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Spatio-temporal Variation in Radon Concentration in Groundwater with Respect to Rock Types: A Case Study from Chitradurga District, Karnataka

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Abstract: An attempt was made in the present study to delineate how the radon concentrations vary with respect to different geological formations and to evaluate annual effective dose exposure due to ingestion of radon. A total of 60 groundwater samples were collected from layered sequential aquifers in Chitradurga district having major rock types such as Bababudan Group, Charnockite, Chitradurga Group, Closepet granite, migmatites and granodiorite – tonalitic gneisses and Sargur Schist complex during pre-monsoon and post-season of the year 2011. Radon measurement was made using Durridge RAD-7 radon-in-air monitor, connected to RAD H_2O accessory with closed loop aeration concept. In the present study, the radon activity ranged from 0 to 186.6 Bq/L and 0 to 150.6 Bq/L during pre- and post-monsoon seasons of the year 2011, with 56.67 % (17 samples) of samples during both the seasons exceeding the EPA's MCL value of 11.1 Bq/L. The annual mean radon activity in the groundwater was higher in the area having Chitradurga rock group formations (78.1 Bq/L) followed by Sargur-Satyamangalam schist complex group (56.8 bq/L), migmatites and granodiorite – tonalitic Gneisses group (56.3 Bq/L), Closepet granite (42.7 Bq/L), Charnonkite (29.1 Bq/L) and Bababudan Group (22.2 Bq/L). It is inferred that radon concentration found to depend on the tectonic structure, geology of the area and on the presence of uranium minerals in these rocks. The annual effective dose resulting from radon in groundwater in the Chitradurga district were significantly lower than UNSCEAR and WHO recommended limit of 1 mSv/y.

Keywords: Radon, Rock types, Ingestion, Health risk, Chitradurga, Karnataka.

INTRODUCTION

Radon is a naturally occurring, chemically inert, colourless, tasteless, odourless and alpha particle emitting radioactive gas, produced by natural radioactive decay of uranium, radium and thorium, found in trace amounts everywhere in the rocks and soils of the Earth's crust. Among the three naturally occurring isotopes of radon [viz., radon (^{222}Rn), thoron (^{220}Rn) and actinon (^{219}Rn)], Radon (^{222}Rn) is the most stable isotope, is produced from the decay of ^{238}U having natural abundance of about 99.3% of the total uranium within the Earth's crust.

Radon plays a dual role in man's life. On one hand its presence in soil, waters and rocks has greatly facilitated the identification and prediction of earthquake occurrence, volcanic activities, fault dislocation and hydrological research. On the other hand, its presence in high level in indoor environment and drinking water constitutes a major health hazard for mankind because of its carcinogenic effects (Karimdoust and Ardebili, 2010). It is possible that radon (^{222}Rn, $T_{1/2}$ = 3.825 day) is the second most important lung cancer-causing factor, after smoking (USEPA, 2009; UNSCEAR, 2000c), because more than 50% of natural radiation doses to the general public are delivered by radon, thoron and their daughter products (UNSCEAR, 2000b, c; Somlai et al., 2007; Prasad et al. 2012).

Being a naturally occurring radionuclide, chemically inert gas, heavier than air and emanating from rocks and soils, Radon exists everywhere in the environment and tends to accumulate in underground spaces such as caves. Although radium occurs in virtually all types of rocks and soils, its concentration varies with specific site and geological material (Gundersen et al. 1992; Choubey et al. 1997). Material with high concentrations of radium, such as granitic rocks and uranium minerals, would be expected to show elevated radon concentration in soil-gas and groundwater of such a mineralized area (Hess et al. 1985). Rock salt mines and caves are seems to be one of the most suitable environment compared with other geological

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formations due to their low level of natural radioactivity (Nikolov et al. 2011). Since, rocks of volcanic or limestone origin contain more uranium and thorium series than rocks of salt origin (Aytekin et al. 2006), Uranium and Thorium content of rocks are the primary control on observed radon activities in salt and fractured crystalline rocks (UNSCEAR, 2000c) while soil is recognized to be an important source of indoor radon. Radon and thoron were intensively studied in relation to lung cancer risk (Nazaroff and Nero, 1988), for geological purposes (Åkerblom and Mellander, 1997) and also for evaluating potential health risk due to human exposure through inhalation of radon in air (Binesh et al. 2010; Nikolov et al. 2011) and direct ingestion of radon in drinking water (Somashekar and Ravikumar, 2010; Ravikumar and Somashekar, 2013).

