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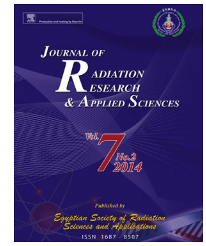

A study of seasonal variations of radon levels in different types of dwellings in Sri Ganganagar district, Rajasthan

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ABSTRACT

An indoor radon survey has been carried out in 50 dwellings situated in Sri Ganganagar district of Rajasthan using a time-integrated passive technique containing LR-115 type II solid state nuclear track detectors exposed for four seasons of 3 months each covering a period of 1 y. Indoor radon concentration values varied from 144 ± 20 to 259 ± 67 Bq m^{-3} in winter, 111 ± 23 to 156 ± 64 Bq m^{-3} in rainy, 97 ± 13 to 156 ± 19 Bq m^{-3} in summer and 103 ± 17 to 213 ± 76 Bq m^{-3} in autumn time and the average values were found to be 182 ± 31, 126 ± 15, 119 ± 20 and 146 ± 30 Bq m^{-3}, respectively. The annual average indoor radon concentration varied from 114 ± 18 to 194 ± 45 Bq m^{-3} with an average of 143 ± 21 Bq m^{-3}, which is less than the lower limit of the action level (200–300 Bq m^{-3}) recommended by International Commission on Radiological Protection. The annual exposure to occupants, annual effective dose and lifetime fatality risk in dwellings varied from 0.50 to 0.85 WLM with an average of 0.63 WLM; 1.95 ± 0.31 to 3.32 ± 0.78 mSv y^{-1} with an average of 2.45 ± 0.36 mSv y^{-1} and 1.51×10^{-4} to 2.56×10^{-4} with an average of 1.89×10^{-4}, respectively. Measured values for winter/summer, winter/rainy and winter/autumn radon ratios were found as 1.54 ± 0.29, 1.48 ± 0.35 and 1.28 ± 0.24. An effort has been made to find possible relationships of indoor radon levels with building construction materials and ventilation condition of dwellings.

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1. Introduction

Radon is a chemically inert, naturally occurring, cancer-causing radioactive gas. Radon gas has no smell, color, or taste and is produced from the natural radioactive decay of uranium which is found in rocks and soil. Radon gas escapes easily from rocks and soils into the air and tends to concentrate in enclosed spaces, such as underground mines, houses, and other buildings. Soil gas infiltration is recognized as the most important source of residential radon (WHO, 2009a, p. 94). The radiation dose from inhaled decay products of radon (^{222}Rn) is the dominant component of radiation exposure to the general population and causes an increased risk of lung cancer (UNSCEAR, 2000).

Radon was classified as a human carcinogen by International Agency for Research on Cancer (IARC, 1988). In general, residential radon is regulated by a reference level of radon concentration between 200 and 300 Bq m^{-3} based on International Commission on Radiological Protection recommendations (ICRP, 2010). About the action level of radon, the World Health Organization has suggested that homeowners take actions when radon levels exceed 100 Bq m^{-3}. This is much more conservative figure than the Environmental Protection Agency (EPA) action level of 148 Bq m^{-3} (EPA, 1991), which has been the U.S. standard for many years (WHO, 2009b). The concentration of indoor radon and its decay products shows large temporal and local fluctuations in the indoor atmosphere due to the variation in topography, house construction type, soil characteristics and weather (Duggal, Rani, & Mehra, 2013; Mehra, Singh, & Singh, 2006). Relatively higher indoor radon levels are observed in winter season (Rani, Singh, & Duggal, 2013). The seasonal variation of the indoor radon levels depends on several parameters such as type of house, radon source, living habits of the inhabitants, ventilation system of the house, heating of the house and outside climate (Durrani & Ilic 1997).

Human beings are exposed to radon through inhalation and ingestion. Radon monitoring has been increasingly conducted worldwide because of the hazardous effects of radon on health of human beings. In many situations such as showering, washing clothes and flushing toilets, radon is released from the water and mixes with the indoor air. The radon from water contributes to the total inhalation risk associated with radon in indoor air. Although radon in drinking water does not pose a direct health risk (Cross, Hartley, & Hoffmann, 1985).

