THE SPATIAL AND VOLUMETRIC VARIATIONS OF RADON IN BANGALORE CITY, INDIA

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Abstract

Radon levels have been measured in houses at ten different locations and rooms of various sizes ranging from 30 to 310 m^3 for Bangalore city, India. The study was focused on the basis of quality of construction, age of building, similar nature of walls and types of floorings etc. Solid state nuclear track detectors were used for measuring the concentrations. The average spatial values of ^{222}Rn and ^{220}Rn concentrations were found to be 33.4 ± 6.1 and 21.6 ± 2.5 Bq m^{-3} respectively. However, the volumetric concentrations were ranged between 4.0-93.0 Bq m^{-3}. The annual dose rate due to ^{222}Rn, ^{220}Rn and their progenies for the population in the studied location ranged from 0.1 to 0.5 mSv. It is alarming that the dwellers of lower volume receive relatively a higher dose rate and the result shows significant radiological risk. The magnitude and its effects of doses are discussed in detail.

Key words: Radon, dwellings, volume, dose rates

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Introduction

Measurement of indoor radon is significant due to the exposure of radon and its daughters, which contributes more than 50% of the total dose from natural sources on human being UNSCEAR (2000). The three radon isotopes, radon – ^{222}Rn, thoron – ^{220}Rn and actinon – ^{219}Rn are gaseous and may be released from the ground, rocks of the Earth's crust and also from building materials and accumulate with their short-lived progeny in closed spaces, particularly in dwellings. The dose deriving from the existence of ^{222}Rn in the air is directly linked to the inhalation of its short-lived daughters, which are deposited in the respiratory organs, if deeply inhaled; emit alpha-particles that are in contact with bronchial and pulmonary epithelium. On account of these, the dose deriving from the exposure of ^{222}Rn in closed spaces has been placed in direct relation to the risk of lung cancer UNSCEAR (2000). Some factors that influences the diffusion of radon from soil into the air are existence of uranium and radium in soil and rock, emanation capacity of the ground, porosity of the soil and/or rock, pressure gradient between the interfaces, soil moisture and water saturation grade of the medium (Schery and Gaeddert, 1984). The concentration of indoor radon also depends on ventilation rate of the dwellings. It is important to note that even though reduced ventilation rate aids to enhance the concentration of radon and its daughters in air. Solid state nuclear track based dosimeters are employed for the long - term integrated measurements (Stranden 1980; Abu-Jarad and Fremlin, 1983). Measurements on volumetric variations of ^{222}Rn and ^{220}Rn in dwellings are limited and this work seems to be first of its kind. The paper reports the relationship between ^{222}Rn, ^{220}Rn and volume of rooms. The measurement for radon and thoron concentrations were also carried out by using plastic track detectors and the results obtained are discussed in detail. The data is continuously obtained for a period of three years since 2007, covering more than 150 dwellings.

Study Area

The location selected for the present study is Bangalore city, India and is shown in Fig. 1. The district lies between the latitudes 12°39' to 13°13' N and longitudes 77°22' to77°52' E. The climate is having four distinct seasons, viz., summer season (March to May), rainy season (June to August), autumn season (September to November) and winter season (December to February). April is usually the hottest month with the mean daily maximum temperature of

