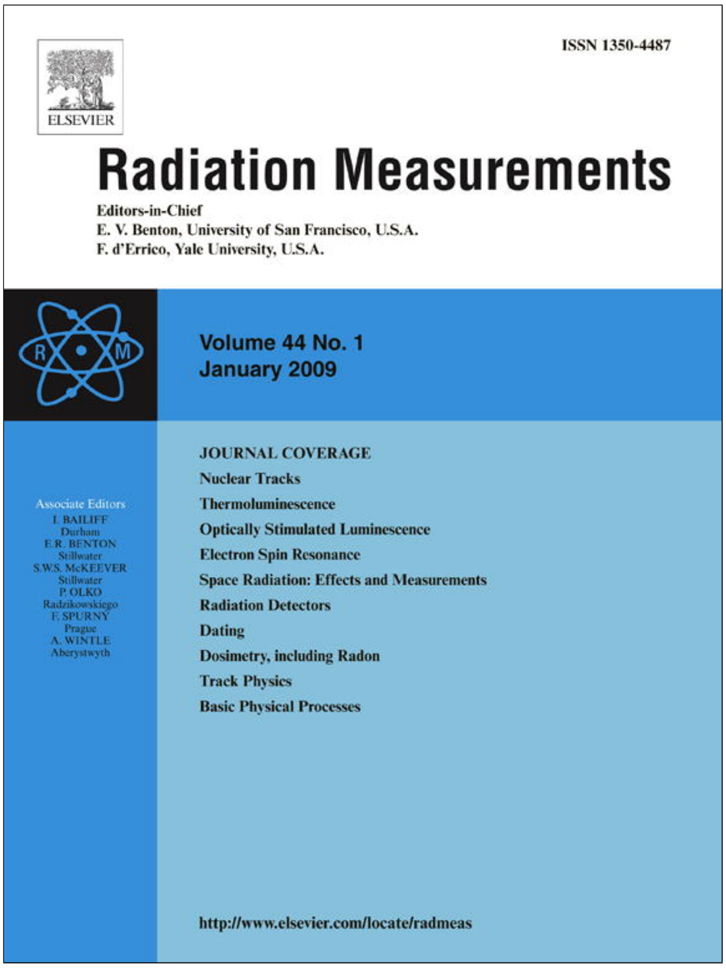

ISSN 1350-4487

Radiation Measurements

Volume 44 No. 1
January 2009

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Radiation Measurements 44 (2009) 122–126

Contents lists available at ScienceDirect

Radiation Measurements

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Short communication

Geohydrological control on radon availability in groundwater

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ARTICLE INFO

Article history:
Received 2 August 2007
Received in revised form
15 July 2008
Accepted 11 October 2008

Keywords:
Radon
Springs
Groundwater
Geohydrology
Himalaya

ABSTRACT

The radon content in groundwater sources depends on the radium concentration in the rock of the aquifer. Radon was measured in water in many parts of the world, mostly for the risk assessment due to consumption of drinking water. The exposure to radon through drinking water is largely by inhalation and ingestion. Airborne radon can be released during normal household activities and can pose a greater potential health risk than radon ingested with water. Transport of radon through soil and bedrock by water depends mainly on the percolation of water through the pores and along fractured planes of bedrock. In this study, radon concentration in springs and hand pumps of Kumaun and Garhwal Himalaya, India was measured using radon emanometry technique. The study shows that radon concentration in springs and hand pumps is controlled by geohydrological characteristics, which in turn is also governed by tectonic processes.

1. Introduction

Uranium, radium and radon are naturally occurring elements and are primarily present in groundwater. Radon can be found in all groundwater with large variations in its concentration. The radon content in groundwater sources depends on the radium concentration in the rock of the aquifer (Choubey and Ramola, 1997). Radon is frequently used for uranium exploration (Smith et al., 1976; Ramola et al., 1989; Nelms and Selby, 2005), searching hidden fault/thrust (Immè et al., 2006; Ramola et al., 2008), radiation protection purposes (UNSCEAR, 1993; Radolić et al., 2005), discrimination between ground and surface water (Burnett et al., 2003; Schubert et al., 2008), subsurface Non-Aqueous Phase-Liquids (NAPL) contamination (Schubert et al., 2001, 2002) and correlation with seismic activities (Ramola et al., 1990; Bilham and England, 2001; Einarsson et al., 2008). High levels of radon are known to occur in spring water of areas underlain by granitic or high-grade metamorphic bedrocks that contain uranium and formed under high temperature and pressure conditions (Tanner, 1986). Radon concentrations in groundwater vary with time because of factors such as dilution by recharge or changes in contributing areas of the aquifer due to pumping. Water borne radon commonly is a concern only for those who use groundwater sources for their drinking water supply.

