

Original Research Paper

Status of Air Quality with Potential Linkage to the Metrological Conditions in Three Major Cities of Pakistan

^{1,2}Naima Hamid, ^{1,2}Muhammad Junaid, ³Syeda Maria Ali, ⁴Maida Zahid and ¹De-Sheng Pei

¹Key Laboratory of Reservoir Aquatic Environment, Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, Chongqing 400714, China

²University of Chinese Academy of Sciences, Beijing 100049, China

³Department of Environmental Sciences, Female Campus, International Islamic University Islamabad, Pakistan

⁴Research and Development Division, Pakistan Meteorological Department, Islamabad, Pakistan

Article history

Received: 26-01-2019

Revised: 7-02-2019

Accepted: 09-03-2019

Corresponding Author:

De-Sheng Pei

Key Laboratory of Reservoir Aquatic Environment, Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, Chongqing 400714, China
Email: peids@cigit.ac.cn

Abstract: Environmental pollution being fatal for all living organisms is growing adversely due to excessive industrialization and urbanization. Vehicular emissions have aggravated the situation and pose detrimental effects on human health. In this study, the trend of ambient air quality was analyzed in the three metropolitan cities of Pakistan, including Karachi, Lahore and Islamabad for a period of three years (2008-2010). Air pollutants, such as NO, NO_x, NO₂ and PM_{2.5} were recorded using mobile air quality monitoring stations in the target areas. Results from statistical analysis revealed PM_{2.5} with highest levels in all the cities, albeit exceeded the World Health Organization (WHO) guideline limits. Spearman correlation revealed that the levels of air pollutants were negatively correlated with the temperature and rainfall, whereas positively correlated with the wind speed. Annual and seasonal variations in the concentrations of the air pollutants was also observed and the highest concentration was recorded in Karachi during the winter season that could be attributed to inversion phenomenon. In addition, the elevated vehicular emissions were observed in Lahore, implied comparatively high air pollution loads, comparison to those of Karachi and Islamabad. The widespread use of low-quality fuel, coupled with a dramatic expansion in the number of vehicles has led to significant air pollution problems, especially in Lahore and Karachi. Therefore, the efficient mass transit system and urban forests should be introduced to abate the ever-increasing levels of organic pollutants and improve the state of ambient air quality in the major cities of Pakistan.

Keywords: Ambient Air Quality Emission Concentrations, Meteorological Parameters, Vehicular Emissions

Introduction

Urban air pollution is rapidly becoming an environmental problem of public concern worldwide. Urbanization and industrialization with an unsustainable use of resources aggravates the problem (Guo *et al.*, 2017; Parekh *et al.*, 2001). Anthropogenic particles are emitted directly into the atmosphere from combustion and industrial processes in the urban areas that contributes to the drastic rise in air pollution (Di *et al.*, 2017a; 2017b; Katsouyanni *et al.*, 1993). Urban air pollution has serious implications for human health and well-being, as well as for the whole environment (Aunan and Pan, 2004; Li *et al.*, 2018). According to

the World Health Organization (WHO), two third of the deaths in year 2000 were caused by exposure to urban air pollution in developing countries of Asia (Ali and Athar, 2010; WHO/UNEP, 1992). A number of air pollution catastrophes occurred in industrial countries between 1950s and 1970s, such as the London smog of 1952, however, air quality in western countries has significantly improved since the 1970s (Cai *et al.*, 2017; McCarroll and Bradley, 1996; Wing *et al.*, 2017).

Meteorology plays a crucial role in ambient distributions of air pollution (Dentener *et al.*, 2006; Hou and Wu, 2016; Srivastava, 2006). In fact, there is a strong seasonality in meteorological variables that modulate air quality levels (Espinosa *et al.*, 2004; Karar

et al., 2005). Wind is a key meteorological variable having a major impact on horizontal transport and distribution of air pollutants, as well as vertical mixing and dispersion in a region (Xie *et al.*, 2018). Downwind areas from proximate emission sources, such as industrial locations and highways exhibited the significantly higher levels of air pollutants (Li *et al.*, 2010). Traffic emissions are known to be responsible for a substantial share of urban air pollution, such as nitrogen dioxide (NO₂), carbon monoxide and particulate matters (Deng *et al.*, 2018). In recent years, the aerosol problem has become increasingly acute due to increased loadings of atmospheric pollutants in Asian countries with monsoonal climates, such as India and China (Christodoulakis *et al.*, 2018, Srivastava, 2006, Tsang, 2008; Zhang *et al.*, 2008).

Air pollution is an emerging environmental issue and is considered to be a critical urban problem in major cities of Pakistan (Shahid *et al.*, 2016). The thickly populated urban areas are more vulnerable to the negative impacts of vehicular emissions due to congestion of vehicles, which has heavily affected quality of life (Cai *et al.*, 2017; Zhang *et al.*, 2008). Moreover, the air pollutants can change the atmosphere compositions through chemical reaction and bring about the long-term climate change impacts (Ilyas *et al.*, 2010; Khreis *et al.*, 2017). Present study

estimated the status of ambient air quality in three metropolitan cities of Pakistan (Islamabad, Lahore and Karachi) for three years. Correlation analysis was also run between the levels air pollutants (NO, NO_x, NO₂ and PM_{2.5}) and meteorological parameters (Minimum temperature, maximum temperature, precipitation, wind speed), using annual and seasonal based to unveil the driving factors of deteriorating ambient air quality in major cities of Pakistan. This study depicts the trends of emissions, associated adverse effects, also defines the role of meteorological parameters as driving factors of air emissions. The statistical findings from this study can be used for urban town planning to adopt appropriate measures to minimize the hazardous effects of the exposure and dispersion of air emissions.

Materials and Methods

Site Description

The study is focused on three cities, *i.e.*, Islamabad (Lat: 33° 40' N and Long: 72° 30'E), Lahore (Lat: 31° 32'N; Long: 74° 22' E) and Karachi (Lat: 24° 51'N; Long: 67° 02' E) (Fig. 1). The climate of Islamabad, Karachi and Lahore is usually humid subtropical/arid with extremely hot summers and dry winters.

