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Seasonal and location dependence of indoor and soil radon concentrations in two villages, Najran region, Saudi Arabia

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HIGHLIGHTS

- Indoor and Soil radon levels are measured in Najran region, Saudi Arabia.
- Indoor radon levels are location independent but seasonal dependant.
- Soil radon levels are seasonal and location dependent.
- Meteorological and geological factors may have caused the differences.

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ABSTRACT

Seasonal (winter-summer) indoor and soil radon comparison is made in two villages in Najran region, south west of Saudi Arabia, using CR-39 Dosimeter. Summer indoor radon concentrations were measured in the villages of Fara Al-Jabal and Hadadah. The respective winter-summer average values of 42 ± 4 Bq m^{-3} and 74 ± 5 Bq m^{-3} are measured in Fara Al-Jable village and the average values of 47 ± 4 Bq m^{-3} and 76 ± 5 Bq m^{-3} are measured in Hadadah village. The respective winter-summer soil values are 1.40 ± 0.21 kBq m^{-3} and 0.99 ± 0.04 kBq m^{-3} in Fara Al-Jabal village while those measured in Hadadah village are 2.90 ± 0.17 kBq m^{-3} and 1.40 ± 0.66 kBq m^{-3}. Indoor radon levels are found to be seasonal dependent while that of soil are found seasonal and location dependent. Meteorological and geological factors are expected to have caused the measured significant differences in radon levels in dwellings and soil in the two villages.

1. Introduction

The longest lived radon gas isotope ^{222}Rn ($T = 3.82$ days) and its progeny are the major source of public exposure to natural radiation. Radon progeny are short lived radioactive and chemically reactive isotopes which may get deposited on the respiratory tract tissue and cause damage to its cells. The average effective dose received due to radon and its progeny is 1.2 mSv y^{-1} while the global average annual effective dose due to exposure to natural radiation is 2.4 mSv y^{-1} (Masahiro Hosoda et al., 2007). It has been established that radon gas is the second source of lung cancer after smoking (Darby et al., 2005).

Radon as a cause of leukemia has also been discussed (Darko et al., 2009; Richardson et al., 1991). It has been reported that indoor radon exposure is associated with the risk of leukemia and other cancers such as melanoma and cancers of the kidney and prostate (Henshaw et al., 1990). In recent years exposure to radon has become a global concern due to its health hazards inside dwellings (IAEA, 2003; ICRP, 1993; Nazaroff et al., 1987; UNSCEAR, 2000; USEPA, 2004; WHO, 2009).

Measured indoor radon levels are found to vary even within the same area.

Differences in building materials, climate (temperature, humidity and pressure) and the geology of the area contribute to these variations. Radon transport into buildings depends on diffusion and convection mechanisms. Diffusion through soil and building materials depends on their uranium content in addition to radon diffusion length while convection is caused by pressure difference due to meteorological factors such as, heating and ventilation (Narula et al., 2009; Shweikani et al., 1995).

A number of studies to measure radon levels have been made in the kingdom of Saudi Arabia in places such as schools and houses but data remain limited (Abu-Jarad and Al-Jarallah, 1986; Al-Ghamdi et al., 2011a, 2011b, 2006; Al-Jarallah et al., 2003; Alyami et al., 2010).

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The present work is an effort to contribute to the radon data in the kingdom of Saudi Arabia. The measurements were taken in summer (18th May – 12th September, 2006) and compared to Alyami (2010) published work taken at the same site in winter (21st, Nov, 2005 – 21st, March, 2006). The locations of the two villages with respect to Najran city and to each others are shown in Fig. 1.

1.1. *Geology of the area studied*

The measurements were taken in Najran region, Saudi Arabia, Fig. 2.

Najran region falls in the southern part of the Arabian Shield which is composed of igneous and metamorphic rocks. These measurements include two villages in Najran region, namely Hadadah and Fara Aljabal villages. Geologically, the two villages are located on the Haddadah Pluton (gdt) which is composed of granodiorite and tonlite, gneissic, with narrow outcrop of biotitemonzogranite (mgb), locally gneissic and schistose. The pluton is surrounded by metadacite (hvd), pyroclastic and volcaniclastic, and Wajid Sandstone (OCW), quartz arenite, Fig. 3 (Sable, 1985).

