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The relationships between meteorological parameters and air pollutants in an urban environment

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ABSTRACT

Meteorological parameters play a significant role in affecting ambient air quality of an urban environment. As Dhaka, the capital city of Bangladesh, is one of the air pollution hotspot among the megacities in the world, however the potential meteorological influences on criteria air pollutants for this megacity are remained less studied. The objectives of this research were to examine the relationships between meteorological parameters such as daily mean temperature (°C), relative humidity (%) and rainfall (mm) and, the concentration of criteria air pollutants (SO_2, CO, NOx, O_3, $PM_{2.5}$ and PM_{10}) from January, 2013 to December, 2017. This study also focused on the trend analysis of the air pollutants concentration over the period. Spearman correlation was applied to illustrate the relationships between air pollutants concentration and temperature, relative humidity and rainfall. Multiple linear and non-linear regressions were compared to explore potential role of meteorological parameters on air pollutants' concentrations. Trend analysis resulted that concentration of SO_2 is increasing in the air of Dhaka while others are decreasing. Most of the pollutants resulted negative correlation with atmospheric temperature and relative humidity, however, they showed variable response to seasonal variation of meteorological parameters. Regression analysis resulted that both the multiple non-linear and linear model performed similar for predicting concentrations of particulate matters but for gaseous pollutants both model performances were poor. This research is expected to contribute in improving the forecast accuracy of air pollution under variable meteorological parameters considering seasonal fluctuations.

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INTRODUCTION

Air pollution in urban area is a major and growing environmental concern in developing countries that poses a significant impact on global public health such as cardiovascular and respiratory illness (Azad and Kitada, 1998; Mayer, 1999; Cohen *et al.,* 2017; Manju *et al.* 2018; Orioli *et al.,* 2018). Different anthropogenic activities for instances, fossil fuel combustion, i.e., natural gas, coal and oil to power industrial processes, motor vehicles, brick kiln and industrial operations are the primary sources of pollutants that cause air quality deterioration (Begum *et al.,* 2008). In addition, rapid urban population growth combined with changes in land uses due to urban expansion is among the main driving forces of urban air quality deterioration in developing countries (Mayer, 1999). Consequently, the air quality of urban areas, both indoor and outdoor, is deviating from its standard condition. Thereby, large numbers of urban residents are being exposed to this harmful air pollutants and related health risks on a continuous basis. According to WHO, about 98% of cities in low and middle income countries do not satisfy air quality guidelines and more than 80% people living in urban areas are exposed to the air having pollutants level over WHO standards (Manju *et al.*, 2018). About 7 million deaths have been noted worldwide due to air pollution in 2012; where 4.2 million deaths were related to exposure to outdoor air pollution (WHO, 2014). Again, outdoor air pollution contributes to 3.3 million premature deaths worldwide per year and it is predicted that this number will double by 2050 if the problem is not addressed accordingly (Lelieveld *et al.*, 2015). Rapid industrialization and urbanization have contributed to the major growth of population and economic development in the urban areas around the world (Begum *et al.,* 2010; Krzyzanowski *et al.,* 2014). It is projected that population in the world will reach 9.3 billion by 2050 where major growth be taken placed in urban areas (Gurjar *et al.,* 2016). Bangladesh is no exception of that as more than one-third of the total population reside in urban areas and it is forecasted to be increased as country's half of population will be migrated in urban areas by 2050 (Begum *et al.,* 2018). Among all cities in Bangladesh, Dhaka, is one of the 20 megacities in the world and ranked the first in terms of population density (Islam *et al.,* 2015). In Dhaka, there have been eightfold increase in population since 1970 and it is likely to become third largest city by 2020 with a total population approximately 20 million (Begum *et al.,* 2018). Currently having more than 18 million inhabitants, Dhaka is facing worst air pollution problems among the megacities of the world and the quality of ambient is deteriorating every day (Krzyzanowski *et al.,* 2014). Problems associated with air pollution have been enhanced due to the increasing number of automobiles and other anthropogenic activities such as industrial operations, urban constructions and adjacent brick kilns around the city (Begum *et al.,* 2008; Begum *et al.,* 2018). In addition, population density is one of the other reasons responsible for poor air quality since there has a high influx of people from rural areas. Meteorological parameters are one of the important factors to influence the urban air quality (Dey *et al.,* 2017; Zhang *et al.,* 2018; Manju *et al.,* 2018). Among them, temperature, relative humidity and wind speed and direction are considered as major factors because they may affect the dispersion process, removal mechanisms and formation of atmospheric particles (Goyal and Chalapati Rao, 2007; Zhang *et al.,* 2015), thus, play a significant role in controlling the concentrations of air pollutants. In addition, rainfall may also have variable impact on concentration of air pollutants by removal of gaseous pollution and deposition of particulate matters through the atmospheric chemical processes (Fisher, 1982; Shukla *et al.* 2008). Several studies have reported the potential influence of meteorological parameters to ambient air quality (Alpert *et al.,* 1998; Giri *et al.,* 2008; Galindo *et al.,* 2011; Owoade *et al.,* 2012; Dominick *et al.,* 2012; Zhang *et al.,* 2015; Islam *et al.,* 2018). Bangladesh is a country of subtropical monsoon climate with seasonal variations of temperature, rainfall and humidity. Air quality of the country is also varied with seasonal variations (Islam *et al.,* 2015). According to national standards, the daily particulate matters ($PM_{2.5}$ and PM_{10}) exceed the optimum limit during dry season, whereas it has been reported slightly lower during monsoon. Meteorological influence has been addressed widely in several studies in China (Li *et al.*, 2014; Zhang *et al.*, 2015; Yin *et al.*, 2016; He *et al.*, 2017) and India (Jayamurugan *et al.*, 2013; Ojha *et al.,* 2015; Manju *et al.*, 2018) but it is understudied in Bangladesh although seasonal variations in relation to meteorology may have variable effects on air pollutants concentration. The objectives of this study were to draw a systematic analysis to investigate the relationships between the concentration of air pollutants i.e., Sulfur dioxide (SO_2), Carbon-mono-oxide (CO), Nitrogen oxides (NOx), Ozone (O_3), $PM_{2.5}$ and PM_{10} and meteorological parameters (temperature, rainfall and relative humidity), analyze the seasonal variations of the concentration of air pollutants' and to conduct a time series analysis of the concentration of air pollutants in Dhaka city. This study has been carried out in Dhaka City, Bangladesh in 2018.

