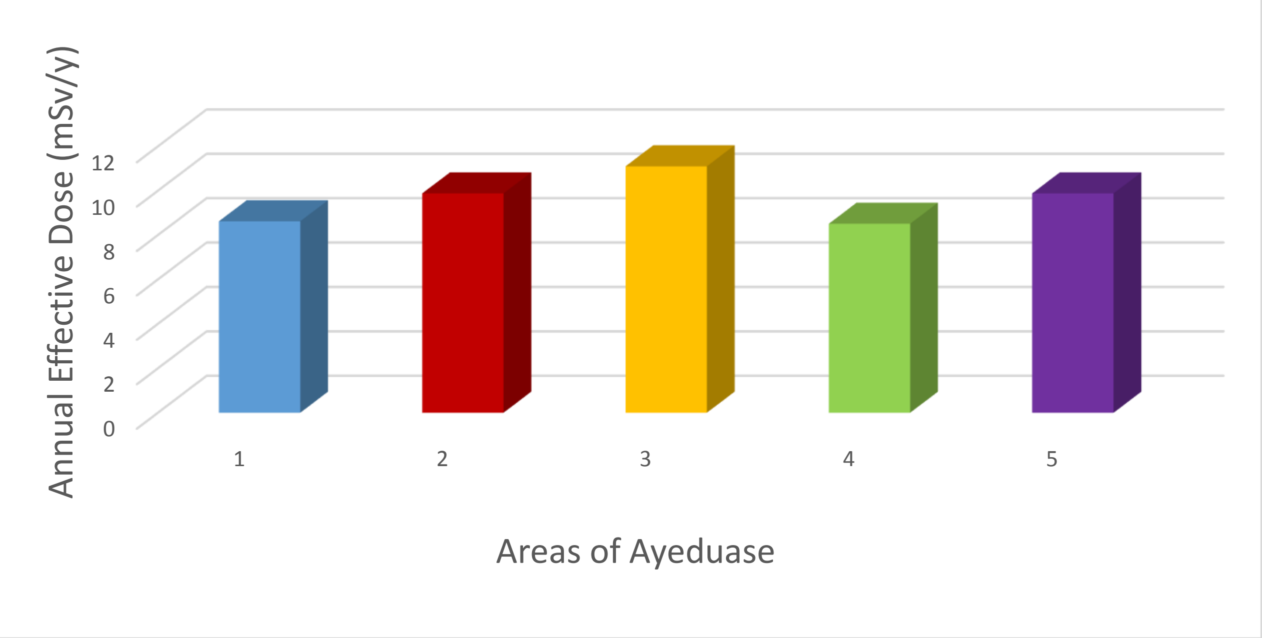

Figure 7: Annual effective dose for various areas in Ayeduase

The yearly effective dosage, which is a product of the absorbed dose and the equivalent dose estimated for air, was computed using the Mondal 3 Software and is shown in Figure 8.