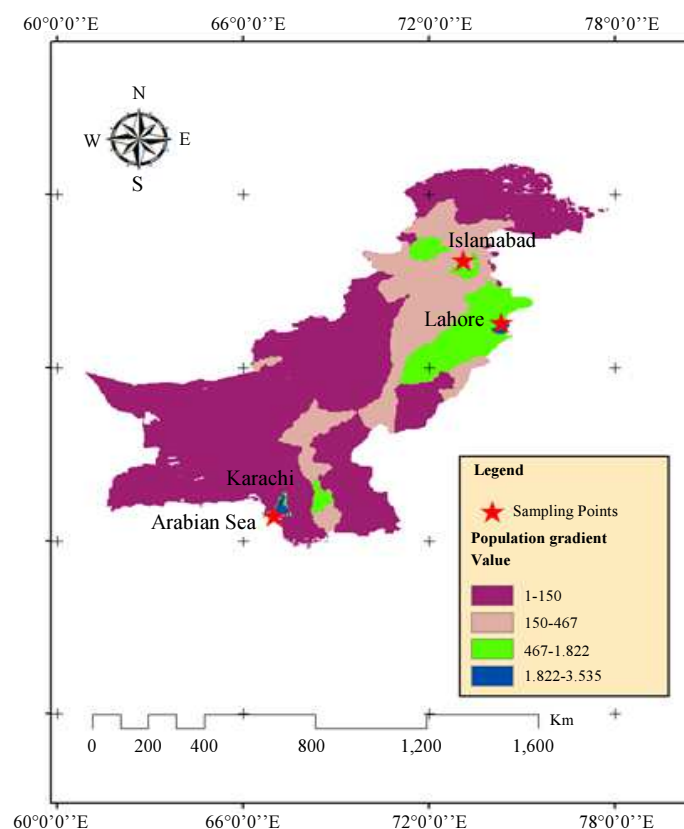


Fig. 1: Map of locations of cities used in study

The temperature ranges 36-38°C in Islamabad and 36-46°C in Lahore during summer. The Karachi lies on the flat, sandy coast facing the Arabian Sea just north of the Indus River delta. There fore, the temperature ranges from 30 to 44°C during summer season (Apr-Aug) and 12 to 25°C during winter season (Dec-Feb).

2.2 Data and Analysis

The monthly mean available emission data (NO, NO_x, NO₂ and PM_{2.5}) was acquired in 2014 from Pakistan Environmental Protection Agency (Pak-EPA) for three cities (Islamabad, Lahore and Karachi) for the years (2008-2010). It was a collaborative project initiated between Pak-EPA and Japan International Cooperation Agency (JICA). The first preliminary active air sampling for the metropolitan cities was completed in 2010. The air quality sampling was conducted using a mobile station that measures hourly concentrations of air emissions. The meteorological data (minimum temperature, maximum temperature, rainfall and wind speed) was acquired from data archives of Pakistan Meteorological Department (PMD). The data were analyzed using Microsoft Excel 2010 and SPSS version 20 (IBM, USA). Arc GIS version 9.3 (ESRI, USA) was used to draw site maps. The annual and seasonal trends of emissions have been investigated for three cities. Pakistan has four well marked seasons winter (Dec-Mar), spring (Apr-May), summer (Jun-Sep) and autumn (Oct-Nov). These seasons has been considered for the seasonal analysis in the study. Then the relationship between meteorological parameters and emission concentration has been determined. The basic statistics (mean, minimum, maximum, variance, standard deviation) for the meteorological parameters and for the emissions has also been observed. Non- parametric correlation was used to explain the significance of meteorological parameters influencing the emissions transport.

Results and Discussion

3.1 Annual Trends of Emissions and Relationship with Meteorological Parameters 2008-10

The annual trends for the air pollutants (NO, NO₂, NO_x and PM_{2.5}) were observed in Islamabad, Lahore Karachi for three consecutive years (2008-2010). The annual mean concentration of pollutants like NO_x and NO was observed high in Islamabad. However, the high levels of NO₂ and PM_{2.5} has been noticed in Lahore as shown in (Fig. 2). This could be due to the aggravated vehicular emissions (diesel and gasoline driven) and the biomass combustion in the metropolitan area. The comparative plots have been drawn between meteorological parameters and the emission concentration, which showed the annual mean minimum, maximum and rainfall on primary axis and

emission concentration on secondary axis. The annual mean concentration of NO_x was reported at 75.86 ppb and 58.33 ppb respectively in Islamabad and Karachi while that of NO observed at 69.84 µg/m³ and 38.47 µg/m³. In case of Lahore, the concentrations NO_x and NO were observed lower, *i.e.*, 47.06 ppb and 26.77 µg/m³, respectively. The mean annual peak concentrations for PM_{2.5} and NO₂ was observed in Lahore with a value of 116.4 µg/m³ and 51.50 µg/m³ and decreases in Islamabad (67.37 µg/m³ and 66.54 µg/m³) and Karachi (43.93 µg/m³ and 49.06 µg/m³) (Fig. 2). The main reason was due to the high traffic load with an increase in minimum temperature, aggravating the situation. According to Pak- EPA, the ambient quality standards for an annual average value of PM_{2.5} acceptable up to 25 µg/m³.

