Radon variation in Spring water before and after Chamoli earthquake, Garhwal Himalaya, India

V.M.Choubey[1], P.K.Mukherjee[1] and R.C.Ramola[2]

[1]Wadia Institute of Himalayan Geology,
33-General Mahadeo Singh Road, Dehra Dun 248 001, India
E-mail: vchoubey1@rediffmail.com
[2]Deptt. of Physics, H.N.B. Garhwal University
Badshahi Thaul Campus, Tehri Garhwal -249 001, India

Abstract: Radon levels measured in the springs of Garhwal Himalaya before Chamoli earthquake (Mb=6.3) of 29th March 1999 have been compared with those measured immediately after the earthquake. Radon levels in springs are found to be affected by the earthquake. In all, 39 springs were surveyed for radon which are divided into three sections across the tectonic structures. The water discharge data were also collected along with the radon measurements. The enhancement/reduction of radon concentration and water discharge rate due to the earthquake were then calculated as Enhancement Factor (EF) by dividing the pre-earthquake data with that of post earthquake measurements.

It was observed that in most of the springs, radon levels were increased after earthquake, particularly in worst effected area around Rudraprayag and Chamoli. Most of the springs that shows very high radon enhancement factor are located in the vicinity of the different thrusts or maximum damaged zones with development of ground cracks. Probably, this may indicate that there is some degree of reactivation of the thrusts and faults present in this area. However, radon concentrations were found to decrease in some springs. A similar variation was also recorded for water discharge from the spring before and after earthquake. The enhancement or depletion of radon and water discharge may be attributed to the combined effect of earthquake and partial mobilization of major structural features and lithological control. The effects of earthquake on the radon levels and water discharge in the springs of Garhwal Himalaya are discussed in details. A significant change in radon concentration and water discharge from springs in relation to earthquake shows that this technique may be exploited as an additional tool in earthquake prediction programme in Himalayan region.

1. Introduction

Himalaya on the whole is experiencing vertical uplift and transverse block movements due to the compression caused by the continued northward movement of Indian plate, even after the collision with Eurasian plate in Paleocene. As a result Himalayan region is being subjected to intense neotectonic movements and seismic activities. During the past decade two major earthquakes struck in the Garhwal region alone, i.e., Uttarkashi earthquake [1] of 20th Oct. 1991 (6.5 Mb) and Chamoli earthquake of 29th March 1999 (Mb 6.3).

Geological and geohydrological signals preceding significant earthquakes have been reported since 1960 and have been successfully used to predict the 1975 Haicheng earthquake in China. Perceptible changes in terms of hydrogeochemical parameters have been reported as a result of noticeable earthquake by several researchers [2,3,4]. During the last few decade, research on seismic precursors have received enormous attention because of its social relevance. Monitoring of radon concentration has been found to have a great potential as a reliable precursor [5]. Several studies suggests that the emanation pattern of radon (^{222}Rn) can be used as a seismic precursor [6,7,8,9,10,11,12,13]. The emanation of radon increases with the increasing stress in the crustal layers, and supposed to be maximum with the release of the stored energy in the form of the earthquakes. Okabe [14] suggested that along the active faults the soil gas is enriched in radon. The concentration of radon in air, groundwater, springs close to the epicentral area increases anomalously just before an earthquake [15]. Deep seated faults and fractures provide passages for migration of the gas and thereby concentration of radon dissolved in water increases. King [7] observed high radon near active faults and temporal variations related to large seismic activity.

The authors have been engaged in radon studies in soil and spring water for last few years in Garhwal region. The data related to radon concentration in spring water were collected from this area in May 1997. This forms the basis for the present study to compare the variation in radon concentration before and immediately after the recent Chamoli earthquake. However, a more meaningful information can be extracted if the radon monitoring along with metrological parameters are made on a continuous basis.

2. Chamoli Earthquake

A moderate earthquake (Mb 6.3) occurred on the early morning hours of March 29, 1999 (0:35:13:59 IST) near the Chamoli town in the higher reaches of Garhwal Himalaya. Apart from the loss of lives and properties, several ground cracks have been observed in the vicinity of the area extending up to 1 km in length with width varying from 10 to 20 cm. Numerous rock falls, landslides and changes in ground water levels have also been observed after the Chamoli earthquake. This earthquake was followed by several aftershocks with magnitude up to 5.3. According to a US Geological Survey report pure thrust faulting has been said to be the cause of the earthquake based on the focal mechanism solution. It is worthwhile to mention that the area is traversed by several thrust/faults. Preliminary reports by the scientists of wadia Institute of Himalayan Geology suggest that the activation of Main Central Thrust (MCT) seems to be the causative factor for this tragic event. It may be noted that the Uttarkashi earthquake of 1991 (Mb 6.5) was also caused by re-activation of MCT.