Fara Al-Jabal and Hadadah are situated at heights of 1900 m and 1740 m above sea level respectively. There are 50 houses in Fara Al-Jabal and 140 houses in Hadadah village. Their populations are 411 and 1770 respectively according to the last population count by the local health centers in the area. Houses in both villages are one floor houses, made of concrete with bricks coming from the same source and have the same ventilation system (Alyami, 2008). The aim of this work is to measure radon levels in dwellings and soil of the two villages and subsequently draw conclusions on seasonal variation.

2. Experimental method

Columbia Resin-39 (CR-39) is the trade name of plastic polymeric form of diethyleneglycolcole bis, allylcarbonate (PADC). CR-39 nuclear track detectors (2.0 × 2.0 cm^2) supplied by Pershore Mouldings Ltd, UK, were used to measure the time integrated radon concentration. A tag type dosimeter is designed where the CR-39 detector is sandwiched between two layers of 1 cm thick porous sponge. The sponge and the detector are inserted in a wooden frame for protection, the details of which can be seen in the published work (Alyami et al., 2010).

The tag Dosimeter was calibrated against an already calibrated cup type which was calibrated at the National Radiological Protection Board (NRPB), UK where a standard source facility exists. The cup Dosimeter calibration factor (F_c) was 5.2 ± 0.6 Tracks/cm^2 kBq m^{-3} h.

The tag type and the cup type Dosimeters were immersed in pairs (one of each type) in twenty soil samples of equal activity. The twenty pairs were left for an accumulation period of 193 days after which a single relative calibration point was obtained. The tag type Dosimeter's calibration factor of 6.4 ± 0.8 tracks/cm^2 kBq m^{-3} h was measured (Al-Ghamdi et al., 2011b). Other calibration values are found one of which is measured by Nidal Dwaikat (2010) to be 0.20 ± 0.01 tracks cm^{-2} day^{-1} per Bq m^{-3} (8.33 ± 0.42 Tracks/cm^2 kBq m^{-3} h) for bare CR-39 detector.

The houses in the two villages are almost identical having the same number of rooms, utility rooms and are all single floor buildings. The floors of houses in the region including these villages are covered by a 10 cm thick layer of concrete, insulating houses from soil. The measurements were taken over a period of 151 days in winter and 115 days in summer. The Dosimeters were placed in both seasons in the same positions in houses and soil at a depth of 0.5 m (Abumurada and Al-Tamimi, 2005; Schumann et al., 1988). Dosimeters distribution according to room type and season is shown in Table 1 for the two villages.

Five houses in winter and four houses in summer from each village are included in the measurement. In every village six dosimeters were used to measure soil radon concentration and all twenty four dosimeters were collected. The *t-test* is used to establish any significant difference between radon levels in the two seasons (Warren Chase and Fred Bown, 1992).

The collected dosimeters were treated chemically under often employed etching conditions (etched in 6 N, NaOH solution at 70 °C) for 3 h after which the detectors were washed in water and dried. The α-tracks on both sides of the detector were counted under an optical microscope with magnification of 400×. The track densities were converted into radon concentrations Bq m^{-3} using the measured calibration factor and an average value for each pair of readings (back and front) is found.

3. Results and analysis

The winter and summer indoor and soil radon concentrations for each of the two villages together with other statistical parameters are presented in Table 2. The data show that the indoor radon averages are higher in summer while those of the soil are higher in winter. The average winter indoor radon level for the two villages is 45 ± 2 Bq m^{-3} and that in summer is 75 ± 2 Bq m^{-3}.

Using the *t-test* at 95% confidence level, the average indoor and soil radon concentrations values are compared in pairs. Location test is taken for values measured in the two villages in the same season and seasonal test is that performed on values measured in the same village in but in both seasons, Table 3.

The average for each pair of readings (back and front) is found and frequency graphs for the two seasons in each village is drawn, figs. (4 and 5). Indoor radon seasonal dependence can be seen in both distributions. The *t-test* values in Table 3 confirm that, pair of average values of indoor radon levels measured in the two villages in the same season (location test), has no significant difference. Summer and winter pair of values in the same village (seasonal test), showed significant difference. In soil, location and seasonal *t-test* values showed significant difference.