The results for statistical analysis of data for all the variables are shown in Table 1. Amongst all the emissions, PM_{2.5} concentrations were the highest with a mean value of 127.6 µg/ m³ in 2009. NO is derived from nitrogen (N₂) in high-temperature combustion processes, such as internal combustion engines and NO_x emissions released from these engines contain over 90% of NO, which is relatively unstable, compared to oxygen (O₂) and N₂ (Dotse *et al.*, 2016; Liu *et al.*, 2018). The main fate of NO is to convert into NO₂ after reaction with ozone (O₃) in the ambient atmosphere (Derwent and Hertel, 1998; Vedrenne *et al.*, 2016). NO_x and NO are the secondary pollutants that require another reactant to change their form, therefore, the concentrations of these pollutants were lower, compared to that of PM_{2.5} and NO₂ (Zawacki *et al.*, 2018). PM_{2.5} and NO₂ are the primary pollutants emitted from the vehicular emissions and industrial activities, which implied the peak emission values in Lahore city during the study years. The maximum rainfall has been observed in Islamabad city with an average value of 81.1 mm, as compared to Lahore and Karachi. It has also been noticed that the influence of rainfall is quite obvious on suspended particulate matter (PM_{2.5}) as compared to other pollutants (NO, NO₂, NO_x) in the atmosphere. The concentration of PM_{2.5} drops with the increase in amount of rainfall most probably due to the wetness and the weight of suspended particulates increases and they are settle down on the ground (Hou and Wu, 2016). As far as NO, NO₂ and NO_x are concerned, they are gaseous pollutants already a part of the atmosphere. Temperature has great influence on pollution in the atmosphere (Chen *et al.*, 2018). Both minimum and maximum temperature showed a negative correlation with the emission concentrations. When the temperature is high, there are turbulent flows and dramatic convective motions and the atmosphere is unstable (Deng *et al.*, 2018). On contrary, when the temperature is low, the atmosphere is so stable that the pollution concentration becomes high (Zhao and Shi, 2012).

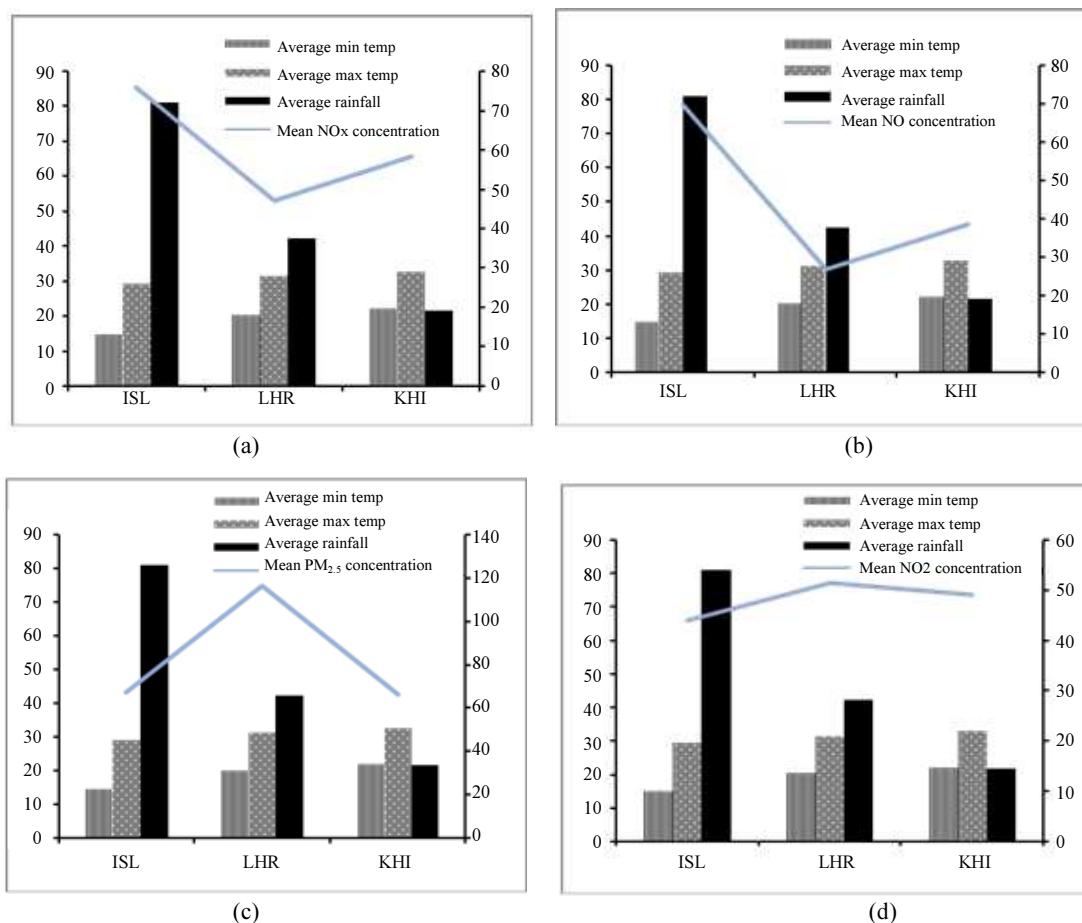


Fig. 2: Annual mean variation of (a) NO_x (ppb) emissions (b) NO (µg/m³) emissions (c) NO₂ (µg/m³) emissions and (d) PM_{2.5} (µg/m³) emissions with meteorological parameters from 2008-2010. Primary y-axis all meteorological parameters (minimum temperature (°C), maximum temperature (°C) and rainfall (mm)) were presented, on secondary y-axis all the emission concentrations are presented

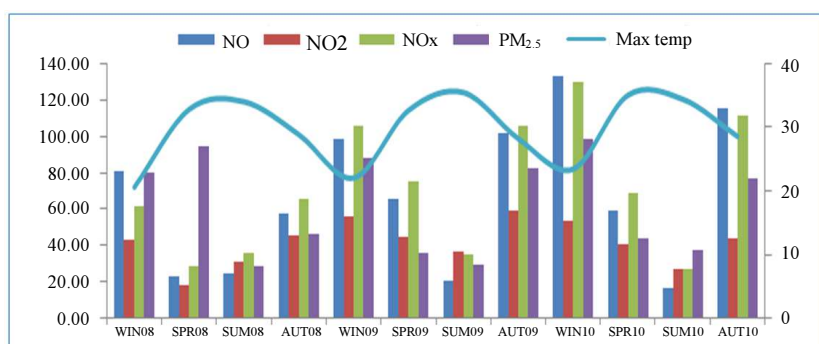
Table 1: Mean, Min-Max value, Variance and SD of Climatic variables (Minimum temperature, Maximum temperature, Rainfall and Wind speed) for Islamabad, Lahore and Karachi cities

