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Surface measurements of atmospheric electrical conductivity at Jnanabharathi campus, Bengaluru (12.96° N, 77.56° E)

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Simultaneous measurements of the atmospheric electrical conductivity and meteorological parameters were carried out during January-December 2014 at Jnanabharathi campus, Bangalore University (urban station), Bengaluru, (12.96° N, 77.56°E), Karnataka for the first time. Gerdien condenser and mini boundary layer mast (micro meteorological tower) were used to study the variation of electrical conductivity and meteorological parameters. The observations show that the change in daily and weekly variations of conductivity is strong dependent of activity of Radon (^{222}Rn) gas and meteorological parameters that defines the stability of the lower troposphere. Significant influence of atmospheric convective instability on conductivity was observed. The negative correlation of 0.56 was found between conductivity and rain for the year 2014. The average conductivity for the study period was found to be 4.02 ± 0.02 x 10^{-14} S/m, with higher values during the winter as compared to summer and monsoon seasons. The atmospheric air conductivity measurements may be used to study the atmospheric stability, pollution and climate change studies.

Keywords: Atmospheric electrical conductivity, Ionization, Small ions, Radon

1 Introduction

The long-term variations in atmospheric electrical parameters are important for the studies of global electric circuit, thunderstorms and lightning activities. Of late, emphasis in the field atmospheric electricity has shifted towards the precise understanding of the possible interaction of different sized aerosols with small air ions in atmospheric physics[1-4] and for geophysical applications[5-7]. Atmospheric electrical conductivity, electric field, air earth current (AEC) and small ion number density are important parameters for understanding the electrical nature of the Earth's atmosphere. The electrical conductivity of the air in an aerosol free atmosphere is mainly due to small ions. However, in polluted atmosphere the small ions soon get attached to the aerosols to form the intermediate and large ions and contribute to air conductivity, which can alter the atmospheric electrical parameters[8,9]. Since, aerosols in air reduces the small ion concentration, the electrical conductivity has an inverse relationship with aerosol concentration and been often proposed to act as an index of aerosol loading in atmosphere[10].

In general, the total electrical conductivity of the atmospheric air is determined by the equation 1,

$$\sigma = \sigma_+ + \sigma_- = q\left(\sum_k n_k{}^+ \mu_k{}^+ + \sum_k n_k{}^- \mu_k{}^-\right) \quad \ldots (1)$$

where σ_+ and σ_- is the positive and negative conductivity in Siemens/meter (S/m) or $\Omega^{-1}m^{-1}$, q is the fundamental electric charge, n_k^+ and n_k^- is the positive and negative small ion concentration, μ_k^+ and μ_k^- is the mobility of positive and negative small ions.

The conductive nature of air is due to these small ions in the lower troposphere which are determined mostly by radon (^{222}Rn), its progenies, gamma rays from soil and galactic cosmic radiations, in which contribution from gamma and cosmic radiations is almost constant near to the Earth's surface. Hence, the variability of small ions near the surface is due to dynamics of the activity of radon and its progenies[11]. The ^{222}Rn is an inert and radioactive gas descending from uranium (^{238}U) decay series with a half-life 3.82 days. Radon being a gas of 7.5 times heavier than atmospheric air will be generated in the Earth's crust. The gas penetrates the pores in the ground and moves upward by diffusion and enters into the air from surface by convection. This process is called exhalation and its rate depends on air pressure and also permeability, thermal gradient and moisture content of the soil[12]. In the atmosphere, ^{222}Rn appears

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mostly in the vicinity of its source, i.e., surface of earth, and its transport is determined by thermal processes.

The knowledge of atmospheric ions is important not only to understand the electrical state of the local atmosphere but also in understanding the global electric circuit[13-15]. It is necessary to fill the gaps in available data, in respect of variation of atmospheric electrical parameters with orography over a particular location in the lower troposphere[16]. Hence, for the first time, an attempt is made to analyze the datasets of conductivity and associated meteorological parameters along with few radon measurements on fair weather days during January – December 2014, at Jnanabharathi campus of Bangalore University, Bengaluru, (12.59° N, 77.57° E & 840 m above mean sea level), Karnataka, India.

