Vertical profile of radon and its progeny concentrations and its effect on atmospheric electrical conductivity near the surface of the earth.

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ABSTRACT

Electrical conductivity of the atmosphere is due to the presence of ions in the atmosphere and depends on the meteorological parameters. The variation of electrical conductivity near the earth's surface is mainly due to the variations of ^{222}Rn and its short-lived daughter nuclei. The diurnal and vertical variations of atmospheric electrical conductivity, radon and its progeny concentrations were studied at Mysore city, Karnataka State, India. Radon concentration varies from 3.70 Bq m^{-3} to 19.40 Bq m^{-3} with a geometric mean of 10.80 Bq. m^{-3}. Ion-pair production rate varies between 1.48 to 5.11 ion –pairs cm^{-3} s^{-1} over a day. The positive and negative conductivity value varies from 2.44 to 5.31×10^{-14} Ω^{-1}m^{-1} with a geometric mean of 3.31 ×10^{-14} Ω^{-1}m^{-1} and 2.41 to 5.06×10^{-14} Ω^{-1}m^{-1} with a geometric mean of 3.31 ×10^{-14} Ω^{-1}m^{-1} respectively. The stable atmosphere during night helps more accumulation of radon near the ground surface and hence the atmospheric electrical conductivity was maximum during early morning hours. A good correlation between electrical conductivity and ion production rate due to radon and its progeny concentrations is observed with a correlation coefficient of 0.87. Vertical variation of atmospheric electrical conductivity is similar to that of radon and its progeny concentrations. Atmospheric electrical conductivity shows positive correlation with wind speed and atmospheric pressure with correlation coefficients 0.72 and 0.47 respectively.

Key words: Radon, Ion production rate, Gerdien condenser, SSNTD, atmospheric conductivity.

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INTRODUCTION

Radon, a decay product of Radium in the naturally occurring Uranium series, is a radioactive inert gas and constitutes about half the radiation dose received by general population. After its formation in the earth crust, radon can slowly diffuse up into the atmosphere until it undergoes radioactive decay. The amount of radon emitted from the earth's surface depends mainly on the amounts of ^{238}U, ^{232}Th and ^{226}Ra present in soil and rocks. The rate of radon diffusion depends on the geological factors such as porosity, temperature difference between top layers of soil, moisture content of the soil and permeability of soil; and meteorological factors such as rainfall, wind, humidity and other environmental conditions [1]. Whereas the radon concentration over the ocean depends upon the radon source, and the time of an air mass spent over a continent and vertical atmospheric stability. The worldwide average of radon flux as 0.016 Bq m^{-2} s^{-1} and world average radon concentration outdoor is about 10 Bq m^{-3} [1].

Radon is known to be a perfect tracer for the study of transport and mixing phenomenon in the atmosphere. Atmospheric radon is removed only by radioactive decay and not susceptible to wet or dry removal processes [2]. The half life of radon (3.82 days) is much larger than the turbulent scales (<1hour) and is therefore suitable for mixing studies in the atmospheric boundary level [3]. The vertical distribution of radon progeny near the ground show radical changes due to attachment and removal processes. Thus the vertical distributions of radon progeny/radon ratios are expected to vary in a nontrivial way near Earth's surface.

The study of the electrical parameters of the atmosphere such as ionization rate, electric field, conductivity and currents is of fundamental importance in the study of global electric circuit, cloud electricity, sun-weather relationship and air pollution [5,6]. The electrical parameters of the atmospheric are influenced by several environmental factors that are constantly varying in the atmosphere. At lower layers of the atmosphere, ionization is mainly due to the radiations emitted by radon and its decay products. Short-lived daughters of radon (^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po) are electrically charged and are chemically reactive. Electrical processes in the earth's atmosphere have their origin in the production of small ions [5]. In a continental station the variations in radon exhalation, ionization, weather, human activity, industrial effluents, automobile exhaust, pollution etc., contribute for the diurnal, seasonal, spatial and vertical variations of atmospheric electrical conductivity [6]. The electrical conductivity of air at lower layers of the atmosphere depends on natural radioactivity and aerosol concentrations and also on other meteorological parameters. The vertical profile of the outdoor radon and its progeny concentrations is useful to study radon gas as a tracer in the atmosphere. Therefore it is of interest to design and conduct the experiment to study the vertical distribution of radon and its progeny near the ground surface and interpreting the measured results [4]. The perceptive of radon sources, transport mechanisms and their distribution in the environment has evolved over few decades. The present paper deals with the studies on diurnal and vertical variations of radon concentrations, its daughter products and atmospheric electrical conductivity.

