

**Original Article**

Measurements of Indoor Radon Levels and Dose Estimation and Lung Cancer Risk Determination for Workers in Health Centres of Some Towns in the Sudan

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Abstract: The indoor radon concentration level and radon effective dose rate were carried out in the health centers of Khartoum, Behri(Khartoum North), Medani and Kassala towns – Sudan, in 222 measurements, using passive integrated solid-state nuclear track devices containing allyl diglycol carbonate plastic detectors. The radon concentration in the corresponding health centers was found to vary from $60 \pm 12 \text{ Bq.m}^{-3}$, in Kassala town health centers, and $34 \pm 9 \text{ Bq.m}^{-3}$ in Wad Medani town health centers, while Khartoum and Behri (Khartoum North) health centers are recording an average values of $49 \pm 12 \text{ Bq.m}^{-3}$ to $46 \pm 11 \text{ Bq.m}^{-3}$, respectively. The overall average of radon concentration for health centers in our study was found to be $47 \pm 11 \text{ Bq.m}^{-3}$. These values are noticed to be far below than the radon action level 200- 600 Bq.m^{-3} as recommended by ICRP. Assuming an indoor occupancy factor of 0.8 and 0.4 for the equilibrium factor of radon indoors, we found that the annual effective dose rate from radon was estimated to be $1.19 \pm 0.28 \text{ mSv.y}^{-1}$, and the relative lung cancer risk for radon exposure was found to be 1.042%. From our study, it is clear that the annual effective dose rate is lower than both the “normal” back ground level as quoted by UNSCEAR and the recommended action level of ICRP, and less than the maximum permissible dose defined by the International Atomic Energy Agency.

Keywords: Radon, Effective Dose, CR-39, Health Centers, Relative Lung Cancer Risk

1. Introduction

Radon (^{222}Rn) is a radioactive gas whose source is the decay of radium (^{226}Ra) from the natural radioactive uranium (^{238}U) series. Radon (^{222}Rn) and its short-lived decay products (^{218}Po , ^{214}Pb , ^{214}Bi , and ^{214}Po) in dwellings are recognized as the main sources of public exposure from the natural radioactivity, contributing to nearly 50% of the global mean effective dose to the public [1].

The interest in studying radon behavior is mainly due to the fact that it can accumulate indoors, and in case of entering the body can be serious damage to human respiratory and gastrointestinal. Indoor radon measurements are generally associated with dwellings. However, a typical person spends

more than eight hours a day in their workplace, so that it is recognized as essential to monitor worker's exposure to radon to control their health risks. The ICRP, 1993 [2] sets limits for the indoor concentrations as follows: normal 200Bq.m^{-3} , attention $200\text{--}400 \text{ Bq.m}^{-3}$, remediation $400\text{--}600 \text{ Bq.m}^{-3}$, and intervention that is higher than 600 Bq.m^{-3} .

But in its recent publication ICRP, 2011 [3], proposed to use the maximum value of 300 Bq.m^{-3} for radon activity in air of dwellings and workplaces considering the upper value for the individual dose reference level for radon exposure of 10mSv.y^{-1} . The US-EPA, 2000 [4], suggests intervention in residences with concentration values above 148 Bq.m^{-3} . The WHO, 2009 [5], recommends that indoor concentrations must be less than 100 Bq.m^{-3} but warns that if this is not possible, the

limit should be taken as 300 Bq.m^{-3} .

The health effect from radon comes from its short-lived daughters, which happened to be metallic radioactive nuclei. Two of these, ^{218}Po and ^{214}Po emit alpha particles with energies 6–7.78MeV, respectively. If the decay process occurs inside the lung, the energy of decay will be deposited and absorbed in the tissue lining of the lung. So, living in an elevated level of radon concentration for a long time means that the probability of inducing lung cancer increases. Therefore, after smoking, the second factor of lung cancer is radon [2, 6].

Indoor air pollution has recently attracted a great deal of attention. With the trend toward reduction of ventilation and infiltration rates in buildings and with measured use of synthetic chemicals in the indoor environment, this problem has become even more serious.