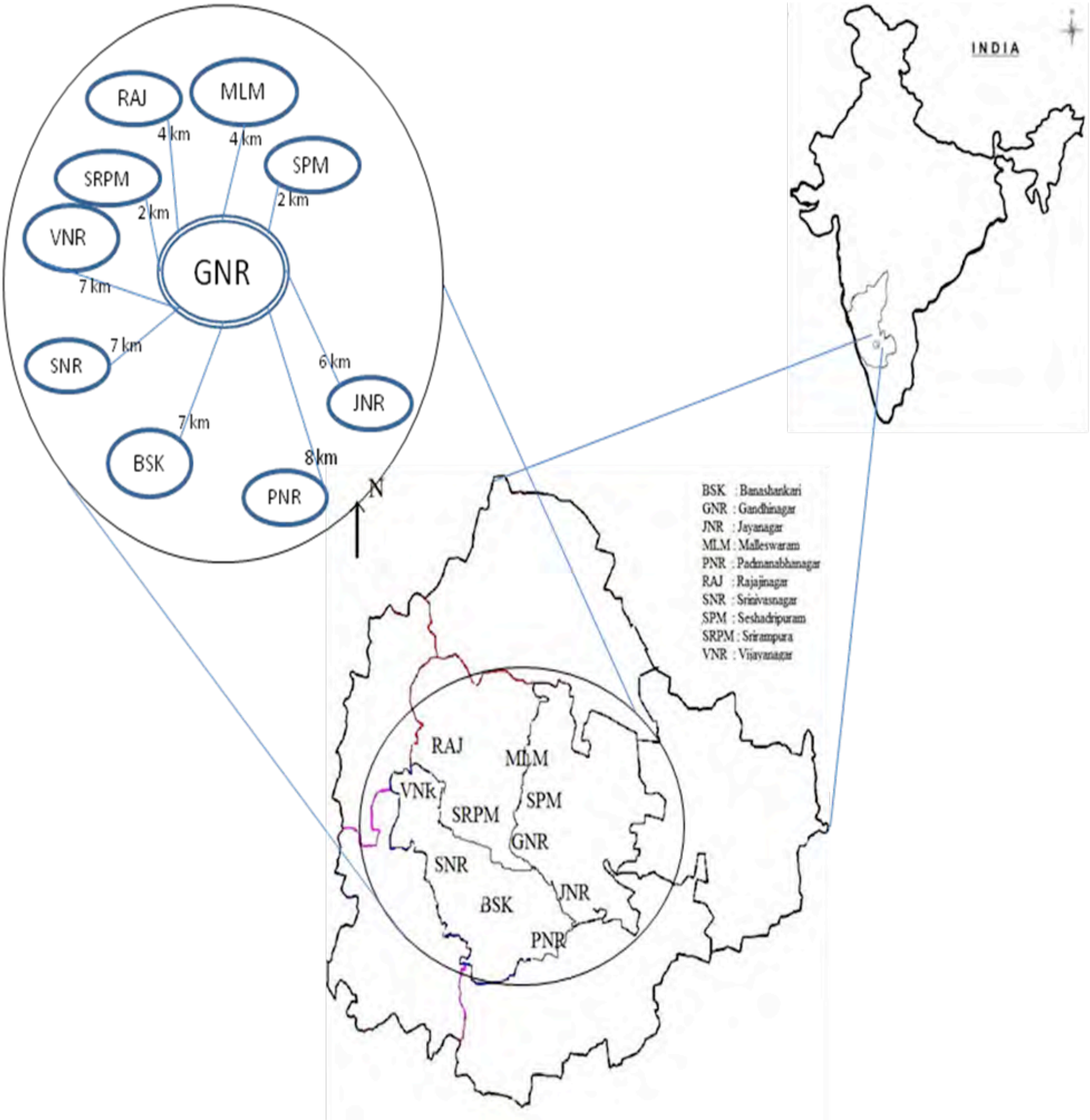


Fig. 1: Map of Bangalore Metropolitan, India

30-35 °C and mean daily minimum at 20-24 °C. The geology of this part forms predominantly a granite terrain with numerous varieties of granites, granitic gneiss, pegmatite and charnockites and so on. The rocks around the study area are called Close pet granites (Ningappa et al, 2008). These rocks are younger than the peninsular gneiss, made up of several types of potassium granites with variable color, texture and multiple intrusion relationship. The common rocks are pink, grey and porphyrite gneisses with large feldspars, black dolerite. These rocks form geological band of a width 15–25 km. Most of the studied houses in Bangalore city were constructed with cement and bricks that were made up of local soil and few were mud houses (Ningappa et al, 2008). The soil radioactivity reported in earlier studies is close to background levels from other regions of the country (Mishra, and Sadasivan 1974). The radioactivity reported for the building materials collected from this region is higher compared with soil radioactivity (Ramachandran et al, 2003). All the monitored houses were on the ground floor. About fifteen houses were chosen in all the monitored locations. Analysis is made on location wide, season wide and room volume.

Methodology

Twin cup dosimeters developed in Bhabha Atomic Research Centre (BARC), Mumbai, India were used in this study. The dosimeter has two cylindrical cups of equal volumes having radius 3.1 cm and height 4.1 cm. The cups are having provision to hold SSNTD films inside the cups and a third SSNTD film outside the cup for progeny measurements. A schematic diagram of the dosimeter is given in Fig.2. The dosimeter is designed to discriminate ^{222}Rn and ^{220}Rn in mixed field situations, where both the gases are present like in monazite rich deposit areas. Track detector used in the dosimeter is cellulose nitrate films, commercially called LR-115 films, made by Kodak Pathe. Films of size 3 cm × 3 cm were affixed at the bottom of each cup as well as on the outer surface of the dosimeter. The exposure of the detector inside the cup is termed as *cup mode* and other one exposed openly is termed as *bare*