2 Experimental methodology

The Atmospheric Electricity Observatory and meteorological tower are located at the Jnanabharathi campus of Bangalore University (BU), Bengaluru India. The campus is covered with moderate forest area and there is no direct source of air pollution in the immediate vicinity of this location, makes it an ideal place for the measurements of atmospheric electrical parameters.

2.1 Bipolar air conductivities

Atmospheric conductivity of both polarities was simultaneously measured using an aspirated Gerdien condenser (Fig. 1). It consists of two identical cylindrical tubes of 10 cm diameter and 41 cm length joined by a U-shaped tube. The air was sucked in with a single fan and the shape of Gerdien condenser ensures that the flow of air is laminar, because turbulence flow can distort the accuracy of measurement. The inner co-axial electrode in both the tubes is of 1 cm diameter and 20 cm length. Opposite but equal potentials of ±35 V are applied to the outer electrodes of the two condensers. The potential applied to the outer electrode will repel the same polarity ions towards the inner electrode generating an electrical pulse in both the pulses. The critical mobility of the instrument[17-18] is greater than 10^{-4} $m^2V^{-1}s^{-1}$ and capable of resolving the values of conductivity as small as 3×10^{-16} $\Omega^{-1}m^{-1}$.

The conductivity is given by,

$$\sigma = \frac{I\varepsilon_0}{CV},$$

$$C = \frac{2\pi\varepsilon_0\ L}{\ln[b/a]} \quad \ldots (2)$$

where C is the capacitance of the Gerdien condenser, ε_0 is the permittivity of free space, L is length of condenser tube, b/a is the ratio of radius of outer cylinder to central electrode, I is current due to air ions at central electrode, ε_0 is the permittivity of free air and V is the voltage applied across the electrodes.

Zeroing of the system was performed by measuring the conductivity when fan and potential were switched off and are incorporated in the actual