	2008				2009				2010			
Islamabad	Mean	Min-Max	Variance	SD	Mean	Min-Max	Variance	SD	Mean	Min-Max	Variance	SD
Min Temp (°C)	28.4	14.8-26.4	52.2	7.23	29.33	19.2-36.9	42.68	6.53	29.89	21.16-37.2	35.29	5.94
Max Temp (°C)	15.3	1.79-24.8	72.3	8.5	13.99	2.5-23.8	55	7.42	14.7	1.49-24.0	65.17	8.07
Rainfall (mm)	109	4.0-353	13866	117.76	48.83	0.4-178.3	2435	49.35	85.01	0-225.8	7487.99	86.53
NO (µg/m ³)	62.6	5.13-166	3078.9	55.49	67.78	8.9-167.1	2338.1	48.35	79.1	7.2-189.3	3909.4	62.53
NO ₂ (µg/m ³)	41.7	12.7-99.1	842.45	29.03	48.72	28.4-68.5	154.6	12.44	41.32	20.2-66.2	195.85	13.99
NO _x (ppb)	67.4	10.7-162	2589.2	50.88	77.53	22-154.2	1712.7	41.39	82.61	17.9-175.6	2867.71	53.55
PM _{2.5} (µg/m ³)	75	11.2-105	872.1	29.53	59.28	21.8-111.8	1126.7	33.57	67.84	27.8-125.9	960.97	31
Lahore												
Min Temp (°C)	30.2	17.87-37.28	38.72	6.22	32.75	20.0-43.56	51.2	7.16	30.79	17.27-39.69	49.26	7.02
Max Temp (°C)	19.77	6.96-27.69	53.17	7.29	19.93	9.32-27.72	50.4	7.1	20.87	7.80-27.78	52.04	7.21
Rainfall (mm)	51.41	0-283.1	6255.1	79.09	31.29	0.1-111.6	1302.7	36.09	44.13	0-296	7761.9	88.1
NO (µg/m ³)	19.81	1.77-65.87	400.82	55.49	9.15	20.02-43.56	167.53	12.94	51.36	0.4-170.2	2526.92	50.27
NO ₂ (µg/m ³)	40.64	13.8-70.5	351.49	29.03	54.19	22.7-84.0	406.5	20.16	59.71	25.3-92.1	393.51	19.84
NO _x (ppb)	36.57	8.71-86.6	578.2	50.88	36.41	13.2-64.4	336.1	18.33	68.23	13.6-162.1	2018.3	44.93
PM _{2.5} (µg/m ³)	116.48	33.5-231.1	2946.3	29.53	127.63	45.6-499.7	15367.5	123.97	105.12	43.9-205	2510.7	50.11
Karachi												
Min Temp (°C)	32.04	23.77-35.47	14.26	3.78	32.94	26.2-36.8	10.66	3.26	33.06	27.5-36.51	9.73	3.12
Max Temp (°C)	21.9	11.14-28.98	37.96	6.16	22.31	13.9-28.7	31.09	5.58	21.95	11.5-28.53	41.62	6.45
Rainfall (mm)	10.27	0-54.5	333.79	18.27	23.47	0-160.5	2351.5	48.49	31.17	0-120.7	2432	49.32
NO (µg/m ³)	34.76	9.66-78.41	458.75	21.42	39.46	14.6-80.1	431.5	20.77	41.2	6.5-94.1	1108.2	33.29
NO ₂ (µg/m ³)	45.22	13.09-75.39	521.87	22.84	54.84	29.0-95.31	457.13	21.38	47.15	20.9-90.8	432.9	20.81
NO _x (ppb)	57.48	14.59-105.4	1187.95	34.47	60.1	33.26-113.7	713.12	26.7	57.43	16.1-121.7	1198.3	34.62
PM _{2.5} (µg/m ³)	71.85	34.5-123.5	757.65	27.53	60.86	24.2-115.5	1138	33.73	66.93	22.5-180.9	2474.6	49.75

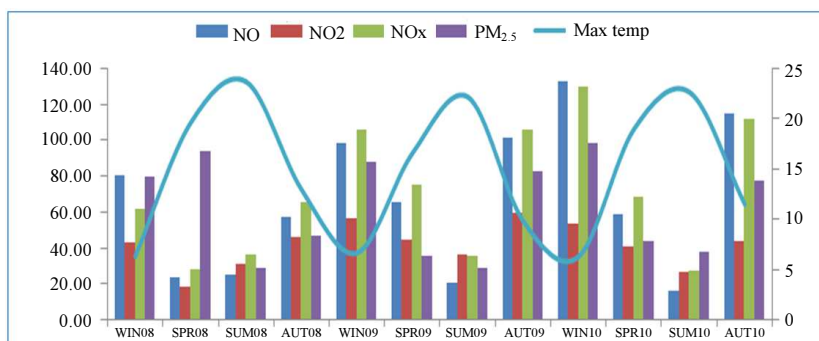
Seasonal Trends of Emissions and Relationship with Meteorological Parameters 2008-10

Seasonal variations in weather have a considerable impact on the levels of pollutants in the atmosphere. Temperature showed the typical seasonal behavior with low values during the summer and high values during the winter (Yang *et al.*, 2015). The analysis of seasonal variations of emissions revealed decrease in the level of air pollutants with the increase in the temperature. For Islamabad city, it was noted that in winter season there is a gradual rise in the concentration of pollutants, among all the concentration of NO_x was recorded highest in winter 2009, with a value of 105.99 ppb, whereas in winter 2010, showed the highest value (133.2 μg/m³) of NO concentration. This could be ascribed that in summer season pollutants move upwards due to higher

