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Diurnal variation in the Atmospheric Electric Field with respect to Aerosol and Meteorological parameters at Islamabad, Pakistan

Samia Faiz Gurmani · Nabeel Ahmad · Tabinda Shamsher · Tariq Mehmood · Waqas Khalid · Asghari Maqsood · Talat Iqbal · Muhammad Ali Shah.

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Abstract Fair weather Atmospheric Electric Field (AEF) data was analyzed at Islamabad observatory for the period of 2015-2019. The influence of meteorological parameters and their temporal variation were studied, primarily in relation to the variation of four local meteorological parameters. The daily variation in the AEF curve shows a single sharp peak and very dull secondary afternoon peak. The purpose is to observe the variation in atmospheric electric field with respect to different meteorological parameters and aerosol. Variation of atmospheric electric field shows a positive correlation with temperature, pressure and wind speed. On the other hand, a negative correlation is observed between the atmospheric electric field and relative humidity. The available simultaneous sampling of aerosol ($PM_{2.5}/PM_{10}$) was carried out and compared with AEF for the four seasons of year 2017.

Keywords Fair-Weather · Atmospheric Electric Field · Meteorological Parameters · Aerosol

1 Introduction

Earth's atmospheric electric field is one of the most important problem which remains under discussion in modern Geo-physics and still needed to be solved completely. Atmospheric electric field is affected by various factors of regional, global and mainly local [34, 56]. The vertical component of AEF at the ground level usually divided into local and global components which mainly depends on the location of sensor installed. Global components are solar radiation,

F. Author
Centre for Earthquake studies, NCP, Islamabad
Tel.: +92-51-2077300 Ext:469
E-mail: samia@ncp.edu.pk

ionospheric potential and natural radioactivity. On the other hand, local components are space charge density, atmospheric conductivity, aerosols and meteorological parameters [50]. The natural periodic variation of atmospheric electric field is due to many factors, the most important local factors are solar radiations, aerosol, and meteorological parameters.

A potential difference of around 250 KV exist between the Earth's surface and the ionosphere [26, 37, 52]. The conductive earth and highly conductive ionosphere potential difference, atmospheric electric field and conductive current are three main closely related parameters of the Global Electric Circuit (GEC). The study of these parameters help to understand the electrical environment at the Earth's surface [24, 38, 51] Results of few studies suggests that thunderstorms conditions may depend on solar activity. The circuit between earth and ionosphere is predominately operated by electrified showers, thunderstorms, lightning and heavy rainfall [18, 39]. Variation in both galactic cosmic rays and solar rays may affect the electrical parameters and significantly aerosol layer of the atmosphere [12, 27, 45, 49, 58].

Aerosol or particulate matter (PM) have also significant effect on climate, atmospheric circulation and causing change in surface temperature. The fair-weather atmospheric electric field intensity at the unpolluted regions varies from the order of one to several hundred V/m and show periodic variations [38]. The local and global variation of atmospheric electric field is controlled by many factors of global, regional and local scales [15, 57]. Global components includes many phenomena integrated over the globe with respect to Universal Time (UT). Mainly, the local component are controlled by few dominant local meteorological parameters, aerosol rich regions, and follows Local Time (LT) [33]. Even the exhalation of radon gas and radioactivity processes going on beneath the Earth surface can also induce the local variation [1, 47]. Many atmospheric processes are directly affected by aerosol particles. The major sources for the production of these aerosol is smoke particles due to combustion processes and also aerosol production from the anthropogenic gaseous species [7]. These aerosol have major effect on the variation of atmospheric electric filed. Previous studies shows the inverse relationship between AEF and electrical conductivity. The change in electrical conductivity also depends on the aerosol size and concentration of particles [10, 11]. Israelsson and Tammet [21] proposed the explanation that numerical reduction of the atmospheric electric field values according to the local meteorological parameters, like pressure, temperature, relative humidity and wind speed, could weaken the meteorological effect. The feature and quality of meteorological parameters accenting the AEF due to a regular changes in seasons [54]. There are strong seasonal effect on variations of the AEF [3, 8, 24, 48].

