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Meteorological and seasonal influences in ambient air quality parameters of Dhaka city

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Abstract

This paper aims at understanding the meteorological and seasonal influences in ambient air quality of Dhaka city by analyzing air quality and meteorological data. Trends in air quality over the past decade show large seasonal variations in both $PM_{2.5}$ and PM_{10} concentrations, exceeding the national standards during the dry season, while remaining somewhat below the standards during the rainy season. High PM concentrations have been found to be associated with winds coming from northern and north-western directions during the dry season, suggesting that the brick kiln clusters situated in the northern periphery of the city are contributing to the degraded air quality. A weak albeit positive correlation of PM with wind speed from north-western direction suggests that dilution of PM due to increased wind speed is very low. The coarse fraction of PM exhibited positive correlation with incident solar radiation suggesting increased formation of coarse nitrate particles by enhanced photochemical activity. Strong negative correlation of PM with relative humidity indicates possible absorption of moisture by particulate matter promoting settling and removal from suspension. Significant negative correlation between PM and temperature indicates that higher PM tends to reduce atmospheric temperature due to its net negative radiative forcing. Strong positive correlation of PM with NO_x concentrations during dry season suggests that apart from PM, the brick kilns may be major sources of NO_x during the dry season. Results from this study emphasize the need for understanding air quality under the context of local meteorological conditions and spatial distribution of major sources.

Keywords: Particulate Matter, Air Pollution, Brick Kilns, Meteorology, Correlation Coefficient

1. Introduction

Dhaka, with more than 15 million inhabitants, is one of the 20 megacities in the world (UN HABITAT, 2008) and facing severe urban air pollution problems. Based on publicly available air quality data from 1,100 cities including cities with populations of more than 100,000 people, WHO assessed that Dhaka is among the top 20 cities with the worst air pollution problem (WHO, 2011).This is primarily due to the high population density in this city (around 8,111 per square kilometer) which places its inhabitants at high risk of significant health impacts due to exposure to airborne contaminants. Vehicular emission, brick kilns and re-suspended dust from roads have been identified as major sources of air pollution in Dhaka city (Guttikunda, 2009). Among the air quality parameters in Dhaka city, the Particulate Matter (PM) has been the most widely studied due to its strong correlation with health outcomes and more recently due to its high concentrations in Dhaka city exceeding national ambient air quality standards during most parts of the year.

In Dhaka city, the major sources of PM_{10} have been found to be soil dust, road dust and motor vehicle emissions, while brick-kilns and motor vehicles have been found to be the main contributors to $PM_{2.5}$ (Guttikunda, 2009; Begum *et al.*, 2004). Among various sources, brick kiln is of particular importance as it is a seasonal pollution source and the brick kiln industry is one of the fastest-growing sectors, supporting the booming infrastructure and construction industry. With a current manufacturing capacity of about 12 billion bricks a year from 4,500 brick kilns surrounding all major cities (especially Dhaka, Khulna, Rajshahi, and Chittagong), the industry is expected to grow 50% by 2020 (World Bank, 2007; UNDP, 2011). The brick manufacturing is primarily confined to the dry periods (October to March) as current technologies do not allow production during wet periods (April to September).The contribution of brick kiln emissions to the ambient air quality have previously estimated from the source apportionment studies conducted in 2001-2002, 2005-2006 and 2007-2009 (Begum *et al.*, 2006, 2008, 2011). These studies estimated an average of 30 – 40% contribution of brick kilns to total ambient $PM_{2.5}$ in Dhaka city during dry season.

Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in precipitation, moderately warm temperatures, and high humidity with minor regional climatic differences. Air quality of Dhaka is also characterized by high seasonal variation (Fig. 1).The daily PM_{10} and $PM_{2.5}$ concentrations exceed the national standards (GoB, 2005) (50 $\mu g/m^3$ and 150 $\mu g/m^3$ for PM_{10} and 15 $\mu g/m^3$and 65$\mu g/m^3$ for $PM_{2.5}$ for annual and 24-hour averaging period, respectively) by a factor of about two during the dry season, whereas during the wet season the ambient concentrations of PM have been found to be somewhat lower. Meteorological parameters such as wind speed and direction, precipitation, temperature, relative humidity and solar radiation can affect dispersion processes, removal mechanisms and formation of atmospheric particles and hence govern PM_{10} and $PM_{2.5}$ concentrations. Many studies indicated that TSP and PM_{10} concentrations in ambient air are affected by wind speed, wind direction, solar radiation, relative humidity and precipitation (Alpert *et al.*, 1998; Galindo *et al.*, 2011; Giri *et al.*, 2008; Owoade *et al.*, 2012).

A number of studies have been carried out on source apportionment (Begum *et al.*, 2004, 2005; Biswas *et al.*, 2001; Guttikunda, 2009), elemental characterization (Begum *et al.*, 2006; Boman *et al.*, 2005), and spatio-temporal distribution (Begum *et al.*, 2006) of PM in Dhaka city. However, a systematic study examining the relationship of various meteorological parameters with air quality is yet to be done. In this paper, the relationship between meteorological parameters and particulate matter (PM) pollution dynamics in Dhaka city has been investigated. This study also attempts to explain the nature of the influence of emissions from brick kilns on the ambient air quality of Dhaka city.

2. Materials & methods

This study is based on the air quality data of Shangshad Bhaban Continuous Air Monitoring Station (CAMS), which is located in an open, flat area approximately 150 meters away from the heavily trafficked Rokeya Sharani and 300 meters from Manik Mia Avenue. The CAMS measures concentrations of CO, SO_2, NO_x, O_3, CH_4 and non-methane hydrocarbon by using multiple gas analyzers. 24 hr average concentrations of $PM_{2.5}$ and PM_{10} are also measured at the CAMS using high volume PM_{10} and $PM_{2.5}$ samplers. Hourly data of NO_x, SO_2, CO, O_3 are available from April 2002 to September 2005. Daily data of $PM_{2.5}$ and PM_{10} are available from April 2002 to May 2004; and monthly data of $PM_{2.5}$ and PM_{10} are available from April 2002 to December 2010. The PM_{10} concentrations have been divided into two size fractions, $PM_{2.5}$ and $PM_{2.5\text{-}10}$ (=PM_{10} – $PM_{2.5}$) for this study.