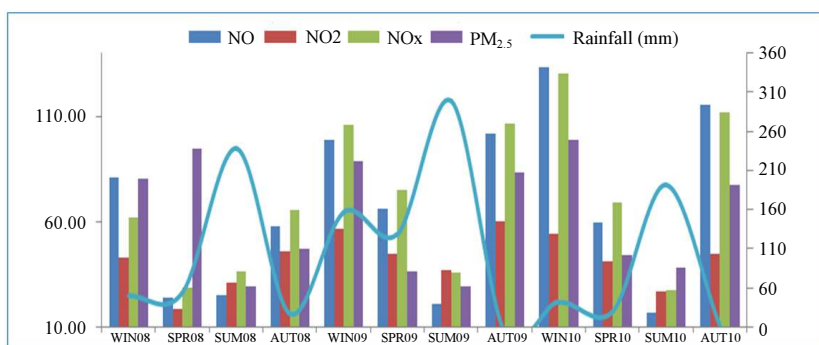
atmospheric turbulence, while in winters air near the earth surface is cooler so the atmospheric turbulence is lower, responsible for lower dispersion of pollutants (Qiu *et al.*, 2018). In the year 2008, PM_{2.5} showed the highest concentration (94.58 μg/m³) in spring season, compared to other years. In spring 2009, the value (44.97 ppb) of NO_x was quite high likewise same trend was observed for NO emission. In summer season with the rise in temperature the levels of emissions were decreased (Ilyas *et al.*, 2010). Thus, maximum temperature is considered as a pollutant control parameter (Kartal, 1998; Xie *et al.*, 2018). Similarly, in autumn season, a gradual increase has been recorded in emissions concentration. Highest concentration of NO (115.6 ug/m³) was observed in 2010 whereas PM_{2.5} showed its maximum concentration (83.09 ug/m³) in autumn 2009 (Fig. 3a).



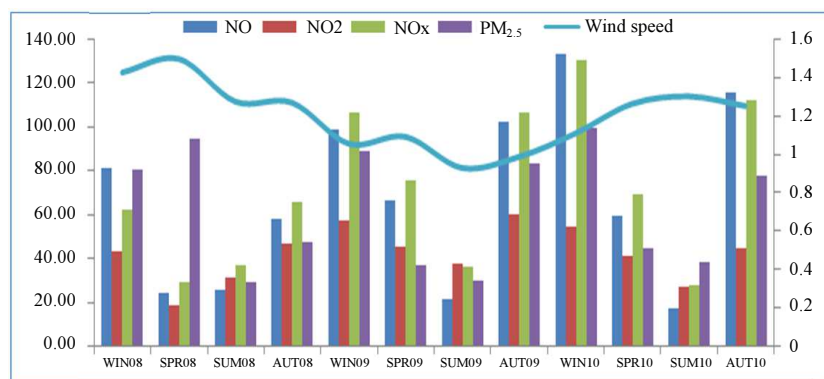
(a)



(b)



(c)



(d)

Fig. 3: Seasonal mean variation of emissions with (a) Maximum Temp (°C) (b) Minimum Temp (°C) (c) Rainfall (mm) and (d) Wind Speed (m/s) for Islamabad City

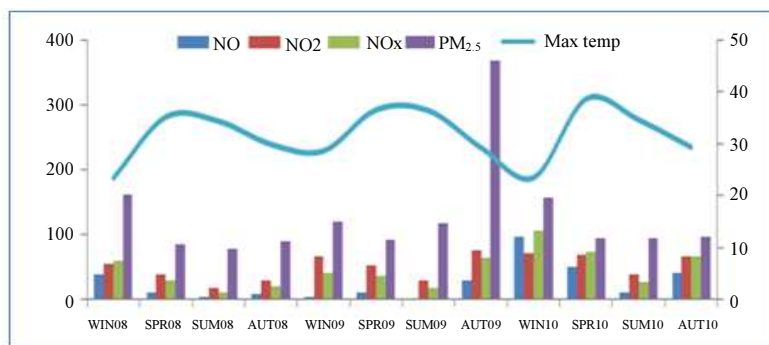
Similar trend with minimum temperature has been observed in Islamabad city, which showed a decrease with increase in level of pollutants. In winter 2010, NO ($133.2 \mu\text{g}/\text{m}^3$) showed maximum value, whereas in spring 2008, PM_{2.5} ($94.58 \mu\text{g}/\text{m}^3$) revealed highest values. Due to increase in temperature, negligible amount of pollutants has been observed in all summer seasons (Xie *et al.*, 2018; Zhao *et al.*, 2015). Likewise, as the minimum temperature drops in autumn. Similarly, an increase in emissions was observed (Qiu *et al.*, 2018). NO with a value of $115.6 \mu\text{g}/\text{m}^3$ showed its highest concentration in autumn 2010 whereas NO₂ showed its maximum value ($59.87 \mu\text{g}/\text{m}^3$) in autumn 2009 respectively (Fig. 3b). The safe level of long-term exposure to NO₂ is set by World Health Organization (WHO) at $40 \mu\text{g}/\text{m}^3$ for 1 year monitoring, while for short-term monitoring (1 hour), the threshold is set at $200 \mu\text{g}/\text{m}^3$ (WHO/UNEP, 1992).

Negative correlation with rainfall was observed during the study years in Islamabad city. As the rainfall increased, the decrease in emissions was recorded. In winter 2010, the concentration of NO ($133.2 \mu\text{g}/\text{m}^3$) and NO_x (129.9 ppb) was the highest. In spring 2008, PM_{2.5} showed its maximum value ($94.58 \mu\text{g}/\text{m}^3$), compared to other studied years. Likewise, in summer 2009 the lowest concentration of PM_{2.5} ($29.51 \mu\text{g}/\text{m}^3$) was observed with the increase in rainfall. The main reason of the lowest concentration of particulate matters in the monsoon can be attributed to the scavenging of particulate pollutants from the atmosphere due to rainfall (Stern, 1976; Xie *et al.*, 2018). In autumn 2010, the maximum concentration of NO with a value of $115.6 \mu\text{g}/\text{m}^3$ was found in comparison to other years (Fig. 3c). Positive correlation with rainfall was observed during the study years. As the wind speed increased, the amount of pollutants was also increased. In winter 2010, the maximum wind speed was recorded with a value of 1.07 m/sec.

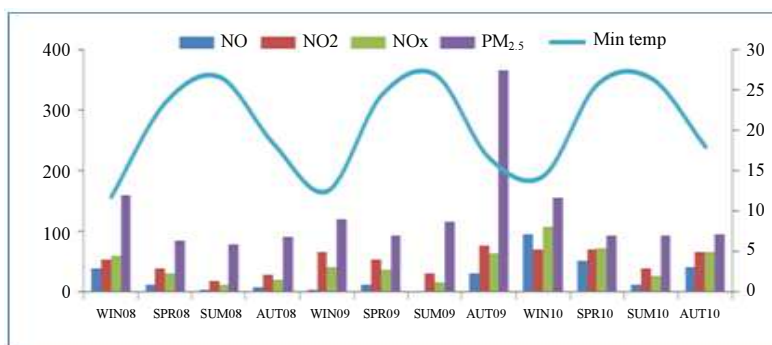
Similarly, in same year the highest concentration of NO ($133.2 \mu\text{g}/\text{m}^3$) was observed (Fig. 3d).

