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Study of Indoor Radon, Thoron, Their Progeny Concentration and Radon Exhalation Rate in the Environs of Mohali, Punjab, Northern India

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ABSTRACT

Radon and its progeny are major contributors that deteriorate the indoor air quality and are the major source of radiation dose received by general population of the world. Keeping this in mind the environmental monitoring of radon-thoron and their progeny in dwellings of district Mohali, Punjab, India has been carried out. The radon-thoron twin dosimeter cups were used for the study. The study of the exhalation rate of the soil samples of Kharar, Kurali and Derabassi of the district Mohali and the sand samples available from the study area has also been carried out for the comparison purpose using can echnique. The aim of the study is the possible health risk assessment in the dwellings of this particular region for which data is not available in literature. The indoor radon concentration varied from 22.8 ± 0.7 Bq/m^3 to 45.0 ± 2.2 Bq/m^3 with an average of 33.7 Bq/m^3 while the thoron concentration in the same dwellings varied from 1.7 ± 0.1 Bq/m^3 to 27.6 ± 1.2 Bq/m^3 with an average of 12.8 Bq/m^3. Annual dose received by the inhabitants in the dwellings under study varied from 0.64 to 1.64 mSv with an average of 1.19 mSv. The radon mass and surface exhalation rates of the soil samples varied from 0.32 to 2.6 mBq/kg/h with an average of 1.36 ± 0.2 mBq/kg/h and from 7.3 to 58.2 mBq/m^2/h with an average of 28.3 ± 5.1 mBq/m^2/h respectively.

Keywords: Radon; Radon decay products; Thoron; Dwellings; Annual effective dose; Exhalation rate; Health effects.

INTRODUCTION

Indoor air quality is the most important issue now days because most individuals spend 90% of their time indoors. There are many pollutants that can deteriorate indoor air quality however radon is a major pollutant for this and is an important global problem of radiation hygiene. Radon is one of decay product of long decay chain of uranium, which is ubiquitous in nature and can be found in trace amount in most rock and soil. Therefore, most rock and soil also contain thorium and radium. The decay of radium leads to radon (^{222}Rn). Being a gas, radon easily migrates away from radium in large amount. Radon in the atmosphere mainly comes from the continents and has a very little input from the oceans (Wang *et al.*, 2014). There are many other natural radionuclides like ^{22}Na, ^{32}P, ^{33}P, ^{210}Pb and ^{7}Be, which are major pollutants in the atmosphere and are dangerous to human being (Papastefanou, 2009a), but radon is more important as it contributes about half of the background radiation to which we are all exposed (Cothern and Lappenbusch, 1986). The primary sources of indoor radon are soils (Akerblom *et al.*, 1984) and rocks source emanations, off-gassing of waterborne radon into a building, emanation from building materials, and entry of radon into a structure from outdoor air. The high levels of radon in home depend upon many factors (Arvela and Winqvist, 1989) but there are three most important factors responsible for this. Firstly the existence of radium the immediate parent of radon in the underlying soil or rock of a dwelling to yield a radon source term (that is a geological condition and vary from region to region). Secondly the home must have cracks in the floor or have a soil floor (which is common in rural India) to facilitate the entry of the radon gas. Thirdly it must have a pressure difference (Eaton and Scott, 1984) between the inside and outside pressure (stack effect). The entry of radon into the home is facilitated by less value of pressure inside the home than the surroundings.

Many researchers have reported the link between exposure to radon and its decay products in mining situations and an increased risk of lung cancer (Thomas *et al.*, 1985). However, it is important to understand that radon itself is not believed to be the major contributor to the possible development of lung cancer (NCRP, 1984). Being an inert gas its deposition in the body does not have any preference. Radon decays

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rapidly into its decay products. The decay products of radon are ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po (Papastefanou, 2009b). The radon decay products have even shorter half-lives than radon and decay rapidly by releasing energy that causes such a significant health risk.