MATERIALS AND METHODS

Diurnal and Vertical variations of atmospheric electrical conductivity

Atmospheric conductivity of both positive and negative polarities is simultaneously studied using a Gerdien condenser [5,6]. The Gerdien condenser consists of two identical cylindrical tubes of 10 cm diameter and 41 cm length joined by a U-shaped tube. The air was sucked through the tubes using a single fan. The inner co-axial electrode in both the tubes are of 1 cm diameter and 20 cm length. Opposite but equal potentials of $\pm$ 35 V are applied to the outer electrodes of the two condensers. The Gerdien condenser is insulated and kept in a third cylinder, which is electrically grounded for shielding the measurements from external electrical disturbances. Inner cylinder was used as the collector and the outer one was used as the driving electrode. For the study of vertical variations, the Gerdien condenser is hanged below a tethered balloon at different altitudes from the ground surface. Each sensor is scanned every one minute using data acquisition system, and hourly average values of atmospheric conductivity of both polarities are recorded on a computer.

Vertical variations of Radon/Thoron and their progeny concentrations.

The concentrations of radon, thoron and their progeny are measured using Solid State Nuclear Track Detectors (SSNTD), which are thin sheets of dielectric materials such as cellulose nitrate (CN) and polycarbonates. They are sensitive to alpha but not to beta and gamma radiations. They are unaffected by moderate humidity, heat and light. In the present study LR-115 TYPE II (Kodak Pathe, France) plastic track detector (C N film) were used [7-9].

The SSNTD films were fixed in twin cup dosemeter were used for monitoring radon, thoron and their progeny concentrations. The schematic diagram of the twin cup dosimeter is shown in figure 1. These dosemeters fixed inside an inverted plastic can and are suspended to a tall coconut tree at different heights from the ground surface. At the end of the stipulated period of exposure, usually about 60 days, the dosemeters are retrieved and SSNTD films are etched with 10% of NaOH solutions for 60 minutes at a constant bath temperature of about 60°C following standard procedure. The track density of alpha particles in the film was determined using a spark counter.
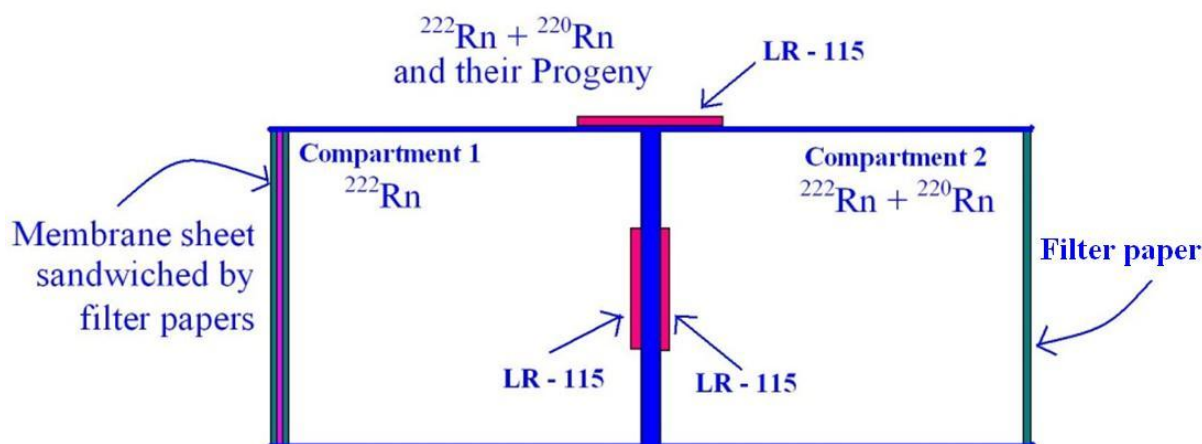
Figure 1. Schematic diagram of a twin cup dosimeter.

