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Measurement of Radon Concentration and Estimation of Cancer Risk in Twenty-Four Model Houses in the Town of Koudougou

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Abstract

The objective of our study is to evaluate the concentration of radon (^{86}Rn) inside houses in the town of Koudougou in order to estimate its impact on the health of the population. Indeed, when uranium-rich minerals are found near the surface of the ground, radon concentrations can reach tens of becquerels per cubic meter in enclosed spaces. Given the nature of the geological base of Burkina Faso, this situation is quite probable and certain places that are sometimes poorly ventilated (house, school, office, etc.) can have radon levels high enough to constitute a health problem for occupants. Thus, twenty-four (24) sample houses were identified. In each house, the Corentium digital detector was between 0.8 m and 2 m for at least one week in a place where the occupants estimate that they spend more time of time and measure the concentration of radon in the long term and short term. The recorded data allowed us to determine the Absorbed Dose and the Annual Effective Dose of radon gas for each house in order to estimate the Risk of Cancer and the probable Number of Cases of Lung Cancer per million inhabitants. Thus, the results indicate that the long-term radon concentration varies between 6 Bq/m^3 and 285 Bq/m^3 respectively in houses 11 and 4 compared to 1 Bq/m^3 to 208 Bq/m^3 in the short term in the same houses. Also, in the long term, in control houses 1, 3 and 4, the radon level is above the recommended threshold interval. For the short term, these are houses 1, 3, 4 and 17 respectively with 110 Bq/m^3, 142 Bq/m^3, 208 Bq/m^3 and 105 Bq/m^3. As for the long-term and short-term effective doses, only houses 1, 3, 4, 17 and 24 have values between 3 - 10 Sv/year. The estimation of the relative risk of lung cancer gives values relatively close to unity and between 1.006 and 1.142 with an average of 1.035 and that of the Number of Lung Cancer Cases per million inhabitants gives values between 8 and 166 with an average of 42. Thus, we can conclude that with the exception of houses 1, 3, 4 and 17, the radon concentrations are relatively low in the twenty-four control houses in the city of Koudougou. The lifestyle of the populations can well explain this situation when we know that people are in the habit of always leaving doors and windows open, especially when they are not sleeping. We can therefore say that the risk of population exposure to radon gas is relatively low in the town of Koudougou.

Keywords

Radon, Absorbed Dose, Annual Effective Dose, Cancer Risk

1. Introduction

Radon (^{86}Rn) is a radioactive gas that has no taste, odor or color [1]. It comes from the decay of uranium 238 (238U) which is a chemical element naturally present in the earth's crust [2]. Several studies show that granites and volcanic rocks have relatively more [3]. And, when uranium-rich minerals are found near the ground surface, radon concentrations can reach tens of becquerels per cubic meter (Bq/m^3) in enclosed spaces [4]. Thus, given the nature of the geological base in Burkina Faso, particularly rich in granites and volcanic rocks [5], it is probable that in spaces that are sometimes poorly ventilated (residential houses, schools, offices, etc.) the proportion radon is high. Because radon can, through cracks in walls, construction joints, floor drains, surfaces in contact with the ground, etc., find its way into homes and be problematic for health [6] [7]. Indeed, the International Agency for Research on Cancer has recognized that radon is a lung carcinogen for humans [8]. Also, certain studies have confirmed the relationship between the quantity of radon inhaled and the risk linked to lung cancer [9] [10]. The risk increases not only with the daily content inhaled but also and especially with the duration of exposure [1] [11] [12]. Thus, the objective of our study is to evaluate the concentration of radon inside houses in the town of Koudougou in order to estimate its impact on the health of the population. Because studies have already found high radon concentrations in residences and offices in Ouagadougou and Kaya [13] [14]. Thus, we used a Corentium type digital detector to measure the radon concentration inside twenty-four (24) houses, in the long and short terms. Also, to estimate the Cancer Risk and the probable Number of Lung Cancer Cases per million inhabitants in the twenty-four control houses, we determined the Absorbed Dose and the Annual Effective Dose of radon gas in each house.

