

Electrical Conductivity of the Atmosphere over an Urban Location

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Abstract—The simultaneous measurements of atmospheric electrical conductivity and meteorological parameters during 2015 over an urban location were carried out, and their variations are presented. During fair weather days, the variations in air conductivity show a pronounced diurnal trend with early morning hour maxima and afternoon minima. A significant Pearson's correlation coefficient was found between measured atmospheric electrical conductivity and most meteorological parameters; among them, the highest positive correlation of 0.79 was observed for relative humidity, and a negative correlation of 0.81, with wind speed. The trend in the variation of conductivity followed the activity of Radon over a day. The diurnally averaged monthly variations clearly show higher air conductivity values during winter months, and lowest, in monsoon months. A well-defined seasonal variation was observed, with the highest in winter and the lowest during the monsoon season. The results show that the correlation of air conductivity with meteorological parameters is strong and valid only when the atmosphere is stable, i.e., during the winter season. For 2015, the mean positive conductivity was $1.23 \times 10^{-14} \Omega^{-1} \text{m}^{-1}$, while the mean negative conductivity was $2.13 \times 10^{-14} \Omega^{-1} \text{m}^{-1}$, with a mean conductivity of $3.35 \times 10^{-14} \Omega^{-1} \text{m}^{-1}$ over Bengaluru. The measured air conductivity values are identical to those found in other similar conditions.

Keywords: air conductivity, air ions, Radon, Bengaluru

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INTRODUCTION

Even though the electrical nature of Earth's atmosphere has been constantly investigated discretely, the long term simultaneous measurements of global electric circuit parameters, viz., vertical potential gradient (E), vertical air–earth current density (J_z) and atmospheric conductivity (σ), can be used in understanding and solving the numerous research problems in atmospheric physics [1–5]. It is reported that there exist a possible correlation between the climate change effects, such as El Nino–Southern Oscillation and atmospheric electricity [6], and a significant link between the former and the latter. In the upper levels of the atmosphere, the significant ionization sources are solar high energy particles and cosmic rays. But near Earth's surface, the generation of air ions mainly depends on the concentration of radioactive gas, Radon and its products [7].

The first sophisticated instrumentation for measuring atmospheric air conductivity was developed by Gerdien and used for balloon ascents to study different atmosphere electrical properties [8]. Israel [9] reported too many complex parameters that made difficult in-situ observations on atmospheric electricity. In the 1960s, the measurement of atmospheric electrical conductivity over the Ocean was carried out by Cobb and Wells (1970), and the signatures were found in 1967

during the worldwide expedition. The results showed a reduction of conductivity by 20% in the North Atlantic and increased the fine aerosol particles. The variations in electrical conductivity for Greece's environment were measured by Retalis and Zervos [10]. A double oscillation exists in the diurnal variation with maximum conductivity during summer and minimum values during winter. Pierce [11] reported the possible use of radon exhalation towards earthquake studies. There is a significant increase in conductivity near the ground before and during the earthquake. Aplin [12] have measured the simultaneous air conductivity and air mobility for a location in the United Kingdom and found well defined diurnal variations.

Any change in the interplanetary or atmospheric environment induces a change in electrical conductivity, thus changing the atmosphere's current/electric field system. Variations in solar surface temperature generate variations in solar wind characteristics, which can be coupled with the stratosphere and troposphere to modulate current density in the global atmospheric electric circuit from the ionosphere to the Earth.

The small-scale chaotic variation of conductivity in the mixing layer makes it difficult to measure the systematic variation of vertical current due to solar wind input [13]. The thunderstorm charging current and ionospheric potential may be affected by even minor

changes (1–3%) in cosmic ray flux in the equatorial areas due to variations in solar wind inputs. The worldwide atmospheric electric circuit is significantly altered by changes in global temperature or climate change. According to reports, a 1% increase in global surface temperature can result in a 20% increase in ionospheric potential [14]. Cloud microphysics, precipitation, cloud electrification, and lightning are all mediated by aerosols. Our study on electrical conductivity, on the other hand, are only of local significance.

This ion density is further affected by the prevailing meteorological conditions and air pollution, leading to change in local weather systems. In the pollution-free environment, the air ions so formed contribute towards observed weak atmospheric electrical conductivity. In a polluted environment, the air ions responsible for conductivity are lost by various attachments and recombination processes due to the presence of aerosols [3]. In an urban environment, the air conductivity measurements are often considered as the index of air pollution and may lead to higher vertical potential gradient values [15–17].

The results show that atmospheric electricity is an essential means to study global thunderstorm behavior and solar-terrestrial connection with Earth's atmosphere [18–22]. Even though several reports are available on the measurements of atmospheric electrical conductivity at different locations in India, no measurements are reported for the environment of Bengaluru. Hence, an attempt is made to measure fair-weather atmospheric electrical conductivity and relevant meteorological parameters during 2015 at the Jnanabharathi campus, Bengaluru, India.