3. Radon Measurement Technique

750 ml of water sample was taken in radon-tight reagent bottle of 1 litre capacity connected in a close circuit with a ZnS coated detection chamber through a hand operated rubber pump and a glass bulb containing $CaCl_2$ to absorb the moisture. Air was then circulated in close circuit for a period of ten minutes till the radon formes a uniform mixture with the air and the resulting alpha activity was recorded. The details of the measurement technique are discussed elsewhere [16,17]. The calibration factor 1 count/min. = 0.11 Bq/l was used to convert the recorded alpha counts in Bq/l [18].

4. Regional geology and structure

The geological structure and tectonics of the area has been studied and published by several researchers [19,20,21,22,23,24,25], however a brief account of the salient features are presented here.

There are four principal lithotectonic units present in the area affected by the said earthquake. From south to north ther are: a) Deoban-Barinag formation b) Rautagara formation c) Ramgarh formation and d) Munsiari formation (Fig.1). The crystalline rocks of Ramgarh formation forms a large antiformal structure overlying the Lesser Himalayan rocks. Deoban and Berinag formations to the north of Chamoli are highly folded into a antiform referred to as Chamoli Window and inturn is thrusted over by the rocks of the Munsiari formation. The contact between the two is tectonic, called Munsiari Thrust [20] or MCT-1 [26,23].

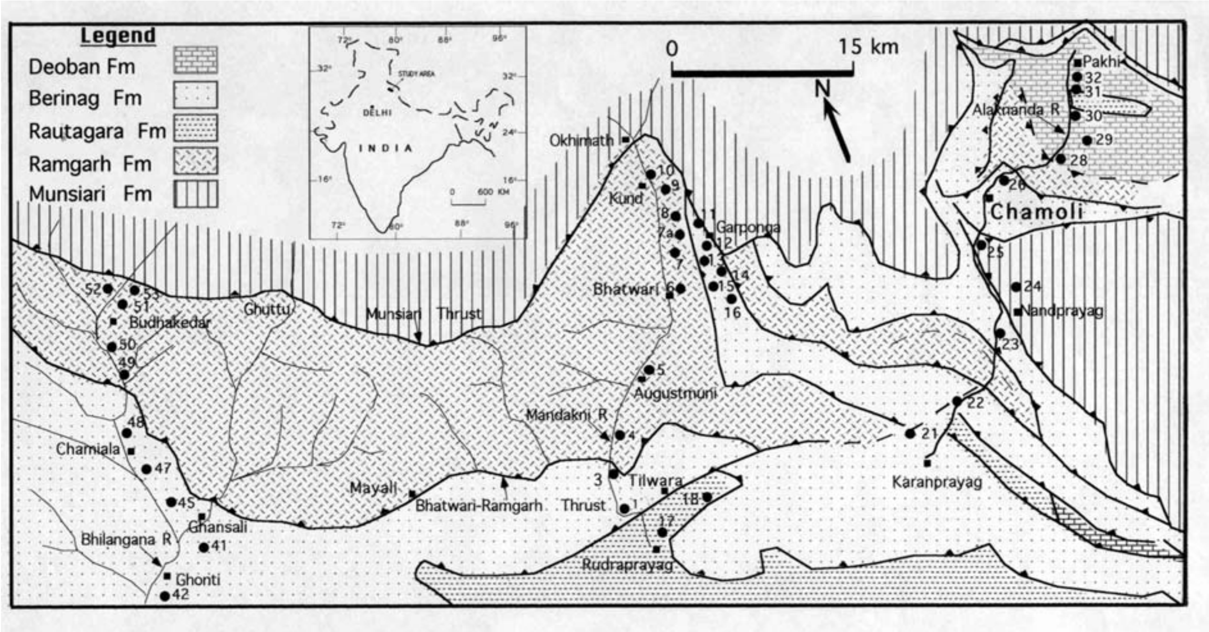

Figure 1 Geological map of Chamoli area [after 20] showing radon sample locations.