Fig. 1. Hadadah and Fara Al-Jabal villages and Najran city geographical location (Google maps).

Fig. 2. Location of Najran region in Saudi Arabia (black rectangle).

Indoor radon levels distributions graphs are skewed to high values but only four readings exceeded the EPA action level of 148 Bq m^{-3}. These were measured in rooms such as stores, dining rooms and toilets that are least used and hence poorly ventilated.

4. Discussion and conclusions

In order to explain these results, the effects of environmental factors, such as temperature and humidity on detector's efficiency are discussed first.

The effect of temperature and humidity on the efficiency of CR-39 detectors has been investigated (El-Sersy et al., 2004). In order to evaluate this effect, the average values calculated from the reported daily minimum, maximum, mean temperature values during the measurements and average humidity in Najran city are tabulated, Table 4 (http://www.wunderground.com/history/airport/OENG/2012/12/28/DailyHistory.html, December 2012). Accordingly, the difference between the daily average temperature values in both seasons is about 12 °C, which could give 5% change on the detector's efficiency considering the finding of El-Sersy et al. (2004). It

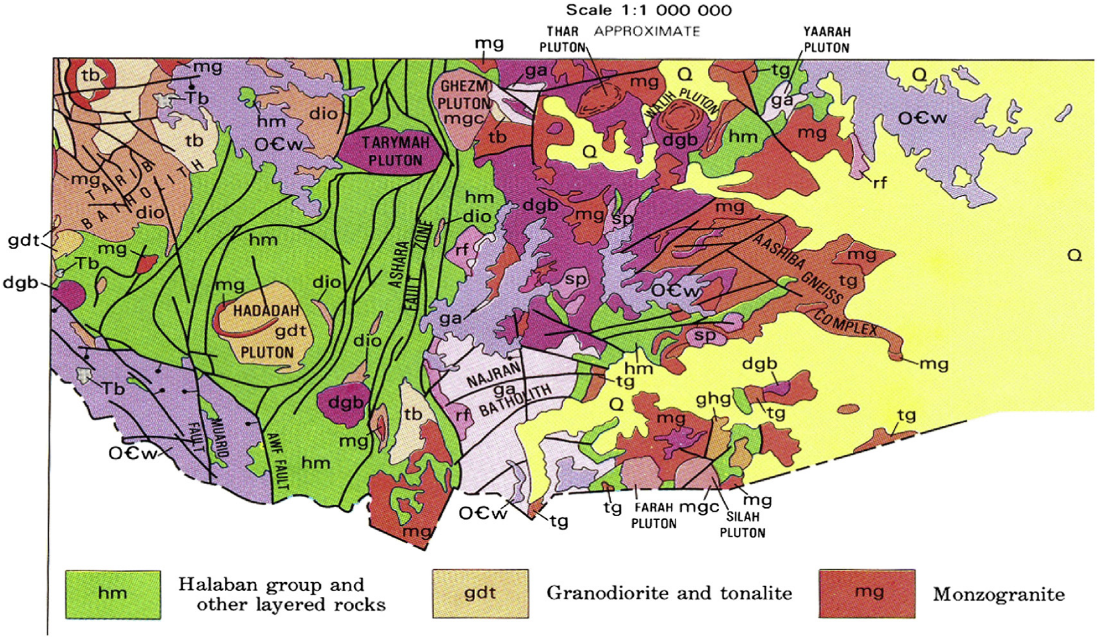

Fig. 3. Geological formation of Hadadah pluton on which Hadadah and Fara AlJabal villages are situated.

Table 1
Dosimeters distribution according to room type.

No	Room type	Hadadah		Fara Aljabal	
		Winter	Summer	Winter	Summer
1	Sitting room	7	8	8	9
2	Bedroom	11	4	10	10
3	Toilet	11	9	10	6
4	Kitchen	5	4	5	4
5	Dining room	3	4	3	1
6	Store	1	3	–	–
–	Total	38	32	36	30

Table 2
Seasonal Soil and Indoor radon levels measured in Najran region, Saudi Arabia.