Efforts have been made to correlate soil-gas radon concentrations with factors such as geology, soil porosity, shears, thrusts and faults (Horton and Rogers, 1945; Fleischer and Mogro-Campero, 1978; Nazaroff and Nero, 1988; Ramola et al. 1989; Choubey et al. 1994; Lee and Kim, 2006). Since, the radioactive isotope and their radiation risk in ground water and their relationship to the major rock types are intermittent in an area. An attempt has been made for the first time in the present study to describe the relation between the geology of Chitradurga district and radon concentration in groundwater. Also efforts have been made to evaluate the extent of radiation dose that could be received due to ingestion of radon dissolved in drinking water in order to bring awareness and concern among the people residing in these areas about the radiological hazards.

STUDY AREA

Chitradurga district covers a geographical area of 8388 sq km located between 13°30'00" – 15°00' 00"N latitude and 76°00'00"E - 77°00'00"E (Fig 1). The area is hilly, with lots of forts and villages and derives its nomenclature from Chitrakaldurga, which is an etymological representation of an umbrella-shaped lofty hill located in the area. Physiographically, the area comprises of undulating plains, interspersed with sporadic ranges and isolated low ranges of bold rocky hills, picturesque valleys and huge towering boulders of different shapes. Geographically, it is 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 to the east. The district is divided into six taluks, namely Chitradurga, Hiriyur, Hosadurga, Holalkere, Challakere and Molakalmuru. Chitradurga district is one of the drought prone districts in the state as it receives low to moderate rainfall. The normal annual rainfall based on 30 years is 574 mm and varies between 600 mm to 700 mm. Normal annual rainfall varies between 668 mm in Holalkere / in western part to 457 mm in Chellakere, in the northeastern part. However, in the last decade (1996-2005) the area received an average annual rainfall of 631.7 mm. Lowest rainfall in Chellakere taluk and highest in Hosadurga taluk has been recorded. It is rich in mineral deposits, including gold at Halekal, Kotemardi or Bedimaradi and copper mines at Ingaldhal. Major soil types include deep and shallow black soil, mixed red and black soil, red loamy and sandy soil.

GEOLOGY AND HYDROGEOLOGY

The district lies in the heart of the Vedavati river valley. Major part of the district lies in Krishna basin and is drained by Vedavathi river, with the Tungabhadra river flowing in the northwest. Reservoir is built across the Vedavathi river near Vanivilaspura, in Hiriyur taluk. The canal network provides irrigation facilities to the farmers in Hiriyur taluk and for a few villages situated outside the taluk limit as well. The other streams are Janagahalli, Chikhagari, Swarnamukhi, Garain and Nayakanahallihalla (Fig.1). Agriculture in the district is mainly dependent on the timely and adequate rainfall. Across Vedavathi river and its tributaries, the following irrigation projects are commissioned; (1) Vanivilassagara, (2) Gayathri reservoir, (3) Rangayanadurga reservoir and (4) Narayanapura anicut. In addition to the above, there are about 300 tanks in the district providing irrigation facilities to small stretches of lands. The area is generally gently sloping from southwest to east. The drainage density varies from 0.72 to 1.70 km/km^2 and general ground elevation ranges from about 500 m amsl to 800 m amsl (Cevik et al. 2006). The groundwater usually occurs at depth in the fractures and fault zone of the crystalline rocks under semi-confined to confined conditions. Major water bearing formations are fractured / weathered gneisses and granite, with thickness of the weathered zone varying from less than a meter near hill slopes and higher altitudes to about 39 m in valleys and low lying areas. The main source of groundwater is through precipitation and return flow from irrigation. The main water bearing formations in the six taluks of Chitradurga district are:

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

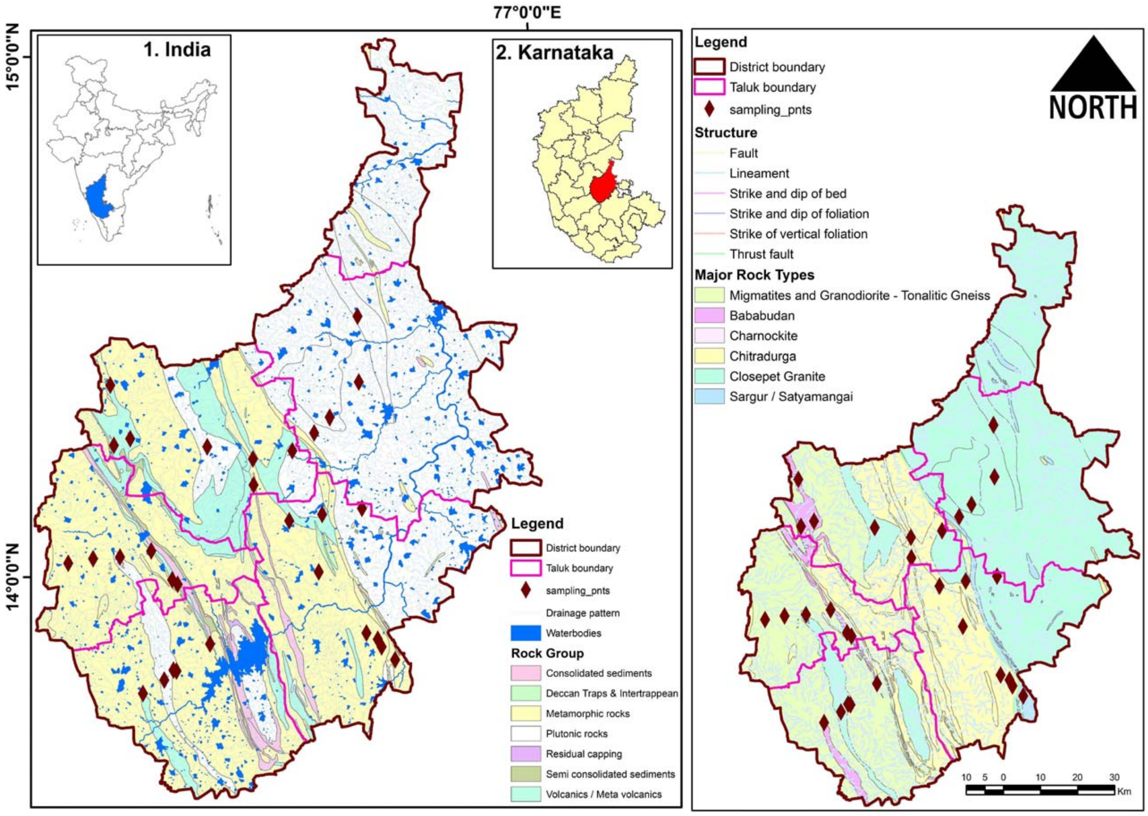

Fig 1. Location map of Chitradurga district showing drainage pattern, sampling stations and major rock groups / types

d Hosadurga and Hiriyur taluks: granitic-gneisses, and schists

e Holalkere taluk: gneisses, schists and greywackes

Groundwater occurs under phreatic condition in the weathered rock formations comprising of granites, gneisses and schists. The major rock type identified in the study area were Bababudan Group, Charnokites, Chitraduga Group, Closepet granite type, migmates and dolerites and Sargur-Satyamangalam schist complex (Fig 1) (CGWB, 2007). Composition of each rock group is given in Table 1. Chitraduga Group is mainly composed of consolidated sediments, Deccan traps and intratrappean beds, metamorphic rocks, plutonic rocks, residual cappings, semi-consolidated sediments and meta-volcanic rock types. These rocks are mainly distributed in Chitraduga and Hiryur taluks and in patches in Holalkere and Hosdurga taluks. Bababudan Group is mainly composed of metamorphic rocks and volcanic / metavolcanic rocks, distributed in patches in Chitradurga, Holalkere and Hosadurga taluks. Charnockites are 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 occurs in Molakalmur, Challakere, Hiriyur taluks and as patches in all other taluks. Migmatites and granodiorite - tonalitic gneisses are distributed mainly in Hosadurga and Holalkere taluks and as patches in Chitradurga taluk. The area has been subjected to deformation resulting in faults and lineaments.

METHODOLOGY

Water Sampling: On-site Activities

The aim of the study was to establish spatio-temporal variation in radon concentration in different bore well samples from various villages in different taluks of Chitradurga district. Random sampling was carried out in such a way that bore well samples represent each of the rock types prevailing in the study area. A total of 30 pre-monsoon and 30 post-monsoon groundwater samples were collected, after purging the well by pumping (to ensure sample quality) from different parts of Chitradurga district during the year 2011. The samples were collected in glass vials of 40 and 250 ml capacity, specially designed for radon-in-water activity measurement ensuring minimum

Table 1. Categorization of different rock formations in Chitradurga district

Stratigraphy	Rock groups	Rock types	Area (km^2)
Archaean	Migmatites and Granodiorite - Tonalitic Gneiss	Metamorphic rocks	36501.13
	Charnockite	Metamorphic rocks Plutonic rocks	15.82 0.55
	Closepet Granite	Plutonic rocks	15784.92
	Sargur / Satyamangalam - Schist complex	Consolidated sediments Metamorphic rocks	5.55 388.16
Archaean to lower Proterozoic	Bababudan	Metamorphic rocks Volcanics / Meta-volcanics	42.31 891.59
	Chitradurga	Consolidated sediments Deccan Traps and Intertrappean Metamorphic rocks Residual capping Semi-consolidated sediments Volcanics / Meta-volcanics	200.66 20.77 5424.85 12.76 44.59 579.51
Upper Proterozoic	Migmatites and Granodiorite - Tonalitic Gneiss	Plutonic rocks	4.42
	Closepet Granite	Plutonic rocks	2368.32
		Grand Total	62285.91

Source: GSI, 2006 [11], http://www.chitradurga.nic.in/maps.html [35]

radon loss by degassing (UNSCEAR, 1988) and without any air contact. The collected samples were then transferred to the laboratory at Department of Environmental Science, Bangalore University for radon analysis.

