Asian Journal of Water, Environment and Pollution, Vol. 17, No. 3 (2020), pp. 101-109.
DOI 10.3233/AJW200044

Investigation of Variability of Some Gaseous and Particulate Pollutants over Delhi, Northern India (28°40′N, 76°50′E)

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Received May 20, 2019; revised and accepted May 13, 2020

Abstract: Air pollution has become a serious concern these days as the pollutants added in the air have a great impact on human health and ecological environment. The pollutants like particulate matter that have a diameter less than 2.5 micrometer ($PM_{2.5}$), nitrogen dioxide (NO_2), ozone (O_3) and sulphur dioxide (SO_2) are mainly responsible for causing respiratory problems, asthma and heart and lung disorder. In the present study, data collected by the Central Pollution Control Board (CPCB) Delhi at Netaji Subhash Chander Institute of Technology (NSIT) location, Dwarka, Delhi, Northern India for airborne particulate and gaseous pollutants $PM_{2.5}$, NO_2, O_3 and SO_2 during November 01, 2017 to June 30, 2018 have been used to investigate the correlation among these pollutants and meteorological variables such as temperature, relative humidity, rainfall, wind speed and mixing height. The meteorological data have been obtained from Indian Meteorological Department. It has been found that the meteorological variables play a major role in modulating the pollutant concentration. The $PM_{2.5}$ is found to be positively correlated with temperature, relative humidity and rainfall, while negatively correlated with wind speed and mixing height in winter. In summer, $PM_{2.5}$ is negatively correlated with temperature and mixing height while positively correlated with relative humidity, rainfall and wind speed. O_3 is found to be positively correlated with temperature and negatively correlated with relative humidity, rainfall and mixing height in winter as well as in summer. The analysis reveals that the meteorological variables behave differently with O_3 when compared with $PM_{2.5}$, NO_2 and SO_2, respectively.

Key words: Air pollution, pollutants, health, meteorological variables, regression analysis.

Introduction

Urban air pollution is a challenging problem in India and rest of the world as it is detrimental to human health and the environment (Cohen et al., 2017). Health effect from air pollution is a serious concern as one-third of deaths caused by stroke, lung cancer and heart disease occur due to air pollution (WHO, 2019). The pollutants like particulate matter that has a diameter less than 2.5 micrometer ($PM_{2.5}$), nitrogen dioxide (NO_2), ozone (O_3) and sulphur dioxide (SO_2) are mainly responsible for causing respiratory problems such as asthma, heart and lung disorder. It is, therefore, essential to find out the possible ways to regulate the concentration of pollutants in the ambient air. Atmosphere plays a significant role in regulating the concentration of pollutants in the ambient air by the process of absorption, dispersion, transformation and removal. The meteorological factors such as temperature, relative humidity, wind speed, rainfall and mixing height significantly contribute in these processes and modulate the air pollution (Ramakrishna and Beig., 2018; Sharma et al., 2003). The temperature determines the transformation of pollutants, wind speed determines the amount of dispersion of pollutants and rainfall determines the removal of the pollutants by the washout effect (Ramasamy et al., 2013). The concentration of particulate pollutants during winter was higher than that in other seasons, because of the longer residence time of particulates in the atmosphere during winter which is due to low winds and low mixing height (Karar et al., 2006). The influence of seasonal variation on air pollutants concentration in Haridwar (India) was observed and found that the concentrations of air pollutants were higher in winter in comparison to summer or monsoon seasons (Chauhan et al., 2010). The influences of temperature, relative humidity and rainfall on the concentration of PM_{10} and NO_x were evaluated during 2014 in Gurgaon (India) and found that PM_{10} had positive correlation with temperature and relative humidity, while significant negative correlation with rainfall. NO_x is negatively correlated with relative humidity during pre-monsoon while positively correlated during spring, monsoon and post-monsoon (Sharma and Sharma, 2016). The relationship between particulate pollutants and meteorological parameters such as wind speed and planetary boundary layer height was analyzed over Delhi and a positive correlation was observed during pre-monsoon season (Ramakrishna and Beig, 2018). The influence of meteorological parameters such as temperature, relative humidity and wind speed on PM_{10} and NO_2 was studied at three selected stations in Malaysia and it was observed that the temperature had a positive correlation to the concentration of PM_{10}, but a negative correlation to relative humidity for all three stations (Dominick et al., 2012). A positive correlation was observed in an interactive study between the particulate and temperature in Malaysia (Zaharim et al., 2009). The associations between meteorological parameters and particulates were studied and found that the increase of rain fall and humidity establishes negative correlation with PM_{10} in Kathmandu valley, Nepal (Giri et al., 2008). The influence of rainfall on concentrations of $PM_{2.5}$, O_3, NO_x, NO_2, NO, SO_2, and CO was evaluated for the year 2016 at three monitoring sites of Haryana State (India) and found that, $PM_{2.5}$, NO_2 and SO_2 are negatively correlated with rainfall and O_3 is found to be positively correlated with rainfall (Sharma and Sharma, 2018).