The meteorological effects on the diurnal variation of fair weather atmospheric electric field is very important and quite interesting [40, 46, 55]. To complete the analysis of Islamabad station, must need the analysis with respect to meteorological parameters and aerosol as the station is not completely in city center. There is always timely movements at some specific time. We can not consider it completely as Urban area due to close to hills and clean environment. In this paper, we report the variation in atmospheric electric field and its possible relation with meteorological parameters and aerosol. Atmospheric electric field for the year 2017 is well compared with the available data of aerosol (PM) at the Islamabad station. Solar activities also play an important role in the variation of atmospheric electric field, which is our next task to observe and get detailed analysis with respect to solar. This is the extension of already studied the annual seasonal variation for Islamabad observatory, Pakistan [13, 14].

2 Data, Instrument and Analysis

The Electric Field Mill (EFM) is used for this study to get the data of atmospheric electric field which is commercially available around the world. The manufacturer of our used mill Mission Instruments and named as ZEBRA field mill. They provided the calibrated system and further the system is calibrated every year in the laboratory. This is one of very famous technology used around the world to measure atmospheric electric field. Few old commonly used methods are potential probes and burning fuses to measure AEF [6, 20].

In case of Islamabad, electric field mill is mounted at the rooftop of single floor building around 7m high from the ground. The data is also calibrated with respect to height by using a reference field mill. Correction factor is added to the present data [35]. The values are considered positive in the downward direction. The accuracy of the sensor is 5%.

Islamabad has a subtropical climate and has been divided into four season. The geographic coordinates of Islamabad are 33.74° N, 73.16° E. Meteorological parameters variation is little complex due to the location, as its close lakes, surrounded with streams and hills. Heavy Winds are observed during spring dry weather or may be less rain. Daily temperature during whole year also varies in few degrees as compared to city center. The four year averaged data is used for this study from 2015 to 2019. The fair weather selection have been controversial long time and still under discussion [19, 22]. Recently, in 2018 Harrison and his team published the detail for the selection of fair weather criteria [17], we followed the same criterion.

Table 1: Number of fair weather days for Islamabad from 2015 to 2019

Year	Fair-Weather days
2015	160
2016	183
2017	189
2018	145
2019	212
Total	889

In this study, we follow the same criteria defined by [17]. We receive the detailed weather data from Pakistan Meteorological Department (PMD) and from the meteoblue which is simulated weather data. Wind speed is considered less than 6 m/s, and cloud cover up to three-eighths cumuliform cloud with no stratus cloud. Precipitation is considered completely zero according to the criteria. Atmospheric electric field for Islamabad ranged from 40-400 V/m [13, 14]. Under the criterion for fair weather mentioned above, the total number of fair weather days for each year from 2015-2019 are provided in Table 1. During 2018, the number of fair weather days are more less as compared to previous the rest of four years which is due to fault in system, data is missing for few days of spring. In total 889 fair weather days were extracted from the period of five years.

3 Results and Discussion

Frequency range of atmospheric electric field is presented in Fig. 1 for fair weather days during the period 2015-2019. The fair weather AEF mean value is 153.7 V/m and the median value is 146.1 V/m.

