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Effect of PM10/PM2.5 on fog in recent years over Indira Gandhi international, airport new Delhi

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Abstract. Fog plays a significant role in many environmental and ecological processes. The aerosol particles present in the atmosphere becomes fog droplets due to condensation of water vapor on them in high humidity conditions. The formation and intensity of fog over an urban area depends on various factors that may promote or mitigate the process. The combustion processes are responsible for the presence of air pollutants in the atmosphere. The urban heat island effect may raise the temperature, lower the humidity and can even change the wind pattern of any region. The urban areas have often reported increase in frequency of fog due to emissions of air pollutants. The objective of the present study is to analyze the effect of air pollutants in formation fog over Delhi. The concentrations of air pollutants and meteorological observations are utilized for a period of six years in the present work. The study focuses on examining the dominant factors involved in formation of fog. It is found although high values of air pollutants aid in formation of dense fog but relative humidity is the most important factor that influence the formation of fog.

Keywords. Fog, air pollution, urban, temperature, humidity.

1. Introduction

Fog is one of the most troublesome phenomena which may cause disastrous low visibility condition over any area leading to adverse effects on traffic, human health and economy of any country. Fog is a near surface cloud that not only depend on the weather conditions [1] but also on land use features and aerosol characteristics [2]. Due to high level of air pollution in cities, thick fog is formed in presence of increased number of aerosol particles [3]. The nature and life cycle of fog may be influenced by any kind of alteration in terrestrial, atmospheric and hydrological system as the formation of fog is governed by different interactions in these systems.

The frequency of occurrence of fog over Indo-Gangetic (IG) plains of India has been increased during winter months in recent decades [4]. However, some of the studies based on the trend analysis carried out in different parts of world do not indicate a prominent decreasing or increasing trend in fog formation. The decrease/increase in fog trends may be associated with a number of factors such as complex interactions and feedbacks between many processes at different scales, synoptic scale circulations [5, 6] and localized changes such as urban expansion [7] and atmospheric composition which depends on the pattern of air pollution. The fog variability shows decreasing trend [8, 9] over some places and it is debatable whether the trends are due to climate change or increase in urbanization. The formation of fog is affected by urbanization due to change in local temperature, moisture content, wind speed and aerosol loading [10].

High temperatures in urban areas and cities leads to decrease in values of relative humidity and inhibits fog formation. The impact of urbanization on fog has been seen in form of fog hole in satellite imagery over cities. The first fog hole was observed in California Central Valley by Lee [11]. The distinct punch of fog hole has been observed over dense fog in satellite imagery of a number of cities around the world. In India, the first fog hole was observed in MODIS images for few cities lying in the northern plains of India [12]. The excessive heat emanating from the urban areas and the lack of vegetation over city area may be the cause of presence of fog hole. A modelling study conducted over Shanghai, China [13], considered the impact of Land Use Land Cover (LU/LC) and anthropogenic heat emission using WRF model and concluded that ground level moisture is not able to achieve dewpoint due to rise in night time temperature and thus makes it difficult for formation of fog. The nature of fog and its formation is also affected due to high concentration of aerosol particles in urban areas. The high concentration of very fine aerosols with high values of relative humidity and low wind speeds aids in formation of dense fog [2]. The greater number of fine aerosol particles results into more fog droplets causing the longer duration of fog over any area. Further the inversion layer in night doesn’t permit the air pollutants to escape from the atmosphere causing the conditions for dense fog. The regional wind circulation was altered in eastern central China leading to low wind speed and water vapor convergence which aided in formation of fog [14]. Although the number of foggy days increased after 1960 in old cities of China whereas a decrease was observed after mid 1980 due to increased urbanization. Similarly, in Europe (Poland) it was observed that number of foggy days declined due to low pollution levels and increased with high level of pollutants [10].

A number of studies conducted over India, indicate a recent (1998-2006) increase in frequency, persistence and duration of fog over northern plains and surrounding regions [15-21]. The interannual variability of fog frequency over Indo-Gangetic regions of India has been related to North Atlantic Oscillation (NAO, [18] and Arctic Oscillation (AO, [21]). However, the trend in frequency of fog doesn’t depend on the changes in large scale circulation. A few studies conducted in past [17, 22, 23] have noted a shift in fog frequency during 1997/1998 and associated it with decrease in temperature and visibility. The shift in fog frequency in late 1990s has also been associated with Western Disturbances (WDs). Although the shift in fog frequency in 1998 coincided with increased WD activity due to strong ElNino year [24], another study indicated a decrease in WD activity during 1996 and 1997 which leads to clear skies causing more radiative cooling and fog [23]. Hence no one factor may be responsible for the changing trend of fog frequency over northern India.

