

## Geological and tectonic influence on water–soil–radon relationship in Mandi–Manali area, Himachal Himalaya

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**Abstract** Radon measurements in soil and groundwater (springs, thermal springs and handpumps) were made in a variety of lithological units including major thrusts between Mandi and Manali in Himachal Himalaya. Analysis of radon data in light of lithological controls and influence of deep-seated thrusts has been made to elucidate the causative factors for anomalous emanation of radon. The lithological types include banded gneisses, schists, quartzite, granite, phyllites, volcanics and mylonites. The low-grade metasedimentaries of Shali and Dharamsala generally show low and narrow range of radon concentration in water (5.6–13.4 Bq/l) as well as in soil (1.8–3.2 kBq/m<sup>3</sup>) except for the samples related to thrusts. On the other hand, sheared and deformed rocks of Chail and Jutogh show moderate radon content (average 5.03 kBq/m<sup>3</sup>, range 2.9–11.1 kBq/m<sup>3</sup>) in soil. However, the groundwater radon concentration shows wide variation in different types of sources (2.1–80.8 Bq/l). The quartzite and volcanic rocks of Rampur formation in this area present as a window separated by Chail thrust. Radon emanations on these rock types are relatively high (6.3–68.1 Bq/l in water and 5.5–15.9 kBq/m<sup>3</sup> in soil)

and are exceptionally high in samples that are related to uranium mineralization, deep-seated thrusts and hot springs (13.5–653.5 Bq/l). It is generally observed that anomalous high radon content is associated with mineralization, deeper source and tectonic discontinuities. Whereas it is obvious that subsurface radioactive mineralization would facilitate enhanced radon production, however, thrust plains provide easy pathways for escape of gases from the deeper sources. Shallow and deep sources of the groundwater have contrasting radon content particularly in the deformed and metamorphosed rocks of Jutogh and Chail. Shallow groundwater sources, mainly handpumps, have lower radon concentration due to limited superficial water circulation, whereas deeper sources, mainly perennial springs, show higher radon content because of larger opportunity for water–rock interaction.

### Introduction

Crustal discontinuities, such as fractures and faults of various dimensions, facilitate degassing flux from the earth to the hydrosphere and the atmosphere (Baubron et al. 2002; Fu et al. 2005). Radon is an omnipresent radioactive gas that can be used as tracer gas in geology, hydrology and geophysical investigations where it accounts for interesting alternative tools (Cho et al. 2004; Przylibski et al. 2004; Steinitz et al. 1999; Kies and Massen 1996; Segovia et al. 1999; Yasuka et al. 2005). Radon due to its short half-life displays poor intrinsic mobility and therefore in diffusive system it obviously comes from a short distance below

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the measuring instrument. Deep origin signals can be observed only if convection/advection occurs; radon being carried upward to subsurface by a rising gas/water column (Etiopie and Martinelli 2002; Yang et al. 2003). The measurement of radioactivity in general and in the tectonically active and seismically sensitive Himalayan, in particular, is of special interest to various researchers (Choubey et al. 2005; Ramola 2005; Virk and Sharma 2000). During recent years, several reports have appeared in the literature regarding the ever-increasing interest in monitoring radon all over the world (Abdulrahman 1999; Choubey et al. 2001; Baubron et al. 2002; Plastino 2001; Sakashita et al. 2004; Swakon et al. 2005; Walia et al. 2005a). The health risks that are associated with inhalation and ingestion of radon and its progeny are also significant. Cross et al. 1985 suggested maximum contamination level (MCL) of radon in public drinking water supply in the range of 37–740 Bq/l. In 1991 the US Environmental Protection Agency proposed an MCL for radon in public water supply to be of the order of 11.1 Bq/l (EPA 1991). However, the risk factor depends on the total mass of radon partitioning from groundwater to the soil gas (Oostrom 1996).

