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Indoor Radon Concentrations in Al-Hasahisa and Rufaa Towns in the Central Part of Sudan

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Abstract: Indoor radon was systematically surveyed in the towns of Al Hasahisa and Rufaa in the central part of Sudan. The radon concentrations were measured in 276 measurements, using CR-39 etched track detectors. The radon concentration in the corresponding towns was found to vary from (86 ± 10) Bqm^{-3} in Al-Hasahisa to (66 ± 8) Bqm^{-3} in Rufaa. Assuming an indoor occupancy factor of 0.8 and 0.4 for the equilibrium factor of radon indoors, we found that the effective dose rate from 222Rn in the studied towns ranges from (2.18 ± 0.26) to (1.67 ± 0.20) mSv y^{-1} and the relative lung cancer risk (RRLC) for radon exposure was 1.078 to 1.059% in Al Hasahisa and Rufaa towns respectively. The recorded values of indoor radon concentration in this study are much lower than the radon action level as recommended by ICRP-1993, lower than the new reference level set by WHO and below the action level recommended by the Environmental Protection Agency (EPA). The values of the radon effective dose rate in this survey are slightly larger than the "normal" background level as quoted by UNSCEAR-2000, but way below even the lower limit of the recommended action level as reported by the ICRP-1993. The reported values of RRLC are almost negligible.

Keywords: Indoor Radon, Effective dose, CR-39, Relative risk of Lung cancer.

1 Introduction

Radon gas is recognized as the most significant natural source of human exposure and the leading cause of lung cancer incidence, with the exception of tobacco. The contribution to the mean effective dose equivalent from inhalation of 222Rn and its short-lived decay products (^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po) has been estimated to be about 50% of the total effective dose equivalent from all natural radiation sources [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

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and gastrointestinal. Indoor radon measurements are generally associated with dwellings. However, radon exposure shows an extreme variation from location to location and from season to season depending on the surrounding environment [2, 3, 4, 5, 6].

There are many sources contributing the variation of indoor radon these sources are soil [7, 8, 9, 10], building materials (rocks, cement, gravel, clay, sand, etc.) [11], surface and ground water sources [12, 13], natural energy sources like (gas, coal, etc.) [14]. Based on the National Academy of Science BEIR VI Report, the US Environmental Protection Agency estimates that about 21,000 annual lung cancer deaths are radon related [15]. The risk is reported to be proportional to the radon level down to the Environmental Protection Agency (EPA), which suggests intervention in residences with concentration values above 148 Bq.m^{-3} [16]. EPA also concluded that the effects of radon and cigarette smoking are synergistic, so that smokers are at higher risk from radon, from which it can be concluded that radon is the second leading cause of lung cancer after smoking [17]. The World Health Organization recommends that indoor concentrations must be less than100 Bq.m^{-3} but warns that if this is not possible, the limit should be taken as 300 Bq.m^{-3}[18]. The ICRP, 1993 sets limits for the indoor concentrations as follows: normal 200Bq.m^{-3}, attention (200–400) Bqm^{-3}, remediation (400–600) Bq.m^{-3}, and intervention that is higher than 600 Bqm^{-3} [19].

Solid-state nuclear track detectors have been widely used for passive measurements of indoor radon and their alpha emitting decay products. The use of 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 daughters activity concentration under different environmental condition [20, 21, 22].

Many investigations carried out in selected regions to study radon concentration in soil, building materials, water and indoor air in some parts of Sudan [3, 4, 5, 7, 8, 9, 11, 12, 13, 21, 23, 24]. In this study, effort has been taken to estimate indoor radon concentration from (276) measurements from Al Hasahisa town (143 measurements) and Rufaa town (133 measurements) in the central part of Sudan (fig. 1).

2 Materials and methods

2.1 The study area

Indoor radon measurements were determined in two towns that located at the central part of Sudan at Gezira State. These towns are namely; Al-Hasahisa town which lies between 14 44’ N and 33°18$^{\backslash}$ E, and Rufaa town which situated at 14°7$^{/}$N and 33°35$^{/}$E both of the towns are about 120 kms from Khartoum town the capital of the Sudan, because they are located at the two banks of blue Nile River Al-Hasahisa at the western bank and Rufaa at the eastern bank of the River). The area at which these towns are located is the most agriculturally productive state in the Sudan (Gezira State). The position of these towns is inside the Gezira State, which lies between the Blue Nile and White Nile rivers; this state is bounded by Khartoum state in the North, Gadarif state in the East, White Nile state in the West and Sennar state in the South. It lies between latitude 13-15.20 N and longitude 32.5–340 E.