Recently, several studies on aerosol particles have been published, evidencing that particles of small size range pose special problems to the lungs (Avino *et al.*, 2011, 2013) and also assessed the potential health risk of ultra fine particles (Patterson *et al.*, 2014). In the case of radon also the decay products formed are metals that are initially associated with aggregates of water molecules in the air. These aggregates attach to airborne dust particles. The most important of these particles are those with dimensions less than 0.7 mm. These particles are small enough and when inhaled can move past the body's ciliary defences into the airways and be deposited in the lungs, usually at the bifurcations where passages split. The decay of the short lived alpha emitting progeny of radon will result in intense local irradiation of the tissue close to the deposited dust. It is this localized irradiation which is believed to trigger the development of lung cancer. Thus it is radon decay products (RDPs) that actually cause the damage to the brachial epithelium and can induce lung cancer, because only they will remain in the lungs for an adequate time to result in significant decay. Brookin's (1990) suggested that breathing radon decay products is known to cause lung cancer. Many studies reported that lung cancers are caused by two of the radon decay products, ^{218}Po and ^{214}Po, which produce very energetic alpha particles (Cohen, 1987; BEIR IV, 1988; Nazaroff and Nero, 1988; Momcilovic and Lykken, 2007). In general, the dwellings with more radon have more radon progeny concentration. Due to these reported adverse health effects of inhaled radon and its progeny, International Commission on Radiological Protection (ICRP) has made recommendations for the control of this exposure in dwellings and work place (ICRP, 1993). ICRP (1993) recommended an action level range of 200–600 Bq/m^3 for dwellings according to risk evaluations being done using different epidemiological studies. However, ICRP (2009) recommended regarding the radon levels in dwellings, the reduction of the upper value of 600 Bq/m^3 to 300 Bq/m^3 and lower limit should be considered according to local circumstances. As regards radon in workplaces, 1000 Bq/m^3 was confirmed as the entry point for applying radiological protection requirements for planned exposures. Due to harmful effects of radon many researchers have reported the values of indoor radon (Blot *et al.*, 1990; Doi *et al.*, 1992; Auvinen *et al.*, 1996; Singh *et al.*, 2001) and radon exhalation rate of the soil/sand/building material samples from the different parts of the world (Khan *et al.*, 1992; Sharaf *et al.*, 1999; Al-Jarallah, 2001; Sroor *et al.*, 2001; Stoulos *et al.*, 2003; Sun *et al.*, 2004) and also from the different parts of Punjab and Haryana (Singh *et al.*, 2005a; Mehra *et al.*, 2006; Mehra, 2009; Chauhan, 2010; Chauhan, 2011; Mehta *et al.*, 2014) the states of India. However, our earlier paper showed that practically no data of indoor radon for Mohali and radon exhalation rate of the soil and sand samples of the study area of Mohali, Kharar, Kurali and Derabassi of Punjab is available (Mehta *et al.*, 2013). These types of studies are useful for the assessment of radiation dose received by the inhabitants and also for producing the data for unreported regions for producing the radon map of the country. Keeping these important points in mind the environmental monitoring of radon, thoron and their progeny in some dwellings of Mohali and the assessment of radon surface and mass exhalation rate of the soil/sand samples collected from Mohali, Kharar, Kurali and Derabassi areas of Punjab has been carried out.

METHODS

Geology of the Study Area

Punjab is located in the northwest of India surrounded by Pakistan on the west, the Indian states of Jammu and Kashmir on the north, Himachal Pradesh on its northeast and Haryana and Rajasthan to its south. It covers a geographical area of 50,362 sq. km which is 1.54% of country's total geographical area. Punjab state is located between 29°30'N to 32°32'N latitude and between 73°55'E to 76°50'E longitude. Its average elevation is 300 m from the sea level. Most of the land of Punjab is fertile plain but one can find the south-east region being semi-arid and desert landscapes. A new district Mohali (S.A.S. Nagar) has been created on 14-04-2006. Two blocks Kharar and Majri of earlier Rupnagar district have been merged with the newly created district. It is located between 30°21'N and 30°56'N latitude and between 76°30'E and 76°55'E longitude. The district is bounded by Patiala and Fatehgrah Sahib districts in the south-west, Rupnagar district in the northwest, Chandigarh and Panchkula in the east and Ambala district of Haryana state in the south. The climate of Mohali district can be classified as subtropical monsoon. The south west monsoon contributes about 80% of annual rainfall. The area can be broadly grouped into two depending upon its geomorphic features as alluvial fan and alluvial plains. Alluvial fans are deposited by hill torrents with a wavy plain rather than a steep slope. Adjacent to the alluvial fan are the alluvial plains which forms a part of large Indo-Gangetic Quaternary basin comprises of thick sand and silty sand layers interbedded with silt and clay beds. The alluvial plains are of vital economic value as it supports the dense population of the district. The soils are mainly developed on alluvium under the dominant influence of climate followed by topography and time. The major soil type of the district is weakly solonized tropical arid brown soils (Rani, 2007). The sources of sand from this district are very limited. Mostly the sand from Siswan river, Mullanpur river and the Ghaggar river has been used in this region for the construction work.