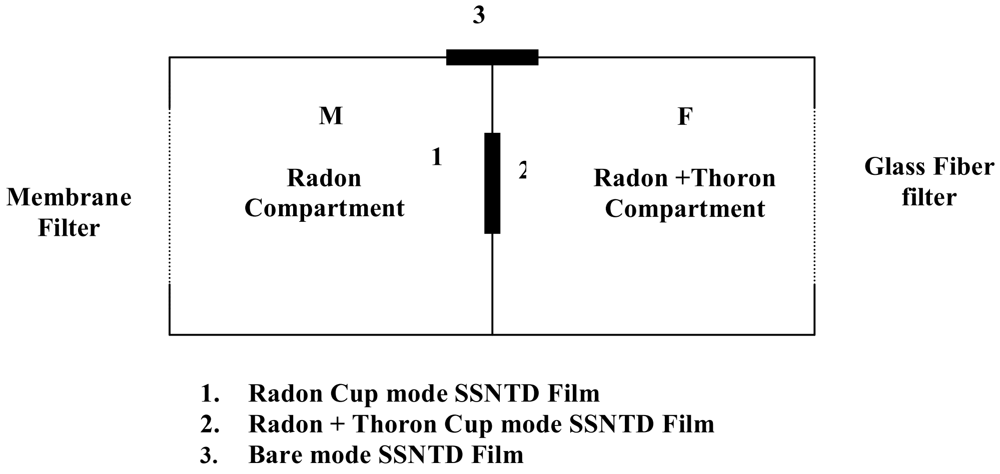


Fig. 2: Schematic diagram of twin cup radon-thoron dosimeter

mode. One of the cups has its entry covered with a glass fiber filter paper that permeates both ^{222}Rn and ^{220}Rn gases into the cup and is called *filter cup*. The other cup is covered with a semi permeable membrane sandwiched between two glass fiber filter papers called membrane cup (Ward et al, 1977). These types of semi permeable membranes have diffusion coefficient for radon gas in the range of 10^{-8}–10^{-7} cm^2 s^{-1} that permeates more than 95% of the ^{222}Rn gas while it suppress the entry of ^{220}Rn gas to (Wafaa, 2002) more than 99%. Thus, the SSNTD films inside the membrane cup register tracks that attributes to ^{222}Rn gas alone, while the *filter film* records tracks due to both ^{222}Rn and ^{220}Rn gases. The third film exposed in the bare mode registers alpha tracks produced by both the gases and their alpha emitting progeny. Eappen and Mayya (2004) have reported that LR-115 (12 μm) film does not register tracks from deposited activity since E_{max} for LR-115 (12 μm) is 4 MeV and all the progeny isotopes of ^{222}Rn /^{220}Rn emit alphas with energies more than 5 MeV. Thus, uncertainty due to deposited activity on film surface is removed for the bare detector estimate; a reason to choose LR-115 (12 μm) film for bare card estimate. The dosimeters were kept at a height of about 1.5 m from the ground, considering least disturbance to the occupants. Care is taken while placing the dosimeter such that the active surface of the SSNTD film used in bare mode exposure is kept at a minimum distance of 10 cm away from any surface to avoid tracks due to attenuated alphas reaching from these surfaces. Measurements were completed in each dwelling for a calendar year covering the four seasons prevailing in the area. After exposure, the dosimeters were retrieved and SSNTD films were removed from the dosimeter for etching. The films were then etched in 10% NaOH solution at 60 ºC for 90 minutes (Eappen and Mayya, 2004). The tracks recorded on LR-115 films were counted using a spark counter (Cross and Tommasino, 1970; Samyogi et al, 1978). Tracks are converted to gas concentrations using Eqs. (1) and (2).

$$\mathrm{C_R}\,(Bqm^{-3}) = \frac{T_m}{d \times S_m} \qquad (1)$$

$$\mathrm{C_T}\,(Bqm^{-3}) = \frac{T_f - d \times C_R \times S_{rf}}{d \times S_{tf}} \qquad (2)$$

where T_m is the track density of the film in membrane compartment (Tr cm^{-2}), d is the period of exposure in days (d), S_m refers to the sensitivity factor of membrane compartment (Tr cm^{-2})/(Bq d m^{-3}), T_f is the track density of the film in filter compartment (Tr cm^{-2}), S_{rf} is the Sensitivity of ^{222}Rn in filter compartment (Tr cm^{-2})/(Bq d m^{-3}) and, C_R and C_T are the concentrations (Bq m^{-3}) of ^{222}Rn and ^{220}Rn, respectively. We followed the protocols given by

Eappen and Mayya (2004) for processing the exposed films; hence sensitivity factors S_m and S_{rf} are taken from their work for computing the gas concentrations. The progeny concentrations in terms of Working Level (WL) can be written as:

$$R_n(mWL) = \frac{C_R \times F_R}{3.7} \tag{3}$$

$$R_T(mWL) = \frac{C_T \times F_T}{0.275} \tag{4}$$

Where F_R and F_T are equilibrium factors for radon and thoron respectively and can be equated with progeny fractions of respective gases as shown in Eqs. (5) and (6).

$$F_R = 0.104F_{RA} + 0.514F_{RB} + 0.37F_{RC} \tag{5}$$

$$F_T = 0.91F_{TB} + 0.09F_{TC} \tag{6}$$

Where F_{RA}, F_{RB}, F_{RC}, F_{TB} and F_{TC} are activity fractions of ^{218}Po, ^{214}Pb, ^{214}Bi, ^{212}Pb and ^{212}Bi, respectively. Mayya et al (1998) have obtained these activity fractions through ventilation parameters applying a root finding method using the deposition velocities for attached and unattached fractions of the progeny nuclides. Since the data in this study is not sufficient for (volumetric variations) deriving ventilation dependent F_{xx} factors, bare card results are not used in deriving F values. Such an exercise will be tried later after large number of measurements data are collected from future study. For the present study, inhalation dose is computed using UNSCEAR (2000) F values. Indoor occupancy factor for the population is taken as 0.8 and the annual inhalation dose (mSv y^{-1}) is calculated using Eq. (7).

$$D\left(mSv\,y^{-1}\right) = 7000 \times \left[\left(0.17 + 9F_R\right)C_R + \left(0.11 + 40F_T\right)C_T\right] \times 10^{-6} \tag{7}$$

Results and Discussion

Volumetric Variations of Indoor ^{222}Rn and ^{220}Rn:

The natural radioactivity contents of soil samples of Bangalore region reported by earlier studies are 15.2, 16.90 and 486.7 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively Mishra and Sadasivan (1971) and the concentrations of ^{238}U, ^{232}Th and ^{40}K in the building rocks of Karnataka region are 33, 30.5 and 412.3 Bq kg^{-1} respectively Ramachandran et al (2003). However, major quantity of bricks used for the construction of the buildings in Bangalore city are brought from places in the city out skirts called Nelamangala, and Magadi and a small quantity from Hoskote, Ramanagara and Channapattana. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40} K in the soils of Nelamangala and Magadi are 31.3 ± 0.6, 52.6 ± 0.9 and 303.1 ± 6.1 Bq kg^{-1} and 16.9 ± 0.6, 57.5 ± 1.1 and 1073 ± 15.6 Bq kg^{-1} respectively Shiva Prasad et al, (2008). Rooms were broadly classified into ‘6-groups’ on the basis of volume ranged from 30 to 310 m^3 such as 30–40, 45–60, 65–75, 80–100, 110–120 and 200–310 m^3. About 7 rooms were selected in each dimension at ten different locations. Hence, the total number of rooms covered in each volume is 42 rooms. However, the total number of rooms monitored is 42 × 10 locations = 420 rooms. These 420 rooms have been analyzed for four seasons and lead to 1680 measurements. The total number of films (LR-115 detectors) exposed during this period of measurement is more than 5000. The frequency distribution of ^{222}Rn and ^{220}Rn levels in dwellings is presented in Figs. 3 and 4.