The radon/thoron concentration and their progeny working level concentrations are calculated using the following relations [7-9].

$$C_R = \frac{T_1}{DS_1} (Bq\,m^{-3})$$

$$C_T = \frac{T_2 - d \cdot C_R \cdot S_{t2}}{D \cdot S_{t2}} (Bq\,m^{-3})$$

where,
T_1 and T_2 are the track densities (tracks/cm^2) of the SSNTD film in compartments 1 and 2 respectively. d is the period of exposure, (60 days), S_1 is the sensitivity factor for radon compartment 1, S_{r2} and S_{t2} are the sensitivity factors for radon and thoron in compartment 2. C_R and C_T are the radon thoron concentration respectively.

$$R_P = \frac{C_R \cdot F_R}{3.7} (mWL)$$

$$T_P = \frac{C_T \cdot F_T}{0.275} (mWL)$$

Where R_P is the Radon Progeny Concentration, T_P is the Thoron Progeny Concentration, F_R and F_T are the equilibrium factors for radon and thoron progeny respectively.

$F_R = 0.104f_{RA} + 0.518\,f_{RB} + 0.37f_{RC}$

$F_T = 0.91\,f_{TB} + 0.09\,f_{TC}$

Where f_{RA}, f_{RB}, f_{RC}, f_{TB} and f_{TC} are activity fractions with respect to parent gas, corresponding to the extracted ventilation rate [7].

Diurnal variations of Radon concentrations.

The diurnal variations of radon concentration is studied using Low Level Radon Detection System (LLRDS) following the well-established procedure [6,10]. The LLRDS consists of a metallic collection chamber of 24 cm diameter and 11.5 cm height and a volume of 5 litres. The pre evacuated collection chamber was used to collect the air sample from the study location. After collection of air sample in the LLRDS chamber, at least 10 minutes delay is allowed for complete decay of thoron, which may be present in the chamber. The positively charged ^{218}Po atoms created in the chamber get collected on a metallic plate maintained at an optimum negative potential. The collection is carried out for an optimized period and thereafter the charged plate is removed from the chamber and alpha activity on the metallic disc is determined using an alpha counting system. The minimum detectable accuracy for radon in LLRDS is as low as 1.7–8.8 Bq m^{-3}, depending on the relative humidity conditions. The concentration of radon (in Bq m^{-3}) is calculated with the expression [6, 10]:

$$^{222}Rn = \frac{1000 \cdot C}{E \cdot V \cdot F \cdot Z} \quad (Bq\,m^{-3})$$

Where
C is the total number of counts observed during the counting period
E is the efficiency of alpha counting system (26%)
F is the efficiency of collection of RaA-atoms on the metallic disc and is empirically related to humidity *H* by
F = 0.9 *(1 – exp (0.039 * H – 4.118))
V is the volume of LLRDS chamber (liters)
Z is the correction factor for build up and decay of radon daughter atoms on the metallic disc during the exposure and counting period.

Diurnal variations of Radon Progeny concentrations.

The diurnal variations of radon progeny concentrations were studied using an Air flow meter, which consists of 15 cm long and 1 cm diameter tube made up of Perspex. The schematic diagram of the Air Flow Meter is shown in figure 2. The tube is embedded in a Perspex block of square cross section of side 3 cm. At one end of the tube a metallic device is provided for fixing the filter paper and a facility to control the air flow. At the other end there is a provision for connecting an air pump. Air is drawn through a glass fiber filter paper by means of a suction pump at a known flow rate. The radon progeny in air sample are retained on the filter paper. The filter paper is then alpha-counted at any specific delay time. Total activity on the filter paper is measured at three different counting intervals of 2 – 5, 6 – 20 and 21 – 30 minutes. Radon progeny concentrations in atmosphere were measured by the modified Tsivoglou method [6,11]. The following equations were used to estimate the individual radon progeny concentrations.