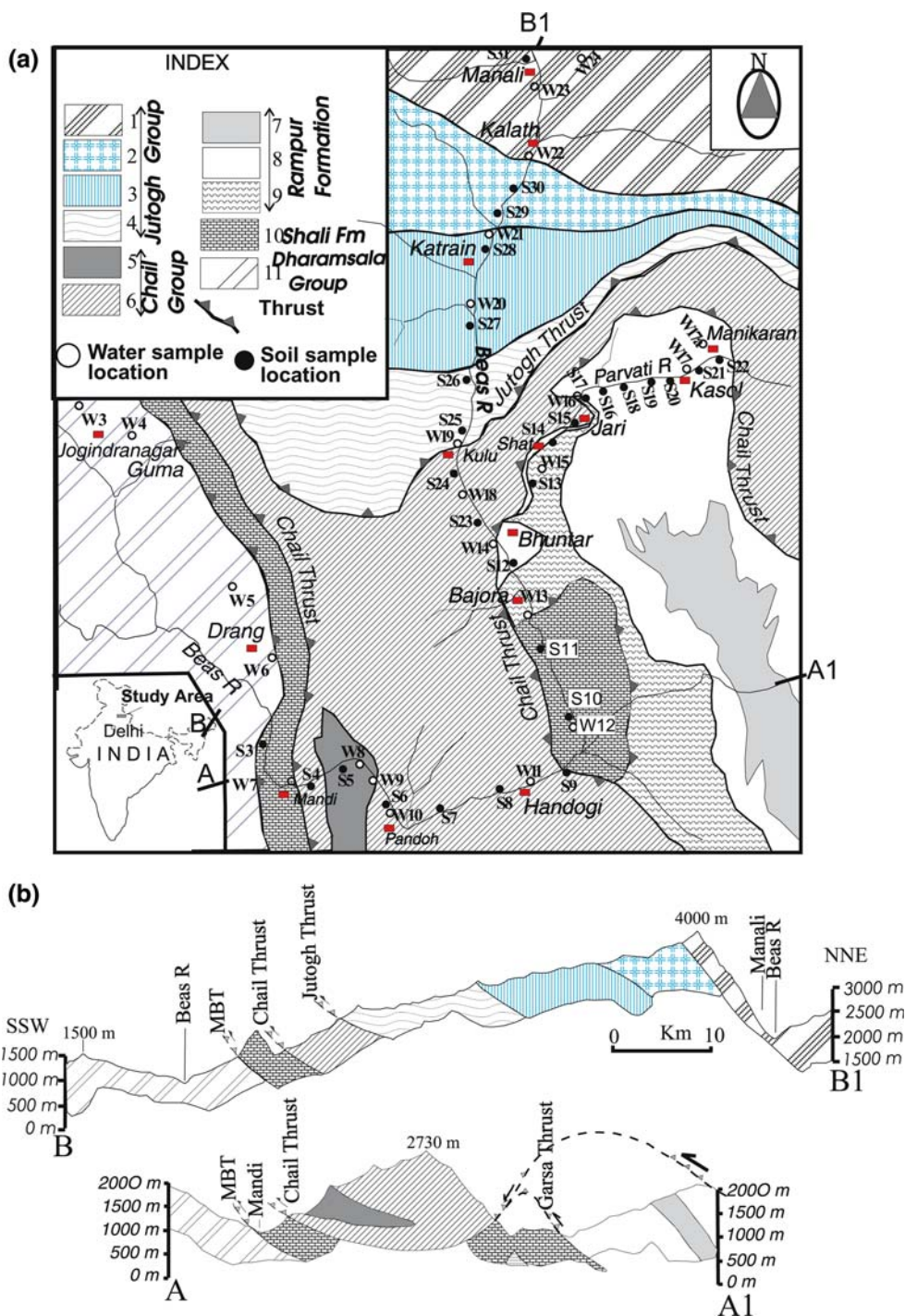
Radon gas is continuously generated within the rock strata as an intermediate decay product of the U or Th radioactive series and its emanation is a well-understood phenomenon. However, its migration from the earth's crust to atmosphere is a complex phenomenon (Tanner 1980). Uranium geochemistry of highly deformed and sheared rocks is not well understood. However, Gundersen and Gates (1989) and Gates and Gundersen (1992) have presented some insight into the reasons for high uranium and favorable conditions for high emanation of radon gas. In view of this, the present area provides better opportunity to study the radon status in this geologically similar situation as the area is extensively traversed by a number of deep-seated thrusts and fault and some of them are still active. Such problems can be better addressed if the soil and groundwater radon emanations are measured and compared with respect to the geological and other relevant parameters. Whereas the handpumps reveal the shallow level radon status, the spring water provides deep-seated conditions. Moreover, there are several reports of radioactive mineralization (not ore deposits) within (Parvati Valley) the study area as well as in similar geotectonic setup elsewhere in Lesser Himalaya (Das et al. 1972, 1979; Nashine et al. 1982; Sharma et al. 1983). Radon exposure studies have been carried out in several parts of the Himachal Himalaya in a variety of medium like indoor air, soil and water