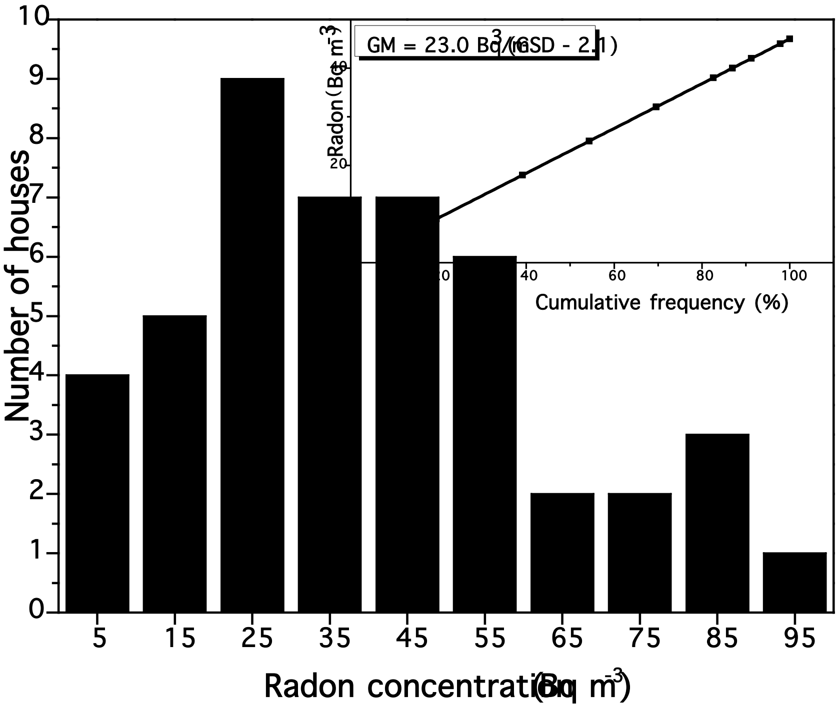


Fig. 3: ^{222}Rn levels in dwellings

Geometric means of indoor ^{222}Rn and ^{220}Rn levels in the study area are 23.0 and 20.0 Bqm^{-3} with GSDs 2.1 and 2.0 respectively. Cumulative frequencies against the ^{222}Rn/^{220}Rn values showed linear regression with correlation coefficient equals 1 for both the cases. A linear correlation with correlation coefficient nearing one indicates a common factor predominant in the various categories of rooms governing the gas concentrations in these houses. A correlation with dwellings volume and gas concentrations is attempted in this study which is explained below.

