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Bangladesh J. Sci. Ind. Res. **55(2)**, 89-98, 2020

BANGLADESH JOURNAL OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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$PM_{2.5}$ concentration and meteorological characteristics in Dhaka, Bangladesh

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Abstract

Air quality in Dhaka city is gradually deteriorating due to increase of pollutants in air. This study aims to assess the concentration of particulate matter (PM) with an aerodynamic diameter ≤2.5 µm ($PM_{2.5}$) and its relationship with meteorological parameters in highly polluted Dhaka city. Data for $PM_{2.5}$ has been collected from the Air Now Department of State (AirNow DOS) and meteorological data from Bangladesh Meteorological Department (BMD). Study observed that 31.9% of hourly Air Quality Index (AQI) category was unhealthy while the percentage of 'Good' was very few. The maximum monthly average concentration was found to be 192.97±89.30 µg/m^3 in the month of January while minimum average concentration was 29.98±19.37 µg/m^3 in July. Besides, it also found that winter season had highest $PM_{2.5}$ concentration among all seasons. Moreover, the annual concentration was found to be 79.94±75.55 µg/m^3 in 2017 which exceeded the National Ambient Air Quality Standard (NAAQS) and World Health Organization (WHO) standard. A number of meteorological factors are affecting to this variation. It is also found that rainfall is negatively strong and significantly correlated with the concentration of $PM_{2.5}$, due to ambient dust are being settle down in the lithosphere. Annual concentration of $PM_{2.5}$ was 5 times higher than standard level.

Received: 12 May 2019
Revised: 27 May 2019
Accepted: 01 July 2019

DOI: https://doi.org/10.3329/bjsir.v55i2.47629

Keywords: Air pollution; Particulate matter; Variation; Meteorology; Bangladesh

Introduction

The ambient air pollution is one of the major concerns in developing country (Tabaku *et al.,* 2011). Among the various pollutants, particulate matter (PM) is the major environmental risk factor worldwide (HEI, 2018). The exact composition and size of PM may vary by region, time year or day, weather conditions and so on (WHO, 2001). Anthropogenic sources of PM that include industrial processes, combustion of fossil fuel, either by stationary sources or by transportation, construction and demolition activities, brick kilns, exciting of road dust in the atmosphere (especially in unpaved roads), domestic solid waste, smoking, and agricultural operations are making Dhaka as one of the most polluted cities in the world (Rouf *et al.,* 2011; USEPA, 2009). Among the various component of air pollutant, $PM_{2.5}$ is more dangerous fine particles with small diameters that remain suspended in air and do not settle (Li *et al.,* 2017). $PM_{2.5}$ refers to the diameters that are generally less than 2.5 micrometers (≤2.5 µm) and it usually about 3% diameter of a human hair (USEPA, 2017). $PM_{2.5}$ is fine inhalable particles which is a strong indicator of adverse health impacts (Cao *et al.,* 2013). Atmospheric $PM_{2.5}$ continues to receive a great deal of interest worldwide due to its negative impacts on human health and welfare in worldwide. (Peng *et al.,* 2008; Valavanidis *et al.,* 2008; Donaldson *et al.,* 2003; Kan *et al.,* 2007; Hassanen *et al*., 2016).

In many studies it has been found that diseases like sore throat, chest pain, nausea, asthma, and bronchitis and lung cancer have chances to occur because of air pollution (Dockery *et al*., 1993; USEPA, 1999a; USEPA, 1999b; Jeff and Hans, 2004). Studies found that over 600 million people in urban areas worldwide were been exposed to dangerous

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levels of air pollutants (Cacciola *et al.,* 2002; Hassanen *et al.,* 2016).Globally, $PM_{2.5}$ causes 4.1 million deaths from heart disease and stroke, lung cancer, chronic lung disease,and respiratory infections in 2016 (HEI, 2018). In Bangladesh, ambient and indoor $PM_{2.5}$ is one of the significant environmental risk, contribute about 21% of all deaths while Bangladesh is the leading country compared to other south Asian countries in terms of air pollution (WB, 2018). The capital Dhaka of Bangladesh experiences 15,000 early deaths along with pulmonary, respiratory and neurological illness caused by low air quality (Ahmed *et al.,* 2016).

A number of campaign-based studies on the ambient air quality characterizations in Bangladesh have already been reported (Begum *et al.,* 2011; Begum *et al.,* 2008; Salam *et al.,* 2003; Salam *et al.,* 2008; Salam *et al.,* 2013). Begum *et al.* (2008) revealed that, vehicular emissions and seasonal brick kilns are more responsible for PM pollution in Dhaka city. It was found that during the winter season the concentration of PM remain much higher than other season due to the variation of meteorological characteristics (Begum *et al.,* 2010). Hossain and Easa (2012) reported that the annual average $PM_{2.5}$ concentration was 95 $\mu g/m^3$ at Dhaka city as well as it increases in relation with high wind speed during the dry winter season. Rana *et al.* (2016) found that $PM_{2.5}$ concentration almost six times higher than the national standards of Bangladesh while 8–13 times higher than the World Health Organization (WHO) guideline value mostly in the winter season. Hence, it has been understood that PM can vary in reference with seasonal variation and metrological characteristics while brick kilns and motor vehicles are the more responsible sources to increase PM. Apart from that, the authors didn't find any scientific literature on Air Quality Index (AQI) score for a whole year of Dhaka city which represents the how air is clean or polluted in a specific place of a region. So, the present study will provide an overview of AQI score for $PM_{2.5}$ concentration of Dhaka city in 2017. Besides, this study aimed to assess the monthly and seasonal, weekly and diurnal variations of Particulate Matter ($PM_{2.5}$) in Dhaka city as well as assessing the correlation between the $PM_{2.5}$ and Meteorological characteristics in Dhaka city.