Fig. 1 shows the areas (shown as big dots) in the different parts of the Mohali where the indoor radon study has been conducted. Three different types of dwellings were selected according to their ventilation conditions viz. poor, average and good ventilated. A room with a door and without window was assumed to be poorly ventilated, with one window and a door as average ventilated and with more than two windows and a door as good ventilated. The building material of

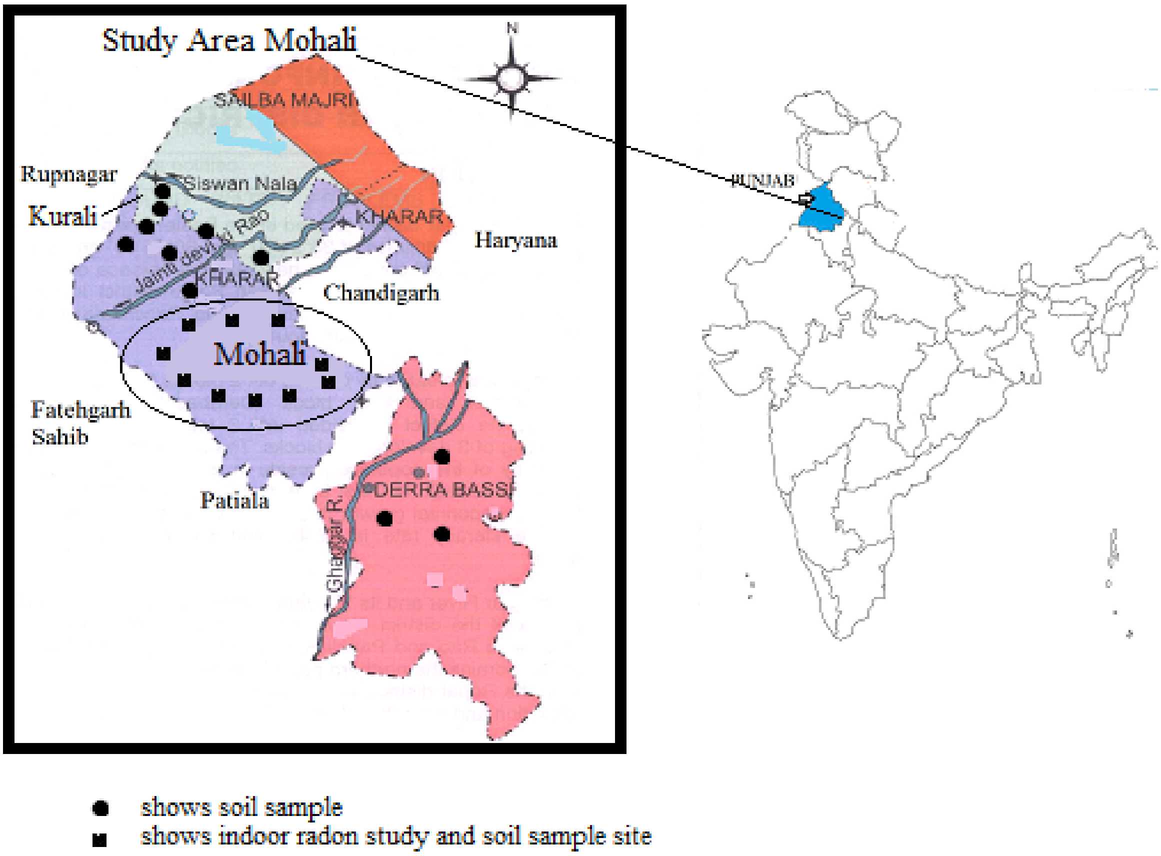

Fig. 1. Location map of the study area.

dwellings was similar and was having cemented walls and floorings. The dwellings monitored were from the different localities of the Mohali for a uniform distribution. The room's choosen were of nearly equal dimension and were at the same level of height. All the measurements were done simultaneously to avoid any error in measured values due to the change in climatic conditions at different times of measurements. The annual effective dose received by the inhabitants was looked into in the light of guidelines given by International Commission on Radiological Protection (ICRP, 2009). The soil samples of Mohali were being taken from the dwellings/area close to dwellings under indoor radon study for conducting a correlation study. However the soil samples collected from the study area of Kharar, Kurali and Derabassi areas of Mohali district were shown in Fig. 1 (different dots than the dots of indoor radon study). The sand samples of the Siswan river and Mullanpur river were collected from the hardware stores of the area.

Measurement of Indoor Radon and Thoron Concentration

Indoor radon and its progeny concentration was measured using passive technique of exposing solid state nuclear track detectors in radon-thoron twin dosimeter cups (Mehta *et al.*, 2014). The radon-thoron dosimeter cup has three different modes namely bare mode, filter mode and membrane mode. The membrane mode detector registers tracks only due to radon; the filter mode detector registers tracks due to radon and thoron while bare mode detector registers tracks due to radon, thoron and their progeny. Three pieces each of size (2 cm × 2 cm) of LR-115 type 2 strippable Solid-State Nuclear Track Detectors were fixed in the dosimeters and were suspended in the room at a height more than 2 m above the ground level and about 1 meter below the ceiling of the room to avoid direct exposure of detectors to the alpha particles emitted from the building material of the ceiling. The detectors were left exposed for a period of three months. At the end of the exposure time, the detectors were removed and subjected to a chemical etching process in 2.5 N NaOH solutions at 60°C for 90 minutes. The detectors were washed and immediately after the completion of washing, the red sensitive layer was stripped for counting using spark counter. The stripping was done by pinching one of the corners of the film between the thumb and the index finger and then pulling the sensitive layer in a direction parallel to the base until the two are completely separated. The tracks produced by the alpha particles were counted using a spark counter. The measured track density (tracks/cm^2/day) was converted into radon and thoron concentration using calibration factors (Eappen and Mayya, 2004). For calculating the radon and thoron progeny levels in mWL the indoor equilibrium factor of 0.4 for radon and 0.1 for thoron are used (UNSCEAR, 1992). Annual dose received by the inhabitants in the dwellings under study in mSv was estimated using the relation (Sannappa *et al.*, 2003)