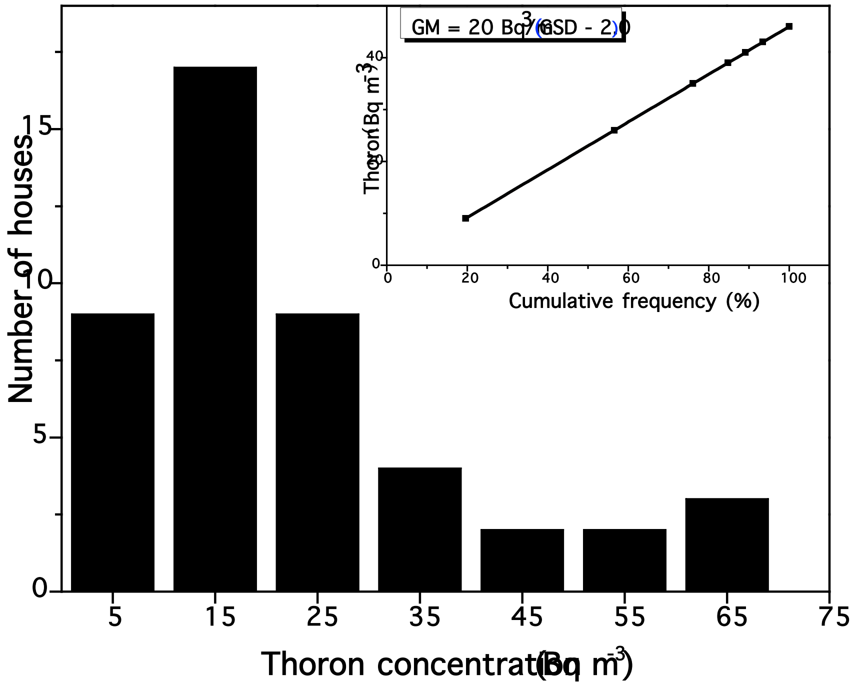


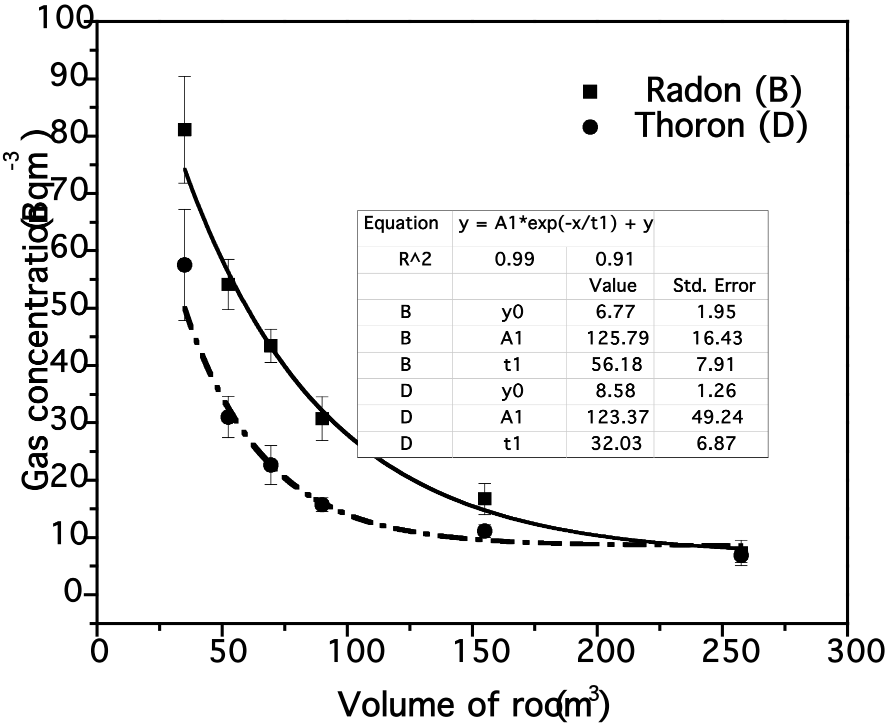
Fig. 4: ^{220}Rn levels in dwellings

Inhalation dose is computed using UNSCEAR (2000) dose conversion factors. Inhalation dose calculated from the total results varied from 0.27 - 4.45 mSv y^{-1} with a geometric mean of 1.34 mSv y^{-1} (GSD 2.1). Table 1 show the range and average values of ^{222}Rn and ^{220}Rn levels in room volume ranging from 35 to 300 m^3. The higher concentrations were observed in a room of lower volume than in larger volume.

Table 1: ^{222}Rn & ^{220}Rn levels in category of rooms

Volume of room (m^3)	^{222}Rn (Bqm^3)			^{220}Rn (Bqm^3)		
	Range		Aver. ± SD	Range		Aver. ± SD
	Min.	Max.		Min.	Max.	
30 – 40	67.3	93.0	81.1 ± 9.3	42.3	69.4	57.5 ± 9.7
45 – 60	48.5	62.0	54.1 ± 4.4	27.5	36.8	31.0 ± 3.6
65 – 75	39.8	47.4	43.4 ± 2.9	18.8	27.1	22.6 ± 3.4
80 – 100	25.2	35.1	30.7 ± 3.8	13.2	17.4	15.7 ± 1.2
110 –200	12.9	20.5	16.7 ± 2.7	09.6	12.5	11.0 ± 1.1
200 - 310	07.1	10.5	07.3 ± 2.2	06.6	09.0	06.9 ± 1.3

A plot of ^{222}Rn and ^{220}Rn concentrations is made against room volume in Fig.5. It is seen from the figure that the concentrations decrease with increase in volume of the rooms. However, in the case of ^{220}Rn the effect is almost nullified beyond room volumes greater than 150 m^3. If we consider that the exhalation rate for ^{222}Rn and ^{220}Rn from the room surfaces is almost same, assuming that the materials used for construction in these houses are similar, it is expected that the gas concentrations will decrease with increase in volume of the room since the surface to volume ratio decreases with increase in room volume.



Equation	y = A1*exp(-x/t1) + y		
R^2	0.99	0.91	
		Value	Std. Error
B	y0	6.77	1.95
B	A1	125.79	16.43
B	t1	56.18	7.91
D	y0	8.58	1.26
D	A1	123.37	49.24
D	t1	32.03	6.87

Fig.5: Gas concentrations with volume of dwellings

A plot of volume against ratio of area to volume (A/V) is shown in Fig. 6. It could be seen from the plot that the A/V ratio also showed an exponential fit in decreasing order with a correlation coefficient 0.99. It is interesting to note that the fitting parameter *t* in Fig. 6 is 61.4 which closely match with effective decay value for radon (56.2) in Fig. 5. This clearly indicates that the radon values inside dwellings covered under the study is predominantly depended on A/V ratio inside the houses. Effect of ventilation seems negligible when the measurement was carried out for long durations. However, the results of thoron were different compared to radon. The *t* value is almost half (32) to that of A/V ratio. One can speculate certain other phenomenon governing the thoron values. It is only logical to say that predominance of thoron profile inside the room exists to some extend and in rooms having larger volumes concentration of thoron is profound from surfaces closer to dosimeter placement.