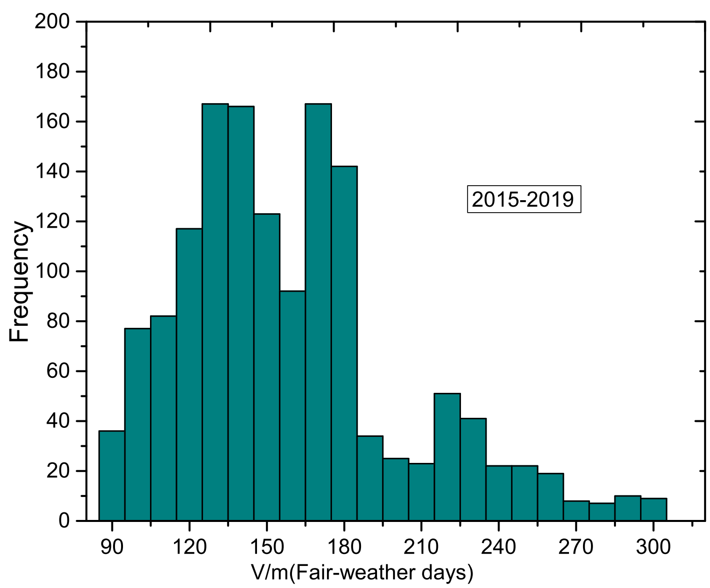


Fig. 1: Histogram of the AEF values of Islamabad station during fair-weather days

Fair weather atmospheric electric field measurements over ocean and at many polar stations are done globally. The diurnal variation of the fair weather AEF is now the most studied and discussed topic in the atmospheric electricity community. And it is continued with the addition of new stations with new comparison all over the world to contribute the Global Electric Circuit (GEC) [8, 20, 34, 48, 51, 52]. The single oscillation of diurnal variation of AEF is mainly observed over ocean named the Carnegie Curve which is considered as standard most of the time [19].

The diurnal annual variation of the atmospheric electric field of Islamabad is presented in Fig. 2. The collective average of five years and each year average is shown in the left plot for the period of 2015 to 2019. In case of Islamabad, mainly single sharp oscillation is observed at 04:00 UT with very weak secondary peak at 14:00 UT [13]. Observing the diurnal variation of the atmospheric electric field in Islamabad, there is a difference in peak values are observed annually. From 2015 to 2019, there is a slight and continuous decline in the values of AEF each year. This could be due to the variation in many significant factors, like meteorological parameters, aerosol and solar cycle. In the present work, we discuss and compare few meteorological parameters and aerosol affect on the AEF.

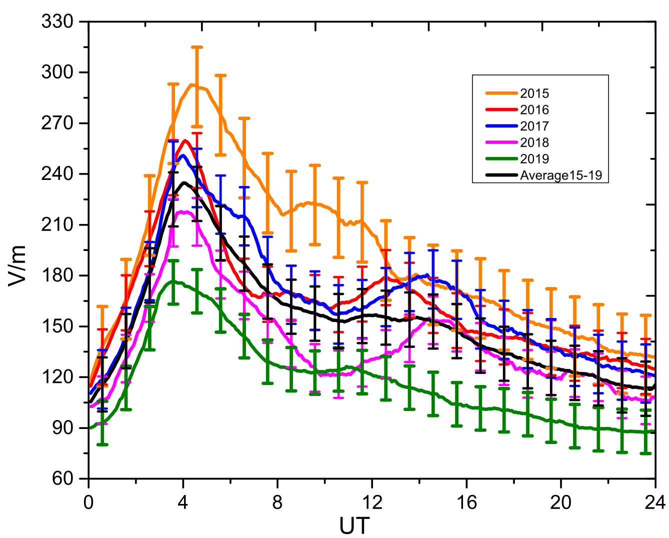


Fig. 2: Annual variation of atmospheric electric filed of Islamabad for the period of 2015-2019.