(Singh et al. 2002; Virk and Sharma 2002; Walia et al. 2003), with special emphasis on its environmental aspects. However, very little attention was given on its geological controls. Therefore, an attempt has been made in this paper to understand the water–soil–radon relationship in such unique geological and geohydrological situation along three transects so that the lithological variations and major structure and tectonic elements are fairly represented (Fig. 1). These are (1) Manali-Handogi, (2) Manikaran-Bhuntar and (3) Handogi-Jogindra Nagar.

### Geology of the area

A detailed account of the geology of the area is beyond the scope of this paper. However, a brief and simplified description is presented here highlighting only geological features that are relevant to the subject of this paper. Four major lithotectonic units, each bounded by deep-seated thrusts may broadly describe the geology of the area (Fig. 1). These are referred to as (1) Rampur window group; (2) Chail group; (3) Jutogh group and (4) Dhramsala and Sali formation. The Rampur formation tectonically rest over the Shali formation along a thrust and made up of volcanics at the lower level and Rampur quartzite towards the top (Misra and Tewari 1988). Rampur quartzite is intruded by the Bandal granite and the low-grade metamorphics of Chail group rocks are intruded by the Mandi granite. Chail thrust between Rampur group and Chail group rocks was also referred as Kullu thrust (Bhargava and Bassi 1994). The Chail group is tectonically overlain by the huge succession of medium-grade metamorphics of Jutogh group separated along the Jutogh thrust (Misra and Tewari 1988; Virdi 1981). The Chail and Jutogh thrust separates metamorphically contrasting grades of rocks. Chail thrust defines the boundary between green-schist facies rocks of Rampur, Shali and Dharamshala group and low-grade metamorphics of Chail group rocks. On the other hand, the Jutogh thrust separates low-grade rocks of Chail and medium-grade (amphibolite facies) rocks of Jutogh group. These thrusts play a major role in the neo-tectonics of the area and are still active. The Jutogh group of rocks is highly deformed and mylonitized and are frequently referred to as imbricate thrust zone. However, the rocks of Chail group are relatively less deformed with development of mylonites along the thrust contacts. The faults, thrusts, metamorphosed and mylonitized rocks are of special importance as they provide enhanced secondary porosity and hence higher radon emission (Gundersen and Gates, 1989). The lithologi-

**Fig. 1 a** Geological map of the Mandi–Manali area showing soil and water radon sample locations. **b** Geological cross section along A–A<sub>1</sub> and B–B<sub>1</sub> illustrating the geological structure of the area. Geological map and section is after Misra and Tewari (1988). 1 Fine-grained banded gneiss, 2 foliated micaceous quartzite, 3 biotite schist with foliated micaceous quartzite, 4 garnetiferous-biotite phyllonite and schist 5 intrusive Mandi granite, 6 sericite-chlorite phyllite, quartzite, mylonitized gneiss, quartz porphyry, carbonaceous slate with bands of limestone, 7 intrusive Bandal granite, 8 Rampur quartzite, 9 volcanics, 10 dolomite, limestone, quartzite, volcanics, shale and slate, 11 fine-grained micaceous sandstone, purple-green clay, claystone and micaceous siltstone



cal make-up of different rock-types is discussed in detail by Misra and Tewari (1988) and is also mentioned in the legend of Fig. 1.