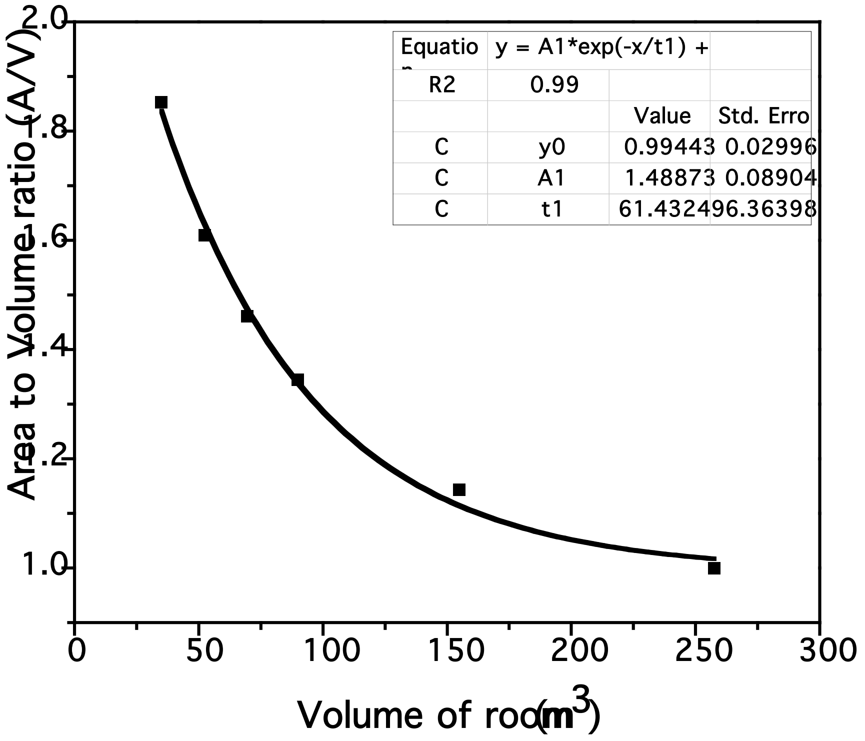


Fig.6: Correlation between A/V ratio and volume of dwellings

Spatial variation of indoor ^{222}Rn and ^{220}Rn levels:

The construction materials used for building the houses are predominantly of cement, concrete and bricks made up of local soil. About 40% of the bricks used for the construction of the buildings in Bangalore city are from the city out skirts called Nelamangala, 46% from Hoskote and the remaining from Magadi, Ramanagara and Channapattana etc. The reported values of natural radioactivity contents of ^{226}Ra, ^{232}Th and ^{40}K for Bangalore soil are 15.2, 16.9 and 486.7 Bq kg^{-1} respectively (Mishra and Sadasivan, 1971), whereas the contents of ^{238}U, ^{232}Th and ^{40}K in the building rocks of Karnataka region are reported as 33.0, 30.5 and 412.3 Bq kg^{-1} respectively (Ramachandran et al, 2003). About 150 dwellings in ten different locations of Bangalore city, India were selected on the basis of construction and age of the building to see the effective dose rates due to indoor ^{222}Rn, ^{220}Rn and their progeny levels in dwellings during different seasons of the year. The houses were categorized on the basis of ventilation that depends on number of windows, doors and usage pattern (such as closed, open, partially open/close) to identify them as poor (no or 1-window), moderate (2-windows) and good (3 and above windows) ventilated houses.

The annual average values of ^{222}Rn, ^{220}Rn and their dose rates in the different locations of Bangalore city are summarized in Table-2 including the number of houses monitored in each area during April 2007 to April 2010.

Table 2: Annual average concentrations of ^{222}Rn, ^{220}Rn and their effective dose rates

Name of the Location	Number of Dwellings monitored	AM ± SD ^{222}Rn (Bq m^{-3})	AM ± SD ^{220}Rn (Bq m^{-3})	Dose rate mSv y^{-1}
Rajajinagar	15	17.2 ± 1.2	16.1 ± 1.4	0.1
Srinivasanagar	15	40.0 ± 1.9	29.2 ± 4.3	0.2
Sheshadripuram	15	31.8 ± 3.1	19.8 ± 2.0	0.2
Srirampuram	20	26.3 ± 3.2	18.8 ± 1.6	0.3
Padhmanabhanagar	15	27.5 ± 1.7	25.9 ± 2.0	0.2
Jayanagar	15	25.3 ± 1.6	19.7 ± 1.2	0.2
Banashankari	12	26.5 ± 2.0	21.4 ± 2.2	0.2
Malleshwaram	13	27.9 ± 2.9	17.8 ± 1.5	0.2
Vijayanagar	15	25.5 ± 3.8	8.3 ± 1.2	0.2
Gandhinagara	15	85.9 ± 2.3	38.3 ± 5.4	0.5
	AM ± SD	33.4 ± 6.1	21. 6 ± 2.5	0.2 ± 0.03

The arithmetic mean of ^{222}Rn concentration varies from 17.2 ± 1.2 to 85.9 ± 2.3 Bq m^{-3} with a mean of 33.4 ± 6.1 Bq m^{-3}, whereas for ^{220}Rn it vary from 8.3 ± 1.2 to 38.3 ± 5.4 Bq m^{-3} with a mean of 21.6 ± 2.5 Bq m^{-3}. The lower values of ^{222}Rn concentrations were observed in Rajajinagar and higher in Government Science College of Gandhinagara. The reason may be due to the fact that the activity concentrations (^{226}Ra) in the surrounding area (Mallathalli - 23.7±0.7) are lower compared to the Gandhinagara (Lalbagh -111.6±1.2). The lower and higher concentrations of ^{220}Rn were seen in Vijayanagar (Mallasandra: 29.5±0.9) and Government Science College of Gandhinagara (Lalbagh: 95.4±1.5), respectively. This is again due to the activity concentrations of ^{232}Th in the respective area (Ashok et al, 2008). Hunse et al, (2010) have reported that the radon in water in Rajajinagar (166.62±8.08 Bq L^{-1}) is low and higher concentrations are in Cubbon Park (Government Science College: 764.05±35.4 Bq L^{-1}). The results show that there is a direct correlation between radon in water and indoor radon. The radons in water of other location are in between these two values with fair correlation between radon in water and indoor radon. The average indoor radon concentration reported for dwellings of different cities across the world varies between 8.7 Bq m^{-3} for Australia and 190 Bq m^{-3} for Saxony and Turingia of Germany, with a weighted arithmetic mean for all the cities considered of 40 Bq m^{-3} (UNSCEAR, 1993). The effective radiation dose due to ^{222}Rn and ^{220}Rn ranged between 0.1 – 0.5 mSv y^{-1} with an arithmetic mean of 0.2 mSv y^{-1}. The observations made for Bangalore region were also of the same order reported elsewhere.