New Delhi, the capital city of India, lies in northern plains of India and according to World Air Quality Report 2020, is the most polluted city globally. The topography and meteorological factors over Delhi contribute significantly in formation of fog and the contribution of air pollutants cannot be ignored. A number of studies conducted in past [25-28] have shown significant effect of aerosols on life cycle of fog. Safai et al [29] analyzed the variation of mass concentration of black carbon (BC) during foggy days at Indira Gandhi International Airport (IGIA), New Delhi and concluded that mass concentration of BC increases before and during the dense fog episode and a decrease is observed after the fog event. It was also observed that decrease in air temperature and increase in relative humidity played a major role in sustaining the dense fog despite the reduction in aerosol concentrations.

An attempt has been made in the present study to analyze the role of air pollution in fog formation over Delhi in recent years. The role of meteorological variables such as temperature and relative humidity is also studied. The study will provide a direction for the research in aerosol fog interaction and may also be beneficial for planning mitigation strategies for controlling the effects of adverse visibility conditions observed in entire IG plains of India during winter months.

2. Dataset and Methodology

The dataset utilized in the present study is the quality controlled observations obtained from India Meteorological Department and post processed at National Centre of Medium Range Weather Forecasting (NCMRWF), Noida. The data set includes visibility, temperature, dew point temperature and wind speed. The observations of Indira Gandhi International Airport (IGIA), (28.57-degree North, 777.12-degree East) New Delhi are utilized for a period of six years 2014-2020 in the present study.

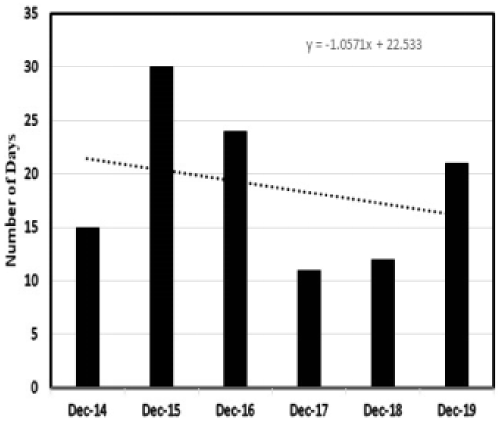
The observations of particulate matter (PM) (PM10/PM2.5) is obtained from System of Air Quality and Weather Forecasting and Research (SAFAR). It provides near real time data along with 1-3 day forecast of PM10/PM2.5 along with other pollutants such as NO_2, CO and O_3 over Delhi, Pune, Mumbai and Ahmedabad [30, 31]. The particulate matter is classified as PM10/PM2.5 depending on their size. The particles with mass median aerodynamic diameter less than 10 µm and 2.5 µm are known as PM10 and PM2.5 respectively. The major source of PM10 and PM2.5 are wind-blown dust, coal combustion, traffic exhausts and biomass burning [32]. The ambient concentration of PM10 and PM2.5 remains high in Delhi due to rapid urbanization and increase in traffic and energy consumption [33].

The visibility observations at 00 UTC are utilized to identify fog over Delhi during 2014-2020. The observations are analyzed during the months of December and January as 66% of the fog events over north India occur during these months [34]. According to India Meteorological Department [35], fog can be classified as light, moderate, thick and dense depending on the values of surface visibility. Fog is considered ‘light’ when observed visibility is reported less than 1000 m but more than 500 m, ‘moderate’ for visibility less than or equal to 500 m but more than 200 m, ‘thick’ for visibility less than or equal to 200 m but more than 50 m and ‘dense’ for visibility less than or equal to 50 m.