MATERIALS AND METHODS

Study area

Dhaka is located in the central part of the country (23°41'N latitude and 90°22'E longitude) lying on the lower reaches of Ganges Delta. It covers a total area of 306.38 km^2. Dhaka is vulnerable to flooding in heavy rainfall and a cyclone during rainy season due to its topographical condition as it is flat and close to sea level. The city is surrounded by Gazipur, Tangail, Munsiganj, Narayanganj and Rajbari districts. This study utilized continuous air quality data from three Continuous Air Monitoring Stations (CAMS) in Dhaka namely Parliament area (CAMS1), Bangladesh Agricultural Research Council (BARC, Farmgate Area, CAMS2) and Darus Salam (Mirpur, CAMS3) established by DoE, MoEFCC, Governtment of Bangladesh under the Clean Air and Sustainable Environment (CASE) project. Fig. 1 shows the map of study area with continuous air pollutants monitoring stations installed in Dhaka city.

Data collection

Air quality data consisted of daily mean concentration of six criteria air pollutants such as PM_{10} (µg/m^3), $PM_{2.5}$ (µg/m^3), NO_x (µg/m^3), CO (ppm), O_3 (µg/m^3), and SO_2 (µg/m^3) over the period of January 2013 to December 2017 were collected from Clean Air and Sustainable Development (CASE) project, Ministry of Environment, Forest and Climate Change, Government of Peoples Republic of Bangladesh. CASE records concentrations of air pollutants of Dhaka hourly from three continuous air monitoring stations

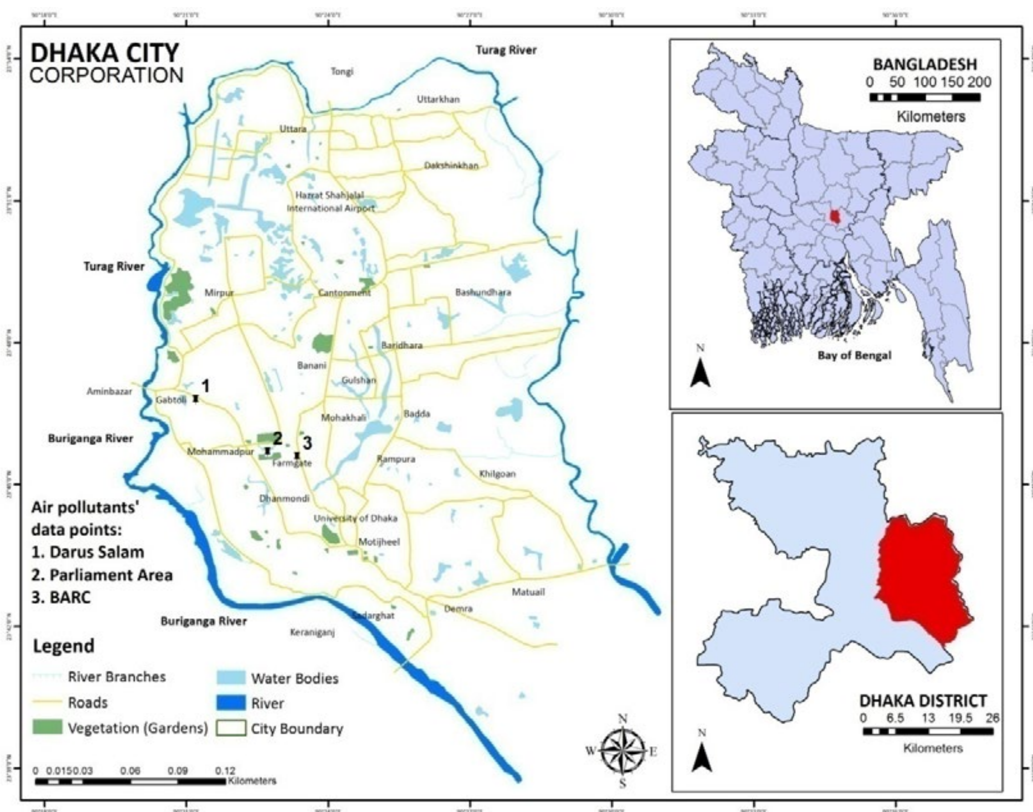

Fig. 1. The geographic location of the study area showing the Continuous Air Monitoring Stations (CAMS) installed in Dhaka City, Bangladesh

indicated in Fig. 1. For measuring concentrations of $PM_{2.5}$ and PM_{10} an automatic and real time suspended particulate monitor (Beta Gauge 101M; ENVIRONMENT SA, France) was installed in each three stations. Chemiluminescence gas analyzer AC32M and UV-Fluorescence AF22M (TELEDYENE/API, USA) were used to monitor concentrations of NO_x and SO_2 respectively. For measuring O_3 an UV photometric Ozone analyzer-42M and a Dispersive Infra-Red carbon monoxide analyzer-12M (ENVIRONMENT SA, France) was used to measure concentration of CO from all three CAMS installed in Dhaka. The air quality data generated at the monitoring stations are centrally retrieved into Central Data Station at the DoE Head Office using EnVIEW 2000 software and as SQL database. Quality assurance and Quality control is an essential part of the CASE air quality monitoring system. CASE routinely performs calibration, servicing and repair of instruments. Calibration of the analyzers is performed using NIST traceable calibration gases usually quarterly or after repair. Particulate monitors based on beta gauge attenuation are calibrated using standard foils of known areal mass density. While processing the data were checked for outliers and if 75 % of the data in a day were not available for any parameter due power failure or equipment's nonoperational, values were considered as non-representative and excluded from analysis. Missing data were dealt with pair-wise deletion method during the data exploration in XLSTAT. Meteorological variables (Temperature, relative humidity and rainfall) consisted of daily mean for the same time periods were collected from Bangladesh Meteorological Department (BMD).