In the present study, the levels of air pollutants $PM_{2.5}$, NO_2, SO_2 and O_3 are measured at Netaji Subhash Chander Institute of Technology (NSIT) station Dwarka, a sub-city, located in South West Delhi District of National Capital Territory of Delhi in India, and these pollutants' concentration were statistically compared using regression analysis with meteorological variables such as temperature, humidity, rainfall, wind speed and mixing height. Our study examines the meteorological parameters' effects on the concentration of these pollutant in a residential green region developed as a smart city.

Material and Methods

For the present study, we used ambient air quality data collected by the Central Pollution Control Board (CPCB) for pollutants $PM_{2.5}$, NO_2, SO_2 and O_3 for the period of November 01, 2017 to June 30, 2018 at NSIT location in Dwarka Delhi, North India. The $PM_{2.5}$, NO_2, SO_2 and O_3 samples were collected by CPCB using their respective analyzers which could be operated for up to 24 hrs. The sampling duration was 24 hrs as accepted by the Environmental Protection Agency (EPA), U.S.A. and the CPCB, India. The particulate pollutant $PM_{2.5}$ analyzer is based on β-ray attenuation (Yadav et al., 2014). Oxides of nitrogen analyzer use proven chemi-luminescence technology to measure NO_2 in ambient air. The SO_2 analyzer operates on the principle of UV Fluorescence, where the SO_2 molecules are excited by absorbing light at one wavelength and later decay to a lower energy state by emitting UV light at a different wavelength, which is proportional to SO_2 concentration. The O_3 analyzer also works on the UV Photometric absorption i.e., O_3 molecules absorbs UV light at 254-nm wavelength. The degree of absorption is directly proportional to O_3 concentration. O_3 measurements are automatically corrected for gas temperature/pressure changes and can be displayed in units of ppm and $\mu g/m^3$. In this study, the regression correlation analysis has been performed between meteorological variables and particulate and gaseous pollutants for winter and summer seasons, respectively, to investigate the relationships between them.

Description of Study Area

NSIT monitoring station is located in Dwarka (Latitude 28^o 40′ N and 28^o 29′ N and Longitude between 76^o 50′ E and 77^o 14' E) which is a sub-city of South west district of Delhi, and a diplomatic enclave. The sub-city is located in the vicinity of Indira Gandhi International Airport and serves as the administrative headquarters of South West Delhi. South West Delhi has a population of 2,292,363 (2011 census), and an area of 420 km², with a population density of 5,445 inhabitants per square kilometer. It is the fourth most populous district in Delhi. Administratively, the district is divided into three sub-divisions, Dwarka, Najafgarh and Kapashera. Dwarka is being developed as residential green area and a smart city under Delhi Development Authority's 'smart sub-city' project. It is bounded by National Highway-8, Outer Ring Road, Najafgarh Road and the Rewari railway line. It is the largest residential suburb in Asia, with a total of 1,718 residential enclaves, and a net population of 1,100,000.

Dwarka has been identified as an air pollution hot spot during the period of study. The main source of pollution in the study area are excessive construction and demolition activities, vehicular emission as the place has become a transit hub, domestic cooking, stubble burning in the neighbouring states, industrial emission and commercial activities in the surrounding areas and other man made perturbation on account of excessive population loading.

Results and Discussion

In the present study, period from November 01, 2017 to June 30, 2018 including winter (December and January are peak) and summer (May and June are peak) months has been selected to determine the correlation of meteorological variables and particulate and gaseous pollutants. The reason for selecting the winter and summer months is influenced by the fact that winter conditions provide low dispersion and high concentrations of pollutants while during the summer months, meteorology gets improved leading to better dispersion conditions for pollutants.

Variations and Correlation of Temperature with Concentration of $PM_{2.5}$, NO_2, SO_2 and O_3.

The temperature variations and their influences on concentration of $PM_{2.5}$, NO_2, SO_2 and O_3 were analyzed and are presented in Figure 1(a-d) and the results of regression analysis are presented in Table 1.

The temperature recorded in the study area ranged between 11.1ºC and 24.6ºC in winter and 25.8ºC and 38.2ºC in summer. The minimum temperature of 11.1ºC