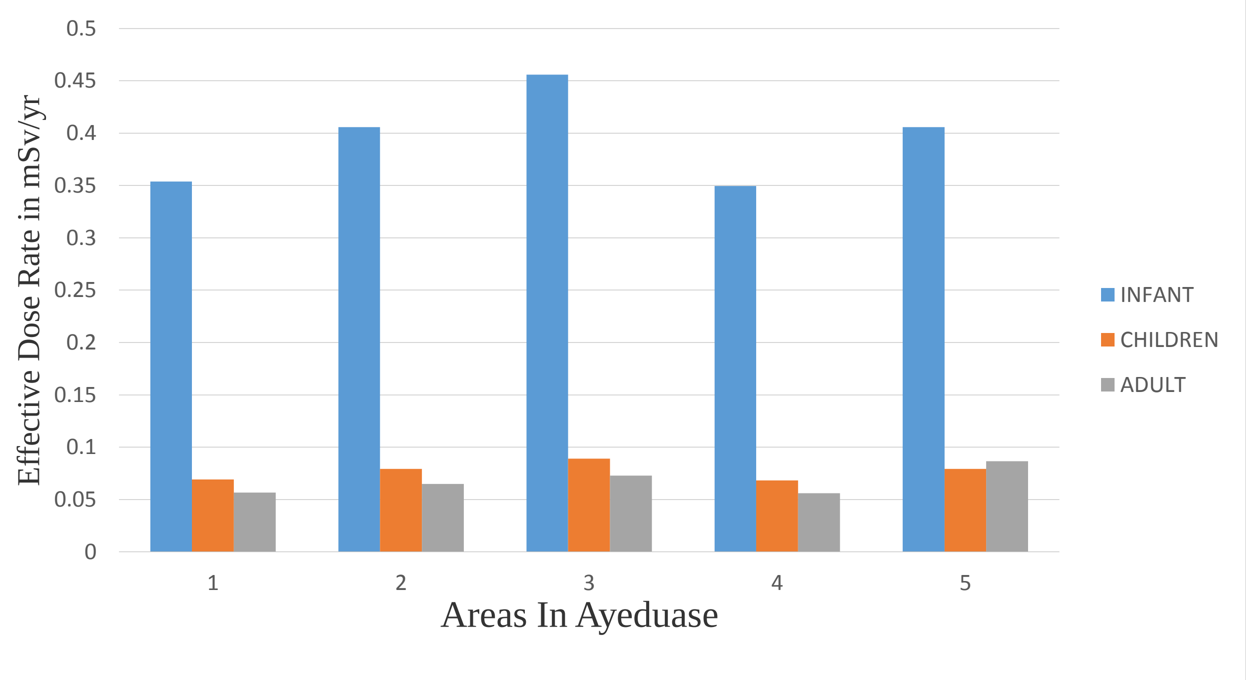

Figure 8: Annual effective dose for the various age groups for air.

The committed effective dosage profile for the body of babies, children, and adults reveals varied doses throughout the body with noticeable effects on the lung, ET airways, bone marrow, and bone surface (see figures 9, 10, and 11 accordingly). These organs corroborate the radon radionuclide route in the respiratory and gastrointestinal organs.