Fig. 1. The map showing the study area of Al-Hasahisa and Rufaa towns that belonging to the Gezira State in the central part of Sudan

2.2 The type of aggregate materials in Rufaa and Al Hasahisa towns

The most common aggregate materials appear in the buildings of Al-Hasahisa town and Rufaa town are red brick, mud and concrete materials. The towns are at connected by a bridge constructed through the blue Nile river. There are many types of ventilation systems where some of the buildings use the roof fans and others use the air condition machines while others use the natural ventilation by opening the doors and windows frequently through the most time of the day. Through our survey period, we noticed that some of the inhabitants use concrete mixture (cement, sand bricks, dolomite and concrete) to construct their buildings. Most of the old buildings at these towns were seen to be constructed from clay and gravel materials. The buildings are at height of 2.0 to 4.0 m from the surface of each building. Each house has many rooms (between two to four) with common no decorated walls, in these rooms the inhabitants are stay most of the day time inside to take rest and in addition to their routine lifestyle.

In this work a precalibrated passive dosimeters containing solid-state nuclear track detectors using allyl diglycol carbonate of super grade quality CR-39 SSNTD, were used to study the indoor radon concentrations inside the buildings at Al-Hasahisa and Rufaa towns in the central part of Sudan (Gezira State). These passive dosimeters used here are similar to those we have used in previous studies [2, 4, 5, 24].

The total number of measurements is 276 at the selected sampling positions in the study area at Al-Hasahisa and Rufaa towns. After three months, the dosimeters were collected and chemically etched using a 30% solution of KOH at a temperature of (70.0± 0.1) oC for nine hours. 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 CRn (in Bq m^{-3}) using the following equation [11, 25]:

$$C_{Rn} = \frac{\rho}{KT} \tag{1}$$

Where ρ_{Rn} is, the track density (tracks per cm^2), K_{Rn} is the calibration constant was previously determined to be K_{Rn} = 4.824x10^{-3} tracks cm^{-2} h^{-1}/(Bq m^{-3}) [24] , and t is the exposure time.

2.3 Effective Dose and Relative risk of lung cancer estimations

In order to estimate the radon effective dose rate (ED) that expected to be received by the inhabitants at these towns due to radon gas, the conversion coefficient from the absorbed dose and the indoor occupancy factor has to be taken into account. In the UNSCEAR-2000 report, the committee recommended to use 9.0 nSv h^{-1} per Bqm^{-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 [1]:

$$ED(mSvy^{-1}) = C_{Rn}D_fO_fE_f \times\ 24 \times 365 \times\ 10^{-6} \tag{2}$$

The relative risk of lung cancer (RRLC) due to indoor exposure to radon was calculated using the equation [4, 24, 26]:

$$RRLC = e^{(0.00087352 \times C_{Rn})} \tag{3}$$

3 Results and disscussions

In this study, we present results of the radon concentration levels, effective dose (ED) and relative risk of lung cancer (RRLC) in buildings of Al-Hasahisa and Rufaa towns.

Table 1. and Figures 2-4. Shows the range and average values of indoor radon concentration (Bqm^{-3}), effective dose (ED) ($mSvy^{-1}$), and relative risk of lung cancer (RRLC) (%), for the buildings in Alsaffa Area and Eastern Area at Al-Hasahisa town. The recorded values were found to be from (119 ± 15) to (50 ± 6) Bqm^{-3}, 1.27 to 3.01 $mSvy^{-1}$ and

1.045 to 1.110 %, while the average values are found to be (86 ±10) Bqm^{-3}, (2.18 ± 0.26) $mSvy^{-1}$, and 1.078 %, respectively.

Table 1. Summary statistic of indoor radon concentrations measurements, effective dose and radon relative lung cancer risk in AlHasahisa town in the central part of Sudan (Gezira State).