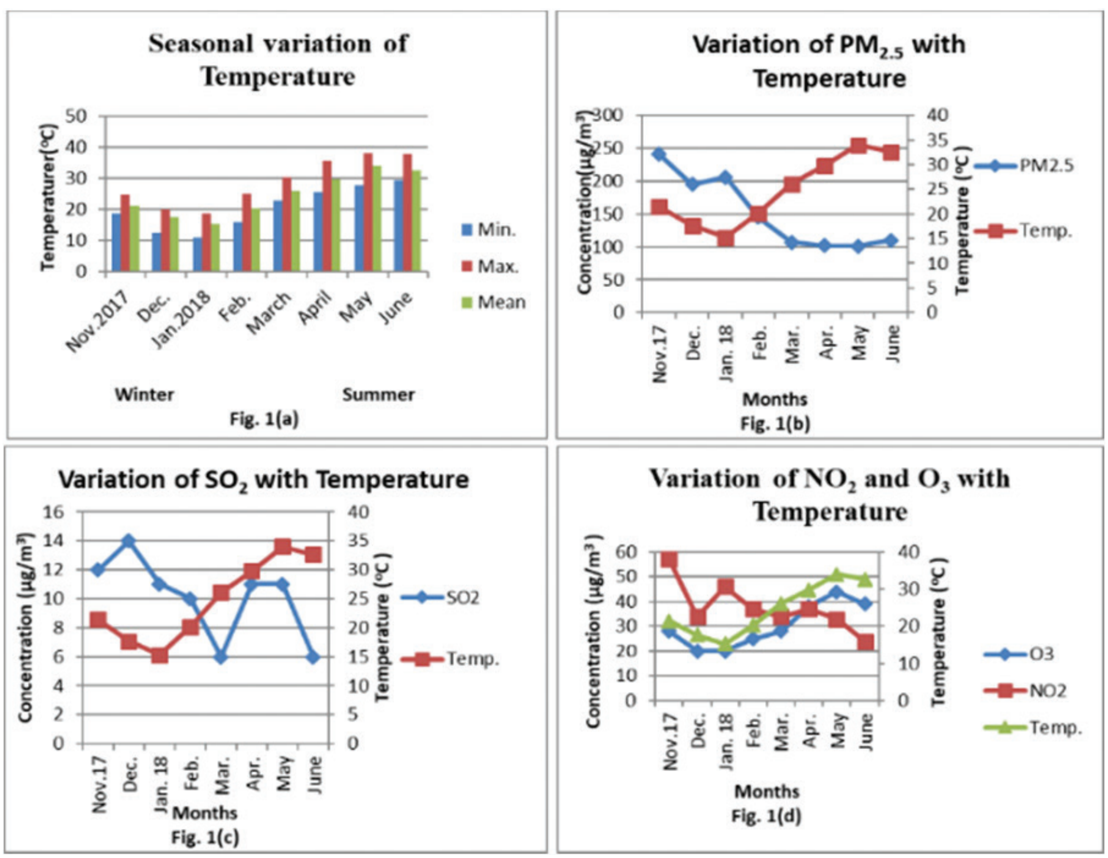

Figure 1: Seasonal variation of (a) temperature (b), $PM_{2.5}$ with temperature (c), SO_2 with temperature (d), NO_2 and O_3 with temperature.

Table 1: Correlation coefficients of temperature, relative humidity, rainfall, wind speed, and mixing height with pollutants concentration during summer and winter

Pollutant	*Season*	*Correlation coefficient (r^2)*				
		Temperature	*Relative humidity*	*Rainfall*	*Wind speed*	*Mixing height*
$PM_{2.5}$	Winter	0.002	0.108	0.008	0.913	0.854
	Summer	0.010	0.999	0.984	0.985	0.393
NO_2	Winter	0.114	0.021	0.208	0.414	0.282
	Summer	0.236	0.831	0.992	0.746	0.781
SO_2	Winter	0.016	0.001	0.368	0.425	0.559
	Summer	0.040	0.986	0.998	0.951	0.494
O_3	Winter	0.864	0.439	0.884	0.041	0.005
	Summer	0.708	0.218	0.115	0.311	0.169

is recorded in the month of January, 2018 and maximum in the month of May, 2018. The monthly minimum, maximum and mean temperatures recorded during November 2017 to June 2018 are depicted graphically in Figure 1(a). Figure 1(b) shows the variability of $PM_{2.5}$ during the study period and is observed to be higher in winter months and lower in summer months and $PM_{2.5}$ is negatively correlated with the mean temperature in both seasons. Figure 1(c-d) shows the variability of SO_2, NO_2 and O_3 with temperature respectively. The NO_2 is positively correlated with temperature in winter, but negatively in summer, SO_2 is negatively correlated both in winter and summer and O_3 is positively correlated both in winter and summer. The correlation of $PM_{2.5}$, NO_2 and SO_2 with temperature is weaker in winter than in summer, but correlation of ozone with temperature is found to be weaker in summer (r^2=0.708; O_3 = 1.275T – 0.638) than in winter (r^2=0.864; O_3 = 1.346T – 1.839). It suggests that, for O_3, the predominant controlling process in winter is dynamical while in summer it is photochemical. The temperature gradient and resulting short term ozone variation are stronger in winter than in summer, owing to the variation of the solar insulation and variation in planetary activity deriving O_3 transport (Fusco and Salby, 1999). The weaker correlation of $PM_{2.5}$ with temperature may be due to lower temperatures (11.2-24.6ºC) experienced in the study area in winter, which leads to increased emission rates from domestic heating and other anthropogenic sources. The weak negative correlation between temperature and NO_2 in summer may be due to minimum vertical mixing because of higher temperature range (25.8–38.2ºC) in summer, which results in greater dispersion and dilution of the air pollutants, probably linked with vertical and horizontal turbulence (Sharma and Sharma, 2016). The lower temperature range during winter (11.2-24.6ºC) reduces the vertical mixing height, thus resulting in positive correlation of NO_2 with temperature. The positive correlation of O_3 with temperature may be due to the fact that ozone is a secondary air pollutant and is formed in the atmosphere by photochemical reaction of hydrocarbons and NO_x in the presence of sunlight. The effect of seasonal variation of PM_{10} and NO_x with temperature has been studied recently over Gurgaon, (28.4595ºN, 77.0266ºE) India, and reported similar results (Sharma and Sharma, 2016). In another study, the effect of seasonal variation on concentration of particulate matter has been determined and reported that PM_{10} are positively correlated with temperature (Zaharim et al., 2009).

