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LETTER

An assessment of indoor radon level in a suburb of Ghana

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Abstract

Radiation and radioactive isotopes form part of our natural environment. Elevated levels of these radioactive isotopes in the environment can pose a threat to our health. A greater proportion of the natural radiation is from the radioactive gas radon. Although it cannot be detected by human senses, radon and its progenies are of health concern as it can cause lung cancer when inhaled over a period of time. This study sought to provide baseline indoor radon data, the life time risk of lung cancer and its interpretation within a suburb of Ghana. Solid State Nuclear Track Detector (LR-115 type II) was deployed in 82 homes within a suburb for a period of three months (September 2017- January 2018). Indoor radon concentration (IRC) for the suburb was within the range of 4.1–176.3 Bq m^{-3}. With mean 57 $\pm$ 39 Bq m^{-3}. The mean radon exposure to the dwellers was recorded as 0.12 $\pm$ 0.08 $WLMy^{-1}$ resulting in 0.7 $\pm$ 0.5 $mSvy^{-1}$ effective dose to the lung with an excess lifetime cancer risk of 0.39 $\pm$ 0.26%. There was a positive correlation between indoor radon concentration and the building type and the association was significant with a P value of 0.047.

1. Introduction

Radon is chemically noble but overly dissolvable in polar solvents and water, with a half-life of 3.84 days. Radon produces progenies which get attached to aerosols although an amount of progeny could also not get attached. These are called 'unattached fraction' which are important especially in caves. These aerosols when inhaled emit alpha particles which damage the basal cells of the lung tissue [1]. Radon has been classified as a known human carcinogen according to the International Commission of Research on Cancer and originally listed in the Seventh Annual Report on Carcinogens in 1994 [2]. Studies have confirmed that radon in homes increases the risk of lung cancer in the general population [3–5]. According to the Environmental Protection Agency (EPA), [6] radon is second leading cause of lung cancer, next to cigarettes smoking. It can be found at higher levels in the air in houses and other buildings [1]. According to studies, most of the radon exposure to the population occurs indoors where most individuals spend their time [7].

The soil, building materials (sand, rocks, cement, etc,), tap water, natural energy sources used for cooking such as (gas, coal, etc,), the topography of the area, house construction type, ventilation rate, atmospheric pressure and even the life style of people are the main natural sources of indoor radon. Similarly different housing characteristics such as building type, foundation type, housing type, and construction year have been found to be predictors of indoor radon. The underling bedrock on which a house is built can be a huge predictor of high Indoor Radon Concentrations (IRC) [8].

The level of health risk associated with radon is related to the concentration of radon and the time an individual is exposed. A study conducted in Ghana showed a mean annual effective dose with a Radon concentration of (14.1 $\pm$ 0.2) mSv and (466.9 $\pm$ 1.2) Bq m^{-3} respectively [9]. The reading was very high according to the annual average individual effective dose (1.15 mSv) and individuals exposed to this dose were at

Table 1. Indoor Radon Levels in some studied areas in Ghana.

Area (year)	Number of houses	Average concentration (Bqm^{-3})	Range (Bqm^{-3})
Dome (1989)	26	91.8	5.2–336.4
Kwabenya (1990)	20	9.4	5.0–34
Biakpa (1993)	14	80.4	31–194
South Eastern (1994)	20	518.7	169.3–2047.7
Prestea (1994)	39	118.9	0.4–909.1
Kassenna-Nakana (2011)	45	132.7	35.3–244.2
Aburi (2014)	30	49.78	19.07–124.36

high risk of lung cancer. Internationally, it is suggested that the only way to know one's level of radon exposure is to test for it within the home [6].