The annual average concentrations of ^{222}Rn and ^{220}Rn for the different seasons and temperature of Bangalore city are tabulated in Table 3. The obtained concentration shows a clear seasonal variation. Higher concentrations of ^{222}Rn and ^{220}Rn in winter months and lower in summer months. This may be due to the enhanced radon exhalation and reduced ventilation as observed elsewhere (Virk and Sharma, 2000).

Table 3: Typical Seasonal Variation of ^{222}Rn and ^{220}Rn concentrations

Season	Period	Mean Temperature (°C)	^{222}Rn Bq m^{-3}	^{220}Rn Bq m^{-3}
Winter	December - February	20	42.6	26.3
Summer	March - May	35	16.2	14.0
Rainy	June - August	30	23.4	18.8
Autumn	September - November	24	24.9	19.2

Radon levels in closed environment are affected both by the degree of exchange with outdoor air as measured by the ventilation rate and by changes in the entry rate of radon rich air from the underlying soil and rocks. Since majority of the houses are well ventilated in summer season, indoor radon concentrations might be expected to be lower for summer than in winter season (Wilkening, 1986).

To get a clear idea of the spatial variations, the observed values are compared with the surveys made in different areas. The range of ^{222}Rn, ^{220}Rn and their progenies for each location are given in Table 4. The elevated radon levels are seen in poor ventilation houses of all the locations where most of the houses were built by local soil and sedimentary gravel.

Some buildings with higher radon levels were found on gravel but all the lower values observed in Rajajinagar area. This may be due to the lower activity concentrations of ^{226}Ra (Ashok et al, 2008) and also low radon in water (Hunse et al, 2010) in the surrounding region.

Table 4: Area wise range of ^{222}Rn, ^{220}Rn and their progeny levels

Name of the Location	RANGE Concentration of ^{222}Rn	Concentration of ^{220}Rn	^{222}Rn progeny	^{220}Rn progeny
	Bq m^{-3}		m WL	
Rajajinagar	4.0 – 36.8	5.5 – 35.4	0.02 – 0.9	0.02 – 0.5
Srinivasanagar	29.8 – 50.3	13.7 – 56.9	0.12 – 1.9	0.04 – 0.7
Sheshadripuram	5.8– 100.0	2.7 – 72.9	0.02 – 1.6	0.02 – 0.9
Srirampuram	10.9 – 65.9	6.1 – 30.9	0.06 – 1.1	0.02 – 1.9
Padhmanabhanagar	4.0 – 76.0	3.4 – 70.1	0.01 – 1.5	0.02 – 3.5
Jayanagar	4.0 – 80.7	4.8 – 63.1	0.02 – 2.2	0.01 – 1.7
Banashankari	5.8 – 89.4	1.3 – 66.6	0.02 – 4.4	0.01 – 1.3
Malleshwaram	5.8 – 92.9	2.0 – 47.9	0.02 – 2.2	0.02 – 4.8
Vijayanagar	11.7 – 99.4	6.7 – 37.5	0.03 – 1.4	0.02 – 0.9
Gandhinagara	73.6–100.0	10.9 – 72.9	0.23 – 4.4	0.03 – 1.0

Figure 7 shows the frequency distribution of ^{222}Rn concentrations in 150 houses. About 81% of indoor ^{222}Rn levels are found to vary between 4 and 39 Bq m$^{-3.}$ The higher concentrations (40 - 80 Bq m^{-3}) were observed in 15% of the studied houses, this may be due to the buildings without the basic concrete slab or the slab that was not properly built or already damaged (Vaupotic et al, 1999). Nearly 4% of buildings show radon concentrations above 80 Bq m^{-3} with a maximum of 100 Bq m^{-3} and they were 40 year old. The poor construction of houses leads to the several cracks in foundation, walls, basic slabs thorough which radon can easily enter the rooms (Vaupotic et al, 1999). The observed values of radon concentration are found comparable with variation observed in the country and ranges from 6.4 to 95.4 Bq m^{-3} with a geometrical mean 25.5 Bq m^{-3} (Ramachandran, 2003). In general the radon concentration was found higher in mud houses than in cement houses. The ground floor of such houses is directly constructed on the top of soil with a coating of mud. The ground floor allows more radon to diffuse inside the houses because of higher porosity of materials used (Ramola et al, 1995).

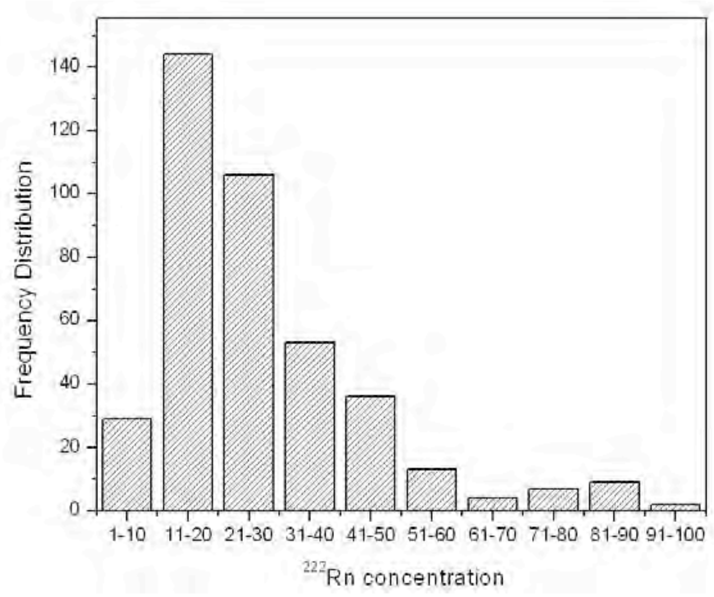


Fig 7: Frequency distribution of radon concentrations (Bq m^{-3})