The main sources of drinking water in the Garhwal and Kumaun regions are the springs and hand pumps. Water transport time of radon from groundwater–air interface to dwellings is of the order of few minutes and can pose significant risk to the inhabitants. It is therefore desirable and possibly necessary to measure radon in drinking water of Himalayan region (Ramola et al., 1999). This study presents the results of radon measurements in the water samples of various springs and hand pumps with different geological settings in Garhwal and Kumaun Himalayas (Fig. 1). Efforts are made to correlate the radon availability in water with types of springs.

2. Geohydrological framework of springs

The Himalayan springs are categorized into four parts according to the water bearing behaviour in these springs and its movement within the recharge zone. Geohydrology is utilized to explore various aspects of radon emission from the groundwater sources having a static geological feature. Groundwater comes up to the surface of the earth as utilizable water in the form of springs and hand pumps through faults, fractures, joints and permeable layers or zones. Direct infiltration of rainwater through joints, fractures and weathered zones is the main cause of recharge of the springs (Valdiya and Bartarya, 1991). In Himalayas, at least following two types of water bearing formation can be recognized:

1. *Fractured hard rocks* of Vaikrita, Munsiari, Bhatwari and Berinag formations having secondary porosity and permeability are characterized by spring and seepages. The zones of lineament,

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doi:10.1016/j.radmeas.2008.10.006

