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Radon Monitoring of Microseismicity in the Kangra and Chamba Valleys of Himachal Pradesh, India

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Abstract—Data on radon emanation collected in soil-gas and groundwater at Palampur in the Kangra valley and Dalhausie in the Chamba valley of Himachal Pradesh is reported. Radon anomalies exhibit correspondence with some of the seismic events that occurred in the region along the Himalayan thrust faults. The study has proven the usefulness of radon as a precursor for recording micro-seismic activity along the major faults.

INTRODUCTION

The northern boundary of the Indian sub-continent, extending from the Hindukush in the west to the hills of Assam and Burma in the east, constitutes a region where the Indian plate collides against the Eurasian plate and has thus been the scene of a large number of major earthquakes in the past century. The Kangra earthquake of magnitude 8.5 which occurred on 4 April 1905 took a toll of 20,000 human lives and damaged most of the buildings in the epicentral tract (Middlemiss, 1910). During the past two decades, the N-W Himalaya has recorded four earthquakes of more than 5 M, viz. Knnaur (19 January 1975), Dharamsala (14 June 1978), Dharchula-Bajang (29 July 1980) and Dharamsala (26 April 1986). The Kangra valley of Himachal Pradesh is considered to be a highly seismic zone in the N-W Himalayan belt and is being monitored by various agencies, e.g. Geological Survey of India (GSI) (Narula and Shome, 1992), Indian Meterological Department (IMD) (Srivastava, 1989), Wadia Institute of Himalayan Geology (WIHG), Dehradun and our own group at Guru Nanak Dev University, Amritsar.

The author and colleagues started radon monitoring at Palampur in the Kangra valley in 1989 and the results of these studies have been reported (Virk and Singh, 1992, 1993). Radon anomalies were recorded in soil-gas and groundwater using both instantaneous and time-integrated techniques. The purpose of this study is to find the usefulness of radon monitoring for the recording of micro-seismicity in the Kangra and Chamba valleys.

EXPERIMENTAL TECHNIQUES

The experimental techniques used for monitoring radon in soil-gas and groundwater are as reported elsewhere (Virk and Singh, 1992, 1993). The present study pertains to radon emanometry data collected at Palampur and Dalhausie stations in the Kangra and Chamba valleys respectively, using a ZnS(Ag) detector system (Model RMS-10) manufactured by ECIL, Hyderabad, India.

RADON MONITORING RESULTS

Radon monitoring stations were set up within a range of 10 km from the Main Boundary Thrust (MBT) of the Himalaya at Palampur and Dalhausie. The Palampur station became operational in

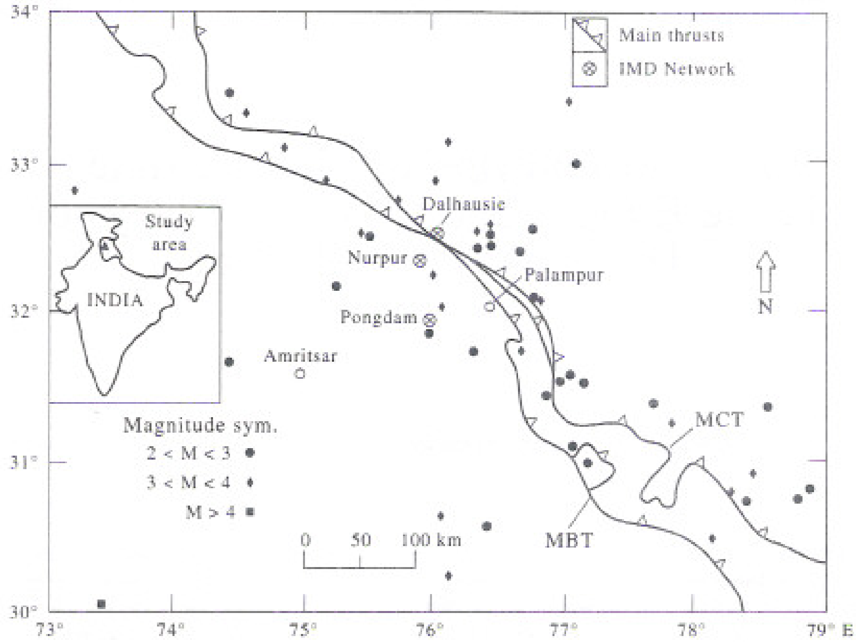

Fig. 1. Microseismic activity recorded by IMD network from April 1992 to September 1993 at Pong Dam, Nurpur and Dalhausie in Himachal Pradesh using seismographs. Radon recording stations at Palampur and Dalhausie are shown along the Himalayan thrusts. MBT, main boundary thrust; MCT, main central thrust.