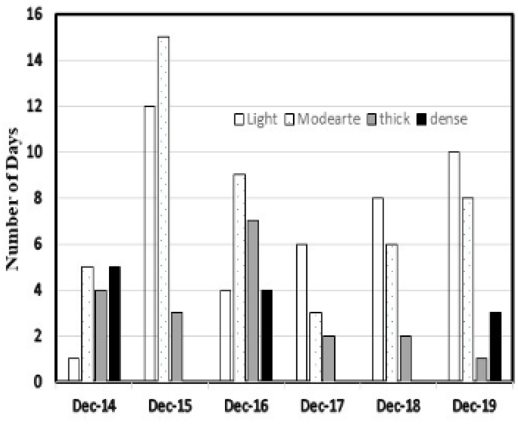
3. Results and Discussion

3.1. Occurrence of Fog during 2014-2020

The observations for six years during the month of December and January are analyzed to ascertain the occurrence and intensity of fog at 00 UTC over Delhi. Fog occurred for maximum number of days (30) in December 2015 and for minimum number of days (11) in December 2017 (Figure 1a). The number of fog days in December 2018 (12 days) are comparable to those observed in 2017 (11 days) and fog occurred for 15, 24 and 19 days in December 2014, 2016 and 2019 respectively. No dense fog was reported and only light to moderate fog dominated over thick fog in December 2015, 2017 and 2018 (Figure 1b). Dense fog is reported during December 2014, 2016 and 2019, however the number of light and moderate fog days are found higher than dense and thick fog days in 2016 and 2019.



(a)



(b)

Figure 1. (a) Number of Fog days and (b) Number of days with light, moderate, thick and dense fog days during Dec 2014-2019.

In the month of January, fog occurred for 29, 28, 28 and 25 days in 2015-2018 respectively. Hence most of the days experienced fog at 00 UTC in the month of January during these years. However, a decrease is observed in the number of fog days in 2019 (19 days) and 2020 (16 days) as compared to previous years (Figure 2a). Though dense fog is reported in all the years during January however the number of dense fog days is always less than the number of light and moderate fog days (Figure 2b).

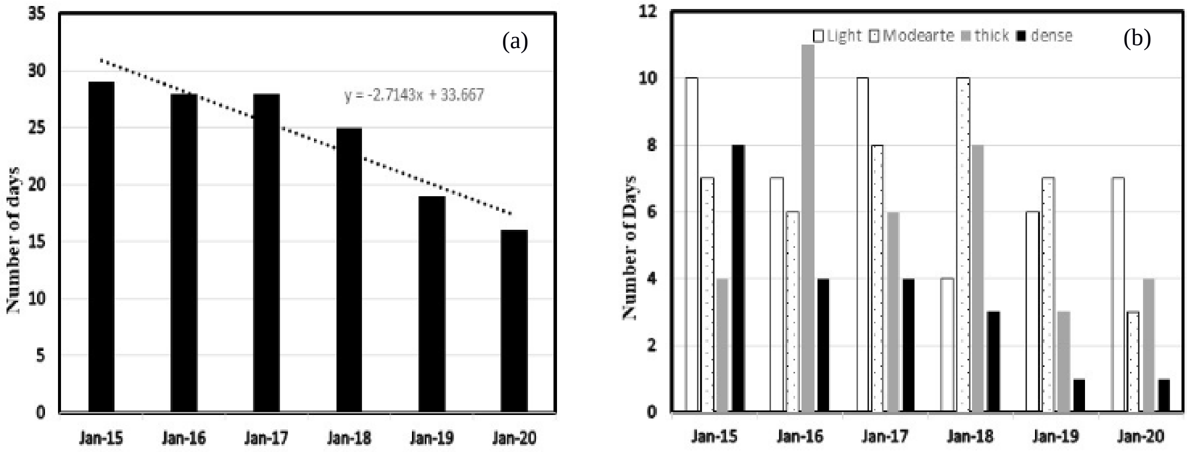


Figure 2. (a) Number of Fog days and (b) Number of days with light, moderate, thick and dense Fog days during Jan 2015-2020

The present study indicates a decrease in number of fog/dense fog days over the years in both the months. The decrease in fog days over Delhi may be associated to the changes in local meteorological conditions such as temperature, humidity and wind speed and air pollution on fog. It has been found that very low mean wind speed over northern India in December and January leads to formation of radiation fog [36]. The decrease of fog events is associated to competing effects between urban heat island effect and aerosol concentrations [37]. In urban areas the fog events are decreased due to dominance of urban heat island effect over aerosol impacts. Though the increase in aerosols results into formation of a greater number of fog droplets, after attaining a critical concentration of aerosols the fog droplet may be suppressed due to water vapor competition causing lower liquid water content (LWC) and droplet number [37]