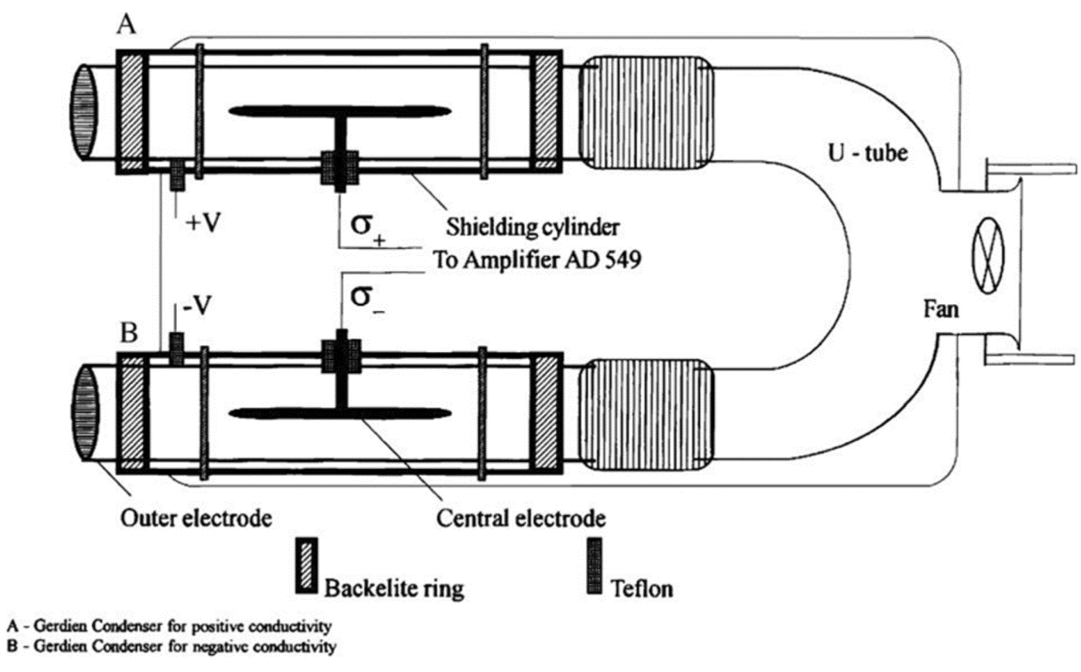

Fig. 1 — Schematic representation of Gerdien condenser for air conductivity measurement

measurements[19]. Few radon gas measurements were carried out using Genitron made Alpha GUARD PQ 2000 PRO and used in this study.

2.2 Meteorological parameters

The Department of Physics, Bangalore University, Bengaluru, Karnataka, India is equipped with two weather monitoring towers namely Mini Boundary Layer Mast and Automatic Weather Station, under the network of Indian Space Research Organization, Government of India for micro-meteorological measurements to characterize the surface layer of atmosphere. Different atmospheric parameters such as ambient temperature, relative humidity, air pressure, incoming and outgoing solar radiation, wind speed and wind direction, rain fall etc are continuously monitored at different heights. Among all, temperature, relative humidity, air pressure and rain fall data were used for the analysis and presented. The ambient temperature was measured using a sensor Rotoronics MP 100H with accuracy of ±0.1° C and can measure from -40 to +60° C. A Hygro Clip was used for the measurement of relative humidity with accuracy of ±1% and a Komoline KDS - 021/ ISRO pressure sensor was used for air pressure which has the accuracy of ±0.2% and measuring range of 600 to 1100 mbar. For rain fall measurements, RM young 52203 models was used which has resolution of 0.1 mm and accuracy of 0.5 mm up to 25 mm/h and 1.5 mm up to 50 mm/h[20,21]. The parameters were measured at one Hertz sampling round the clock and were averaged for desired time intervals using a program. The quality control of data made by checking the validity of data and omitted erroneous values beyond 3-sigma values.

3 Results and Discussion

3.1 Nocturnal stability and mixing processes

The fair weather behaviour of nocturnal radon accumulation and air conductivity for a continuous period of 4 days in January 2014 is shown in Fig. 2. The higher value of activity of radon and air conductivity was observed in early morning hours and subsequent, decreased during afternoon hours immediately indicates the conditions of high nocturnal stability, temperature inversions and good daytime mixing conditions, especially in the afternoon hours. This type of diurnal trend has been well reported and frequently observed in summer and rare in winter[22-23].

3.2 Diurnal variations

The diurnal variation of activity of radon along with the temperature and relative humidity for a typical fair weather day is shown in Fig. 3. Activity of Radon varied from 2-66 Bq/m^{3}with an order of 33. The concentrations showed maxima during early