The average concentration of indoor radon in countries where there is monitoring recorded by WHO, 2009 [5], remains below the 148 Bq.m^{-3} limit of the US-EPA, 2000 [4]. However, surveys conducted in Europe and United States have often found dwellings where the radon concentration levels are between 2000 and $50,000 \text{ Bq.m}^{-3}$, while acceptable recommended levels IAEA,2003 [7]; ICRP,1991 [8]; NRPB, 2009 [9]; UNSCEAR,1993 [10] are between 148 and 200 Bq.m^{-3} .

Solid-state nuclear track detectors have been widely used for passive measurements of indoor radon and their alpha emitting decay products. The use of the CR-39 plastic track detector in air volume of cups has become the most reliable procedure for time-integrated, long measurements of radon and their daughter activity concentrations under different environmental conditions [11-12]. Using this procedure, there have been some surveys measuring indoor radon in dwellings and public buildings such as schools, shops and pharmacies [13-20], in workplaces [21- 24].

This work is also considered as the continuation of our other surveys conducted in Sudan aimed at establishing the base-line data on indoor, soil gas, building materials, and water radon concentrations in Sudan [25-39]. This survey is conducted to present and discuss the data obtained from radon measurements, effective dose and lung cancer risk carried out in health centers of Khartoum, Behri (Khartoum North), Wad Medani and Kassala towns in Sudan.

2. Measurement Technique

2.1. The Study Area

Indoor radon measurements, dose estimation and lung cancer risk were done in health centers of the most populated towns namely: Khartoum, Behri (Khartoum North), Wad Medani and Kassala towns (see Fig. 1).

Khartoum town is located in the central part of Sudan, it is the capital of Khartoum State and it is also the capital of the Republic of Sudan. Khartoum town is located at latitude of $15^{\circ}36'N$ and longitude of $32^{\circ}32'E$, Behri (Khartoum North) town, is located in Khartoum state, Sudan, it is located

between latitude of $15^{\circ}38' N$ and longitude of $32^{\circ}38'E$. Wad Medani town is the capital of the Gezira state. It is located at latitude of $14^{\circ}24'N$ and longitude $33^{\circ}31' E$ and at a distance of 196 km from Khartoum town. Kassala town is the capital of Kassala state which located in eastern part of Sudan. Kassala town is located at latitude of $15^{\circ}27'N$ and longitude $36^{\circ}24'E$ and at a distance of 625 km from Khartoum.

This study has covered the most populated towns, which are the capitals of the most important and larger States in Sudan.

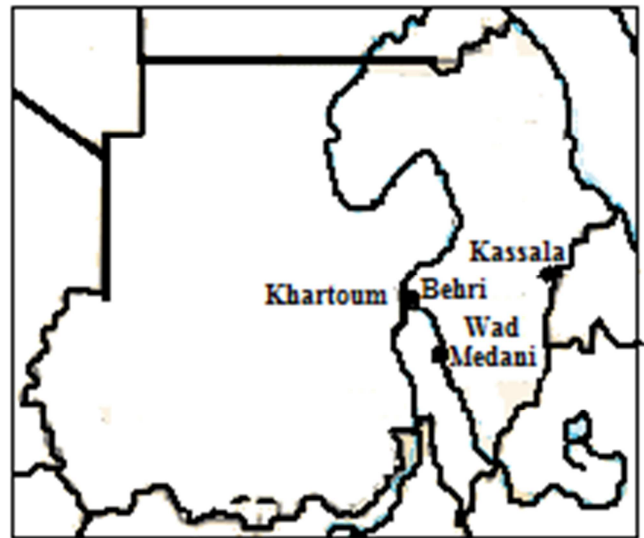


Figure 1. The map showing the towns in which the health centers are located in Sudan.

2.2. Indoor Radon Measurements

A correct calibration procedure is paramount for good accuracy of results. Hence, precalibrated passive dosimeters containing solid-state nuclear track detectors using allyl diglycol carbonate of super grade quality (CR-39 SSNTD, Pershore Moulding, Ltd., UK) were used to study radon-222 concentrations. These passive dosimeters used here are similar to those we have used in previous studies [15, 16, 26, 28].