**Geohydrological framework**

The study area is drained by main river Beas and its tributaries river Parvati. Parvati River originates from

glacier in the higher Himalaya and flows through gneiss, granite porphyroids, schist of Vaikrita, Jutogh and Chail formations and quartzites of Rampur Group and join finally river Beas at Bhuntar. Though the Beas and Parvati River originate from glacier in the higher Himalaya, and passes through a variety of rock types, their catchment area and sub-tributaries in the Lesser Himalaya are predominantly fed by the springs and surface runoff of local extent.



While most of the rainfall leaves the area as direct surface runoff, little amount infiltrates to augment the groundwater. The groundwater eventually returns to the surface as springs and seepages through faults, fractures, joints and permeable layers or zones which are favorably perched or are under confined and unconfined conditions. Direct infiltration of rainwater through joints, fractures and weathered zones is the main cause of recharge of the springs.

Genesis and conditions governing the formation of springs in river-valley slopes typify the residency of infiltrating water, rock–water interaction and its path before it flows out as springs. Thus the geochemistry, including radon, of the spring water would strongly depend upon the residency period and more specifically on the extent of closeness of the system in case of dissolved gas contents. Four major conditions of valley springs have been recognized by Bhartarya (1988) that are controlled by fracture, joints, fault/thrust and other geomorphological conditions in Lesser Himalayan terrain. Relatively flat areas and gently sloping land characterized by deep weathering such as hilltops, ridges, saddles, spurs and cones of old landslide debris, river terraces, fluvial fans form the recharge areas; while steeper hill slopes, first- and second-order streams at break-of-slope, and terrace scarps and fans are favorable discharge sites. Fractured zones related to folds, faults and other lineaments, characterized by sheared and crushed rocks are good locations for springs, even in rocks that are otherwise impermeable (Bhartarya 1988; Choubey et al. 2000a, b).

In Kulu–Manali area several hot springs are located; the famous thermal springs at Manikaran and Kasol in Parvati valley are located in the vicinity of Chail Thrust where hot water gushes out through the joint planes of the quartzite which is traversed by several tension joints due to anticlinal folding and thrusting. Also, the presence of Chail thrust near Manikaran and Kasol play an important role in the formation of these hot springs. Possibly, the water descends very deep down along prominent structural opening and return to the surface aided by steams, after getting superheated by internal heat of the earth (Sharma 1977). Beside the Parvati valley hot springs are also located near Kullu town along Beas River and in Vashishat near Manali.

Mostly the spring water is a major source for drinking whereas the hot water of the thermal springs is normally used both for washing and bathing. A large number of shallow wells equipped with handpump (henceforth referred to as “handpumps”) are also dug along the river valleys that partially supplement the drinking water requirements. Some of

these handpumps are also selected for radon measurement in this study.