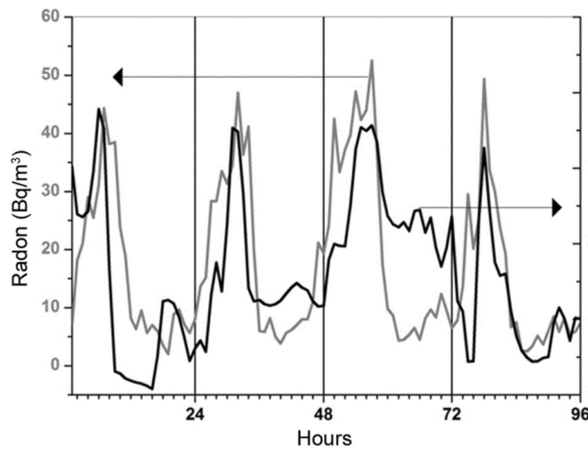

Fig. 2 — Nocturnal stability and mixing processes of radon and air conductivity

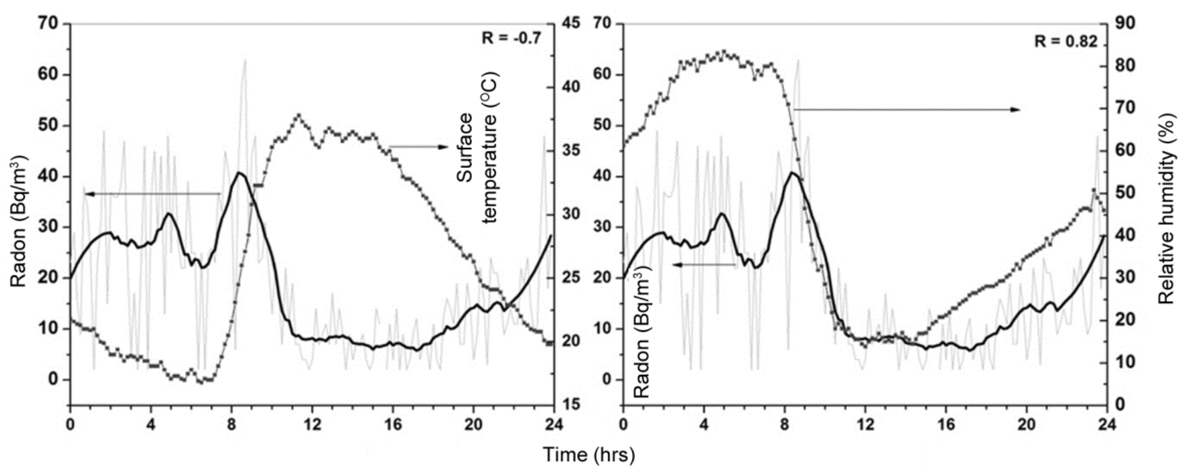

Fig. 3 — Diurnal variations of activity of radon

morning hours, generally between 0600 and 0830 h of Indian Standard Time (IST) and decreased after the sunrise, attaining minima during afternoon, 1400 to 1600 h of IST at Bangalore University[24]. The in-situ diurnal cycle of radon is triggered by emissions from the soil and atmospheric dynamics (primarily small scale vertical mixing) and was well reported[25,26].

The diurnal variation of air conductivity (σ) along with temperature and relative humidity for fair weather days in the months of January, April and August representing typical winter, summer and monsoon seasons respectively, are shown in Figs 4 & 5.

The similar types of observations were obtained for most of fair weather days, thus, the observations described can be reasonably generalized for other fair weather days as well. As reported earlier, an early morning peak and significant decrease during afternoon hours was observed. Conductivity exhibits negative correlation with temperature and positive correlation with humidity during the study period[27]. It is also found that the local radioactivity (radon and its progeny) plays a very important role in defining the diurnal variation of air conductivity. The air conductivity, for given days Figs 4 & 5), varied between 4.5 to 8.5 x 10^{-14} S/m for January, 1.5 to 4.5x10^{-14} S/m for April, 1.3 to 3.2 x 10^{-14} S/m for August. In Table 1, the experimentally measured values of air conductivity for different environments are compared with present observations.

From Table 1, it was clear that experimentally observed air conductivity values were higher for higher altitude regions[23] compare to lower altitude regions as theoretically estimated and reported[28–35]. However, the effect of air pollution on conductivity is not discussed.

3.3 Effect of precipitation on activity of Radon and air conductivity

During the study period, several convective instabilities were recorded. The significant effects on activity of radon, air conductivity were observed. It was found that, the radon activity decreases during and after the rain fall event and the activity during monsoon season was relatively lesser compared to winter seasons at Bangalore University. The results on radon activity are well reported, whereas variation of air conductivity is not reported for Bengaluru environment till now and hence discussed in detail.

The behaviour of atmospheric electrical conductivity is highly variable, which depends on ionization rate, aerosol concentration and meteorological parameters. The value of electrical conductivity during precipitation changes appreciably.