Meteorological data for Dhaka city have been collected from two sources: Shangshad Bhaban CAMS and Bangladesh Meteorological Department (BMD). In Shangshad Bhaban CAMS, recorded data on atmospheric temperature, rainfall, relative humidity, and solar radiation are available from October 2002 to May 2004 as hourly averages. 24-hour average data on atmospheric temperature, rainfall, relative humidity and solar radiation have been used in this study. Daily wind speed and wind direction data have been collected from Bangladesh Meteorological Department (BMD); these data are not available at the Shangshad Bhaban CAMS. The BMD maintains a network of surface and upper air observatories, radar and satellite stations, agro-meteorological observatories, geomagnetic and seismological observatories and meteorological telecommunication systems. Data of almost all meteorological parameter are available at BMD since 1953.

As mentioned earlier, the daily recorded PM data from the Shangshad Bhaban CAMS is only available for the period October 2002 to May 2004, while monthly PM data are available up to 2010. In order to analyze the influences of meteorological parameters, the CAMS daily PM data from October 2002 to May 2004 have been used. The Shangshad Bhaban CAMS meteorological data was used for the period during which it was available, whereas for the remaining periods, meteorological data from BMD were used. For the analysis on meteorological influences, the October 2002 to May 2004 period was further subdivided into three periods which are referred to as Dry period-1 (October 2002 to March 2003), Wet period (April 2003 to September 2003) and Dry period-2 (October 2003 to March 2004). Generally each period has its own unique meteorological conditions that can affect the concentrations of the particulate matter. Dry period is characterized by dry soil conditions, low relative humidity, low or no rainfall and prevailing winds of low speed from the northwest. Heavy rainfall occurs in wet period, which is characterized by high relative humidity, prevailing winds from southeast and a closure of brick-kiln operation. Pearson's correlation was used to determine the degree of association between different climatic variables and PM concentrations. A significance level of 5% ($p = 0.05$) has been chosen to be the threshold for determining the significance of the correlation coefficient.

3. Results & discussion

Fig. 1 shows the time series of monthly $PM_{2.5}$ and $PM_{2.5\text{-}10}$ concentrations during the period 2002-2010. The figure shows strong seasonal variation of both PM fractions. Monthly PM show higher concentrations in dry period (October to March) compared to wet period (April to September). Usually wet deposition due to precipitation and seasonal pollution source (i.e., brick kilns operating in the dry period only) are considered as the main reasons for this seasonal variation. The number of rainy days in a month during the wet period has been found to have strong negative correlation with average monthly PM concentrations (Fig. 2) with correlation coefficients -0.85 and -0.94 for $PM_{2.5}$ and $PM_{2.5\text{-}10}$, respectively. This indicates that during the closure period of the brick kilns in the wet season, the prevalence of PM in air is strongly associated with rainfall period. However, the daily amount of rainfall during the wet period does not seem to have any effect on the daily PM concentration as $PM_{2.5\text{-}10}$ showed insignificant negative correlation ($r = -0.15$, $p = 0.379$), while $PM_{2.5}$ showed insignificant positive correlation ($r = 0.06$, $p = 0.734$) (Figure 3). This indicates that although precipitation in general may promote wet deposition of particulates, the daily rainfall itself does not significantly dictate the magnitude of PM concentrations and therefore it may not be a significant indicator of air pollution potential.