### Experimental technique

Radon concentrations from different water sources (handpump/spring) were measured during the winter season, whereas the soil-gas radon measurements were carried out in the summer season. The weather conditions were fairly stable during measurements in both the seasons. Radon measurements in water samples were carried out by scintillometry, using silver-activated zinc sulfide, ZnS (Ag). Alpha Scintillometer (GBH 2002) with Lucas cell assembly supplied by International Environmental Consulting, Germany, was used to record the alpha counts from 1 l of water over an interval of 10 min. Radon gas emanated from radium present in the water or dissolved in it was sucked by a pump connected to a radon bubbler with an extraction efficiency of more than 90%. The electronic digital counter records the alpha counts and radon concentration in water is measured by using the calibration constant (10 counts = 1 Bq/l). The detection limit for the Lucas cells used in alpha scintillometer is 0.02 Bq/l. Radon-222 in water has to be measured in the gas phase. The radon gas from 1 l water is separated from the matrix water and all the other radionuclides by bubbling air through and continuously measuring of radon–air mixture under flow condition in the Lucas cell on the ZnS(Ag) detector. The method blows out completely all radon-222 from the water and measure radon–air mixture continuously. The sum of counts after 10-min flows gives qualitative results. The total number of radon counts blown out is directly proportional to the radon-222 activity in the sample in Bq/l (10 counts = 1 Bq/l). By circulation de-gassing equilibrium in the system has been established after 10 min bubbling and is taken for measuring as per calibration.

In soil radon emanometry, auger holes each 60 cm in depth and 6 cm in diameter were left covered for 24 h so that the amount of radon and thoron became stable. The soil-gas probe was fixed in the auger hole and formed an airtight compartment (Ghosh and Bhalla 1981). The rubber pump, soil-gas probe and alpha detector were connected in a close circuit. Air was circulated through a ZnS coated chamber for a period of 15 min till the radon formed a uniform mixture with the air. The detector was then isolated by clamping both the ends and observations were taken after 4 h. The resulting number of the alpha counts is converted into Bq/m<sup>3</sup> by using the calibration constant determined by Choubey et al. (2000a, b) under similar conditions.

**Results**

The soil-gas radon measurements were mostly made along the roadside. The soil cover is generally <1 m thick except in Kullu valley. The thin soil cover is mainly because of the hilly topography having steep slopes which does not allow soil to accumulate. Therefore observed soil radon variation may be considered to be mainly due to the lithology and the tectonic features associated. The site selected for water–soil–radon concentration are confined to Jutogh, Chail, Rampur Shali and Dharamsala formations of Kullu valley between Mandi and Manali in Himachal Pradesh. The sample locations and detailed lithology are shown in Fig. 1 and the corresponding radon concentration data in Tables 1 and 2. Overall, the radon concentration in the water from handpumps and springs (hot and cold) varies from 2.1 to 653.5 Bq/l with an average of 86.9 Bq/l and geometric mean of 21.8 Bq/l and that of soil-gas concentration varies from 1.5 to 15.9 kBq/m<sup>3</sup> with an average of 6.5 kBq/m<sup>3</sup>. The results of radon measurements in spring and soil underlain by different geological formations are dis-

cussed in relation to rock-type, structural and geomorphologic context.

**Dharamsala and Shali formation**

In Dharamsala and Shali formation, radon concentration (5.6–25 Bq/l) in water was measured mostly from handpumps except one spring (5.6 Bq/l). Water–soil–radon concentrations, in general, were found relatively low in these formations because of the sedimentary lithologies. However, #W6 (handpump) and #S3 (soil) samples located just on the main boundary thrust (MBT) show considerably high radon concentration of 25 Bq/l and 8 kBq/m<sup>3</sup>, respectively, whereas in Shali formation two soil–radon samples show comparatively low values, i.e. 1.8 and 3.2 kBq/m<sup>3</sup>.

**Rampur formation**

Rocks of Rampur formation consists of massive quartzite with chlorite schist and meta-basics and further intruded by Bandal granite. Uranium mineraliza-