5. Results and Discussion

In any comparative earthquake related studies on the variation of radon concentration, it is important to consider the effects due to seasonal and meteorological parameters. In the present case, however, the data collection period is almost the same (i.e. May 1997 and April 1999). As such, the effects due to the above factors may be considered as minimum. In order to have a meaningful comparison, the post earthquake data were collected from the same springs, as many of them as possible, at the same spot using the same instrumentation and methodology. In addition, few more springs were also sampled in the vicinity of the maximum damage zone. In all, 39 springs were surveyed which are divided into three sections across the tectonic structures. (Table 1 and Fig.1). The water discharge data were also collected along with the radon measurements (Table 1). The enhancement/reduction of radon concentration and water discharge rate due to the earthquake were then calculated as Enhancement Factor (EF) by dividing the pre-earthquake data with that of post earthquake measurements.

Along Karanprayag–Chamoli-Pakhi section a total of 11 springs were sampled out of which only 7 were repeated in the post earthquake measurements. Pre-earthquake radon concentration varies from 0.9 to 35.9 Bq/l as against 1.2 to 68.4 Bq/l observed in post-earthquake measurements with enhancement factors as high as 26.4 to the lowest of 0.6. It was observed that most of the radon concentration in spring water and its discharge in this section has invariably shown some degree of enhancement (EF>1) or remain nearly same, except for the sample no. eq22. In case of sample no. eq21, however, the discharge rate has drastically decreased where as the radon enhancement factor is highest (26.4). It may be noted that these two samples lie on the faults of local extent north of Karanprayag as well as a series of thrusts within a few km radius. The next highest radon value as well as discharge is also located in the same area (sample no. eq23).

The post earthquake radon measurements in 8 springs out of total 12 samples were carried out along Rudraprayag-Tilwara-Okhimath section. The comparison of the data reveal that the springs located in Tilwara (sample nos.eq3 & eq4) and Kund (sample nos.eq8 & eq9) show significant enhancement (EF=3.6 to 26.4) of radon as well as the water discharge (EF=1.2 to 3.0) with the exception of sample no. eq3 where the water discharge has decreased by a factor of 0.25. All these four samples are again related to the same fault extending from north of Karanprayag and a couple of thrusts (Fig.1). The Bhatwari–Garponga area witnessed notable damage and therefore additional measurements were made in the springs of this section (sample nos. eq11 to eq16). Despite of the increase in water discharge from springs (samples eq6, eq7 and eq7a), the radon concentrations were found to decrease. The reason for the depletion in spite of considerable damage, may be attributed due to escape of radon gas through the ground cracks that has developed extensively in this area during the earthquake. The additional water, transported from non-mineralised area, may also have diluted the radon content in the springs.

In Ghonti-Budhakedar section there are 7 springs that have been sampled in both the sessions. In addition 5 more springs were also studied during the post-earthquake measurements. Strikingly the discharge of the spring have drastically reduced up to 75% (EF= 0.25 to 0.8) after the earthquake. Some of the previously studied springs have even completely dried up. The earlier measurements indicate that radon levels were moderately high, ranging between 4.5 to 159.7 Bq/l. In the later measurements, three of the springs recorded marginal increase in radon contents (EF=1.03 to 3.9), where as rest four springs have recorded the lower radon concentrations (EF= 0.2 to 0.5). The drying up of the springs and reduction in discharge rate suggest that there has been a narrowing down of the fractures and weak planes. This has resulted in the lower radon concentration due to obstruction of the radon pathways in the subsurface strata. Probably the emanation of radon might have increased many fold due to the earthquake in this area, however, it was restricted to a large extent due to the same reason. It is worthwhile to mention here that uranium concentration in the granitic rocks near Budhakedar is high [27] and there are reports of uranium mineralisation also [28]. The anomalous radon concentrations of 622.9 and 106.8 Bq/l, observed in sample nos. eq52 and eq53, respectively, near Budhakedar, are due to the combine effect of the earthquake and high uranium contents of the rocks.

6. Conclusions

The behavior of radon gas built up and its release before and after the earthquake has been well established based on the continuous monitoring. However, in the present case, we have collected data a couple of year prior to the Chamoli earthquake and about a week later. Although we have lost many of the signatures in between, nevertheless there are some valuable information that can be drawn based on the available data:

1. There is an overall enhancement of radon concentration in the post-earthquake measurements of the spring along Karanprayag-Chamoli-Pipalkoti and Rudraprayag-Ukhimath sections. This is also coupled with an increase in water discharge rate of springs.

2. The discharge rate of the springs in Budhakedar-Ghonti section have considerably diminished, even some of the springs studied earlier have dried up. Except for two springs towards north near Munsiari thrust, the radon concentration have decreased after the earthquake.

3. Most of the springs that shows very high radon enhancement factor are located in the vicinity of the different thrusts or maximum damaged zones with development of ground cracks. Probably, this may indicate that there is some degree of reactivation of the thrusts and faults present in this area.

