ORIGINAL RESEARCH PAPER

Earth Science

Volume - 7 | Issue - 4 | April-2017 | ISSN - 2249-555X | IF : 4.894 | IC Value : 79.96

Nonlinear and Pre-seismic observations using data of Radon Emissions in Kachchh, Gujarat

KEYWORDS

Soil radon, Earthquake Precursor, non-linear,Humidity, Pressure, Temparature

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ABSTRACT

In this paper, we carried out the study of possible earthquake precursors and understand the nonlinear phenomenon using the soil radon-222 data recorded both in Kachchh and Gandhinagar, Gujarat. We established a network of geochemical laboratories to monitor Geochemical signals continuously (mainly) by using RTM-1688 probe manufactured by Sarad Instruments, Germany at Desalpar, Vamka, Badargadh of Kachchh region which is considered to be seismically active. On the other hand, the same kind of instrumental set up has been installed at ISR, Raisan campus, Gandhinagar in order to compare the signal for both the seismically active and quiet regions. The data is also used in understanding the nature of soil radon-222 emission process.The average value of radon for soil-gas at Desalpar is found to be 1.91 kBq/ m3 with a standard deviation (Std.) of 0.98 kBq/ m3.With few exceptions radon in general shows small negative correlation with temperature i.e., the value of radon concentration decreases as temperature increases and increases with decrease in temperature. The correlation coefficient between radon and temperature is found to be -0.3. Positive correlation coefficient 0.3 between radon and pressure has been found i.e., radon decreases with decrease in pressure and increases with increase in pressure. The correlation of radon with humidity is found to be 0.05 which is statistically insignificant.

INTRODUCTION

Monitoring of Pre-seismic Geochemical signals have been drawn immense attention of researchers through decades due to its accomplishment as a precursor to earthquake occurrences. Among different geochemical parameters, radon is chosen for the study of short term precursor of earthquakes because of its long life period. It is a decay product of radium having 39 isotopes. Among those isotopes, Rn^{222} is the most stable isotope having half-life of 3.82 days. It is used as a trace gas in various studies of earth like hydrogeology, atmosphere etc. Due to its wide implications, the anomalous fluctuation of radon became an important element in the short-term earthquake precursor study. The pre-seismic changes in the variation of the radon concentration have been intrinsically linked with the time-dependent interactions between the tectonic stress, fluid flow, pore-pressure changes in fluid-rock interactions, rock deformation, development of micro-cracks and generation of charged particles within the inner earth (Choudhuri et.al, 2013).In another study by Jaishi et.al, 2014,concluded that there is a positive correlation between the variation of the geochemical gases (radon and thoron) and the occurrence of the seismic activities by studying the variation of the soil radon and thoron(Rn^{220}) along the Mat fault, Mizoram, India. But there was a serious drawback in the linear relationship by the assumption that the emanation of radon concentration is only controlled by the seismic activity, but also it is influenced by the meteorological parameters like the atmospheric pressure, humidity, temperature etc.(Chaudhuri et al. 2010, Walia et al. 2005).Here, we studied the pre-seismic observations in radon time series, differences in active and inactive regions, background values of various parameters and non-linear characteristics of the study region.

DATA AND METHOD

Continuous monitoring of soil gas radon at Badargadh, Vamka and Desalpar is carried out in Kachchh region where seismic activity is more, to study the correlation of radon anomalies in relation to seismic activities of the region. Similarly, We also monitored the soil gas radon at Raisa, Gandhinagar where seismic activity is less. Radon monitoring in soil gas was carried out by using RTM-1688 probe manufactured by Sarad Instruments, Germany. It measures radon, temperature, humidity and pressure in soil gas. The effect of meteorological parameters viz. Temperature, humidity and pressure on soil gas radon emission has been studied.

The average value of temperature for the given time window was 31.9°C with a standard deviation of 3.3°C and percentage variation coefficient of 103.7%. The temperature variation is about 14°C (min of 24 °C and max of 38 °C). The increase in radon concentration with temperature may be due to the increase in the diffusion rate with temperature (Singh et al. 1988; Sharma et al. 2000).We have analyzed the recorded soil radon-222 time series by means of nonlinear techniques such as FFT power spectral analysis, empirical mode decomposition (EMD). A daily-quasi-periodic fluctuation (which may sometimes dominate the recordings) is demonstrated and a signal-adaptive periodicity removal process based on the EMD method is used for robust processing. The entire analytical method aided us to recognize the nature and pattern of soil radon-222 emanation process. Moreover the recording and statistical and non-linear analysis of soil radon data at Kachchh region will assist us to understand the preparation phase of an imminent seismic event in the region.