Seasonal variation of indoor radon concentration and some influencing factors have been studied during a 1 y period in the dwellings made of different building materials in Sri Ganganagar district of Rajasthan. The annual exposure to occupants, the annual effective dose received by them, and their lifetime fatality risk estimates were assessed in light of guidelines given by International Commission on Radiological Protection (ICRP, 1993). An effort has been made to find possible relationships of indoor radon levels with building construction materials and ventilation condition of dwellings.

2. Materials and methods

2.1. Study area

Rajasthan is located in northwest of India. The Sri Ganganagar district is situated in the northern most region of the state and forms a part of Indo-Gangatic plain. It is located between 28° 42′ and 30° 11′ North latitudes and between 72° 38′ and 74° 17′ East longitudes. It has a geographical area of 10,978 km^2. The population of Sri Ganganagar district is approximately 20 lakh. It is bounded on the south by Bikaner district and on the east by Hanumangarh district and on the north by Faridkot & Ferozpur districts of Punjab and on west by Bahawalpur district of Pakistan (Fig. 1). The climate of the district is marked by the large variation of temperature, extreme dryness and scanty rainfall. The area is covered by windblown isolated sand and alluvium except few patches of recent calcareous and sandy sediments associated with gypsite. The oldest

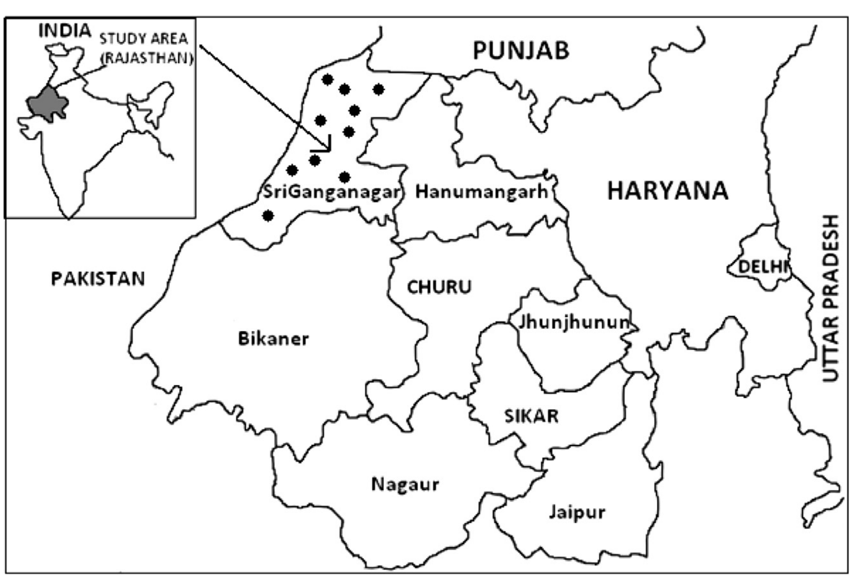

Fig. 1 – Map of Rajasthan showing the surveyed area during the present investigations.

Table 1 – Annual average indoor radon levels in some villages of Sri Ganganagar district, Rajasthan, the annual exposure to occupants; the annual effective dose received by them and their lifetime fatality risk estimates.