$$D = [(0.17 + 9F_R)\, C_R + (0.11+32F_T)\, C_T] \times 7000 \times 10^{-6} \quad (1)$$

where, F_R and F_T are equilibrium factor for Radon and thoron having value of 0.4 and 0.1, C_R and C_T are radon and thoron concentration

Measurement of Radon Exhalation Rates from Soil Samples

The radon exhalation rates of soil samples were measured by closed canister techniques (Abu-Jarad *et al.*, 1980; Khan *et al.*, 1992; Singh *et al.*, 1997; Kumar *et al.*, 2003; Mahur *et al.*, 2013). The soils samples collected from the dwellings and other areas under study were dried and sieved through a 100-mesh sieve and 100 g was placed in the canisters similar to those used in the calibration experiment of Singh *et al.* (1997) and were sealed. Solid State Nuclear Track detector LR-115 type II (2 cm × 2 cm) was fixed at the lid of the canister so that the sensitive surface of the LR-115 detector freely exposed to radon. After the exposure for 100 days, the detectors were etched in 2.5 N NaOH at 60°C for a period of 90 minutes in a constant temperature water bath. The detectors were washed and immediately after the completion of washing, the red sensitive layer was stripped for counting using spark counter. From the track density, the radon activity was obtained, using the calibration factor of 0.056 tr./cm^2/d per Bq/m^3 obtained from an earlier calibration experiment (Singh *et al.*, 1997). The radon mass and surface exhalation rates from the soil samples were calculated using Eqs. (2) and (3) used by various researchers (Abu-jarad *et al.*, 1980; Kant *et al.*, 2003)

$$E_A = \frac{CV\lambda}{A(T + \frac{1}{\lambda}(e^{-\lambda T} - 1)} \tag{2}$$

$$E_M = \frac{CV\lambda}{M(T + \frac{1}{\lambda}(e^{-\lambda T} - 1)} \tag{3}$$

where C is equilibrium radon activity inside the canister, V and A are volume and area of cross-section of the canister, M is the mass of the sample and λ is the radon decay constant, T is the time of exposure.

RESULTS AND DISCUSSION

Indoor Radon, Thoron Concentration, Their Progeny Levels and Annual Dose

The measurement of indoor radon and thoron concentrations in some dwellings of Mohali were carried out by twin cup dosimeters. The results are listed in Table 1 for autumn season. Table 1 provides the whole information of the study area regarding the radon, thoron and their progeny levels. It also shows the amount of annual dose received by the occupants of these dwellings. The indoor radon concentration in Mohali varied from 22.8 ± 0.7 Bq/m^3 to 45.0 ± 2.2 Bq/m^3 with an average of 33.7 Bq/m^3 while the thoron concentration in the same dwellings varied from 1.7 ± 0.1 Bq/m^3 to 27.6 ± 1.2 Bq/m^3 with an average of 12.8 Bq/m^3. The radon progeny levels in the dwellings under study varied from 2.46 to 4.86 mWL with an average of 3.65 mWL, while the thoron progeny levels varied from 0.08 to 0.74 mWL with an average of 0.35 mWL. Annual dose received by the inhabitants in the dwellings under study varied from 0.64 to 1.64 mSv with an average of 1.19 mSv.

Table 2 provides the average annual dose received by

Table 1. Radon, thoron and their progeny levels in some dwellings of Mohali in autumn season.

Location	Ventilation condition	Latitude & Longitude	Radon Concentration C_R (Bq/m^3)	Thoron Concentration C_T (Bq/m^3)	Progeny levels of Radon C_R (mWL)	Progeny levels of Thoron C_T (mWL)	Annual Dose (mSV)
MH-1	Poor	30°40'58"N 76°42'32"E	45.0 ± 2.2	21.0 ± 1.1	4.86	0.57	1.67
MH-2	Average	30°42'45"N 76°43'16"E	31.8 ± 1.7	11.3 ± 0.8	3.43	0.30	1.10
MH-3	Poor	30°41'32"N 76°43'14"E	38.1 ± 1.9	27.6 ± 1.2	4.11	0.74	1.64
MH-4	Good	30°42'57"N 76°43'45"E	22.8 ± 0.7	1.7 ± 0.1	2.46	0.05	0.64
MH-5	Average	30°41'52"N 76°43'04"E	33.3 ± 1.4	3.5 ± 0.2	3.60	0.10	0.96
MH-6	Poor	30°41'30"N 76°43'16"E	33.3 ± 1.3	21.1 ± 0.6	3.60	0.57	1.37
MH-7	Good	30°41'10"N 76°44'27"E	30.7 ± 1.2	3.2 ± 0.1	3.32	0.09	0.88
MH-8	Good	30°42'46"N 76°43'16"E	28.6 ± 1.1	2.8 ± 0.1	3.09	0.08	0.82
MH-9	Poor	30°42'45"N 76°43'16"E	40.2 ± 2.0	20.3 ± 0.5	4.35	0.55	1.53
MH-10	Average	30°42'36"N 76°43'06"E	33.9 ± 0.9	15.2 ± 0.7	3.66	0.41	1.24