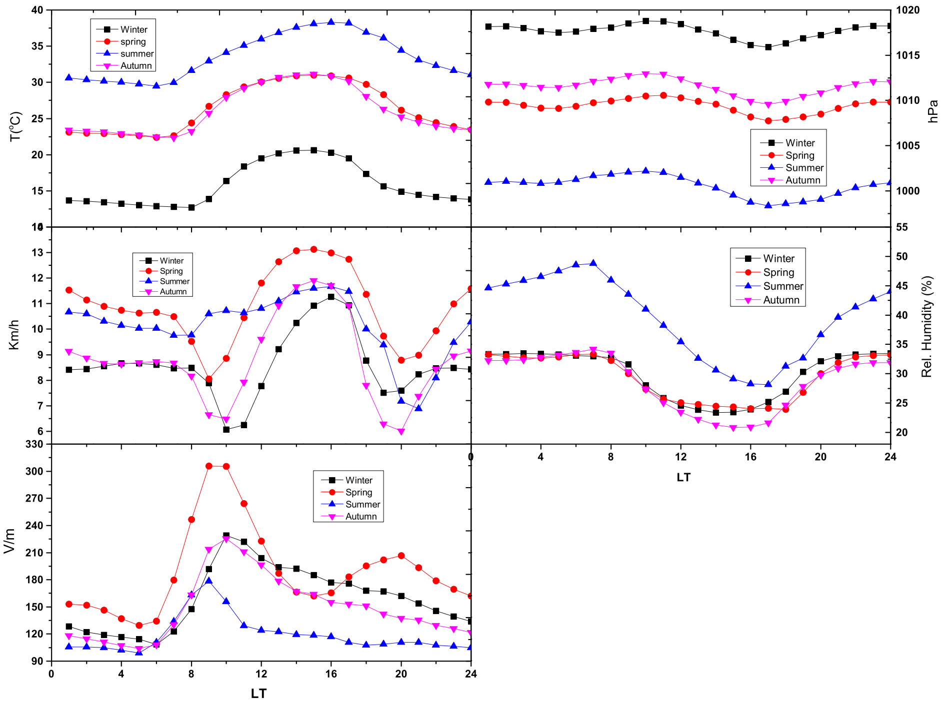


Fig. 3: Diurnal variation of the atmospheric electric field in fair weather for the period of 2015-2019 on the annual and seasonal scales

The hourly variation of atmospheric electric field is shown in the Fig. 3, which represent the seasonal variation of pressure, temperature, relative humidity, wind speed, and the AEF for the period 2015-2019. During the winter and spring, the temperature, relative humidity and wind speed is low and pressure is high, rise in atmospheric electric field is observed. This could be due to dry and cold weather, and the high concentration of aerosol. Wind is related to a very complex hydro-meteorological characteristics. High speed of wind is observed in spring as compared to other seasons. The lowest value of atmospheric electric filed in summer is as expected due to monsoon season and increase in temperature and relative humidity. Pressure is lowest during the summer. The summer peak is appeared little early in time as compared to other seasons which is due to early sunrise and late sunset. These variation of peaks with respect to time is possibly related to sunrise effect and human activities. Sunrise effect with respect to height could also be the reason and this affect is also associated with the production of local space charges[28]. This effect is observed by different observatory around the world including Islamabad and Muzaffarabad [3, 13]. During the night, the decrease of exchange layer heights could be dominant which is observed from other observatory in Asia [24]. The variation in the atmospheric electric field values are largely affected by local factors of aerosol, meteorological parameters, geographical coordinations, space charge, solar activities and natural radioactivity [2, 8, 9, 16, 19, 23, 44, 48, 55]. Overall, the highest peak of atmospheric electric field is observed during the spring. Spring is considered as the pre-monsoon season, and the lowest amount of rain is usually observed.