Empirical mode decomposition is one of the important decomposition method. This is a data adaptive method and easy to use. This method can be used on time series of non-stationary signal. EMD iteratively decomposes the signal into severalIntrinsic Mode Functions (IMF). IMFs are considered as the characteristic (physically meaningful) modes of the signal in different frequency regions which catch local oscillations within the signal. The method does not need any apriori knowledge and definedbasis. In "sifting" process, which is the main procedure of the method, fast oscillations in the signal are isolated from the slow ones iteratively. The first IMF which consistsof locally highest frequency components is obtained after thefirst sifting. This IMF is subtracted from the signal and thesiftingprocedure is repeated using remainder signal to getthe nextIMF.Iterations are run until some stopping criteria are fulfilled (G. Rilling et.al., 2003). IMFs are zeromean signals having the same number of zerocrossing points and local extrema (minimumand maximum) points (or differ by 1 at most.) The signal,x(t), can perfectly be constructed by summing up the IMFs, i.e.,

$$x(t) = \sum_{k=1}^{k-1} dk(t) + r(t)$$

Here, dk(t) is thekth IMF, r(t) is the residual signal which canbe considered as the last (Kth)IMF. Each IMF covers thelower frequency regions locally in timefrequency plane thanthe previous IMF. For wideband signals, EMD behaves likea dyadic filter bank (G. Rilling et.al., 2003;Z. Wu, N. Huang, 2004).

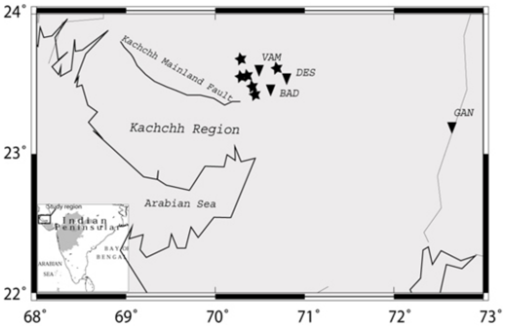


Figure 1: Location of Soil Radon Monitoring Stations (triangles) along with earthquake locations (star). The study region is shown as rectangle in India map (inset).

RESULTS AND DISCUSSION

The regular observation of soil radon monitoring is in progress at MPGO of Badargadh, Vamka, Desalpar in Kachchh since January 2010. One radon monitoring station is installed at ISR, Gandhinagar, Gujarat. The location of observing stations and epicenter of earthquake considered in this study are shown as Fig.1. Figure 2 depicts the schematic diagram of the experimental set up. The radon monitor is installed at a sub- surface depth of 1 meter surrounded by PVC pipe. The upper end of the PVC pipe is completely sealed in order to reduce the rain water penetration onto the probe. The gravels down to the pipe protect the probe from ground water. The measured radon-222 concentration profile as well as soil temperature and pressure are logged in a data logger kept in adjacent laboratory. The instrument records data at 10 minutes interval and the recorded data are transferred to ISR, Raisan from all field stations for further analysis.

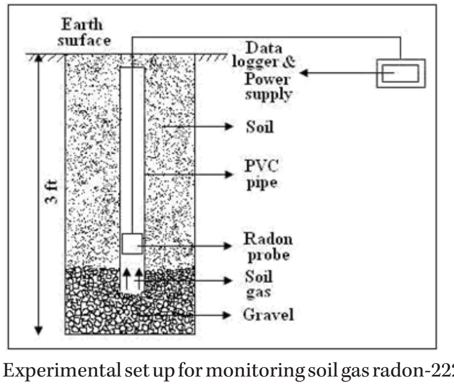


Figure 2: Experimental set up for monitoring soil gas radon-222.

Soil radon-222 data along with other meteorological parameters recorded at ISR, Gandhinagar and Desalpar, Kachchh are presented here. Figure 3 shows the soil radon data of ISR campus during the period October 10, 2013 to March 03, 2014. On the other hand, figure 4 displays the concentration profile of soil radon-222 recorded at Desalpar, Kachchh during November 20, 2013 to December 05, 2013. Apparently, both the radon data of ISR campus & Desalpar do not indicate the presence of any significantly irregular behavior of the concentration variation. However, some hidden information may be extracted applying some linear as well as nonlinear statistical tools on this data set.