April 1992, while at Dalhausie the data has been recorded since July 1992. Radon emanometry data shows some anomalies at both stations in soil-gas and groundwater. Since there was no major seismic event in the Kangra valley and its environs during the period from April 1992 to September 1993, it was necessary to take recourse to micro-seismic activities of the region recorded at a network of stations operated by IMD, New Delhi for correlation of these anomalies. From October 1992 to May 1993, the Pong Dam station (31.92N, 75.92E) recorded 16 seismic events with magnitude between 2 and 4 M with epicentres lying within a range of 100 km. The total number of events recorded in the grid 30–34N, 73–79E of 2–4 M is reported to be about 50 in the given time window. Most of these events have epicentres along the MBT trend line (Fig. 1). Radon recording stations show anomalies corresponding to nearly 40% of the events.

Radon emanometry data at Palampur

At Palampur station, the first radon anomaly occurred on 9 April 1992 in groundwater 2 days before an event of 2.2 M was recorded with epicentre 31.36N, 77.67E. However, there was no corresponding peak in soil-gas. The radon peak is 195% higher than the mean radon value $\bar{X} = 23.01$ Bq/L in groundwater and it crosses $\bar{X}+2\sigma$ level, where σ is the SD. The second peak occurred on 23 May 1992 in groundwater with a radon value of 165% above the mean, 3 days before the seismic event of 2.7 M was recorded with an epicentre at 31.51N, 77.17E. There is a false radon anomaly which occurred on 16 June 1992 but this had no corresponding micro-seismic event in the region. On 21 July 1992 there was a negative radon anomaly in the groundwater which may correlate with a seismic event of 3.6 M occurring on the same day with its epicentre 31.25N, 77.83E outside the Kangra valley. Another radon peak is recorded on 1 May 1993 in groundwater with a maximum radon value 152% above the mean value. This anomaly correlates with a seismic event of 1.9 M occurring on the same day with its epicentre at 30.67N, 78.44E. There were large scale fluctuations of radon signals in May 1993 in both groundwater and soil-gas. These fluctuations may be caused by seismic events which occurred on 13 May (2.0 M) and 15 May (3.2 M) at epicentres 30.98N, 77.16E and 30.48N, 78.13E respectively. The radon data shows a negative trend

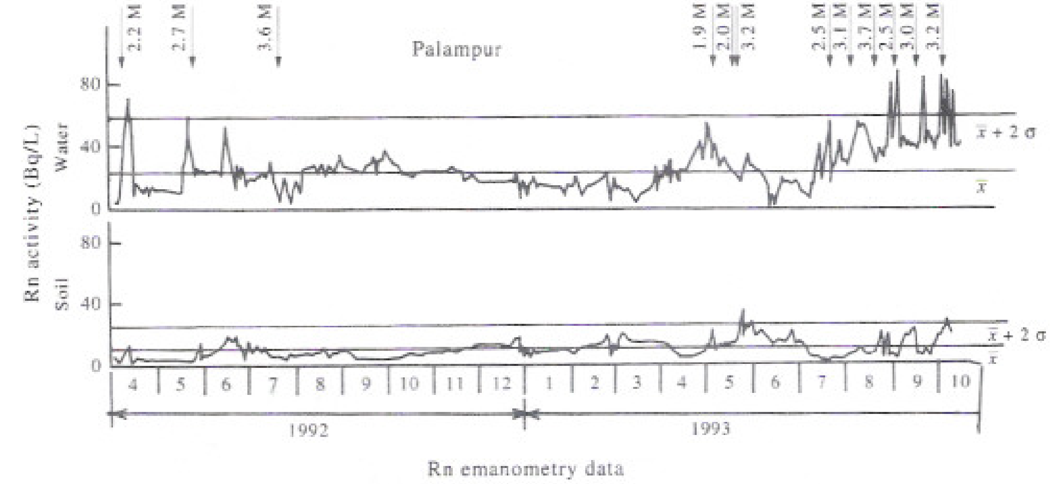

Fig. 2. Time-series radon emanometry data in soil-gas and groundwater recorded at Palampur from April 1992 to October 1993 in Kangra valley.