2. Materials and Method

2.1. Geographical Location of the Show Houses

The third largest city in Burkina Faso, Koudougou is located in the Center-West region, about a hundred kilometers from the capital Ouagadougou and has approximately 88,184 inhabitants. The Koudougou area is essentially made up of Paleoproterozoic formations belonging to the Birimian basement of the Man/Léo ridge. This base includes volcano-sedimentary and plutonic terrains metamorphosed during the Eburnean which constitute the greenstone belts. TTG granitoids and biotite granites are intrusive in the latter and flow over most of the study area. Thus, for this study, twenty-four (24) houses were identified in the ten (10) sectors of the city Koudougou. The geographic coordinates recorded using a GPS made it possible to locate the measurement locations on the map below (**Figure 1**).

2.2. Measurement Methods

The AIRTHINGS CORENTIUM Home Digital Radon Monitor measures radon gas in indoor air. It is a simple, precise and flexible device that displays on a screen the average concentration for one (1) day, seven (7) days and the average concentration for one year. It runs on batteries. AIRTHINGS CORENTIUM Home is the radon monitor suitable for family homes, public buildings and workplaces. A simple and quick instrument can be used by everyone. Operating on batteries, AIRTHINGS CORENTIUM Home can easily be moved throughout the building, allowing you to obtain a complete overview of the distribution of radon in the home.