Study area

The capital Dhaka (Latitude: N23˚43'40"; Longitude: E90˚23'52") one of the largest and most densely populated cities in the world. Dhaka is the economic, political and cultural center of Bangladesh. It is one of the major growing cities of South Asia. As part of the Bengal plain, the city is bounded by four rivers. The climate in Bangladesh is categorized by high temperature and high humidity most of the year with a separate seasonal variation of precipitation (Salam *et al*., 2003; Salam *et al*., 2008; Salam *et al*., 2013). There are four seasons in Bangladesh which can be categorised by the pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February). The exact sampling location is situated on the roof of the U.S. Embassy consulate building, Banani, Dhaka, Bangladesh (Fig 1)

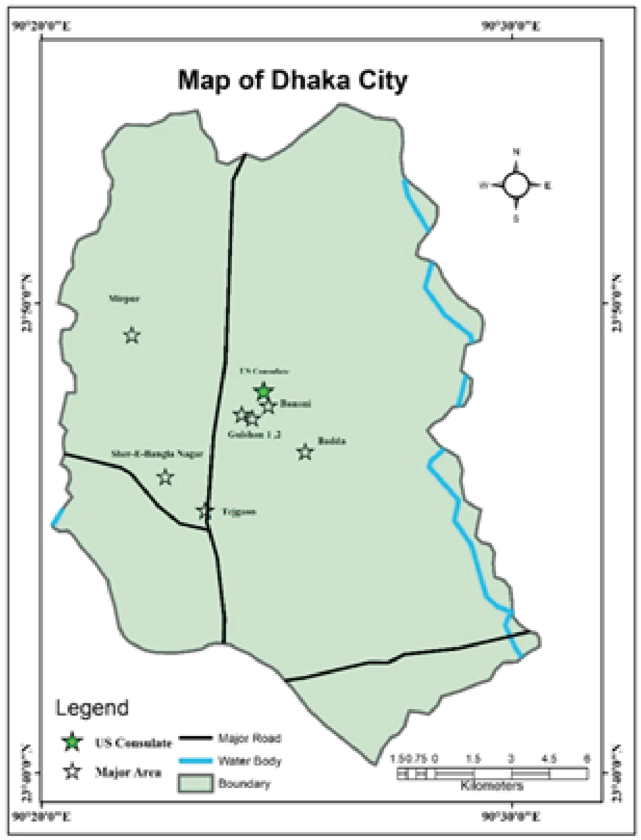

Fig. 1. Map of the study area

Data collection and analysis

Since 2016, the US Embassy in Dhaka, Bangladesh has been collecting real-time air-quality data from a monitor on the Embassy's rooftop and sharing that data publicly through the AirNow Department of State (AirNow DOS) website. (https://www.airnow.gov/index.cfm?action=airnow.global_summary#Bangladesh $Dhaka). The AirNow DOS provides maps of real-time hourly AQI conditions and daily AQI forecasts worldwide. The $PM_{2.5}$ instrument installed at the U.S. Embassy in Dhaka and measured on an hourly basis using a beta attenuation monitor BAM-1020, PM-Coarse System (Met One Instruments Inc., Grant Pass OR) from the roofs of the U.S. Embassy in Dhaka. The BAM-1020 is a designated EPA FEM for continuous $PM_{2.5}$ monitoring and is used for over 80% of $PM_{2.5}$ measurements at the federal, state, and local levels (EPA, 2015). Particles larger than 2.5 µm in diameter are removed by a filter, and air is then passed through a chamber that is heated to 20°C before particles are impacted onto a filter tape that, after a period of exposure, is exposed to a source of beta radiation (EPA, 2009). The degree of absorption of that radiation by particulate matter collected on the filter tape is a sensitive measure of $PM_{2.5}$, which is quantified by careful calibration procedures (Castellani *et al.,* 2014; EPA, 2015). Besides, Meteorological Data has been collected from the Bangladesh Meteorological Department (BMD). After collection of information, data processing, analysis and interpretation have been done separately.

Results and discussion

Monthly variation of $PM_{2.5}$

The monthly discrepancy of average $PM_{2.5}$ concentration levels at Dhaka city on 2017 is shown in table I. Maximum concentration was found 192.97±89.30 µg/m^3 in the month of January while minimum concentration was 29.98±19.37 µg/m^3 in July. Much higher concentration was identified from December to February which is winter season. $PM_{2.5}$ concentration touched a minimum from July-September and going to amplify again from October to November (Fig. 2). Rouf *et al.* (2011) reported that monthly average PM concentration (2002-2005) during rainy months was less than NAAQS for 24-hour as well as day-to-day variation were much higher in the winter season than rainy season. Apart from, Total annual average $PM_{2.5}$ concentration was 79.94±75.55 µg/m^3 in 2017. Hence, it can be seen that $PM_{2.5}$ concentrations exceed the annual average of BNAAQS(15 µg/m^3) and WHO standard (10 µg/m^3) (Table I).

Seasonal variation of $PM_{2.5}$

Strong seasonal patterns were detected and the maximum concentration of $PM_{2.5}$ found during winter time which reaches as higher concentration among the other seasons. Statistically significant differences in PM concentrations between winter and monsoon were identified. The concentration of $PM_{2.5}$ during the winter vs. monsoon season was much higher in winter than during the monsoon season (163.75±90.00 µg/m^3 vs. 33.20±22.53 µg/m^3) (Table II).