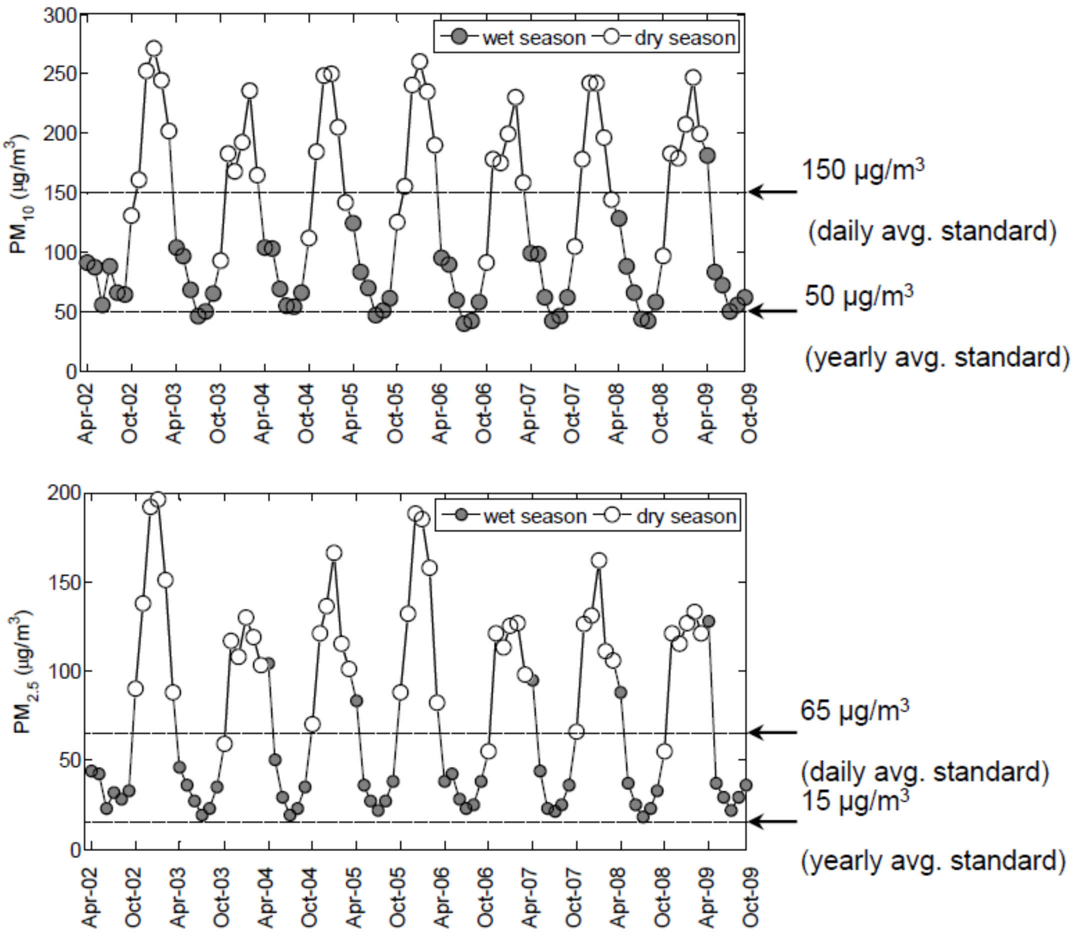

Fig. 1. Monthly average PM_{10} and $PM_{2.5}$ trend in Dhaka city as measured at the Shangshad Bhaban CAMS.

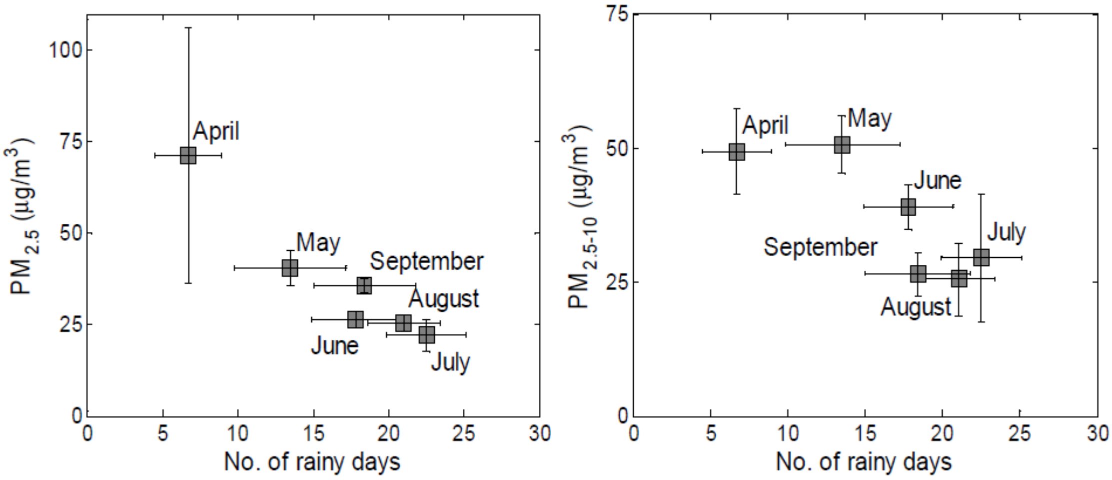

Fig. 2. Average monthly PM concentrations against number of rainy days in a month during wet period showing a decrease in particulate matter concentration with increased number of rainy days

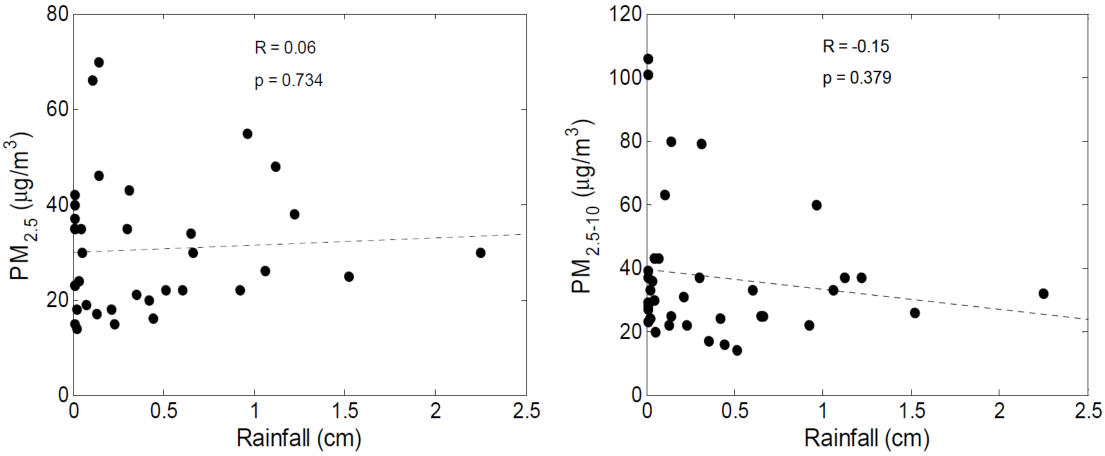

Fig. 3. Scatter plot of different PM fractions and rainfall intensity during wet period showing a weak correlation between them. The dashed line represents the trend of the relationship as determined through linear regression.