We distributed a total of 222 dosimeters at the selected health centers in the studied towns. After three months, the dosimeters were collected and chemically etched for nine hours using a 30% solution of KOH at a temperature of $70.0 \pm 0.1^{\circ}C$. An optical microscope was used to count the number of tracks per cm^2 recorded on each detector used. The track density was determined and converted into activity concentration C_{Rn} [Bq.m^{-3}] using the following equation [15, 16].

$$C_{Rn} = \frac{\rho_{Rn}}{K_{Rn}T} \quad (1)$$

Where: Where ρ_{Rn} is, the track density (tracks per cm^2), K_{Rn} - is the calibration constant which was previously determined to be $4.824 \times 10^{-3} \text{ tracks cm}^{-2} \text{ h}^{-1}/(\text{Bq.m}^{-3})$ [15, 16], and t - is the exposure time.

2.3. Dose Estimation and Lung Cancer Risk

To estimate the radon effective dose rate (ED) expected to

be received by the workers of these health centers at any town due to indoor radon, the conversion coefficient from the absorbed dose and the indoor occupancy factor has to be taken into account. In the UNSCEAR, 2000 report [1], the committee recommended to use 9.0 nSv h^{-1} per Bq.m^{-3} for the conversion factor (D_f) (effective dose received by adults per unit ^{222}Rn activity per unit of air volume), 0.4 for the equilibrium factor of radon indoors (E_f) and 0.8 for the indoor occupancy factor (O_f). We used the following formula to calculate the effective dose rate (ED) [15, 16]:

$$\text{ED (mSv.y}^{-1}) = C_{\text{Rn}} D_f O_f E_f \cdot 24.365 \cdot 10^{-6} \quad (2)$$

The relative risk of lung cancer (RRLC) due to indoor exposure to radon was calculated using the following equation [15, 16, 26, 28]:

$$\text{RRLC} = \exp(0.00087352 C_{\text{Rn}}) \quad (3)$$

3. Results and Discussion

In this study we present results of the average radon concentrations, effective dose (ED) and relative risk of lung cancer (RRLC) in health centers at four towns in Sudan.

Table 1 shows the radon concentration, effective dose (ED) and relative risk of lung cancer in health centers at the studied towns. As shown in table 1. and Fig. 2, the highest concentration values were recorded in Kassala town health centers to be $60 \pm 12 \text{ Bq.m}^{-3}$ while the minimum concentration value of $34 \pm 9 \text{ Bq.m}^{-3}$ was recorded in Wad Medani town health centers. Khartoum and Behri (Khartoum North) health centers are recording an average values of $49 \pm 12 \text{ Bq.m}^{-3}$ to $46 \pm 11 \text{ Bq.m}^{-3}$, respectively. The overall average of radon concentration for all health centers was found to be $47 \pm 11 \text{ Bq.m}^{-3}$.

The recorded values of radon concentrations in this study (see Table 1) are much lower than the radon action level 200-600 Bq.m^{-3} as recommended by ICRP-1993 [2], lower than the new reference level of 100 Bq.m^{-3} as set by WHO [5] and below the action level of 148 Bq.m^{-3} , that recommended by the Environmental Protection Agency (EPA) [4]. The mean value of radon concentration throughout this study, is slightly higher than the average world-wide value (population weighted) since the average radon of 40 Bq.m^{-3} has been reported by UNSCEAR, 2000 [1], but is well within the values

reported for various locations in Sudan and worldwide (see Table 3).

The US-EPA recommendations [40] are that no intervention is required if the indoor radon level is below 74 Bq.m^{-3} , indicating that this level is safe for worker of these health centers. For more safety the workers advised to improve ventilation; since it is well known that an increased ventilation rate is an important factor in reducing the indoor radon level [41]. We also found that the radon concentrations in moderately ventilated health centers were relatively higher when compared to those in well-ventilated ones.