3.2. Variation of Mean Visibility, Relative Humidity, Wind Speed and Particulate Matter during Fog

Figure 3 shows the variation of mean visibility, relative humidity, wind speed and particulate matter (PM10/PM2.5) during December 2014-2019 and January 2015-2020. The mean values of visibility have been increased over the years in both the months. This may be due to the fact that the number of thick and dense fog days is either less or comparable to the number of light and moderate fog days in both December and January. The mean values of visibility in December are always higher than that observed in January except in 2014 (Figure 3a). The mean values of visibility ranges from 200-560 m and 300-400 m during December and January respectively. Minimum value of mean visibility occurred in December 2014 and Jan2018 and maximum value of mean visibility was found in December 2017 and January 2020 (Figure 3a). The mean values of relative humidity for both the months are shown in Figure 3b. Over the years a decrease is observed in the mean values of relative humidity during December whereas an increase is observed during January This may be one of the reasons of lower values of mean visibility in January as compared to December. The mean values of relative humidity lie in the range of 90-99% and 95-97% in December and January respectively and are always higher in January than December. Similarly, the mean values of wind speed depicted a slight increase over the years during December whereas a decrease is observed during January (Figure 3c), which might have favored the formation of dense fog during January. Figure 3d and 3e shows the variation of mean values concentration of PM10/PM2.5 during both the months. An increase in mean values of PM10/PM2.5 is noticed in both the months. The mean concentration of both PM10/PM2.5 is comparable during December and January, with smaller values during January.

Thus, it may be concluded that fog formation at 00 UTC is mostly affected by meteorological conditions. To analyze further the role of air pollution on visibility the daily variation of visibility, relative humidity, wind speed and PM10/PM2.5 is analyzed in these months during fog.

3.3. Daily Variation of Visibility, Meteorological Variables and Particulate Matter during Fog

Figure 4 shows the daily variation of visibility, relative humidity, wind speed and PM10/PM2.5 in the month of December 2016 and January 2018. It is seen that the visibility values are much more dependent on the values of relative humidity and wind speed than on the values of particulate matter on any day. For the visibility values less than 200 m the value of relative humidity is always observed close to 100% (Figure 4a and 4d) and wind speed values ranges from 0-2 m s^{-1} (Figure 4b and 4e). The increase in PM10/PM2.5 doesn't affect the visibility values if the relative humidity is below 90% (Figure 4c and 4f). The correlation coefficient is computed between the visibility, relative humidity, wind speed and PM10/PM2.5 for all the foggy days (Table 1.) It is clear that visibility in both the months are negatively correlated with relative humidity and PM10/PM2.5. However, the correlation coefficient is higher for relative humidity than PM10/PM2.5 which indicates that fog at 00 UTC is much more dependent on the values of relative humidity and not the values of PM10/PM2.5 do not affect fog in presence of low values of relative humidity. The correlation coefficient for wind speed and visibility values is not very significant in both the months implying that wind speed doesn't affect the fog as much as the relative humidity.