Table 1. Correlation of radon anomalies recorded at Palampur with microseismic activity in Himachal Pradesh

Date of radon anomaly	% change above mean	Magnitude	Latitude N	Longitude E	Date of earthquake
9 April 1992	195*	2.2	31.36	77.67	11 April 1992
23 May 1992	165*	2.7	31.51	77.17	26 May 1992
21 July 1992	−83*	3.6	31.25	77.82	21 July 1992
30 April 1993	152	1.9	30.67	78.44	1 May 1993
25 July 1993	99*	3.1	30.23	76.14	30 July 1993
11 August 1993	152*	3.7	30.73	78.79	15 August 1993
28 August 1993	252*	2.5	32.54	76.76	28 August 1993
17 September 1993	247	3.0	32.84	73.24	9 September 1993
28 September 1993	273	3.2	33.43	74.59	28 September 1993

*Anomaly in water.

during June 1993 with the lowest value recorded on 14 June in groundwater. During July 1993 radon emanation again shows a rising trend in groundwater with its peak value approaching $\bar{X}+2\sigma$ on 25 July. There was a sudden fall on 26 July and again a rise towards the end of July. There occurred two seismic events of magnitude 2.5 and 3.1 M on 18 July and 30 July with epicentres at 31.68N, 74.42E and 30.23N, 76.13E respectively. Unfortunately the radon emanation was highly suppressed in soil-gas during July 1993 due to heavy rainfall in the Kangra valley during this month. Radon emanation approached the $\bar{X}+2\sigma$ level during the second week of August in groundwater. This peak may be correlated with the seismic event of 3.7 M on 15 August with an epicentre at 30.73N, 78.79E. Radon emanation showed a peak on 28 August followed by a seismic event of 2.5 M within a few hours on the same day with epicentre at 32.54N, 76.76E. Two radon anomalies were recorded during September 1993 in groundwater and, corresponding to these anomalies, there occurred two seismic events of magnitude 3.0 and 3.2 M on 9 and 28 September with epicentres at 32.84N, 73.24E and at 33.43N, 74.59E respectively. Time-series radon emanometry data from April 1992 to September 1993 is presented in Fig. 2 showing some radon anomalies. A correlation of radon anomalies with micro-seismic events is presented in Table 1.

Radon emanometry data at Dalhausie

Radon data recorded at Dalhausie in the Chamba valley shows a peculiar trend (Fig. 3). In contrast with Palampur, radon emanation is more pronounced in the soil-gas compared to the groundwater. This may be due to the different geological conditions of the region. The mighty Dhauladhar range of mountains separates Dalhausie from Kangra valley. Another interesting trend

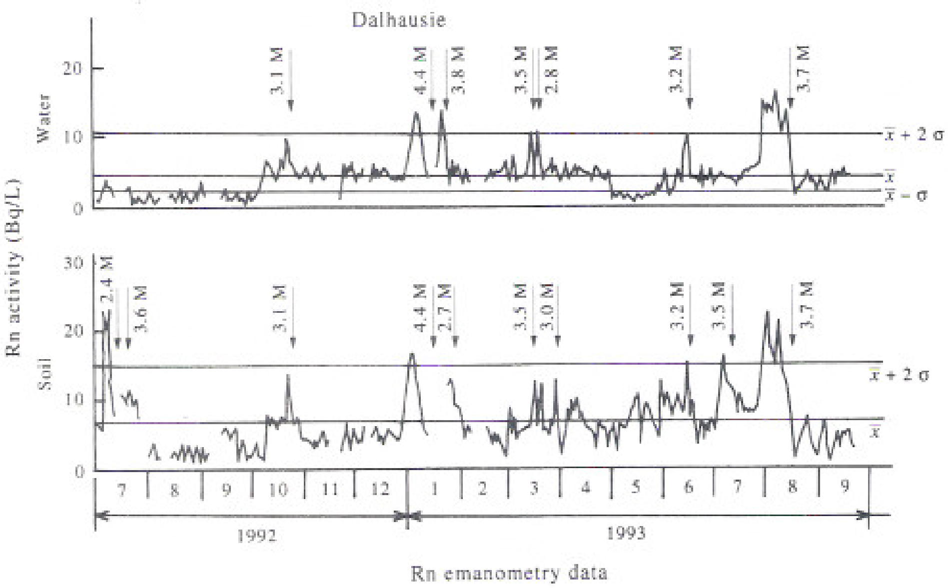

Fig. 3. Time-series radon emanometry data in soil-gas and groundwater recorded at Dalhausie from July 1992 to September 1993 in Chamba valley.