Analysis of Radon: Laboratory Measurements

Radon concentration in water samples were measured using RAD-7 radon-in-air monitor instrument (Durridge Co., USA) connected to RAD-H_2O accessory with closed loop aeration concept (Marian Romeo Calin, 2012). RAD H_2O technique employs closed loop concept, consisting of three components, (a) the RAD7 or radon monitor, (b) the water vial with aerator and (c) the tube of desiccant, supported by the retort stand (Fig 2). The methodology followed to measure radon concentration has been detailed in the articles by Somashekar and Ravikumar (2010) and Ravikurmar and Somashekar (2013). The instrument will express ^{222}Rn activities in Bq/m^3 (disintegration per second per m^3) with 2σ uncertainties. But, radon concentrations in water can be very high, in the hundreds of thousands of Becquerels per cubic meter (Bq/m^3) and hence, it was multiplied by 1000 to express in Becquerels per litre (Bq/L).

Health Risk

An Internationally prescribed radioactivity exposure limit is 1 mSv/year (UNSCEAR, 2000b; Xinwei and Xiaolan, 2004). For calculation of annual effective dose, a dose conversion factor of 5 x 10^{-9} Sv/Bq for ^{222}Rn suggested by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1996) has been used. Annual effective dose due to ingestion of ^{222}Rn dissolved in drinking water has been calculated considering that an adult (Age > 18 y), on average, takes 730 L water annually (Binesh, 2010; Somashekar and Ravikumar, 2010; Ravikurmar and Somashekar, 2013). The annual effective dose is usually expressed in terms of sievert (Sv) or micro-sievert (μSv) or mili-sievert (mSv) per year. The annual effective doses (mSv/y) and effective doses per litre (nSv/L) were calculated using the equation:

Annual effective dose = (radon activity concentration, Bg/L) x (annual water consumption, L) x (dose conversion factor, Sv/Bq)

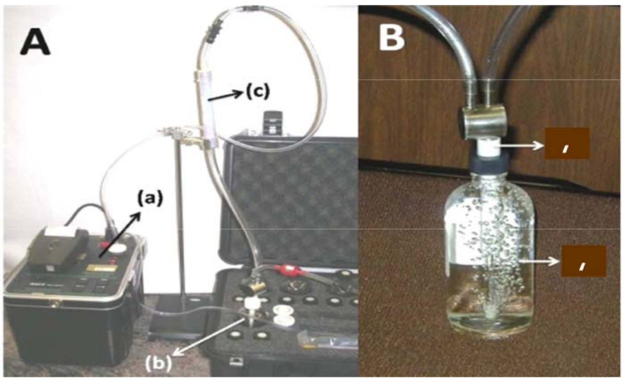

Fig.2. **(A)** Experimental set-up **(B)** Aerating a water sample in 250 ml glass vial

Table 2. Radon concentration and Annual effective dose in bore wells samples of Chitradurga district and sampling location details

