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Measurement of radon activity in soil gas using RAD7 in the Environs of Chitradurga District, Karnataka, India

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ABSTRACT

A ^{222}Rn survey was carried out in order to explore the pattern of geographical and seasonal changes of ^{222}Rn activity in soil-gas at different locations in Chitradurga district of Karnataka State using RAD7 radon detector coupled with special accessories, without dilution by outside air technique. Radon activity in the soil gas varied from 0.5 to 812.9 (mean: 93.78 Bq/m^3) and 0.8 to 810.4 Bq/m^3 (mean: 92.84 Bq/m^3) during pre- and post-monsoon seasons respectively, with an annual mean of 0.65 to 811.65 Bq/m^3 (mean: 93.31 Bq/m^3). A significant spatial and insignificant temporal variation in soil radon activity has been observed in the study area, which is in the order of Hosadurga taluk (346.56 Bq/m^3)> Hiriyur taluk (95.10 Bq/m^3) > Challakere taluk (36.45 Bq/m^3) > Chitradurga taluk (20.40 Bq/m^3) > Holalkere taluk (2.87 Bq/m^3). The results showed the radon values in the soil-gas of Chitradurga district are low (< 0.8 kBq/m^3) enough to categorize them under low radon risk areas (viz., 10 kBq/m^3).

Introduction

Radon, a naturally occurring radioactive gas comes from the natural decay of uranium (i.e., uranium-bearing minerals) found in nearly all soils and rocks [7]. Radon typically moves up through the ground to the air above and into homes through cracks and other holes in the foundation and radon entering home's indoor air through the soil is usually much higher than that through water supply. Radon concentration in the soil air are known to vary with time and it is believed to be the main source of radon in homes, measurements of soil gas radon concentrations can be used to estimate variations in radon potential of indoor environments [19, 20, 21, 25]. The number of radon atoms, which is transferred from the soil to the atmosphere, is controlled by different lithological, physical soil and meteorological conditions, which can be pictured through three processes, namely emanation, migration and exhalation, which finally determine the soil ^{222}Rn potential [36]. Hence, the radon risk potential of an area can be determined by two most important parameters namely, soil radon concentration and soil gas permeability [18, 20, 21, 25]. While soil radon concentration is affected by the uranium / radium concentration in the soil / rocks, the diffusion of radon through the soil into air is primarily affected by changes in porosity / permeability of the rocks and soil, soil moisture, wind, air temperature, air pressure, emanation capacity of the ground, water saturation grade of the medium [4, 8, 24, 26,28, 30,33]. The diffusion rate of radon in soil and sand decreases with increasing in moisture content and is lowest near the saturation state. The soil radon concentration varies directly with barometric pressure between the interfaces and inversely with wind speed. Rainwater normally passes quickly through to deep subsoil, and affects soil radon measurements (at a depth of 80 cm) only during or shortly after precipitation. Efforts have been made to correlate soil-gas radon concentrations with factors such as geology, soil porosity, shears, thrusts and faults [9, 12]. Further, the type of made ground (backfill) is more important because of the limited migration distance of ^{222}Rn, which means that a ^{222}Rn signal from the bedrock at depth will not trace through a thick made ground. The second most important parameter of the soil ^{222}Rn potential is the type of bedrock beneath the soil. Nearly all studies investigating the soil ^{222}Rn potential made the observation that the geological situation (viz., type of bedrock beneath the soil) is not the second, but the most important parameter [13,17]. Radon transfer from the soil to the building also depends on constructional features and usage peculiarities, which change from building to building and are hardly predictable. On the other hand, the occurrence and availability of radon in the soil (described by the term 'soil ^{222}Rn potential'), is more predictable, if the processes controlling this potential are sufficiently understood. Soil data may also provide a basis for predicting whether houses built in certain areas or regions will have the potential for developing elevated indoor concentrations. Much attention, however, has been given to radon as a radiological health hazard, as human beings are continuously exposed to radon (and its decay products) originating as soil gas in the indoor environment / buildings they live in [2], where radon can accumulate [36].