Residential Area	No. Meas.	Min. Con. (Bqm^{-3})	Max. Con. Bqm^{-3}	Aver Con. Bqm^{-3}	ED ($mSvy^{-1}$)	RRLC%
Eastern Area	18	16	87	50 ± 6	1.27 ± 0.16	1.045
Arkauiet Area	19	55	171	115 ± 13	2.90 ± 0.32	1.106
Alsadaqa Area	19	42	152	94 ± 10	2.37 ± 0.26	1.086
Alimtidad Area	16	34	109	73 ± 8	1.85 ± 0.21	1.066
Alfayha Area	17	47	162	102 ± 13	2.58 ± 0.32	1.094
Alsaffa Area	19	39	194	119 ± 15	3.01 ± 0.37	1.110
Alzhoor Area	17	27	86	54 ± 8	1.37 ± 0.21	1.049
Almazad Area	18	36	133	82 ± 10	2.06 ± 0.26	1.074
Overall	143	16	171	86 ± 10	2.18 ± 0.26	1.078

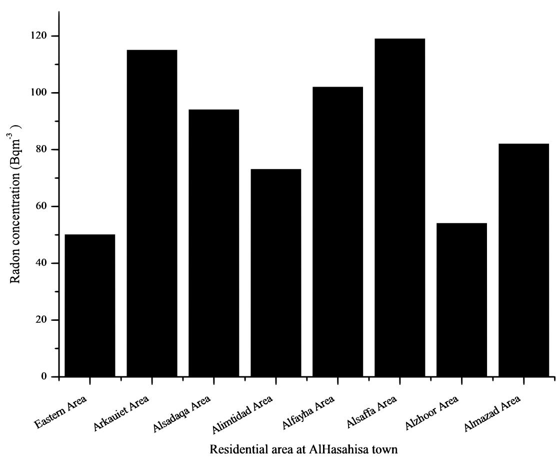

Fig. 2. Indoor radon concentration vs residential areas at AlHasahisa town.

Table 2. and Figures 5-7. Shows the range and average values of indoor radon concentration (Bqm^{-3}), effective dose (ED) ($mSvy^{-1}$), and relative risk of lung cancer (RRLC) (%), for the buildings in Alhisynab Area and Area number 5 at Rufaa town. The calculated values were ranging from (98 ± 10) to (66 ± 8) Bqm^{-3}, 1.11 to 2.48 $mSvy^{-1}$ and 1.039 to 1.090 %, while the average values are found to be (86 ± 10) Bqm±, (1.67 ± 0.20) $mSvy^{-1}$, and 1.059 %, respectively.

From these results we can find that, radon concentration levels, effective dose (ED) and relative risk of lung cancer (RRLC) are in general quite larger in AlHasahisa town

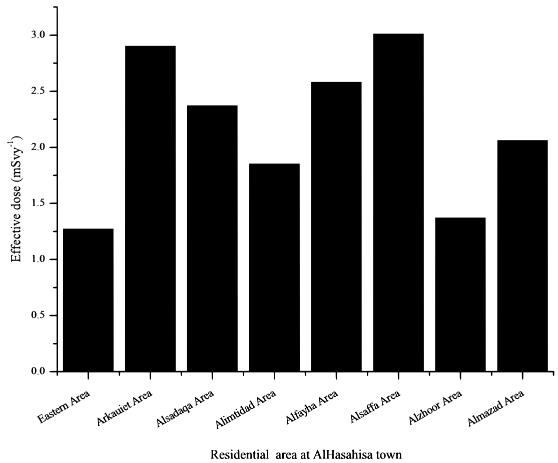

Fig. 3. Effective dose vs residential areas at AlHasahisa town.

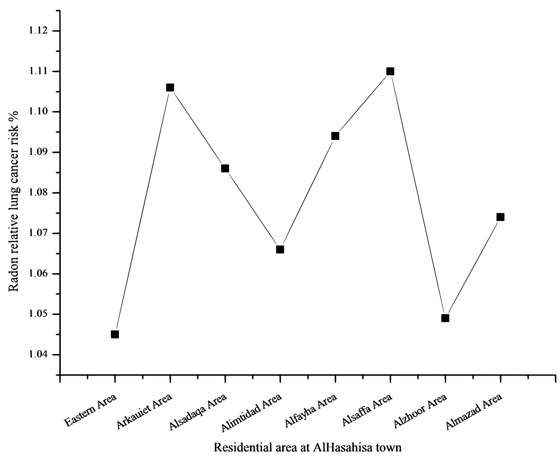

Fig. 4. Radon relative lung cancer risk vs residential areas at AlHasahisa town.

than the values that obtained from the areas in Rufaa town. The higher values of indoor radon concentration, effective dose (ED) and relative risk of lung cancer (RRLC), may be attributed to that Alhisynab Area (AlHasahisa town), is the one of the oldest areas in the town, the buildings are constructed from bricks and mud in addition to that the dwellings are close to each other. The ventilation rate is not good due to the reason of that the buildings of the area are very old; whatever the windows are very small and they are usually closed. The bad ventilation rates received by the inhabitants of these buildings resulting in increasing the concentration values of the area. In Alsaffa Area (Rufaa town), some of the area buildings are noticed to be constructed from brick with cemented materials. These areas are also to some extent nearer to the Blue Nile River bank hence its soil classified as being belonged

Table 2. Summary statistic of indoor radon concentrations measurements, effective dose and radon relative lung cancer risk in Rufaa town in the central part of Sudan (Gezira State).