$$RaA = \frac{4.249019(C_1) - 2.062417(C_2) + 1.949949(C_3)}{VE} \quad (\mathrm{Bq\,m^{-3}})$$

$$RaB = \frac{-0.355129(C_1) + 0.006232(C_2) + 0.240618(C_3)}{VE} \quad (\mathrm{Bq\,m^{-3}})$$

$$RaC' = \frac{-0.215175(C_1) + 0.371319(C_2) - 0.502945(C_3)}{VE} \quad (\mathrm{Bq\,m^{-3}})$$
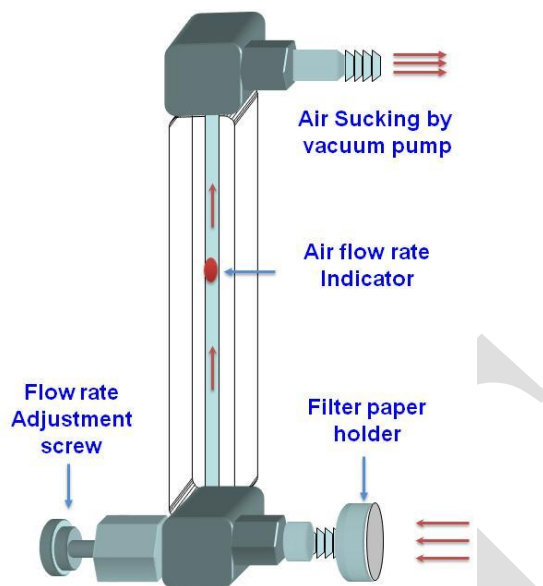
Where
where Rn, RaA, RaB and RaC' are the concentrations (Bq m^{-3}) of ^{218}Po, ^{214}Pb and ^{214}Po respectively.
C_1, C_2 and C_3 – are the gross counts during the three counting intervals
E – The efficiency of alpha counting system (26%)
V – The sampling rate in liters per minute (LPM)
R_d – The concentration of radon progeny

Figure 2. Schematic diagram of Air Flow Meter.

Ion Pair production rate

The total energy released E (eV cm^{-3} s^{-1}) due to both radon and its progeny is computed from radon and its individual progeny concentrations and is used to calculate ion-pair production rate Q (No. cm^{-3} s^{-1}):

$$E = 5.49 \times 10^6 Rn + 6.00 \times 10^6 RaA + 0.85 \times 10^6 RaB + 7.69 \times 10^6 RaC"$$

$$\text{and} \quad Q = E/32 \quad \text{ion pairs cm}^{-3}\text{s}^{-1}$$

where Rn, RaA, RaB and RaC' are the concentrations (Bq m^{-3}) of ^{222}Rn, ^{218}Po, ^{214}Pb and ^{214}Po respectively [6].

RESULTS AND DISCUSSIONS

Diurnal variations:

The average diurnal variations of radon and its progeny concentrations for a typical fair weather day are shown in the table 1. The average diurnal variation of meteorological parameters such as atmospheric pressure, relative humidity, ambient temperature and wind speed are shown in figure 3. All the measurements were carried at simultaneously at the same location. Concentrations of radon and its progeny in the outdoor environment are affected not only by the magnitude of the exhalation rates but also by atmospheric mixing processes. The atmosphere is relatively calm during night time with low winds and little convective motion. Radon exhaled from the soil surface accumulates near the ground leading to gradual increase in the radon concentration. The concentrations of radon and its progeny show maxima during the early morning hours (04–06 hrs) and decrease after sunrise and become lower during day time (10−16 hrs) [12,13].

Table 1. Diurnal variation of radon, its progeny concentrations, ion production rate and electrical conductivity of the atmosphere.