MEASUREMENT SITE

The continuous measurements of atmospheric electrical conductivity and relevant meteorological parameters were carried out at Atmospheric and Space Science Research Lab (12°56'44" N, 77°30'25" E, 840 m above MSL), Department of Physics, Bangalore University, Jnanabharathi campus, Bengaluru, India. The study location is situated on the western side of Bangalore city, is covered with moderate forest area, and there is no immediate source of air pollution around the radius of 5 km. Due to low background pollution levels, the measuring site is ideal for carrying out atmospheric electricity measurements [23].

METHODOLOGY

With two Gerdien condenser tubes, the electrical conductivity of the atmosphere is measured in both positive and negative polarities. It is made up of cylinders with a diameter of 100 mm and a length of 410 mm. An external fan at the end of the U-shaped tube samples air at a steady flow rate of 19 litres per second. The inner co-axial tubes have a diameter of 10 mm and a length of 200 mm that is fixed inside Teflon-separated

outer electrodes. Electrodes were protected from the external electric field by two co-axial cylinders of 110 mm diameter and 350 mm length using Bakelite rings. A potential of ± 35 V is applied for driving the ions to respective electrodes [24]. The critical mobility for detecting ions $2.93 \times 10^{-4} \text{ m}^2 \text{ V}^{-1} \text{ s}^{-1}$ and has a resolution of $3 \times 10^{-16} \Omega^{-1} \text{ m}^{-1}$ [23–25]. The polar conductivity can be determined using equation (1), where i is the current flowing due to air ions collected at the central electrode, C is the capacitance of Gerdien condenser, which can be calculated by equation (2) and ϵ_0 is the permittivity of free space [12, 26, 27]:

$$\sigma_{\pm} = \frac{i\epsilon_0}{CV_{\pm}}, \quad (1)$$

$$C = \frac{2\pi\epsilon_0 L}{\ln(b/a)}. \quad (2)$$

The total air conductivity

$$\sigma_{\text{total}} = \sigma_{+} + \sigma_{-} = e \sum ([n_{+}\mu_{+}] + [n_{-}\mu_{-}]), \quad (3)$$

where σ_{+} is the positive atmospheric electrical conductivity, σ_{-} is the negative atmospheric electrical conductivity, n_{+} is the positive small ion concentration, n_{-} is the negative small ion concentration, e is the elementary charge, μ_{+} is the mobility of positive small ions, μ_{-} is the mobility of small negative ions [28].

The data of meteorological variables were obtained from the two weather monitoring towers, viz., Automatic Weather Station (AWS) and Mini Boundary Layer Mast (MBLM) of ISRO network, which is functioning near the Department of Physics, Bangalore University [29].

The observations reported are only for fair weather days. During the storm and rainy conditions, the Gerdien condenser goes for saturation, and such observations are not included in our analysis. One of the limitations is that whenever relative humidity reaches 100%, the conductivity values were saturated. For the Bangalore environment, the relative humidity observed has not exceeded 95%.

RESULTS AND DISCUSSION

The diurnal, monthly, and seasonal variations in atmospheric electrical conductivity over Bengaluru during 2015 were analyzed and presented. The possible correlation of atmospheric electrical conductivity with the relevant meteorological parameters during the fair weather conditions at different time scales are discussed.

The diurnal variations in negative and positive atmospheric electrical conductivity for a typical fair-weather day on February 10, 2015, are shown in Fig. 1. The higher values were observed during the early morning hours before sunrise, and lower values were observed during the afternoon and evening hours. This kind of behavior is very well reported by several research-

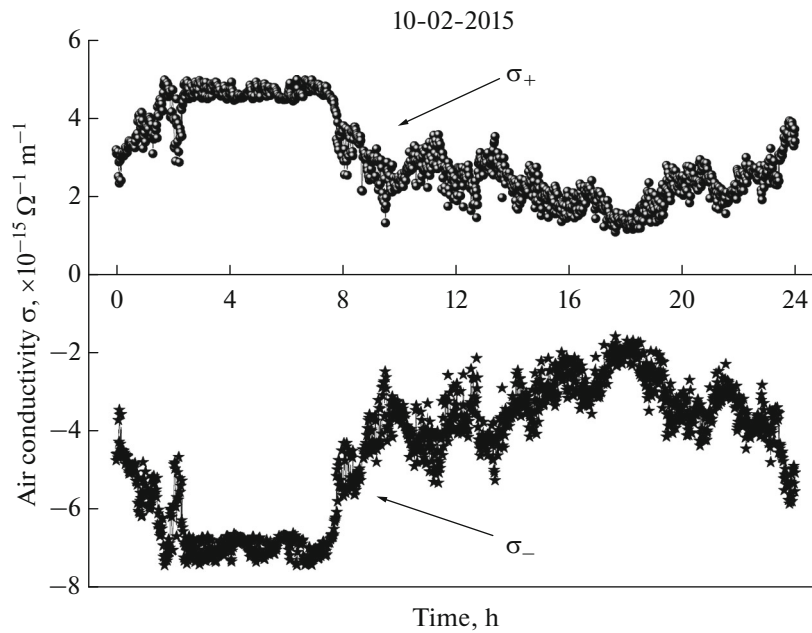


Fig. 1. Diurnal variations in atmospheric electrical conductivity on February 10, 2015.

ers worldwide [23, 30, 31]. On February 10, 2015, the σ_- varied from 0.3×10^{-15} to $7.8 \times 10^{-15} \Omega^{-1} \text{m}^{-1}$ whereas σ_+ varied from 0.2×10^{-15} to $4.9 \times 10^{-15} \Omega^{-1} \text{m}^{-1}$. The well-known diurnal behavior may be attributed to the formation of temperature inversion before sunrise leading to accumulation of air ions near Earth's surface and increased vertical mixing of lower atmospheric constituents to the higher altitudes during afternoon hours leading to lower availability of air ions near the surface.