Table I. Monthly variation of $PM_{2.5}$with meteorological characteristics

Month	$PM_{2.5}$ (µg/m^3)	Rainfall (mm)	Relative humidity (%)	Ambient temperature (ºC)
January	192.97±89.30	0	55.39	28.74
February	165.84±98.59	2	48.00	27.70
March	92.12±58.38	100	62.10	22.90
April	60.52±38.50	228	66.30	25.80
May	50.35±26.73	188	64.50	33.40
June	32.72±24.81	414	76.90	33.00
July	29.98±19.37	584	76.10	30.50
August	33.18±19.36	544	57.41	27.10
September	37.18±25.59	381	57.20	27.00
October	50.48±35.99	412	52.70	30.00
November	95±68.55	6	47.00	29.40
December	135.02±72.94	33	60.80	26.80
Annual Average	79.94±75.55	-	-	-
BNAAQ Standard (Annual)	15	-	-	-
WHO Standard (Annual)	10	-	-	-

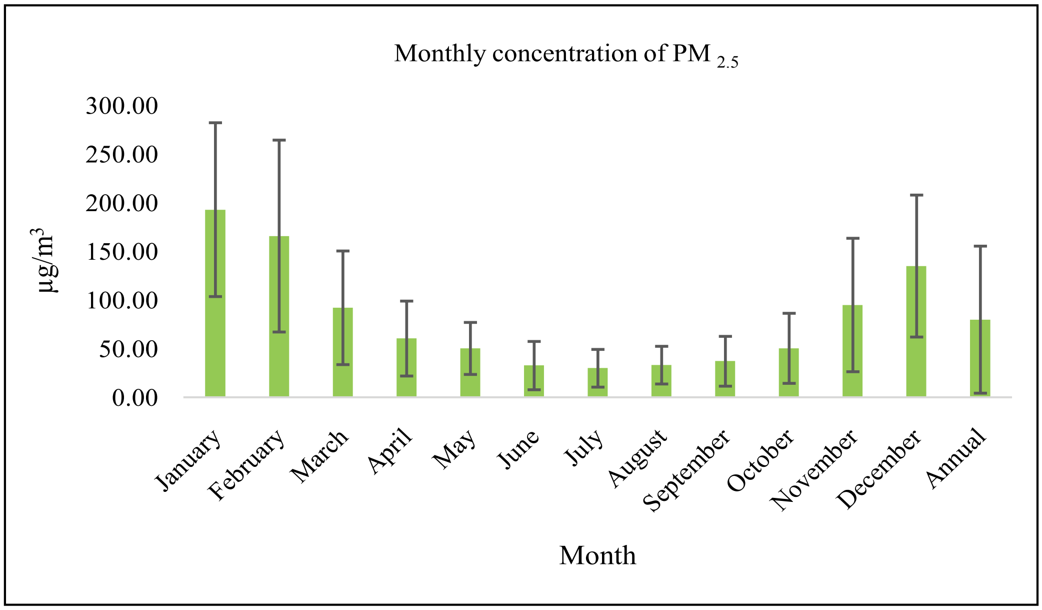

Fig. 2. Monthly variation of $PM_{2.5}$

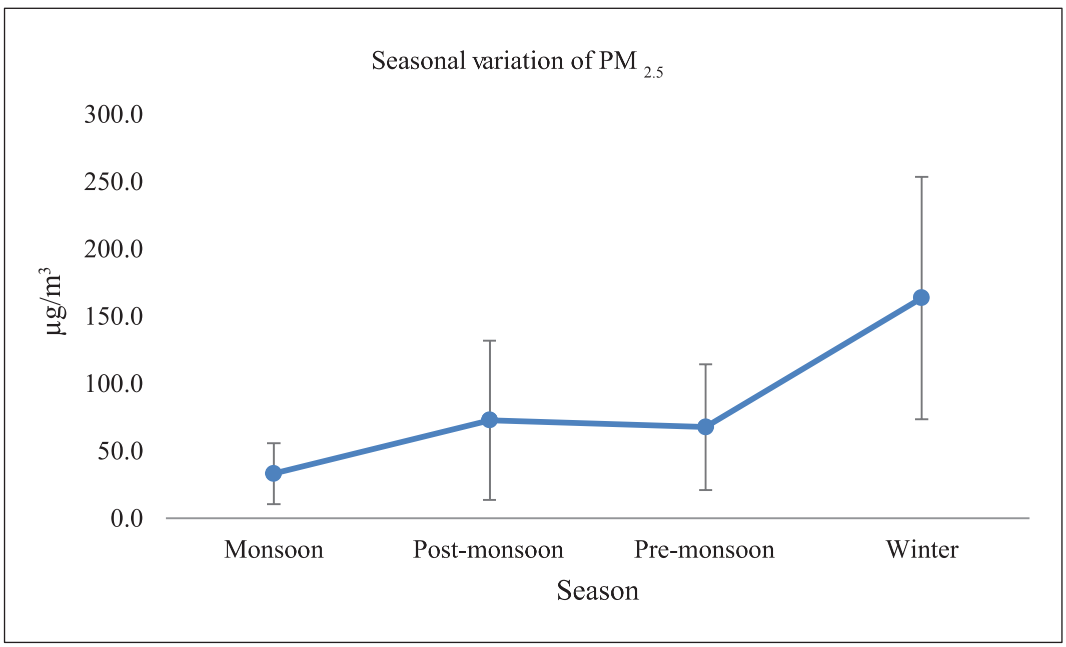

Fig. 3. Seasonal variation of $PM_{2.5}$

Figure 3 shows the seasonal variation of $PM_{2.5}$ in the year of 2017. During winter, including thermal inversions, less rainfall and the high emissions from brick kiln industries are thought to contribute to the increased PM concentrations (Begum *et al.,* 2011). Thus, the suspended road dust and soil dust also amplify the PM concentration during winter. The high and low level concentration of $PM_{2.5}$ during winter and monsoon indicate a strong seasonal influence on $PM_{2.5}$ in Dhaka city. Large amount of $PM_{2.5}$ components are removed by the rainfall activities during monsoon period while it increased more in dry winter season (Hossain and Easa, 2012). Studies found that during the winter season brick kilns start their production which contribute to total air pollution beside the other sources in Dhaka city (Guttikunda *et al.*,