Sample location	Detector no.	Indoor radon concentration ($Bq\ m^{-3}$)												Annual average radon concentration ($Bq\ m^{-3}$)	Annual exposure		Annual effective dose ($mSv\ y^{-1}$)	Lifetime fatality risk $\times 10^{-4}$
		Winter			Rainy			Summer			Autumn							
		Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD		WLM	mJhm^{-3}		
Sri Ganganagar District																		
Malkana	1–5	142	227	192 ± 29	92	160	116 ± 27	82	156	112 ± 25	96	174	134 ± 26	138 ± 32	0.61	2.15	2.36 ± 0.55	1.82
Sangatpura	6–10	149	256	187 ± 36	89	163	119 ± 24	85	146	111 ± 20	110	174	135 ± 22	138 ± 30	0.61	2.15	2.36 ± 0.51	1.82
23Z	11–15	131	235	183 ± 35	78	153	114 ± 25	85	124	105 ± 13	71	171	121 ± 35	131 ± 31	0.58	2.04	2.24 ± 0.52	1.73
Radewala	16–20	146	235	165 ± 37	75	167	129 ± 32	92	149	113 ± 24	114	227	178 ± 38	146 ± 26	0.64	2.28	2.50 ± 0.45	1.93
SriGanganagar city	21–25	156	359	259 ± 67	75	245	156 ± 64	85	217	147 ± 49	117	320	213 ± 76	194 ± 45	0.85	3.03	3.32 ± 0.78	2.56
Gulabawala	26–30	110	171	144 ± 19	89	146	113 ± 20	75	114	97 ± 13	78	124	103 ± 17	114 ± 18	0.50	1.78	1.95 ± 0.31	1.51
3H	31–35	92	203	148 ± 36	75	153	128 ± 27	124	174	156 ± 18	107	174	148 ± 23	145 ± 10	0.64	2.26	2.48 ± 0.18	1.92
Kalian	36–40	149	220	184 ± 27	78	156	121 ± 28	82	135	108 ± 18	89	174	137 ± 32	137 ± 29	0.60	2.14	2.34 ± 0.49	1.81
Karanpur	41–45	114	249	197 ± 48	99	224	153 ± 43	96	163	141 ± 24	92	185	159 ± 34	162 ± 21	0.71	2.53	2.77 ± 0.36	2.14
14Q	46–50	121	199	158 ± 28	67	131	111 ± 23	75	149	103 ± 26	99	163	131 ± 24	126 ± 21	0.55	1.97	2.15 ± 0.36	1.67

Min: Minimum, Max: Maximum, SD: Standard Deviation.

rocks of the area belong to Aravalli Super Groups which includes phyllite, shale and quartz vein. These are overlaid by the rocks of the upper Vindhyan which are entirely made up of bright to pale red, fine and medium grained compact sand stone and siltstone.

The soils are mainly developed from the alluvium of variable texture and at places the alluvium is buried under the wind worked sand. These alluvial soils are moderately coarse textured, deep to very deep, underlained by weak concretionary zone and have been classified as Torrifluvents. The only major mineral of the district is gypsite. The Ghaggar River is an ephemeral and divides the district into two halves.

2.2. *Building characteristics*

Most of the houses in the surveyed area are of cemented construction and partially ventilated and only a few are mud-type with poor ventilation. Local mud, rocks, cement, sand, bricks, marble and concrete have been used in the construction of these houses. Most of the houses in the surveyed area have single storey, while few of them have a double storey also. In the study area, most dwellings are of 5–30 years and only a few dwellings are more than 30 years. In our survey no house was found using mechanical ventilators and fans are used only in a few limited houses. The mud-type earthen-floored houses were built with local mud, unfired bricks and most of them are poorly ventilated having no windows. The sizes of these houses and their rooms are different from area to area and also within the location.

2.3. *Indoor radon study*

LR-115 type II plastic track detector films and the bare mode technique were used to measure the concentration of radon in the indoor environment (Duggal et al. 2013; Mishra & Ramachandran 1997; Ramola et al. 1998). The houses were chosen in such a manner that the dwellings constructed with different types of building materials and in different localities of the towns/villages were covered. The detectors of size 1.5 cm × 1.5 cm were suspended in the rooms of the dwellings at a height >2 m above the ground level (so that the detectors were not disturbed by the movement of the residents) and about 1 m below the ceiling of the room so that direct alpha particles from the building material of the ceiling did not reach the detectors. The authors assumed that a room with a door and without window would be poorly ventilated, that with one window and a door as partially ventilated and with two or more windows and a door as well ventilated. After exposure the detectors were removed and etched using 2.5 N NaOH solutions at 60 °C for 90 min. After thorough washing, the detectors were scanned for track density measurements using an optical microscope at a magnification of 400×. The track density so obtained was converted into the units of $Bq\ m^{-3}$ of the radon concentration using the calibration factor of 0.020 ± 0.002 tracks $cm^{-2}\ d^{-1}\ (Bq\ m^{-3})^{-1}$ determined experimentally by Eappen, Ramachandran, Shaikh, & Mayya (2001), which satisfies the conditions prevailing in the Indian dwellings. In the bare mode technique there can be some contribution from thoron (^{220}Rn) also. However, the report by UNSCEAR (2000) reveals that the contribution from ^{220}Rn and

Table 2 – The building construction materials, ventilation conditions and winter/summer; winter/rainy; winter/autumn ratios of the radon concentration for all the dwellings.