Sl No	Rock types	Sample ID	Taluk	Place Name	Latitude	Longitude	Elevation (m)	Depth (ft)	Well type	Premonsoon 2011			Post-monsoon 2011		
										Water level	^{222}Rn (bq/l)	EDE (mSv/ y)	Water level	^{222}Rn (bq/l)	EDE (mSv/ y)
1	Bababudan group	BA-1	Chitradurga	Kolahalu	14.369 N	76.175 E	655	480	Bore	80	64.2	0.234	95	60.0	0.219
2		BA-2	Hosadurga	Adavisangenahalli	13.777 N	76.240 E	600	700	Bore	150	32.8	0.120	160	20.5	0.075
3		BA-3	Chitradurga	Medakeripura	14.267 N	76.214 E	480	320	Bore	115	0.0	0.000	110	0.0	0.000
4		BA-4	Chitradurga	Sirigere	14.254 N	76.182 E	757	900	Bore	300	0.0	0.000	285	0.0	0.000
5	Charnokite	C-1	Hosadurga	Ramajanahalli	13.872 N	76.372 E	785	700	Bore	200	143.0	0.522	205	89.4	0.326
6		C-2	Holalkere	Gundikere	13.987 N	76.308 E	760	900	Bore	330	0.0	0.000	340	0.0	0.000
7		C-3	Holalkere	Madderu	14.051 N	76.256 E	501	780	Bore	140	0.0	0.000	135	0.0	0.000
8		C-4	Holalkere	Ghattihosahalli	13.996 N	76.297 E	855	520	Bore	150	0.0	0.000	155	0.0	0.000
9	Chitraduga group	CH-1	Hiriyur	Metakurike	14.011 N	76.586 E	800	300	Bore	80	186.6	0.681	85	150.6	0.550
10		CH-2	Hiriyur	Maradidevagere	14.109 N	76.528 E	674	620	Bore	150	99.6	0.364	180	89.6	0.327
11		CH-3	Chitradurga	Kurumaradikere	14.178 N	76.457 E	602	650	Bore	250	54.8	0.200	260	34.3	0.125
12		CH-4	Hiriyur	Bagganadukaval	13.893 N	76.680 E	657	900	Bore	200	27.6	0.101	210	20.2	0.074
13		CH-5	Chitradurga	Kanchiganhal	14.228 N	76.456 E	576	400	Bore	120	63.2	0.231	125	54.3	0.198
14	Closepet granite group	CL-1	Hosadurga	Chennasamudra	14.039 N	76.194 E	507	360	Bore	120	0.0	0.000	130	0.0	0.000
15		CL-2	Hosadurga	Duggavara	13.803 N	76.281 E	685	850	Bore	110	125.5	0.458	95	78.4	0.286
16		CL-3	Challakere	Varavookaval	14.121 N	76.593 E	787	300	Bore	55	59.0	0.215	60	36.9	0.135
17		CL-4	Chitradurga	Kurudahalli	14.278 N	76.577 E	810	680	Bore	460	104.7	0.382	430	65.5	0.239
18		CL-5	Chitradurga	Lingarahatti	14.308 N	76.608 E	784	720	Bore	200	132.8	0.485	202	83.0	0.303
19		CL-6	Challakere	Hirehalli	14.501 N	76.663 E	518	120	Bore	3	0.0	0.000	3	0.0	0.000
20		CL-7	Challakere	Chenaganahalli	14.375 N	76.665 E	830	850	Bore	100	0.0	0.000	104	0.0	0.000
21		CL-8	Hiriyur	Kandikere	14.133 N	76.671 E	844	900	Bore	110	0.0	0.000	110	0.0	0.000
22		CL-9	Chitradurga	Ayyanahalli	14.252 N	76.366 E	780	150	Bore	40	96.8	0.353	50	72.2	0.264
23		CL-10	Chitradurga	Sajjanakere	14.244 N	76.534 E	582	750	Bore	150	0.0	0.000	150	0.0	0.000
24	Migmatites and Granodiorite - Tonalitic Gneiss	MI-1	Holalkere	Hoannakalve	14.036 N	76.141 E	485	270	Bore	80	0.0	0.000	85	0.0	0.000
25		MI-2	Hosadurga	Sivanakatte	13.822 N	76.300 E	477	680	Bore	250	138.6	0.506	260	90.2	0.329
26		MI-3	Holalkere	Chikkayammiganuru	13.820 N	76.306 E	798	320	Bore	110	120.6	0.440	115	101.2	0.369
27		MI-4	Hosadurga	Rangapura	14.027 N	76.092 E	950	400	Bore	130	0.0	0.000	135	0.0	0.000
28	Sargur / Satyamangalam -Schist complex	SC-1	Hiriyur	Javanagondanahalli	13.866 N	76.710 E	571	750	Bore	80	80.8	0.295	85	71.5	0.261
29		SC-2	Hiriyur	Kariyala	13.842 N	76.736 E	600	350	Bore	50	2.4	0.009	55	2.0	0.007
30		SC-3	Hiriyur	Alur	13.881 N	76.702 E	607	500	Bore	50	99.2	0.362	60	85.0	0.310

Note: EDE - annual effective dose or effective dose equivalent rate; EDL- Effective dose per litre

Construction of Distribution Map

Geostatistical Analytical tool uses sample co-ordinates at different locations in a landscape and creates (interpolates) a continuous surface. Hence, in the present study, Kriging algorithm method available under Geostatistical Analyst tool in ArcGIS v 9.2 software was employed to construct contour / iso-concentration map to represent "spatio-temporal variation in radon and annual effective dose.