Globally, indoor radon exposure is estimated to lead to 22 000 deaths annually [10]. The EPA quantifies the extent of death caused by radon per year to be more than that caused by drank driving, falls in the home, drowning, or home fires [11]. In India, the findings of Singh and Kumar [12] were below the recommended indoor radon average of 100 Bq m^{-3} but these values were higher in winter than in summer. In Morocco, a study conducted by Choukri and Hakam [13] identified radon concentration to vary in houses, between 31 and 136 Bq m^{-3}. Currently, Ghana lacks a national average on radon concentration in homes due to few studies conducted [14] (table 1).

Considering public health implication of radon exposure, the WHO released a comprehensive global initiative on radon recommending a reference level of 100 Bq m^{-3} [10] and not exceeding 300 Bq m^{-3} for indoor radon. However, work done in Ghana is not comprehensive enough to arrive at a national average and as well zone potential hazard area. The goal of this study was to increase global database of residential radon exposure at the national level in line with the WHO International Radon Project [15] towards reducing the risk of lung cancer attributable to radon exposure.

The World Health Organization Multiple Exposures Multiple Effects (MEME) model was used as the theoretical framework for this work [16]. The MEME model examines both exposures and health outcomes, in addition to the associations between them, in terms of contextual conditions such as social, economic or demographic factors.

2. Methodology

2.1. Research design

Quantitative method with the help of a survey was used in the study, to measure the indoor radon concentration. Solid State Nuclear Track Detector (LR-115 type II) was deployed in 82 homes within a suburb of Ghana from September 30, 2017 to January 18, 2018. Exposure assessment of inhabitants to radon gas was conducted within the chosen suburb. Detectors were etched in 2.5 M sodium hydroxide solution at (60 $\pm$ 1) °C for 90 min, digitally scanned and counted at the Nuclear Track Detection Laboratory of the National Nuclear Research Institute (NNRI) in Ghana.

2.1.1. Survey questionnaire and Geo referencing technique

An Indoor Radon Assessment Survey was used for data collection within the study population on the dwellings of the participants. The variables included radon concentration, and housing characteristics such as the age of house, type of building, number of windows, forms of ventilation, floor type, and altitude. The annual absorbed dose, effective dose to the lung and the effective life time cancer risk were also measured. The socio-demographic characteristics of the occupants as well as information about the housing characteristics were either reported or observed. In addition, the respondents were asked to answer questions on the presence of smoke within the suburb and any prior knowledge of radon. The geographical reference of each participating house was taken using GPS. Once a homeowner agreed to participate in the study, a survey questionnaire was administered.

2.1.2. Sampling

A multi stage sampling method was used for the study. The suburb was divided into geographical units following the administrative boundaries of the communities. This sampling method was chosen due to a recommendation by IAEA [17] on indoor radon local survey. According to IAEA, the sampling would give a true representation of the indoor readings of the area. For an estimated total housing population of 665 within the selected communities in the suburb with an allowable error of 5%, the total sample size needed for the study was 243 with a 95% confidence level. Simple random sampling was used to select the housing units in each community. The

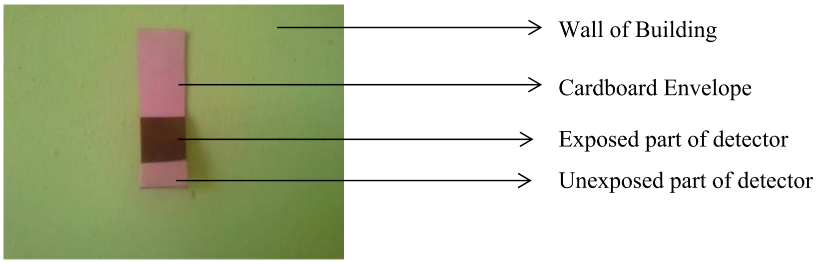

Figure 1. A picture showing how the detector was deployed in the rooms.