Table II. Seasonal variation of $PM_{2.5}$ in Dhaka city

Season	Duration (Month)	$PM_{2.5}$ ($\mu g/m^3$)
Monsoon	June-September	33.20±22.53
Post-monsoon	October-November	72.88±59.18
Pre-monsoon	March-May	67.74±46.80
Winter	December-February	163.75±90.00

2012). Begum and Hopke (2018) reported that high concentration of PM during the winter season is caused by the seasonal fluctuations of the emissions as well as by the meteorological effects. Studies also found that $PM_{2.5}$ pollutant transported from the north and northwesterly directions (Begum and Hopke, 2018; Begum *et al.,* 2011c; Ommi *et al.,* 2017) which indicates that $PM_{2.5}$ are influenced by trans boundary, particularly in winter season (Begum and Hopke, 2018).

Weekly variation of $PM_{2.5}$

In the day-of-week analysis, the pollution levels generally follow a common pattern for each day of the week. No particular weekend effect has been identified by this analysis. Figure 4 shows the fine particulate matter ($PM_{2.5}$) concentrations were maximum on Wednesday (90.36±86.17 $\mu g/m^3$) and minimum on Saturday (68.35±63.72 $\mu g/m^3$). Very little variation of $PM_{2.5}$ concentrations on the day of week could be attributed to the variation of traffic flows in Dhaka city. It is expected that local transport services could be reduced on weekend (Friday and Saturday), but textile shipment delivery trailer trucks were reported to be a maximum on Friday (Hoque *et al.,* 2013; Khan and Hoque, 2013), which could compensate for expected reductions in local commuter emissions on Friday, which is a religious observance day of the week in Dhaka.

Shifting variation of $PM_{2.5}$

The peak $PM_{2.5}$ concentrations (94.08±86.56 $\mu g/m^3$) were observed at night, between 8pm to 6am (Table III).

Table III. Shift wise average concentration of $PM_{2.5}$

Shift	Duration (GMT+6, Local time)	$PM_{2.5}$ ($\mu g/m^3$)
Morning	06:01am – 12:00pm	78.79±74.67
Afternoon	12:01pm – 05:00pm	57.18±56.11
Evening	05:01pm – 08:00pm	78.03±58.92
Night	08:01pm – 06:00am	94.08±86.56

Shift-wise variations are governed by interplays among the pollution sources, photochemical processes, and weather factors. High pollution concentrations measured during

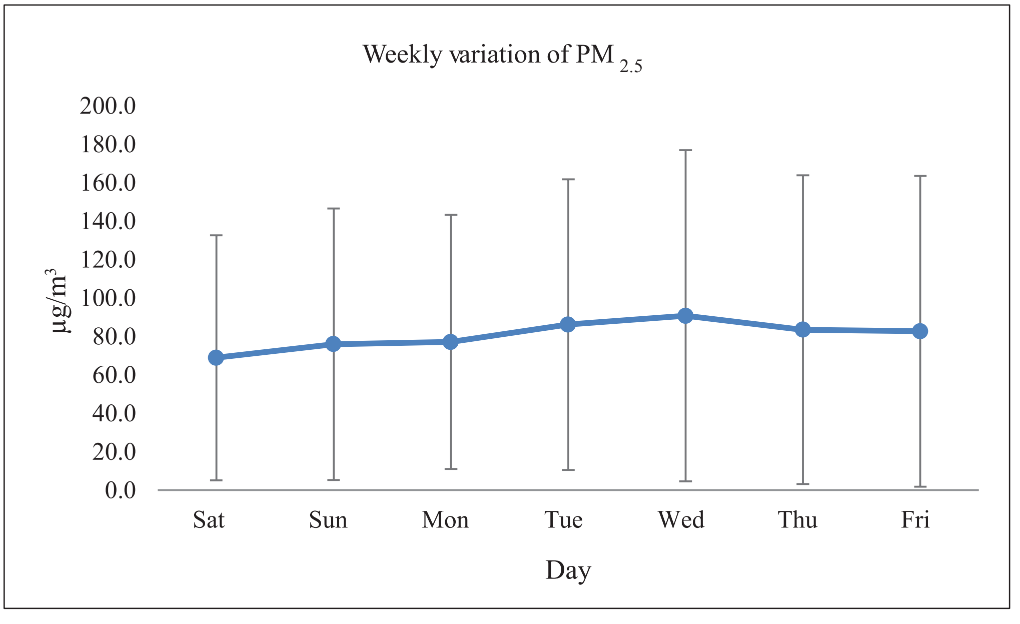

Fig. 4. Weekly variation of $PM_{2.5}$ in Dhaka city in 2017

night time could result from the local rules on traffic flow in Dhaka (as the diesel-powered buses and freight trucks can use Dhaka city route only at night time in between 8pm-6am), low mixing height during night time (Rahman, 2018; Begum *et al.,* 2011). Long-route buses and any kind of heavy-duty diesel trucks are barred from using any highway inside Dhaka during the daytime (DTCB, 2011).The concentration of $PM_{2.5}$ are almost same at morning and evening, where it gets lowest during afternoon and reach highest at night (Fig. 5) which is also reported by the Rana *et al.* (2016).