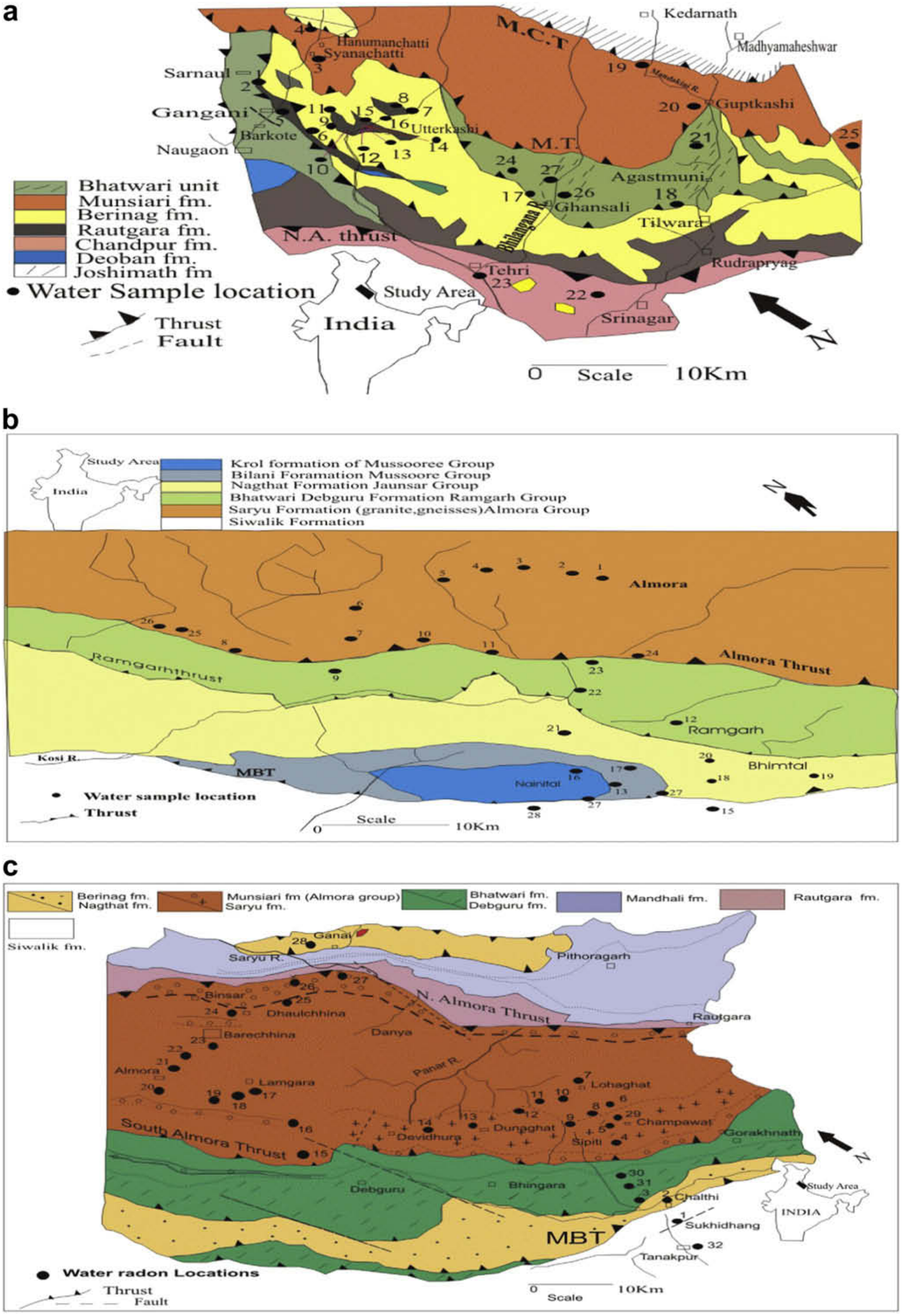

Fig. 1. Locations of water samples in (a) Garhwal, (b) South Kumaun and (c) North-East Kumaun Himalayas.

faults and thrusts show pockets of high secondary porosity and permeability. The groundwater/surface water in this zone occurs largely as disconnected local bodies on favourable zones of jointing, fractures and joints and from weathered material. The springs in the rocks having secondary porosity show great variability in yield even within short distance.

2. *Fluvial and colluvial deposits* lying along the lower and middle valley slope in lower reaches of the stream or near the confluence of two streams in the form of fans and terraces and old landslide deposits are highly porous and permeable and therefore hold sufficient quantities of water. The spring shows wide variability in discharge.

Based on the genesis, nature of water bearing formation and conditions governing the formation of springs such as recharge and discharge areas (as discussed above) and their relationship with geomorphology, lithology and structure of the rocks and on the pattern of earlier work of Valdiya and Bartarya (1991) and Choubey et al. (2000a), four types of springs have been identified in the study area (Fig. 2):