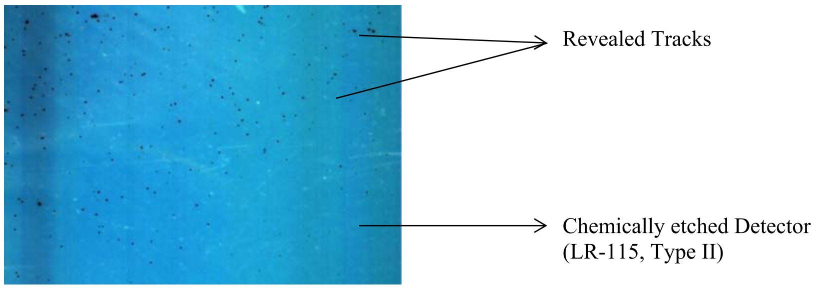

Figure 2. A picture of a scanned detector showing radon tracks.

total houses with their house numbers were obtained and random numbers were generated to select the require sample from each cluster.

2.1.3. Ethical consideration

Ethical clearance and approval for the study were obtained from the research ethics committee of a higher institution. Permission was sought and gained from the designated traditional leaders because of the cultural implication within the country. All study participants consented before participating in the data collection activity. To ensure confidentiality and anonymity, participants were identified with specially created identification blinded to others. Inconvenience of entering home owner's rooms were addressed by consent and ensuring the presence of room owner as well as researchers before a detector was installed.

2.2. Indoor radon concentration measurement

2.2.1. Indoor radon kit placement

Kits were prepared from SSNTD, cut into rectangles of size (2 cm × 3 cm) and placed in specially made cardboard envelopes to hold detectors in place. The detectors were fixed on the walls (figure 1) of the bedroom or halls of households at a height 1.65 m from the floor level. Two third of the detector was exposed to the emergent radon in the room. The 1/3 of the detector was used to compare the intrinsic factory readings. The detectors were placed for a period of 111 days.

For quality control checks, the placements of the detectors (Figure 2) were about 2–3 cm apart for every fifth house. Every other fifth house had detector placed in the room to check the uniformity of the reading.

2.2.2. Etchant preparation and track counting

After the three months' exposure, the detectors were collected and subjected to chemical etching in a 2.5 M NaOH solution. The solution was prepared from 100grams of NaOH pellets dissolved in about 100 cm^3 of distilled water and topped up to 1 litre. The detectors were etched for a period of 1 hr 30 min in a constant temperature (60 ± 1) °C. Then washed and dried. For image processing and track counting, a commercial scanner (Epson Perfection V600) and Image J digital image-processing software were used. These procedures were performed at the NNRI.

2.3. Calculation for the lung cancer risk

2.3.1. Track density

The number of tracks per unit surface, measured in a direction perpendicular to the direction in which the tracks are read.

$$\text{Track density } (\rho) = \frac{\textit{Mean number of counts}}{\textit{Area}}. \tag{1}$$

2.3.2. Concentration of indoor radon gas (Bq m^{-3})

$$\textit{Conc.} = \frac{\textit{Track density}(\rho)}{\textit{Calibration Factor}(\varepsilon) \times \textit{Exposure Time}(T)}. \tag{2}$$

$$\text{Radon Conc. } (C_{Rn}) = \frac{\textit{Track density}(\rho) - \textit{Background track density}(\rho B)}{\textit{Calibration Factor}(\varepsilon) \times \textit{Exposure Time}(T)}. \tag{3}$$

Calibration Factor (ε) = 3.96 (Tracks.m^3/cm^2 kBq.h) of the LR-115 (Type II)
Exposure Time = hrs ($\geqslant$92 days) for indoor passive monitoring
Background track density (ρB) = Average count on unexposed part of the detector

2.3.3. Absorbed dose (mSv or Gy)
Absorbed dose is derived from the mean value of the stochastic quantity of energy imparted [18, 19].

$$\text{Annual absorbed dose } (D_T) = C_{Rn} \times D \times H \times F \times T. \tag{4}$$