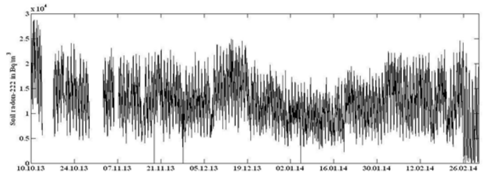


Figure 3: Soil radon-222 time series recorded at ISR, Gandhinagar during the period October 10, 2013 to March 03, 2014.

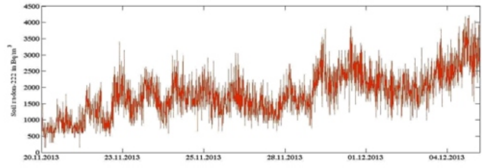


Figure 4: Soil radon-222 time series recorded at Desalpar, Kachchh during November 20, 2013 to December 05, 2013.

In order to obtain basic idea about the randomness or chaos of the data sets, phase space plots are generated and presented in figure 5. This implies that ISR campus data seems to be more chaotic than the Desalpar data. Contrarily, Desalpar data exhibits more periodic or oscillatory features in nature than the other one.

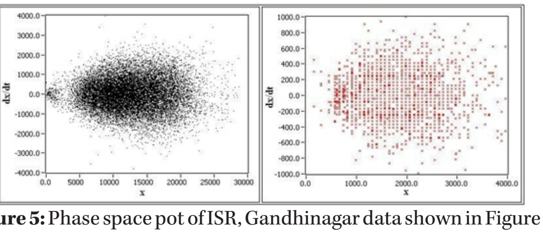


Figure 5: Phase space pot of ISR, Gandhinagar data shown in Figure 2 (left panel) and Desalpar data shown in Figure 3(right panel).

Moreover the probability density function of the ISR data (left panel of Figure 6) exhibits normal distribution. However, it shows an asymmetry in between its two end tails. But in case of Desalpar data (right panel of Figure 6), the normal distribution is very weak.Again, to study the periodicity of these data sets FFT periodograms are figured out in figure 7.

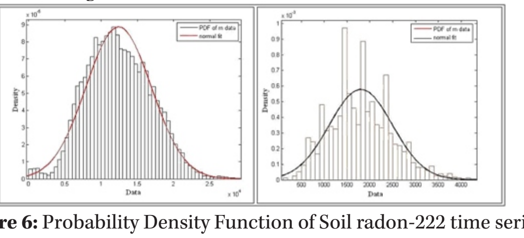
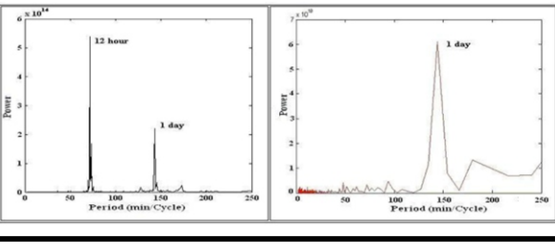


Figure 6: Probability Density Function of Soil radon-222 time series recorded at ISR, Gandhinagar (left panel) and Desalpar, Kachchh (right panel).

The left panel represents the periodogram of the ISR data. It clearly indicates the presence of two sharp harmonic periodic modes i.e. 12 hours and 1 day. These two harmonics may be considered as semi diurnal and diurnal variations respectively. But in case of Desalpar data (right panel), it shows only one harmonic mode of 1 day period. Now in order to find out the possible source of all these harmonics same FFT periodograms are generated for the soil temperature and soil pressure data recorded at both the two sites.



Volume - 7 | Issue - 4 | April-2017 | ISSN - 2249-555X | IF : 4.894 | IC Value : 79.96

Figure 7: FFT Periodogram of Soil radon-222 time series recorded at ISR, Gandhinagar (left panel) and Desalpar, Kachchh (right panel).

In figure 8 periodogram of the soil temperature data of ISR campus is presented in the left panel whereas for the soil pressure data of the same site it is shown in the right panel. Although the periodogram of the soil temperature data of ISR campus does not reveal any clear harmonic periods, the periodogram of soil pressure data of this site depicts two sharp harmonic periods of 12 hour as well as 1 day (figure 9).