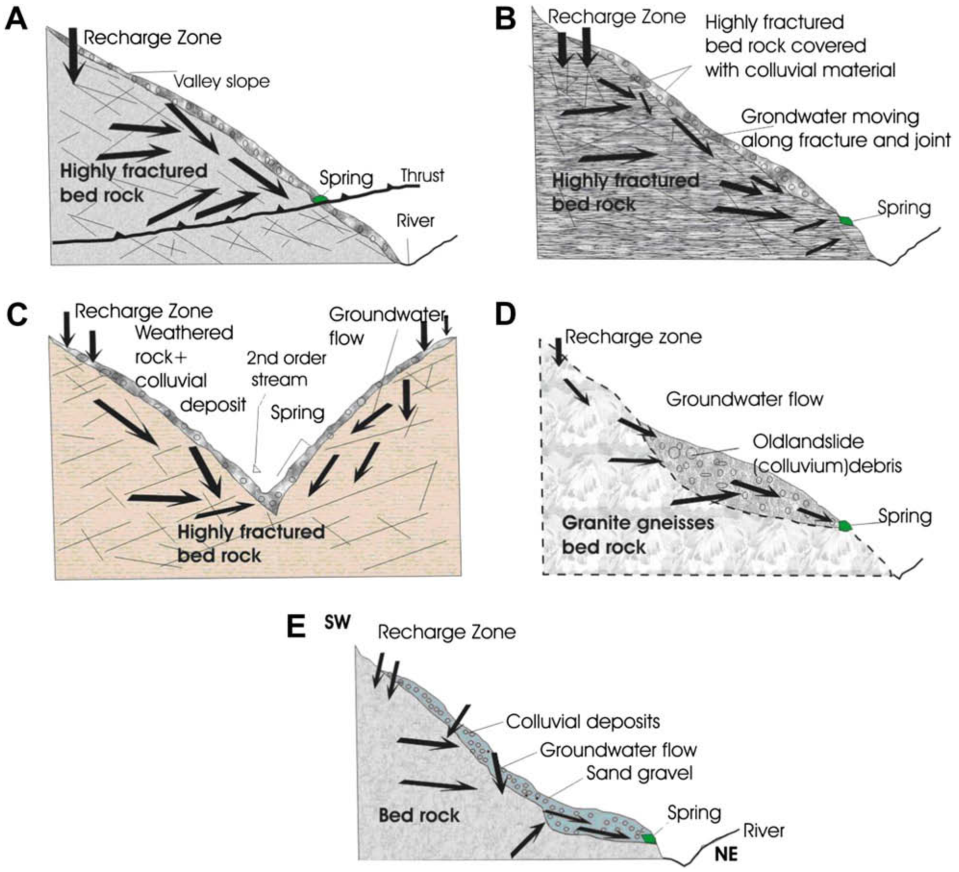

Fig. 2. Cross-section of different spring types, (A) Fault-lineament related spring, (B&C) Fracture-joint related spring, (D) Colluvial-related spring and (E) Fluvial related spring.

- Fault-lineament related spring (FL)
- Fracture -joint related spring (FJ)
- Colluvial spring and seepages (CL)
- Fluvial springs (FD)

They are classified in such a way that if fractures and joints are major controlling factors and colluvial/fluvial deposits have played an important role in their formation, they are termed, respectively, as fracture-joint related and colluvial/fluvial related springs. Locally, colluvial and fracture related springs occur in conjunction so that the discharge of colluvial deposits also receives groundwater flowing down along fractures and joints. However, the water discharge of the springs fluctuates with the rainfall during rainy season.

3. Experimental method

The radon measurements were made in springs and groundwater from hand pumps being used as drinking water sources by general population. The hand pumps and springs were selected near the dwellings and workplaces, where the general public utilizes these water sources for their daily needs. The water samples from springs were collected in an air-tight bottle from the original discharge point (outlet) of the spring having distinct geological unit and geo-hydrological regime. The water was transferred from discharge point of the spring to the bottom of the bottle using PVC tubing. For hand pumps, the water was pumped out for some time and the samples were collected in 1 L bottle directly from the pump outlet.

After allowing the sample bottle to overflow for a while and when no bubbles were visually observed, the sample volume was reduced to a pre-marked position leaving 250 ml of air in the bottle above the water surface. The sample bottle was then connected in a close circuit with Lucas cell, hand operated rubber pump and a glass tube containing $CaCl_2$ to absorb the moisture (Fig. 3). The air was then circulated in close circuit for a period of 15 min till the radon formed a uniform mixture with the air and the resulting alpha activity was recorded (Ramola et al., 1989). The resulting number of the alpha counts were then converted into Bq/l by using the calibration factor 1 count/min = 0.0663 Bq/l (Choubey et al., 2000b).

4. Results and discussion

The results of radon measurements in springs and hand pumps from the study area are given in Table 1. Radon concentrations in springs and hand pumps were found to vary from 1 Bq/l to 624 Bq/l,

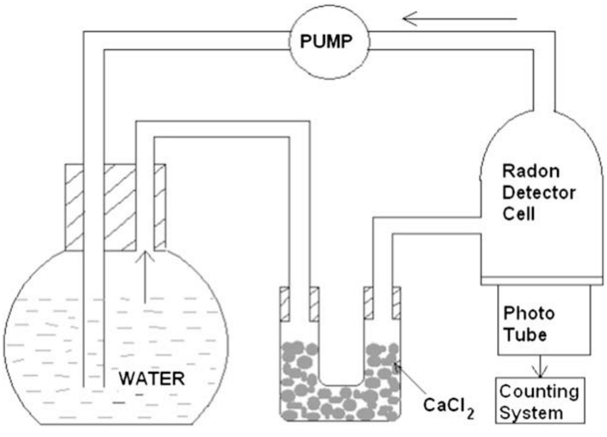

Fig. 3. Schematic diagram for radon measurement in water.

Table 1
Radon concentration (Bq/l) with spring type.