Time Hours (IST)	Concentrations (Bq m^{-3})				Ion pair production rate (no.cm^{-3} s^{-1})	Conductivity (10^{-4} Ω^{-1}s^{-1})	
	^{222}Rn	RaA	RaB	RaC'		Positive	Negative
00	11.20	7.16	1.40	1.23	2.84	3.64	3.52
02	13.73	10.58	1.73	1.56	3.54	4.23	4.00
04	19.06	14.43	2.99	2.56	5.11	5.31	5.06
06	19.40	12.70	2.81	2.23	5.03	4.98	4.90
08	12.12	6.56	2.74	1.37	3.34	3.59	3.55
10	8.65	3.84	1.42	1.91	2.39	2.71	2.46
12	3.70	2.21	1.28	2.48	1.48	2.60	2.61
14	7.15	4.45	1.18	2.19	2.12	2.44	2.41
16	9.01	7.19	1.34	1.96	2.54	2.58	2.62
18	10.69	7.58	1.43	2.44	2.97	2.72	3.29
20	15.15	9.14	1.32	2.35	3.80	2.62	2.81
22	10.96	11.08	2.17	2.58	3.31	3.75	3.65
Min	3.70	2.21	1.18	1.23	1.48	2.44	2.41
Max	19.40	14.43	2.99	2.58	5.11	5.31	5.06
Median	11.08	7.39	1.43	2.21	3.14	3.16	3.41
GM	10.80	7.19	1.72	2.02	3.04	3.31	3.31

Radon concentration varies from 3.70 Bq m^{-3} to 19.40 Bq m^{-3} with a geometric mean of 10.80 Bq. m^{-3}. Concentrations of radon in the outdoor environment are affected both by the rate of radon exhalation ground surface and also by atmospheric mixing phenomena. During the daytime solar heating tends to induce atmospheric turbulence, so that radon is readily transported to higher altitudes away from the ground and lower concentrations were observed.

Ion-pair production rate varies between 1.48 to 5.11 ion –pairs cm^{-3} s^{-1} over a day. The positive and negative conductivity value varies from 2.44 to 5.31×10^{-14} Ω^{-1}m^{-1} with a geometric mean of 3.31 ×10^{-14} Ω^{-1}m^{-1} and 2.41 to 5.06×10^{-14} Ω^{-1}m^{-1} with a geometric mean of 3.31 ×10^{-14} Ω^{-1}m^{-1} respectively. The estimated ion pair production rate shows a maximum in the early morning 04 –06 hours and minimum during 10 to 14 hrs and polar conductivities show a maximum in the early morning 02–06 hours and minimum during 10 to 16 hrs. The positive and negative conductivities are approximately equal and their diurnal variations are generally mirror images of each other. Atmospheric electrical conductivity shows positive correlation with wind speed and atmospheric pressure with correlation coefficients 0.47 and 0.72 respectively.

The diurnal variation of conductivity is similar to ion pair production rate and the observed maximum value of conductivity during the early morning (04 -06 hours) is mainly because of the ionization produced by radioactive substances present in the atmosphere. During day time

the UV radiation generates very small aerosols by stimulating gas to particle conversion process. The number of small ions may be reduced in the atmosphere due to ion aerosol recombination [13-16]. The ionization rate due to radon and its progeny concentrations show a good correlation with total atmospheric conductivity with a correlation coefficient of 0.87.
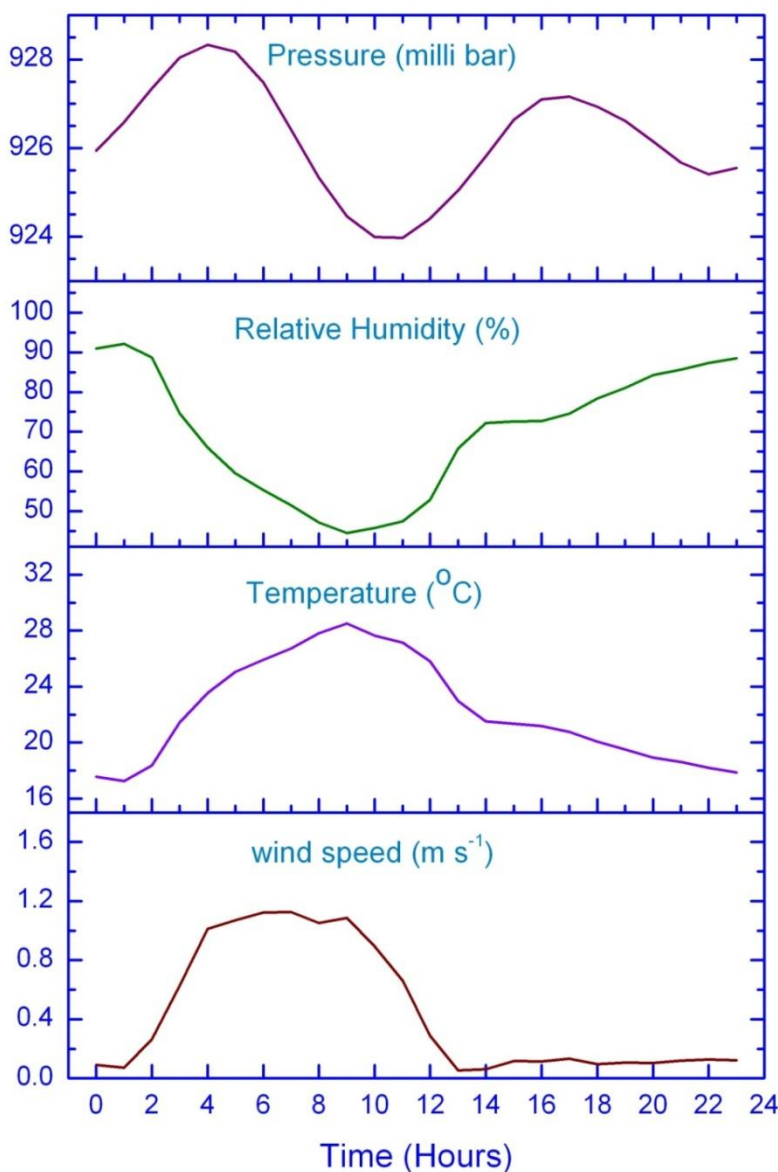
Figure 3. Diurnal variation of meteorological parameters.