Number of AQI of $PM_{2.5}$

A summary of the AQI ratings for Dhaka city in 2017 is presented in the Figure 6. According to US AQI chart, in 2017, there were 312 hourly AQI "Good", 2322 were "Moderate," 1801 were rated "Unhealthy for sensitive groups," 2714 were considered "Unhealthy", 1094 were rated "Very unhealthy" and 273 were found hazardous. Although few data couldn't be avail, but the amount of missing data is as few that can be ignorable.

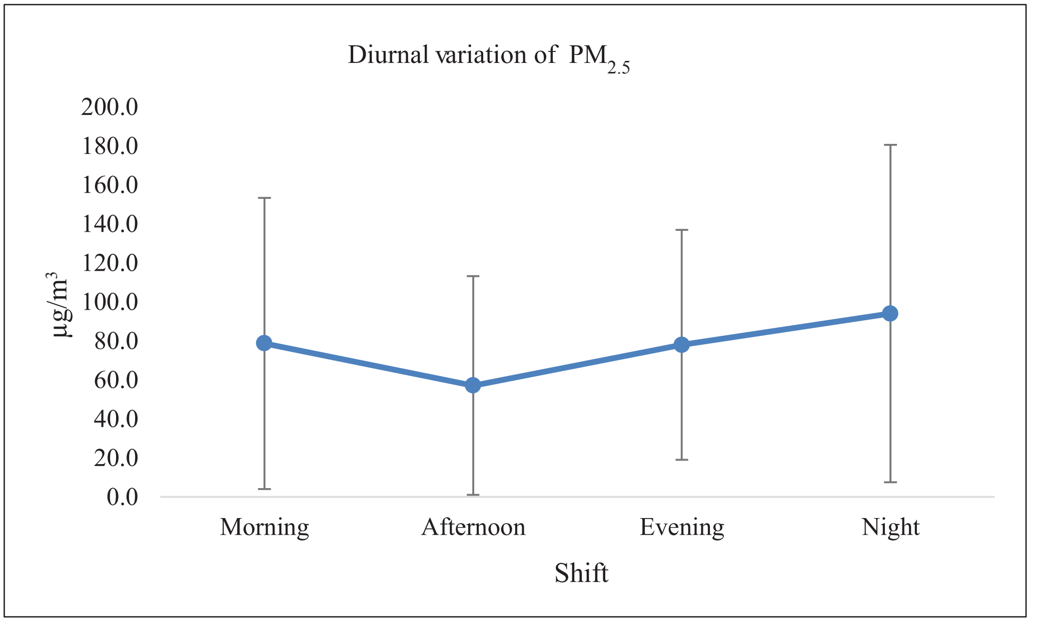

Fig. 5. Diurnal average concentration of $PM_{2.5}$

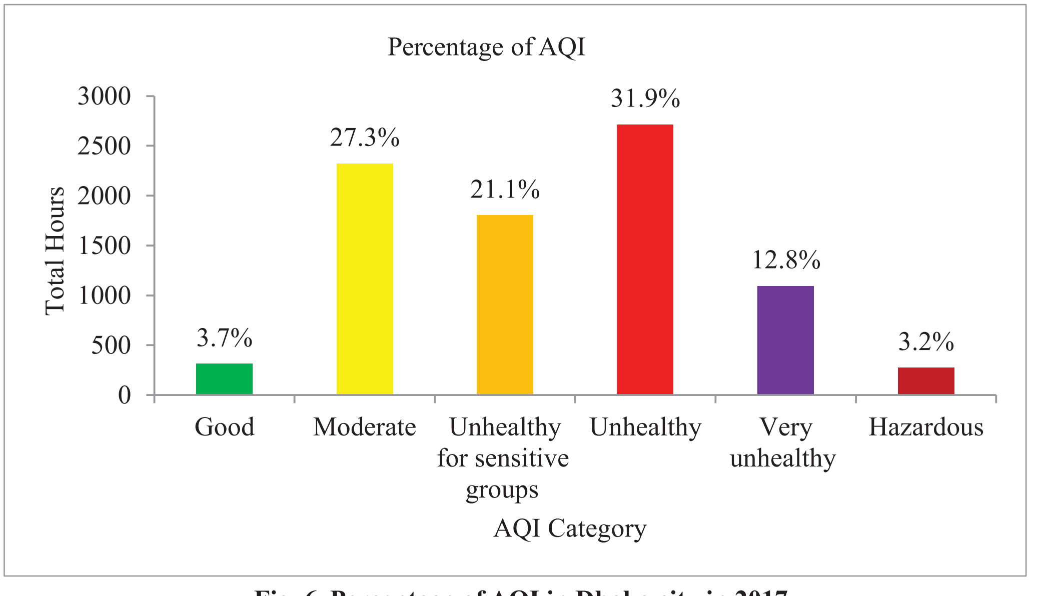

Fig. 6. Percentage of AQI in Dhaka city in 2017

It can be observed that 31.9% of hourly AQI were "Unhealthy" and the percentage of "Good" was very few. Although the category "Very unhealthy" were 12.8% and "Hazardous" were 3.2%, but this is enough to effect on human health. This statistic of AQI indicates that air quality in Dhaka city is considered unhealthy most of the time, so that pollution is bad enough to adversely affect people living or spending time in this city.

Correlation between $PM_{2.5}$ concentrations and selected meteorological parameters

A linear regression analysis (Table V) was performed to predict means $PM_{2.5}$ concentrations (dependent variable) in Dhaka city by considering rainfall, humidity and temperature are independent variable. As R^2 was found to be. 0.715 i.e. it was observed that 71.5% variation in dependent variable had been influenced by independent variable.