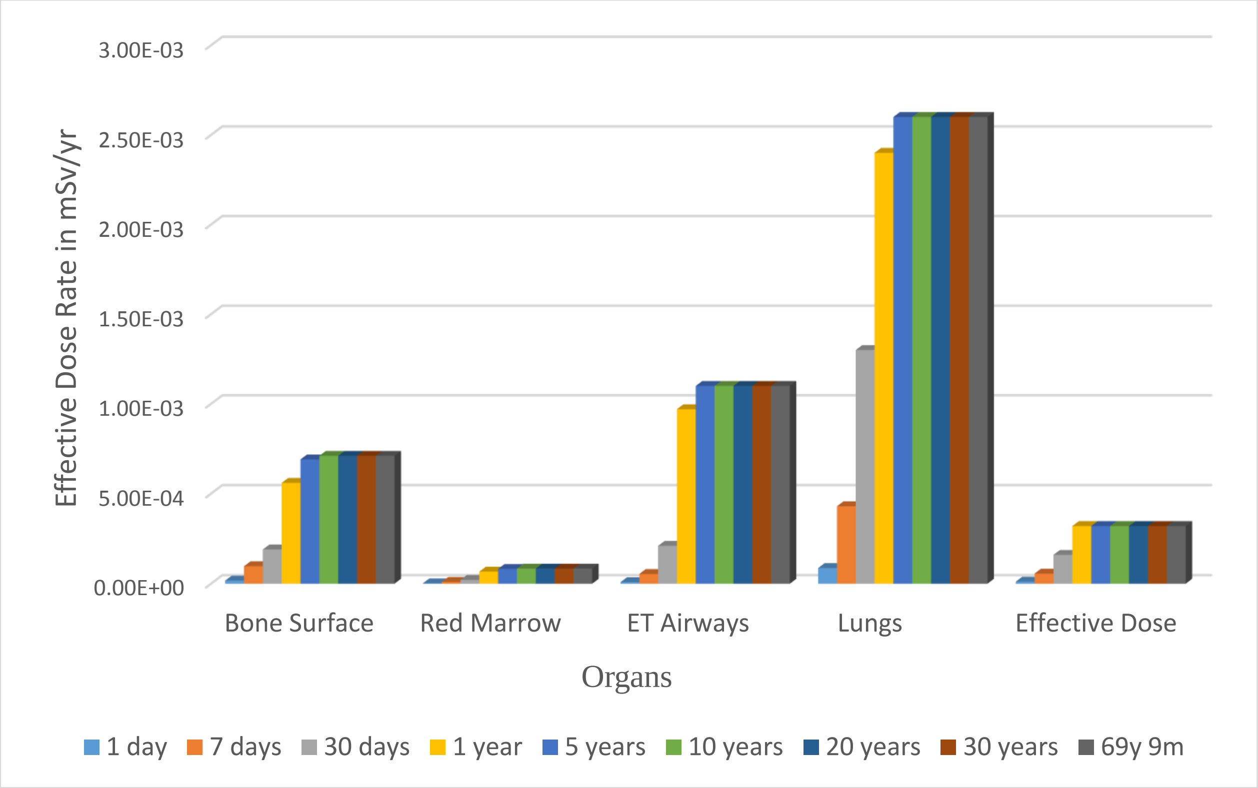

Figure 9: Average effective dose rate for the various organs for infants.

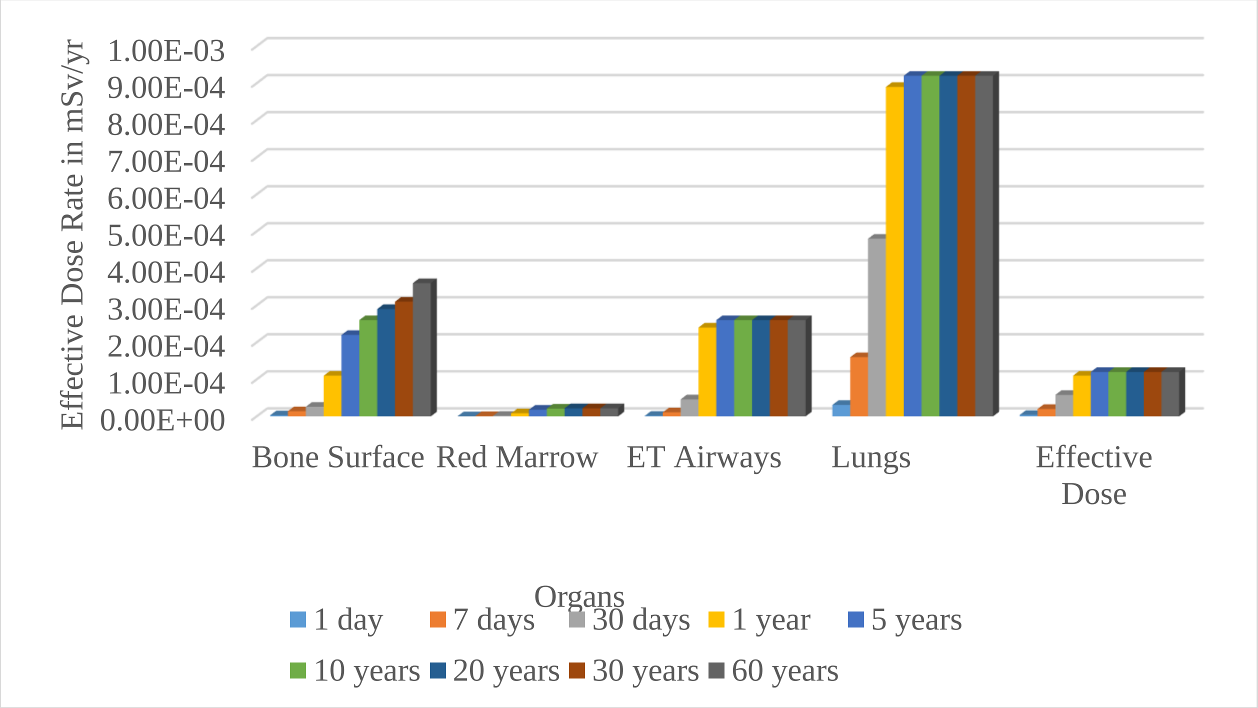

Figure 10: Average effective dose rate in the air for the various organs in children.