Interestingly, the variations in atmospheric electrical conductivity within a day were the same for all fair weather days, but the magnitude differs from day to day [31]. There is a link between the influence of meteorological parameters on electrical conductivity. The comparison of σ with relevant meteorological parameters was made, as shown in Fig. 2. It was observed that there exists a significant Pearson correlation coefficient between air conductivity and measured meteorological parameters except for air pressure and incoming short wave radiation. Pearson's correlation coefficient (r) for continuous (interval level) data ranges from -1 (data lie on a perfectly straight line with a negative slope) to 0 (no linear relationship between the variables) to $+1$ (data lie on a perfectly straight line with a positive slope). The highest correlation coefficient was found with relative humidity of $+0.79$ and wind speed of -0.81 .

It was discovered that the relative humidity at the study location is most significant in the early morning hours before the sun rises and that during this period, most atmospheric constituents are trapped within a few meters of the Earth's surface due to the presence

of a temperature inversion (lowest height of atmospheric boundary layer). During this period, the atmosphere is stable, and wind speed is at its lowest. So during this period, the probability of availability of air ions near the surface is highest; hence, higher atmospheric electrical conductivity values were observed during 06:00–08:00 (IST). After the sun rises, the temperature inversion becomes weak, and due to thermal energy, the atmospheric constituents near the surface of Earth start to disperse. This phenomenon is known as vertical mixing, and during this process, the atmospheric boundary layer reaches higher altitudes. The solar radiations form the pressure gradient, which drives the wind, and during afternoon hours, the vertical mixing and wind speed is at their highest values. During this period, the atmospheric constituents are lifted to higher altitudes, and hence air ion concentration depletes. Wind speed and temperature peak between 13:00 and 18:00, while atmospheric electrical conductivity is the lowest. Several researchers report this kind of behavior for similar environments [4, 32], and present results show that this kind of correlation between air conductivity and meteorological conditions is valid only during fair weather conditions. During disturbed weather conditions, the correlation between air conductivity and meteorological parameters becomes very weak and can not be considered.

Near the Earth's surface, the primary source of air ionization is the presence of inert radioactive gas, Radon ($T_{1/2} \sim 3.62$ days) and its progenies. Radon emits an α particle with an energy of ~ 5.67 MeV during its decay, which can produce ~ 177 thousand ion pairs in an oxygen and nitrogen-rich environment [33]. During the study period, few simultaneous mea-

