Measurement of soil-gas radon in some areas of northern Rajasthan, India

Vikas Duggal[1,*], Asha Rani[2] and Rohit Mehra[3]

[1]*Department of Applied Sciences, Punjab Technical University, Jalandhar 144 601, India.*
[2]*Department of Applied Sciences, Ferozpur College of Engineering and Technology, Ferozshah, Ferozpur 142 052, India.*
[3]*Department of Physics, Dr B. R. Ambedkar National Institute of Technology, Jalandhar144 001, India.*
[*]*Corresponding author. e-mail: vikasduggal86@yahoo.in*

The health hazards of the radioactive gas radon on general public are well known. In order to understand the level and distribution of ^{222}Rn concentrations in soil-gas in Sri Ganganagar district of Rajasthan, a ^{222}Rn survey was carried out for the first time using RAD7, an electronic radon detector manufactured by Durridge Company (USA), at different locations covering a total area of 10,978 km^2, having a population of approximately 20 lakh. The measurement of ^{222}Rn concentration in soil-gas was carried out at four different depths (10, 40, 70, and 100 cm). The radon concentration in soil-gas for 10, 40, 70, and 100 cm depths ranged from 0.09–4.25, 0.15–6.30, 0.50–9.18, and 0.72–10.40 kBq m^{-3}, respectively. The minimum value of radon concentration is observed in 33 GB village at 10 cm depth and maximum for Mohanpura village at 100 cm depth. As expected, our data show an increase of soil-gas radon concentration levels with depth. The present results are compared with the available radon data from other studies.

1. Introduction

Radon is a naturally occurring odorless, colourless, tasteless, inert gas which is imperceptible to our sense. It is produced continuously from the decay of naturally occurring radionuclide such as U-238, U-235, Th-232. The isotope ^{222}Rn, produced from the decay of U-238, is the main source (approximately 55%) of the internal radiation exposure to human life (ICRP 1993). Radon comes from the natural decay of uranium that is found in nearly all soils. It typically moves up through the ground to the air above and into homes through cracks and other holes in the foundation. There are two main sources for the radon in home's indoor air – the soil and the water supply. Compared to radon entering the homes through water, radon entering homes through the soil is usually much higher. So the radon from soil gas is the main cause of radon problem. Based on the National Academy of Science 1998 BEIR VI Report, the US Environmental Protection Agency estimates that about 21,000 annual lung cancer deaths are radon related. 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 (USEPA 2012).

The factors which influence the diffusion of radon from the soil into the air are:

- The uranium and radium concentration in soil and rocks;
- The emanation capacity of the ground;
- The porosity of the rock and soil;

Keywords. Health hazards; RAD7; radon; Rajasthan; soil.

- Barometric pressure gradient between the interfaces;
- Soil moisture and water saturation grade of the medium;
- Other variables (UNSCEAR 1993).

The movement of radon through rocks under the earth largely depends on lithology, compaction, porosity, and fractural and tectonic features like faults, thrust, and joints (Choubey *et al.* 1997). In the past decades, systematic radon surveys in soil-gas were carried out in different parts of India (Prasad *et al.* 2005, 2008; Bajwa *et al.* 2010; Singh *et al.* 2010a; Mehra and Bala 2013).

High radium content in soil samples and uranium content in water samples were reported in Sri Ganganagar district of Rajasthan State by our group (Duggal *et al.* 2013; Rani *et al.* 2013). The aim of the present investigation is to examine the concentration of radon in the soil-gas of Sri Ganganagar district, Rajasthan at different depths and to find a relationship between the soil-gas radon concentration and depth.

2. Geology of Sri Ganganagar district

Rajasthan is located in northwest of India. The Sri Ganganagar district is situated in the northernmost region of the state and forms a part of Indo-Gangetic plain. It is located between 28°42′ and 30°11′N latitudes and between 72°38′ and 74°17′E longitudes. Figure 1 shows the layout of Gang canal as well as the location of sampling sites in Sri Ganganagar district, Rajasthan. It has a geographical area of 10,978 km^2. The population of Sri Ganganagar district is approximately 20 lakhs. It is bounded on the south by Bikaner district and on the east by Hanumangarh district and on the north by Faridkot and Ferozpur districts of Punjab and on west by Bahawalpur district of Pakistan.