Table 2. Average annual dose and ventilation conditions of the dwellings of Mohali.

S. No	Ventilation Condition	No. of dwellings	Average annual Dose (mSv)
1	Good	3	0.78
2	Average	3	1.10
3	Poor	4	1.55

the inhabitants of these dwellings according to the ventilation condition of these dwellings. Fig. 2 clearly shows that the amount of annual dose received by the occupants of the poorly ventilated dwellings was on higher side in comparison to the average and good ventilated dwellings. This clearly indicates that the risk from radon can be reduced by lowering the radon level in your home by increasing the ventilation. The high value of indoor radon in dwellings with poor ventilation was also reported by Mehra and Bala (2013).

Measurement of Radon Exhalation Rates from Soil/Sand Samples

The measurement of radon mass and surface exhalation rates of soil sample collected from the area under study were carried out by canister technique and results of the measurement are listed in Table 3. The equilibrium radon concentration in various soil samples of city Mohali varied from 8.9 Bq/m^3 to 71.4 Bq/m^3 with an average of 34.7 ± 6.3 Bq/m^3. The radon mass exhalation rates from the soil samples varied from 0.32 to 2.6 mBq/kg/h with an average of 1.36 ± 0.2 mBq/kg/h and radon surface exhalation rates varied from 7.3 to 58.2 mBq/m^2/h with an average of 28.3 ± 5.1 mBq/m^2/h.

The results of study of exhalation rate of Kharar, Kurali and Derabassi are shown in Table 4. The equilibrium radon concentration in various soil samples of Kharar area of district Mohali varied from 12.9 Bq/m^3 to 83.1 Bq/m^3 with an average of 37.8 ± 15.6 Bq/m^3. The radon mass exhalation rates from the soil samples varied from 0.46 to 3.0 mBq/kg/h with an average of 1.4 ± 0.6 mBq/kg/h and radon surface exhalation rates varied from 10.5 to 67.6 mBq/m^2/h with an average of 30.7 ± 12.7 mBq/m^2/h. The equilibrium radon concentration in various soil samples of Kurali area of district Mohali varied from 10.4 Bq/m^3 to 35.0 Bq/m^3 with an average of 21.0 ± 6.2 Bq/m^3. The radon mass exhalation rates from the soil samples varied from 0.37 to 1.3 mBq/kg/h with an average of 0.7 ± 0.2 mBq/kg/h and radon surface exhalation rates varied from 8.4 to 28.5 mBq/m^2/h with an average of 17.1 ± 5.1 mBq/m^2/h. The equilibrium radon concentration in various soil samples of Derabassi area of district Mohali varied from 9.6 Bq/m^3 to 25.7 Bq/m^3 with an average of 18.2 ± 4.7 Bq/m^3. The radon mass exhalation rates from the soil samples varied from 0.35 to 0.92 mBq/kg/h with an average of 0.65 ± 0.2 mBq/kg/h and radon surface exhalation rates varied from 7.9 to 20.9 mBq/m^2/h with an average of 14.8 ± 3.8 mBq/m^2/h.

A comparative graph of equilibrium radon concentration and exhalation rates in soil samples of all the areas of Mohali, Kharar, Kurali and Derabassi is shown in Fig. 3. The radon mass and surface exhalation rates of the soil sample of these areas were found to be lower than that of the world wide average. The soil is the main source of the indoor radon coming out from floor by diffusion and advection. A