Figure 7 presented the seasonal relationship between $PM_{2.5}$ and Meteorological parametrs at dhaka city in 2017. It shows that, during the winter and pre-monsoon season $PM_{2.5}$ is higher when the temperature range is in moderate level. On ther other hand, less amount of hummidty infulence in incresing of $PM_{2.5}$. Besides, during the rainy season, concentration of $PM_{2.5}$ is less than winter season. It also revealed that rainfall and $PM_{2.5}$are strongly coorelated with each other. Less amount of rainfall during winter were the top influencing factor in incresing $PM_{2.5}$ in 2017.

Table IV. Correlation between $PM_{2.5}$ and selected meteorological parameters

		$PM_{2.5}$	Rainfall	Humidity	Temperature
$PM_{2.5}$	Pearson correlation	1	-0.839**	-0.528*	-0.275
	Sig. (1-tailed)		0.000	0.039	0.194
Rainfall	Pearson correlation	-0.839**	1	0.533*	0.269
	Sig. (1-tailed)	0.000		0.037	0.199
Humidity	Pearson correlation	-0.528*	0.533*	1	0.298
	Sig. (1-tailed)	0.039	0.037		0.173
Temperature	Pearson correlation	-0.275	0.269	0.298	1
	Sig. (1-tailed)	0.194	0.199	0.173	

** Correlation is significant at the 0.01 level (1-tailed).
* Correlation is significant at the 0.05 level (1-tailed).

Table V. Regression between $PM_{2.5}$ and metrological parameters

Model summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.845[a]	0.715	0.608	35.52889

a. Predictors: (Constant), Temperature, Rainfall, Humidity

There is a negative Pearson correlation between the rainfall, humidity and atmospheric temperature with $PM_{2.5}$. Table IV shows that humidity and temperature are not much significantly correlated with the $PM_{2.5}$. But, rainfalls are strongly and significantly correlated with the $PM_{2.5}$ while humidity and temperature had weak relationship.