Statistical factors	Winter (Alyami et al., 2010)				Summer (this work)			
	Fara Al-Jabal		Hadadah		Fara Al-Jabal		Hadadah	
Conc. (Bq m^{-3})	Soil	Indoor	Soil	Indoor	Soil	Indoor	Soil	Indoor
Min.	590	9	2200	9	720	23	1000	25
Max.	2800	163	3900	144	1300	155	1700	178
Average	1400	42	2900	47	990	74	1400	76
σ_{sem}	210	4	170	4	40	5	66	5

Table 3
Location and Seasonal *t-test* values.

t-test *FFapplication*	Location test (Fara Al-Jabal-Hadadh)		Seasonal test (summer-winter)	
	Summer	Winter	Fara Al-Jabal	Hadadah
Indoor Radon	0.35σ	1.18σ	6.4σ	5.1σ
Soil Radon	4.94σ	5.38σ	2.01σ	8.37σ

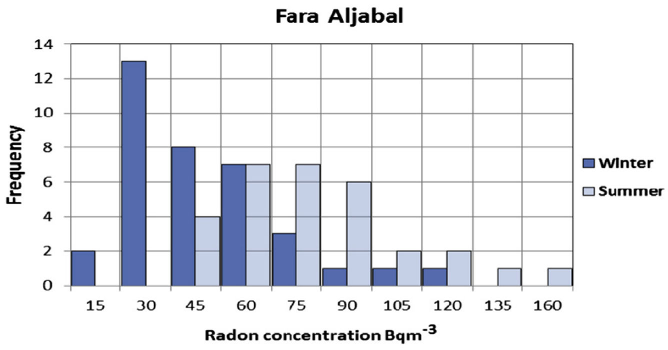

Fig. 4. Winter-summer, Indoor radon levels frequency graph in Fara Al-Jabal village.

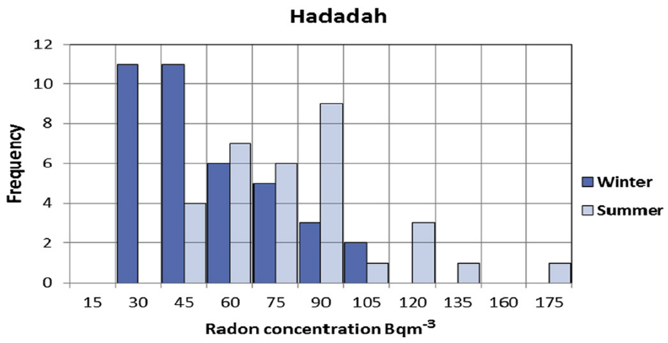

Fig. 5. Winter-summer, Indoor radon levels frequency graph in Hadadah village.

should be remembered that12 °C difference is outdoor, however indoor temperatures are expected to remain the same because homes are cooled in summer and warmed in winter therefore temperature effect on detectors efficiency in both seasons is ruled out. The effect of humidity on detectors efficiency within the range of measurement 10–90% is negligible as reported by El-Sersy et al. (2004). It is worth mentioning that in the present work the respective range is only 27%, which is much narrower than the range reported. Therefore the effect of humidity on the detector's efficiency during this measurement can be ignored. Contributions from other sources such as, building materials etc., to indoor radon levels are expected to be the same in both villages within the same season.

4.1. *Soil radon concentrations*

Radon gas in soil is transported by diffusion and convection which are governed by concentration and pressure gradients respectively. Diffusion and convection are dominant in soil of low and high permeability respectively. Soil radon concentrations correlate with different geological and meteorological factors such as soil properties, precipitation, pressure differentials and temperature gradients.

The final form of the soil may differ from the parent soil, hence soil's characteristics such as, grain size, shape, radon parent nuclides placement within soil grains and soil moisture conditions may differ from one place to another. Radon emanation power and transport characteristics of the soil is dependent on the soil final form (Schumann, 1993).