As presented in Table 1 and Fig. 3, the range of the radon effective dose rate varied from 0.86 to 1.51 mSv.y^{-1} . The average radon effective dose rate was calculated as $1.19 \pm 0.28 \text{ mSv.y}^{-1}$. The effective dose is slightly larger than the "normal" background level of 1.1 mSv.y^{-1} ; as quoted by UNSCEAR, 2000 [1], but way below even the lower limit of the recommended action level 3-10 mSv.y^{-1} , as reported by the ICRP-1993 [2].

As showed in table 2 and Fig. 4, the frequency distribution vs radon concentrations in Bq.m^{-3} , for all health centers in the studied towns. The radon concentration varied from 15 to 101 Bq.m^{-3} , but more than about 2% of the health centers presented radon concentrations lower than 20 Bq.m^{-3} , 90% had radon concentrations between 20 and 70 Bq.m^{-3} , and the other 8 % had values in the range between 70 and 110 Bq.m^{-3} . Due to this results we can notice that all health centers in the studied towns have radon concentrations lower than the action level of 200 Bq.m^{-3} [42].

The RRLC ranging from 1.030 % to 1.054 % with an average of 1.042 % is almost negligible [43], which is consistent with other findings shown in Tab. 3.

Having close observation at Table 3, which compares values of radon concentration, effective dose and lung cancer risk from different regions in Sudan and other Countries. Our average values obtained here is lower than that reported values from Omdurman and Sinnar, Sudan [16], Brazil [47], Iraq [49], and Pakistan [50], higher than the recorded values for Jordan [13], Saudi Arabia [41] and India [46], nearer to the values reported from Al-Hosh (Sudan) [16] and USA [44].

Table 1. Summary statistics of indoor radon concentration measurements, effective dose and radon relative lung cancer risk in Health Centers in the studied locations in Sudan.

Health Centres locations	No of samples	Radon concentration (Bq.m^{-3})			ED (mSv.y^{-1})	RRLC%
		Min	Max	(Mean \pm s.d)		
Khartoum	56	31	101	49 ± 12	1.24 ± 0.30	1.044
Behri (Khartoum North)	54	15	81	46 ± 11	1.16 ± 0.28	1.041
Wad Medani	53	27	65	34 ± 9	0.86 ± 0.23	1.030
Kassala	59	19	96	60 ± 12	1.51 ± 0.30	1.054
Average	222	15	101	47 ± 11	1.19 ± 0.28	1.042

Table 2. Summary statistics of indoor radon concentration measurements, number of measurements and the percentage in the studied locations in Sudan.

Radon Concentration (Bq.m ⁻³)	Number of measurements	Percentage %
0-10	0	0.00%
10-20.	4	1.80%
20-30.	22	9.91%
30-40.	26	11.71%
40-50.	70	31.53%
50-60.	44	19.82%
60-70.	38	17.12%
70-80.	6	2.70%
80-90.	4	1.80%
90-100.	6	2.70%
100-110.	2	0.90%