Variations and Correlation of Relative Humidity with concentration of $PM_{2.5}$, NO_2, O_3 and SO_2

The variations in relative humidity with concentration of $PM_{2.5}$, NO_2, O_3, and SO_2 were analyzed and are presented in Figure 2(a-d) and the results of regression analysis are presented in Table 1.

The relative humidity ranged between 30.6% and 85.2% in winter and 16.5% and 76.6% in summer months. The monthly minimum, maximum and mean relative humidity recorded from November 2017 to June 2018 is depicted graphically in Figure 2(a).

It can be seen that, in winter, all the pollutants except O_3 have a positive correlation with relative humidity. In summer, the behaviour of $PM_{2.5}$ is observed to be different from NO_2, SO_2 and O_3. $PM_{2.5}$ is found to be strongly positively correlated with Relative Humidity (r^2 =0.999: $PM_{2.5}$ = 0.561 RH +81.387), while with NO_2 (r^2=0.831; NO_2 = -0.690 RH + 59.571), SO_2 (r^2=0.986: SO_2 = -0.326 RH + 22.669), and O_3 (r^2=0.218) it is negatively correlated. The correlation is found to be stronger in summer than in winter except in case of

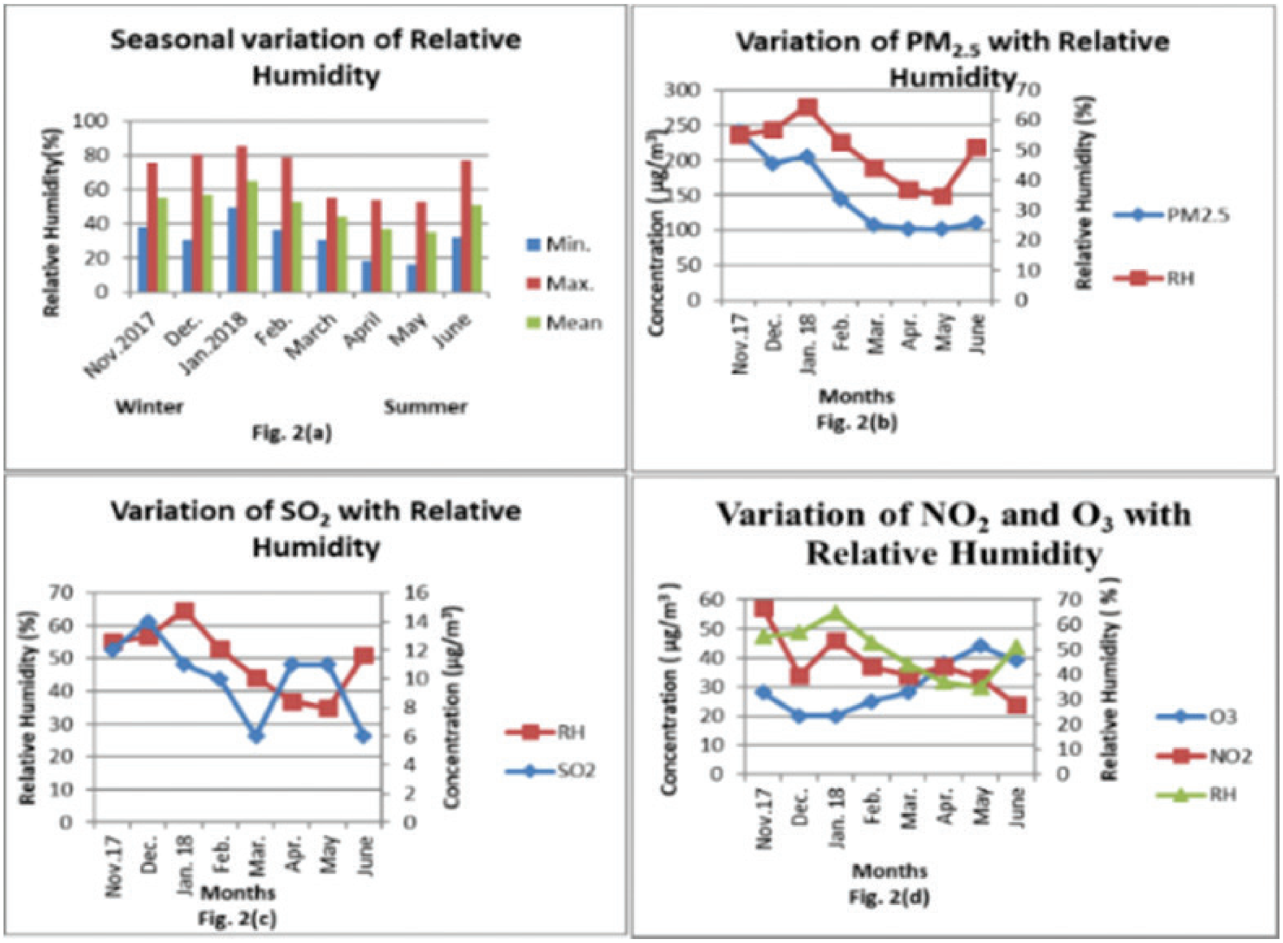

Figure 2: Seasonal variation of (a) relative humidity, (b) $PM_{2.5}$ with relative humidity, (c) SO_2 with relative humidity, (d) NO_2 and O_3 with relative humidity.

O_3, where the correlation is weak in summer (r^2=0.218) than in winter (r^2=0.439). It is because, increase in humidity in the atmosphere reduces the amount of solar radiations reaching the earth surface, thereby reducing the up going air current and hence increase in pollutants concentration (Ramasamy et al., 2013). Relative humidity affects the air quality by affecting the flux of utraviolet radiation, by favouring the reaction of the NO_2 with particles of sodium chloride salt, and in creating secondary aerosols such as sulphate and nitrate ions, which contribute positively to particulate concentration (Duenas et al., 2002; Sharma and Sharma 2016).

Variations and Correlation of Rainfall with Concentration of $PM_{2.5}$, NO_2, O_3 and SO_2

The variations in rainfall with concentration of $PM_{2.5}$, NO_2, O_3 and SO_2 were analyzed and are presented in Figure 3(a-d) and the results of regression analysis are presented in Table 1.

The rainfall ranged from 0 to 7.4 mm in winter and 26.0 to 75.0 mm in summer. The minimum rainfall (6.0 mm) is recorded in the month of January 2018 and maximum (75 mm) in the month of June 2018. The monthly mean rainfall recorded from November 2017 to June 2018 is depicted in Figure 3(b).

It can be seen that $PM_{2.5}$ shows positive correlation and NO_2, SO_2 and O_3 shows negative correlation with rainfall and this correlation is weak in winter than in summer. The positive correlation of rainfall with $PM_{2.5}$ is observed to be poor (r^2 = 0.008) in winter and strong in summer (r^2 = 0.984; $PM_{2.5}$ = 0.175 RF + 9.684). It may be due to poor rainfall in winter and weak rainfall in summer because the effect of rain events does not always result in lower average $PM_{2.5}$ concentrations, especially if the rain event is not particularly strong. The emission somewhat negates the washout effect of precipitation (Zalakeviciute et al., 2018).