Data analysis

At first, descriptive statistics were calculated for both air pollutants and meteorological data. Spearman correlation method was used to determine significant correlation between the air pollutants and meteorological data from January 2013 to December 2017. Mann Kendall (MK) trend test was used to identify the patterns of air pollutants concentration for the same time period. Seasonal differences among the concentration of air pollutants across the years were tested using Tukey's HSD multiple comparison at 5 % level of significance. After that, Bartlett's test was applied to investigate the seasonal homogeneity of pollutants concentration across the years. Based on significant homogeneity among the seasonal temperature and relative humidity data across the years, spearman correlation coefficient was calculated to determine relationships between the air pollutants and, temperature and relative humidity. Due to heterogeneous nature of rainfall data during monsoon season across the years (Bartlett's *p*-value = 0.000001), correlation between rainfall and air pollutants was established across the years separately. Seasonal classification in this research was adopted from Azad *et al.* (1998) and Salam *et al.* (2003) such as pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February). Finally, multiple linear and non-linear (polynomial) models were compared to investigate potential effects of temperature and relative humidity on air pollutants' concentration (non-linear model is shown in Eq. 1). For regression analysis rainfall was discarded from the models because of negligible influence on model performances. Yin *et al.* (2016) also considered only temperature and relative humidity as explanatory variables to estimate daily particulate matter concentration in Beijing, China.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1^2 + \beta_4 X_2^2 \quad (1)$$

Here, β_0 is the model constant $\beta_1, \beta_2, \beta_3,$ *and* β_4 are the model parameters, *Y* is the dependent variables

Table 1. Summary statistic of criteria air pollutants based on daily mean and meteorological parameters during January 2013 to December 2017 in Dhaka city

Statistic	SO_2 (µg/m³)	CO (ppm)	NO_x (µg/m³)	O_3 (µg/m³)	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	Temp*	RH*	RF*
Minimum	0.4454	0.29	3.95	0.36	7.07	15.52	10.4	34	0
Maximum	236.114	7.488	594.48	92.78	307.44	617.85	34.4	97	149
Median	16.113	1.82	93.29	10.99	56.07	105.3	27.6	73	0
Mean	23.635	1.999	126.53	14.70	80.81	144.397	26.33	72	5.13
SD	24.003	0.97	98.24	11.03	61.96	103.11	4.11	11	14.3
SE	0.5634	0.027	2.41	0.268	1.46	2.45	0.10	0.26	0.33

*Temp= Temperature (^{0}C), RH= Relative humidity (%), RF= Rainfall (mm) (pollutants) and X_1 and X_2 are the independent variables (temperature and relative humidity respectively). Lilliefors test was applied to normality test of the air pollutants and meteorological parameters. All statistical analysis was performed by using statistical software R (version 3.4.4) and XLSTAT (version 14).

RESULTS AND DISCUSSION

Descriptive statistics

Table (1) shows the summary statistics of air pollutants' data during January 2013 to December 2017 in Dhaka city. Overall, the mean concentration of SO_2, CO, NOx, O_3, $PM_{2.5}$ and PM_{10} ranged from 0.4454 to 236.1144 µg/m^3, 0. 2977 to 7.4883 ppm, 3.9537 to 594.4875 µg/m^3, 0.36 to 92.78 µg/m^3, 7.07 to 307.44 µg/m^3, 15.52 to 617.85 µg/m^3 respectively from 2013 to 2017. On the other hand, meteorological parameters i.e., temperature and relative humidity ranged from 10.4 to 34.4°C and 34 to 97 % respectively.

Trends of concentrations of air pollutants and meteorological variables during 2013 to 2017

Overall trends of all six criteria air pollutants concentration and meteorological parameters considered for this study (temperature, rainfall and relative humidity) from January 2013 to December 2017 in Dhaka is illustrated in Fig. 2. A fluctuating trend is evident throughout the study period for all air pollutants concentration as well as in meteorological parameters (Fig. 2). To investigate the trends (increasing or decreasing) of air pollutants concentration change over time Mann-Kendall (MK) trend test was applied in this study. Moreover, to emphasize the results from the MK test, homogeneity test was also used. Table 2 shows the overall results from the MK trend test.

Since null hypothesis of MK test was there was no trend of air pollutants' concentration over the study period and the computed p-values were lower than the significance level alpha= 0.05, the study rejected the H_o and accepted the alternative hypothesis. Except SO_2, the risk to reject the H_o while it was true was lower than 0.01% for other pollutants. From the Table 2, it was clear that, all the variables showed a trend over the period. Among the pollutants, all five pollutants concentration showed a decreasing trend; in contrast, SO_2 had an increasing trend over the period. The illustration of the MK test is displayed in Fig. 3.

Comparison of regression models

This research compared between multiple linear regression and nonlinear regression to determine potential effects of meteorological parameters on air pollutants concentration. Coefficient of determination (R^2) was calculated for models to examine the performances. Table (3) presents the comparison of the two models where multiple non-linear regression (MNLR) models performed better than the linear model. In both cases, variations in CO concentration was least explained by temperature, rainfall and humidity (R^2 = 0.15 and 0.20 respectively) whereas, variations in concentration of $PM_{2.5}$ explained best by the meteorological parameters (R^2 = 0.72 and 0.73 respectively). Yin *et al.* (2016) also reported better performance of MNLR models in explaining concentration $PM_{2.5}$ in relation to meteorological parameters in China. Both MLR and MLNR resulted similar R^2 value for PM_{10} (R^2 = 0.63) while considering all three meteorological parameters as independent variable in the model. However, no model performed well for O_3. On the other hand, NOx exhibits better relation with the meteorological parameters than SO_2. Overall, R^2 values ranges from 0.15 to 0.72 for MLR and 0.19 to 0.73 for MNLR (Table 3), similarly, Wise and Comrie, (2005) reported coefficients of determination values 0.1 to 0.5 while modeling effects of meteorological values on particulate matters in air in US.