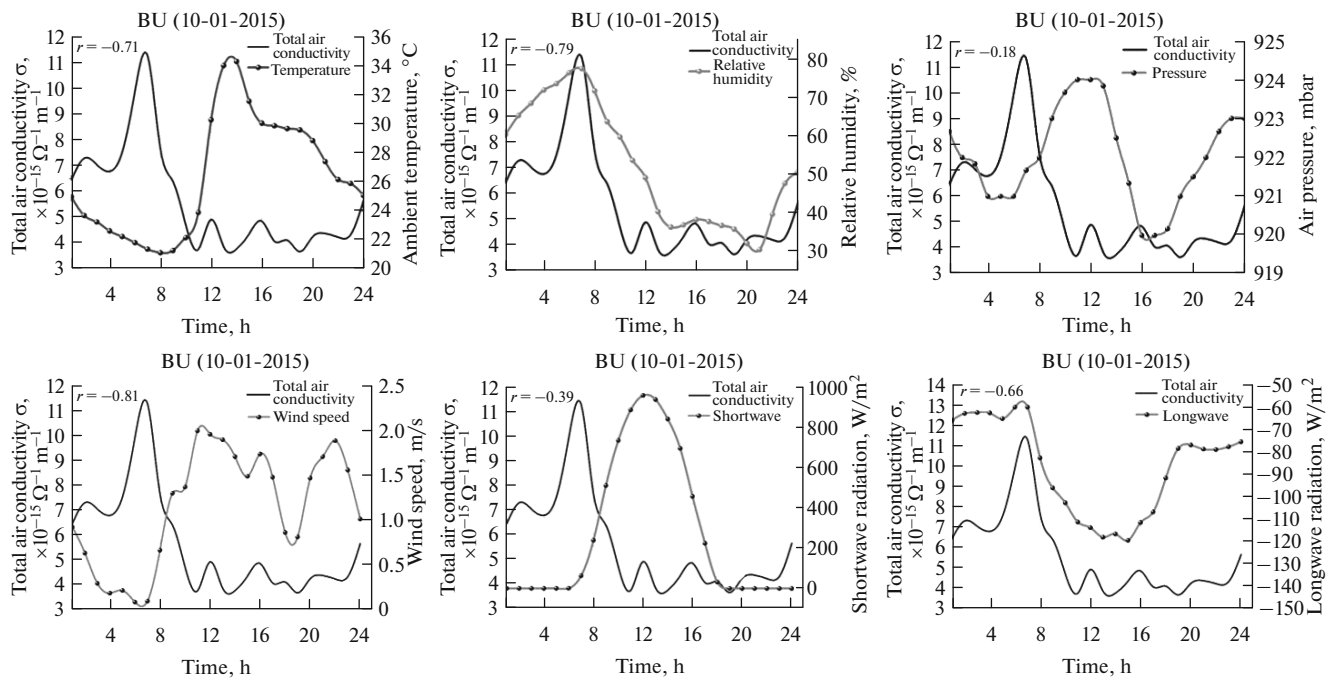


Fig. 2. Variations in air conductivity with relevant meteorological parameters on January 10, 2015.

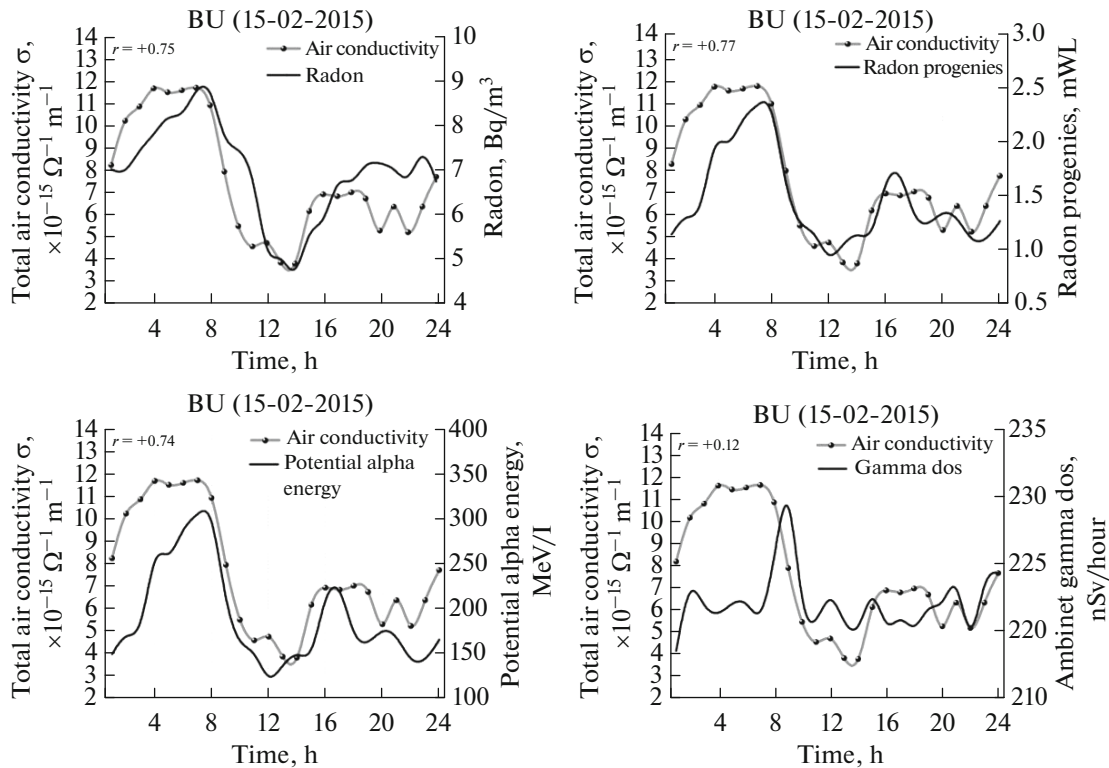


Fig. 3. Variations in air conductivity with atmospheric radioactivity parameters on February 15, 2015.

measurements of air conductivity with atmospheric radioactivity parameters were carried out, and it was found that during fair weather day on February 15, 2015, there exists a strong correlation between former and later, as shown in Fig. 3. The activity of Radon and its

progenies and the potential alpha energy available for air ionization have also shown peaks in early morning hours when the temperature and wind speed are the lowest [34]. The air conductivity has positive correlations with Radon activity, Radon progenies activity,

Table 1. The statistics of air conductivity and meteorological parameters for 2015

Month	σ_+	σ_-	σ_{total}	SE on mean	SD	RH	T	P
	$(\times 10^{-14} \Omega^{-1} \text{m}^{-1})$					(%)	(°C)	(mbar)
Jan	2.79	-4.21	7.0	0.23	2.74	73	23.8	920
Feb	3.01	-4.33	7.34	0.16	1.98	76	24.8	918
Mar	1.3	-2.06	3.36	0.12	1.4	66	29.4	921
Apr	1.21	-1.89	3.1	0.16	1.86	66	28.7	918
May	0.7	-1.04	1.73	0.1	1.14	58	26.8	917
Jun	0.79	-1.18	1.97	0.11	1.37	48	26.2	916
Jul	0.38	-0.57	0.94	0.01	0.11	52	26.4	917
Aug	0.59	-0.84	1.44	0.06	0.68	58	26.2	917
Sep	0.69	-1.14	1.83	0.09	1.03	66	26.5	918
Oct	0.91	-1.39	2.3	0.09	1.05	76	27.4	920
Nov	0.9	-2.89	3.8	0.11	1.38	72	25.4	919
Dec	1.47	-3.95	5.43	0.12	1.44	75	25.7	920
Mean	1.23	-2.13	3.35	0.13	—	65.5	27.1	919