Figure 8 shows the frequency distribution of indoor ^{220}Rn concentration. About 83% of the dwellings have shown the concentrations below 30 Bq m^{-3}, 11% ranged between 31- 49 Bq m^{-3} and 6% of the dwellings showed the concentrations above 50 Bq m^{-3} with a maximum of 72.9 Bq m^{-3}. The reported values of mean indoor radon and thoron concentrations for India is

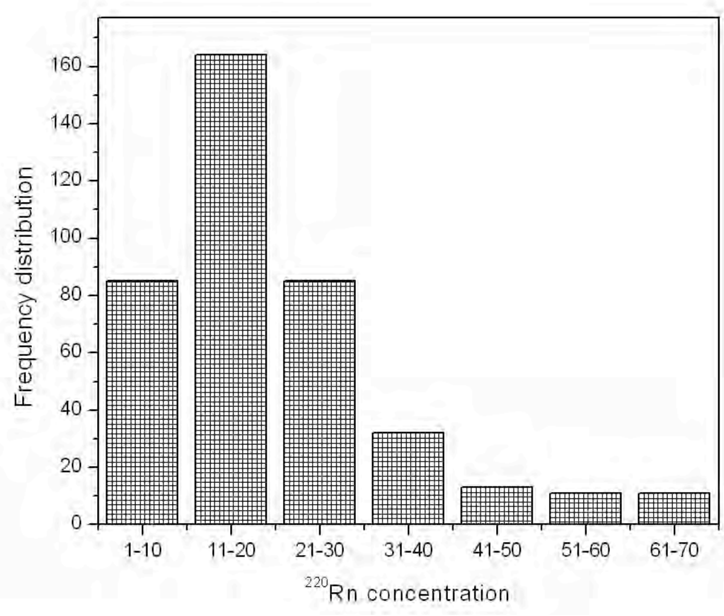


Fig 8: Frequency distribution of thoron concentrations (Bq m^{-3})

23.0 and 12.2 Bq m^{-3} respectively and the total inhalation dose rate is 0.9 mSv y^{-1} (Ramachandran et al, 2003).

A comparison of indoor ^{222}Rn and ^{220}Rn concentration for different seasons of all the studied locations are shown in Table 5. Due to poor ventilation, the radon is accumulated inside the houses and thus results higher concentration. The ^{222}Rn and ^{220}Rn concentrations were found higher in winter and low in summer. The high values in winter are mainly because of ventilation factor (Vaupotic et al, 1999). The indoor ^{222}Rn and ^{220}Rn were influenced mainly by the ventilation condition of the house. In Government Science College high ^{222}Rn and ^{220}Rn concentrations in summer is observed than in winter. This anomaly observed in the college is may be due the fact that the class rooms will be closed for longer duration in summer holidays.

Table 5: Location wise seasonal variations of indoor ^{222}Rn and ^{220}Rn concentrations

Name of the Location	winter		summer		Rainy		Autumn	
	^{222}Rn	^{220}Rn	^{222}Rn	^{220}Rn	^{222}Rn	^{220}Rn	^{222}Rn	^{220}Rn
	Bq m^{-3}		Bq m^{-3}		Bq m^{-3}		Bq m^{-3}	
Rajajinagar	24.9	18.6	10.9	14.2	14.8	15.3	18.2	16.2
Srinivasanagar	36.6	19.9	18.2	16.2	24.9	15.3	29.6	21.3
Sheshadripuram	43.9	25.9	18.3	15.5	28.3	18.1	36.6	19.9
Srirampuram	38.8	21.8	17.3	12.2	20.5	20.5	28.5	20.7
Padhmanabhanagar	41.9	35.2	15.6	14.3	22.6	24.8	29.6	29.3
Jayanagar	37.4	22.4	12.9	14.6	23.2	20.1	27.3	21.5
Banashankari	41.8	31.5	13.7	14.4	22.2	18.2	27.9	21.3
Malleshwaram	50.3	26.9	14.3	12.4	19.7	13.9	27.4	18.2
Vijayanagar	61.9	21.3	26.2	16.6	35.6	17.8	43.8	20.4
Gandhinagara	73.6	49.7	24.5	20.1	40.3	24.5	51.4	25.8

The emanation of radon also contributes higher radon from rocks and local stones. In addition, the mud houses have small doors and a small window, which remain closed for most of the time to conserve the energy (Ramachandran et al,2003).

The observed winter/summer ratio was found maximum while the winter/autumn ratio was found minimum. The winter /summer ratio in different locations are found to vary between 1.9 and 3.7 and this ratio is high compared to the ratios of winter/rainy and winter/autumn. Again this is correlated with the ventilation condition of houses. The concentrations of ^{222}Rn and its progeny also follow the same trend as it was recorded maximum in winter and minimum in summer (Virk and Sharma, 2000; Wilkening, 1986; Vaupotic et al, 1999). However the ^{220}Rn and its progeny concentration was found maximum during winter and minimum during rainy. This behavior is may be due to low emanation rate of ^{220}Rn during rainy season and also it may be due to the possibility of brief half life, it cannot escape easily from the soil capillaries that are mostly occupied by water during the rainy season (Sathish et al, 2001).

Conclusions

It is observed that the concentrations of indoor ^{222}Rn, ^{220}Rn and their progeny levels are higher in poor ventilated houses than in well ventilated houses. The higher ^{222}Rn and ^{220}Rn concentrations are may be due to the presence of radioactive contents in the building. Radon levels in houses were found to be inversely related to room sizes. Thoron levels did not show much effect with increase in room volumes. Inhalation dose measured in the houses were comparable with natural background areas.

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