**Table 1** Radon concentration, temperature and pH in water from handpumps, springs and the associated lithology

Sample nos.	Water source	Radon concentration (Bq/l)	Temperature (°C)	pH	Group/formations	Rock types
W22	Spring	64.0 ± 2.5	18.1	8.2	Jutogh group	Fine-grained banded gneiss
W23	Handpump	3.4 ± 0.6	19.2			
W24	Hot water	80.8 ± 2.8	65.4	7.05	Chail group	Biotite schist with foliated micaceous quartzite
W20	Handpump	10.2 ± 1.0	18.6	7.21		
W21	Handpump	9.2 ± 1.0	17.9			
W19	Hot water	12.3 ± 1.1	38.2	6.35		
W8	Spring	2.1 ± 0.5	17.8			
W9	Spring	18.0 ± 1.3	17.6	7.54	Rampur formation	Mandi granite
W10	Handpump	11.0 ± 1.0	19.3	7.08		
W11	Spring	3.7 ± 0.6	17.4		Rampur formation	Sericite-chlorite phyllite, quartzite, mylonitized gneiss, quart porphyry, carbonaceous slate with bands of limestone
W14	Handpump	38.1 ± 1.9	18.1			
W18	Handpump	6.8 ± 0.8	17.7	7.62		
W16	Spring	68.1 ± 2.6	18.1			
W17	Hot water	499.5 ± 7.1	71.9	7.07		
		487.1 ± 7.0	70.1	6.96		
		653.5 ± 8.1	68.5	7.35		
W17a	Hot water	221.9 ± 4.7	65.3	7.02	Shali formation	Dolomite, limestone, quartzite, volcanics, shale and slate
		21.4 ± 1.5	88.4	6.78		
		13.5 ± 1.2	88.2	6.83		
W13	Handpump	48.0 ± 2.2	18.5		Dharamsala formation	Fine-grained micaceous sandstone, purple-green clay, claystone and micaceous siltstone
W15	Handpump	6.3 ± 0.8	17.9			
W12	Handpump	12.5 ± 1.1	18.2	7.82	Dharamsala formation	Fine-grained micaceous sandstone, purple-green clay, claystone and micaceous siltstone
W7	Handpump	13.4 ± 1.2	17.8			
W6	Handpump	25.0 ± 1.6	18.2	6.91	Dharamsala formation	Fine-grained micaceous sandstone, purple-green clay, claystone and micaceous siltstone
W5	Spring	5.6 ± 0.7	17.7	7.01		
W4	Handpump	6.4 ± 0.8	18.4	7.33		
W3	Handpump	5.6 ± 0.7	17.6			

**Table 2** Radon concentration in soil and the associated lithology

Sample nos.	Radon concentration (kBq/m <sup>3</sup> )	Group/formations	Rock types
S31	11.1 ± 0.6	Jutogh group	Fine-grained banded gneiss
S29	3.6 ± 0.3		Foliated micaceous quartzite
S30	2.9 ± 0.3	Chail group	Biotite schist with foliated micaceous quartzite Garnetiferous-biotite phyllonite and schist Mandi granite Sericite-chlorite phyllite, quartzite, mylonitized gneiss, quart porphyry, carbonaceous slate with bands of limestone
S27	2.9 ± 0.3		
S28	3.1 ± 0.3		
S25	8.1 ± 0.5		
S26	4.7 ± 0.4		
S5	6.5 ± 0.5		
S4	5.7 ± 0.4		
S6	2.2 ± 0.3		
S7	1.5 ± 0.2		
S8	3.7 ± 0.3		
S9	9.8 ± 0.6	Rampur formation	Rampur quartzite
S23	7.9 ± 0.5		
S24	4.7 ± 0.4		
S16	8.2 ± 0.5		
S17	7.6 ± 0.5		
S18	6.3 ± 0.5		
S19	5.5 ± 0.4		
S20	6.3 ± 0.5		
S21	7.3 ± 0.5		
S22	15.9 ± 0.7		
S12	8.3 ± 0.5	Volcanics	
S13	10.2 ± 0.6		
S14	9.2 ± 0.5		
S15	11.8 ± 0.6	Shali formation	Dolomite, limestone, quartzite, volcanics, shale and slate
S3	8.0 ± 0.5		
S10	3.2 ± 0.3		
S11	1.8 ± 0.2		

