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Radiation Measurements 36 (2003) 393–396
Radiation Measurements
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Relationships between radon anomalies and seismic parameters in N-W Himalaya, India

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Received 21 October 2002; received in revised form 27 February 2003; accepted 29 April 2003

Abstract

Radon data accumulated during 1992–1999 in the grid (30–34°N, 74–78°E) in N-W Himalaya have been anlaysed vis a vis seismic data recorded in the same area, supplied by Indian Meteorological Department (IMD) network. In general, there is a positive correlation between the total radon emission and the microseismicity in the area under investigation. The earthquake magnitude has moderate positive correlation with epicentral distance and low positive correlation with amplitude of radon precursory signal, whereas both show low negative correlation between them.

Empirical scaling relations are proposed using the best fit straight line from the log-linear graphs between magnitude of the events and log of the product of amplitude of radon anomaly and epicentral distance. The error between the recorded and calculated magnitude is also taken into account. The error range is higher at lower epicentral distances and magnitudes, showing that the local geology and tectonics have predominant influence on radon signals.

Keywords: Microseismicity; Magnitude; Epicentral distance; Radon anomaly

1. Introduction

The research on seismogeochemical algorithms is aimed at defining quantitative relations between seismic parameters, such as earthquake magnitude and epicentral distance, and geochemical anomalies occurring in subsurface gas and groundwater. Such relations can be classified both theoretically and empirically (Etiope et al., 1997).

Empirical algorithms are often based on a limited number of data and need validation for different geological environments. Nevertheless empirical algorithms represent a unique tool to predict earthquakes without a full understanding of rock-mechanics and fluid geochemistry interactions, and local and regional stress-field recognition.

To understand the mechanism of radon anomalies and establish its earthquake prediction capability and reliability, empirical scaling relationships between radon data and earthquake data are needed. In this paper an attempt has been made to interpret the available radon data (Sharma, 1999; Virk and Walia, 2001) of the Kangra and Chamba valleys of Himachal Pradesh recorded during the period 1992–1999 and to establish an empirical relationship with the seismic data monitored using Indian Meteorological Department (IMD) network in the area represented by the grid (30–34°N, 74–78°E). It is evident from the Fig. 1 that both radon emanation and seismicity show a rising trend during the time window 1992–99.

2. Empirical relationships for earthquake prediction

Some empirical relations have been proposed in the past relating precursor time of radon anomalies to earthquake magnitude and epicentral distance. Rikitake (1979) had given a relationship as $\log T = 0.6M - 1.01$, between precursor time (T) and earthquake magnitude (M) which was obtained on the basis of the best-fitting straight line and is based on a general linear equation $\log T = a + bM$, which holds well for all the precursor disciplines.

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doi:10.1016/S1350-4487(03)00158-6

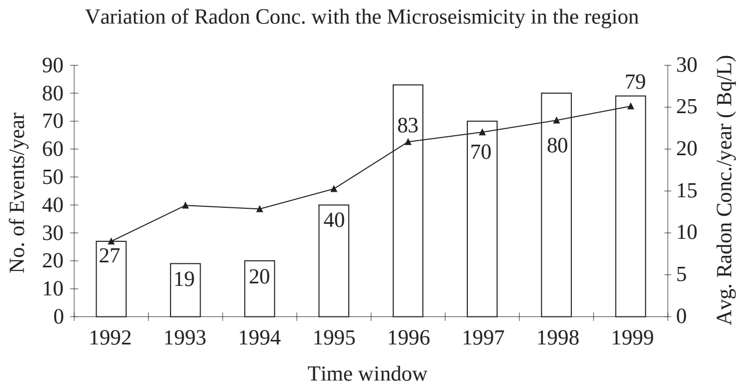

Fig. 1. Microseismic trend in the grid (30–34°N, 74–78°E) during 1992–1999 based on radon and IMD network data.

Dobrovolsky et al. (1979) and Fleischer (1981) had given relations between earthquake magnitude and the radius of the effective precursory manifestation zone respectively as $D = 10^{0.43M}$ and $D = 10^{0.813M}/1.66$ ($M < 3$) and $D = 10^{0.480M}/1.66$ ($M > 3$), where D is the epicentral distance in km and M is the magnitude of the earthquake on Richter scale.

Hauksson and Goddard (1981) proposed a modified relationship i.e. $M = 2.4 \log D - 0.43$ and Friedmann (1991) further modified the relationship as $M = 2.4 \log D - 0.43 - 0.4$. Sultankhodzhayev (1984) established an empirical formula relating precursor time T (days) to magnitude M and epicentral distance D (km) i.e. $\log DT = 0.63M - 0.15$. Taking recourse to the strain field models, Virk (1996) proposed four relations for fitting worldwide radon data of different epicentral distances as $D = 10^{0.32M}$ ($10 < D < 50$), $D = 10^{0.43M}$ ($50 < D < 100$), $D = 10^{0.56M}$ ($100 < D < 500$) and $D = 10^{0.63M}$ ($500 < D < 1250$).