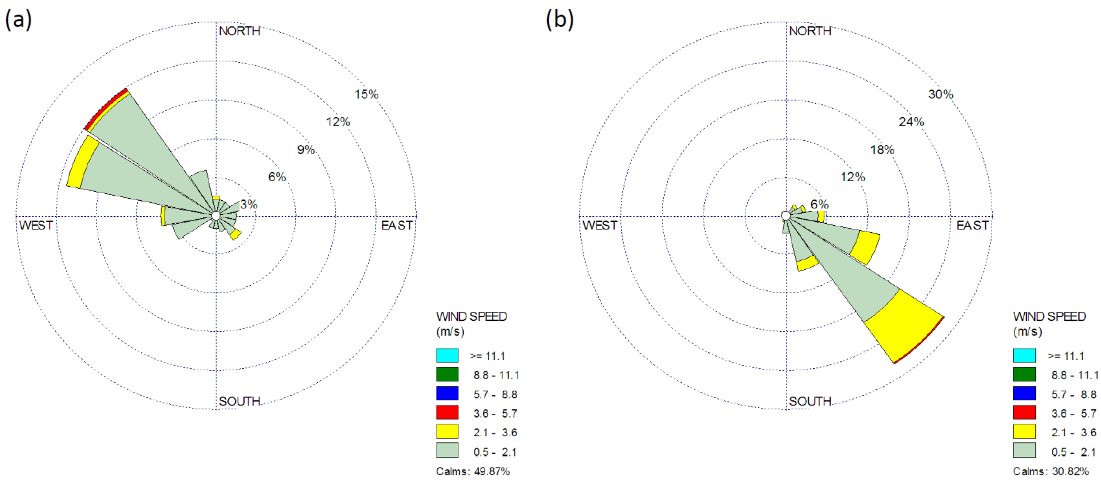

Fig. 4. Wind rose plot in (a) Dry period and (b) Wet Period

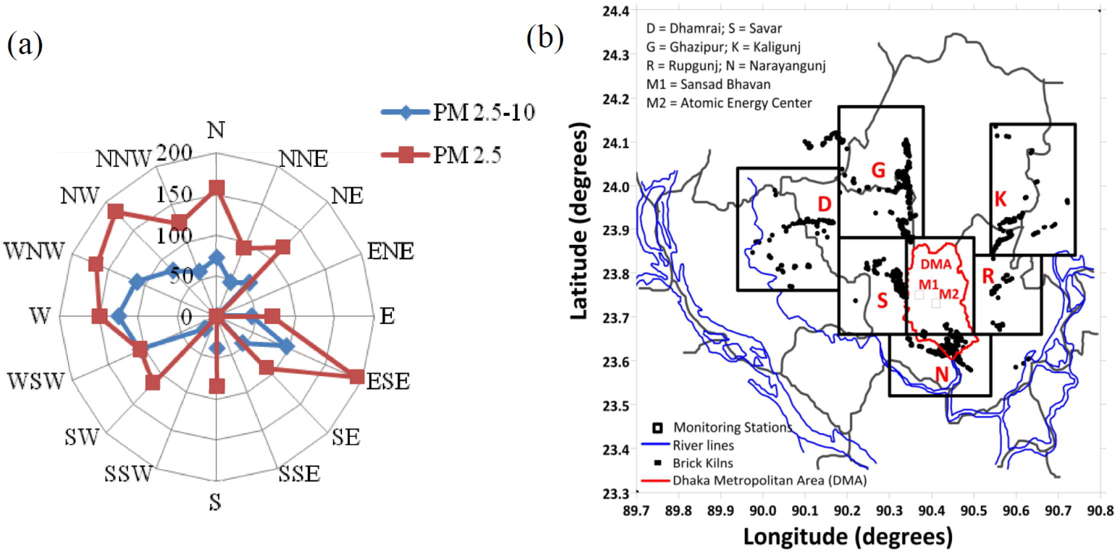

Fig. 5. (a) Radar plot showing the concentration of $PM_{2.5}$ and $PM_{2.5\text{-}10}$ corresponding to different wind directions during the dry period and (b) Brick clusters around Dhaka City (Guttikunda and Khaliquzzaman 2013)

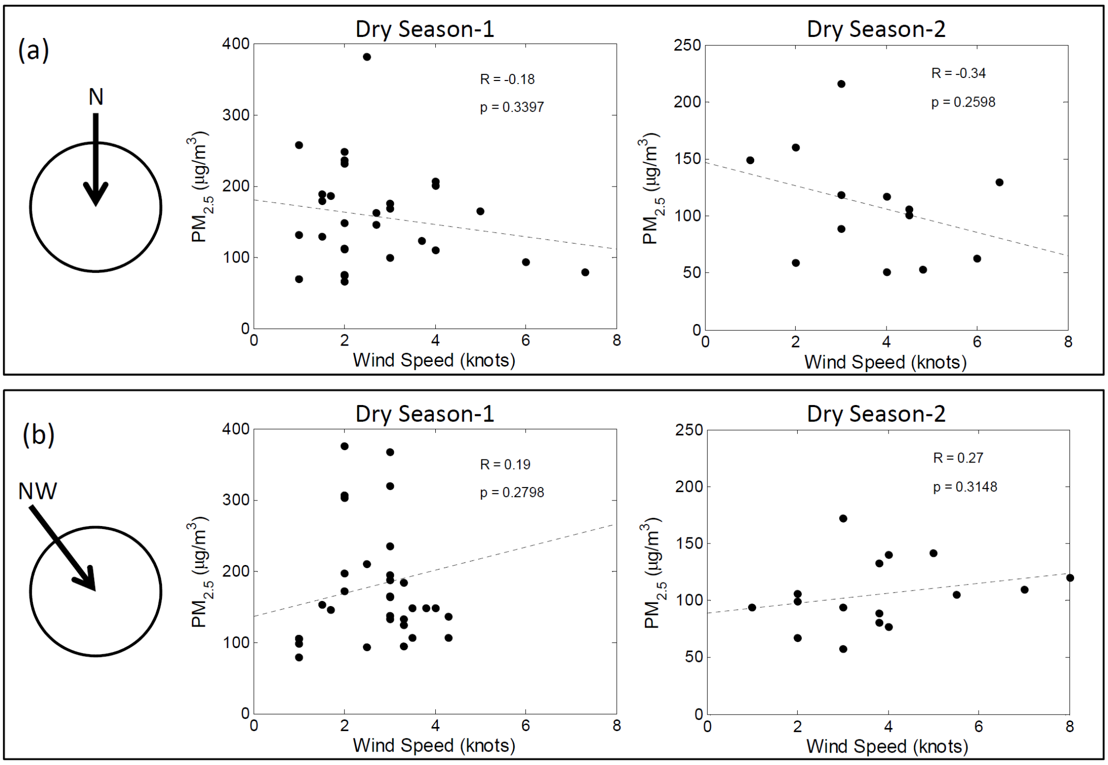

Fig. 6. Scatter plot showing the relationship between $PM_{2.5}$ and wind speed in dry season for two different wind directions: (a) north, and (b) and northwest