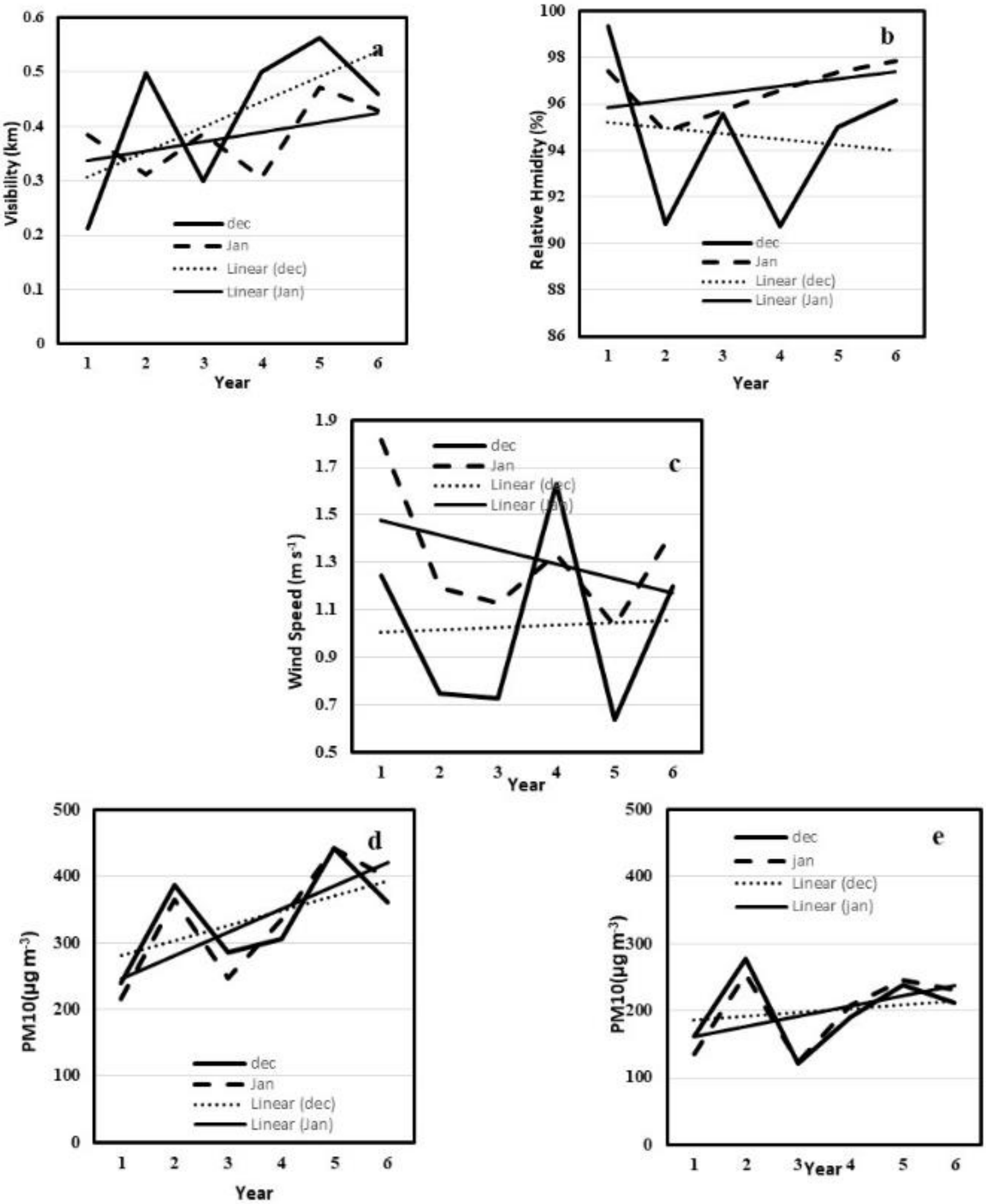


Figure 3. Variation of Mean (a) Visibility (b) Relative Humidity (c) Wind Speed (d) PM10 and (e) PM2.5 in December and January during 2014- 2020

Table 1. Correlation Coefficient between Visibility, relative Humidity, Wind speed and Pm10/PM2.5 for the month of December and January during 2014-2020

Correlation Coefficient of Visibility	Relative Humidity	Wind speed	PM10/Pm2.5
Dec	-0.64	0.021	-0.008/-0.025
Jan	-0.34	-0.16	0.011/-0.055