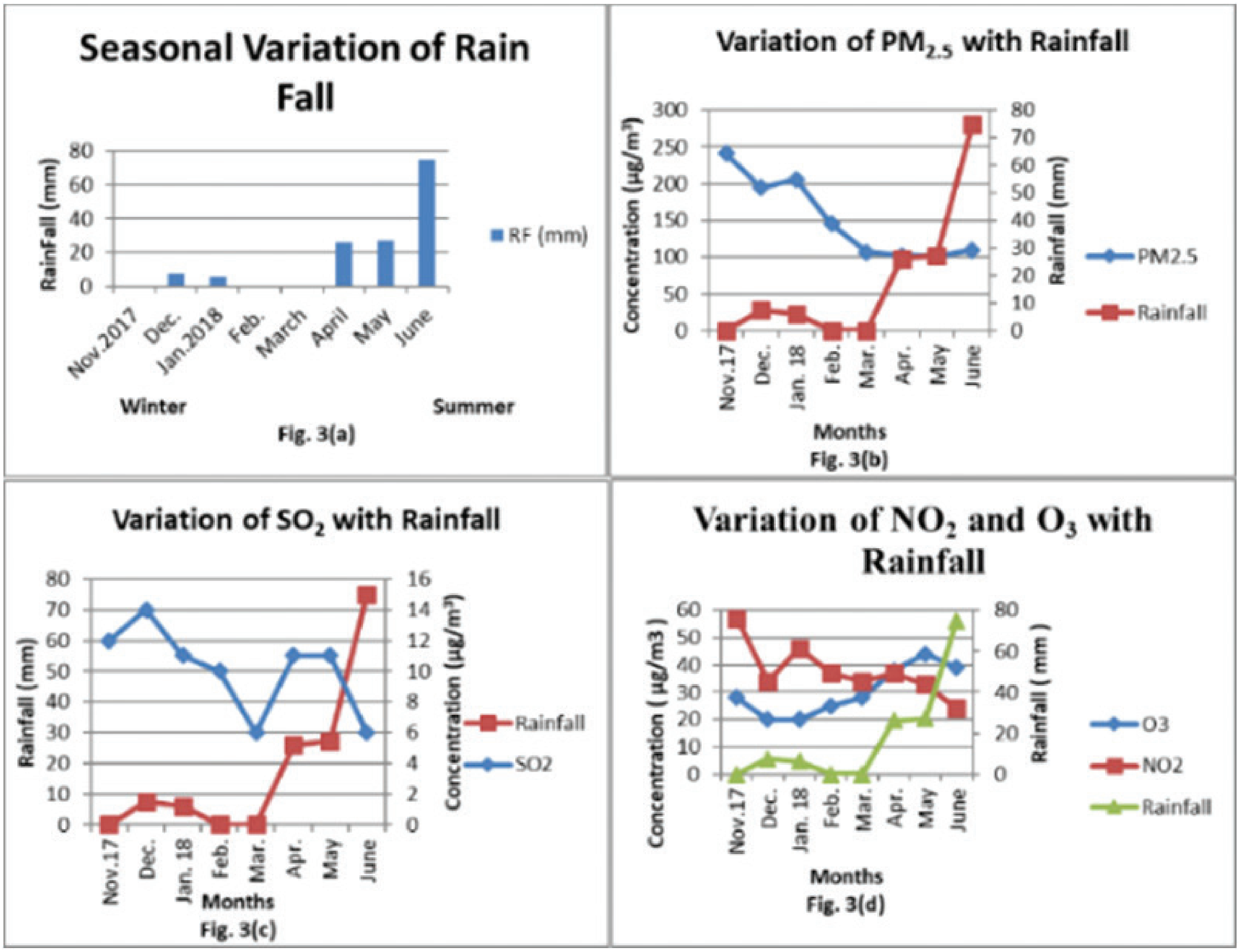

Figure 3: Seasonal variation of (a) rainfall, (b) $PM_{2.5}$ with rainfall, (c) SO_2 with rainfall, (d). NO_2 and O_3 with rainfall.

Variations and Correlation of Wind Speed with Concentration of $PM_{2.5}$, NO_2, O_3 and SO_2

The wind speed variations with concentration of $PM_{2.5}$, NO_2, O_3, and SO_2 were analyzed and are presented in Figure 4(a-d) and the results of regression analysis are presented in Table 1.

The wind speed ranged from 1.83 to 3.09 m s^{-1} in winter and 2.84 to 3.4 m s^{-1} in summer. The monthly minimum, maximum and mean values of wind speed recorded from November 2017 to June 2018 are depicted graphically in Figure 4(b).

The regression analysis reveals that in winter $PM_{2.5}$, NO_2, SO_2 and O_3 are negatively correlated with wind speed. The degree of correlation based on coefficient of determination is found as $PM_{2.5}$ (r^2 = 0.913), SO_2 (r^2=0.425), NO_2 (r^2 = 0.414) and O_3 (r^2 = 0.041). In summer, NO_2, SO_2 and O_3 are negatively correlated, but $PM_{2.5}$ is positively correlated with wind speed. O_3 is found to be weakly correlated (r^2 = 0.311) and $PM_{2.5}$ is found to be strongly correlated (r^2 = 0.985; $PM_{2.5}$ = 16.705 WS + 53.047). The negative correlation may be due to horizontal dispersion of the pollutants in the study area. The positive correlation of $PM_{2.5}$ in summer may be due to rising particles from surface and roadside areas, and addition of pollutants in the ambient air from the surrounding areas as the wind from the surrounding areas can bring pollutants to the region (Dave and Aggarwal, 2018; Trivedi et al., 2014).

Variations and Correlation of Mixing Height with Concentration of $PM_{2.5}$, NO_2, O_3 and SO_2

The variations in mixing height with concentration of $PM_{2.5}$, NO_2, O_3 and SO_2 were analyzed and are presented in Figure 5(a-d). The results of regression analysis are presented in Table 1.

The mixing eight ranged from 478.03 to 685.92 m in winter and 707.25 to 749.57 m in summer. The monthly minimum, maximum and mean values of mixing height recorded from November 2017 to June 2018 are depicted graphically in Figure 5(b).