The present study aimed at determination of natural background variation of radon activity in soil gas at a specific depth within the soil at selected locations in different taluks of Chitradurga district, Karnataka, India during 2011. The air contained in the soil was removed and analyzed with the help of RAD7 radon detector (DURRIDGE Co., USA) coupled with special accessories, without dilution by outside air technique.

Study area

Chitradurga district is geographically located between 13^0 30' – 15^0 00' N latitude and 76^0 00'E - 77^0 00' E, with a total area of 8388 sq.kms (Fig 1). The district is geographically bordered by Tumkur district to the southeast and south, Chikmagalur district to the southwest, Davanagere district to the west, Bellary District to the north, and Anantapur district of Andhra Pradesh state to the east. The district is divided into six taluks namely,Chitradurga, Hiriyur, Hosadurga,Holalkere, Challakere a nd Molakalmuru. Physiographically, the district comprises of undulating plains, interspersed with and isolated low ranges of

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bold rocky hills, picturesque valleys and huge towering boulders in unimaginable shapes, generally gently sloping from southwest to east.

Major portion of Chitradurga district fall under the Central dry zone of the tenfold agro-climatic zone of Karnataka and very small portions of it towards north and west direction respectively fall under northern dry zone and southern transition zone. Chitradurga district is one of the drought prone districts in the state, receives low to moderate rainfall. The normal annual rainfall in the district is 574 mm, which varies between 600 mm to 700 mm. It is rich in mineral deposits, including gold prospecting at Halekal, Kotemardi or Bedimaradi, etc., and open cast copper mines at Ingaldhal. Major soil types include deep and shallow black soil, mixed red and black soil, red loamy and sandy soil. Major portion of the district is characterized by various geological formations belonging mainly to the Archean period (84.6%) followed by archean to lower proteozoic (11.59 %) and upper Proteozoic (3.81%) periods. Hydrogeology, groundwater occurs under phreatic condition in the weathered rock formations of the'Peninsular Gneissic Group' of rocks comprising of Granites, gneisses and schist. The major rock groups identified in the study area were Bababudan, Charnokite, Chitraduga, Closepet granite, Migmates and dolerites (viz., peninsular Gneisses) and Sargur-Satyamangalam Schist complex, respectively covering 1.5, 0.03, 10.09, 29.14, 58.61 and 0.63 % of the total area of the district. Geologically, major geological formations are Charnokite, gneisses & unclassified crystallines, slates, phyllites, schists and granite. *Chitraduga* rock groups mainly composed of consolidated sediments, deccan traps and intrapean beds, metamorphic rocks, plutonic rocks, residual cappings, semi-consolidated sediments and volcanic / metavolcanic rock types. These groups are mainly distributed in chitarduga and Hiryur taluks and in patches in Holalkere and Hosdurga taluks. *Bababudan rock* group mainly composed of metamorphic rocks and volcanic / metavolcanic rock types, distributed in patches in Chitradurga, Holalkere and Hosadurga taluks. *Charnokite* rocks groups mainly composed of metamorphic and plutonic rocks, distributed in patches in Molakalmur, Holalkere, Hiriyur and Hosadurga taluks. *Sargur-Satyamangalam schist complex* is mainly composed of consolidated sediments and metamorphic rocks, which are distributed as patches in Molakalmur, Hiriyur, Chitradurga and Challakere taluks. *Closepet granite* rock group of total area) mainly composed of plutonic rocks mainly spread along Molakalmur, Challakere, Hiriyur taluks and as patches in all other taluks. *Migmatites and Granodiorite - Tonalitic Gneiss rock* groups composed of metamorphic and plutonic rocks, distributed mainly in Hosadurga and Holalkere taluks and as patches in Chitradurga taluks. Major part of the district lies in Krishna basin and is drained by Vedavathi River, with the Tungabhadra River flowing in the northwest. The main source of ground water occurring in the district is through precipitation and return flow from applied irrigation. Major water bearing formations are fractured / weathered gneisses and granite and their distribution among six taluks of Chitradurga district is as follows – (a) Molakalmur taluk: granites, granitic-gneisses and amphibolite gneisses; (b) Chitradurga taluk: fractured granitic-gneisses, gneisses and hornblende-schists (c) Challakere taluk: gneisses, granitic-gneisses and amphibolites (d and e) Hosadurga and Hiriyur taluks: granitic-gneisses, and schists and (f) Holalkere taluk: gneisses, schists and greywackes. Geologically the area containing the weak structures are found faults lineaments strike and dip beds and strike and dip foliation and the trust faults.