σ —atmospheric electrical conductivity, SE on mean—standard error on mean, SD—standard deviation of total air conductivity, T —ambient temperature, RH—relative humidity, P —air pressure.

and potential alpha energy ($r = 0.75, 0.77, \text{ and } 0.74$, respectively). Interestingly, there is a weak correlation between air conductivity and ambient gamma dose levels, confirming that the contribution from gamma radiations towards air ionization is constant [31].

So the results show that there exists a strong correlation of air conductivity with Radon, its progenies and meteorological conditions only during fair weather days. Similar variations were observed for most fair weather days with a difference in magnitudes, and hence the diurnal trend can be generalized to all fair weather days for the Bengaluru environment.

For a better understanding of the magnitude shift in atmospheric electrical conductivity, if any, the diurnally averaged values for individual months are shown as a contour plot in Fig. 4. It can be seen that during January, February, November, and December, higher values of air conductivity were observed during early morning hours, indicating a stable atmosphere [4]. The lowest air conductivity values were observed during July–September, when the south-west monsoon is prominent over Bengaluru.

The thunderstorm activity creates instability in the atmosphere with higher wind speeds, and hence lowest conductivity values were observed during monsoon months as reported elsewhere [33]. During these months, the correlation between air conductivity values with meteorological conditions is weak.

The detailed statistics of all the measured parameters at Bengaluru is presented in Table 1. It was found that when the temperature is highest, the polar conductivity values have shown the lowest values indicating the dependency of σ on the stability of the atmosphere.

The averaged positive and negative air conductivity values for individual seasons were observed to understand air conductivity's seasonal dependence better, as shown in Fig. 5. It was found that during the winter season, the averaged polar conductivity values have shown the highest positive conductivity ranging from 1.5×10^{-14} to $4.3 \times 10^{-14} \Omega^{-1} \text{m}^{-1}$ and negative conductivity ranging from 2.5×10^{-14} to $6.5 \times 10^{-14} \Omega^{-1} \text{m}^{-1}$.

The lowest air conductivity values were observed during monsoon season, and it may be due to washout of air ions due to precipitation and reduction in an

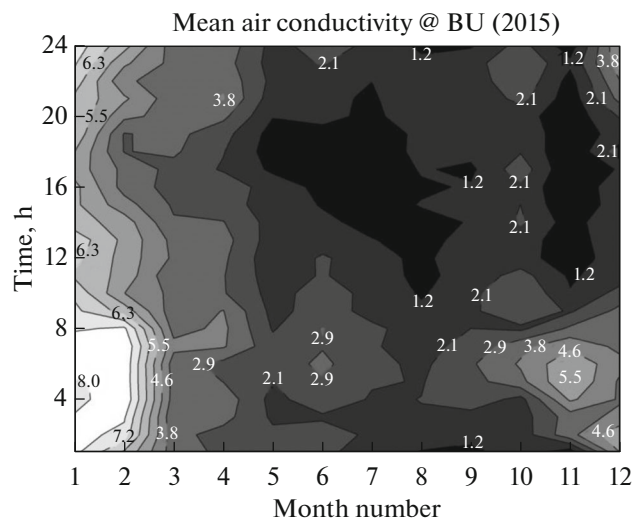


Fig. 4. Diurnally averaged values of air conductivity for individual months during 2015.

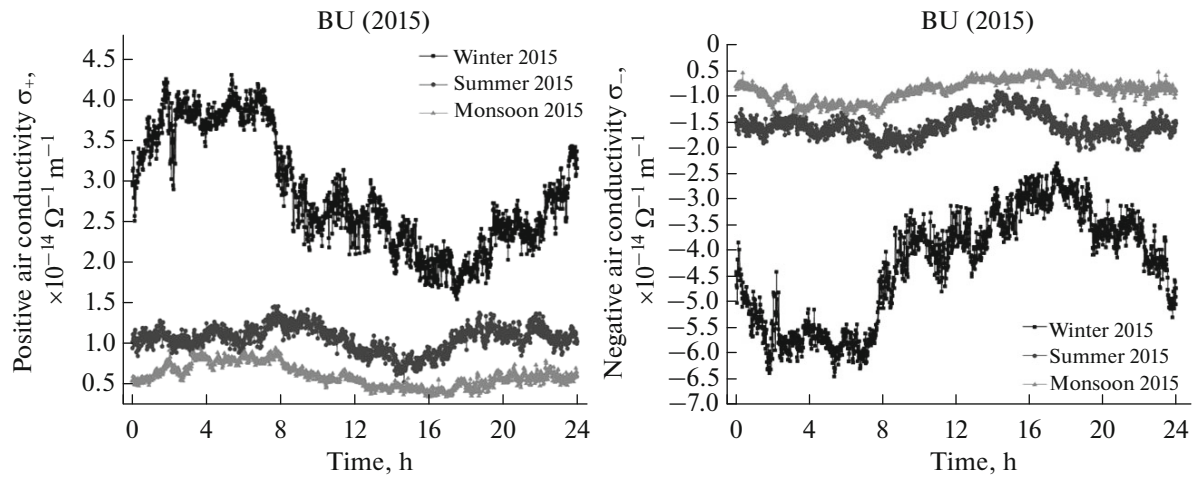


Fig. 5. Seasonal variations in air conductivity at Bengaluru during 2015.