tion associated with Rampur quartzite in the form of disseminated uraninite, pitchblende grains, uraninite-rutile aggregates in chlorite schist along foliation and as fracture and joint fillings in quartzite has been reported by Das et al. (1979). Famous Manikaran and Kasol hot water spring systems are found in the northern proximity of Rampur formation and are associated with Chail thrust which is a major tectonic discontinuity in this region. The hot water (up to 80°C) of these springs are extensively used by local population for different purposes. Six samples of this hot water springs show 13.5 Bq/l to a maximum of 653.6 Bq/l of radon, and in a normal spring from the same area, radon was found to be as high as 68.1 Bq/l, even though both the hot springs (Manikaran and Kasol) are separated by few hundred meters within same geological setup. Manikaran springs show very low values (sample #W17a) of radon (13.5 and 21.4 Bq/l) as compared to Kasol suite of thermal springs (#W17) that are at least ten times more enriched in radon with values ranging from 221.9 to 653.5 Bq/l. Moreover, the uranium concentration in these water samples was also found consistent, i.e. 0.1–0.02 ppb in

Manikaran as compared to 3.63–4.36 ppb in Kasol hot spring (V. Walia, personal communication). On the other hand, range of soil-gas radon content underlain by contrasting lithologies of Rampur quartzite and metavolcanics were found to be 5.5–15.9 kBq/m<sup>3</sup> and 8.3–11.8 kBq/m<sup>3</sup> respectively.

#### Chail group

Radon measurements were carried out in few springs and handpumps that are located within low-grade metamorphics (sericite-chlorite quartzite, mylonitized gneiss, carbonaceous slate) of Chail group of rocks. Radon concentration generally varies from 2.1 to 11 Bq/l; however, a relatively deeper handpump located on Chail thrust show remarkably high radon concentration (38.1 Bq/l). This group of rocks is further intruded by younger granite (Bandal granite). Two springs sampled on this granitic lithology show 2.1 and 18 Bq/l of radon. Both these springs are of different types with lower values associated with fluvial type and higher value is associated with joint controlled spring.

## Jutogh group

Jutogh group of rocks are characterized by medium-grade amphibolite facies metamorphism represented by fine-grained gneisses, schist and phyllonites. The spring water–radon concentrations within this lithology show wide variability. In spite of higher porosity, the schistose rocks are consistently low in radon 9.2–12.3 Bq/l but the springs on banded gneissic rocks are many fold enriched (64–80.8 Bq/l) except for a shallow handpump (3.4 Bq/l). In the both cases the hot water springs shows marginally higher values with respect to normal springs. Both these hot water springs have contrasting geomorphic conditions and lithologies.

## Discussion

Superficial and shallow fluvial and colluvial springs show relatively low Rn concentration. These spring systems are related to higher porosity and transitivity that neither allows accumulation or emanation of Rn gas (Lawrence et al. 1991; Choubey et al. 2000a, b). On the other hand, higher radon concentration values are, in general, found to be associated with springs that are controlled by fault/joint or thrust lineaments irrespective of the underlain rock type within the same geological formation. Thus, the radon contents in spring samples are found to be highly variable in accordance with its genetic type and depth of groundwater circulation. Handpumps, on the other hand, being shallower (up to 20–50 m) generally show low radon. However, few handpumps that are right on the thrust (e.g., sample #W6, W13, W14) show very high radon suggesting that the radon emission is strongly influenced by the deep-seated thrust structure. The thermal springs being deep seated in origin and are related to thrust planes show expectedly high Rn compared to adjacent normal springs. Except for Manikaran hot water springs, in the rest of the three thermal springs sampled (two from Jutogh and one from Rampur), the Rn content is generally found to be very high (12.3–653.5 Bq/l). The depletion of Rn in Manikaran thermal spring may be due to its loss enroute to surface. Since this spring is situated right over the thick riverbed deposits (mostly gravel and coarse-grained sediments), the gas finds an easy escape before the hot water reaches on surface resulting in high Soil Rn in and around Manikaran. The nearby Kasol hot water spring that is situated slightly off the riverbed, having hardly any sediments/soil cover, however, shows abnormally high Rn concentration (221.9–653.8 Bq/l).