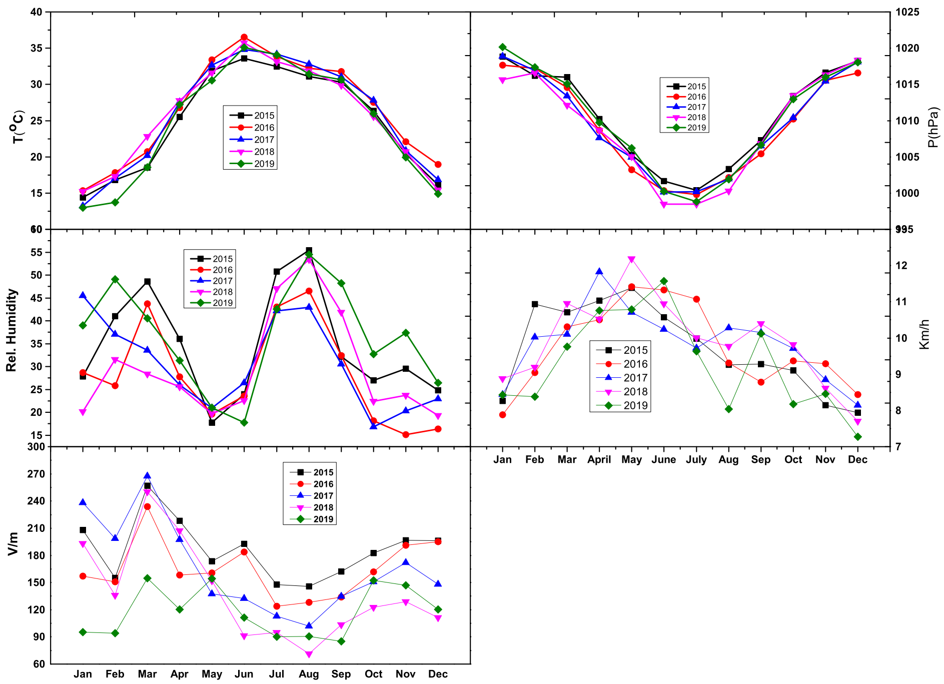


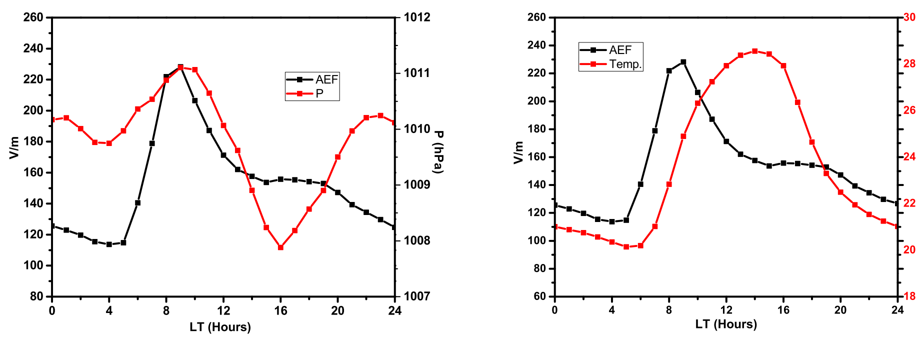
Fig. 4: Diurnal variation of the atmospheric electric field in fair weather for the period of 2015-2019 on the annual and seasonal scales

Fig. 4 illustrates the monthly annual variation of relative humidity, temperature, pressure, wind speed, and AEF at the Islamabad observatory for the period of 2015-2019. Comparing each meteorological parameter for five year,

Table 2: Average of Met-parameters for each year

year	2015	2016	2017	2018	2019
Temperature °	24.895	26.415	25.751	25.588	24.5
Rel. Humidity (%)	34.887	28.403	30.447	29.663	36.6
Pressure (hPa)	1010.72	1009.29	1009.54	1009.18	1010.26
Wind Speed (km/h)	9.72	9.73	9.85	9.92	9.5

a difference in relative humidity is observed from year to year. But in case of pressure and temperature there is very slight difference during these five years. Temperature get down from 2015 to 2019 during the winter especially. Wind speed is in increasing order form 2015 to 2018, in 2019 gets little slower as compared to few previous years. Pressure also show a slight descending order. Average values of each year for pressure, temperature, wind speed and relative humidity is also present in Table 2. There is roughly around less then 1 degree difference of temperature from 2015 to 2018, then in 2019 temperature again gets down. With respect to months of each year, there is no significant difference. But these all parameters give the best information of correlation with the atmospheric electric field.