Sample location	Radon concentration ($Bq\ m^{-3}$) in Dwelling 1					Radon concentration ($Bq\ m^{-3}$) in Dwelling 2					Radon concentration ($Bq\ m^{-3}$) in Dwelling 3					Radon concentration ($Bq\ m^{-3}$) in Dwelling 4					Radon concentration ($Bq\ m^{-3}$) in Dwelling 5				
	Type	V.C.	W/S	W/R	W/A	Type	V.C.	W/S	W/R	W/A	Type	V.C.	W/S	W/R	W/A	Type	V.C.	W/S	W/R	W/A	Type	V.C.	W/S	W/R	W/A
Sri Ganganagar District																									
Malkana	D_2	I	1.45	1.42	1.30	D_4	I	1.86	1.47	1.34	D_3	II	1.47	1.80	1.36	D_1	I	1.70	1.70	1.35	D_1	II	1.73	1.54	1.48
Sangatpura	D_2	I	1.75	1.57	1.47	D_4	II	1.62	1.58	1.37	D_3	I	1.63	1.53	1.29	D_1	I	1.66	1.5	1.41	D_1	II	1.75	1.67	1.35
23Z	D_2	II	1.89	1.54	1.37	D_4	I	1.78	1.59	1.39	D_3	I	1.76	1.64	1.83	D_1	II	1.65	1.58	1.39	D_1	II	1.54	1.68	1.84
Radewala	D_2	I	1.58	1.41	1.14	D_3	I	1.27	1.12	0.75	D_4	II	1.52	1.08	0.82	D_3	III	1.39	1.09	0.77	D_1	II	1.59	1.95	1.28
SriGanganagar city	D_2	I	1.65	1.46	1.26	D_4	I	1.52	1.37	0.91	D_3	I	2.0	1.84	1.47	D_1	II	2.06	2.20	1.37	D_3	III	1.83	2.08	1.33
Gulabawala	D_3	II	1.5	1.17	1.38	D_3	II	1.50	1.23	1.45	D_1	II	1.42	1.52	1.25	D_3	II	1.89	1.25	1.54	D_1	III	1.20	1.24	1.41
3H	D_3	I	1.17	1.54	1.22	D_4	II	0.95	2.17	1.12	D_3	III	0.74	0.66	0.63	D_2	I	0.91	1.07	0.86	D_1	II	0.92	0.88	1.26
Kalian	D_2	I	1.63	1.41	1.26	D_3	I	1.73	1.44	1.23	D_4	II	1.76	1.59	1.41	D_1	II	1.62	1.45	1.32	D_1	I	1.82	1.91	1.67
Karanpur	D_3	I	1.63	1.43	1.35	D_4	I	1.71	1.60	1.34	D_2	II	1.28	0.89	1.14	D_1	I	1.13	1.53	1.11	D_3	III	1.19	1.15	1.24
14Q	D_3	I	1.34	1.52	1.22	D_2	II	1.62	1.47	1.39	D_1	II	1.90	1.22	1.37	D_3	III	1.36	1.23	0.88	D_3	III	1.61	1.81	1.22

V.C.: ventilation condition, I: poorly ventilated, II: partially ventilated, III: well ventilated; W/S: winter/summer, W/R: winter/rainy, W/A: winter/autumn; D_1: Floor: cemented, Roof: cement + concrete, Wall: burnt clay bricks, cemented, white wash; D_2: Floor: mud, Roof: bricks + mud, Wall: mud, clay wash; D_3: Floor: cemented, Roof: bricks + cemented, Wall: burnt clay bricks, cemented, white wash; D_4: Floor: marble, Roof: cement + concrete, Wall: burnt clay bricks, cemented, white wash.