For Lahore city, general trend showed a negative correlation of emissions with both maximum and minimum temperature. Among all the pollutants, PM_{2.5} concentrations were the highest and observed in autumn 2009 with a value of $366.8 \mu\text{g}/\text{m}^3$. WHO guidelines limit for 24-hour monitoring for PM_{2.5} is set at $50 \mu\text{g}/\text{m}^3$ that is quite high from the set limits and detrimental for health (Fig. 4a, b). As the rainfall increased, the decrease in the emissions concentration was recorded. In summer 2009, the rainfall was recorded as 249.3 mm and the emissions concentration was below the threshold limits. Similarly, in autumn 2009, as the rainfall decreased the level of pollutants particularly PM_{2.5} with a value was increased to $366.87 \mu\text{g}/\text{m}^3$ (Fig. 4c). Temperature showed an inverse relation with most of the pollutants because of the role of the heat in warming up the surface of the earth by the incoming radiation that strike the earth and warms it, thus making the surface air warmer and consequently reducing its density, so it expands and goes upward to be replaced by cold air and so on. This process increases the amounts of the up going air currents (Deng *et al.*, 2018; Ilyas *et al.*, 2010). When the horizontal and vertical air mixing processes increase, they reduce the concentration of the pollutants in it. Wind speed showed positive correlation with emission concentrations (Deng *et al.*, 2018; Guo *et al.*, 1999). In Autumn 2009, PM_{2.5} ($366.87 \mu\text{g}/\text{m}^3$) maximum concentration was recorded with an increase in wind speed with a value of 1.21 m/sec (Fig. 4d).

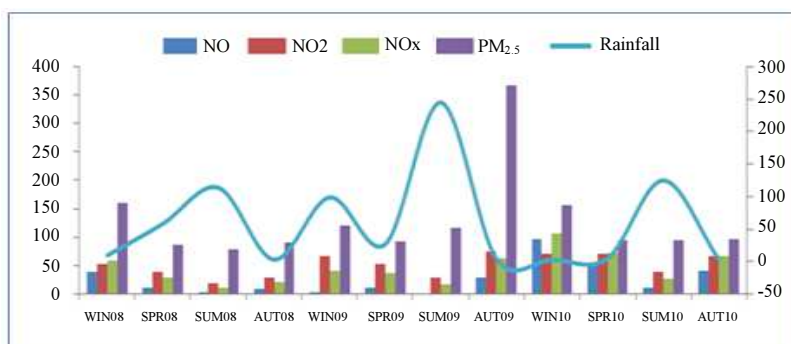
For Karachi city, pollutant emissions showed a negative correlation with maximum temperature throughout the study period. As in winter season when the temperature drops increase in the level of pollutants has been observed (Qiu *et al.*, 2018). But if we compare the general trend of pollutants in winter, spring and summer season a decrease has been recorded.



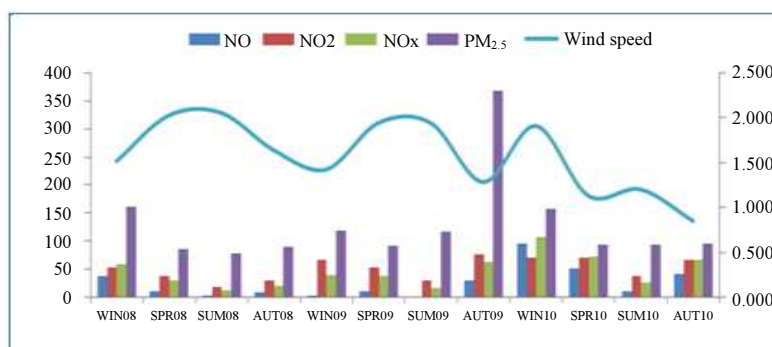
(a)



(b)

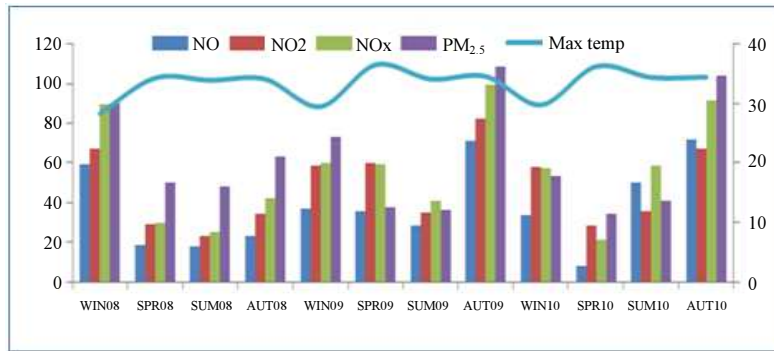


(c)

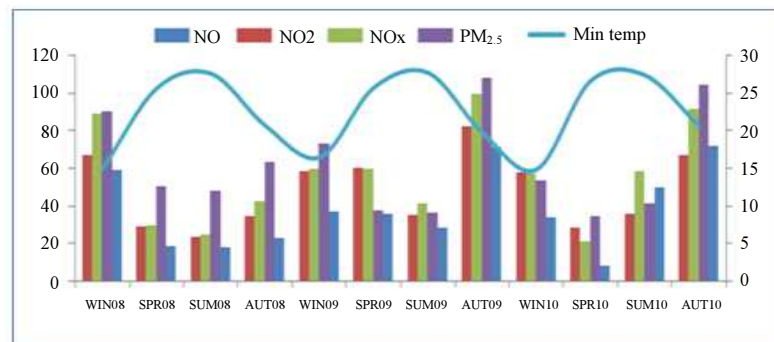


(d)