Where: C_{Rn} = measured radon concentration (in Bq m^{-3})
D = Dose conversion factor (9 × 10^{-6} mSv hr^{-1} per Bq m^{-3}) [17]
H = Indoor occupancy factor (0.4) [9]
F = Indoor radon equilibrium factor (0.4) [16]
T = Hours in a year (24 h×365 days=8760 hrs yr^{-1})

2.3.4. Effective dose to the lung (mSv)

$$\text{Annual effective dose } (E_T) \text{ to lung } = D_T.W_R.W_T. \tag{5}$$

Where D_T= Annual absorbed dose
W_R = Radiation weighting factor (20 for alpha particles) [20]
W_T = Tissue Weighting Factor (0.12 for the Lung) [21]

2.3.5. Radon exposure

$$\mathrm{E_R} = \mathrm{C_{Rn}} \times \mathrm{H} \times \mathrm{F}(2.7 \times 10^{-4}) \times 8766/170 \tag{6}$$

2.7 × 10^{-4} is the conversion of radon concentration to working level (WL per Bq m^{-3}),
8766 are hours in a year (h y^{-1}), and 170 are working hours in mine in a month (h M^{-1})

2.3.6. Excess lifetime cancer risk (ELCR)

$$\mathrm{ELCR} = \mathrm{E_R} \times \mathrm{T} \times \mathrm{F_R}. \tag{7}$$

Where ER = radon daughter exposure in WLM per year
T = average lifetime expectancy 62.5 for Ghana [19]
$\mathrm{F_R}$ = Risk coefficient for exposure to 222Rn gas in equilibrium with its progeny (5 × 10^{-4} per WLM) [22]

2.4. Data analysis
The data was line listed at EPI Info into MS Excel before exporting to R and STATA for analysis. A descriptive analysis, bivariate and multivariate analyses were run on the data set. Regression analysis was used to test for association predictions. All tests were set to an allowable error of 5%.

3. Results

3.1. Household recruitment
Recruitment logs of houses visited were kept to represent houses that in three categories; houses approached and allowed testing, those approached but nobody was home (unanswered) and those approached but did not want to participate in the study. Of the 287 recorded visitor logs, the willingness to participate houses were 109