Seasonal variations of air pollutants concentrations

The variation in air pollutants concentrations based on Tukey's multiple comparison tests among different seasons across the years are illustrated in Fig. 4. According to the Tukey's multiple comparison tests there were no significant differences among the seasonal concentrations of SO_2, CO and NOx across the years. However, seasonal fluctuations among the pollutants were evident. Although the differences were not statistically significant, the minimum concentration of all air pollutants was observed during the monsoon season and maximum during winter. The maximum concentration of O_3 was observed during winter season in 2013 and it was significantly higher than the winter concentrations of 2014 and 2016. While considering seasonal variations

Table 2. MK trend test with 5% level of significance

Statistic	SO_2 (μg/m^3)	CO (ppm)	NO_x (μg/m^3)	O_3(μg/m^3)	$PM_{2.5}$(μg/m^3)	PM_{10}(μg/m^3)
Tau Value	0.0417	-0.0821	-0.1169	-0.2594	-0.1049	-0.0899
Sen's slope	0.002	-0.2658	-0.0296	-0.0082	-0.0159	-0.023
p-value	0.0145	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Test interpretation	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho	Reject Ho

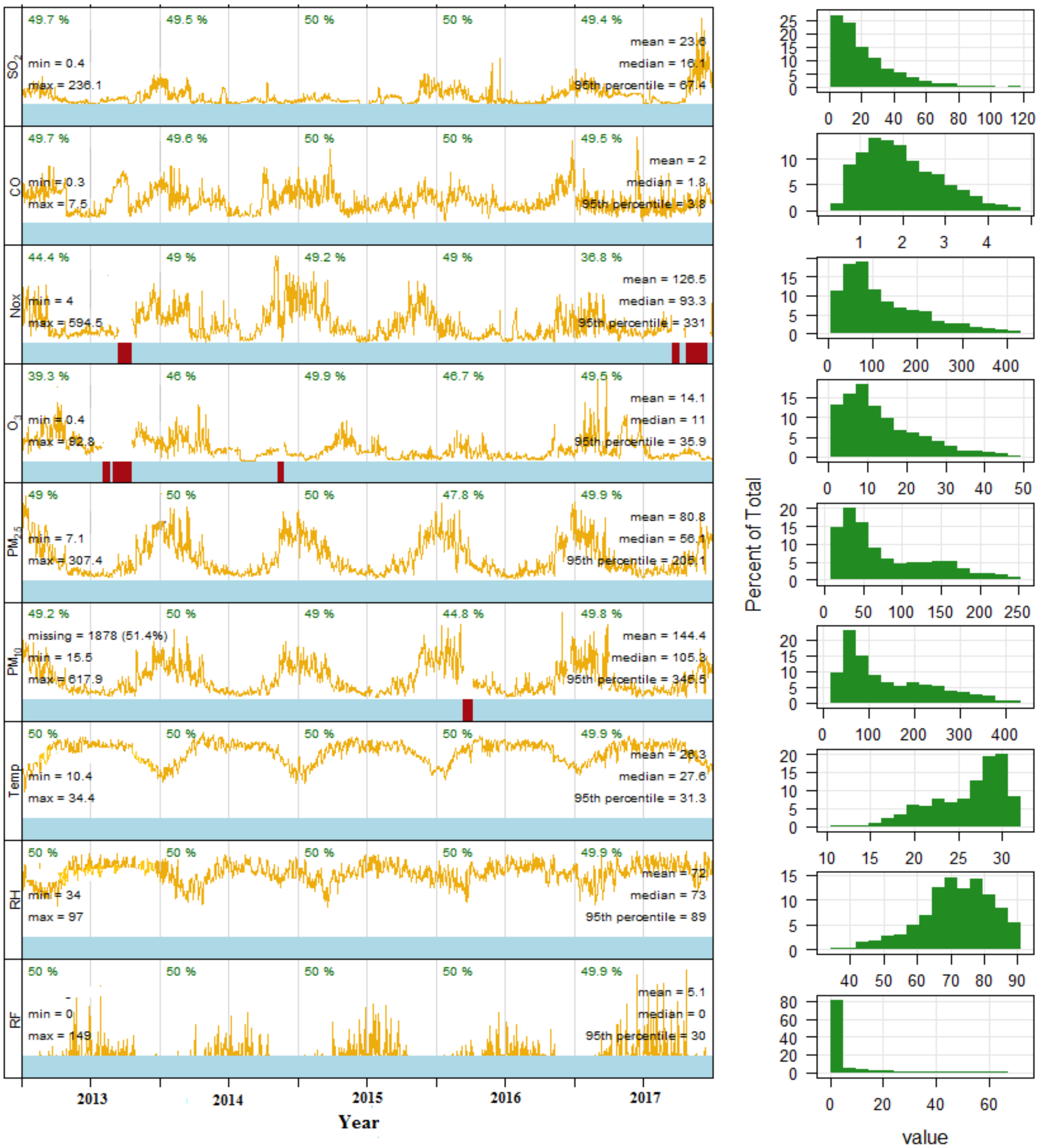

Fig. 2. Trends of air pollutants concentration and meteorological parameters from January 2013 to December 2017 in Dhaka