Table 3 – Frequency distribution of seasonal average indoor radon concentration among various dwellings.

Number of dwellings	Indoor radon concentration ($Bq\ m^{-3}$)					Season
	<100	100–150	150–200	200–300	>300	
	Percentage					
50	2	32	38	26	2	Winter
50	26	52	16	6		Spring
50	36	56	16	2		Summer
50	16	42	34	6	2	Autumn
50	4	28	16	2		Annual

its progeny in dwellings is in general about 10% of that of ^{222}Rn and its progeny. So this component can be neglected from the point of view of inhalation dose.

3. Results and discussion

As mentioned above, indoor radon levels have been measured in 50 dwellings (5 dwellings in each of the 10 villages/towns) in Sri Ganganagar district of Rajasthan, India. The results obtained are summarized in Table 1. The radon concentration values varied from 144 ± 20 to 259 ± 67 $Bq\ m^{-3}$ in winter, 111 ± 23 to 156 ± 64 $Bq\ m^{-3}$ in rainy, 97 ± 13 to 156 ± 19 $Bq\ m^{-3}$ in summer and 103 ± 17 to 213 ± 76 $Bq\ m^{-3}$ in autumn time and the average values were found to be 182 ± 31, 126 ± 15, 119 ± 20 and 146 ± 30 $Bq\ m^{-3}$, respectively. The annual average indoor radon concentration varied from 114 ± 18 in village Gulabawala to 194 ± 45 $Bq\ m^{-3}$ in Sri Ganganagar city with an average of 143 ± 21 $Bq\ m^{-3}$, which is less than the lower limit of the action level (200–300 $Bq\ m^{-3}$) recommended by International Commission on Radiological Protection (ICRP, 2010). These values are higher than that of the world average value of 40 $Bq\ m^{-3}$ (UNSCEAR, 2000). The present results of annual average radon concentration are higher than the action level (100 $Bq\ m^{-3}$) recommended by World Health Organization (WHO, 2009b).

The annual exposure to the occupants, the annual effective dose and lifetime fatality risk for each of the 10 villages/towns were calculated. The calculations were made using the conversion factors given elsewhere (ICRP, 1993; Raghavayya 1994) according to which the exposure of an individual to radon progeny of 1 WLM is equivalent to 3.54 $mJh\ m^{-3}$. The conversion factor of $3 \times 10^{-4}\ WLM^{-1}$ and 3.88 WLM^{-1} were used for calculating the lifetime fatality risk and the annual effective dose, respectively. The annual effective dose received by the residents of the study area varies from 1.95 ± 0.31 to 3.32 ± 0.78 $mSv\ y^{-1}$ with a mean value of 2.45 ± 0.36 $mSv\ y^{-1}$. In most of the villages/towns, the annual effective dose received by the residents is less than the lower limit of the recommended action level 3–10 $mSv\ y^{-1}$ (ICRP, 1993). The annual exposure to the occupants in the study area varies from 1.78 $mJh\ m^{-3}$ (0.50 WLM) to 3.03 $mJh\ m^{-3}$ (0.85 WLM) with an average of 2.23 $mJh\ m^{-3}$ (0.63 WLM). The lifetime fatality risk of the residents of the study area varies from 1.51×10^{-4} to 2.56×10^{-4} with an average of 1.89×10^{-4}. The average value of the lifetime fatality risk of 1.89×10^{-4} (0.02%) is relatively a small fraction (about 4%) of the lifetime risk of lung cancer due

Table 4 – Indoor radon levels in dwellings constructed with different types of building materials.

Dwelling types	Floor	Roof	Wall	Number of dwellings	Average radon concentration (Bq m^{-3})	
					Range	Mean
D_1	Cemented	Cement + Concrete	Burnt clay bricks, Cemented, White wash	14	91–159	120 ± 20
D_2	Mud	Bricks + Mud	Mud, Clay wash	10	118–276	177 ± 40
D_3	Cemented	Bricks + Cemented	Burnt clay bricks, Cemented, White wash	18	90–190	136 ± 28
D_4	Marble	Cement + Concrete	Burnt clay bricks, Cemented, White wash	8	131–254	159 ± 38

to cigarette smoking and chewing of tobacco (Evans et al., 1981).