Table 2. Correlation of radon anomalies recorded at Dalhausie with microseismic activity in Himachal Pradesh

Date of radon anomaly	% change above mean	Magnitude	Latitude N	Longitude E	Date of earthquake
7 July 1992	250	2.4	31.08	77.06	14 July 1992
9 July 1992	250	3.6	31.25	77.82	21 July 1992
23 October 1992	109 117*	3.1	31.73	76.68	24 October 1992
3 January 1993	153 183*	4.4	30.02	73.48	12 January 1993
23 January 1993	205	3.8	32.73	75.75	24 January 1993
28 January 1993	93	2.7	31.37	76.90	29 January 1993
17 March 1993	93 128*	3.5	32.04	76.06	22 March 1993
20 March 1993	161	2.8	32.41	76.35	23 March 1993
30 March 1993	94	3.0	32.52	75.43	31 March 1993
17 June 1993	109	3.2	32.86	76.02	24 June 1993
17 June 1993	140*				
9 July 1993	138	3.5	33.14	76.14	12 July 1993
5 August 1993	242 227*	3.7	30.73	78.79	15 August 1993

*Anomaly in water.

of radon data is that radon peaks are recorded in both soil-gas and groundwater followed by the seismic events.

First, radon anomalies were recorded at Dalhausie on 7 and 9 July in soil-gas with peak values nearly 250% above the mean value of $\bar{X}=6.71$ Bq/L for this station. Two seismic events of 2.4 and 3.6 M were recorded on 14 and 21 July 1992 with epicentres at 31.08N, 77.06E and at 31.25N, 77.82E respectively. Sharp radon spikes were recorded on 23 October in both soil-gas and groundwater approaching the $\bar{X}+2\sigma$ level. These anomalies precede the seismic event of 3.1 M recorded on 24 October 1992 with epicentre at 31.73N, 76.68E.

On 3 January 1993 radon anomalies are recorded in groundwater and soil-gas which precede the seismic event of 4.4 M on 12 January with epicentre at 30.02N, 73.48E. This is the only major seismic event exceeding magnitude 4 M.

Radon peaks were recorded on 23 January in groundwater and on 28 January in soil-gas. These peaks correlate with seismic events of magnitude 3.8 and 2.7 M occurring on 24 and 29 January respectively in the Kangra valley. Radon data sets are missing in January and February 1993. During March 1993 three radon spikes were recorded in soil-gas on 17, 21 and 31 March but only two appeared in groundwater on 17 and 20 March, approaching the $\bar{X}+2\sigma$ level. These anomalies are obvious signals for seismic events of magnitude 3.5, 2.8 and 3.0 M, which occurred on 22, 23 and 31 March respectively, in the Chamba valley. Radon activity remained suppressed during the months April and May 1993. However, in June there was an increase in radon emanation culminating in anomalies on 17 June in both soil-gas and in groundwater. These anomalies were followed by a seismic event on 24 June (magnitude 3.2 M) in the Dalhausie area. A radon anomaly was recorded in soil-gas only on 9 July: it correlated with a seismic event of 3.5 M on 12 July with an epicentre at 33.15N, 76.14E. On 5 August sharp radon spikes were recorded in both soil-gas and groundwater and the radon level remained above $\bar{X}+2\sigma$ until 11 August in soil-gas and 15 August in groundwater. These large scale anomalies are caused by a seismic event of magnitude 3.7 M on 15 August with an epicentre at 30.73N, 78.79E. Radon activity was below normal during September 1993 and no anomaly was recorded. A correlation between radon anomalies and the seismic events is given in Table 2. The record of time-series radon data for Dalhausie station is shown in Fig. 3.

CONCLUSIONS

The following conclusions are drawn from this study based on time-series radon emanometry data collected at Palampur and Dalhausie stations in close proximity to MBT traversing Kangra and Chamba valleys of Himachal Pradesh.

(1) There is high micro-seismic activity in the region and this shows a definite trend along the fault line of the main boundary thrust (MBT) of Himalayas as shown in Fig. 1.

(2) Radon anomalies in soil-gas and groundwater correlate with some of the micro-seismic events which occurred during the time-window with epicentres within a radius of 200 km, as shown in Tables 1 and 2.

(3) Meterological variations have minimal effect on radon anomalies in groundwater. Hence they can serve as a better precursor in comparison to radon anomlies in soil-gas which are affected significantly by environmental factors.

(4) Sensitivity of a radon recording station depends upon the geological conditions of the region. Dalhausie station appears to be more sensitive to radon fluctuations caused by micro-seismic events in the Kangra and Chamba valleys in comparison with the Palampur station, although both are located in close proximity to the MBT.

(5) While most of the earthquakes occur following positive radon anomalies in both the recording media, some appear during negative anomalies. This dilemma needs to be resolved after collection of data over a longer time interval at a number of stations set up in the grid pattern.

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