Spring type	Zones																
	Garhwal Himalayas (Bq/l)				South Kumaun (Bq/l)				North-East Kumaun (Bq/l)				Total value (Bq/l)				
	Min	Max	GM	AM	Min	Max	GM	AM	Min	Max	GM	AM	Min	Max	GM	AM	Median
Colluvial	1	19	6	8	1	21	6	9	5	51	17	22	1	51	8	12	8
Fracture-joint	12	46	23	29	N.A	N.A.	N.A.	N.A.	94	336	123	143	12	336	81	115	106
Fault-lineament	13	116	51	62	51	68	59	60	52	279	107	126	13	279	72	90	69
Colluvial/fracture-joint	88	168	122	128	2	76	12	30	33	44	36	37	2	168	33	57	39
Fluvial spring	6	12	8	9	N.A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A	6	12	8	9	9
Hand pump	35	624	82	145	3	392	40	75	14	502	68	122	3	624	56	105	62

with geometric and arithmetical mean values of 35 Bq/l and 75 Bq/l, respectively. The study is divided into different groups on the basis of the samples collected from Garhwal, South Kumaun and North-East Kumaun Himalayas.

The radon concentrations in spring water and hand pumps of Garhwal Himalaya vary from 1 Bq/l to 168 Bq/l with a geometric mean value of 28 Bq/l and from 35 Bq/l to 624 Bq/l with a geometric mean value of 82 Bq/l, respectively. The maximum radon values, both in spring and hand pump (168 Bq/l and 624 Bq/l), were found at two different locations in the same geological formation (Bhatwari Formation) near Main Central Thrust in Garhwal Himalaya. The main rock types of this formation are granite and granite porphyry. The rock succession of Bhatwari formation is separated from the underlying Berinag formation of Jaunsar group by Bhatwari thrust. The minimum radon concentrations in spring water and hand pump (1 Bq/l and 35 Bq/l) were recorded in Rautgara formation but at different locations. Rock types of this formation are basic sills and slates. Since no accumulation of uraniferous surficial sediments is known to occur in the study area, it is likely that radon comes from some nearby bedrock source where uranium has been concentrated such as fault/thrust zone or fracture zone within the granite, gneiss and porphyry of Bhatwari and Munsiari formations (Choubey et al., 2000a; Nashine et al., 1982). The radon concentration in spring water of south Kumaun Himalaya varies from 1 Bq/l to 76 Bq/l with a geometric mean of 10 Bq/l, whereas in hand pumps it varies from 3 Bq/l to 392 Bq/l with a geometric mean of 40 Bq/l. The higher values of radon in the water samples of hand pumps are possibly because of its greater depth, which allows water to interact with a greater thickness of aquifer and thus adds more radon to hand pumps and tube wells water.

In North-East Kumaun Himalaya, the radon concentration in spring water varies from 5 Bq/l to 336 Bq/l with a geometric mean value of 61 Bq/l, while in hand pumps it was found to vary from 14 Bq/l to 502 Bq/l with a geometric mean value of 68 Bq/l. The minimum recorded radon value in this region is higher than those recorded in Garhwal and south Kumaun Himalaya regions. The springs and hand pumps in North-East Kumaun region drain through predominantly augen gneiss of granite to granodiorite, composition of Champawat granodiorite and thus produce high radon concentration in water.

The distribution of radon in the springs of Garhwal and Kumaun Himalayas may also be interpreted with the residence time of water to interact with lithology and flow rate. The high radon concentrations in two spring types i.e. fracture-joint (FJ) (12 Bq/l to 336 Bq/l) and fault-lineament (FL) (13 Bq/l to 279 Bq/l) are due to the localized ^{238}U or ^{226}Ra near the springs in shear zones of Almora thrust, Munsiari thrust and Bhatwari thrust. Bhatwari thrust having U_3O_8 from 0.037 to 0.78% in the form of pitchblende uraninite and flour-apatite associated with sericite–biotite granite, pelitic gneiss and sheared mylonites (Nashine et al., 1982). In this area, most of the springs are generated by the faults and fractures. The deep situated uranium and radium may act as the source of radon near thrust and fault. The water gets enriched in radon by dissolving radon, which emanates from the deeper parts of the crust through deep-seated thrust and faults (Choubey and Ramola, 1997).