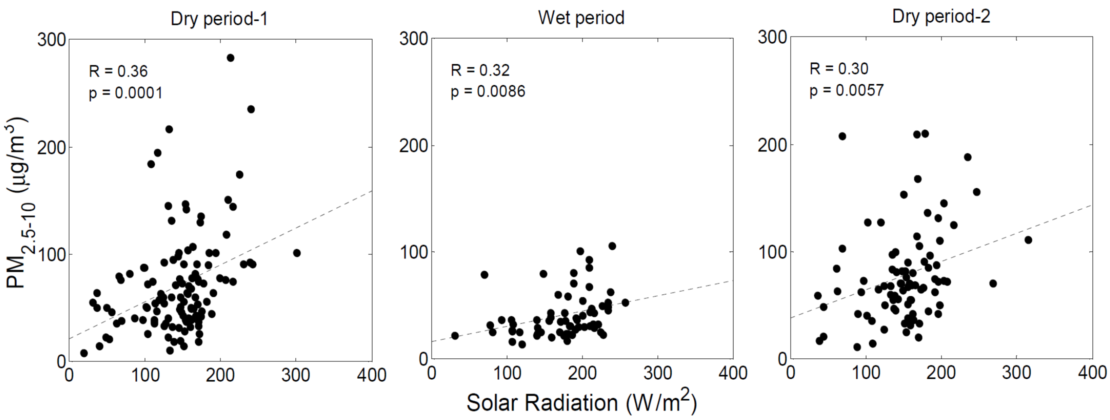

Fig. 7. Scatter plot of $PM_{2.5\text{-}10}$ and Solar Radiation during dry period-1, wet period and dry period-2 showing positive correlation between the two variables in all three periods

The air pollutants can get airborne from the ground surface (e.g. re-suspension of particulates due to vehicular movement in the urban environment), they can be emitted from an elevated stack (e.g., emission from a brick kiln), and they can be formed in the atmosphere (secondary PM). Their residence in the atmosphere and transport are controlled not only by the rate of emission/formation but also by certain physical parameters such as wind speed and direction. The direction and speed of the prevailing wind may significantly affect the concentration, distribution and translocation of the particles (Giri *et al.*, 2008; Van der Wal et al., 1996, 2000). Wind speed and direction provide real-time information on pollutant transport in a region and can be used to assess the relationships between sources and pollutant levels.

The two wind rose plots for Dhaka city in Fig. 4 shows that the predominant wind direction for dry and wet periods are north-west (NW) and south-east (SE), respectively. In order to study the effect of wind speed and direction on PM concentrations, the dry period dataset during October 2002 – May 2004 has been used. The wet period was not considered in the analysis because the major pollution sources located outside the city boundary (i.e., the brick kilns) remain closed during that period. Winds coming from different directions are grouped into 16 categories such as N, NNE, NE, ENE, E etc. and for each specific direction, the days on which winds were coming from that direction have been identified and the concentrations of PM for those particular days have been averaged. The radar plot in Fig. 5a shows the average PM concentrations of each of these categories for the dry period. Both $PM_{2.5}$ and $PM_{2.5\text{-}10}$ show higher concentrations when winds come from north-west direction (Fig. 5a). This is expected as the major brick clusters of Gazipur, Savar and Dhamrai are situated along the northwestern periphery of Dhaka city (Fig. 5a), and wind blowing from those directions will likely carry the particulate pollution load. There is a slight confounding factor of increased concentration due to southeastern wind direction because there are no known brick kiln clusters in that direction. This indicates that there might be industries in that direction other than brick kilns that might contribute higher particulate concentrations. The likely contributors are the industrial installations in Narayanganj which are mostly located along the banks of the Sitalakhya River. The degraded airshed in that region is documented in several reports (BRTC, 2012). The strong association between wind blowing from the north and northwestern direction and PM concentrations supports the hypothesis that during the dry period brick clusters of Gazipur, Savar and Dhamrai significantly dominate the air quality of Dhaka city.

In order to understand whether wind speed has any bearing on the PM concentrations of Dhaka city, the dry season data was further filtered and PM data associated with N and NW wind directions were considered. The wind from North (N) and Northwestern (NW) directions were correlated with the corresponding daily $PM_{2.5}$ concentrations and the scatter plots are shown in Figure 6. For winds blowing from the north (N) direction, a weak negative correlation was found between wind speed and $PM_{2.5}$ concentration for both dry period-1 ($r = -0.18$) and dry period-2 ($r = -0.34$). A weak positive correlation was found corresponding to wind blowing from north-west (NW) ($r = 0.19$ and 0.27 for dry period-1 and dry period-2 respectively). However, all of these correlations were found to be insignificant ($p>0.05$) indicating that wind speed does not appear to have a significant influence on PM concentration in Dhaka.

$PM_{2.5\text{-}10}$ showed fairly good positive correlation (Fig. 7) with solar radiation ($r = 0.36$, 0.32 and 0.30 respectively for dry-1, wet and dry-2 periods, $p>0.05$ in all cases) while $PM_{2.5}$ showed no significant correlation (not shown in figure, see Table 1). The correlation coefficients corresponding to $PM_{2.5}$ are -0.004, 0.02 and -0.08, respectively for dry-1, wet and dry-2 periods. This could be due to formation of coarse nitrate particles by photochemical activity (Giri et al., 2008; Nicolas *et al.*, 2009). Nitrogen oxides are oxidized to nitric acid in the atmosphere, which in turn form nitrate particles (Matsumoto and Tanaka, 1996). This conversion is dependent on the degree of photochemical activity (Chang *et al.*, 1979) i.e. the intensity of incident solar radiation. Mehlmann and Warneck (1995) reported that particulate nitrate existed mainly in the coarse size range and it can be expected that larger fraction of PM would be positively correlated with the degree of solar radiation.