The climate of the district is marked by the large variation of temperature, extreme dryness, and scanty rainfall. The area is covered by wind-blown, isolated sand and alluvium except for a few patches of recent calcareous and sandy sediments associated with gypsite. The oldest rocks of the area belong to Aravalli Super Groups, which include 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 a 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.

3. Materials and methods

The soil-gas radon concentration was measured at 10 locations in 10 villages (one location from each village) of Sri Ganganagar district, Rajasthan and at each location the radon concentration was determined at four different depths (10, 40, 70, and 100 cm). The measurements were performed by RAD7, an electronic radon detector manufactured by Durridge Company, USA. The RAD7 radon monitor apparatus uses an air pump and a solid state alpha detector which consists of a semiconductor material (generally silicon) that converts alpha radiation directly to an electrical signal. It has desiccant ($CaSO_4$) tubes and inlet filters (pore size 1 μm) that block fine dust particles and radon daughters from entering the radon test chamber. The RAD7's internal sample cell is a 0.7 litter hemisphere, coated on the inside with an electrical conductor. The centre of the hemisphere is occupied by a silicon alpha detector. One important benefit of solid state devices is ruggedness. Another advantage is the ability to immediately differentiate radon from thoron by the energy of the alpha particle released. The RAD7 has also the ability to tell the difference between the new radon daughters and the old radon daughters left from previous tests. The equipment is portable and battery operated, and the measurement is fast.

The soil-gas samples of each site were collected with the help of the stainless steel probe supplied by Durridge Company (USA), immersed in the soil to a specified depth, which was then connected to the RAD7 detector with a special accessory for the purpose. Figure 2 shows the schematic diagram of RAD7 soil-gas setup. The probe was penetrated in the soil with a rotating handle or immersed with gentle strokes of a hammer. The measurements were performed where the soil is uniform and generally free of rocks. The depth of the sampling point is determined by the length of the probe inserted into the ground, taking into consideration the location of the sampling points on the probe shaft. Before the counting process started, the hole was properly sealed in order to prevent mixing of soil-gas with air from atmosphere.

The sniff protocol and grab mode were used for the soil-gas sampling on the RAD7 detector at each site. The measuring instrument was then attached to the probe for sucking the soil-gas from the deep soil. The soil was sucked through the tube pipe into the measuring instrument for 5 min