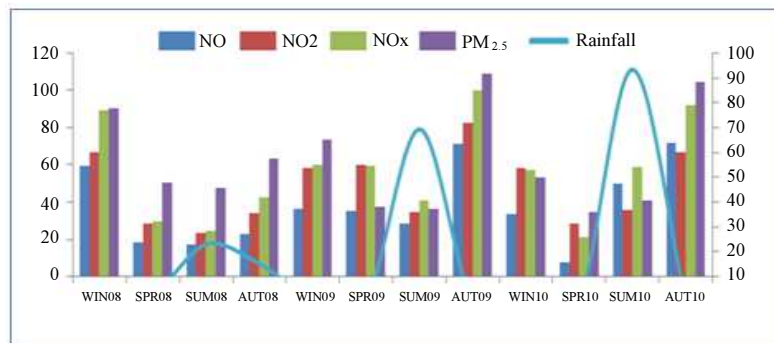
Fig. 4: Seasonal mean variation of emissions with a) Maximum Temp (°C) b) Minimum Temp (°C) c) Rainfall (mm) and d) Wind Speed (m/s) for Lahore City



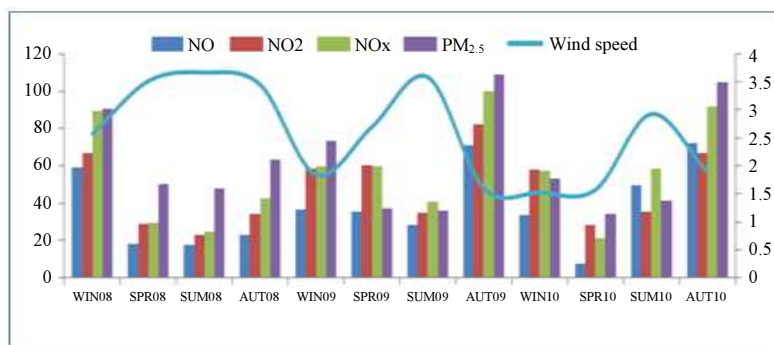
(a)



(b)



(c)



(d)

Fig. 5: Seasonal mean variation of emissions with a) Maximum Temp (°C) b) Minimum Temp (°C) c) Rainfall (mm) and d) Wind Speed (m/s) for Karachi City

In autumn season 2009, the concentration of NO_x and PM_{2.5} with values of 99.65 ppb and 108.5 ug/m³ were highest as compared to other years. Pak-EPA ambient quality standards for NO_x and PM_{2.5} were 40 ug/m³ and 25 ug/m³ that were quite high, compared to permissible limits. Same trend was observed with minimum temperature. Generally, it was noted that highest level of emissions concentration was observed in the autumn season (Adeeb, 2014) (Fig. 5a and b). Maximum rainfall was experienced in summer season in 2010, *i.e.*, 93.2 (mm), but at the same time, the lowest level of emissions was recorded (Fig. 5c).

It was found out that meteorological factors such as rainfall and relative humidity had significant negative impacts on emission concentrations in the city (Bhaskar *et al.*, 2008; Xie *et al.*, 2018). In contrast, temperature and wind speed showed positive correlation with the pollution load dispersion. In Winter 2008 as the wind speed increased the level of pollutants also increased. Maximum level of emissions were recorded in autumn 2009 with a wind speed of 3.58 m/sec (Fig. 5d)

Correlation analyses were carried out to quantify the relationship, between the meteorological and pollution variables as shown in Table 2. In all cities, there is a negative correlation of both maximum and minimum temperature that has been observed. The reason behind the negative correlation is that high temperatures enhance convection currents, which helps in good air mixing and reducing emissions specially PM_{2.5} concentrations. Lower air temperatures cause the stable atmosphere, hence, result in the poor air quality (Lepeule *et al.*, 2018). Wind speed showed a positive correlation with emissions concentrations (Table 2). As wind blows it distributes the exhaust

gases from the industries into metropolitan area that mainly includes NO, NO_x, PM_{2.5}, which poses detrimental impacts in human health (Di *et al.*, 2017b). Similarly, rainfall showed negative correlation as it removes the pollutants from the atmosphere. Usually, Karachi experience less precipitation due to inversion layer that traps the contaminants during winter season. In winter season Islamabad is more polluted because winter smog is caused when a mixture of pollutants builds up at ground level and layer of cold air traps the warm air containing pollutants and elevates the levels (Amato *et al.*, 2014; Deng *et al.*, 2018).

Annual mean concentration and their relative percentage of pollutants were also calculated (Table 3). The highest average mean counts were recorded in Lahore with a value of 238.16 ug/m³ followed by Islamabad (256.0 ug/m³) and Karachi (53.28 ug/m³). In Lahore and Karachi, PM_{2.5} showed its major contribution with an average of 119.2 ug/m³ and its percentage contribution (91.69%), (65.13 ug/m³, 87.97%) to the total atmosphere whereas in Islamabad NO_x contributes 57.68% respectively (Table 3). If we compare ambient air quality situation among three cities, Lahore is the most polluted one followed by Islamabad and Karachi. The main reason is that the vehicular emissions have been dominated by emissions from old and poorly maintained vehicles that contribute to enhanced ambient concentrations of fine particulates (Deng *et al.*, 2018; Lodhi, 2006). Anthropogenic sources contributed for about 15% of the total hydrocarbon emissions in the atmosphere. The gases acted like a blanket where ever their concentration increased. However, local heat and increased differences between hotter and colder regions were reported as driving factors (Ahmed *et al.*, 2014; Li *et al.*, 2018).