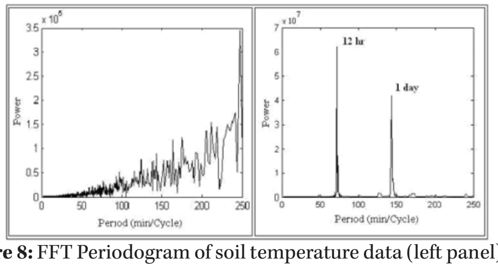


Figure 8: FFT Periodogram of soil temperature data (left panel) and soil pressure data(right panel) recorded at ISR, Gandhinagar.

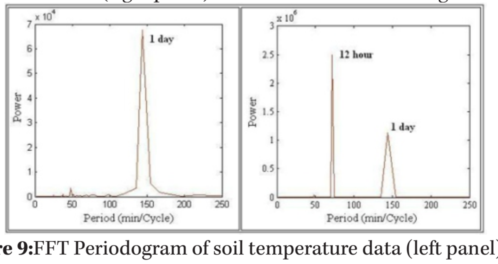


Figure 9:FFT Periodogram of soil temperature data (left panel) and soil pressure data (right panel) recorded at Desalpar, Kachchh (right panel).

The presence of these two harmonic periods in case of both the soil radon-222 and soil pressure data of ISR campus clearly indicates the influence of earth tides on the soil radon-222 emanation process at ISR campus. Additionally, the same feature is evident in case of Desalpar data set. In the next stage, to investigate the seismic contribution in the soil radon concentration profile one may consider the diurnal and semi diurnal oscillations as a background variation and easily remove those background variations by means of some sophisticated nonlinear techniques.

Correlation coefficient has been calculated between radon in soil gas, soil temperature, humidity and soil pressure. The variation of radon concentration in soil gas along with the soil temperature and pressure at Desalpar from Feb-Dec 2011 is shown in Fig. 10. The average value of radon for soil-gas at Desalpar is found to be 1.91 kBq/ m 33 with a standard deviation (Std.) of 0.98 kBq/ m 3. The percentage variation coefficient (Std. /Avg.) of radon is 51.5% (Table 1). With few exceptions radon in general shows small/no negative correlation with temperature i.e., the value of radon concentration increases as temperature increases and decreases with decrease in temperature.

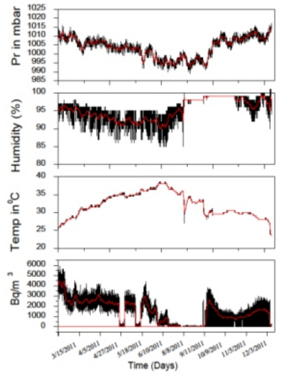


Figure 10: Time series of radon, temp, humidity and pressure during the entire year

The correlation coefficient between radon and temperature is found to be -0.3 (Table 1). The average value of temperature for the given time window was 31.9°C with a standard deviation of 3.3°C and percentage variation coefficient of 103.7% (Table 1). The temperature variation is about 14°C (min of 24 °C and max of 38 °C). The increase in radon concentration with temperature may be due to the increase in the diffusion rate with temperature (Singh et al. 1988; Sharma et al. 2000). Positive correlation coefficient 0.3 between radon and pressure has been found i.e., radon decreases with decrease in pressure and increases with increase in pressure.

Table 1: Average values of Rn and correlation coeffients with other parameters during the year 2011

Parameters	Avg	Std. dev	% var. coeff	Correlation co.eff
Radon(KBq/m^3)	1.910	0.983	51.5	
Temp.(° C)	31.934	3.32	10.37	-0.3
Humidity (%)	95	3.4	3.57	0.005
Press.(mbar)	1005	5	0.5	0.3

The radon anomalies observed in the region have been correlated with the seismic events in the magnitude range 3.0 to 4.5 recorded by our seismic network. In order to identify possible threshold values of the anomalous radon concentration various statistical methods have been used by different authors in the past (Walia et al. 2005; Kumar et al. 2009). The very common practice of considering the mean plus "n" standard deviation is generally accepted as an anomaly in soil gas and is found to be convenient for soil gas survey interpretations (Singh et al. 2006; Walia et al. 2008). In our context of radon concentration the statistical threshold value of anomalies is fixed at the average plus two standard deviation (2σ) for positive anomaly and average minus two standard deviation (2σ) for negative anomalies in soil gas.