The above mentioned results and discussion reveal that there is a significant relationship between ground water radon concentration and earthquakes. Therefore, continuous measurements of radon both in soil-gas and spring/groundwater at several sites in a well organised grid pattern are necessary to make it as useful precursor in earthquake prediction programme. In addition, the combination of radon measurements with the measurements of CO_2, CH_4, N_2, H_2, He, Cl and F along with the temperature and electric conductivity of the spring water may prove a useful hydrogeochemical precursor for any destructive earthquake.

References

1. Thakur, V.C. and Kumar S. 1994. Seismotectonics of the 20 October 1991 Uttarkashi earthquake in Garhwal, Himalaya, north India. Terra Nova **6**, 90-94.

2. Roeloffs, E.A., 1988, Hydrologic precursors to earthquakes–A review: Pure and Applied Geophysics, v. 126, p. 177-209.
3. Sharma, S.C. 1993. Isotope and geochemical studies on the thermal discharge in the Alaknanda and Bhagirathi Valleys, Chamoli and Uttarkashi district. Geol. Surv. Indi. Recd., 126, pt. 8, 211-213.
4. Sharma, S.C. 1997. Thermal springs as gas monitoring sites for earthquake prediction. In: Rare gas Geochemistry (Ed. H.S. Virk), GND Univ., Amritsar, pp. 193-199.
5. Braitenberg, C., Garavaglia, M., Magnoni, S. and Zadro, M. 1997. Radon and crustal deformation monitoring in seismic area of Friuli, north-east of Italy. In: Rare gas Geochemistry (Ed. H.S.Virk), GND University, Amritsar, pp. 143-157.
6. Fleischer, R.L. and Mogro-Campero 1979. Radon enhancement in the earth, evidence for the intermittant upflow. Geophys. Res. Lett. 6, 361-364.
7. King, C.Y. 1978. Radon emanation on San Andreas Fault. Nature 271, 516-519.
8. King, Y.C., Koizumi, N. and Kitagawa, Y. 1995. Hydrogeochemical anomalies and the 1995 Kobe earthquake. Science, 269, 33-34.
9. H. Friedmann, F. Hernegger: A Method for Continuous Measurement of Radon in Water of Springs for Earthquake Prediction. Geophys. Research Letters 5, No.7, p.565-568, 1978.
10. Wakita, H., Nakamura, Y., Notsu, K., Noguchi, M. & Asada, T. 1980. Radon anomaly: A possible precursor of the 1978 Izu-Oshima-Kinkai earthquake. Science, 207, 4433: 882-883.
11. Ramola, R.C., Singh, M., Sandhu, A.S., Singh, S. and Virk, H.S. 1990. The use of radon as an earthquake precursor. Nucl. Geophys. 4, 275-287.
12. Virk, H.S. 1993. Radon and earthquake prediction in India : Present Status. Nucl. Tracks Radiat. Meas. 22(1-4), 483-494.
13. Virk, H.S. 1995. Radon monitoring of microseismicity in the Kangra and Chamba Valleys of Himachal Pradesh, India. Nucl. Geophys. 9(2), 141-146.
14. Okabe, S. 1956. Time variation of atmospheric radon content near the ground surface with relation to some geophysical phenomena. Memoir Sci. Coll. Univ. Kyoto Sev. A28, 99-115.
15. Duarah, R., Baruah, S., Yadav, D. and Sitaram, M.V.D. 1997. Anomalies in radon emanation as earthquake precursor phenomena. In: . In: Rare gas Geochemistry (Ed. H.S.Virk), GND University, Amritsar, pp.175-187.
16. Ramola, R.C., Rawat, R.B.S., Kandari, M.S. and Choubey, V.M. 1997. Measurement of Radon in drinking water and indoor air. Radiation Protection Dosimetry, 74(1/2), 103-105.
17. Choubey, V.M. 1998. Radon measurements in soil and water and its relation with geology, Garhwal Himalaya. In Proceeding volume of the 7th Tohwa International Symposium “Radon and thoron in the human environment” Japan, (Eds. A.Katase and M. Shimo) World Scientific Publisher, pp. 193-198.
18. Singh, M., Singh, N.P., Singh, S and Virk, H.S. 1986. Calibration of radon detectors. Nucl. Tracks-Radiat. Meas., 12, 739-742.
19. Gansser, A. 1964. Geology of the Himalaya. Inter Science Publication. John Wiley & Sons, 289p.
20. Valdiya, K.S. 1980.Geology of Kumaun Lesser Himalaya. WIHG Publ. Dehra Dun.291p.
21. Saklani, P.S. and Bahuguna, V.K. 1986. Thrust tectonics of the Garhwal Himalaya. In: Himalayan thrust and associated rocks (Ed. Saklani. P.S.), Today & Tommorow Pub. New Delhi, 1-25.
22. Roy, A.B. and Valdiya, K.S. 1988. Tectonometamorphic evolution of the Great Himalayan Thrusts sheets in Garhwal region, Kumaun Himalaya. Jour. Geol. Soc. India. **32**, 106-124.
23. Bist, K.S. and Sinha, A.K. 1990. Imbrication of Main Central Thrust and its significance in the central sector of the Himalaya. In: Crustal evolution and orogeny, Ed. S.P.H.