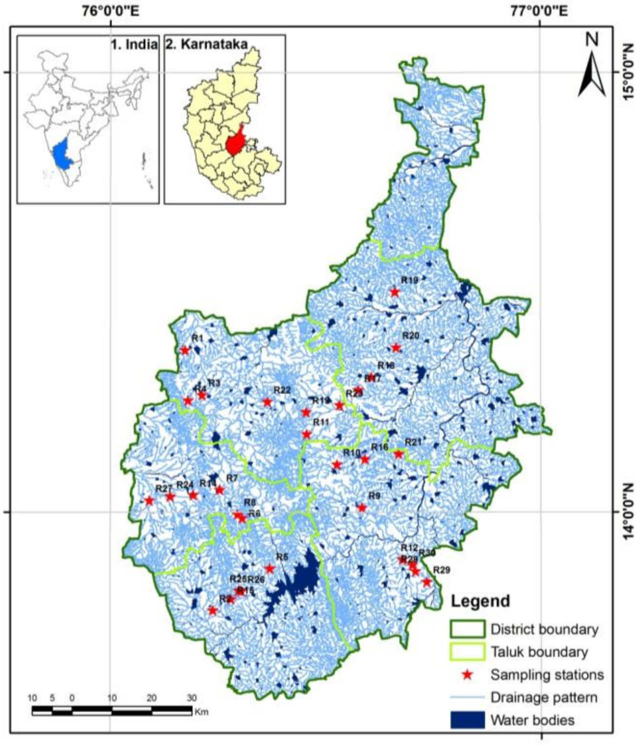

Fig 1. Location map showing sampling stations

Methodology

In order to measure and determine spatio-temporal variation in soil radon activity in Chitradurga district, 30 locations spread across five taluks were selected and analyzed during the pre- and post-monsoon seasons of the year 2011 (viz., Chitradurga, n=7; Challakere, n=4; Holalkere, n=6; Hiriyur, n=8); and Hosadurga, n=5).

Radon monitoring in soil involves either measuring radon in soil air or measuring the radon flux from a soil [2]. In the present study, radon concentration in soil gas was measured using a portable, calibrated, electronic, battery operated, alpha spectrometer, RAD7 radon detector (DURRIDGE Co., USA) coupled with special accessories. The RAD7 detector converts alpha radiation directly to an electric signal and has the possibility of determining electronically the energy of each alpha particle released. This allows the identification of the isotopes (^{218}Po, ^{214}Po) produced by radiation, so that it is possible to instantaneously distinguish between old and new radon (new radon daughters and the old radon daughters left from previous tests), radon from thoron, and signal from noise (viz., alpha spectrometry). Figure 2 shows the schematic diagram of RAD7 soil-gas setup.