Humidity influences particles to gather mass and settle down on the ground. Because of this, the average PM concentrations have been found to show a decreasing trend with the increase in ambient relative humidity (Giri *et al.*, 2008). From the air quality data of Dhaka city, the coarser fractions ($PM_{2.5\text{-}10}$) of particulate matter show comparatively better negative correlation with humidity (Fig. 8) in all periods (r = -0.48, -0.58 and -0.61 respectively for dry-1, wet and dry-2 periods, p<0.05 in all cases), compared to finer fraction (not shown in figure, see Table 1). The correlation coefficient of finer fractions for the three periods have been found to be -0.09,-0.42 and -0.17, respectively. This may be due to the fact that coarser PM fraction dominated by soil/road dust are likely to absorb more moisture compared to finer PM fraction coming mainly from vehicular and industrial (including brick kiln) sources.

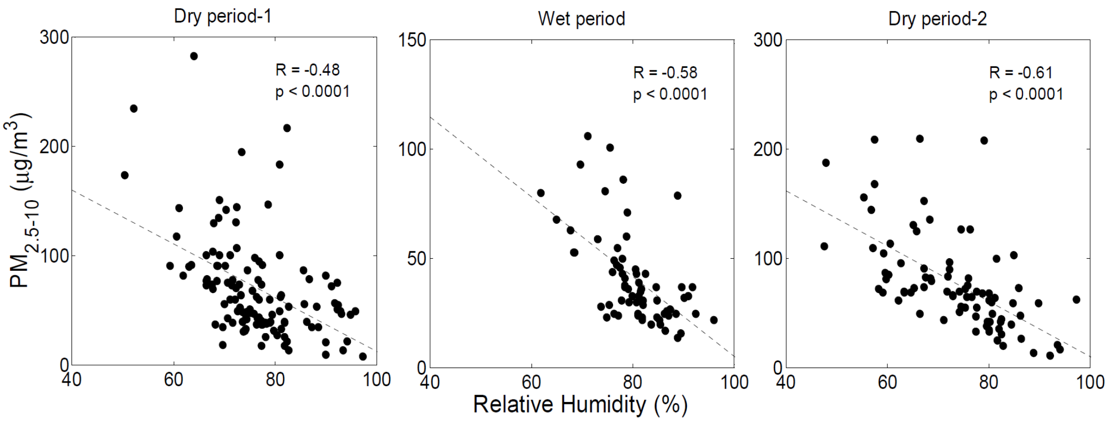

Fig. 8. Scatter plot of $PM_{2.5\text{-}10}$ and Relative Humidity during dry period-1, wet period and dry period-2 showing negative correlation between the two variables in all three periods

Table 1
Pearson's correlation coefficient (r) of Solar Radiation (SR), Relative Humidity (RH), Precipitation, NO_x and Wind Speed (WS) with PM fractions

Time Period	PM Fractions	SR	RH	Precipitation	NO_x	WS	
						N-Direction	NW-Direction
Dry Period-1	$PM_{2.5}$	-0.004 (0.965)	-0.09 (0.3)		0.63 (<0.0001)	-0.18 (0.339)	0.19 (0.279)
	$PM_{2.5\text{-}10}$	0.36 (0.0001)	-0.48 (<0.0001)		0.16 (0.136)		
Wet Period	$PM_{2.5}$	0.02 (0.859)	-0.42 (0.0005)	0.06 (0.734)	0.62 (<0.0001)		
	$PM_{2.5\text{-}10}$	0.32 (0.009)	-0.58 (<0.0001)	-0.15 (0.379)	0.07 (0.595)		
Dry Period-2	$PM_{2.5}$	-0.08 (0.512)	-0.17 (0.109)		0.64 (<0.0001)	-0.34 (0.259)	0.27 (0.315)
	$PM_{2.5\text{-}10}$	0.30 (0.006)	-0.61 (<0.0001)		0.31 (0.0015)		

A wider range of temperature prevails during the dry periods and $PM_{2.5}$ show strong negative correlations (r = -0.46, p<0.05) with it, while a weak negative (r = -0.09, p = 0.2109) is obtained for $PM_{2.5\text{-}10}$ (Fig. 9). Similar observations have been reported for Cairo (Elminir, 2005) and Kathmandu Valley (Giri *et al.*, 2008). Significant negative correlation between PM and temperature implies that higher PM tends to reduce atmospheric temperature due to net negative radiative forcing, which induces a cooling effect. Wet period shows narrow range of temperature in Dhaka city which is not significant to establish any trend.

NO_x can be considered an indicator of vehicle emissions (Artíñano *et al.*, 2004; Smargiassi et al., 2005).To investigate the contribution of traffic to PM levels, correlations between PM concentrations and NO_x are calculated separately for the dry and wet periods. $PM_{2.5\text{-}10}$ shows weak positive correlations (r = 0.16, 0.07 and 0.31, respectively for dry-1, wet and dry-2). Good positive correlations (r = 0.63, 0.62 and 0.64, respectively for dry-1, wet and dry-2, $p<0.05$ for all cases) are obtained for the fine fraction ($PM_{2.5}$) in all time periods (Fig. 10), suggesting that traffic is a major source of $PM_{2.5}$ in Dhaka city throughout the year. This finding is in agreement with various studies undertaken for Dhaka city (Begum et al. 2004, 2005, 2010; Biswas *et al.* 2000; Guttikunda 2009).