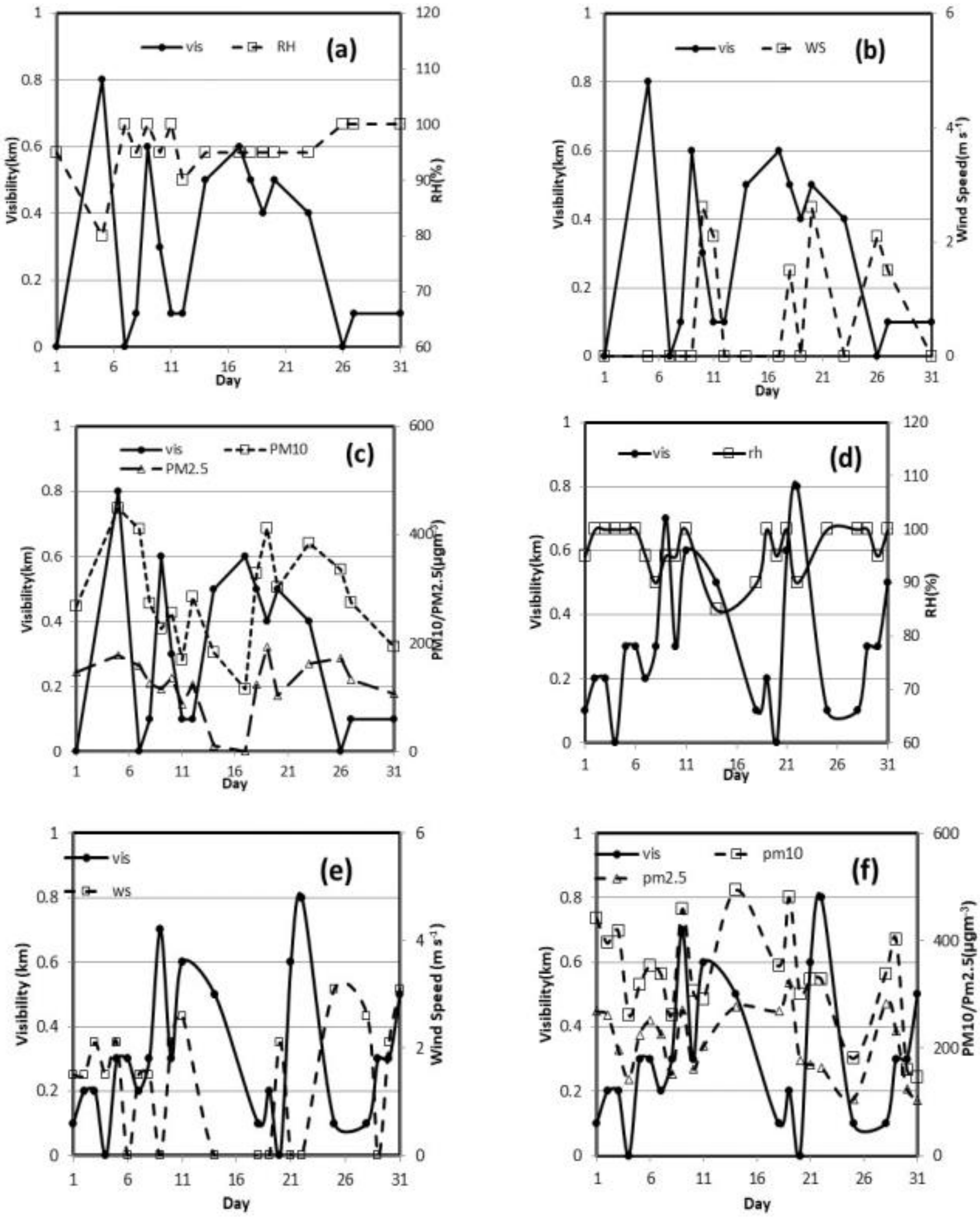


Figure 4. Daily Variation of Visibility with Relative humidity, Wind Speed and PM10/PM2.5 during Dec2016 (a), (b) and (c) and Jan2018 (d), (e) and (f) respectively

4. Conclusions

In this study, the visibility observations in the month of December and January during 2014-2020 are used to reveal the occurrence of fog at 00 UTC over IGIA, New Delhi. Further, the respective contributions of meteorological variables such as relative humidity, wind speed and air pollution to fog occurrence are quantified. The result indicates that the number of fog days in the January were higher than December and a decrease is observed in both the months over the period of six years. Similarly, the number of thick and dense fog in January were higher than those observed in December. However, the thick and dense fog days are always less than the moderate and light fog days in both the months. Thus, the mean value of visibility increased over the years during both the months.

As the formation of fog is mainly controlled by meteorological and air pollution, their contributions need to be quantitatively separated. By analyzing the mean and daily values of visibility, relative humidity, wind speed and PM10/PM2.5, preliminary it is found that fog at 00 UTC is mainly dependent on the availability of abundance moisture in the atmosphere and not all the time affected by the value of PM10/PM2.5. However, the analysis showed that zero visibility conditions with thick fog were always accompanied with high value of relative humidity close to 100% and low wind speed < 2 m s^{-1} and the value of PM10/PM2.5 more than 500/300 µg m^{-3}.

To corroborate this finding, the quantitative contribution of relative humidity, wind speed and PM10/PM2.5 is computed in terms of correlation coefficient. The highest correlation is found between visibility and relative humidity. The study concludes that high values of PM10/PM2.5 favors the formation of thick fog only in the presence of high values of relative humidity and in the absence of ample moisture the high value of PM10/PM2.5 is not conducive to formation of thick fog.

As the interactions among the visibility, relative humidity, wind speed and PM10/PM2.5 are complex it is difficult to analyze their interactions using only the observational dataset and thus it is recommended to use an advanced high-resolution numerical weather model to investigate the influence of different factors on formation of fog. Further investigations are required to determine whether the concentrations of aerosols in Delhi have reached their critical value. As after reaching the critical value, they are in repressed regime which results into insignificant trends in dense fog frequency

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Conflict of Interest

There is no conflict of Interest in the paper.

Authors Contribution

The study is based on the analysis of observations by the authors during the winter months.

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