Table 2: Correlation coefficients of air emissions and meteorological parameters for the years 2008-2010

Emissions	Met parameters	2008			2009			2010		
		ISL R	LHR R	KHI R	ISL R	LHR R	KHI R	ISL R	LHR R	KHI R
NO (µg/m ³)	Max temp (°C)	-0.51	-0.79	-0.84	-0.70	-0.34	0.10	-0.83	-0.56	-0.13
	Min Temp (°C)	-0.64	-0.81	-0.94	-0.83	-0.22	-0.35	-0.96	-0.72	-0.17
	Wind Speed (m/s)	0.49	0.70	0.71	0.62	0.53	0.54	0.52	0.49	0.54
	Rainfall (mm)	-0.58	-0.43	-0.23	-0.55	-0.53	-0.22	-0.77	-0.37	0.04
NO ₂ (µg/m ³)	Max temp (°C)	-0.32	-0.70	-0.65	-0.60	-0.41	-0.15	-0.74	-0.35	-0.63
	Min Temp (°C)	-0.44	-0.83	-0.91	-0.73	-0.79	-0.64	-0.91	-0.57	-0.78
	Wind Speed (m/s)	0.68	0.71	0.57	0.58	0.71	0.76	0.46	0.51	0.76
	Rainfall (mm)	-0.46	-0.60	-0.31	-0.62	-0.67	-0.38	-0.73	-0.44	-0.44
NO _x (ppb)	Max temp (°C)	-0.49	-0.79	-0.68	-0.72	-0.50	0.00	-0.82	-0.55	-0.29
	Min Temp (°C)	-0.61	-0.85	-0.90	-0.84	-0.64	-0.48	-0.96	-0.71	-0.37
	Wind Speed (m/s)	-0.53	-0.74	-0.49	0.64	-0.74	-0.65	-0.53	-0.55	-0.65
	Rainfall (mm)	-0.56	-0.51	-0.24	-0.57	-0.70	-0.29	-0.78	-0.39	-0.10
PM _{2.5} (µg/m ³)	Max temp (°C)	-0.30	-0.60	-0.22	-0.74	-0.44	-0.47	-0.91	-0.81	-0.63
	Min Temp (°C)	-0.43	-0.68	-0.50	-0.83	-0.42	-0.77	-0.94	-0.90	-0.71
	Wind Speed (m/s)	0.33	0.47	0.47	0.29	0.45	0.74	0.54	0.57	0.74
	Rainfall (mm)	-0.67	-0.60	-0.27	-0.50	-0.22	-0.28	-0.60	-0.30	-0.39

Table 3: Annual mean concentration and relative percentage of each of pollutant type in the atmosphere of Islamabad, Lahore and Karachi, Pakistan

Emissions	Yearly mean count			%age contribution to total atmosphere		
	2008-2009	2009-2010	Average	2008-2009	2009-2010	Average
Islamabad						
NO ($\mu\text{g}/\text{m}^3$)	65.21	73.44	69.33	26.08	28.02	52.42
NO ₂ ($\mu\text{g}/\text{m}^3$)	45.24	45.02	45.13	18.09	17.62	34.22
NO _x (ppb)	72.49	80.07	76.28	28.99	30.55	57.68
PM _{2.5} ($\mu\text{g}/\text{m}^3$)	67.14	63.56	65.35	26.85	24.25	49.43
Total	250.09	262.09	256.09			
Lahore						
NO ($\mu\text{g}/\text{m}^3$)	14.48	30.26	22.37	6.56	11.82	17.10
NO ₂ ($\mu\text{g}/\text{m}^3$)	47.41	56.94	52.18	21.5	22.25	40.06
NO _x (ppb)	36.49	52.32	44.40	16.55	20.44	34.04
PM 2.5 ($\mu\text{g}/\text{m}^3$)	122.05	116.37	119.21	55.36	45.47	91.69
Total	220.43	255.89	238.16			
Karachi						
NO ($\mu\text{g}/\text{m}^3$)	37.11	40.33	38.72	69.92	75.38	52.29
NO ₂ ($\mu\text{g}/\text{m}^3$)	50.03	50.99	50.51	94.27	95.30	68.22
NO _x (ppb)	58.79	58.77	58.78	110.77	109.85	79.39
PM 2.5 ($\mu\text{g}/\text{m}^3$)	66.36	63.90	65.13	125.04	119.43	87.97
Total	53.07	53.50	53.28			

Conclusion

The study conducted in three major metropolitan cities (Islamabad, Lahore and Karachi) of Pakistan showed annual and seasonal variability of atmospheric emissions from 2008-2010. The four different types of pollutants (NO, NO₂, NO_x, PM_{2.5}) were analyzed, out of which, PM_{2.5} was the most significant. The meteorological conditions such as temperature and rainfall depicted a negative correlation with emissions whereas wind speed showed a positive correlation. The annual mean concentration of PM_{2.5} was found highest in Lahore. The maximum concentrations of emissions (NO, NO₂, NO_x, PM_{2.5}) were observed in all cities during winter. The comparison among the cities based on statistical analysis revealed Lahore as the most polluted city, compared to Karachi and Islamabad. Finally, it could be considered that the atmospheric pollution comes from anthropogenic activities in urban area and is predominantly due to auto-vehicular traffic. The level of air pollution in the Pakistan's two largest cities, Karachi and Lahore are estimated to be 20 times higher than World Health Organization standards and is continuously rising. The increased number of vehicles, use of low-quality fuel and industrial activities are the significant driving forces of air pollution. There fore, an efficient mass transit system and control of industrial emission would help to cope with current emissions and future worse scenarios.

Acknowledgment

The authors are sincerely grateful for the supports from the CAS Team Project of the Belt and Road (to D.S.P.), the Three Hundred Leading Talents in Scientific

and Technological Innovation Program of Chongqing (No. CSTCCXLJRC201714) and the University of Chinese Academy of Sciences (UCAS) for CAS-TWAS Scholarship (No. 2017A8018537001 to N.H).

Author's Contributions

Naima Hamid: Extracted, analyzed the data and wrote the first draft.

Muhammad Junaid and Syeda Maria Ali: Develop illustration, analyze and revise the paper.

Maida Zahid: Assisted to assemble the meteorological data from Pakistan Meteorological Department.

De-Sheng Pei: Conceived, designed and revised the paper.

Ethics

All the primary data acquired were in agreement from the Pakistan Metrological Department (PMD), Research and Development Division, Islamabad, Pakistan.

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Highlights:

- Air quality trend was monitored in metropolitan cities of Pakistan (Karachi, Lahore, and Islamabad)
- Among all primary pollutants, PM_{2.5} was the highest levels in all the cities
- Pollutants are positively correlated with wind speed and negatively correlated with temperature and rainfall
- Elevated pollution levels were observed in Lahore followed by Karachi and Islamabad
- The highest annual and seasonal variation in Karachi could be attributed to the inversion process

Graphical Abstract