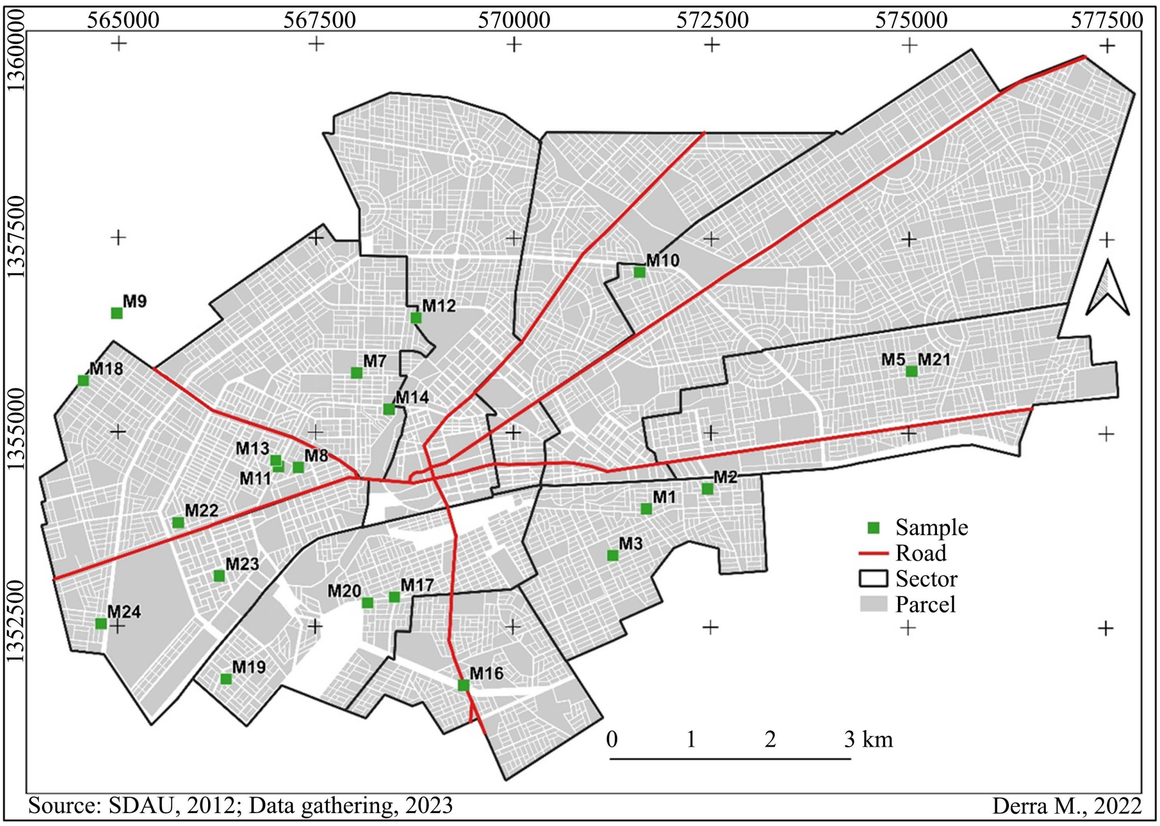

Figure 1. Geographical location of houses.

The AIRTHINGS CORENTIUM Home radon monitor samples indoor air through a passive diffusion chamber and uses alpha spectrometry to accurately calculate radon concentration. Detection is done using silicon photodiodes both to count and to measure the energy of the alpha particles resulting from the radon gas decomposition chain. For each measurement session, the radon detector was placed between 0.8 m and 2 m for at least one week in a location in the house where the occupants estimate that they spend more time there. For concentration measurements, the device was placed in each house for a minimum period of one week. Concentration values are recorded every 24 hours for a week. The values recorded are the short-term average and the long-term average.

The choice of measurement sites was made on the basis of the nature of the materials used for the construction of the house (cinder block), openings generally closed; houses whose construction duration is between 5 to 10 years, besides, and also to guarantee the safety of the measuring devices.

2.3. Dose Estimation

Radon is one of the main sources of human exposure. It is present in homes and workplaces. Calculations of the annual absorbed dose and the annual effective dose are the parameters in estimating the radon dose.

2.3.1. Annual Absorbed Dose

The concentration of radon gas measured in each home was used to estimate the annual absorbed dose. The calculation of the annual absorbed dose is made from the concentration of radon gas (C_{Rn}), the dose conversion factor (Dc), the equilibrium factor (F), the exposure time in hours for one year (T), and occupation time (H). Equation (1) was used to estimate the annual absorbed dose [15]-[20].

$$D_{abs}\left(\text{mSv}\cdot\text{y}^{-1}\right) = C_{Rn}\left(\text{Bq}\cdot\text{m}^{-3}\right)\times F\times H\times T\left(\text{h}\cdot\text{y}^{-1}\right)\times Dc\left(\text{nSv par}\left(\text{Bq}\cdot\text{h}\cdot\text{m}^{-3}\right)\right) \quad (1)$$

2.3.2. Effective Dose to the Lung (mSv)

The annual absorbed dose (D_{abs}), radiation weighting factor (W_R) and tissue weighting factor (W_T) for the lung are used for estimation of the effective dose to the lung [21]. Radon, a radioactive gas which emits alpha particles, therefore the radiation weighting factor used to calculate the effective dose is 20. The target organ being the lung therefore the tissue weighting factor is 0.12 [21]. Formula (2) below was used to calculate the effective dose to the lung [13] [15] [16] [17] [22].

$$E_T\left(\text{mSv}\right) = D_{abs}\cdot W_R\cdot W_T. \quad (2)$$

2.4. Health Risk of Radon

The health risk of radon was assessed based on the calculation of exposure to radon, lifetime cancer risk and the number of cases of lung cancer per year and per million people.

2.4.1. Radon Exposure

The formula used to calculate radon exposure (E_R) is given as follows:

$$E_R\left(\text{WLM par an}\right) = C_{Rn} \cdot O \cdot F \cdot C_{WL} \cdot T/T_W \ . \tag{3}$$

C_{WL}: Conversion of the radon concentration into working level, which has a value 2.7 × 10^{-4}; T: Number of hours in a year; T_w: Number of working hours in a month. The working level is equivalent to a radon activity volume of 12,000 Bq/m^3 and 1 WLM corresponds approximately to exposure for one year to an atmosphere where the radon activity would be 230 Bq/m^3.