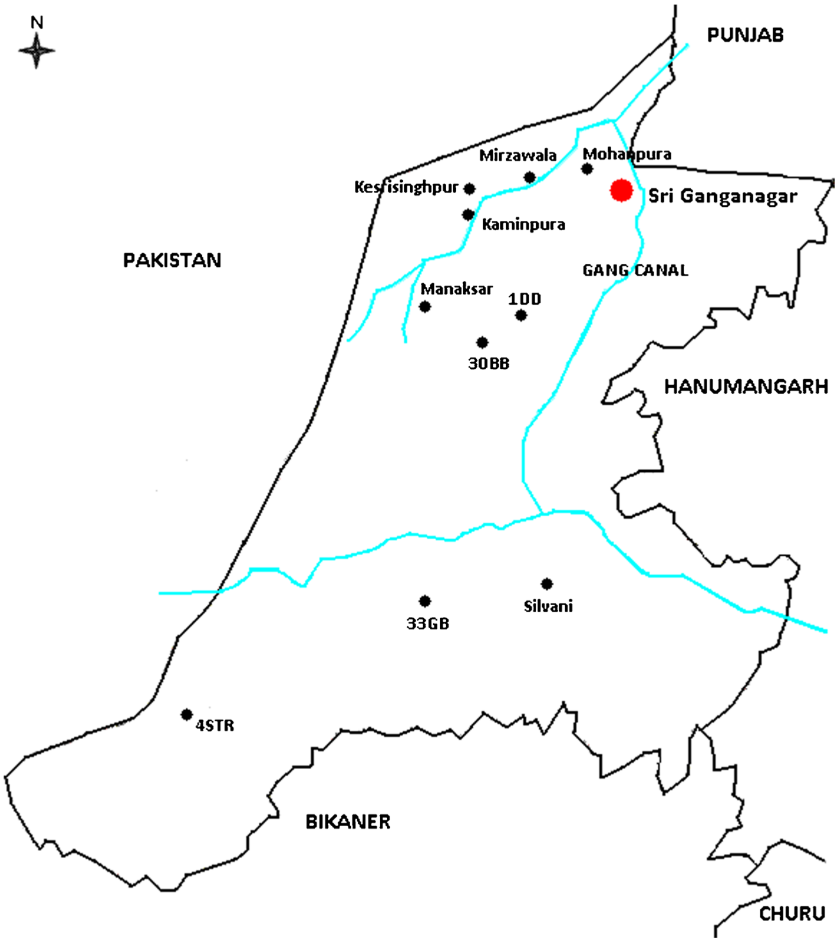

Figure 1. Map of Sri Ganganagar district showing the layout of Gang canal as well as the area surveyed during the present investigations.

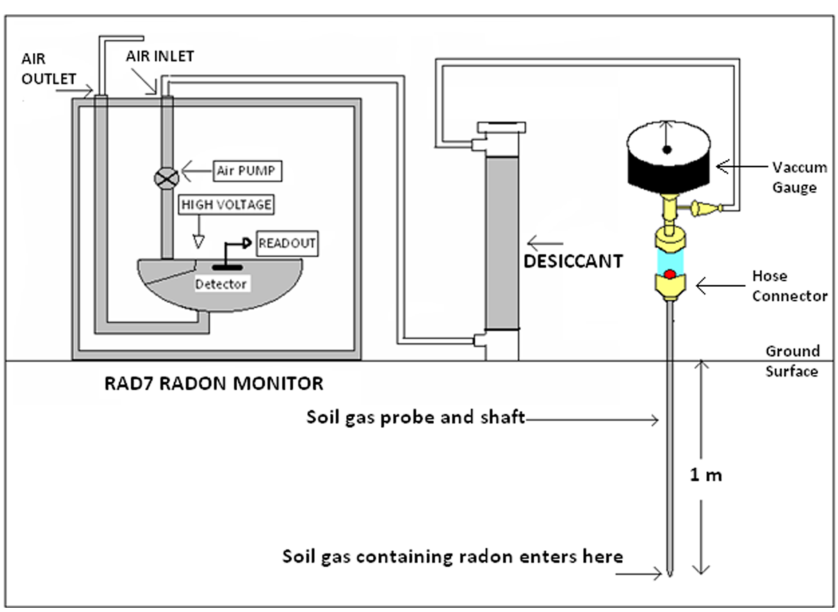

Figure 2. The schematic diagram of the RAD7 soil-gas setup.

pumping phase. The instrument waits another 5 min and then counts for four 5-min cycles. At the end of the half-hour period, the RAD7 will print out a summary of the measurement, including an average radon concentration in the soil-gas from the four 5-min cycle measurements. This method gives a quick (half-hour) reading and uses the least amount of soil-gas (RAD7 Manual).

All these samples were collected in the month of September 2012, during which the temperature remained in the range of 25°–42°C. The average relative humidity of the experimental sites ranges from 25 to 45%. The sampling test was carried out between 9.00 and 18.00 hrs and not in the rain. When it rained, the test was carried out on the next day.

4. Results and discussion

The results of ^{222}Rn measurements in soil-gas in Sri Ganganagar district are presented in table 1. The radon concentration in soil-gas varied from

Table 1. *Radon concentration in soil gas at specified depths in villages of Sri Ganganagar district of Rajasthan.*