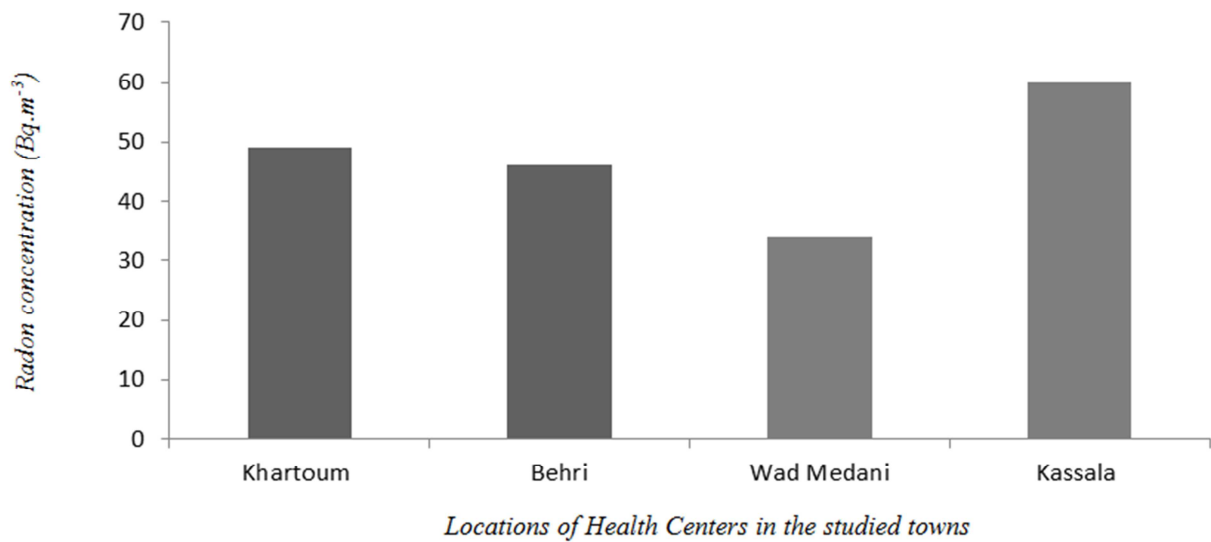


Figure 2. Radon concentration (Bq.m⁻³) vs the locations of health centers in the studied towns.

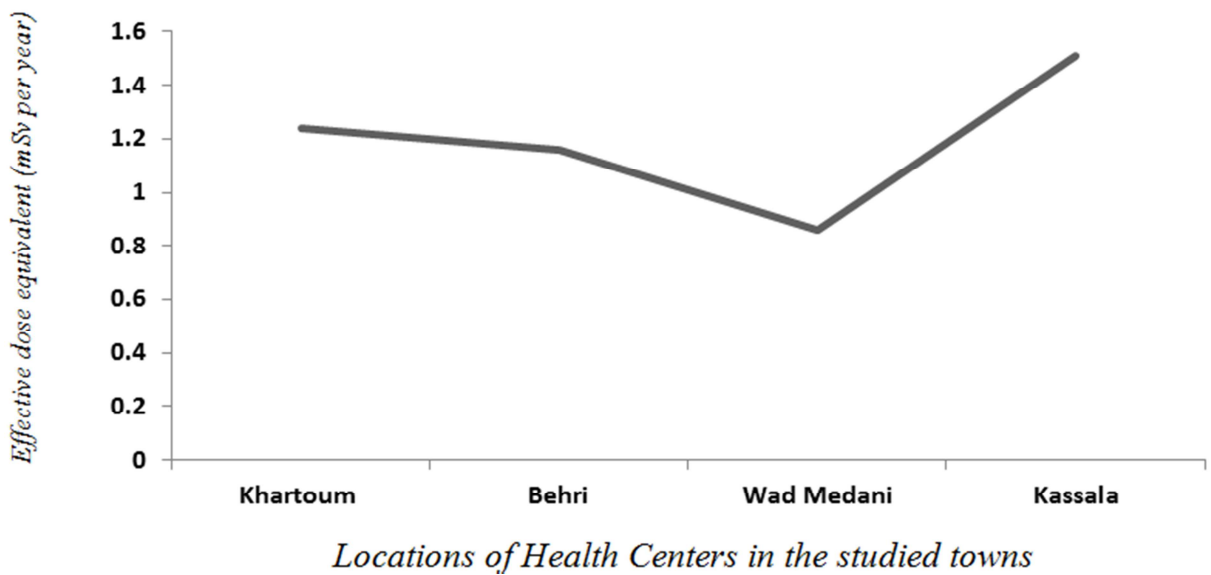


Figure 3. Effective dose equivalent with respect to the location of health centers in the studied towns in Sudan.