The building construction materials, ventilation conditions and winter/summer; winter/rainy; winter/autumn ratios of the radon levels have been computed for all the 50 dwellings. The results are summarized in Table 2. It is evident from Table 2 that the radon level in well-ventilated dwellings is lower compared with that in the poorly ventilated dwellings. This is because in well-ventilated dwellings the radon can easily escape out. Moreover, the results reveal that the seasonal variation of indoor radon shows high values in winter and low values in summer. This is because the doors and windows of the dwellings remained closed most of the times in winter season compared with summer season hence the ventilation is poor in winter season. Our results of seasonal variations shows a behavior which agrees with the findings of Singh, Mehra, and Singh (2005) for the dwellings of Malwa region, Punajb and that of Duggal et al. (2013) for Northern Rajasthan, India. Measured values for winter/summer, winter/rainy and winter/autumn radon ratios were found as 1.54 ± 0.29, 1.48 ± 0.35 and 1.28 ± 0.24. Table 3 shows the frequency distribution of seasonal average indoor radon concentration among various dwellings.

In order to find the distribution of radon levels in the different types of dwellings, we have classified the data according to the building material used for roof, floor and walls in these dwellings. The results are summarized in Table 4. The indoor radon concentration with respect to the type of dwellings of D_1, D_2, D_3 and D_4 ranges from 91 to 159 Bq m^{-3}, 118–276 Bq m^{-3}, 90–190 Bq m^{-3} and 131–254 Bq m^{-3} with overall mean values of 120 ± 20, 177 ± 40, 136 ± 28 and 159 ± 38 Bq m^{-3}, respectively. Fig. 2 shows the variation of mean radon concentrations in the dwellings constructed with different types of building materials. Highest level of indoor radon concentration was found in the mud type dwellings (D_2). This may be attributed to the rich content of radium in the local soil used for construction of these dwellings (Duggal, Rani, Mehra, & Ramoal, 2014). Relatively higher indoor radon concentration in the mud dwellings (D_2) was due to the little exchange of air in these dwellings. This may be attributed to the age and poor ventilation condition of these dwellings compared to others. Furthermore, the exhalation of radon from the walls, roofs and floors of mud dwellings (D_2) is higher than that of modern dwellings because of cracks and defective joints in their walls, roofs and floors.

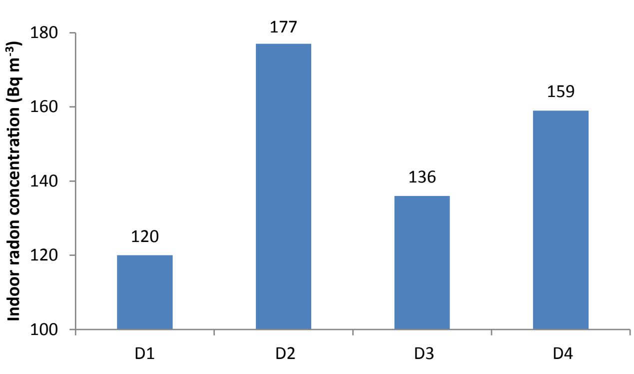

Fig. 2 – Mean value of radon concentration for the different types of dwellings in Sri Ganganagar district.

4. Conclusion

- In majority of the dwellings, the annual average radon concentrations are less than the lower limit of the action level (200–300 Bq m^{-3}) recommended by ICRP.
- In most of the villages/towns, the annual effective doses received by the residents are lower than the recommended action level (3–10 mSv y^{-1}).
- The seasonal variations of indoor radon reveal the maximum values in winter and minimum in summer.
- Results show that ventilation rate is inversely proportional to radon level. Hence high levels of indoor radon from the building material and from the household water may be reduced by increasing ventilation rate.
- Highest level of indoor radon concentration was found in the mud type dwellings compared with dwellings made of concrete, cement and marble.

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