Sl. no.	Sample location	Latitude and longitude	Sampling depth (cm)	Radon concentration (kBq m^{-3})	Standard deviation (kBq m^{-3})	Temperature (°C)
1	4STR Village	29.02°N; 73.05°E	10	0.15	0.09	33
			40	0.20	0.12	36
			70	0.50	0.21	41
			100	1.86	0.17	29
2	33GB Village	29.25°N; 73.54°E	10	0.09	0.08	34
			40	0.15	0.13	35
			70	1.80	0.25	33
			100	2.13	0.05	32
3	Silvani	29.33°N; 73.78°E	10	0.19	0.12	42
			40	0.48	0.18	34
			70	0.71	0.29	38
			100	0.72	0.13	37
4	30BB Village	29.68°N; 73.57°E	10	0.26	0.16	31
			40	0.93	0.36	26
			70	1.46	0.21	27
			100	2.04	0.38	29
5	IDD Village	29.73°N; 73.63°E	10	1.08	0.04	37
			40	1.78	0.26	41
			70	2.70	0.25	33
			100	3.18	0.33	28
6	Manaksar	29.75°N; 73.50°E	10	2.70	0.60	27
			40	3.12	0.53	29
			70	4.16	0.16	25
			100	5.41	0.27	26
7	Kaminpura	29.89°N; 73.63°E	10	1.19	0.09	38
			40	3.48	0.21	36
			70	5.84	0.25	36
			100	6.41	0.56	36
8	Kesrisinghpur	29.94°N; 73.62°E	10	0.51	0.09	31
			40	0.83	0.21	30
			70	2.28	0.26	33
			100	7.09	1.04	39
9	Mirzawala	29.96°N; 73.74°E	10	0.35	0.08	28
			40	2.60	0.23	31
			70	9.18	0.68	34
			100	10.20	1.18	30
10	Mohanpura	29.97°N; 73.82°E	10	4.25	0.24	30
			40	6.30	0.57	33
			70	6.55	0.28	33
			100	10.40	0.64	26

0.09 ± 0.08 kBq m^{-3} in 33GB village to 4.25 ± 0.24 kBq m^{-3} in Mohanpura village with an average value of 1.08 kBq m^{-3} at 10 cm depth; from 0.15 ± 0.13 kBq m^{-3} in 33GB village to 6.30 ± 0.57 kBq m^{-3} in Mohanpura village with an average value of 1.99 kBq m^{-3} at 40 cm depth; from 0.50 ± 0.21 kBq m^{-3} in 4STR village to 9.18 ± 0.68 kBq m^{-3} in Mirzawala village with an average value of 3.52 kBq m^{-3} at 70 cm depth; from 0.72 ± 0.13 kBq m^{-3} in Silvani village to 10.40 ± 0.64 kBq m^{-3} in Mohanpura village with an average value of 4.94 kBq m^{-3} at 100 cm depth.

Figure 3 shows the variation of soil-gas radon concentration with the depth of the soil in different villages of Sri Ganganagar district. The results suggested that the maximum radon concentration is observed at 100 cm depth and minimum at 10 cm depth. The results obtained from the study prove that the soil-gas radon increases with depth. This may be due to the increase in moisture content with depth of the soil. The concentration of radon in the air in soil pores increases with increasing water content in the pores. This is because of the equilibrium relationships between the ratios of radon in air to the radon in water, which is dependent on the temperature. It is also due to the fact that the emanation of radon to the pore space increases with moisture. The radon content of the pore is thus considerably lower in dry soil than in moist soil (Durrani and Ilic 1997). Our result shows a behaviour which agrees with the findings of Shashikumar *et al.* (2008) for Mysore city, India, Jayasheelan *et al.* (2013) for Tumkur area of Karnataka, India, Hasan *et al.* (2012) for Al-Kufa City, Iraq, Korany *et al.* (2013) for Wadi Naseib Area, southwestern Sinai, Egypt and that of Johner and Surbeck (2001).

From table 1, the radon level at the depth of 100 cm is nearly 2.5 times the level at 40 cm in the experimental area, where the soil is mainly developed from the alluvium. This is similar to the result found by Jonsson (2001) in moraine and Kristiansson and Malmqvist (1982) in sand, which indicates that the alluvial soil, moraine, and sand may have the same influence on the radon transport at shallow depths.