The source of hot water in both cases is certainly deep seated and is related to the Chail thrust system.

Thus, from the above observations we conclude that the Rn content of springs may be a good indicator of the underlying geology and depth of water circulation versus the shallow depth local springs. Shallow springs along the mountain slopes normally results from the seepage of superficial water through the weathered regolith or highly porous soil/sediments terraces. Under this condition radon gas would escape easily and hence low radon would be encountered. In case of deep-seated origin or the water circulating deeper into the strata, the radon gas would remain dissolved in the water under confining pressure for longer period. Therefore, hill slope springs with high radon would possibly indicate deep groundwater circulation. It may be noted that in Himalayan terrain, different genetic type of springs occur which may or may not be structurally controlled. Some are even related to local geomorphologic features with shallow water circulation on the hill slopes. Rn study thus seem to be a potential tool to distinguish such dubious nature of the spring in hilly terrain provided the geological aspects (such as faults, thrust, fractures, lithological and mineralization) are taken into account.

The soil radon values in Parvati valley is generally high which may be controlled by the known presence of uranium mineralization; this in turn is controlled by the Chail thrust. These high values are particularly restricted around the Manikaran, Kullu and Bhuntar triangle. In addition to this, there are three more soil samples in the studied area that shows considerably high Rn content, viz., Handogi (S9), Mandi (S3) and Manali (S31). While the Handogi and Mandi samples are measured right above the thrust (Chail thrust), however, the Manali sample is relatively away from the Vakrita thrust to its north. Also, the nearby hot water spring w24 and a deep-water spring w22 near Manali also show anomalously high radon. The shallow hand-pump sample (w23), however, shows expected low value. Therefore, some deep-seated structure (fault and thrust) and/or uranium mineralization in this area are predictable. Apart from this the rest of the soil samples show radon concentration within 2–12 kBq/m<sup>3</sup> irrespective of the underlying rock types. We therefore infer that in relation to the structural and tectonic influence, the lithological control on Rn content is much less predominant in case of soil-Rn. Thus a value of 10 kBq/m<sup>3</sup> may be considered as background in the area, which are many folds higher than the worldwide soil gas average value. Like Parvati valley, other quartzite terrains in lower Himalaya normally show high radon (Choubey et al. 1997, 1999) due to the occurrence of sporadically dis-

seminated uranium mineralization. In the present case also the reported uranium mineralization east of Shut-Jari are hosted by quartzite. Thus, the observed high radon in soil and also in deep spring water within quartzite near Kasol and Manikaran further substantiate the possibility of uranium mineralization in this area. Volcanic province is generally depleted in uranium and radium concentration and hence the soil–radon concentration should also be low. However, the high soil–radon values south of the Jari and Shat within volcanic lithology may be attributed to the soil derived from the upstream of Parvati valley catchments that are naturally high in radioactive elements.

## Conclusion

The observed concentration of radon both in soil and water in this area is controlled by the presence of uranium mineralization and associated different thrust that help in easy escape of gases from the deeper part of the crust. It has been also noticed that the coarse sediment cover on valleys may deplete the radon contents substantially through near surface de-emanation as observed in Manikaran thermal spring. The lithological controls on radon content of the overlying soil seem to be less prevalent compared to structural and tectonic discontinuities. The enhancement may be as much as order of magnitude higher than the normal expected concentration within the same lithology. Shallow handpumps normally show low Rn content but may also show enhanced Rn concentration if situated on thrust/faults, whereas deep springs normally show relatively high radon concentration. Thus, the radon measurements on spring may be useful in discriminating between deep-source and shallow superficial springs in hilly terrain provided other influencing factors like uranium mineralization, fault, thrusts, and sediment cover are accounted for.

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