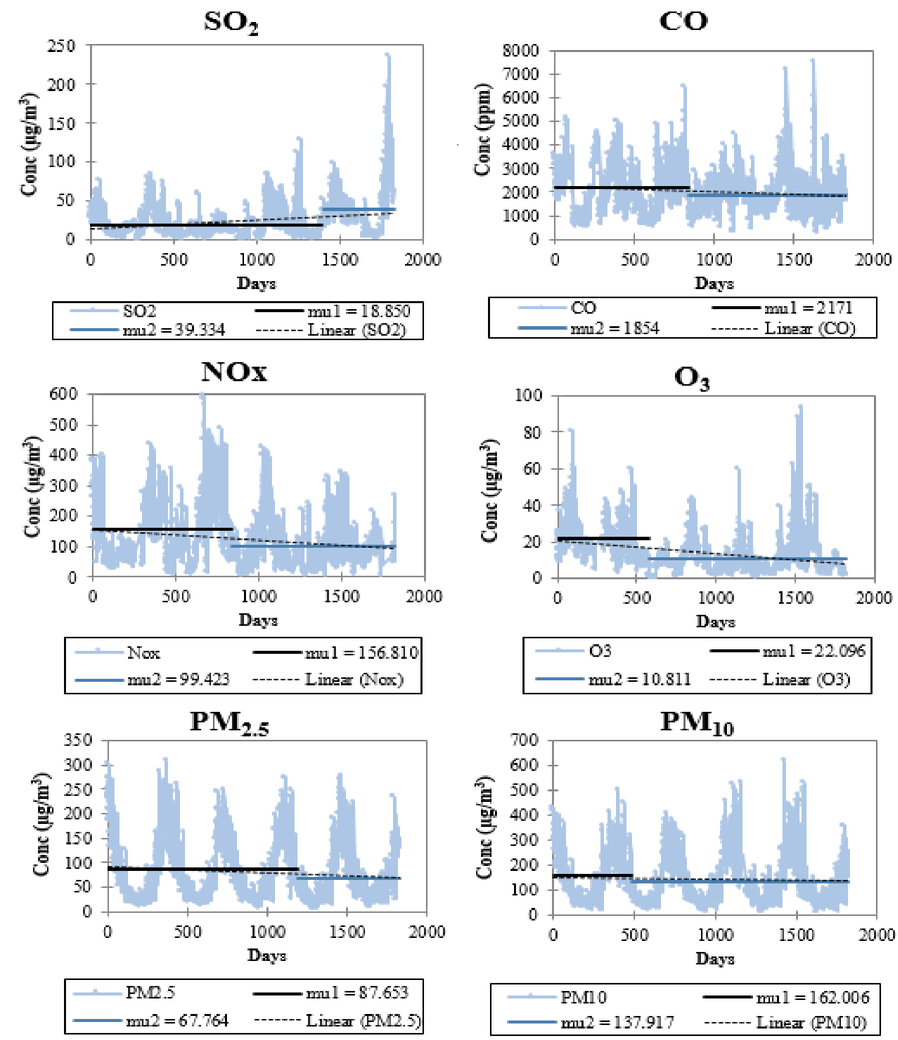

Fig. 3. MK trend analysis with homogeneity test among the concentration of air pollutants over study period

Table 3. Comparison of the results of multiple linear regression and non-linear regression model

Pollutants	MLR	R^2	MLNR	R^2
SO_2	$Y = 115.56-2.39X_1-0.4X_2$	0.2223	$Y = 44.7+2.4X_1-0.2X_2-0.09X_1^2-0.002X_2^2$	0.32
CO	$Y = 5130-72.98X_1-16.78X_2$	0.1494	$Y = 3302+67.5X_1-7.5X_2-2.9X_1^2-0.09X_2^2$	0.19
NO_x	$Y = 564.65-11.16X_1-2.001X_2$	0.3233	$Y = -33.8+28.9X_1+2.3X_2-0.8X_1^2-0.03X_2^2$	0.37
O_3	$Y = 42.31+ 0.02X_1-0.4X_2$	0.1717	$Y = 52.7+1.4X_1-1.2X_2-0.03X_1^2+0.005X_2^2$	0.19
$PM_{2.5}$	$Y = 499.4-11.006X_1-1.8X_2$	0.7027	$Y = 451.8-19.1X_1+2.5X_2+0.2X_1^2-0.03X_2^2$	0.72
PM_{10}	$Y = 818.2-15.476X_1-3.696X_2$	0.6167	$Y = 499.8-7.8X_1+3.3X_2-0.15X_1^2-0.05X_2^2$	0.63

Here, Y= the concentration of pollutants, X1 = Temperature and X2 = Relative humidity

in case of particulate matters it is clearly evident that, mean concentration of $PM_{2.5}$ was significantly higher during the winter compared to monsoon seasons for all the years (Fig. 4). Maximum concentration of $PM_{2.5}$ was observed during the winter of 2014 compared to all other years. There was increase of fine particulate matter concentrations during post-monsoon every year. Though differences are minute but pre-monsoon concentrations of $PM_{2.5}$ across the years were lower than winter season but higher than