An analysis of relation between precursor time (Rikitake, 1979), epicentral distance (Dobrovolsky et al., 1979; Fleischer, 1981; Virk, 1996) and earthquake magnitudes (Hauksson and Goddard, 1981; Friedmann, 1991) shows that there is no universal empirical relationship, which is valid for interpretation of radon data for all earthquake magnitudes. There is a large scatter in the data set for low magnitudes (2–4M) and short distances (< 500 km) because local geology has a significant effect on radon emanation and it differs from area to area. At the best we may use the scaling developed on the basis of fitting parameters that depend upon local geology, meteorological variables and other geophysical effects encountered at the monitoring site.

3. Analysis of radon data and the proposed empirical relationship

Keeping in mind the published formulations and local geological, meteorological and geophysical variables, a new empirical relationship is proposed between earthquake magnitude, epicentral distance and amplitude of radon anomaly for interpretation of radon data recorded at Palampur and Dalhousie stations for the period June 1992–August 1995 (Sharma, 1999) and June 1996–September 1999, using emanometry technique in both the media (i.e. soil-gas and groundwater) and both the data sets for the region under study. Radon data set pertains to 142 cases of radon anomalies in soil-gas and groundwater correlated with earthquakes of magnitude range between 2.1 and 6.8.

Relationships between the amplitude of radon anomaly (A), epicentral distance (D) and earthquake magnitude (M) from the given data set are evaluated. The correlation coefficients (R) between these variables are as follows:

Seismogeochemical parameters	Correlation coefficient (R)
M–D	0.54
M–A	0.13
D–A	−0.10
M–log(AD)	0.33

From the above analysis it can be concluded that magnitude of earthquake and epicentral distance have moderate correlation whereas these parameters show low correlation with amplitude of radon anomaly. Amplitude of radon anomaly is positively correlated with magnitude and negatively correlated with epicentral distance. Amplitude of anomaly is also controlled by other parameters like meteorological, geophysical and geological variables. In general, both amplitude of anomaly and epicentral distance increase with the increase in magnitude of earthquake whereas amplitude decreases with increase in epicentral distance and the same trend was also observed for other geochemical precursors (Kissin, 1992).

To find an empirical relation for the given grid, the average values of radon anomaly amplitudes and epicentral distances are calculated for all recorded magnitudes of earthquakes (Table 1). On the basis of magnitude of earthquakes the data is divided into two regimes i.e. one with earthquakes of magnitude 2.0–3.5 and the other with magnitude > 3.5.

Table 1
Average values of radon anomaly amplitudes and epicentral distances for different magnitude events taken for analysis

S. no.	Magnitude (M)	Amplitude of radon anomaly (A)	Epicentral distance (D)
1	2.1	61.3 ± 25.4	64.2 ± 27.8
2	2.2	60.7 ± 39.0	58.0 ± 2.8
3	2.3	49.9 ± 20.4	77.0 ± 16.7
4	2.4	68.7 ± 39.2	53.0 ± 35.2
5	2.5	98.4 ± 52.5	62.8 ± 17.6
6	2.6	71.7 ± 44.1	84.3 ± 25.9
7	2.7	125.8 ± 53.6	96.7 ± 20.1
8	2.8	133.4 ± 58.7	71.2 ± 31.8
9	2.9	93.3 ± 28.2	106.5 ± 22.1
10	3.0	88.2 ± 42.8	86.5 ± 50.0
11	3.1	129.1 ± 49.1	120.4 ± 59.4
12	3.2	82.4 ± 32.2	76.7 ± 41.1
13	3.3	111.7 ± 22.7	$66.2 \pm 30.$
14	3.4	78.7 ± 33.0	123.5 ± 47.2
15	3.5	69.5 ± 37.3	113.4 ± 44.3
16	3.6	69.9 ± 27.6	140.6 ± 46.6
17	3.7	65.3 ± 12.0	135.0 ± 0.0
18	3.8	78.0 ± 24.4	79.1 ± 48.8
19	4.0	140.1 ± 70.3	113.5 ± 35.8
20	4.1	60.6 ± 48.6	106.3 ± 56.6
21	4.2	74.8 ± 14.5	118.5 ± 48.8
22	4.5	243.1 ± 169.1	64.7 ± 20.2
23	4.7	123.8 ± 0.0	103.9 ± 0.0
24	4.8	59.9 ± 0.0	75.0 ± 0.0
25	6.8	64.3 ± 58.6	393.0 ± 0.0

The following scaling relations are proposed using the best fit straight line from the log-linear graphs between magnitude of the events (M) and log of the product of amplitude of anomaly (A) and epicentral distance (D):

$$\log(AD) = 0.30M + 3.00, \quad 2.0 \leqslant M \leqslant 3.5, \tag{1a}$$

$$\log(AD) = 0.22M + 3.13, \quad M > 3.5. \tag{1b}$$

In the generalised form the above relationship can be written as

$$\log(AD) = aM + b,$$

where 'a' and 'b' are constants. The value of both the constants varies from area to area and depends on local geology and other geophysical factors.