2.4.2. Lifetime Cancer Risk

The formula used to calculate lifetime cancer risk (CR) is as follows:

$$CR = E_R \cdot T \cdot F_R \tag{4}$$

T: Average life expectancy which is 61.9 years in Burkina in 2019; F_R: Risk coefficient of exposure to 222Rn gas in balance with its descendants (5 × 10^{-4} by WLM).

2.4.3. Number of Lung Cancer Cases per Year per Million People

The formula used to calculate the number of lung cancer cases per year per million people ($NLCC$) is given as follows [17]:

$$NLCC = E_T * \left(18 \times 10^{-6}\ \text{mSv}^{-1} \cdot \text{an}\right) \tag{5}$$

3. Results and Discussion

3.1. Long-Term and Short-Term Radon Concentration

Table 1 presents the long-term average concentrations, minimum and maximum concentrations and standard deviations of radon gas concentrations in the houses studied in the town of Koudougou.

The long-term radon concentration varies between 6 Bq/m^3 and 285 Bq/m^3 respectively in houses 11 and 4. And, the average varies from 7.28 Bq/m^3 to 285 Bq/m^3. The maximum average value is observed in house 4 and the minimum in house 11. Thus, in the long term, there are houses where the radon concentration is above the reference value which is 100 Bq/m^3 - 300 Bq/m^3 [23] [24]. These are houses 1, 3 and 4. For this purpose, the average of 152.429 Bq/m^3 recorded in house 4 deserves attention even if it did not reach the maximum limit which is 300 Bq/m^3 [23] [24]. Overall, we note that the risk of exposure to radon in Koudougou is relatively low because, with the exception of house 4, the average radon activity in all the control houses is below the recommended threshold. The lifestyle of the populations can well explain this situation when we know that people are in the habit of always leaving doors and windows open when they are present and not sleeping.

Table 2 presents the short-term average concentrations, minimum and maximum concentrations and standard deviations of radon gas concentrations in the houses studied in the town of Koudougou.

Table 1. Concentration of long-term radon gas in the houses studied (Bq/m^3).

Place	Mean	Maximum	Minimum	Standard Deviation
House 1	71.429	107	58	16.298
House 2	21.857	24	19	1.676
House 3	85.143	102	51	17.382
House 4	152.429	285	119	59.696
House 5	33.429	38	30	2.82
House 6	28.714	32	27	1.799
House 7	35.143	41	31	3.485
House 8	23.857	28	18	3.848
House 9	21.571	27	18	3.207
House 10	35.571	46	28	7.892
House 11	7.286	8	6	0.756
House 12	13.857	16	7	3.237
House 13	25.429	32	22	3.994
House 14	17.143	29	14	5.336
House 15	16.571	22	10	3.952
House 16	48.429	65	39	9.199
House 17	67.143	75	61	5.64
House 18	35	40	30	3.742
House 19	15.857	21	13	2.911
House 20	14.286	24	12	4.309
House 21	34.571	44	27	6.024
House 22	55.286	68	41	11.427
House 23	15	18	12	2.16
House 24	49.571	60	32	8.619

Table 2. Concentration of short-term radon gas in the houses studied (Bq/m^3).