Residential Area	No. Meas.	Min. Con. (Bqm^{-3})	Max. Con. (Bqm^{-3})	Aver.Con. (Bqm^{-3})	ED ($mSvy^{-1}$)	RRLC%
Alsuqe Area	15	23	84	52 ± 6	1.32 ± 0.16	1.047
Frontal Area	17	37	104	77 ± 10	1.95 ± 0.26	1.070
Alhisynab Area	19	36	159	98 ± 10	2.48 ± 0.26	1.090
Hospital Area	16	29	78	65 ± 8	1.64 ± 0.21	1.058
Area number 6	17	27	95	59 ± 8	1.48 ± 0.21	1.052
Area number 5	16	18	72	44 ± 6	1.11 ± 0.16	1.039
Daim Lutfy Area	18	37	106	73 ± 8	1.85 ± 0.21	1.066
Alhila Aljadida Area	15	26	98	61 ± 6	1.53 ± 0.16	1.054
Overall	133	18	159	66 ± 8	1.67 ± 0.20	1.059

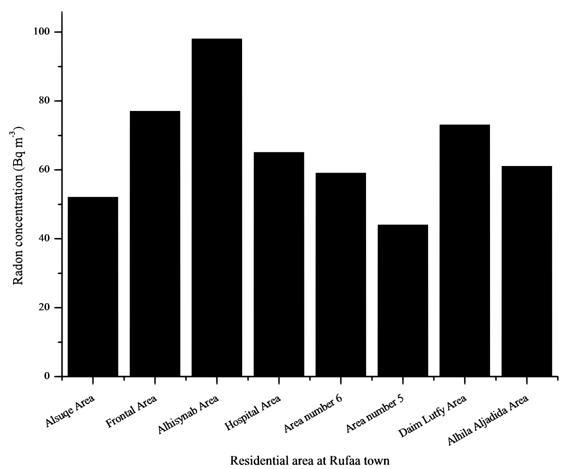

Fig. 5. Indoor radon concentration vs residential areas at Rufaa town.

to river terrace soils some of the inhabitants uses this soil in constructing their houses either directly or produce it as red bricks this may increase the indoor radon concentration at this area. It was found that since the flooding period, the Blue Nile River carries and drift a suspended material which re-sediments as silt clay, sandy clay, and sand and gravel [8].

The lower values of concentration value, effective dose (ED) and relative risk of lung cancer (RRLC), are recorded for the Eastern Area (Al-Hasahisa town) may be due to the reason of that, the area is an open small area situated in the external side of the town, the buildings are far apart with respect to each other, some buildings are constructed from strew and red bricks. The area is to some extent far away from the riverbanks, situated in an open flat area, so the area is good ventilated for this reason we found the lower values

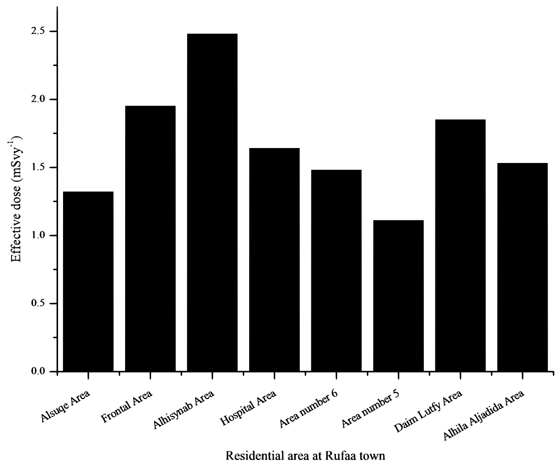

Fig. 6. Effective dose vs residential areas at Rufaa town.