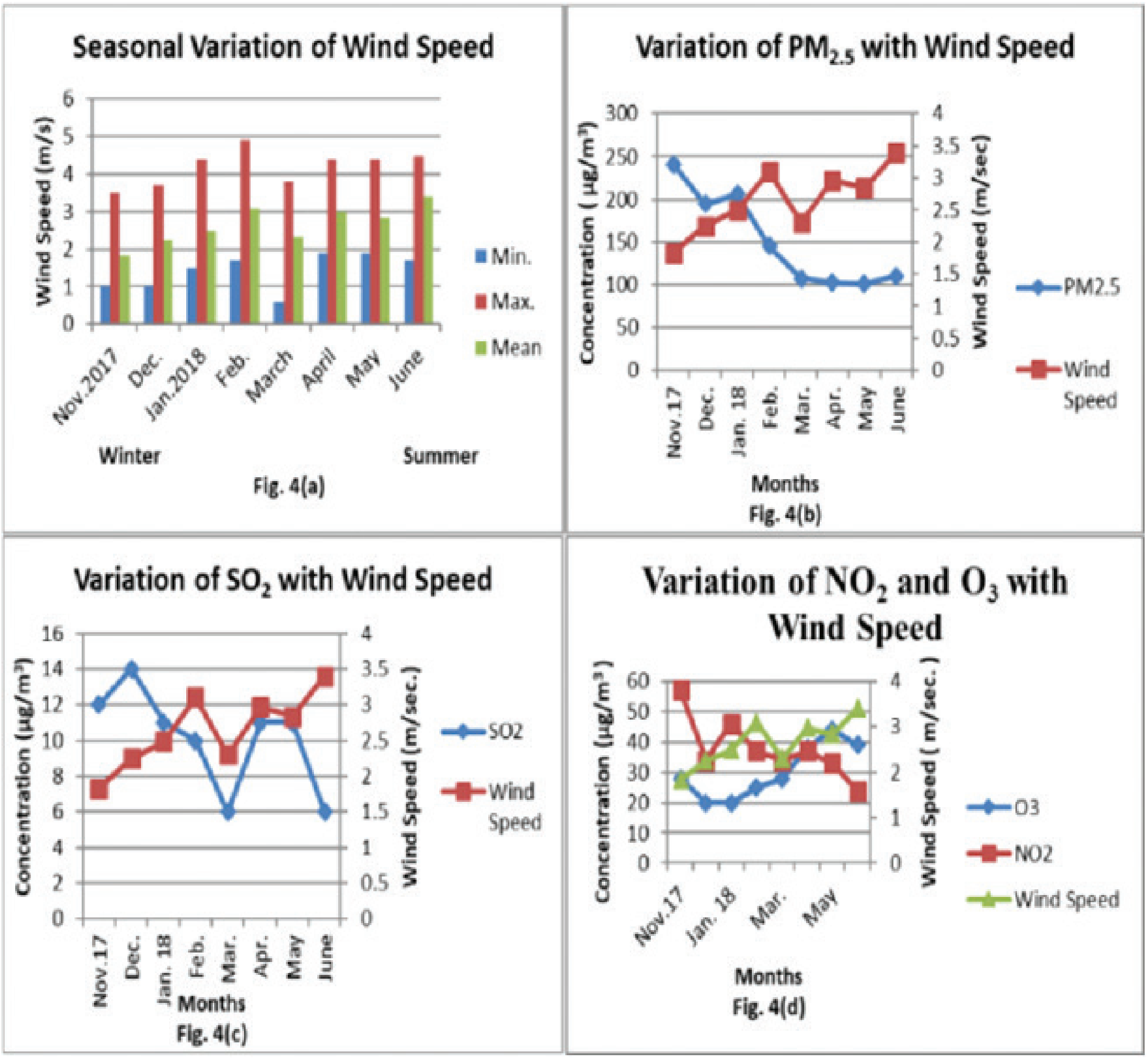

Figure 4: Seasonal variation of (a) wind speed, (b) $PM_{2.5}$ with wind speed, (c) SO_2 with wind speed, (d) NO_2 and O_3 with wind speed.

The regression analysis reveals that in winter $PM_{2.5}$, SO_2 and O_3 are negatively correlated with mixing height, whereas in summer $PM_{2.5}$ and O_3 are negatively correlated, but SO_2 and NO_2 are positively correlated with mixing height. In summer, O_3 is found to be independent of Mixing Height and NO_2 is found to be highly relatable (r^2=0.781; NO_2 = 0.268 MH + 16.218). In summer, the relation of $PM_{2.5}$, NO_2 and SO_2 with mixing height (Figure 5b-d) is observed to be opposite to that of relative humidity (Figure 2b-d) and wind speed (Figure 4(b-d)). Soni Kirti et al, (2014) observed positive correlations between Mixing Height and NO_2, SPM suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM) concentrations whereas negative correlation has been found for SO_2 concentrations in Delhi. It is because the mixing height is mostly affected by other meteorological parameters such as temperature, relative humidity and wind speed. Both temperature and wind speed positively influences the mixing heights during the winter and summer seasons. The variation in surface temperature controls the existence of atmospheric convection; therefore, it strongly affects the mixing height. This is an indicative, explaining the variation in mixing height regulating the concentration of pollutants. In another study, it has been found that when the Mixing Height decreases, the concentration of atmospheric particles increases (Tang et al., 2015); however, they are not strongly correlated (Li et al., 2015).