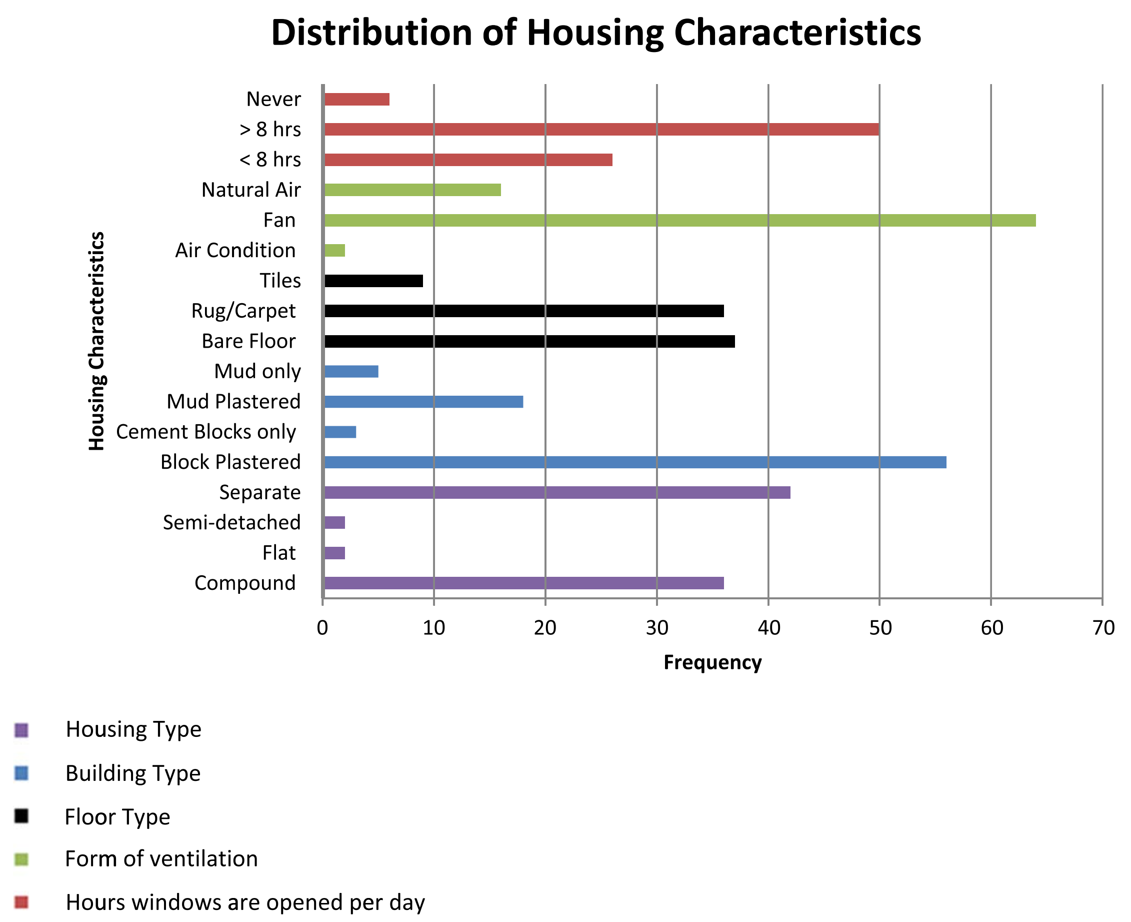

Figure 3. Housing Characteristics.

(37.9%), the unanswered were 157 (54.7%), and the unwilling to participate were 48 (16.7%). After all recruitment was completed and unanswered were revisited, a total of 118 homes participated in the study. Of the 118 tested households, 17 detectors were lost to follow-up and 19 results came back invalid. The analysis was therefore based on 82 valid tested households.

3.2. Description of surveyed houses

The summary of the participated houses included majority (48%) of buildings constructed in the early 90 s to date. Houses built in this era use modern methods and improved building practices. It is not surprising that the majority (72%) of houses were built with cement blocks, only few (28%) were built with mud/earth (figure 3). Two-thirds (63.9%) of all dwelling units within the municipality were compound houses; 25.3% are separate houses and 5.2% are semi-detached houses [23]. But with this study more than half (52%) of sampled dwelling units were separate houses; (42%) were compound houses and (2%) semi-detached. This might be due to the fact that most dwellings units were quite difficult to categorize. Detail descriptive analysis of other housing characteristics are found in figure 3. Most of the 82 households opened their windows more than 8 hours in a day, own fans, have bare floors with plastered blocks and the house are separate or they stand alone respectively.

Most (48%) of the houses were below 25 years and ranges between 1 to 8years with a mean $\pm$ standard deviation of 28 $\pm$ 17years. Majority (44%) of rooms had two windows.

3.3. Indoor radon concentration measurements

Majority (57%) of the measured indoor radon concentrations were below 50 Bqm^{-3}. Meanwhile approximately 16% were above 100 Bq m^{-3} (WHO recommended reference point).

There seem to be an even distribution of homes with Indoor radon concentrations above 100 Bq m^{-3} within the studied area. The red dot are values $>$100 Bq m^{-3} and the green dot are values $<$100 Bq m^{-3}.

There is no significant relationship between radon concentration and altitude of actual Scatter plot (*Top*) and adjusted log-transformed (*Below*) plots.

All housing characteristisc showed a very weak correlation with radon concentration and with postive correlation except for the Age of house that showed a negative correlation.

Table 2. Correlation between indoor concentration and Housing characteristics.