Soil sampling: on-site activities

The stainless steel probe with a hollow tube and sampling holes near the tip (supplied by Durridge Co., USA) was penetrated in the soil to a specified depth (~60-80 cm), with a rotating handle or immersed with gentle strokes of a hammer, where the soil was hard. The probe was then connected to RAD7 detector through desiccant tube (drying unit, CaSO4) and inlet filters (pore size 1 μm) by pushing the plug-in hose connector into the probe. 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. Further, care was taken to perform the measurements where the soil is uniform and generally free of rocks, to avoid cracking the probe. Before the counting process started, the hole made in the soil surface was properly sealed by tamping down the soil around the probe in order to prevent mixing of soil-gas with air from atmosphere and the leakage of fresh air / gas into the sample acquisition path. This not only prevents fresh air from descending from the surface, vertically down along the outside of the shaft / probe to the sampling point, but also helps to locate the gas sampling point at the position of the probe point. The actual sampling point position will depend on the probe depth, the volume of air removed and also, perhaps, the technique used and the probe design while the volume of gas removed depends on the technique used to extract it and the porosity of the soil.

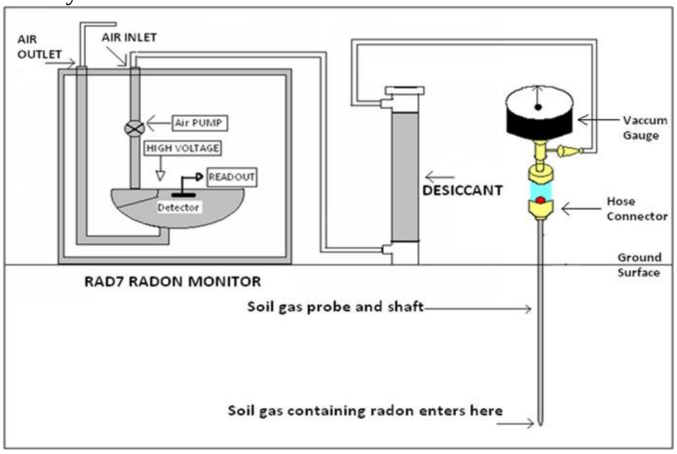

Fig 2. Schematic diagram showing Experimental RAD7 soil-gas setup

Analysis of radon: Laboratory measurements

The internal sample cell of RAD-7 analyzer is a 0.7 dm^3 (0.7 L) hemisphere, coated on the inside with an electrical conductor. The center of the hemisphere is occupied by the solid state, passivated, ion implanted, planar silicon alpha detector (PIPS), a semiconductor material. The high voltage power circuit charges the inside conductor to a potential of 2000-2500V relative to the detector, creating an electric field throughout the volume of the cell, which pushes the positive charges (viz., alpha particles) onto the detector. RAD7 is also provided with built-in air pump with a flow rate of ~ 1 L/min to remove soil gas from sub-surface / deep soil and deliver to internal accumulation chamber of RAD7. The desiccant (CaSO4) tubes and inlet filters (pore size 1 μm) block fine dust particles and radon daughters from entering the RAD7 test chamber.RAD7 detector was configured to sniff protocol and grab mode, which permits detecting rapid changes in radon concentration using least amount of soil-gas at each of the sampling stations. The soil gas was sucked / drawn up through the tube pipe into the internal accumulation chamber of the measuring instrument for 5 min pumping phase during which electrostatic collection of alpha emitters with spectral analysis take place. The instrument waits another 5 min and then counts for four 5-min cycles. The sniff mode covers the energy range from 5.40 to 6.40 MeV, showing the total counts from 6.00 MeV alpha particles of the ^{218}Po decay (daughter of ^{222}Rn). Thus, alpha emissions with energy of 6.00 MeV attributed to ^{218}Po decay allowed ^{222}Rn activity to be produced [6]. At the end of the half-hour period, the RAD7 will print out a summary of the measurement, including data on average radon concentration in the soil-gas from the four 5-min cycle measurements along with the respective bar charts and cumulative spectra for each sample. The results in the units of Bq/m^3 were determined by the mean value of four measurements with an error of ± 5%.