It is reported that low level (15–20%) soil moisture enhances radon emanation but higher levels may hinder radon transport as water fill pore spaces in the soil. When the uppermost layer of soil is saturated, capping effect is created hindering radon release and increasing radon concentration in soil. Decreasing atmospheric and wind created pressures pull air from the soil and increasing pressures push it in, hence respective low and high radon concentrations in soil are found (Stewart Whittlestone et al., 2003). Reports on temperature effect on soil radon concentration ranged from having no effect to observed negative correlations between both soil and air temperature and radon concentrations due to convective soil-gas transport resulting from temperature gradients within the soil. This idea is supported by an experiment in which 50–200% increase in radon exhalation rate from soil samples was observed when their temperature increased from 5 to 22$^{\mathrm{O}}$C (Schumann et al., 1988).

a) Location effect

Significantly higher soil radon average concentrations are measured in Hadadah village, which is at a height of about 200 m lower than Fara Aljabal village in both seasons, Table 2. If one assumes similar meteorological situations in both villages due to their proximity (direct distance is 7 km) then geological factors might be contributing to this difference. Factors such as grain size, shape, radon parent nuclides placement within soil grains and soil moisture conditions may have higher hindrance on radon gas transport mechanisms in Hadadah village, creating significantly higher soil radon gas concentrations in both seasons. In addition to that, Radium content in soil may be different in the two villages.

b) Seasonal effect

The average daily temperature and humidity in addition to the average pressure values during the measurements in Najran are calculated in both seasons, Table 4. In winter the temperature is lower by about 12 °C and the average humidity in winter is about three times that in summer indicating higher moisture

Table 4
Temperature, humidity and pressure average values during the summer and winter seasons (http://www.wunderground.com/history/airport/OENG/2012/12/28/DailyHistory.html, December 2012).

Season	Statistical factor	Temperature (°C)			Humidity %			Pressure (hPa)		
		Min	Max	Daily average	Min	Max	Daily average	Min	Max	Average
Sum	Average	25.14	39.14	31.87	8.65	24.13	14.70	1010.0	1014.0	1012.0
	σ	2.23	1.43	1.47	2.70	6.35	3.98	2.0	2.0	2.0
	σ_{sem}	0.18	0.12	0.12	0.22	0.51	0.32	1.0	1.0	1.0
Win	Average	11.59	27.71	19.46	24.70	62.95	42.18	1017.0	1022.0	1019.0
	σ	3.71	4.21	3.64	11.24	19.06	14.75	3.0	3.0	3.0
	σ_{sem}	0.30	0.34	0.30	0.91	1.55	1.20	1.0	1.0	1.0

concentration in winter. In this work, measured soil radon concentrations in both villages are higher in winter, Table 2. This may be explained as due to lower radon gas exhalation rate due to lower temperature and higher moisture concentration in winter (Schumann et al., 1988).

4.2. Indoor radon concentration

a) Location effect

The indoor radon concentrations within the same season are found to be the same in both villages, Table 2. Diffusion and convection from soil are usually significant contributors to indoor radon that are enhanced by concentration and pressure gradients respectively (Schumann et al., 1988). Houses with cement flooring are found to reduce radon diffusion from soil into dwellings by about 31% compared to that with mud flooring. The concrete floor in these houses is expected to reduce significantly soil contribution to indoor radon (Narula et al., 2009).

b) Seasonal effect

Significantly high indoor radon concentrations measured in both villages in summer may be due to the advection effect. In summer, radon exhalation rate from soil is higher due to higher temperatures hence more radon is expected to be available for transfer into dwellings by the advection process (Schumann et al., 1988). An additional contributor may be the air conditions used in summer where outside air is exchanged with indoors. Convection through cracks and openings in the buildings is another possible contributor (Narula et al., 2009).

In summary: the higher indoor radon values in summer may be due to higher temperature in this season. Convection, diffusion and higher advection rate of radon into houses increases its level in summer in addition to that air conditions are used in this season. The soil's radon higher concentrations in Hadadah village in both seasons may be location related leading to different properties of the soil which may have hindered radon transport and raising the radon levels in both seasons in this village. Significantly high soil radon concentration in winter in both villages may be due to higher moisture concentration which hinder the radon exhalation rate from soil.

This preliminary survey has led to some interesting results which may be confirmed if a larger, more representative survey is taken.

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