RESULTS AND DISCUSSION

Variation in Radon Activity with respect to Different Rock Types

The radon activity in the groundwater samples collected in areas with different rock formations are as follows:

a) In the area of Bababudan Group of rocks, it ranged from 0 to 64.2 Bq/L (avg. 24.25 Bq/L) and 0 to 60 Bq/L (avg. 20.13 Bq/L) respectively during pre- and post-monsoon season.

b) In the area consisting of charnokite, it varied from 0 to 143 Bq/L (avg. 35.75 Bq/L) and 0 to 89.4 Bq/L (avg. 22.35 Bq/L) respectively during pre- and post-monsoon season.

c) In the area with Chitradurga Group of rocks, it ranges from 27.6 to 186.6 Bq/L (avg. 86.36 Bq/L) and 20.2 to 150.6 Bq/L (avg. 69.8 Bq/L) respectively during pre- and post-monsoon season.

d) In the area encompassing Closepet granite, it varies from 0 to 132.8 Bq/L (avg. 51.88 Bq/L) and 0 to 78.4 Bq/L (avg. 33.6 Bq/L) respectively during pre- and post-monsoon season.

e) In the area containing migmatites and granodiorite - tonalitic gneisses, it range between 0 to 138.6 Bq/L (avg. 64.8 Bq/L) and 0 to 101.2 Bq/L (avg. 47.85 Bq/L) respectively during pre- and post-monsoon season.

f) In the area with Sargur / Satyamangalam schist complex, it varies between from 2.4 to 99.2 Bq/L (avg. 60.8 Bq/L) and 2 to 85 Bq/L (avg. 52.83 Bq/L) respectively during pre- and post-monsoon season.

The mean radon activity in groundwater samples for pre- and post-monsoon seasons (Fig 3) of the year 2011 was in the order of

g) Pre-monsoon 2011: Bababudan Group < Charnonkite Group < Closepet granite < Sargur-Satyamangalam schist complex < migmatites and granodiorite – tonalitic gneisses < Chitradurga Group.

h) Post-monsoon 2011: Bababudan Group < Charnonkite < Closepet granite < migmatites and granodiorite – tonalitic gneisses < Sargur-Satyamangalam schist complex group < Chitradurga Group.

Overall, the annual mean radon activity and exposure dose rate in the groundwater was higher in the area having Chitradurga Group of rocks (78.1 Bq/L) followed by Sargur-Satyamangalam schist complex (56.8 Bq/L), migmatites and granodiorite – tonalitic gneisses (56.3 Bq/L), Closepet granite (42.7 Bq/L), Charnonkite (29.1 Bq/L) and Bababudan Group (22.2 Bq/L). Potential factors for high radon concentration could be structure, geology and even presence of uranium minerals in these rocks (Fig 3). The presence of thrusts, faults and shears can facilitate upward migration of radon gas (Choubey et al. 1994). There is also possibility that radium can migrate during weathering and be separated from the parent ^{238}U. Simultaneously, the water gets enriched in radon by dissolving radon which emanates from the deeper parts of the crust (CGWB, 2007) through these structures.

Spatio-temporal Variation in Radon Concentration

The US Environmental Protection Agency (USEPA, 1991) proposed a standard for radon contamination in drinking water known as the maximum contaminant level (MCL) of 11.1 Bq/L (300 pCi/L or 11.1 kBq/m^3) for public water supplies. In the present study, the radon activity ranged from 0 to 186.6 Bq/L during pre-monsoon (Fig.4) and 0 to 150.6 Bq/L during post-monsoon (Fig.5) seasons of the year 2011. Highest radon activity was noticed in sample no. CH1 (viz., 186.6 and 150.6 Bq/L) during both the seasons while the twelve samples (viz., C-2, C-3, C-4, BA-3, BA-4, CL-1, CL-6, CL-7, CL-8, CL-10, MI-1, MI-4) showed zero radon activity. It is evident from the results (Table 2) that 56.67 % of the samples (i.e., 17 samples) exceeded the EPA's MCL