Sychanthavong., Oxford & IBH Publ. Delhi. 293-302.

24. Thakur, V.C. 1992. Geology of Western Himalaya. Physics and Chemistry of the earth. Pergamon press, 19, (I-VI), 1-363.
25. Metcalfe, R.P. 1993. Pressure, temprature and time constraints on metamorphism across the Main Central Thrust Zone and High Himalayan slab in the Garhwal Himalaya. Himalayan Tectonics. Geol. Soc. Special Publication , 74, 485-509.
26. Fuchs, G. and Sinha, A.K. 1978. The tectonics of the Garhwal Kumaun Lesser Himalaya. Jaharb. Geol. B-A ,**121**, 219-241.
27. Choubey, V.M., Bist K.S., Saini N.K. and Ramola, R.C. 1999. Relation between soil-gas radon variation and the different lithotectonic units of Garhwal Himalaya, India. Applied Radiation and Isotopes. 51 (5), 587-592.
28. Nashine, S.K., Dhanaraju, R., Bhatnagar, G.S. and Narayan Das, G.R. 1982. Uranium occurrences close to Main Central Thrust around Sileth, Dhargaon, Chamyala Balganga Valley, Tehri Garhwal (U.P.). Him. Geol. **12**., 305-316.

Table 1. Insitu measurements of the Radon concentrations and Water discharge data during post (April, 1999) and pre(May, 1997) Chamoli earthquake of Garhwal Himalaya (March 29, 1999)

	Radon		**Water Discharge**			
	Post-EQ Bq/l	**Pre-EQ Bq/l**	**Pre-EQ Lt/min.**	**Post-EQ Lt/min.**	**Rn-EF**	**Dis-EF**
1. Karanprayag-Chamoli-Pakhi						
eq21	68.4	2.6	6	2.5	26.38	0.42
eq22	1.9	3.2	1	0.25	0.59	0.25
eq23	4.5	0.9	2.5	6.0	5.17	2.40
eq24	8.0					
eq25	4.2					
eq26	27.8	24.3	12	20.0	1.15	1.67
eq28	59.4	35.9	3	5.0	1.66	1.67
eq29	11.3	4.2	5	6.5	2.71	1.30
eq30	1.2					
eq31	2.1					
eq32	3.0	2.3	6	8.0	1.28	1.33
2.a) Rudraprayag-Tilwara-Okhimath						
eq1	0.6					
eq3	15.0	3.5	2	0.5	4.27	0.25
eq4	22.8	0.9	15	40	26.44	2.67
eq5	2.1					
eq6	56.9	60.0	3	4	0.95	1.33
eq7	6.1	10.2	1.5	3	0.61	2.00
eq7a	5.0	39.7	6	10	0.13	1.67
eq8	219.2	60.4	3	9	3.63	3.00

eq9	28.2	7.8	3	3.5	3.63	1.17
eq10	3.4					
eq17	25.5	25.8	16	20	0.99	1.25
eq18	4.5					
2.b) Subsection: Bhatwari-Garponga						
eq11	19.6					
eq12	14.6					
eq13	97.8					
eq14	3.9					
eq15	162.4					
eq16	61.6					
3. Ghonti-Ghansali-Budhakedar						
eq41	2.2	4.5	3	2.5	0.50	0.83
eq42	18.5	18.0	4.5	3	1.03	0.67
eq45	5.4	19.5	4.5	1.5	0.27	0.33
eq47	1.9	6.5		0.5	0.29	
eq48	1.3			1		
eq49	31.9	87.3		3	0.37	
eq50	22.6					
eq51	10.3					
eq52	622.9	159.7	10	2.5	3.90	0.25
eq53	106.8	66.7	6	2	1.60	0.33

EQ=Earthquake, EF=Enhancement factor, Dis.=Spring discharge, Rn=Radon