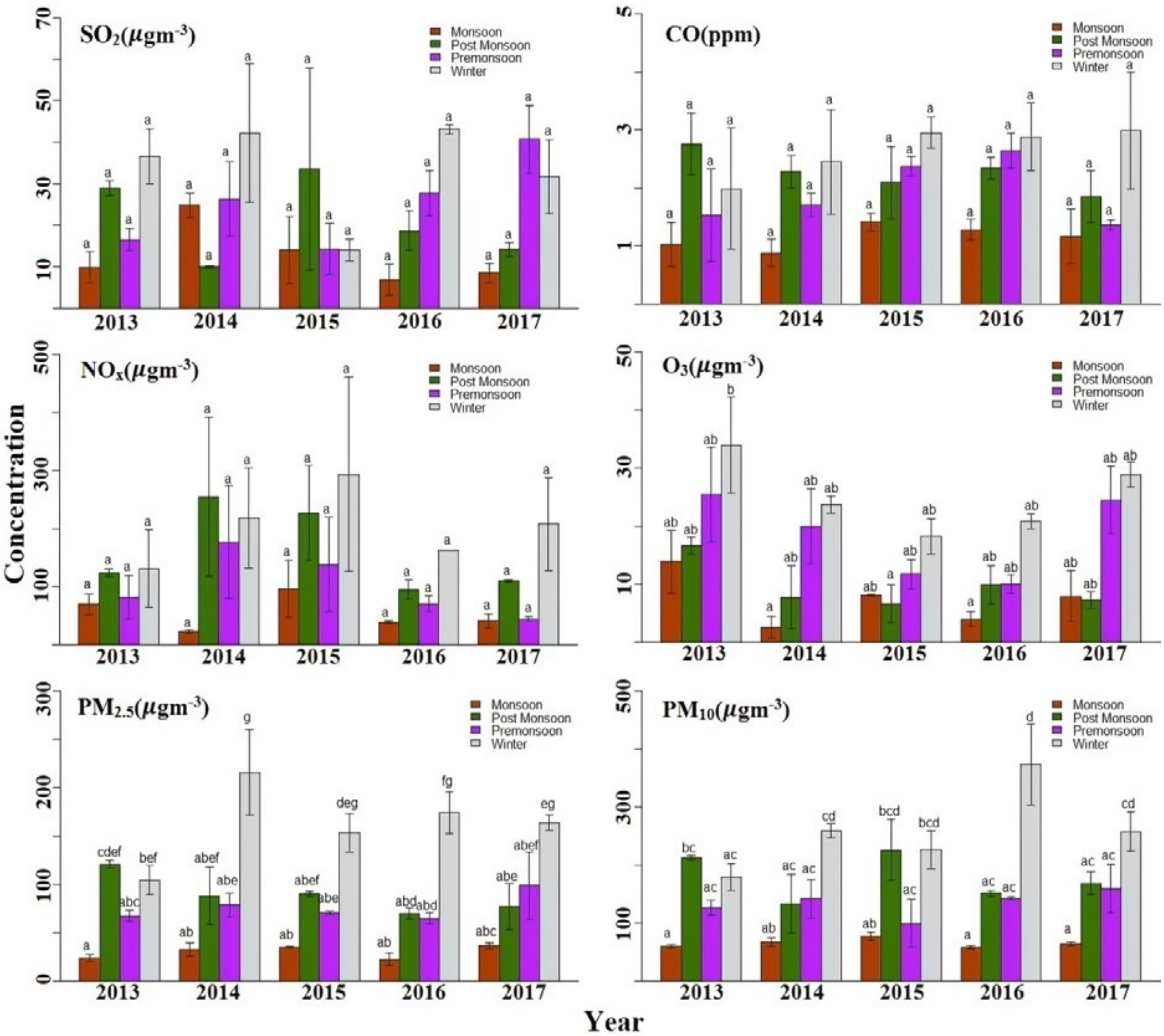

Fig. 4. Bargraphs showing seasonal variations of mean air pollutants concentration across the years. Different letters above the error bars denote significant differences at α≤0.05. Homogeneous subsets are not significantly different based on Tukey's HSD post-hoc test.

Table 4. Summary of season wise Spearman correlation coefficient (r) values between air pollutants and meteorological parameters (Values in bold are different from 0 with a significance level alpha=0.05)

MP*	Season	Air pollutants					
		SO_2	CO	NO_x	O_3	$PM_{2.5}$	PM_{10}
Temp*	Pre-Monsoon	-0.3175	-0.0795	-0.5088	-0.0361	-0.1718	-0.7104
	Monsoon	-0.0256	-0.1238	-0.0061	0.1318	0.0751	0.3549
	Post-Monsoon	-0.5526	-0.3152	-0.4908	-0.2677	-0.5621	-0.5201
	Winter	0.1309	-0.0324	-0.0654	0.0877	-0.3868	-0.1149
RH*	Pre-Monsoon	-0.3063	-0.4732	-0.3108	-0.2163	-0.6834	-0.1718
	Monsoon	0.0194	0.1442	-0.0208	-0.1348	-0.0005	-0.2660
	Post-Monsoon	-0.2183	-0.1532	-0.4570	-0.1917	-0.5264	-0.7065
	Winter	-0.1050	0.1914	-0.002	-0.3748	0.1811	-0.0253

*MP= Meteorological parameters, Temp= Temperature, RH= Relative humidity monsoon. Similarly, winter concentrations of PM_{10} were significantly higher in 2014, 2016 and 2017 than monsoon. Although differences were not significant, PM_{10} concentrations during monsoon in 2013 and 2015 were lower than winter (Fig. 4). The reasons for the seasonal fluctuations of the pollutants are not only caused by seasonal variations but also meteorological variable (Manju *et al.,* 2018). Brick kiln industries around the city are fully operational during winter. Moreover, urban construction activities, vehicular exhaust during dry winter and road dusts may contribute to higher concentration of pollutants. On the other hand, the wet deposition of particles is less significant than monsoon season (Azad *et al.,* 1998; Islam *et al.,* 2003).

Relationship between seasonal variations of meteorological parameters and air pollutants concentration

Relationship between seasonal variations of the concentrations of air pollutants with temperature and relative humidity was determined by using spearman correlation analysis with 5% significant level. Table 5 shows the correlations coefficients values. Fig. 5 represents graphical presentation of correlation between air pollutants concentration and seasonal temperature during pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February) while Fig. 6 shows graphical presentation of correlation between air pollutants concentration and seasonal relative humidity during pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February).

From Table 4 it is evident that, PM_{10} had strong negative correlation (r = -0.7104) with atmospheric temperature during pre-monsoon (March-May) and moderate negative correlation during post-monsoon (October-November). Similar observations were reported by Elminir (2005) and Giri *et al.* (2008). They argued that particulate matters made of mainly soil or road dusts absorbs water vapors from atmosphere and thereby deposits to the ground easily. Significant negative correlation between PM and temperature during pre-monsoon and monsoon indicate denser PM in the air may reduce atmospheric temperature as a result of net negative radiative forcing (Islam *et al.,* 2015). However, there was a moderate positive correlation (r = 0.35) between atmospheric

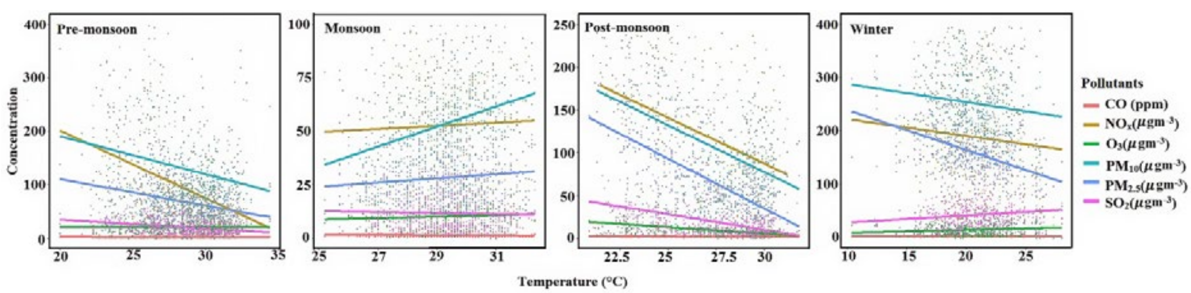

Fig. 5. Correlation between air pollutants concentration and seasonal temperature a) pre-monsoon (March-May) b) monsoon (June-September) c) post-monsoon (October-November) and d) winter (December-February)