Place	Mean	Maximum	Minimum	Standard Deviation
House 1	65	110	35	25.677
House 2	22.571	38	12	8.715
House 3	82.714	142	54	32.071
House 4	86.571	208	31	60.863
House 5	34.286	51	24	10.161
House 6	22.857	36	1	12.185
House 7	28.857	42	17	10.007

Continued

House 8	30.714	56	20	12.842
House 9	26.143	45	14	12.348
House 10	26.286	41	17	8.655
House 11	8.714	17	1	5.407
House 12	15.714	23	9	4.716
House 13	28.286	44	9	11.772
House 14	14.143	24	8	5.64
House 15	19	25	11	5.859
House 16	37.857	65	19	15.678
House 17	83	105	69	13.856
House 18	41.714	56	24	11.586
House 19	11.571	27	4	7.525
House 20	12.429	23	3	6.106
House 21	36.286	55	24	12.23
House 22	52.143	79	24	22.535
House 23	18.714	26	9	5.559
House 24	61.857	91	46	16.015

The concentration of radon in homes in the short term varies from 1 Bq/m^3 to 208 Bq/m^3. And, the average of this concentration is between 08.71 Bq/m^3 and 86.87 Bq/m^3 respectively for houses 11 and 4. It is also house 4 which has the highest average concentration and house 11 the lowest one. The minimum concentration is also observed in house 11 with a value of 1 Bq/m^3. In the short term, the radon concentrations in houses 1, 3, 4 and 17 are above the minimum recommended threshold with respectively 110 Bq/m^3, 142 Bq/m^3, 208 Bq/m^3 and 105 Bq/m^3 [23] [24]. In total, out of 24 houses, only 4 have maximum radon levels above the minimum threshold of 100 Bq/m^3 or 16.67%.

3.2. Evaluation of the Absorbed Dose and the Annual Effective Dose

Table 3 shows the absorbed dose and annual effective dose of radon gas_in the houses studied in the town of Koudougou.

Long-term absorbed dose of radon: The long-term absorbed dose of radon varies between 3.85 and 0.18 with an average of 0.97.

Long-term effective dose: The long-term effective dose ranges from 0.44 to 9.23 with an average of 2.33. Houses 1, 3, 4, 17, 22 and 24 have long-term effective doses within the threshold interval of 3 - 10 mSv/year [25].

Short-term absorbed dose of radon: The short-term absorbed dose of radon varies from 0.22 to 2.18 with an average of 0.91.

Table 3. Absorbed dose and annual effective dose of radon gas in homes (mSv/year).

Place	Absorbed dose of radon in the long term	Absorbed dose of radon in the short term	Long-term effective dose	Short-term effective dose
House 1	1.802	1.64	4.325	3.936
House 2	0.551	0.569	1.323	1.367
House 3	2.148	2.087	5.155	5.008
House 4	3.846	2.184	9.229	5.242
House 5	0.843	0.865	2.024	2.076
House 6	0.724	0.577	1.739	1.384
House 7	0.887	0.728	2.128	1.747
House 8	0.602	0.775	1.445	1.86
House 9	0.544	0.66	1.306	1.583
House 10	0.897	0.663	2.154	1.592
House 11	0.184	0.22	0.441	0.528
House 12	0.35	0.396	0.839	0.951
House 13	0.642	0.714	1.54	1.713
House 14	0.432	0.357	1.038	0.856
House 15	0.418	0.479	1.003	1.15
House 16	1.222	0.955	2.932	2.292
House 17	1.694	2.094	4.065	5.026
House 18	0.883	1.052	2.119	2.526
House 19	0.4	0.292	0.96	0.701
House 20	0.36	0.314	0.865	0.753
House 21	0.872	0.915	2.093	2.197
House 22	1.395	1.316	3.348	3.157
House 23	0.378	0.472	0.908	1.133
House 24	1.251	1.561	3.002	3.745
Mean	**0.972**	**0.912**	**2.333**	**2.188**
Maximum	**3.846**	**2.184**	**9.229**	**5.242**
Minimum	**0.184**	**0.22**	**0.441**	**0.528**

Short-term effective dose: The short-term effective dose ranges from 0.53 to 5.24 with an average of 2.19. Houses 1, 3, 4, 17, 22 and 24 have short-term effective doses within the threshold interval of 3 - 10 mSv/year [25].