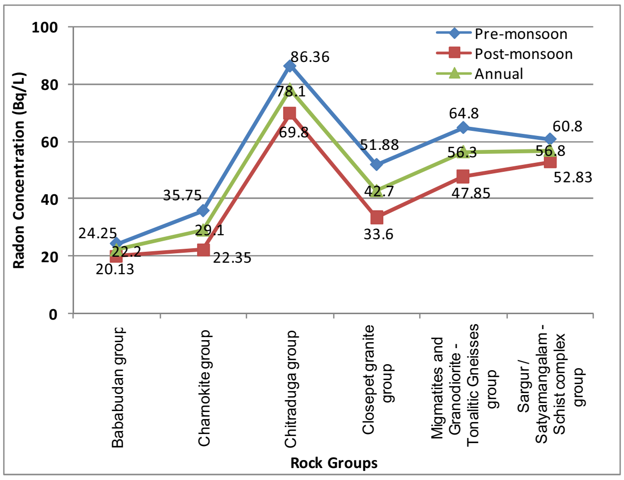

Fig.3. Temporal variation in the mean radon activity in various rock groups

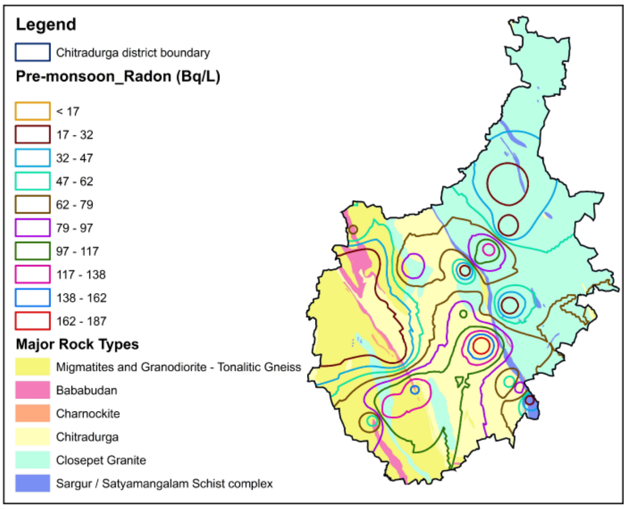

Fig.4. Lithology map overlaid with Radon distribution map in the bore wells samples of Chitradurga district (Pre-monsoon 2011).

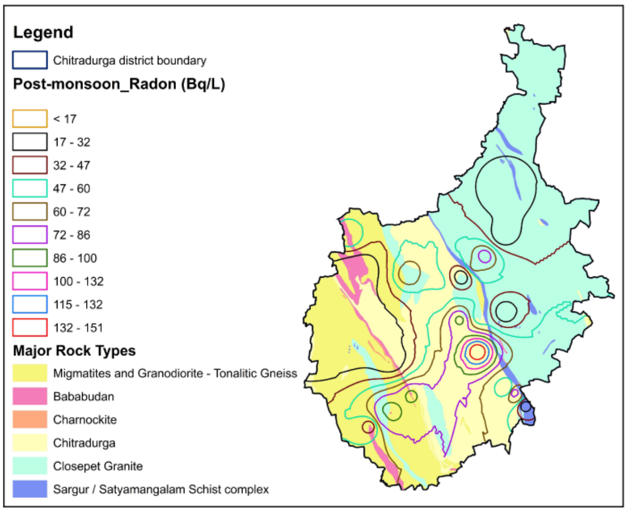

Fig.5. Lithology map overlaid with radon distribution map in the bore wells samples of Chitradurga district (Post-monsoon 2011).

value of 11.1 Bq/L during both pre- and post-monsoon seasons .

In the present study, the annual effective dose (EDE) varied from 0 to 0.681 mSv/y and 0 to 0.55 mSv/y respectively during pre-monsoon post-monsoon seasons (Fig 6), while the effective dose per litre (EDL) ranged from 0 to 933 nSv/L and 0 to 753 nSv/L during pre- and post-monsoon seasons (Table 2) respectively. The dose rates due to ingestion of radon in drinking water in the present study were significantly lower than the UNSCEAR (2000a) and WHO (1993) recommended limit of 1 mSv/y. These values were very high compared to the dose gathered by Somashekar and Ravikumar in the Varahi river basin (0.73 to 36.87 µSv/y) in Udupi district and Markandeya river basin (8.07–99.65 µSv/y) in Belgaum district in Karnataka (Somashekar and Ravikumar, 2010). Similarly, Xinwei and Xiaolan (2004) studied radon effective dose rates in males and females due to ingestion of tap and well water used for drinking purposes from three main cities namely Xi'an, Xianyang and Baoji of Shaanxi province, China and it was noticed that the mean annual effective dose of radon to male and female was varying from 0.068 to 0.457 mSv/y and 0.060 to 0.402 mSv/y respectively. It has been shown that the overall radiation dose due to radon emanating from water can increase with increase in age and water consumption rates (Ravikumar and Somashekar, 2013).