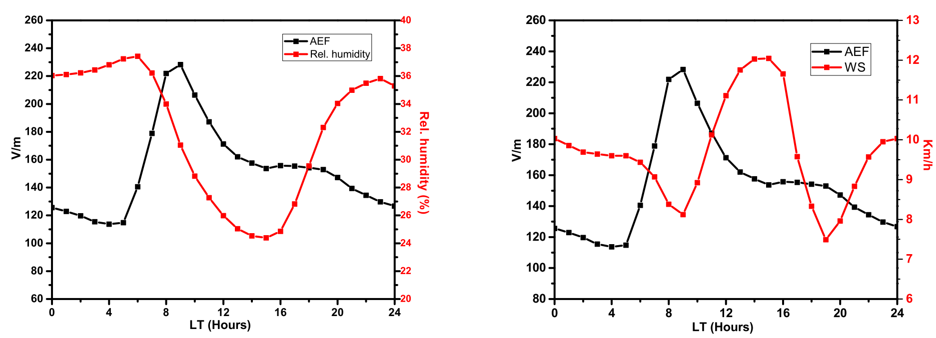
(a) AEF and Pressure (b) AEF and Temperature

Fig. 5: Variation of atmospheric electric field with respect to temperature and pressure during the period 2015-2019 for Islamabad.

The diurnal variation of fair weather atmospheric electric field shows one sharp peak after averaging over five years, similar to that of pressure (five year average pressure) as shown in Fig. 5(a). The AEF begins to rise rapidly in pre-sunrise hours and similarly pressure peak starts increasing but little before from AEF. Both peaks of AEF and air pressure reaches at maximum at about local time around 09:30 to 10:00 LT. After that the AEF starts falling slowly to minimum at the pre-sunset hours and small evening peak appears.

Later, AEF changes more slowly in the evening. Minimum of AEF and pressure are approximately at the same time, a little sharp dip of pressure is observed. During the pre-sunrise time, a small dip is observed in both pressure and AEF. The decrease in pressure increase the upward mass flux and convergence. The increased flux give rise to the aerosol current which decreases the AEF [41]. A very slight dip is also appeared at at sunset hours in both plots which shows the similarity as sunrise effect. This all phenomenon of maximum and minimum also include the so-called sunrise and sunset effect [24, 28]. Overall, a strong positive correlation is observed between air-pressure and fair-weather atmospheric electric field. The same result is also observed at YBJ, Tibet [55] and opposite correlation is observed at Jinghong, China [53]. The simple Pearson correlation coefficient between AEF and meteorological parameters is presented in the table 3.

Fig. 5(b) shows the diurnal variation of AEF and temperature. We can observe that diurnal variation of AEF and its trend, is similar with the surface temperature. The plot shows the strong positive correlation of AEF and Temperature. Temperature is a key parameter contributing in daily atmospheric electrical activity. The diurnal variation of AEF is directly or indirectly affected by local meteorological parameters. Thus, the hypothesis advanced (presented by Israelsson and Tammet) that component of local variation may be predicted when the variation of selected meteorological parameters are known [21, 46].



(a) AEF and Rel. Humidity

(b) AEF and Wind Speed

Fig. 6: Variation of atmospheric electric field with respect to relative humidity and wind speed during the period 2015-2019 for Islamabad.

The average atmospheric electric field over five years is plotted versus relative humidity in the Fig. 6(a). There is a strong negative correlation is observed between AEF and relative humidity (%). These Pearson's correlation coefficient (r) is a common quantitative of similarity between the measurement of two variables. Wind speed for the period 2015 to 2019 is drawn to see the

Table 3: Observed Pearson's correlation between atmospheric electric field and meteorological parameters for Islamabad Station

Islamabad Station	Pearson's r
AEF & Temperature	0.5157
AEF & Rel. Humidity	-0.4518
AEF & Pressure	0.3242
AEF & Wind Speed	0.0599

variation with respect to diurnal variation of atmospheric electric field in the Fig. 6(b). The correlation coefficient value between AEF and wind speed is very low. The first phases of our results showed the strong deviation from the Carnegie curve in both magnitude and peaks [13, 14]. These deviations can be explained as local diurnal variations and local Planetary Boundary Layer (PBL) [4]processes like, turbulence, convection, evaporation, etc [8, 14, 24]. In our case, the sensor location is very different, as at some specific time and period it is like urban site. Most of the time it is a quite place, so there are many local dominant effects, like aerosol, meteorological and solar effect as discussed earlier [13, 14].