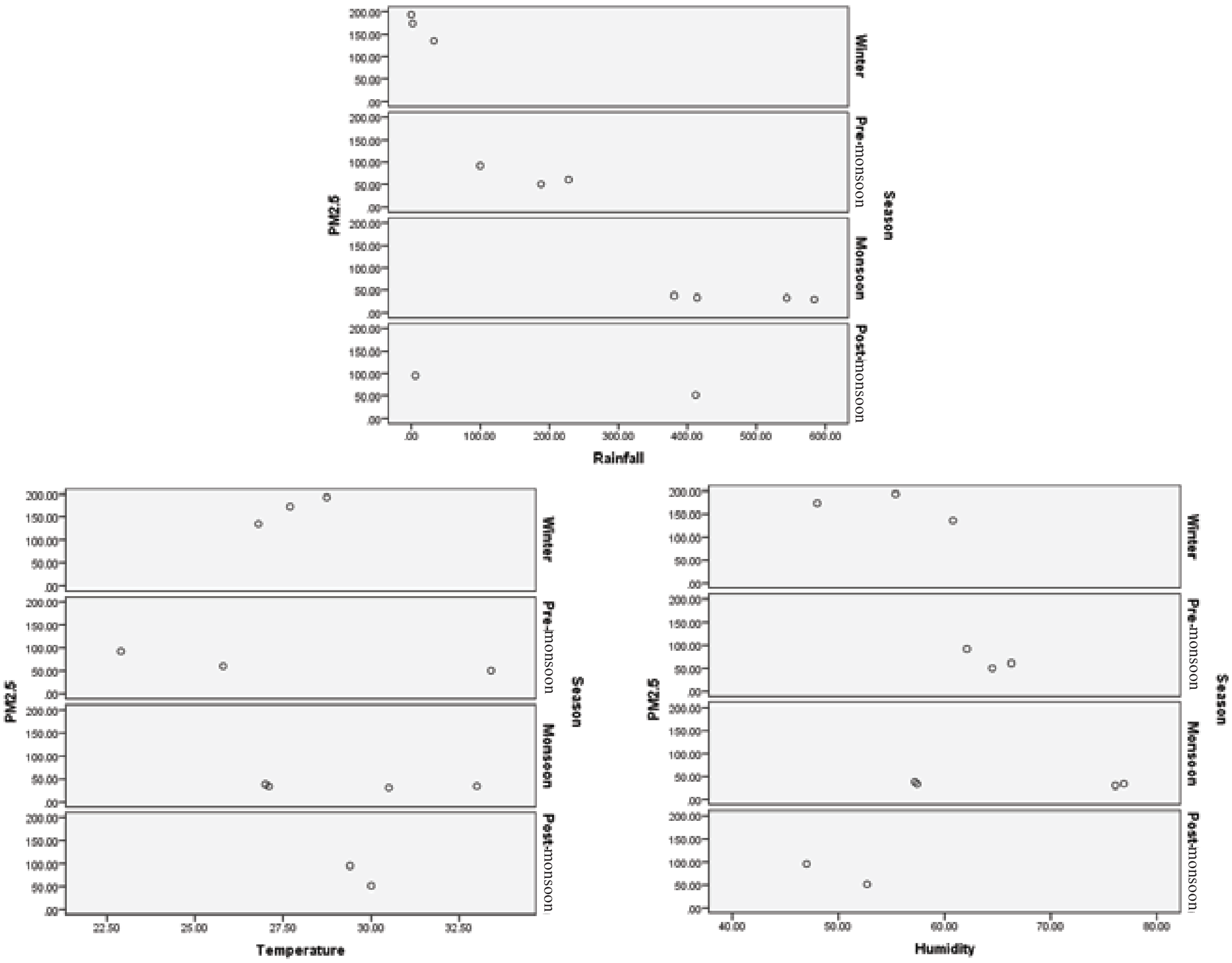

Fig. 7. Seasonal relationship between $PM_{2.5}$ and meteorological parametrs

Conclusion

Air pollution in Dhaka city has reached an alarming level. It has been afflicted with severe air pollution where particulate matter is being identical as the main pollutant. This study investigates the concentration level of $PM_{2.5}$ in Dhaka city in 2017. It has been found that there is a considerable change of $PM_{2.5}$ with different months in a year. The maximum concentration was found in January while minimum was in the month of July. During the seasonal variation, it shows that winter season dominated the whole year in terms of air pollution in 2017. It also found that meteorological characteristics are one of the key factors to influence the concentration of $PM_{2.5}$ in Dhaka city. Especially, rainfall and $PM_{2.5}$ had a strong and negative relationship. This study also found that during the shifting variation night time (8:00 pm to 6:00 am) is leading hour for peak level of PM concentration. Overall airquality score was dominated by unhealthy position (31.9 %) in Dhaka city in 2017. Hence, it is observed that $PM_{2.5}$ and meteorological parameters have a good relationship and for that reason the concentration level are varying with different months and season in a year. Apart from that, more metrological parameter is required to know the exact result as well as need to show the relation between metrological parameters and other pollutants ($PM_{10,}$ BC, $SO_{2,}$ $NO_{2,}$ CO). Improvement and introduction of public transport system and upgradation of mass transportation may contribute to reduce air pollution in Dhaka city. Besides, enforcing the existing regulations and policies, such as ban on traditional high polluting kilns (e.g. FCK, BTK), or alternative use of fire brick such as sand brick could be an effective steps to control the air pollution.

Acknowledgment

The authors are thankful to US Embassy of Dhaka, Bangladesh to provide the $PM_{2.5}$ data publicly through the AirNow Department of State website. Appreciation also goes to Center for Atmospheric Pollution Studies (CAPS) for such an idea to conduct this study.

References

Ahmed S, Akter Q S, Eva H and Bhowmik M (2016), Effect of air pollution on FVC, FEV1 and FEV1/FVC% of the traffic policemen in Dhaka city, *J Bangladesh Soc Physiol* **11(2):** 39–42.

Begum BA, Biswas SK and Hopke PK (2008), Assessment of trends and present ambient concentrations of PM2.2and PM10in Dhaka, Bangladesh Air Quality, *Atmosphere and Health*. **1**(3): 125–133. DOI: 10.1007/s11869-008-0018-7.

Begum BA, Biswas SK, Markwitz A and Hopke PK (2010), Identification of sources of fine and coarse particulate matter in Dhaka, Bangladesh, *Aerosol and Air Quality Research* **10(4):** 345–353. DOI: 10.4209/ aaqr. 2009.12.0082.

Begum BA, Biswas SK and Hopke PK (2011), Key issues in controlling air pollutants in Dhaka, Bangladesh, *Atmospheric Environment* **45**(40): 7705–7713. DOI: 10.1016/j.atmosenv.2010.10.022

Begum BA, Biswas, SK, Pandit GG, Saradhib IV, Waheed S, Siddique N, Seneviratne MCS, Cohen DD, Markwitz A and Hopke PK (2011c), Long range transport of soil dust and smoke pollution in the south Asian region, *Atmos. Pollut. Res*. **2:** 151–157

Begum BA and Hopke PK (2018), Ambient Air Quality in Dhaka Bangladesh over Two Decades: Impacts of Policy on Air Quality, *Aerosol and Air Quality Research*. **18**(7): 1910–1920. DOI: 10.4209/ aaqr.2017.11.0465

Cacciola RR, Sarva M and Polosa R (2002), Adverse respiratory effects and allergic susceptibility in relation to particulate air pollution: Flirting with disaster, *Allergy* **57:** 281-286.

Castellani B, Morini E, Filipponi M, Nicolini A, Palombo M, Cotana F and Rossi F (2014), Comparative analysis of monitoring devices for particulate content in exhaust gases, *Sustainability* **6**(7): 4287–4307. DOI: 10.3390/ su6074287.

Cao J, Chow JC, Lee FSC and Watson JG (2013), Evolution of $PM_{2.5}$ Measurements and Standards in the U.S. and Future Perspectives for China, *Aerosol and Air Quality Research*. **13:** 1197–1211. DOI: 10.4209/ aaqr.2012.11.0302

DTCB, (2011), Dhaka Urban Transport Network Development Project: Environmental Impact Assessment Study, Ministry of Communications (MoC), Government Of The People's Republic Of Bangladesh. Retrieved from: https://libportal.jica.go.jp/ library/Data/DocforEnvironment/EIA-EPC/EastAsia-SouthwesternAsian/DhakaMRT/DhakaMRTEIA.pdf

Donaldson K, Stone V, Borm PJ, Jimenez LA, Gilmour PS, Schins RP, Knaapen M, Rahman I, Faux SP, Brown DM and Macnee W (2003), Oxidative stress and calcium signaling in the adverse effects of environmental particles (PM10), *Free Radic. Biol. Med*. **34**: 1369–1382.

Dockery DW, Pope CA, Xu XP, Spengler JD, Ware JH, Fay ME, Ferris BG and Speizer FE (1993), An association between air pollution and mortality in six U. S. cities, *New England Journal of Medicine* **329:** 1753-1759.

EPA (2009), Standard operating procedure for the continuous measurement of particulate matter. [Available at https://www3.epa.gov/ttnamti1/files/ambient/pm25/sop_ project/905505_BAM_SOP_ Draft_Final_ Oct09. pdf.]

EPA (2015), List of designated reference and equivalent methods. [Available at https://www3.epa.gov/ttnamti1/ files/ambient/criteria/reference-equivalent-methods-lis t.pdf.]