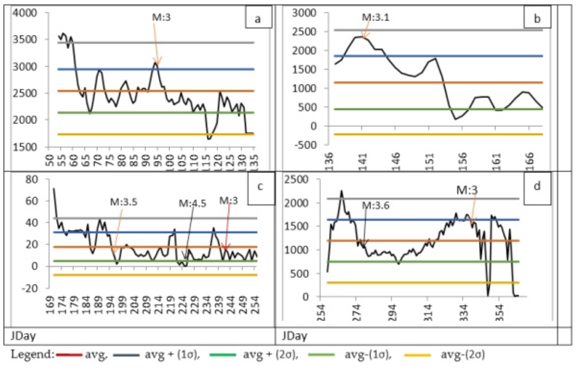


Figure 11: Radon anomalies at the average plus two standard deviation (2σ) for positive anomaly and average minus two standard deviation (2σ) for negative anomalies in soil gas at Desalpar.

Six soil gas radon anomalies were observed. The observed precursory time is 1-5 days prior to earthquakes of magnitude Mw (3.0-4.5) with epicentral distance of 5-50 Km. The first radon anomaly was recorded on 04 April, 2011 which was followed by the event of magnitude 3.0 which occurred on 05 April 2011. Other anomalies are shown in figure 11 (arrow marks). Most of the radon anomalies started within 4-5 days prior to the earthquake. In some cases as shown in fig-11, radon anomalies initiated and terminated before the earthquake, while in other cases the radon anomaly continued after the time of the earthquake. Thus, there does not appear to be any diagnostic behaviour of either the beginning or end of a radon anomaly that gives consistent clue about when an earthquake is to happen. The best that can be said is that most of the time the earthquake takes places within a month of the time of that an increase in radon gas is observed.

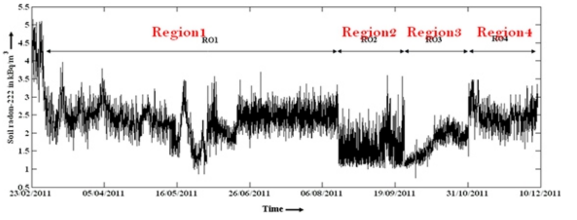


Figure 12: Soil radon-222 time series recorded at Desalpar, Kachchh, Gujarat

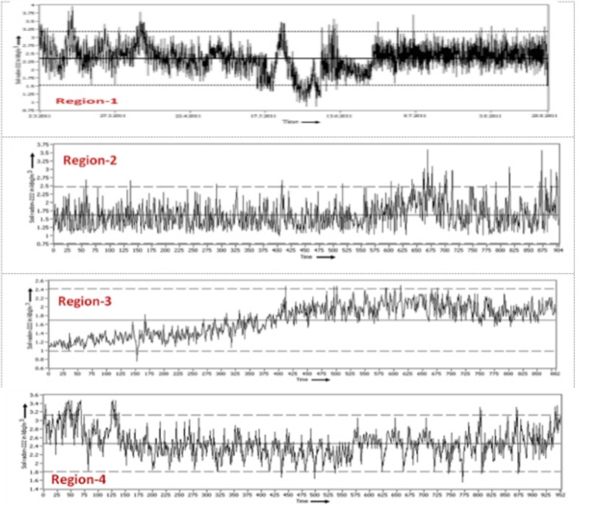


Figure 13: The radon time series with mean (middle solid line), +2 , -2σ (up and down dashed lines) for all the four regions as shown in fig.12

An earthquake (>4M) is followed by several forms of geophysical and geochemical changes in the crust that occur prior to eventual rupture. These changes, called "earthquake precursors", which are manifested as large deviations or "anomaly" in the parameter that is being observed (King, 1986). In order to find out the possible geochemical precursory signals for earthquake events, we monitored radioactive gas radon-222 in sub surface soil gas at Kachchh region. The earth's tide (periodic or semiperiodic), meteorological parameters such as ambient humidity, ambient temperature, ambient pressure, rainfall and soil characteristics such as soil moisture, soil temperature, soil pressure, soil porosity etc. also play vital role in the radon emanation process from sub-soil gases (BARNET et al., 1997).