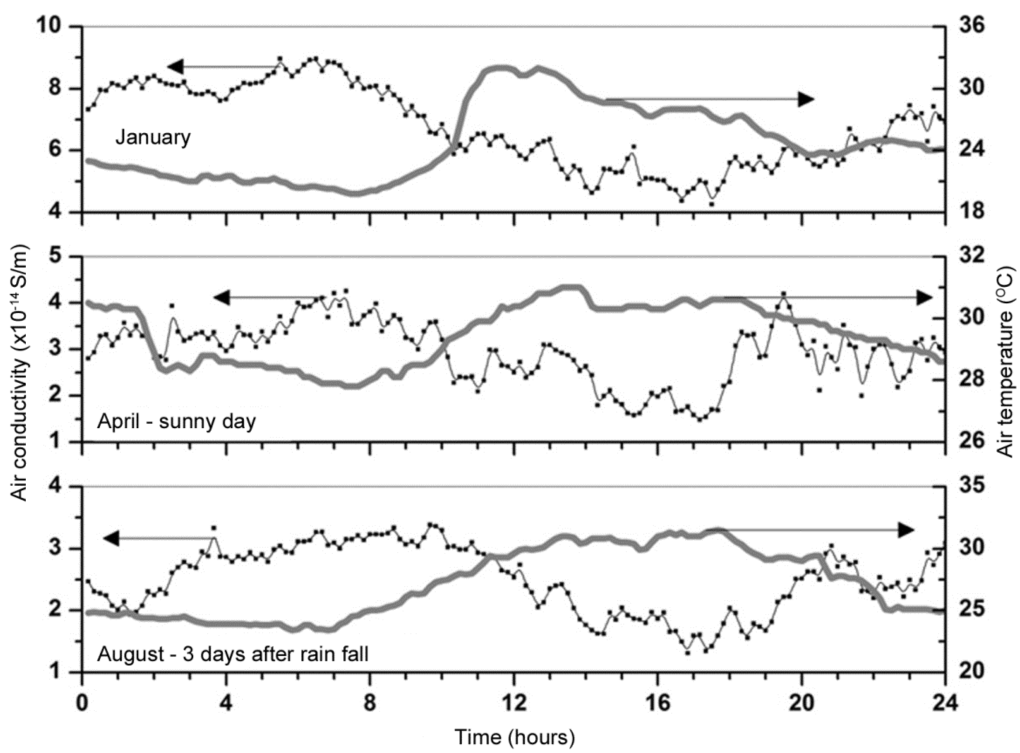

Fig. 4 — Diurnal variations of air conductivity with temperature for different months