Gang canal seems to largely influence the measured ^{222}Rn concentration at different locations. The three locations 4STR (29.02°N), 33GB (29.25°N), and Silvani (29.33°N) are the part of Thar Desert and far away from the east–west branch of the canal and hence show the lowest ^{222}Rn concentration. Sandy dunes are present in these areas. Other locations are likely to be influenced by both the two north–south branches of the canal in that the moisture content may enhance radon level and hence register higher ^{222}Rn concentration. The station Mohanpura (29.97°N) showing the largest ^{222}Rn concentration is located in between the two branches of the canal. It is evident from figures 1 and 3 that the peak shows higher ^{222}Rn concentration at Kaminpura location (29.89°N) than in Manaksar location (29.75°N) probably due to the fact that the Kaminpura station is nearer to the canal. After Kaminpura location (29.89°N), the peak shows a sudden decrease in ^{222}Rn concentration at Kesrisinghpur location (29.94°N) perhaps due to the fact that the Kesrisinghpur village is farther from the canal. After Kesrisinghpur location (29.94°N), the peak shows

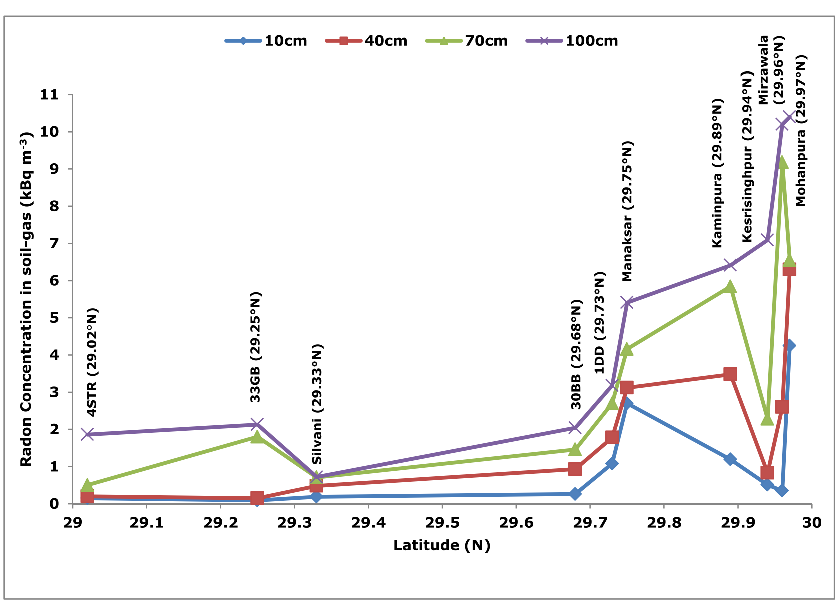

Figure 3. Variation of soil-gas radon concentration with depth of the soil in different villages of Sri Ganganagar district.

Table 2. *Comparison of radon concentration in soil-gas with those reported by other investigators.*

Region	Radon concentration in soil (kBq m^{-3}) Range	Mean	References
Islamabad, Pakistan	17.34–72.52	45.08	Ali *et al.* (2010)
Murree, Pakistan	0.61–3.89	1.70	Ali *et al.* (2010)
Southern Punjab, Pakistan	0.42–3.56	–	Mujahid *et al.* (2010)
Budhakedar, Tehri Garhwal, India	1.10–31.80	7.46	Prasad *et al.* (2008)
Hamirpur district, HP, India	0.03–2.28	0.46	Mehra and Bala (2013)
Garhwal Himalaya, India	0.01–2.33	0.30	Bourai *et al.* (2013)
Upper Siwaliks, India	11.50–78.47	–	Singh *et al.* (2010a, b)
Malwa belt, Punjab, India	1.90–16.40	–	Kumar *et al.* (2011)
Tusham ring complex, Haryana, India	42.80–71.50	61.00	Bajwa *et al.* (2010)
Kangra district, HP, India	1.10–82.20	–	Singh *et al.* (2006)
Sri Ganganagar district, Rajasthan, India	0.09–10.40	–	Present investigation

the higher soil-gas ^{222}Rn level at Mirzawala location (29.96°N) probably due to the fact that the Mirzawala location is nearer to Gang canal. The large variations in the soil-gas radon concentrations at the studied areas may be due to the factors that include the radium content distribution, the moisture content and density of soil, the porosity, the underlying bedrocks, and meteorological parameters.