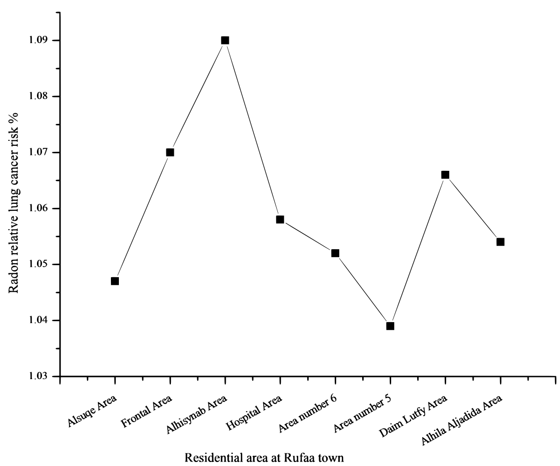

Fig. 7. Radon relative lung cancer risk vs residential areas at Rufaa town.

in our study. The lower values recorded for the Area number 5 (Rufaa town) may be due to the type of construction materials, which are mainly red brick and strew materials; these materials constitute low concentration values, rather than cement and concrete materials [11], for this reason the recorded values are minimum.

From our study we can find that the recorded values of indoor radon concentration are far below than the radon action level (200- 600) Bqm^{-3} as recommended by ICRP-1993 [19], lower than the new reference level (100 Bqm^{-3}) set by WHO [18] and below the action level (148 Bqm^{-3}) recommended by Environmental Protection Agency (EPA) [16]. The overall calculated average values for radon concentration in both towns are seen to be higher than the world-wide, population weighted, average radon of 40 Bqm^{-3} as reported by UNSCEAR [1] and well within values reported for various locations in the Sudan and worldwide (Table 3). If we compare our concentration values in this study with national values we can find that (from Table 3) the recorded concentration values in Kassala, Halfa Aljdadida, Aroma and Kordufan are relatively higher values than the measured values in this study, while the recorded values for Khartoum, USA and Elmanagil are similar to that recorded for Rufaa town. As it is known that no intervention is required if the radon level is below 74 Bqm^{-3}, we can conclude and indicating that our calculated levels are safe for occupancy [27]. From the results we find that the average value of radon concentration in Rufaa town is lower than this level, but the average value of radon concentration in Al-Hasahisa exceeded this value, concerning this it is clear that in all probability the only intervention needed is to improve ventilation since it is well known that increased ventilation rate is an important factor in reducing indoor radon level [28].

From the results we can see that the average values of effective dose is found to be larger than the “normal” background level of 1.1 $mSvy^{-1}$; as quoted by UNSCEAR-2000 [1], less than even the lower limit of the recommended action level (3–10 $mSvy^{-1}$) as reported by the ICRP-1993 [19]. The obtained values of relative lung cancer risk for the two towns are seen to be comparable with other findings as shown in Table 3.

Table 3. Comparison of results with other results in various locations in the world

Country(town)	MeanConc. Bqm^{-3}	DE ($mSvy^{-1}$)	*RRLC%*	Ref.
Jordan	32.4	0.46	–	[2]
Sudan(Khartoum)	44.3	1.20	–	[3]
Sudan(Kassala)	92.38	2.14	1.08	[4]
Sudan(Aroma)	91.15	2.29	1.08	[5]
Sudan(HalfaAljadida)	94.2	2.36	1.09	[5]
Sudan(KhashmAlgirba)	64.1	1.60	1.06	[5]
Pakistan	138	3.94	–	[6]
Sudan(Kordufan)	109.43	4.16	–	[23]
Sudan(Medani)	57	1.40	1.051	[24]
Sudan(ElHosh)	50	1.30	1.045	[24]
Sudan(Elmanagil)	45	1.20	1.040	[24]
Sudan(HajAbdallah)	54	1.40	1.49	[24]
Sudan(WadAlmahi)	41	1.10	1.037	[24]
SaudiArabia	36.2	0.61	–	[28]
USA	46	–	–	[29]
Brazil	82	–	–	[30]
Italy	52	–	–	[31]
India	30.3	0.46	–	[32]
Sudan(Rufaa)	66	1.67	1.059	Present study
Sudan(AlHasahisa)	86	2.18	1.078	Present study

4 Conclusion

The average values of indoor radon concentration measured at Al-Hasahisa and Rufaa towns in the Gezira State – Central Sudan were below the action level recommended by ICRP. The ventilation rate in the buildings plays a very important role in the controlling of 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 for radon exposure is low in these buildings and they can be considered safe when the hazardous health effects of radon are concerned.

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