CONCLUSION

The present study showed that the radon concentration in more than 50% of the groundwater samples of the Chitradurga district during both the seasons was higher than EPA's MCL values. The annual mean radon activity as well as annual effective dose in the groundwater was higher in the area having Chitradurga Group of rocks followed by Sargur-Satyamangalam schist complex, migmatites and granodiorite – tonalitic gneisses, Closepet granite, charnonkite and Bababudan Group. This clearly indicates that radon concentration primarily depends on the lithology / geology, tectonic structure and even presence of uranium minerals in rocks. The total annual effective dose resulting from radon in groundwater in the Chitradurga district were significantly lower than the UNSCEAR and WHO recommended limit of 1 mSv/y. Due to high radon concentrations in the groundwater samples and low effective dose rate resulting from them, continuous monitoring of groundwater samples to keep a watch on the radon exposure dose rate is very much necessary. Hence, a detailed investigation of radon concentration in all the groundwater sources throughout the Chitradurga district needs to be initiated in future to increase awareness and mitigate possible hazards.

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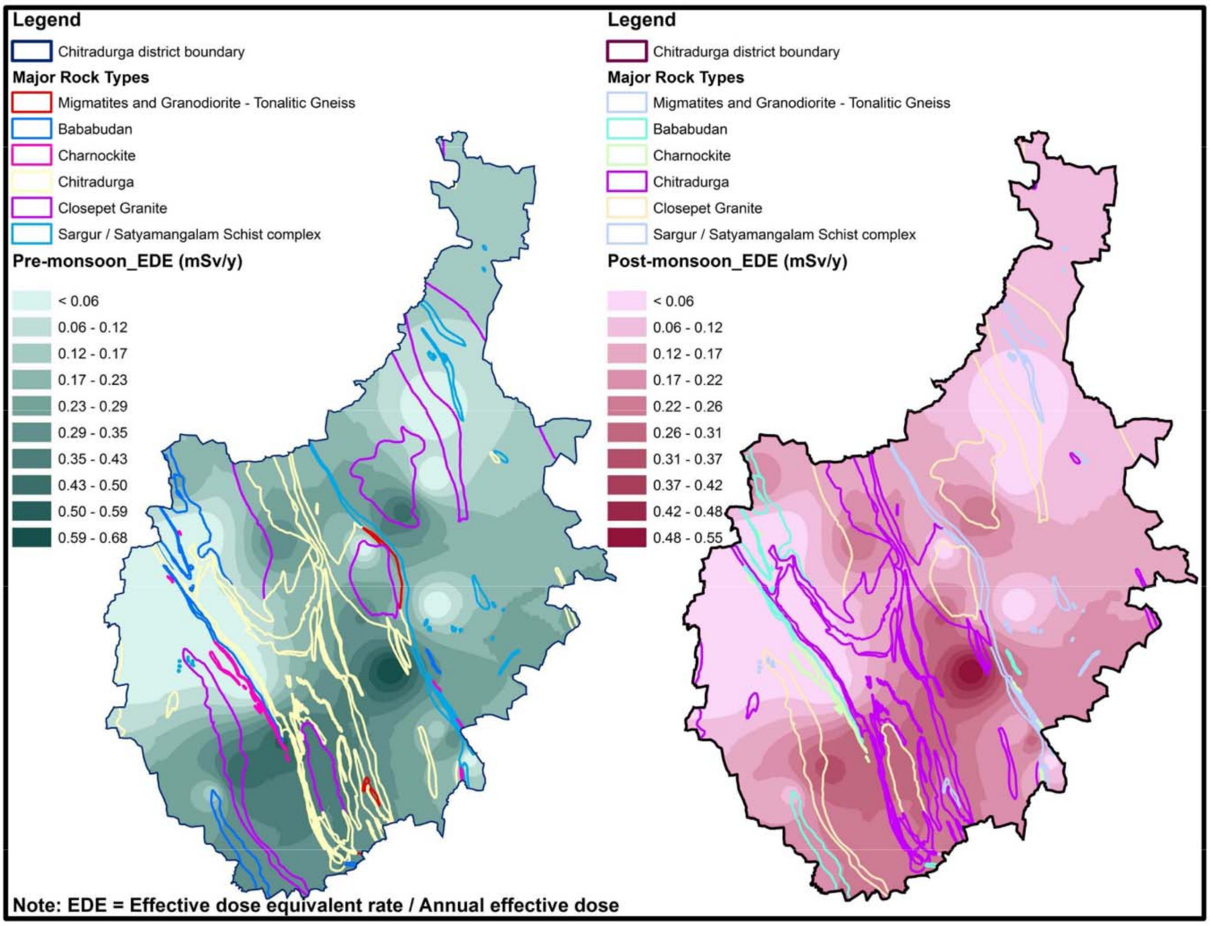

Fig.6. Distribution map of Annual Effective dose showing spatio-temporal variation in bore wells samples of Chitradurga district (Pre- and Post- monsoon 2011)

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