Table 4 present the correlation between AEF and few meteorological parameters of three different stations. In both Tibet and Jinghong observatory, it is shown there is no direct pollution in the vicinity [53, 55]. At Islamabad observatory as we discussed about the location and its seasonal effect, it may have some direct aerosol effect which we are presenting with some available data at the observatory with respect to seasonal variation of the year 2017. As this location of Islamabad observatory is few kilometers away from city centre, so we may call it suburban station.

Table 4: Correlation observed for three different location between atmospheric electric field and meteorological parameters around the Globe

	Islamabad	YBJ, Tibet	Jinghong
AEF & Temperature	Positive	Positive	Positive
AEF & Rel. Humidity	Negative	Positive	Negative
AEF & Pressure	Positive	Positive	Negative

Seasonal variation of both Particulate Matter (PM) and atmospheric electric field is plotted in Fig. 7 for the same period of year 2017. From the figure, it can be seen that during the winter and autumn PM pollution is higher as compared to summer (monsoon). For all four seasons, the mean $PM_{2.5}$ and PM_{10} concentration at Islamabad station were 51.6 and 102.8 $\mu g/m^3$ respectively. $PM_{2.5}$ and PM_{10} levels varies from 11.58 to 121.50 $\mu g/m^3$ and from 22 to 231 $\mu g/m^3$ respectively over the entire sample time as shown in Fig. 7. Mass Concentration of $PM_{2.5}$ remained above to permissible limit (35 $\mu g/m^3$) in about 80% of total sampling days. Nevertheless, the PM_{10} concentration was found at between 35 and 80 $\mu g/m^3$ for more than two thirds of the time, while remaining 10% days observed more than 80 $\mu g/m^3$ concentration of $PM_{2.5}$.

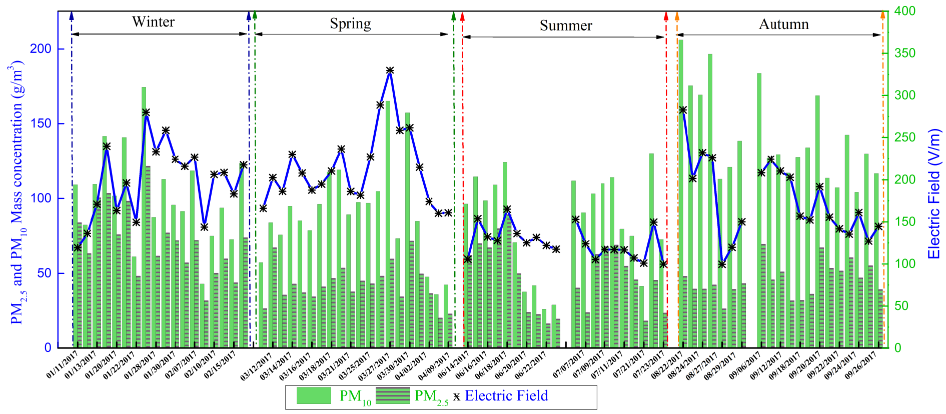


Fig. 7: Variation of aerosol(PM) and AEF during the year 2017 with respect to four seasons for Islamabad

On the other hand, PM_{10} concentration remained within the acceptable limit of 150 $\mu g/m^3$ for 24-h as specified by Pak-NEQS for most of the sampling time (86 percent). In Islamabad, winter and autumn were the major polluted seasons of 2017 (7). The maximum $PM_{2.5}$ (149.80 $\mu g/m^3$) level was found in winter, on 23 February. Compared to summer, two times greater $PM_{2.5}$ concentrations were found in winter, which is comparable to those recorded by Rasheed et al. [36]. Higher hourly average levels of $PM_{2.5}$ were recorded in Islamabad, i.e., 495.0 $\mu g/m^3$ (November 2008); 259.8 $\mu g/m^3$ (September 2009); 456.0 $\mu g/m^3$ (October 2010) and 303 $\mu g/m^3$ (January 2011). Likewise, in the winter and autumn periods, Mansha et al. [25] have found a comparatively higher degree of $PM_{2.5}$ mass concentration than at other times of the year.