The value of radon concentration obtained in the soil-gas was compared with those reported by other investigators (table 2). Ali *et al.* (2010) have reported the radon concentration in soil from Islamabad and Murree, Pakistan in the range of 17.34–72.52 and 0.61–3.89 kBq m^{-3}, respectively. The radon concentration in soil-gas in Southern Punjab, Pakistan lies in the range of 0.42–3.56 kBq m^{-3} (Mujahid *et al.* 2010). Prasad *et al.* (2008) have reported a radon concentration range of 1.10–31.80 kBq m^{-3} in the Budhakedar area of Tehri Garhwal, India. Mehra and Bala (2013) have reported a radon concentration range of 0.035–2.28 kBq m^{-3} in soil gas from Hamirpur district of Himachal Pradesh, India. The radon concentration in soil-gas from Garhwal Himalaya, India lies in the range of 0.012–2.33 kBq m^{-3} (Bourai *et al.* 2013). The soil radon concentration in Upper Siwaliks, India lies in the range of 11.50–78.47 kBq m^{-3} (Singh *et al.* 2010b). Kumar *et al.* (2011) have reported a radon concentration range of 1.90–16.40 kBq m^{-3} in the Malwa belt of Punjab, India. The radon concentration in soil-gas from Tusham ring complex of Haryana lies in the range of 42.80–71.50 kBq m^{-3} (Bajwa *et al.* 2010). Singh *et al.* (2006) have reported a radon concentration range of 1.10–82.20 kBq m^{-3} in Kangra district of Himachal Pradesh.

Radon activity concentration obtained in soil-gas in the present investigation generally lies well with the range reported by other investigators except those in the Islamabad district of Pakistan, Upper Siwaliks, Tusham ring complex of Haryana, and Kangra district of Himachal Pradesh, India, as given in table 2. The obtained values in this study are less than the worldwide average value for outdoor radon activity recommended by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000).

5. Conclusions

The radon concentrations were measured in soil-gas from Sri Ganganagar district of Rajasthan at sampling depths of 10, 40, 70 and 100 cm. The measurements were performed by RAD7 radon detector manufactured by Durridge Company, USA. A systematic increase of soil radon concentration levels with depth is observed for all the locations. The radon values in soil-gas from the study area lies well within the range reported by other investigators. The radon values in the soil-gas of Sri Ganganagar district of Rajasthan are low. Moreover, these values seem to be safe from the point of view of health hazards.

Acknowledgements

The authors are thankful to the residents of the study area for their cooperation during the fieldwork and to the Department of Physics, Dr B R Ambedkar National Institute of Technology, Jalandhar, India for providing experimental facilities.

References

Ali N, Khan E U, Akhter P, Khan F and Waheed A 2010 Estimation of mean annual effective dose through radon concentration in the water and indoor air of Islamabad and Murree; *Radiat. Prot. Dosim.* **141(2)** 183–191.

Bajwa B S, Singh H, Singh J, Singh S and Sonkawade R G 2010 Environmental radioactivity: A case study in HHP granitic region of Tusham ring complex Haryana, India; *Geophys. Res. Abst.* **12** EGU2010–1888.

Bourai A A, Aswal S, Dangwal A, Rawat M, Prasad M, Naithani Prasad N, Joshi V and Ramola R C 2013 Measurement of radon flux and soil-gas radon concentration along the main central thrust, Garhwal Himalaya, using SRM and RAD7 detectors; *Acta Geophys.* **61(4)** 950–957.

Choubey V M, Sharma K K and Ramola R C 1997 Geology of radon occurrence around Jari in Parvati Valley, Himachal Pradesh, India; *J. Environ. Radioact.* **34(2)** 139–148.

Duggal V, Rani A, Mehra R and Ramola R C 2013 Assessment of natural radioactivity levels and associated dose rates in soil samples from northern Rajasthan, India; *Radiat. Prot. Dosim.*, doi: 10.1093/rpd/nct199.

Durrani S A and Ilic R (eds) 1997 Radon measurements by etched track detectors: Applications in radiation protection, earth science, and the environment; World Scientific, Singapore.

DURRIDGE Company, RAD7, RAD H_2O accessory owner's manual. http://www.durridge.com/documentation/RAD H_2OManual.pdf.

Hasan A K, Subber Abdul R H and Shaltakh Ahmed R 2012 The measurements of radon concentration and thoron to radon ratio in soil gas in the Al-Kufa City-Iraq; *Caspian J. Appl. Sci. Res.* **2(1)** 23–30.