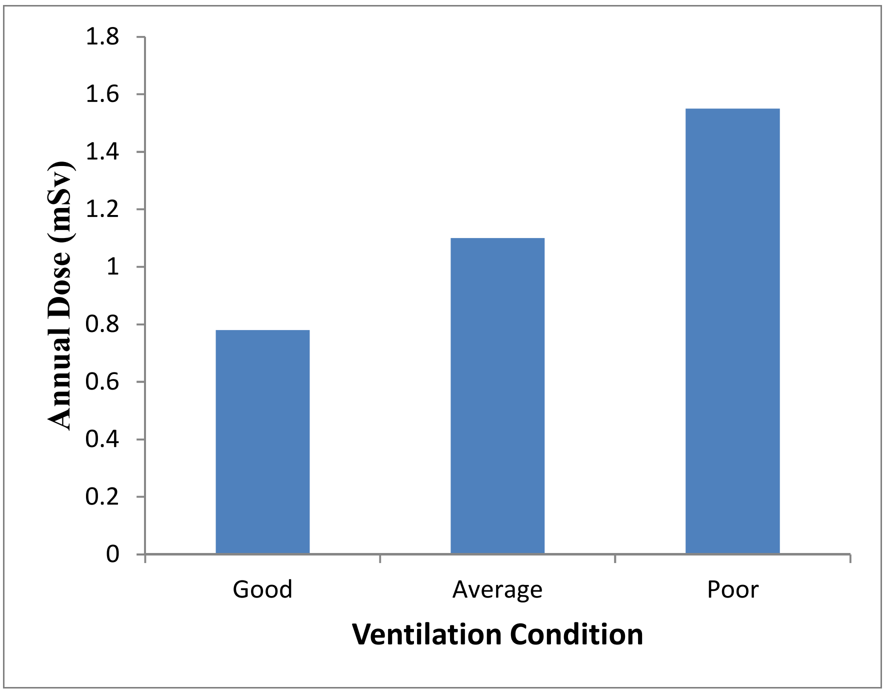

Fig. 2. Dependence of Annual Dose Received by the Mohali Occupants on Ventilation Conditions.

Table 3. Equilibrium radon concentration, radon mass and surface exhalation rates from soil samples of Mohali

Sr. No	Location	Latitude & Longitude	Equilibrium Radon concentration (Bq/m^3)	Radon mass exhalation rates (mBq/kg/h)	Radon surface exhalation rates (mBq/m^2/h)
1	MH-01	30°40'58"N 76°42'32"E	43.9	1.6	35.8
2	MH-02	30°42'45"N 76°43'16"E	14.5	0.52	11.8
3	MH-03	30°41'32"N 76°43'14"E	71.4	2.6	58.2
4	MH-04	30°42'57"N 76°43'45"E	28.9	1.0	23.6
5	MH-05	30°41'52"N 76°43'04"E	8.9	0.32	7.3
6	MH-06	30°41'30"N 76°43'16"E	55.5	2.0	45.2
7	MH-07	30°41'10"N 76°44'27"E	30.0	1.1	24.4
8	MH-08	30°42'46"N 76°43'16"E	19.1	0.69	15.6
9	MH-09	30°42'45"N 76°43'16"E	25.7	0.92	21.0
10	MH-10	30°42'36"N 76°43'06"E	49.3	1.8	40.1
AM ± SE			34.7 ± 6.3	1.36 ± 0.2	28.3 ± 5.1

AM (arithmetic mean); SE (standard error) = σ/√N, where σ is SD (standard deviation) and N is the no. of observations.

Table 4. Equilibrium radon concentration, radon mass and surface exhalation rates from soil samples of Kharar, Kurali and Derabassi.

Sr. No.	Location	Codes	Equilibrium Radon conc. (Bq/m^3)	Mass exhalation rate (mBq/kg/h)	Surface exhalation rate (mBq/m^2/h)
1	Kharar	KH-1	12.9	0.46	10.5
2		KH-2	83.1	3.0	67.6
3		KH-3	31.4	1.1	25.6
4		KH-4	23.6	0.85	19.2
AM ± SE			37.8 ± 15.6	1.4 ± 0.6	30.7 ± 12.7
1	Kurali	KR-1	35.0	1.3	28.5
2		KR-2	27.9	1.0	22.7
3		KR-3	10.4	0.37	8.4
4		KR-4	10.5	0.38	8.6
AM ± SE			21.0 ± 6.2	0.7 ± 0.2	17.1 ± 5.1
1	Derabassi	DB-1	25.7	0.92	20.9
2		DB-2	9.6	0.35	7.9
3		DB-3	19.3	0.69	15.7
AM ± SE			18.2 ± 4.7	0.65 ± 0.2	14.8 ± 3.8

AM (arithmetic mean); SE (standard error) = σ/√N, where σ is SD (standard deviation) and N is the no. of observations.

weak positive correlation (R^2 = 0.14) was found between indoor radon concentration and radon surface exhalation rate of the area of Mohali as shown in Fig. 4. The presence of the moisture in soil, concrete floor in between soil and indoor and the ventilation condition of dwellings may act as a cause of weak but positive correlation found in the present study.

The results of the study of exhalation rate of the sand samples from two different sources of sand in the district Mohali has been shown in Table 5. The equilibrium radon concentration in sand samples of Mohali varied from 30.0 to 35.9 Bq/m^3 with an average of 32.0 ± 3.0 Bq/m^3 while the mass exhalation rates varied from 1.08 to 1.29 mBq/kg/h and the surface exhalation rates in sand samples of Mohali found to vary from 24.4 to 29.2 mBq/m^2/h.