Radon values are recorded high at different locations in Saryu formation, Munsiari formation, and Berinag formation of the study area. The hard rocks in these formations have very low granular porosity and high accumulation power, but are characterized by fissures, fractures, joints and lineaments. The Himalayan spring related to fractures and joints has 18–41% of the total discharge as base flow (Valdiya and Bartarya, 1991). Statistical analysis in Table 1 shows that the geometric mean, average and median have highest value in the fracture and fault related springs. Spring in Siwalik formation near Nainital in the southern part of the study zone is identified as fault-lineament spring and produce high radon value due to the sandstone interbeded with mudstone near Main Boundary Thrust.

The colluvial and fluvial related springs have radon values ranging from 1 Bq/l to 51 Bq/l. The lower radon values were observed in the springs from Blaini and Rautagara formations, draining mainly through the alternating limestone and green slates with fine grained and cross-bedded muddy quartzite in lower region of Ramgarh group. The higher radon values were found in the colluvial springs of Saryu formation having mylonitized quartz porphyry. The relatively low radon concentrations in colluvial and fluvial related springs are due to the dilution of radon through their high water-carrying capacity. The colluvial-related springs in Himalayan region have permanent groundwater flow ranging from 45 to 57% and have highest water discharge rate among the above-mentioned springs (Valdiya and Bartarya, 1991). The high porosity, permeability and transmissivity of colluvial and fluvial deposits do not allow radon to accumulate in these springs (Choubey et al., 2000a). The turbulent flow within such deposits causes natural degassing of radon before its collection. Statistical analysis in Table 1 shows that the geometric mean, average and median have lowest values for the colluvial–fluvial type springs. Since the environmental conditions do not affect the radon transport through groundwater, the variation in radon concentrations is only due to geological and geohydrological setup of the springs.

Radon concentrations along with temperature, conductivity and the total dissolved solids were also measured in some thermal springs of Garhwal Himalaya (Table 2). Radon concentration in these thermal springs varies from 4 Bq/l to 46 Bq/l with an average value of 25 Bq/l. Most of these springs are deep seated and identified as Fault-lineament related springs. The Fault-lineament related normal water spring close to landslide zone of Uttarkashi in Garhwal Himalaya (Ramola et al., 2008) also shows high radon activity (104 Bq/l). The radon concentration was found to be negatively correlated (−0.70) with the water temperature of the springs. However, a strong positive correlation (0.99) was observed between radon concentration and total dissolved solids in the spring water.

5. Conclusions

Based on the present study, it is concluded that the radon occurrence in groundwater is controlled by geohydrology of the

Table 2
Radon concentration with conductivity, temperature and total dissolved solid in hot springs.

Sample location	Radon concentration (Bq/l)	Conductivity (μSeiman/cm)	Temparature (°C)	TDS (mg/l)
Manpakoti	46	1470	52	650
Manpakoti II	40	N.A	52	650
Ojari	13	1742	60	856
Banas	43	662	73	334
Gangnani	4	1890	63	940
Bhukki	19	2140	51.3	1060
Gaurikund	7	1130	54	566
Matali (Utterkashi)	104	1660	27.4	826

study area. Geohydrological characteristics of water bearing rocks are also governed by tectonic activity experienced by the region. Amplifying factors for radon concentrations in spring water and hand pumps are uranium mineralization in different rock types and presence of thrust, fault and shear zones in the area. The radon concentrations in the fault-joint/fault-lineament types of springs are higher than that in colluvial and fluvial springs. The high porosity and permeability of sedimentary rocks in colluvial and fluvial settings do not allow the radon to accumulate and thus produce low radon concentration in spring water. It was observed that the radon contents in spring water and hand pumps have a sensible relationship with geological and geohydrological patterns of the study area.

Acknowledgements

Authors are thankful to Board of Research in Nuclear Sciences, Department of Atomic Energy, Government of India for providing financial support in the form of a project. One of the authors (YP) is also thankful to Council of Scientific and Industrial Research, New Delhi for providing Senior Research Fellowship.

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Dr. Yogesh Prasad, the first author of this paper died in a road accident on 14th October 2008. He was on the way to Multi-Parametric Geophysical Observatory (MPGO) located at Ghuttu in Garhwal Himalaya, India. During his short scientific career, he had worked exclusively on radon emanation studies and published several research papers in the journals of international repute. His sudden untimely sad demise at the age of 28 years is a great loss to the scientific community.