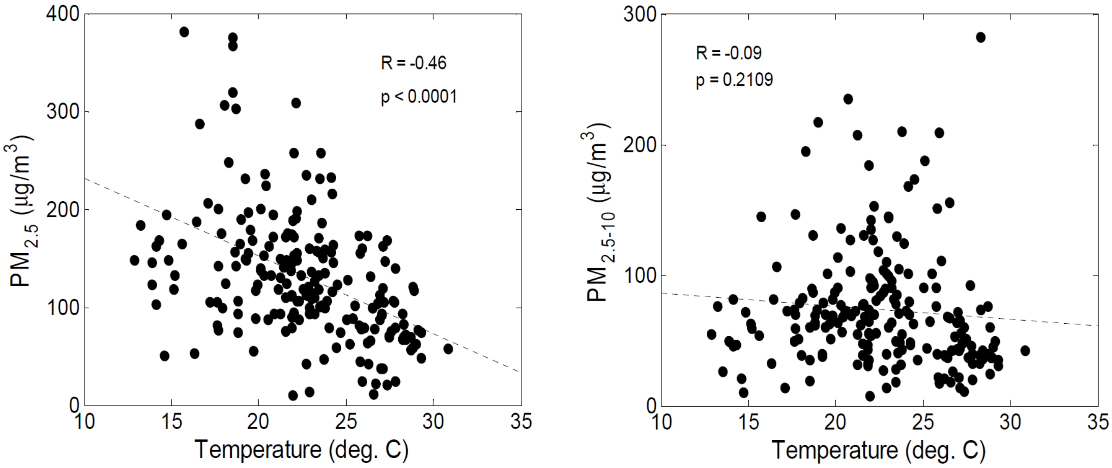

Fig. 9. Scatter plot of different PM fractions and temperature. The dashed line represents the trend of the relationship as determined through linear regression.

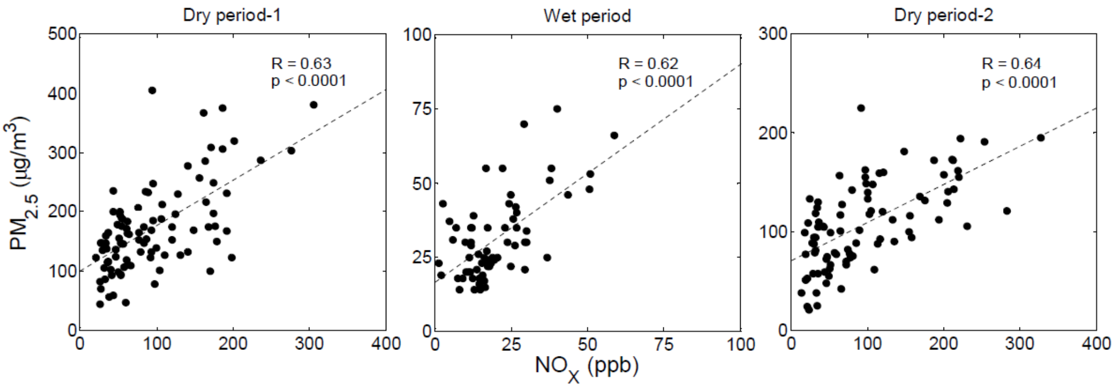

Fig. 10. Scatter plot of $PM_{2.5\text{-}10}$ and NO_X during dry period-1, wet period and dry period-2 showing positive correlation between the two variables during all three periods.

Vehicular emission is a major source of both $PM_{2.5}$ and NO_x. Hence, strong correlations between these two are expected during the wet season, when brick kilns are not operational. However, significant positive correlation between these two parameters during the dry seasons possibly indicates the brick kilns are also contributing NO_x, in addition to to $PM_{2.5}$. A recent study (Guttikunda et al. 2012) also reported brick kilns as a source of NO_x along with other pollutants such as PM, SO_2, heavy metals etc.

4. Conclusions

In this study, the probable association between meteorological parameters and particulate matter (PM) pollution dynamics in Dhaka city has been explored Daily precipitation appears to have trivial influence on PM reduction through wet deposition, though the number of rainy days in a month showed significant negative correlation with PM concentration. Analysis of wind direction suggests that brick-kilns are major contributors to PM concentration in Dhaka air during dry season (October to March).The brick-kilns located to the north-west direction of Dhaka city have been found to be the most likely contributors to the high PM concentration. Besides vehicular and industrial emissions, brick kilns appear to be a major source of NO_x as well. The insignificant correlation between wind speed and PM for winds coming from northern and northwestern direction indicates that wind speed does not appear to have a significant influence on PM concentration in Dhaka. Statistically significant negative association between relative humidity and coarser PM fraction ($PM_{2.5\text{-}10}$) indicates the reduction of coarser PM concentrations, possibly through promotion of wet deposition. Significant negative correlation between PM and temperature implies that higher PM tends to reduce atmospheric temperature. The solar radiation appears to contribute to increase coarse PM fractions, possibly by increasing formation of coarse nitrate particles. These results indicate that apart from prevailing wind direction and prevalence of rainfall, solar radiation, relative humidity and air temperature can be contributing factors in governing the PM concentrations in Dhaka city. Some of these meteorological events are not completely dissociative (e.g. increased humidity would naturally be positively correlated with rainfall events) and hence drawing a conclusion based on a particular meteorological parameter to predict the PM concentration would be unwise. This study clearly shows that location of pollution sources with respect to densely populated urban centers may play an important role in determining their adverse impacts. While all traditional brick kilns are polluting, those located directly up-wind (of major wind direction) are contributing the most to the pollution in densely populated Dhaka. Thus, meteorological parameters should be given due consideration while selecting locations of industrial clusters that are major sources of emissions. This type of study can be useful in suggesting mitigation measures to control ambient PM concentrations. Such mitigation measures may include relocating the brick kiln clusters to a location which will cause the minimum impact on Dhaka city under the prevailing meteorological conditions.

References

Artíñano, B., Salvador, P., Alonso, D. G., Querol, X. and Alastuey, A. (2004). Influence of traffic on the PM_{10} and $PM_{2.5}$ urban aerosol fractions in Madrid (Spain). Science of the Total Environment, 334– 335, 111 –123.