In the surroundings of Islamabad, open burning of agricultural waste materials and forest fires in the Margalla Hills were possibly the key explanation for high PM emissions in winter and fall [32]. On the other side, PM_{10} displayed a declining mass concentration pattern, i.e., autumn (104-231) ¿ winter (42.9-163) ¿ spring (32-155) ¿ and summer (21.9-130). In the context of PM_{10}, the most polluted season was fall of 2017, which was in close alliance with those recorded in Islamabad by Shah and Shaheen [42]. They recorded autumn with high TSP level (198 $\mu g/m^3$) as the most polluted period compared to winter, summer and spring with 138,148,190 $\mu g/m^3$ TSP mass concentration respectively. Shah and shaheen [43] identified the lower PM level in spring and summer due to the higher monsoon (July-August) and pre-spring (February) rainfall due to the ambient washout of PM [31]. Likewise, the number of coarse particles (21-231 $\mu g/m^3$) was comparatively higher in 2017 (this study) than (123-202 $\mu g/m^3$) reported by Bulbul et al. [5] in Islamabad for the year 2016. The high concentration of $PM_{2.5}$ therefore indicated a marked health risk than PM_{10} in Islamabad [29, 30].

Table 5: Correlation analysis of $PM_{2.5}$, PM_{10} and AEF.

PM Species	Seasons	AEF
PM_{10}	Winter	0.645**
$PM_{2.5}$	Winter	0.567**
PM_{10}	Spring	0.789**
$PM_{2.5}$	Spring	0.635**
PM_{10}	Summer	0.44
$PM_{2.5}$	Summer	0.35
PM_{10}	Autumn	0.719**
$PM_{2.5}$	Autumn	0.17
PM_{10}	Annual	0.473**
$PM_{2.5}$	Annual	0.357**

" **Correlation is significant at the 0.01 level (2-tailed)"

In general, the AEF increased with the increase of PM10 and PM2.5 concentration. In addition, the annual data showed significant but weaker correlations of PM2.5 and PM10 for AEF (r: 0.35 and 0.47). However, AEF- PM2.5 and PM10 correlations changed in different seasons as shown in Table 5. For instance, the correlation between AEF and PM ($PM_{2.5}$ and PM_{10}) were statistically positive (p ¡ 0.01) and very strong in winter (r: 0.57 and 0.65) spring (r: 0.64 and 0.79). In contrast, in summer the both fractions do not show any significant correlation while in autumn only PM_{10} was significantly correlated with AEF (r: 0.71, p ¡ 0.01). We need more analysis of Aerosol Optical Depth (AOD) and PM for all stations of Pakistan. Our future main task to analyze the AEF in detail with respect to aerosol and solar activities.

4 Conclusions

Five years measurements have been explored for the temporal variation of the atmospheric electric field and its interaction with the meteorological parameters, and one-year with the particulate matter (PM, aerosol).

1. Atmospheric electric field presents double fluctuation, one with maximum and second with very small minimum happening to occur at sunrise and pre-sunset, respectively.

2. The annual behavior of AEF from 2015 to 2019 is in descending order, which could be due to local parameters, meteorological parameters, solar activities, aerosol, and seasonal variation

3. The overall meteorological parameters play significant role by affecting the air and its conductivity, especially in winter and spring. Linear positive correlation is observed between fair weather AEF with the temperature and pressure. Negative correlation is observed with the relative humidity.

4. Atmospheric electric field fluctuates more in polluted conditions, it increases with the increase of PM_{10} and $PM_{2.5}$. Aerosols are inversely proportional to electrical conductivity.

Still, we need further analysis of the atmospheric electric field with respect to Aerosol Optical Depth (AOD) and mainly with respect to solar activities for our all eight stations of Pakistan.

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