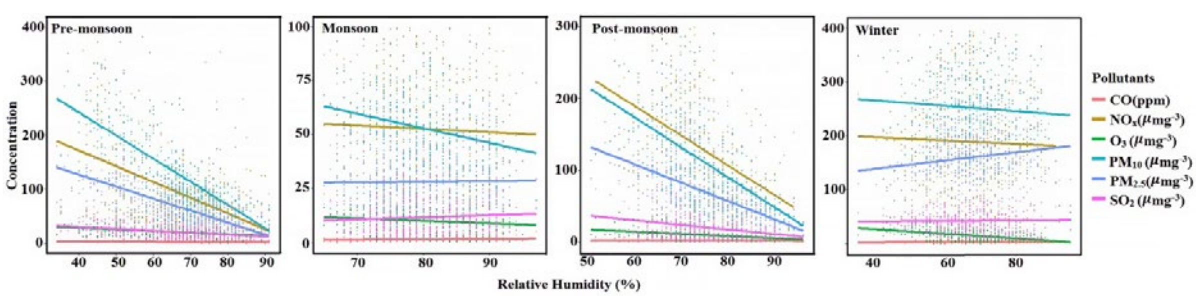

Fig. 6. Correlation between air pollutants concentration and seasonal relative humidity a) pre-monsoon (March-May) b) monsoon (June-September) c) post-monsoon (October-November) and d) winter (December-February)

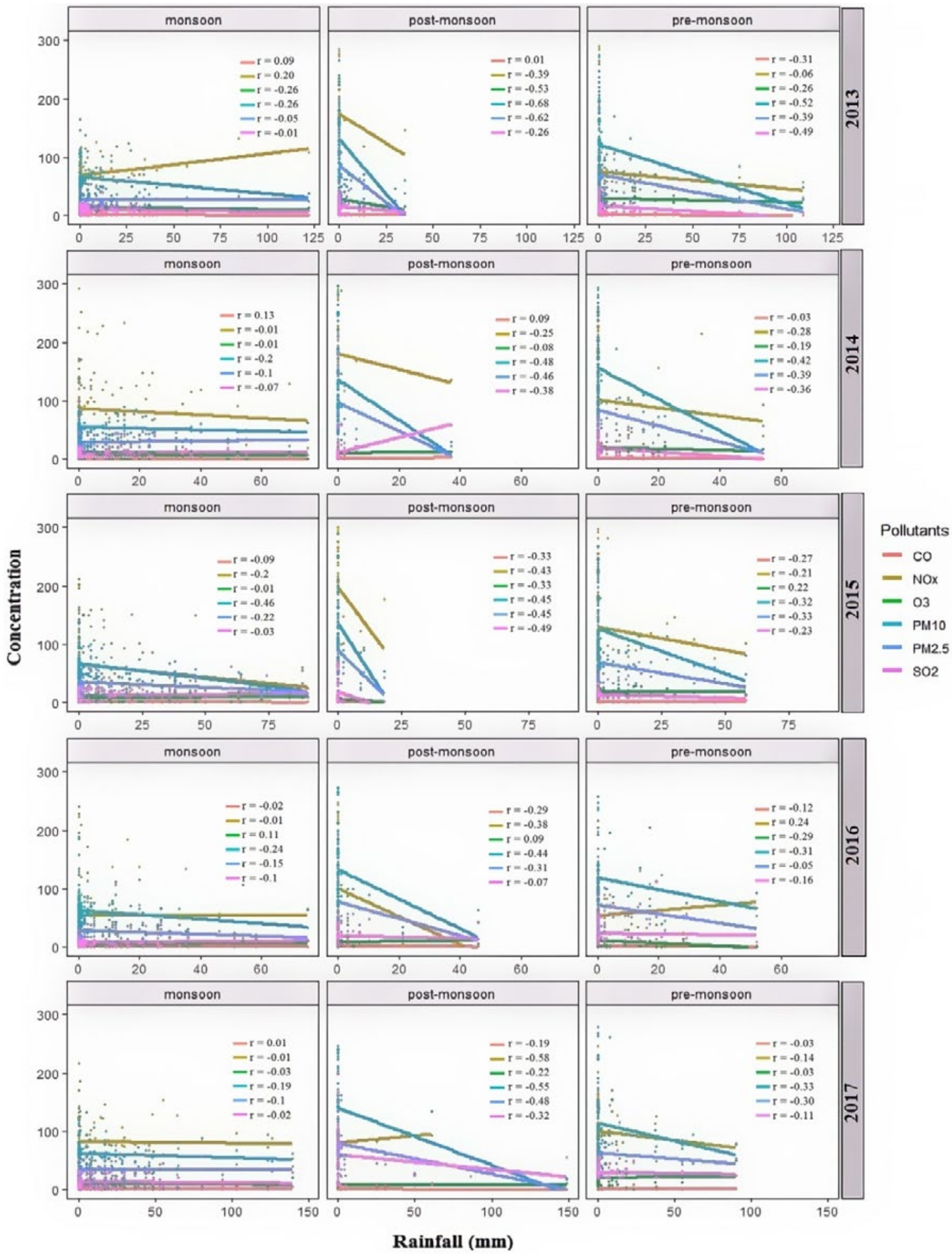

Fig. 7. Line plots showing correlation (*r*) between air pollutants concentration and rainfall during pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November) across the years