3.3. Estimated Cancer Risk and Number of Lung Cancer Cases per Million Inhabitants

The Cancer Risk and Number of Lung Cancer Cases per million inhabitants of radon gas in the houses studied in the town of Koudougou are shown in **Table 4**.

Table 4. Cancer risk and number of lung cancer cases per million inhabitants.

House code	Relative risk of lung cancer	NLCC *per million inhabitants*
House 1	1.064	78
House 2	1.019	24
House 3	1.077	93
House 4	1.142	166
House 5	1.03	36
House 6	1.025	31
House 7	1.031	38
House 8	1.021	26
House 9	1.019	24
House 10	1.032	39
House 11	1.006	8
House 12	1.012	15
House 13	1.022	28
House 14	1.015	19
House 15	1.015	18
House 16	1.043	53
House 17	1.06	73
House 18	1.031	38
House 19	1.014	17
House 20	1.013	16
House 21	1.031	38
House 22	1.049	60
House 23	1.013	16
House 24	1.044	54
Mean	**1.035**	**42**

RRCP: The estimation of the relative risk of lung cancer gives values relatively close to unity and between 1.006 and 1.142 respectively for houses 11 and 4 with an average of 1.035.

NLCC: The estimate of the Number of Lung Cancer Cases per million inhabitants gives values between 8 and 166 respectively in houses 11 and 4 with an average of 42; or 4.2×10^{-3} percent.

3.4. Comparisons of Concentrations with Other Studies Carried out

Table 5 shows the average concentration of radon in homes in the city of Kaya,

Table 5. Comparison of the average concentration with other studies.

Locality	Average concentration of radon in Bq/m^3	Reference
This Study	38.52	
Kaya	28.47 ± 22.22	[26]
Ouagadougou	26.90 ± 2.58	[13]
Banlieue du Ghana	57 ± 39	[27]
Soudan (Kordufan)	109.43	[28]
Soudan (Wad Almahi)	41.52	[28]
Maroc	80	[29]

Ouagadougou and other cities in Africa. The average concentration of radon in the houses studied in Koudougou is 38.52 Bq/m^3 and higher than that obtained in homes in the city of Ouagadougou and Kaya. The average radon concentrations in similar studies carried out in Ghana, Sudan, and Morocco show that the average concentration of houses in Koudougou is lower compared to that obtained in these countries.

4. Conclusion

The results of this work reveal that the long-term radon concentration varies between 6 Bq/m^3 and 285 Bq/m^3 respectively in houses 11 and 4 compared to 1 Bq/m^3 to 208 Bq/m^3 in the short term in the same houses. Thus, in the long term, in control houses 1, 3 and 4, the radon level is above the recommended threshold interval of 100 Bq/m^3 - 300 Bq/m^3 [23] [24]. In addition, the average of 152.429 Bq/m^3 recorded in house 4 deserves attention even though it did not reach the upper limit of 300 Bq/m^3. For the short term, the values 110 Bq/m^3, 142 Bq/m^3, 208 Bq/m^3 and 105 Bq/m^3 recorded respectively in houses 1, 3, 4 and 17 are above the lower limit of 100 Bq/m^3. Also, the long-term and short-term absorbed doses have respective averages of 0.97 and 0.91. As for the long-term and short-term effective doses, they are between the interval 3 - 10 mSv/year [25] in houses 1, 3, 4, 17 and 24. For houses 11 and 4, the estimation of the relative risk of lung cancer gives values relatively close to unity and between 1.006 and 1.142 with an average of 1.035 and the estimate of the Number of Lung Cancer Cases per million inhabitants gives values between 8 and 166 with an average of 42. From the above, we see that with the exception of houses 1, 3, 4 and 17, the radon concentrations are relatively low in the 24 control houses in the city of Koudougou. The lifestyle of the populations can well explain this situation when we know that people are in the habit of always leaving doors and windows open when they are present and not sleeping. Thus, we can say that the risk of population exposure to radon gas is relatively low in this part of the country.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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