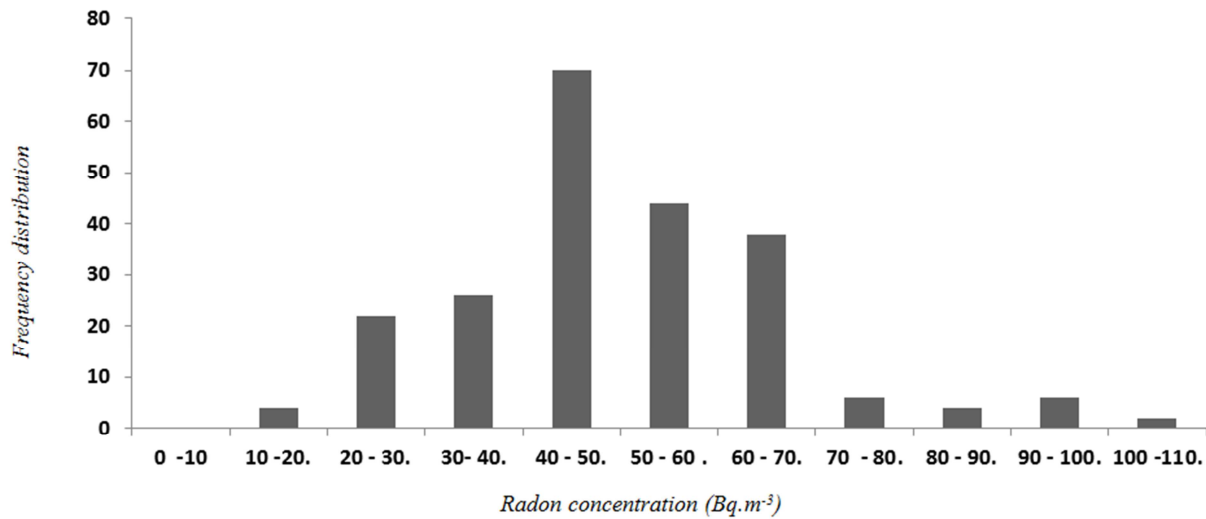


Figure 4. Frequency distribution vs. indoor radon concentration in the cities in Sudan.

Table 3. Values of concentration and exhalation rates of radon and radium concentration in different countries as compared with our study.

Country	Mean Conc. (Bq.m ⁻³)	DE (mSv.y ⁻¹)	RRLC %	Reference
Jordan	32	0.46	-	[13]
Saudi Arabia	36	0.61	-	[41]
USA	46	-	-	[44]
Demark	53	-	-	[45]
India	30	0.46	-	[46]
Brazil	82	-	-	[47]
Italy	52	-	-	[48]
Iraq	75	1.3	-	[49]
Pakistan	138	3.49	-	[50]
India	52	0.49	-	[51]
Austria	52	-	-	[52]
Croatia	71	-	-	[53]
U S A	148	-	-	[54]
Ireland	93	-	-	[55]
Kassala (Sudan)	92	2.14	1.08	[2]
Wad Medani (Sudan)	57	1.43	1.051	[15]
Omdurman (Sudan)	76	0.72	1.069	[16]
Medani (Sudan)	58	0.55	1.052	[16]
Sinnar (Sudan)	55	0.52	1.049	[16]
Al Hosh (Sudan)	48	0.45	1.043	[16]
Khartoum (Sudan)	44	1.2	-	[27]
Kassala (Sudan)	60	1.51	1.054	Present study
Khartoum (Sudan)	49	1.24	1.044	Present study
Wad Medani (Sudan)	34	0.86	1.030	Present study
Behri (Khartoum North- Sudan)	46	1.16	1.041	Present study

4. Conclusion

This study reports the results of a survey carried out to evaluate the radon concentration, effective dose and lung cancer risk for the workers in health centers at four towns situated in Sudan, namely: Khartoum, Behri (Khartoum North), Wad Medani and Kassala towns. The survey covered a number of 222 measurements spread throughout in all health centers of these towns. The mean value of indoor radon

concentration measured at these health centers was below the action level recommended by ICRP. The ventilation rate in the residential areas plays a very important role in controlling the indoor radon concentration. Furthermore, the calculated effective dose is lower than the average value given by UNSCEAR and below the ICRP action level. Consequently, the relative lung cancer risk from radon exposure is low in these health centers of the studied towns and these health centers can be considered safe for workers when the hazardous health effects of radon are concerned.

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