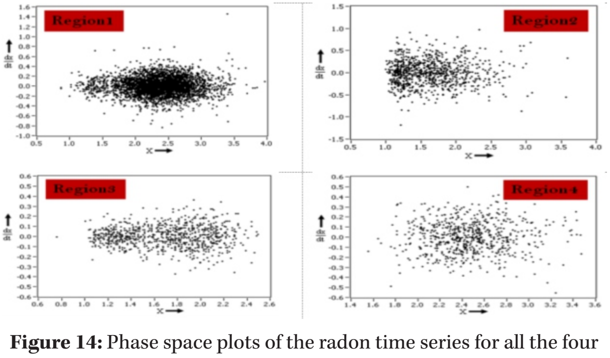


Figure 14: Phase space plots of the radon time series for all the four regions

The entire soil radon emanation process is a complex phenomenon. To understand the dynamics of radon emanation process and its relation with tectonic activities several attempts have been made worldwide over the last three decades (GHOSH *et al.,* 2009; TOUTAIN and BAUBRON, 1999).

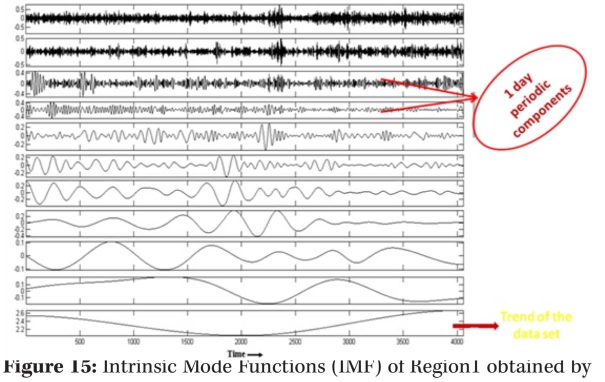


Figure 15: Intrinsic Mode Functions (IMF) of Region1 obtained by EMD

Various mathematical models were also proposed by some workers (FLEISCHER R L, 1981, WALIA et al., 2005). However, as per our present understanding it is very difficult to explore the complex phenomena of seismic induced radon emanation process by means of conventional mathematical models and statistical analysis. Nonlinear methods such as power spectrum analysis, wavelet analysis, fractal analysis etc. may assist to reveal nonlinear characteristics of the under earth physical-chemical mechanism involved in radon emanation process (CHAUDHURI et al., 2013, DAS et al., 2006). In the present work, we have applied the technique of EMD based Hilbert Huang Transform to the soil radon time series data recoded at Desalpar Multi Parametric Geophysical Observatory, Gujarat, India. The essence of applying this method lies in the fact that for the first time soil radon-222 data set is analyzed considering its non stationary features. The entire time series is divided in to 4 regions based on its base line (fig 12). We have calculated mean, +2σ and -2σ for all the regions and shown as figure 13.Phase space plots of all the regions are plotted as figure 14. Here the region 1 shows concentration of all the values and for other regions it is scattered. Intrinsic mode functions (IMF) of region-1 obtained by EMD is shown as fig.15.

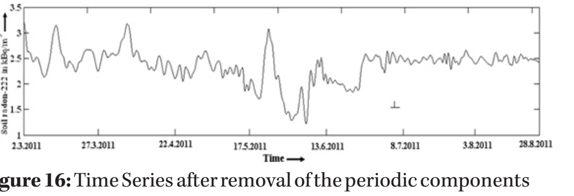


Figure 16: Time Series after removal of the periodic components

We have removed these periodic components from the original time series and the residual time series is shown as fig.16. The EMD technique is effective in separating various sources of noises recorded in radon time series.

CONCLUSIONS

The possible earthquake precursors and the nonlinear phenomenon using the soil radon-222 data recorded both in Kachchh and Gandhinagar, Gujarat are studied in this study. Radon data recorded at Desalpar, Vamka, Badargadh of Kachchh region and ISR, Raisan campus, Gandhinagar are used in this study. Both regions falls in the seismically active and quiet regions. The data is also used in understanding the nature of soil radon-222 emission process.The average value of radon for soil-gas at Desalpar is found to be 1.91 kBq/ m^3 with a standard deviation (Std.) of 0.98 kBq/ m^3.With few exceptions radon in general shows small negative correlation with temperature i.e., the value of radon concentration decreases as temperature increases and increases with decrease in temperature. The correlation coefficient between radon and temperature is found to be -0.3. Positive correlation coefficient 0.3 between radon and pressure has been found i.e., radon decreases with decrease in pressure and increases with increase in pressure. Diurnal and semi-diernal signals identified. We applied EMD technique on the radon time seies and we found that the EMD technique is effective in separating various sources of noises recorded in radon time series.

ACKNOWLEDGEMENT
The authors are thankful to the Director General, ISR for his encouragement, scientific support and permitting us to publish this work.

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