Vertical profile studies:

Radon/thoron and their progeny concentrations have been measured at different heights from 0.2 m to 12 m using solid state nuclear track detectors (SSNTD). The concentrations were observed

to be decreasing up to about 5 m and then concentration is almost same with small fluctuations as shown in the figure 4. The atmospheric electrical conductivities are studied at different heights from the ground surface using balloon borne measurements. Figure 5 show the average vertical profile of atmospheric conductivities of both polarities from 0.25m to 12 m from the ground surface. From the figure it can be clearly seen that, as height increases, near the ground surface, the conductivity goes on decreases. Maximum values are observed very close to ground surface at 0.25m and minimum values are observed above 4m from the ground surface [3,17,18]. As height increases radon concentration gradually decreases resulting in decrease of ion–pair production rate and atmospheric electrical conductivity. From the figure 5 it can be seen that up to 4m conductivity values show a sharp decrease and after that the values remains almost constant. Vertical variations of atmospheric electrical conductivity are similar to that of radon and its progeny concentrations. A good correlation was observed between atmospheric electrical conductivity and radon concentration.
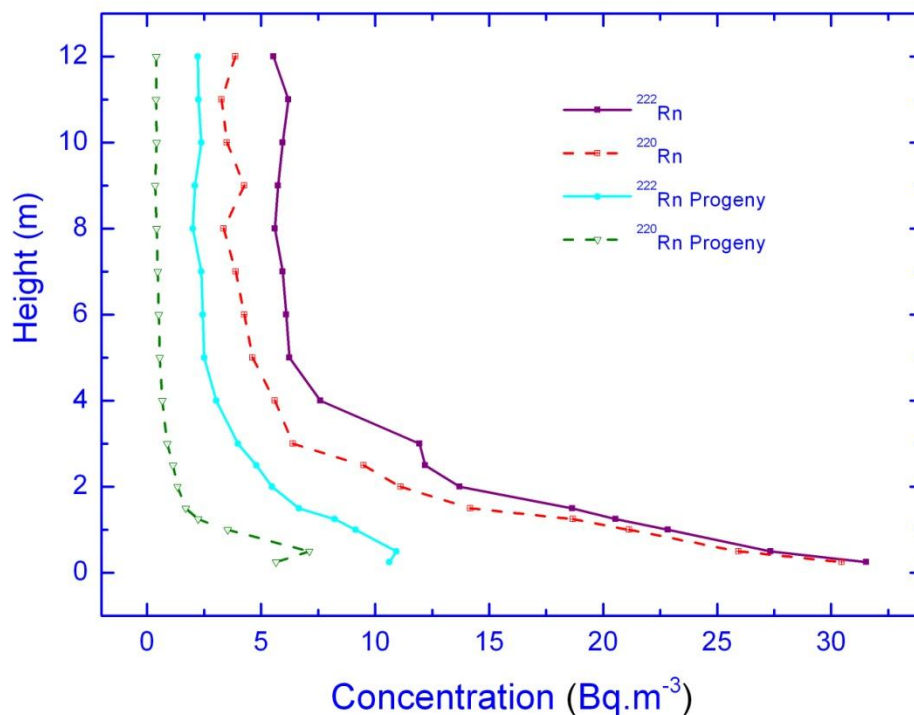