The observed values of mass and surface exhalation rate in soil/sand samples of our study has been compared with other Indian studies reported for soil/sand samples of areas of Punjab, Haryana and Delhi as shown in Table 6. The values reported by present study were slightly different from the other studies as the area studied in the present investigation is situated at quite a distance from the other regions (which may leads to the difference in the nature of soil and its radium content). The difference may also be understood in the terms of difference in techniques for the measurement and for the counting as well. In most of the other studies reported, the counting was done using an optical microscope instead of a spark counting.

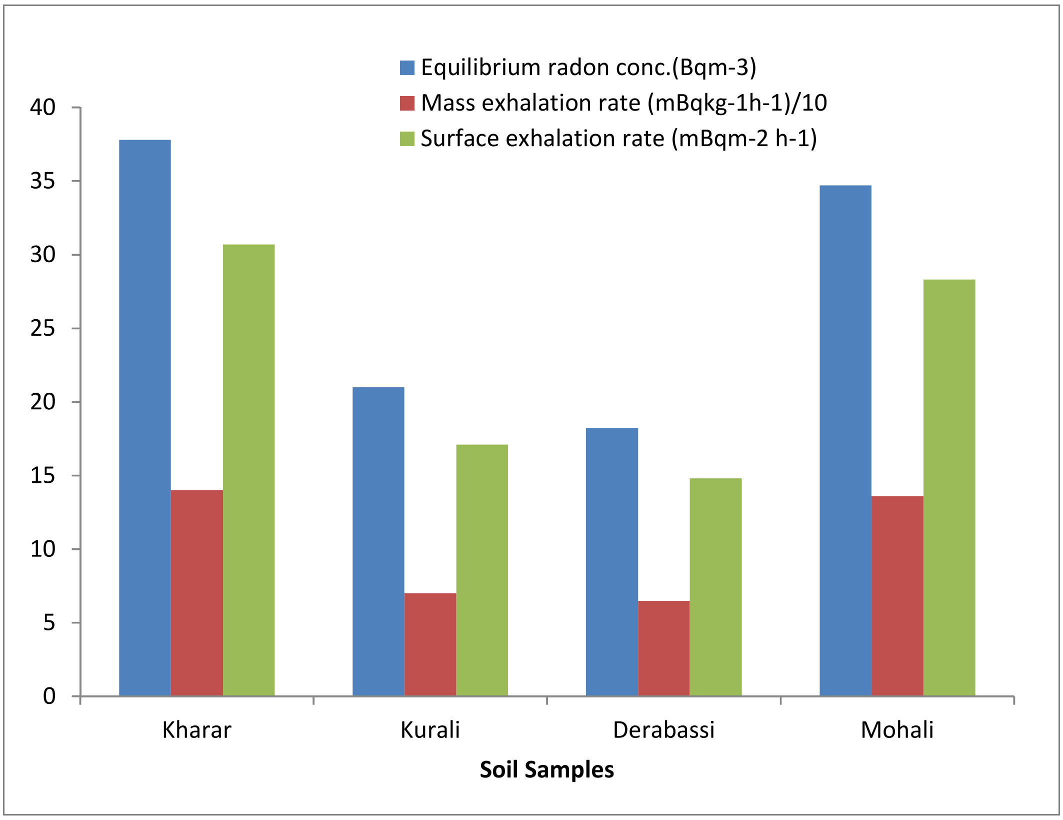

Fig. 3. Comparative Graph of Equilibrium Radon Concentration and Exhalation Rates in Soil Samples of the Study Area.