Results and discussion

Measurement results (minimum, maximum and mean values) of soil radon activity for all 30 surveyed sites for pre- and post-monsoon seasons of the year 2011 for different taluks are summarized in Table 1. The mean soil radon activity was 20.90 and 19.9 Bq/m^3 in Chitradurga taluk, 36.38 and 36.53 Bq/m^3 in Challakere taluk, 2.78 and 2.95 Bq/m^3 in Holalkere taluk, 96.48 and 93.70 Bq/m^3 in Hiriyur taluk and 346.59 and 346.52 Bq/m^3 in Hosadurga taluk respectively for pre- and post-monsoon seasons of the year 2011. In different taluks of Chitradurga district, the mean soil radon activity was in the order of Hosadurga (346.56 Bq/m^3)> Hiriyur (95.10 Bq/m^3) > Challakere (36.45 Bq/m^3) > Chitradurga (20.40 Bq/m^3) > Holalkere (2.87 Bq/m^3). A considerable spatial variation in soil radon activity between sampling points has been observed in the Chitradurga district, varying from 0.5 to 812.9 during pre-monsoon and 0.8 to 810.4 Bq/m^3 during post-monsoon season (Fig 3). Spatially, the mean annual soil radon activity for the year 2011 ranged from 0.65 to 811.65 Bq/m^3 while temporal variation in the mean soil radon activity was not significant in the study area (viz., PRM: 93.78; POM: 92.84 and mean: 93.31 Bq/m^3). This is in agreement with the literature that no significant temporal fluctuations in the radon gas content or differences in radon concentrations in water can be detected [22, 27]. Further, Sundal et al., [27] opines that it is not unusual to expect large variations in soil radon concentrations in the same measuring point during one year, which is not been noticed in the present case due to insignificant seasonal variations. Several other authors [1, 5, 23, 32] were of the opinion that interpretation of soil gas measurements in conjunction with geological data will be useful for estimates of indoor radon concentrations. Otherwise, single soil gas measurements become insufficient to describe the large seasonal and geographical variation in the soil radon concentrations [27]. And, it is very apparent from the present study that soil radon concentration (and radium / uranium) varies with specific site and geological material [10, 14] and soil types. At some stations in the present study, higher radon activity in soil gas was observed which is in accordance with the conclusions drawn by Varley and Flowers [31] that enhanced concentrations of radon in soil air have been reported above fractures and fault zones. While the material with high concentration of radium would be expected to show elevated radon concentration in soil-gas and groundwater of such a mineralized area [15].

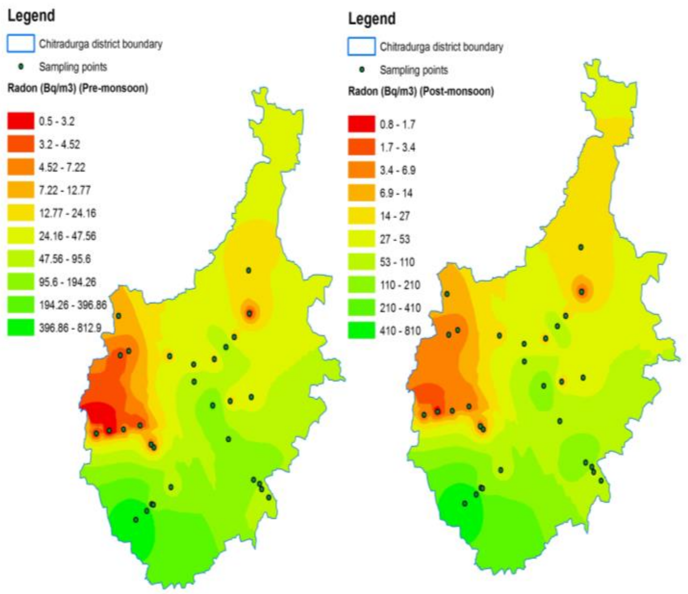

Fig 3. Spatio-temporal variation in Soil radon activity in Chitradurga district

Table 1. Variation in soil radon activity in different taluks of Chitradurga district