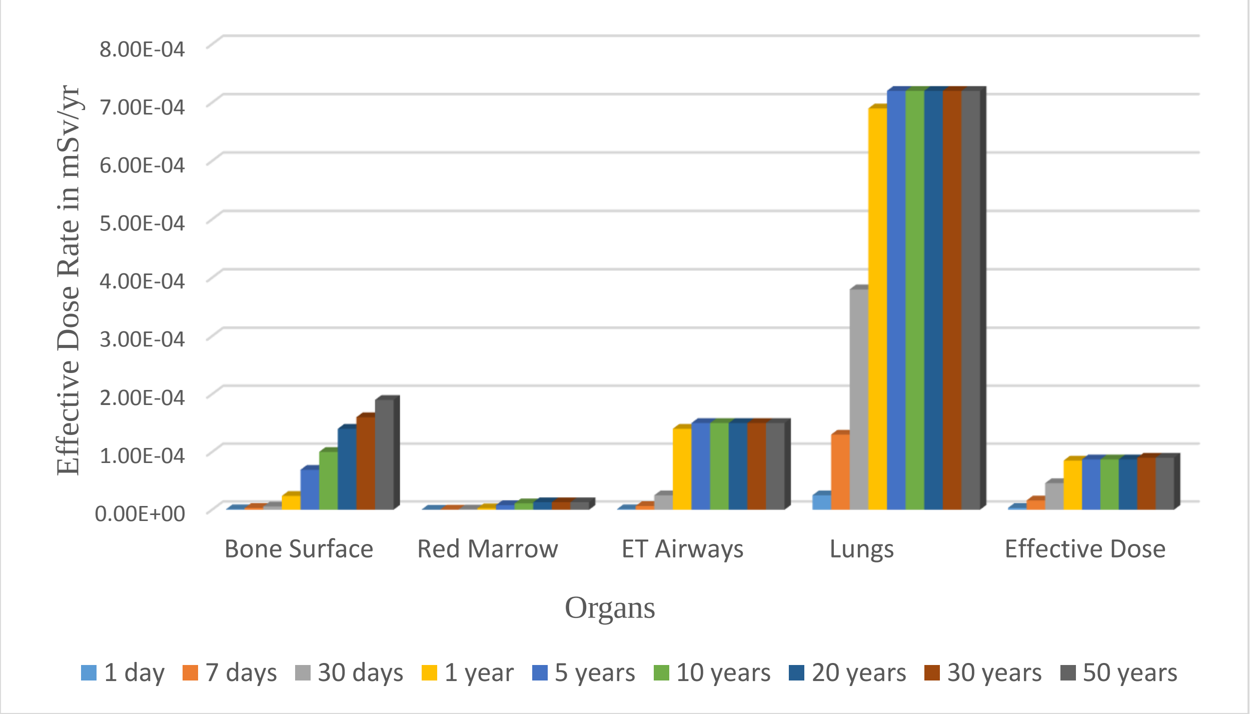

Figure 11: Average effective dose rate in the air for the various organs in adults.