	Correlation	p-value
Building type	0.1796	0.047
Housing type	0.0098	0.856
Ventilation type	0.0999	0.200
Floor type	0.1150	0.124
Number of windows	0.1564	0.161
Age of house	−0.0173	0.944

F-Test = 1.47, Prob > F = 0.2, R-squared=0.105, Adj. R-squared = 0.03.

In table 2, the F-Test = 1.47 at an allowable error of 5% and P value 0.20 (>0.05) hence we fail to reject the null hypothesis and conclude that there is no significant relationship between radon concentration and housing characteristics. Adj.R^2 = 3.35% (only 3.35% of the variability in radon concentration is being explained by housing characteristics). Based on the p. values of all housing characteristics, building type shows a significant relationship with IRC hence a good predictor of radon concentrations at 95% confidence level.

3.4. Determination of excess life time lung cancer risk

From the radon exposure, it was found that the Mean ± Std. of the radon concentration, radon exposure, effective dose to the lung and the excess lifetime cancer risk were 57.2 ± 38.9 Bq m^{-3}, 0.12 ± 0.08 WLM y^{-1}, 0.7 ± 0.5 mSv y^{-1}, 0.4 ± 0.3 (%) respectively. There were other range of values of radon concentration, radon exposure, effective dose to the lung and the excess lifetime cancer risk between 4.1–176.3 Bq m^{-3}, 0.01–0.4 WLM y^{-1}, 0.05–2.3 mSv y^{-1} and 0.03–1.2 (%) respectively. Apart from the building type that was statistically significant, all other variables were not.

4. Discussion

4.1. Indoor radon concentration

Indoor radon exposure due to vapor invasion can lead to 22,000 deaths annually [15]. The only way to know the presence of the naturally occurring, odorless, tasteless, and colorless gas is to test your home [24]. In this study it was found that of the homes tested 84% resulted in detection of radon below 100 Bq m^{-3} with 16% above the recommended reference limit (100 Bq m^{-3}) by WHO [15]. A requirement for accurate testing requires that there is no direct air or heat blowing on the detectors once it is fixed. However, authors may not know whether or not the study participants complied with this condition especially after thorough briefing on the whole process during the time of consenting before fixing the detectors. The survey indicated that the average IRC was 57.2 ± 38.9 Bq m^{-3}. The concentrations range from 4.1–176.3 Bq m^{-3} with house ZG23 recording the lowest and KT6 recording the highest. This mean value (57.19 Bq m^{-3}) is 43% higher than the world's average IRC of 40 Bq m^{-3} [16].

Other similar studies conducted in the country particularly in the Eastern and Accra of the country by Yeboah [21] recorded 518.7 Bq m^{-3}, and 19 Bq m^{-3} respectively. The value from the eastern part of the country is high and might be from the common bedrock formation originating from the republic of Togo (neighboring country). The Togo bedrock formations (schists, quartzite and phyllites, unaltered shale and sandstone) are rocks forming a range of hills trending from the northeast of the country through the west coast into the Republic of Togo [24]. Other reason of the huge variation may be the difference in soil composition. A study conducted by Dampare *et al* [25] in the eastern part of the country, indicated soil enrichment though according to the findings, none of the soil was enriched with toxic elements.

In figure 4, the red dots represented concentration which was 100 Bq m^{-3} and above, representing a higher concentration above the WHO recommendation. These areas may require mitigation according to the WHO comprehensive global initiative [15]

4.2. Correlation of indoor radon concentrations with other factors

Most studies [26–28] have confirmed that housing characteristics have influence on the level of IRC. In this study, all housing characteristics (Housing Type, Building Type, Floor Type, Form of ventilation, age of house and number of windows) selected correlated with IRC although very weak. As was evident in the results (table 2), all housing characteristics showed postive correlation with the exception of age of house. Though there was an association, there was no significant relationship between IRC and housing characteristics because the F-Test