temperature and PM_{10} concentration during the monsoon season (June-September) (Table 4 and Fig. 6). Likewise, in case of fine particulate matter ($PM_{2.5}$), there were moderate correlations with atmospheric temperature (Table 4) during pre-monsoon, post-monsoon and winter but no relationship during monsoon (r = 0.07) (Fig. 6). Although this study reveals concentration of $PM_{2.5}$ and PM_{10} decreases to their minimum during monsoon season compared to others season of the year (Fig. 4), however, we found a positive correlation between atmospheric temperature and coarse particulate matter (PM_{10}) during monsoon (Table 4 and Fig. 5). This positive correlation between atmospheric temperature and coarse particulate matter (PM_{10}) during monsoon can be explained by climatic characteristics of monsoon season and interactions of these with air particulate matters. Monsoon season of Bangladesh is characterized by heavy rainfall, southern or south-western wind and high temperature (Salam *et al.,* 2003; Begum *et al.,* 2006). Due to rainfall in this season particulate matter in the air may deposit in the ground, however, it is possible to increase their concentration by drying up as a result of high summer temperature after rain. Again, high wind speed may also have combined effects with the temperature in this season. Tai *et al.* (2010) also reported positive correlation between fine particulate matters and temperature in US. Among other pollutants, SO_2 resulted a positive correlation (r = 0.1309) with temperature in winter (Table 4).

In case of relative humidity, most of the air pollutants concentration resulted negative correlation with relative humidity among the seasons (Table 4). Specifically, the concentration of coarse particulate matter PM_{10} resulted negative correlation during pre-monsoon, monsoon and post-monsoon (r = - 0.17, -0.26, -0.706 respectively) whereas, minimal or no correlation during winter (r = -0.02). For fine particulate matter $PM_{2.5}$ a positive correlation was resulted with relative humidity during winter season (r = 0.18) (negative in all other seasons, see Table 4 and Fig. 6). Because, relative humidity influences the particle movement and it can settle down particulate matters on the ground. Therefore, with increase of relative humidity the concentration of air pollutants become lower (Giri *et al.*, 2008). Likewise, our study found, in most cases, there were negative correlation with the concentration of particulate matters and relative humidity. However, a positive correlation between fine particulate matters ($PM_{2.5}$) with the humidity during winter implies that absence of rainfall during winter water vapors in the air may facilitates ventilation effects of $PM_{2.5}$. Moreover, Islam *et al.* (2015) suggested that, north-western wind during winter may transports more particulate matters from brick kilns located in that direction in Dhaka city. Again, most of the construction activities are carried out in winter due to favorable weather condition. While temperature was positively correlated with O_3 during the monsoon, but correlation between relative humidity and O_3 was negative across the seasons. Monsoon season in Bangladesh is characterized by high summer temperature also and the high temperature catalyzed complex chemical reactions in the atmosphere (Jacob and Winner, 2009; Han *et al.* 2011), thus, it my increase the concentration of O3 during summer monsoon season in Dhaka. In this research, the negative correlation between O_3 and relative humidity coincides with the studies of Swamy *et al.* (2012), Kumar *et al.* (2014) and Manju *et al.* (2018). Similarly, CO resulted positive correlation during monsoon and winter (r = 0.1403 and 0.1914 respectively) with relative humidity. Ojha *et al.* (2015) reported that CO and O_3 concentration during summer monsoon is higher than other season. Zang *et al.* (2015) also reported similar results in China and argued that wind direction significantly affects concentration of CO and O_3 in the air. According to Islam *et al.* (2015), wind from south-western direction blows over Bangladesh and Ojha *et al.* (2015) claimed that, these air pollutants could be transported from African region over Indian subcontinent by monsoon wind from south-western direction. During winter it is possible to emit more CO in the air from vehicular sources and thus, it shows positive correlation with humidity.

Fig. 7 illustrates the correlation between the pollutants' concentration and seasonal rainfall across the years. In case of rainfall data, winter season was not considered due to no or minimal rainfall (see Fig. 2). In 2013, 2014 and 2015 it showed significant negative correlation with rainfall and pollutants for pre-monsoon and post-monsoon season. However, in 2016 and 2017, it also shows negative but weak correlation comparatively for these two seasons. Among the pollutants, $PM_{2.5}$ and PM_{10} shows the highest response (in terms of negative correlation) with rainfall across the years. In 2015, the correlation coefficient values of PM_{10} and $PM_{2.5}$ with rainfall were the same (r= -0.26). Like 2013, it shows a better correlation for $PM_{2.5}$ and PM_{10} in 2015. However, the rest of the years for monsoon season did not show any significant correlation for other pollutants.

CONCLUSION

The study revealed that air quality of Dhaka city is highly polluted. However, concentrations of criteria air pollutants in Dhaka are slowly decreasing while SO_2 concentration is increasing. Despite presence of other air pollutants, $PM_{2.5}$ and PM_{10} showed negative relationship with temperature and relative humidity. While relationships of PM and temperature in all other seasons are negative, this research resulted positive relationship during monsoon season implied that high temperature with higher humidity during this season contribute to suspension of PM. However, among the seasons, concentrations of air pollutants were higher during winter season indicating dry air with lower humidity aggregates higher pollutants in urban environment. Current research used only temperature, relative humidity and rainfall as meteorological parameters to establish the relationships but effects of wind speed, wind direction and solar radiations on pollutants behaviors are well documented and thus, future research should include these variables to address the issue more efficiently.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

ABBREVIATIONS

%	Percent
$\mu g/m^3$	Microgram per cubic meter
BARC	Bangladesh Agricultural Research Council
BMD	Bangladesh Meteorological Department
CAMS	Continuous Air Monitoring Stations
CASE	Clean Air and Sustainable Development Project
CO	Carbon monoxide
E	East
h	Hour
H_0	Null hypothesis
km^2	Kilometer square
MK	Mann-Kendall
MLR	Multiple linear regressions
mm	Millimetre
MNLR	Multiple non-linear regression
N	North
NIST	National Institute of Standards and Technology
NOx	Oxides of nitrogen
O_3	Ozone
^oC	Degree Celsius
PM	Particulate matter
ppm	Parts per million
R^2	Coefficient of determination
RF	Rainfall
RH	Relative humidity
SO_2	Sulphur dioxide
WHO	World Health Organization

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