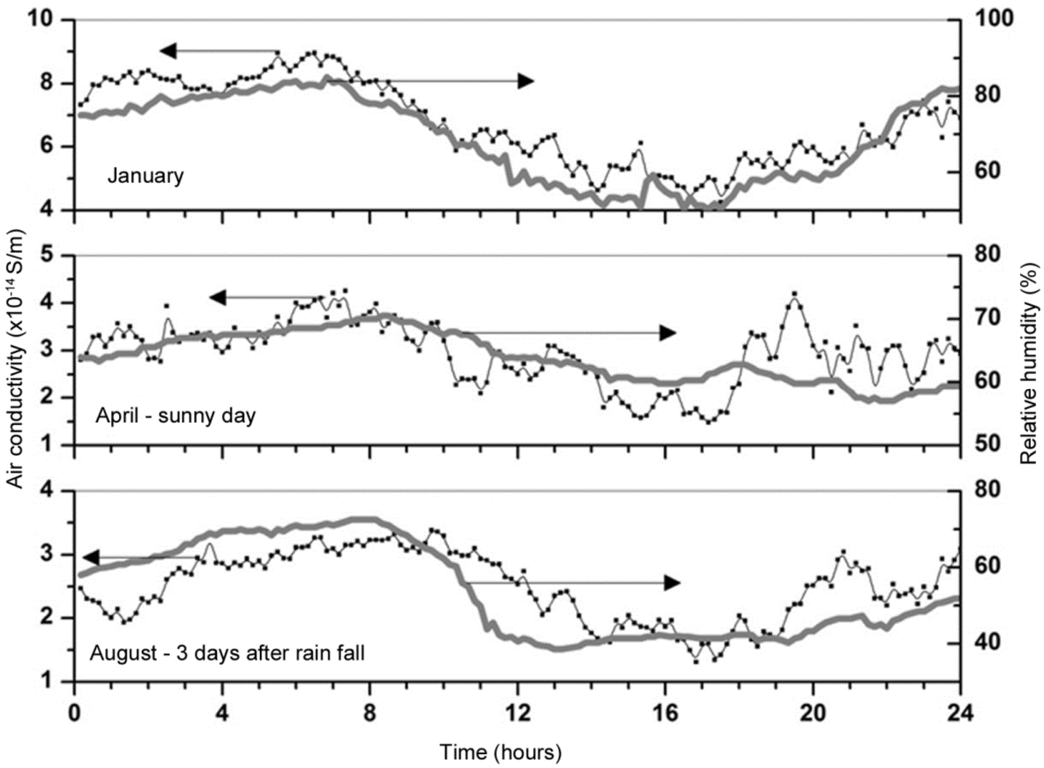

Fig. 5 — Diurnal variations of air conductivity with relative humidity for different months

Table 1 — Comparison of air conductivity for different environments[23, 28-35]

Study Region (Elevation)	Air Conductivity (x 10^{-15} S/m)
Mysore, India (763 m)	34.8 x 10^{-15} S/m [23]
Roorkee, India, (268 m)	3.44 x 10^{-15} S/m [28]
Pune, India (560 m)	21.5 x 10^{-15} S/m [29]
Maitri, Antarctica (103 m)	21 x 10^{-15} S/m [30]
Indian Ocean	2.9 - 7.8 x 10^{-15} S/m [31]
Arabian Sea	5 - 30 x 10^{-15} S/m [32]
Eskdalemuir, Scotland (245 m)	9.8 ± 0.7 x 10^{-15} S/m [33]
Berlin, Germany (34 m)	6 - 8 x 10^{-15} S/m [34]
Reading, UK (61 m)	3 - 9 x 10^{-15} S/m [34]
Immediately above the continental surface (Generally)	2 - 20x10^{-15} S/m & upto 40x10^{-15} S/min clean marine air [35]
Bengaluru, India (840 m)	40.2±0.2x10^{-15} S/m [This Study]

Early researchers reported that, the small ions produced by radioactivity should soon be attached with falling of cloud droplets, and hence reduces conductivity values that are expected during precipitation compared to the fair weather days[27,35]. But later, on contrary, few researchers have also reported that the conductivity values increase during the rain because of the availability of charged particles during precipitation[36,37]. Also, the contribution from charged radioactive aerosols attach to rain droplets[38].

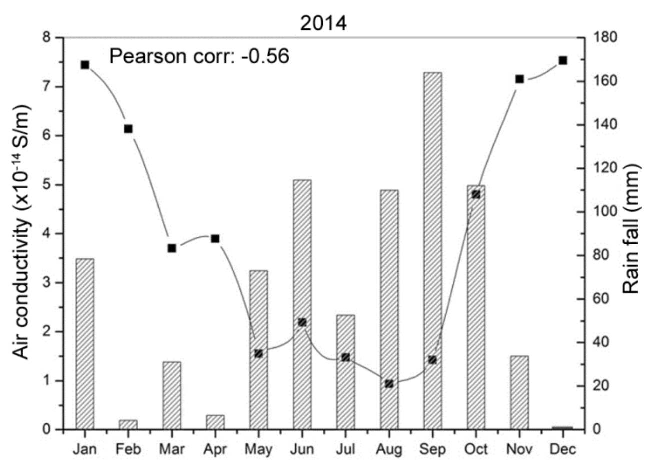

Fig. 6 — Monthly averaged air conductivity with accumulated rain

The monthly averaged values of air conductivity are correlated with total monthly accumulated rainfall for the study period over Bengaluru and found negative correlation of 0.56 and is shown in Fig. 6. These results are in agreement with the earlier results in the region of south India and elsewhere[3,23,27,37].