Fig 4. Vertical profile of [222]Rn, [220]Rn and their progeny concentrations.
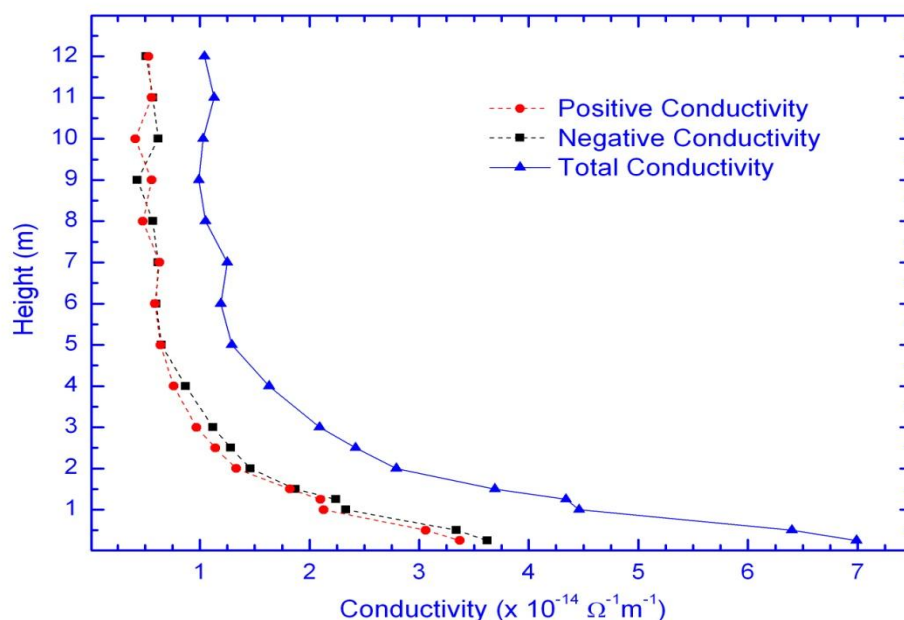
Fig 5. Vertical profile of atmospheric electrical conductivity.

CONCLUSION

The measured concentrations of radon, its progeny, and polar conductivity show maximum in the early morning hours and minimum in the afternoon. The stable atmosphere during night helps more accumulation of radon near the ground surface and hence the atmospheric electrical conductivity was maximum during early morning hours. Radon concentration varies from 3.70 Bq m^{-3} to 19.40 Bq m^{-3} with a geometric mean of 10.80 Bq. m^{-3}. Ion-pair production rate varies between 1.48 to 5.11 ion –pairs cm^{-3} s^{-1} over a day. The positive and negative conductivity value varies from 2.44 to 5.31×10^{-14} $\Omega^{-1}m^{-1}$ with a geometric mean of 3.31 $\times 10^{-14}$ $\Omega^{-1}m^{-1}$ and 2.41 to 5.06×10^{-14} $\Omega^{-1}m^{-1}$ with a geometric mean of 3.31 $\times 10^{-14}$ $\Omega^{-1}m^{-1}$ respectively. A good correlation between electrical conductivity and ion production rate due to radon and its progeny concentrations is observed with a correlation coefficient of 0.87. Vertical variation of atmospheric electrical conductivity is similar to that of radon and its progeny concentrations. Atmospheric electrical conductivity shows positive correlation with wind speed and atmospheric pressure with correlation coefficients 0.72 and 0.47 respectively.

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