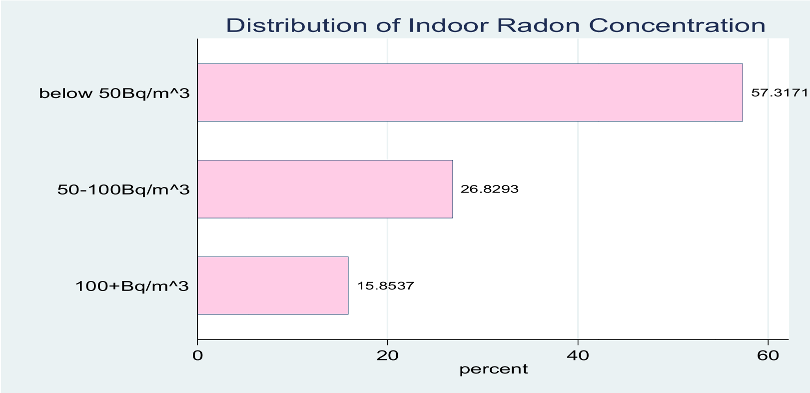

Figure 4. Frequency distribution of indoor radon concentration N = 82.

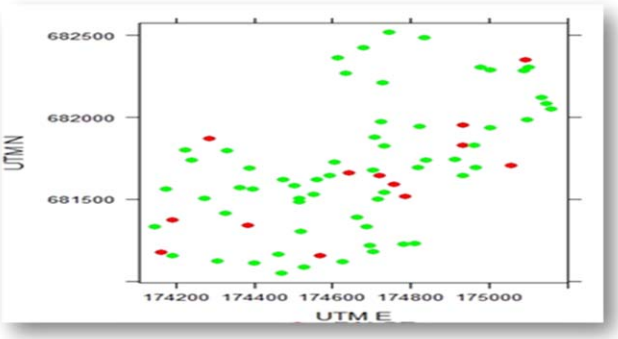

Figure 5. Spatial distribution of radon concentration.

was 1.47 at an allowable error of 5% and P value 0.20 (>0.05). A study by Quarto *et al* [29] reported higher radon concentration values for older houses with an explanation on ventilation rate being less than the new ones with much lower concentration. Authors further reiterated that older buildings have greater structural deterioration and poor ground insulation causing higher radon concentrations which were consistent to that of other studies [30, 31] that observed a statistically significant relationship between radon concentrations and dwelling age (Figure 5). The findings of this study showed a negative correlation for the age of the houses indicating a lower radon concentration for older houses.

Meanwhile, in the multivariate analysis (table 2), only 3.35% (Adj.R^2) of the variability in the IRC was explained by the housing characteristics. Based on the p. values of all housing characteristics, building type showed a significant relationship with IRC, which implies a good predictor of radon concentrations at 95% confidence level. In the same vain, altitude showed a weaker negative correlation (−0.039) but it was not significant ($P > |t| = 0.72$). Both linear correlation and log transformed graph indicated similar results as seen in figure 6.

The results from the study were consistent with the findings of Choukri and Hakam [13] where radon concentration was 47 Bq m^{-3} in a house in stones and 31 Bq m^{-3} in other construction not in stones. The EPA [32] has indicated that the greatest risk of radon exposure is from tight, insufficiently ventilated buildings and buildings that have leaks allowing soil air from the ground into the basement and upper dwelling rooms. Results from the study indicated no significant relationship between radon concentration and housing characteristics.