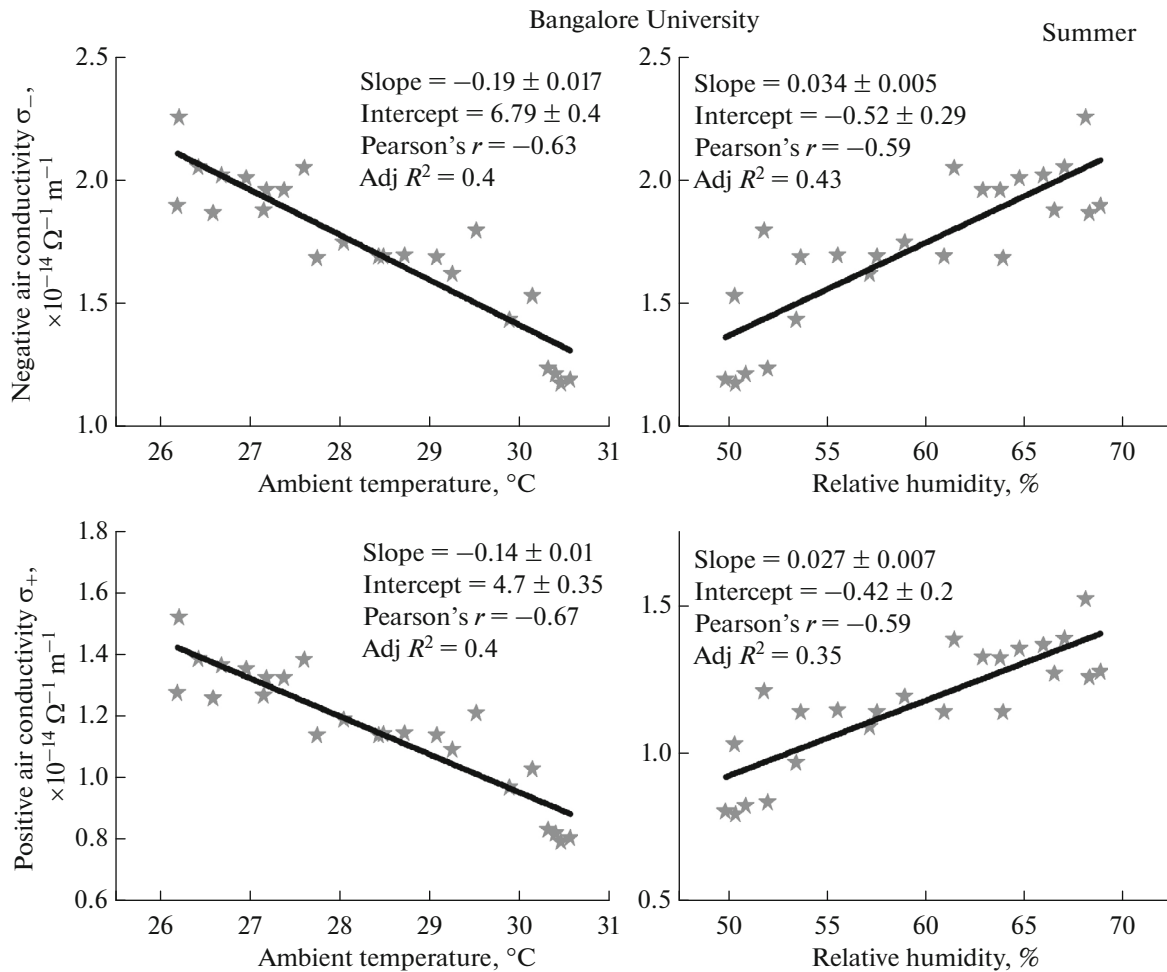


Fig. 6. Scatter plot of air conductivity and meteorological parameters during summer.

exhalation of Radon gas from the surface of Earth due to filling up of pores, voids by precipitation water [35]. The scatter plots between polar air conductivity values and temperature and relative humidity for individual seasons are shown in Figs. 6–8. It was found that the

highest r coefficient was found during the winter season, and the lowest was found during the monsoon season. When the atmosphere is stable with low winds and clear sky during fair weather days, a well-defined diurnal variation in atmospheric electrical conductivity