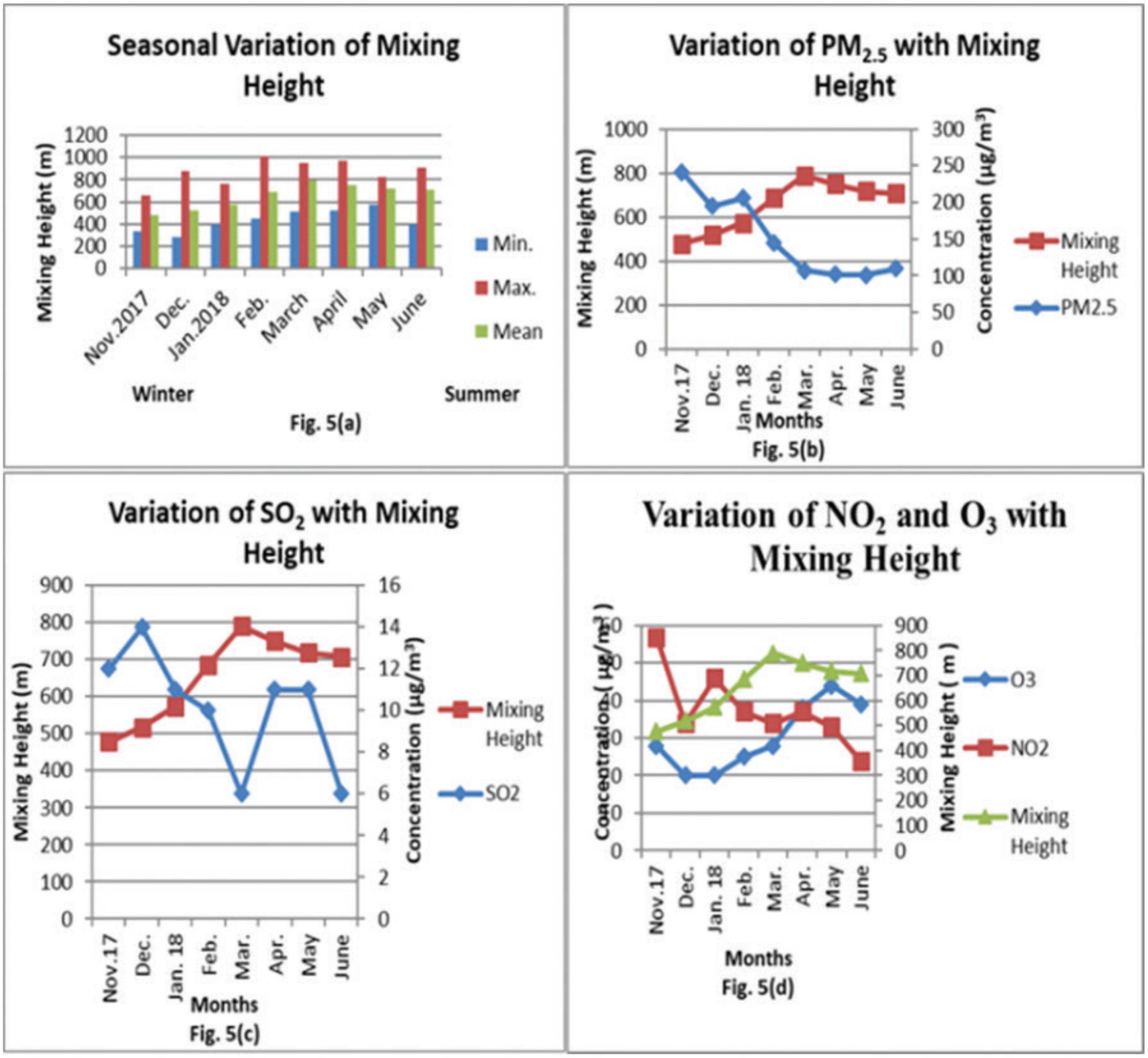

Figure 5: Seasonal variation of (a) mixing height, (b) $PM_{2.5}$ with mixing height, (c). SO_2 with mixing height, (d) NO_2 and O_3 with mixing height.

The variability of $PM_{2.5}$, NO_2, SO_2 and O_3 with meteorological variables such as temperature, relative humidity, rainfall, wind speed and mixing height has been investigated for the period ranging from November 01, 2017 to June 30, 2018 at NSIT location, Dwarka in Delhi, using regression analysis and the main findings are concluded as follows:

(i) The correlation coefficients between pollutants and meteorological variables are higher in summer than in winter, which indicates that the influence of temperature, relative humidity, rainfall and wind speed on the concentration of $PM_{2.5}$, NO_2, SO_2 and O_3 are much more effective in summer than in winter months.

(ii) In winter months, the wind speed and mixing height have strong impact on $PM_{2.5}$ and a moderate impact on NO_2 and SO_2. The impact of mixing height on O_3 is found to be poor.

(iii) A statistically significant negative correlation was found between air pollutants under study (except $PM_{2.5}$ in summer) and wind speed in winter and summer months. This suggests that wind speed is much more effective in lowering these pollutant levels in the study area.

The results of this study would not only help us to understand the existing pollutants and their interaction with meteorological variables, but also, provide solution to shield the environment in the regions being developed as smart city in India.

Acknowledgement

The author is very grateful to Shree Guru Gobind Singh Tricentenary (SGT) University for providing an excellent research environment, infrastructure facilities, encouragement and support to carry out this study. The author thanks the Central Pollution Control Board for providing $PM_{2.5}$, NO_2, SO_2 and O_3 data for the measuring site and Indian Meteorological Department for providing Meteorological data.

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