4. Discussion

To find out the efficacy of the proposed empirical relationships in the area under study, the values of earthquake magnitudes are calculated. The error between recorded and the calculated magnitude are also calculated. A comparison of recorded and calculated magnitudes of earthquakes shows some interesting features. The error is assigned a positive value if calculated magnitude is more than the recorded one and vice versa. The maximum value of percentage error is 96.48, which is recorded for an earthquake of magnitude 3.2 having epicentral distance of 46 km. There are three cases which show percentage error more than 90 and all these are having magnitude $\leqslant 3.5$ and epicentral distance less than 100 km. The number of points lying within $\pm 25\%$ limit is 74 out of the total 142 cases, i.e. more than half within this error limit, on which the test is applied. The various percentage error ranges are given below:

Range of % error ($\pm$)	Number of cases
0–10	36
11–20	27
21–50	52
> 50	27

A graph between percentage error and epicentral distance is plotted (Fig. 2). From the graph it can be inferred that for distances less than 100 km the error is higher, i.e. its average value is $\pm 33.10\%$ as compared to $\pm 29.15\%$ for the whole data set, whereas the error is $\pm 22.31\%$ when the distance is more than 100 km. Also error shows positive values for

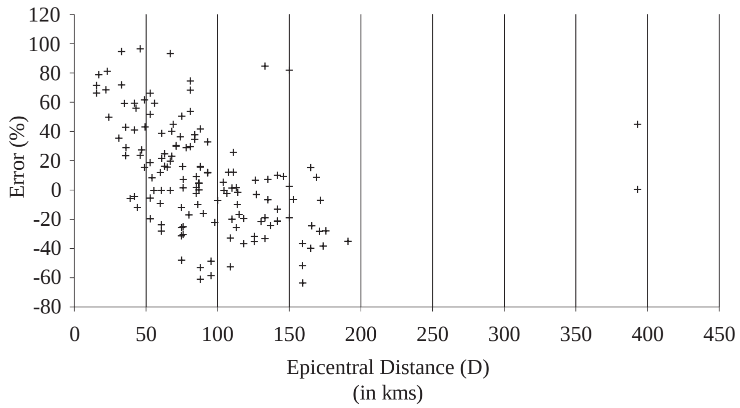

Fig. 2. Plot of percentage error between recorded and calculated magnitudes versus epicentral distance.

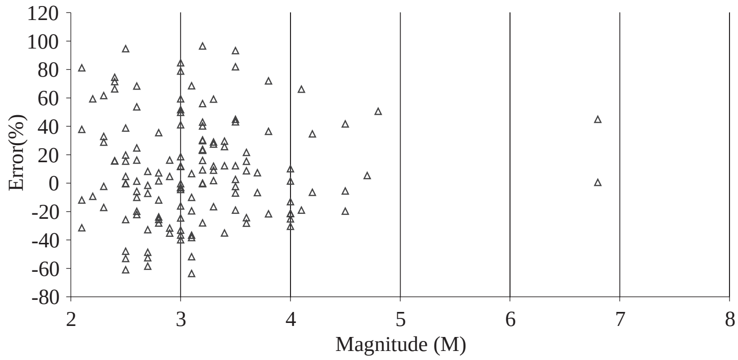

Fig. 3. Plot of percentage error between recorded and calculated magnitudes versus recorded magnitude of earthquakes.

lesser distance and negative for greater ones. The graph between magnitude and percentage error (Fig. 3) shows that with increase in magnitude the error range decreases. From the two graphs it can be concluded that error range is higher at lower epicentral distance and magnitude, which shows that the local geology has significant influence on radon signals.

High range in the percentage error may be due to the reason that the data set is an accumulation of radon data taken from two different stations having different geological and geophysical environments, and also the different nature of media. This shows that radon anomalies are not only influenced by the magnitude and epicentral distance of earthquakes but also by the mechanism of radon migration. The large scattering in the data set for low magnitudes (2–4M) and short distances (< 500 km) is reported by various authors (Hauksson, 1981; Virk, 1996).

5. Conclusions

1. In general, the microseismicity and radon emanation has been showing a rising trend during the time window 1992–1999 in Kangra and Chamba valleys of Himachal Pradesh.
2. The epicentral distance and magnitude of earthquake has moderate correlation whereas these parameters show low correlation with amplitude of radon anomaly. In general, it can be stated that the greater the magnitude of a seismic event the greater is the distance where precursors can be recorded and the larger the signal appears to be.
3. Due to inhomogeneity of the geophysical medium and nonlinearity of the precursor, the percentage error between observed and calculated earthquake magnitudes found to be high with maximum value of error 96.48% but in more than half of cases it lies under $\pm 25\%$.
4. It is established from the analysis that there is no universal empirical relationship which holds good for interpretation of radon data for all earthquake magnitudes and epicentral distances.

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