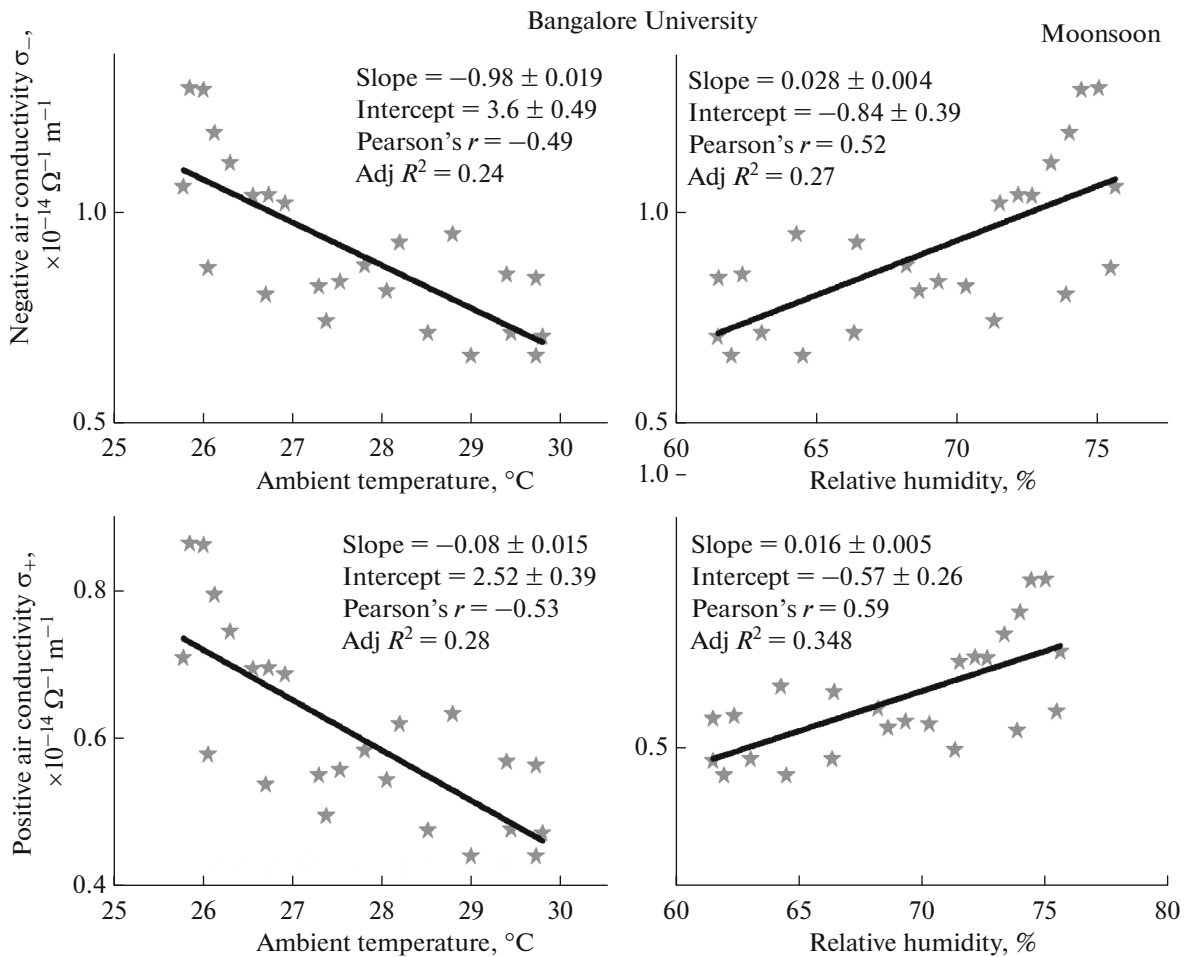


Fig. 7. Scatter plot of air conductivity and meteorological parameters during monsoon.

ity was observed with early morning maximum and late afternoon minimum. Also, the highest Pearson's correlation coefficient was found between measured air conductivity values and meteorological variables. As the atmosphere becomes more unstable with eddies, currents, and turbulence, the small ions formed due to ionization near the Earth's surface is

transported horizontally or drifted vertically upward due to convection. Hence, a reduction in electrical conductivity was observed near the Earth's surface and is prominent during unstable weather conditions.

The atmospheric electrical conductivity at a location depends on several factors, such as geological features,

Table 2. Comparison of atmospheric electrical conductivity for different locations

Region (altitude above MSL)	Air conductivity σ_{total} , $\times 10^{-15} \Omega^{-1} \text{ m}^{-1}$	Reference
Athens (107 m)	5.37	[15]
Maitri, Antarctica (103 m)	21	[36]
Indian Ocean	5.3–9.8	[19]
Eskdalemuir, Scotland(245 m)	9.8 ± 0.7	[20]
Reading, UK (61 m)	5.7 ± 2.3	[37]
Above the earth surface	2–20 & up to 40 in clean marine air	[20]
Pune, India(560 m)	5–30.8	[28]
Roorkee, India (268 m)	3.3	[23]
Mysore, India (763 m)	34.8	[31]
Bengaluru, India (840 m)	33.5 ± 0.13	Bangalore University (This study)