International Commission on Radiological Protection (ICRP) 1993 Protection against Radon-222 at homes and at work; ICRP Publication 65, Annals of ICRP 23(2).

Jayasheelan A, Manjunatha S, Sannappa J, Umeshareddy K and Ningappa C 2013 Radon concentration in atmosphere and its variation with depth of the soil in and around Tumkur, Karnataka, India; *Int. J. Adv. Scient. Tech. Res.* **2(3)** 158–162.

Johner H U and Surbeck H 2001 Soil gas measurements below foundation depth improve indoor radon prediction; *Sci. Total Environ.* **272(1–3)** 337–341.

Jonsson G 2001 Soil radon depth dependence; *Radiat. Meas.* **34** 415–418.

Korany K A, Shata A E, Hassan S F and Nagdy M S E 2013 Depth and seasonal variations for the soil radon-gas concentration levels at Wadi Naseib Area, southwestern Sinai, Egypt; *Phys. Chem. Biophys.* **3(4)** 1–6.

Kristiansson K and Malmqvist L 1982 Evidence for nondiffusive transport of ^{222}Rn in the ground and a new physical model for the transport; *Geophys.* **47** 1444–1452.

Kumar S, Singh S, Bajwa B S and Sabharwal A D 2011 *In situ* measurements of radon levels in water and soil and exhalation rate in areas of Malwa belt of Punjab (India); *Isotop. Environ. Health Stud.* **47(4)** 446–455.

Mehra R and Bala P 2013 Estimation of annual effective dose due to radon level in indoor air and soil gas in Hamirpur district of Himachal Pradesh; *J. Geochem. Explor.*, doi: 10.1016/j.gexplo.2013.07.005.

Mujahid S A, Hussain S and Ramzan M 2010 Measurement of radon exhalation rate and soil gas radon concentration in areas of southern Punjab, Pakistan; *Radiat. Prot. Dosim.* **140(3)** 300–303.

Prasad B S N, Nagaraja K, Chandrashekara M S, Paramesh L and Madhava M S 2005 Diurnal and seasonal variations of radioactivity and electrical conductivity near the surface for a continental location Mysore, India; *Atmos. Res.* **76(1–4)** 65–77.

Prasad Y, Prasad G, Gusain G S, Choubey V M and Ramola R C 2008 Radon exhalation rate from soil samples of South Kumaun Lesser Himalayas, India; *Radiat. Meas.* **43** 369–374.

Rani A, Mehra R, Duggal V and Balaram V 2013 Analysis of uranium concentration in drinking water samples using ICPMS; *Health Phys.* **104(3)** 251–255.

Shashikumar T S, Ragini N, Chandrashekara M S and Paramesh L 2008 Studies on radon in soil, its concentration in the atmosphere and gamma exposure rate around Mysore city, India; *Curr. Sci.* **94(9)** 1180–1185.

Singh S, Sharma D K, Dhar S and Randhawa S S 2006 Geological significance of soil gas radon: A case study of Nurpur area district Kangra, Himachal Pradesh, India; *Radiat. Meas.* **41(4)** 482–485.

Singh J, Singh H, Singh S and Bajwa B S 2010a Measurement of soil gas radon and its correlation with indoor radon around some areas of Upper Siwaliks, India; *J. Radiol. Prot.* **30(1)** 63–71.

Singh S, Kumar A, Bajwa B S, Mahajan S, Kumar V and Dhar S 2010b Radon monitoring in soil gas and ground water of earthquake prediction studies in northwest Himalayas, India; *Terr. Atmos. Ocean. Sci.* **21(4)** 685–695.

U.S. Environmental Protection Agency 2012 A Citizens Guide to Radon: The Guide to Protecting Yourself and Your Family from Radon; EPA 402/K-12/002, May 2012, www.epa.gov/radon.

UNSCEAR 1993 Sources and effects of ionizing radiation; United Nations Scientific Committee on the Effects of Atomic Radiation, New York.

UNSCEAR 2000 Sources and effects of ionizing radiation; United Nations Scientific Committee on the Effects of Atomic Radiation report to the General Assembly with Scientific Annexes, United Nations, New York.

MS received 13 January 2014; revised 3 May 2014; accepted 8 May 2014