4.3. Determination of exposure and lifetime lung cancer risk

Using the equations (5)–(7), radon exposure, effective dose and corresponding lung cancer risk in household have been estimated and summarized. The analyses indicated that lung cancer risk increases proportionally with increasing radon exposure and IRC and vice versa. Estimated average annual effective dose due to radon decay products received by inhabitants has been found lower than the upper annual dose limit of 1 mSv, recommended by the ICRP [33]. The excess lifetime cancer risk attributed to the dwellers has range 0.03–1.2 (%) with an average value of 0.4 ± 0.3 (%). The estimated risks are very small as compared with the estimated risk of

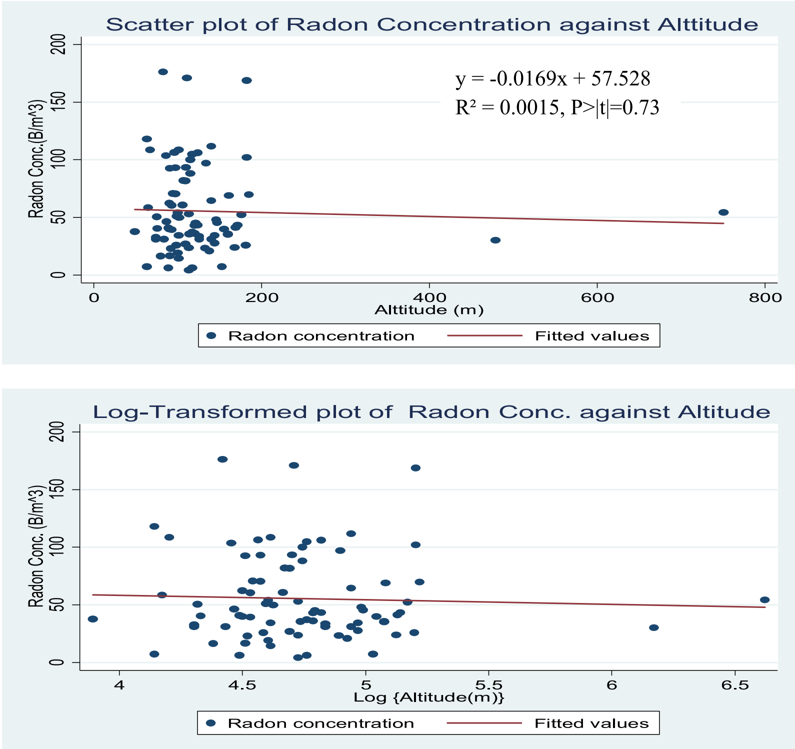

Figure 6. Correlation between indoor radon concentration and altitude.

2.3 for entire population from the lifetime exposure at 4pCi/l (148 Bq m^{-3}); the action level proposed by EPA [32]. Seemingly, the time spent by individuals in home varies widely worldwide.

The occupancy factor of 0.8 [33] over estimates the excess lung cancer risk in the tropical regions but may be valid for the inhabitants of the temperate zone. In the tropical regions, people spend most of their time outdoors and mainly go indoors to sleep at night hence an occupancy factor of 0.4 was suitable for such instance [9]. The low occupancy might contribute to the very low excess lung cancer risk estimated in this study.

5. Conclusions

The average indoor radon concentration at the suburb was below the WHO international recommended limit although 15% of the houses were above this limit and therefore required the needed remediation. Averagely, the area could be described as safe with respect to the health hazards effects. The estimated lung cancer risk for the suburb was insignificant compared with the EPA recommended estimated risk hence dwellers may be described as safe with respect to risk attributable to radon exposure. Houses constructed with mud on the other hand showed significant relation hence a good predictor of IRC.

Based on these conclusions, some recommendations were made. The inhabitants with concentration levels above 100 Bq m^{-3} were advised to ensure good ventilation practices as the cost effective means of mitigation of indoor radon gas level. Occupants were encouraged to seal opening or cracked areas in contact with soil such as spaces around bathtub, shower or toilet drains. Dwellers were asked to use materials that provide permanent air tight seal such as non- shrink mortar, grouts expanding foam or similar. The regulatory authorities such as EPA, Ghana Health Service and Radiation Protection Board of GAEC are encouraged to consider national policy on radon mitigation measures assessment of radon levels in households, workplaces, and places like schools within the country. Finally, the EPA of Ghana should work hand in hand to organize public forums to sensitize the general public about the related health risk to indoor radon exposure.

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