Sl. no.	Name of the taluk (no. of samples)	Sample ID	Soil Radon activity (Bq/m^3)						
			PRM			POM			Annual Mean
			Min	Max	Mean	Min	Max	Mean	
1	Chitradurga (n=7)	1, 3, 4, 11, 13, 22, 23	3.44	62.16	20.90	3.20	60.00	19.9	20.40
2	Challakere (n=4)	17, 18, 19, 20	1.60	113.23	36.38	1.30	112	36.53	36.45
3	Holalkere (n=6)	6, 7, 8, 14, 24, 27	0.50	4.97	2.78	0.80	4.90	2.95	2.87
4	Hiriyur (n=8)	9, 10, 12, 16, 21, 28, 29, 30	10.07	218.97	96.48	9.40	210.0	93.70	95.10
5	Hosadurga (n=5)	2, 5, 15, 25, 26	36.39	812.90	346.59	38.20	810.40	346.52	346.56

Note: PRM: pre-monsoon; POM: post –monsoon

Effective dose calculation

The methodology described in the article by Al-Mosuwi and Subber [3] has been used to arrive at the amount of radon in soil that could emigrate to atmosphere and their resultant equivalent dose, which are as follows:

- 1 Bq/m^3 of radon level contributes ~ 0.025mSv/y [16]
- If 2% of radon in soil emigrates to the atmosphere, the average radon concentration in the atmosphere will be 94.16 Bq/m^3 [29] and the average calculated equivalent dose will be 2.354 mSv/y, which is in the range of WHO recommended value [34].
- The probability of getting lung cancer from a radon concentration of 37 Bq/m^3 is equal to 1.65 x 10^{-3} [11].

In view of above, the concentration of radon in soil (0.65 to 811.65 Bq/m3) recorded in the present study that can emigrate to the atmosphere was found to range from 0.013 to 16.23 Bq/m^3 and their effective dose varied from 0.0003 to 0.406 mSv/y. Moreover, the highest mean annual radon concentration of 811.65 and 784.28 Bq/m^3 at two of the monitored stations are respectively equivalent to 16.23 and 15.69 Bq/m^3 in the atmosphere. As a result, the effective doses in contact with point at these two places are respectively 0.406 and 0.392 mSv/y, which are below the recommended range of 1 mSv/y [35]. Further, the calculated probability value is very less in the present case (viz., < 0.72 x 10^{-3}), as the highest radon activity expected in air was 16.23 Bq/m^3.

Conclusions

The radon activity in soil air varies during the year owing to changes in the permeability and water content of the soil as well as ventilation of the upper horizons. Based on the classification adopted by Kemski et al., [18], the radon values in the soil-gas of Chitradurga district are low (< 0.8 kBq/m^3) enough to categorize them under low radon risk areas (viz., 10 kBq/m^3). The present study revealed that in the area under investigation, significant spatial variation in soil radon activity has been observed between sampling points (viz., annual mean radon activity: 0.65 to 811.65 Bq/m^3) wherein some samples showed higher radon activity and some the least; but temporally the variation were insignificant. Moreover, these values seem to be safe from the point of view of health hazards. It is worth to mention that variation in soil radon activity across the district can be attributed to the heterogeneity of uranium / radium distribution and mineralization in the soil / rocks and local permeability of the soil in addition to influence of lithology, soil types and structural attributes (thrusts faults and shears) in the study area. Further, the diffusion of radon through soil are governed by concentration of parent material in soil / rocks, emanation capacity of the ground, porosity of soil and rock, soil moisture in addition to meteorological parameters. There is a need for further study to discern systematic variation (increase / decrease) of soil radon concentration levels with depths from the ground surface. Measurements of soil gas radon along with soil air permeability could also promote investigating the sources and entry mechanisms of radon into homes to comply new radiation protection regulation to estimate health hazard index due to radiation exposure.

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