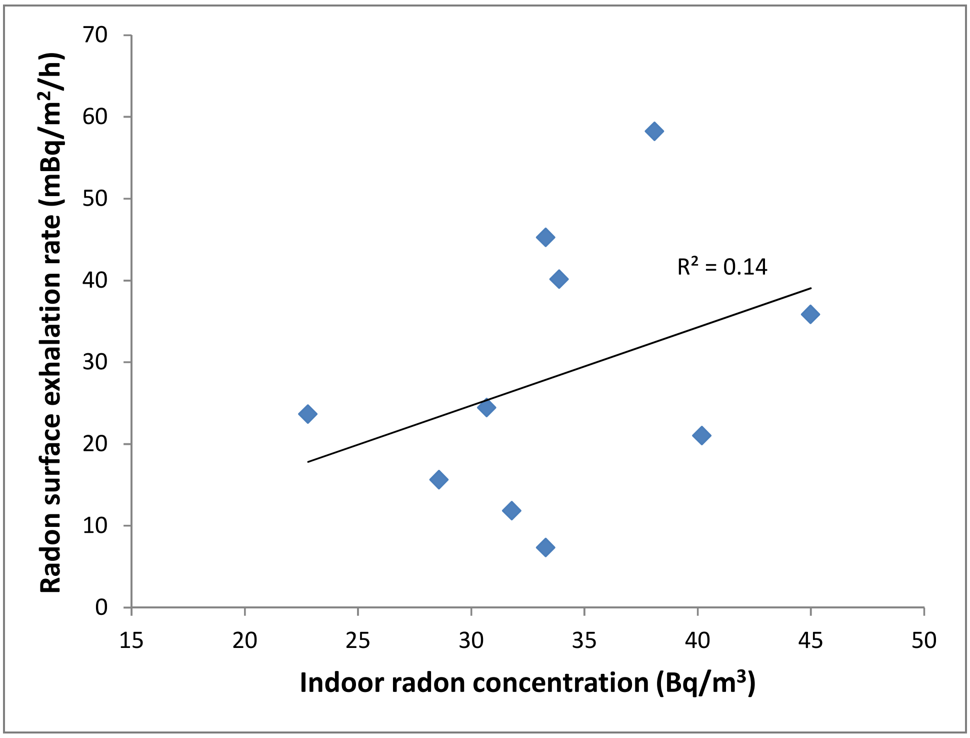

Fig. 4. Correlation between indoor radon concentrations and exhalation rate.

Table 5. Equilibrium radon concentration, mass exhalation and surface exhalation rate in the sand samples.

Sr. No.	Location	Codes	Equilibrium radon conc. (Bq/m^3)	Mass exhalation rate (mBq/kg/h)	Surface exhalation rate (mBq/m^2/h)
1	Mohali	MHS-1	30.0	1.08	24.4
2		MHS-2	35.9	1.29	29.2
	AM ± SE		32.0 ± 3.0	1.2 ± 0.1	26.8 ± 2.4

AM (arithmetic mean); SE (standard error) = σ/√N, where σ is SD (standard deviation) and N is the no. of observations.

Table 6. Comparison of mass exhalation rate and surface exhalation rate of the present study with other studies of the nearby areas.

Sample Name	Location	Mass exhalation rate (mBq/kg/h)	Surface exhalation rate (mBq/m^2/h)	Reference
Soil	Amritsar, Punjab	2.23	74.4	Singh *et al.* (2008)
	Sangrur, Punjab	20.58	724.9	Mehra *et al.* (2006)
	Faridkot, Punjab	19.90	702.0	Mehra *et al.* (2006)
	Patiala, Punjab	14.78	520.4	Mehra *et al.* (2006)
	Mansa, Punjab	18.50	652.0	Mehra *et al.* (2006)
	Ludhiana, Punjab	12.84	451.8	Mehra *et al.* (2006)
	Moga, Punjab	10.98	386.4	Mehra *et al.* (2006)
	Bathinda, Punjab	14.54	500.69	Singh *et al.* (2005b)
	Tosham Ring, Haryana	7.69	255.9	Singh *et al.* (2008)
	Kurukshetra, Haryana	5.60	154.2	Chauhan and Chakarvarti (2002)
	Ambala, Haryana	7.40	203.6	Chauhan and Chakarvarti (2002)
	Delhi	1.13	12.4	Sonkawade *et al.* (2008)
	Mohali, Punjab	**1.36**	**28.3**	**Present Study**
Sand	Amritsar, Punjab	0.76	25.34	Kumar and Singh (2004)
	Delhi	1.05	9.0	Sonkawade *et al.* (2008)
	Mohali, Punjab	**1.20**	**26.8**	**Present Study**

CONCLUSIONS

- The measurement of indoor radon, thoron and their progeny concentrations in some dwellings of Mohali was carried out using twin cup dosimeters. The indoor radon concentration varied from 22.8 ± 0.7 Bq/m^3 to 45.0 ± 2.2 Bq/m^3 with an average of 33.7 Bq/m^3 while the thoron concentration in the same dwellings varied from 1.7 ± 0.1 Bq/m^3 to 27.6 ± 1.2 Bq/m^3 with an average of 12.8 Bq/m^3. The amount of annual dose received by the occupants of the poorly ventilated dwellings was on higher side in comparison to the average and good ventilated dwellings.
- Radon exhalation rates from soil sample were measured using canister technique. The radon mass exhalation rates from the soil samples of the dwellings (areas close to the dwellings) of Mohali varied from 0.32 to 2.6 mBq/kg/h with an average of 1.36 ± 0.2 mBq/kg/h and radon surface exhalation rates varied from 7.3 to 58.2 mBq/m^2/h with an average of 28.3 ± 5.1 mBq/m^2/h. The radon exhalation rates from Kharar, Kurali and Derabassi of district Mohali were also measured for the comparison sake.
- The mass exhalation rates of sand samples of Mohali district varied from 1.08 to 1.29 mBq/kg/h and the surface exhalation rates found to vary from 24.4 to 29.2 mBq/m^2/h.
- A weak positive correlation (R^2 = 0.14) was found between indoor radon and exhalation rates of Mohali. The measurements indicate normal levels of natural radioactivity in soil and sand samples of the study area.

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