The air conductivity of lower atmospheric air was mainly due to small ions produced by radioactive substances such as radon, its progenies in the atmosphere and gamma radiations from soil. Radon

Table 2 — Complete statistics of air conductivity along with selected meteorological parameters

2014	Air Conductivity (x 10^{-14} S/m) [±SE on mean]	σ (SD)	Median	Temperature (^{0}C)	RH (%)	W.S (m/s)	Pressure (mbar)	Rain (mm)	No of days
Jan	7.44 ± 0.03	1.02	7.29	22.06	55.52	1.09	919.9	78.37	21
Feb	6.14 ± 0.03	1.24	5.96	23.95	37.72	0.84	917.4	4.20	19
Mar	3.70 ± 0.02	0.91	3.72	26.10	43.13	1.08	919.4	31.00	18
Apr	3.90 ± 0.04	1.56	3.65	28.07	46.16	0.76	918.1	6.60	18
May	1.55 ± 0.01	0.43	1.55	27.04	60.60	0.85	916.3	73.00	9
Jun	2.19 ± 0.02	0.67	2.00	25.41	68.84	0.92	915.2	114.60	15
Jul	1.47 ± 0.02	0.67	1.24	23.51	75.14	0.97	915.7	52.60	11
Aug	0.93 ± 0.01	0.15	0.89	23.31	77.28	0.75	916.1	109.90	14
Sep	1.42 ± 0.01	0.52	1.28	23.94	72.70	0.85	910.9	164.00	14
Oct	4.80 ± 0.02	0.63	4.75	23.29	76.30	0.58	918.7	112.00	16
Nov	7.16 ± 0.01	0.46	7.17	22.18	65.98	0.68	919.4	33.80	21
Dec	7.54 ± 0.03	1.15	7.75	21.85	66.35	0.79	919.8	0.20	17
Average	4.02 ± 0.02	0.78	3.93	24.22	62.14	0.84	917.24	65.02	16

and its progeny are considered as very good indicators of atmospheric stability and air mass movement[10,39,40]. During monsoon season, the convective instability associated high wind speed reduced the concentration of radon and its progeny in air, and precipitation reduced the exhalation of radon from soil. The reduction in ion-pair production rate leads to smaller values of conductivity. Hence, a pronounced negative correlation was observed between rainfall and monthly averaged conductivity values over Bengaluru.

The statistics of all the measured parameters are presented in Table 2. As reported in south Indian region, the conductivity of air was relatively higher during winter days compared to summer and monsoon. This may be due to possible occurrence of longer temperature inversions and trapping of radioactive gases near to the Earth's surface over Bengaluru region.

4 Conclusion

The measurements of bipolar air conductivities and meteorological parameters were carried out during January - December, 2014 at Jnanabharathi campus, Bangalore University, Bengaluru (12.96° N, 77.56° E), Karnataka, India for the first time. The study was carried out, in order to see the electrical signatures of atmospheric air for Bengaluru environment (urban site) and relate them with meteorological parameters. The observed values of air conductivity were comparable with the earlier results in similar environments of India. A well-defined diurnal variation in conductivity suggests its dependence on several meteorological parameters.It wasobserved that a significant effect of atmospheric convective instability on the air conductivity and a negative correlation of 0.56 was found with amount of rain. The average air conductivity for the study period was found to be 4.02 ± 0.02x10^{-14} S/m with higher values during winter compared to summer and monsoon seasons. The simultaneous measurements of electrical conductivity along with local radioactivity have number of applications and to use the same to study atmospheric stability, pollution and climate change studies.

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