Guttikunda SK, Begum BA and Wadud Z (2012), Particulate pollution from brick kiln clusters in the Greater Dhaka region, Bangladesh. **6:** 357–365. Retrieved from: http://www.urbanemissions.info/wp-content/uploads/d ocs/2013-02-AQAH-Brick-Kilns-in-Dhaka.pdf

Hassanen RA (2016), Leaf Dust Accumulation and Air Pollution Tolerance Indices of Three Plant Species Exposed to Urban Particulate Matter Pollution from a Fertilizer Factory, *International journal of plant research* **29**(3): 146-151.

Health Effects Institute (HEI) (2018), State of Global Air 2018, Special Report, Boston, MA.

Hossain KA and Easa SM (2012), Pollutant Dispersion Characteristics in Dhaka City, Bangladesh, *Asia-Pacific J. Atmos. Sci*. **48**(1): 35–41. DOI: 10.1007/s13143-012-0004-8.

Hoque MS, Ullah MA and Nikraz HN (2013), Investigation of Traffic Flow Characteristics of Dhaka, *International Journal of Civil Engineering and Technology* **4**(4): 55–65.

Jeff G and Hans P (2004), Assessment of Environmental Impact of the Holcim Cement—Dundee Plant, *Ecology Centre*, Retrieved from http://www.wbsed.org/web/project/cement/tf5/holcmm.htm.

Kan H, London SJ, Chen G, Zhang Y, Song G, Zhao N, Jiang L and Chen B (2007), Differentiating the effects of fine and coarse particles on daily mortality in Shanghai, China, *Environ. Int.* **33:** 376–384.

Khan SM, and Hoque MS (2013), Traffic Flow Interruptions in Dhaka City: Is Smooth Traffic Flow Possible? *Journal of PU*, Part: B **2:** 46-54

Li X, Chen X., Yuan X, Zeng G, Leon T, Liang J and Yuan X (2017), Characteristics of Particulate Pollution (PM 2 . 5 and PM 10) and Their Spacescale-Dependent Relationships with Meteorological Elements in China, *Sustainability* **9:** 1–14. DOI: 10.3390/ su9122330

Ommi A, Emami F, Zikova N, Hopke PK and Begum BA (2017), Trajectory-based models and remote sensing for biomass burning assessment in Bangladesh, *Aerosol Air Qual. Res.* **17**: 465–475

Peng RD, Chang HH, Bell ML, McDermott A, Zeger SL, Samet JM and Dominici F (2008), Coarse particulate matter air pollution and hospital admissions for cardiovascular and respiratory diseases among Medicare patients, *JAMA* **299:** 2172–2179. DOI: 10.1001/jama.299.18.2172

Rana MM, Sulaiman N, Sivertsen B, Khan MF and Nasreen S (2016), Trends in atmospheric particulate matter in Dhaka, Bangladesh, and the vicinity, *Environmental Science and Pollution Research* **23**(17): 17393–17403.

Rahman M (2018), Monitoring and Characterization of PM_{10} and $PM_{2.5}$ Air-borne Particulate Matter in Dhaka city, *M.Sc.* Thesis, Department of Chemical Engineering, Bangladesh University of Engineering and Technology.

Rouf MA, Nasiruddin M, Hossain AMS and Islam MS (2011), Trend of Particulate Matter $PM_{2.5}$ and PM_{10} in Dhaka City **46**(3): 389–398. DOI: 10.3329/ bjsir.v46i3.9049

Salam A, Bauer H, Kassin K, Ullah SM and Puxbaum H (2003), Aerosol Chemical Characteristics of an Island Site in the Bay of Bengal (Bhola-Bangladesh), *Journal of Environmental Monitoring* **5:** 483-490. DOI: 10.1039/b212521h.

Salam A, Hossain T, Siddique MNA and Alam AMS (2008), Characteristics of Atmospheric Trace Gases, Particulate Matters, and Heavy Metal Pollutions in Dhaka, Bangladesh, *Air Quality, Atmosphere and Health* **2:** 101-109. DOI: 10.1007/ s11869-008-0017-8

Salam A, Ullah MB, Islam MD, Salam MA and Ullah SM (2013), Carbonaceous Species in Total Suspended Particulate Matters at Different Urban and Suburban Locations in the Greater Dhaka Region, Bangladesh, *Air Quality, Atmosphere and Health* **6:** 239-245. DOI: 10.1007/ s11869-011-0166-z

Tabaku A, Bejtja G, Bala S, Toci E and Resuli J (2011), Effects of air pollution on children's pulmonary health, *Atmospheric Environment* **45:** 7540- 7545

USEPA (2017), Particulate Matter (PM) Basics. Retrieved from: https://www.epa.gov/ pm-pollution/ particulate-matter-pm-basics

USEPA (2009), Air Quality Index: A Guide to Air Quality and Your Health, Research Triangle Park, Office of Air Quality Planning and Standards.

USEPA (1999a), Environment Fact Sheet: Management Standards Proposed for Cement Kiln Dust Waste. Retrieved from http://www.epa.gov/fed.gstr/EPA-AIR/199/Some/Day-14/a12893.htm.

USEPA (1999b), National Emission Standards for Hazardous Air Pollutants for Source Categories, Cement Manufacturing Industries Federal Register **64:** 113. Retrieved from http://www.epa.gov/fed.gstr/EPA-AIR/199/ Some/Day-14/a12893.htm.

Valavanidis A, Fiotakis K and Vlachogianni T (2008), Airborne particulate matter and human health: toxicological assessment and importance of size and constituent of particles for oxidative damage and carcinogenic mechanisms, *Journal of Environmental Science and Health* **26:** 339–362.

WB (World Bank) (2018), Enhancing Opportunities For Clean And Resilient Growth In Urban Bangladesh, Country Environmental Analysis Report.

WHO (World Health Organization) (2001), Outdoor Air Pollution. WHO, Geneva.