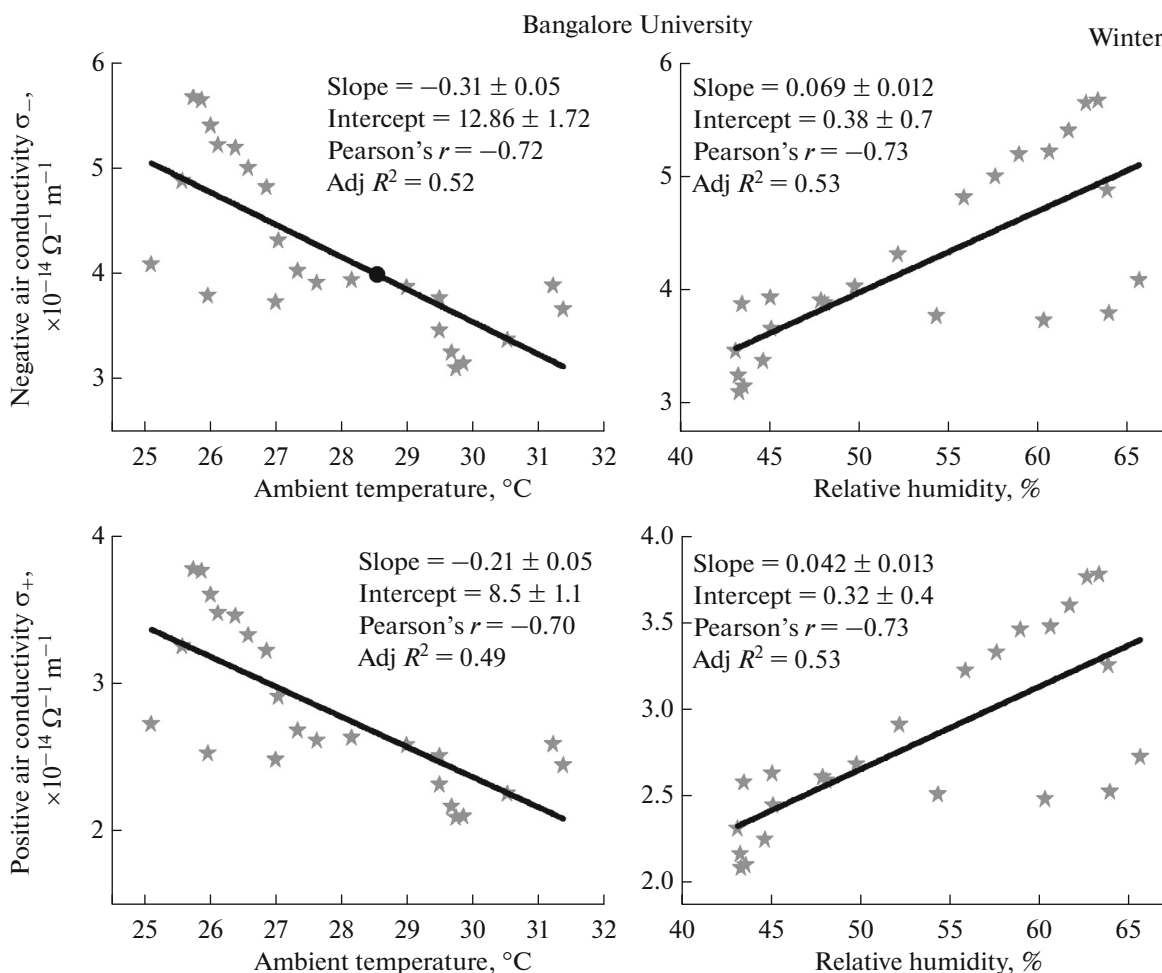


Fig. 8. Scatter plot of air conductivity and meteorological parameters during winter.

radon exhalation, meteorological conditions, and pollution levels. The possible sources and loss mechanism of air ions in the atmosphere vary from place to place. Table 2 compares the recorded values of atmospheric electrical conductivity for various locations with the current study's findings. It was found that the air conductivity values at Bangalore University are comparable with reported values of similar environments such as Pune and Mysuru. The locations were chosen for observations at Bangalore, Pune [28], and Mysore [31] at an altitude of 1 m from the Earth surface, where the areas are relatively free from tall buildings, trees, and shrubs. The selected locations are also free from vehicular activity with minimal influence on air pollution. Climate-wise, all three stations are of similar weather conditions as continental sites situated in the southern part of peninsular India.

CONCLUSIONS

This paper presents the results of measurements of atmospheric electrical conductivity and related mete-

orological parameters conducted at Bangalore University. Air conductivity showed well-defined diurnal variations, and there was a good association with most meteorological parameters. The measured Pearson's correlation coefficient between air conductivity and meteorological parameters yields the highest values during the winter season. Radon and its progenies showed a positive correlation, while temperature, wind speed, and longwave radiations were negatively correlated. The average negative conductivity was found to be $2.13 \times 10^{-14} \Omega^{-1} \text{m}^{-1}$ and the positive conductivity was found to be $1.23 \times 10^{-14} \Omega^{-1} \text{m}^{-1}$ with total conductivity of $3.35 \times 10^{-14} \Omega^{-1} \text{m}^{-1}$, which is comparable with reported values elsewhere.

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Charan Kumar worked on a project as a research student and was in charge of experimental measurements and anal-

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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