The concentration of indoor radon is determined by the kind of structure and its ventilation. According to research, the average worldwide outdoor radon level rises between 5 and 15 Bq/m^3 (0.135 and 0.405 pCi/L), although indoor radon levels are greater (BEIR VI, 1999; ATSDR, 1990). Radon concentrations in homes, schools, and workplaces in various nations ranged from 10 Bq/m^3 to more than 10,000 Bq/m^3 (Efstratios and Dimitrios, 2014; Barros-Dios et al., 2006; Aforlabi et al., 2015; Marcinowski et al., 1994; Swedgemark and Mjönes, 1984; Oikawa et al., 2006; Vaupot The data analysis for Ayeduase indoor air in this research revealed that the lowest level of radon indoor concentration was 8.51 Bq/m^3 (0.233 pCi/L) in Area 4 and the maximum level was 11.1 Bq/m^3 (0.301 pCi/L) in Area 3. When compared to the WHO generally acceptable threshold of 100 Bq/m^3 (2.7 pCi/L) (WHO, 2009) and the ICRP permitted range of 200 – 300 Bq/m^3, these values are considerably lower, lowering the risk of getting lung cancer (ICRP, 2010). Indoor radon measurements have been done in other countries (Papaefthvmiou et al., 2003; Kyusun et al., 2016; Yousef & Zimami, 2020).

Ingestion and inhalation are the most common ways that radon enters the human system. Children have primitive cells, cells that proliferate rapidly, and a low mitotic phase. Infants are more radiosensitive than adults based on the three characteristics presented, as seen in Figure 8. Because of its half-life of 3.84 days, most breathed radon gas is exhaled again, but some radon offspring, both unattached and associated with dust, may linger in the lungs and undergo radioactive decay. The radiation emitted during this process interacts with lung tissue, potentially causing lung radiobiological consequences. When radon enters the circulation, the majority of it immediately travels to the lungs and is breathed. Radon that is not expelled enters other organs and adipose tissue, where it may linger and degrade. Figure 5 depicts the average radon level concentrations in the five research regions in Ayeduase. The manually computed effective dose rate for indoor air for each age group was based on a combined effective dose. Using the (Monitoring to Dose Calculation

(MONDAL, Japan) Mondal 3 software, the effective annual dose rate for indoor air for the various age groups was 0.32 mSv/year to 0.37 mSv/year with an average of 0.36 mSv/year for infants, 0.11 mSv/year to 0.14 mSv/year with an average of 0.12 mSv/year for children, and 0.084 mSv/year to 0.097 mSv/year with an average of 0. The baby dosage rate was greater owing to the rate of mitotic activity (proliferation rate), mitotic phase, and cell primitivism. Some residential homes in the City of Shiraz were assessed and found to have an average annual effective dose of radon gas of 1.45 mSv/y (Yarahmadi, Maryam Shahsavani, Abbas Mahmoudian, Mohammad Hassan, 2016) which is above the result in this study for all groups but below the permissible threshold.

CONCLUSION

Ayeduase's radon toxicity profile in terms of air showed distinct features. The maximum value of indoor air radon concentration level determined by data analysis was 11.1 Bq/m^3, which is lower than the global average value of 40 Bq/m^3 of indoor radon concentration level suggested by UNSCEAR (2000) and also lower than the reference level of 100 Bq/m^3 recommended by ICRP (2010). To measure public exposure owing to radon inhalation in air, the maximum annual effective dose received by newborns, children, and adults in Ayeduase was found to be 0.37 mSv/year, 0.14 mSv/year, and 0.097 mSv/year, respectively. The reported average values in Ayeduase were likewise determined to be 0.36 mSv/year for babies, 0.13 mSv/year for children, and 0.094 mSv/year for adults. In Ayeduase, the estimated average effective dosage over a year for babies, children, and adults were lower than the 1.2 mSv/year indicated by ICRP Publication 126. (ICRP, 2014).

RECOMMENDATION

Radon toxicity due to water and soil sources are required to access the total toxicity levels in the township. Reliable evaluation of the potential for human exposure to radon depends in part on the reliability of supporting analytical data from environmental samples and biological specimens is highly recommended, as well as, concentrations of radon in unpolluted atmospheres and in pristine surface waters are typically within the limits of current analytical methods. Radon levels are susceptible to change with modifications to buildings or the renewal of the building stock, or the efficiency of regional or national action programmes. Regular national surveys or targeted surveys of new buildings or buildings of concern are, therefore, necessary to assess the evolution or efficiency of a policy.

Declarations

Acknowledge the source of the Software to the Department of Research Promotion, NIRS, Japan. All data analyzed during this study are included in this published article.

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