Alpert, P., Kaufman, Y. J., Shay-El, Y., Tanré, D., DaSilva, A. S., Schubert, S. and Joseph J. H. (1998). Quantification of dust-forced heating of the lower Troposphere. Nature, 395, 367–370.

Bureau of Research, Testing & Consultation (BRTC), (2012). Environmental Impact Assessment of the World Bank financed 335 MW power plant at Siddhirganj, Narayanganj. Department of Civil Engineering, BUET.

Begum, B. A., Biswas, S. K. and Hopke, P. K. (2011). Key issues in controlling air pollutants in Dhaka, Bangladesh. Atmos Environ 45:7705–7713.

Begum, B. A., Biswas, S. K. and Nasiruddin, M. (2010). Trend and spatial distribution of air particulate matter pollution in Dhaka City. Journal of Bangladesh Academy of Sciences, Vol. 34, No. 1, 33-48.

Begum, B. A., Biswas, S. K. and Hopke, P. K. (2008). Assessment of trends and present ambient concentrations of $PM_{2.2}$ and PM_{10} in Dhaka, Bangladesh. Air quality. Atmos Health 1:125–133.

Begum, B. A., Biswas, S. K. and Hopke, P. K. (2006). Temporal variations and spatial distribution of ambient $PM_{2.2}$ and PM_{10} concentrations in Dhaka, Bangladesh. Science of the Total Environment, 358 (1-3), 36-45.

Begum, B. A., Biswas, S. K., Hopke, P. K. and Cohen, D. D. (2006). Multi-element analysis and characterization of atmospheric particulate pollution in Dhaka. Aerosol and Air Quality Research 6(4), 334-359.

Begum, B. A., Biswas, S. K., Kim, E., Hopke, P. K. and Khaliquzzaman, M. (2005). Investigation of sources of atmospheric aerosol at a hot spot area in Dhaka, Bangladesh. Journal of the Air & Waste Management Association, 55 (2), 227-240.

Boman, J., Gatari, M. J., Wagner, A. and Hossaini, M. I. (2005). Elemental characterization of aerosols in urban and rural locations in Bangladesh. X-Ray Spectrometry, 34 (5), 460-467.

Begum, B. A., Kim, E., Biswas, S. K. and Hopke, P. K. (2004). Investigation of sources of atmospheric aerosol at urban and semi-urban areas in Bangladesh. Atmospheric Environment, 38 (19), 3025-3038.

Biswas, S. K., Tarafdar, S. A., Islam, A. and Khaliquzzaman, M. (2001). Investigation of Sources of Atmospheric Particulate Matter (APM) at an Urban area in Bangladesh. Chemistry Division, Atomic Energy Centre, Dhaka.

Biswas, S. K., Islam, A., Tarafdar, S. A. and Khaliquzzaman, M. (2000). Monitoring of Atmospheric Particulate Matter (APM) in Bangladesh. Joint UNDP/RCA/IAEA Project Conference on Sub Project: Air Pollution and its Trends, Manila: Philippines.

Chang, T. Y., Norbeck, J. M. and Weinstock, R. B. (1979). An estimate of the NO_x removal rate in an urban atmosphere. Environ. Sci. Technol., 13, 1534–1537.

Elminir, H. K. (2005). Dependence of urban air pollutants on meteorology. Sci. Total Environ., 350, 225-237.

Guttikunda, S. and Khaliquzzaman, M. (2013). Health benefits of adapting cleaner brick manufacturing technologies in Dhaka, Bangladesh. Air Qual Atmos Health, DOI 10.1007/s11869-013-0213-z.

Guttikunda, S., Begum, B. A. and Wadud, Z. (2012). Particulate Pollution from brick kiln clusters in the greater Dhaka region, Bangladesh. Air Qual Atmos Health, DOI 10.1007/s11869-012-0187-2.

Galindo, N., Varea, M., Gil-Molto, J., Yubero, E. and Nicolas, J. (2011). The Influence of Meteorology on Particulate Matter Concentrations at an Urban Mediterranean Location. Water Air Soil Pollut., 215:365-372, DOI 10.1007/s11270-010-0484-z.

Guttikunda, S. (2009). Impact Analysis of Brick Kilns on the Air Quality in Dhaka, Bangladesh. SIM-air Working Paper Series: 21-2009, available online at: www.urbanemissions.info/simair.

Giri, D., Murthy, K. V. and Adhikary, P. R. (2008). The Influence of Meteorological Conditions on PM_{10} Concentrations in Kathmandu Valley. Int. J. Environ. Res., 2(1), 49-60, ISSN: 1735-6865.

Government of Bangladesh (GoB), (2005). Revision of the Environment Conservation Rules (1997). SRO No. 220-Rule/2005, Ministry of Environment and Forest, Government of the People's Republic of Bangladesh, Dhaka.

Matsumoto, K. and Tanaka, H. (1996). Formation and dissociation of atmospheric particulate nitrate and chloride: an approach based on phase equilibrium. Atmos. Environ., 30 (4), 639–648.

Mehlmann, A. and Warneck, P. (1995). Atmospheric gaseous HNO_3, particulate nitrate, and aerosol size distributions of major ionic species at a rural site in Western Germany. Atmos. Environ., 29 (17), 2359–2373.

Nicolas, J.F., Galindo, N., Yubero, E., Pastor, C., Esclapez, R. and Crespo, J. (2009). Aerosol inorganic ions in a semiarid area on the southeastern Spanish Mediterranean coast. Water, Air and Soil Pollution, 201, 149-159.

Owoade, O.K., Olise, F.S., Ogundele, L.T., Fawole, O.G. and Olaniyi, H.B. (2012). Correlation between particulate matter concentrations and meteorological parameters at a site in Ile-IFE, Nigeria. Ife Journal of Science vol. 14, no. 1.

Smargiassi, A., Baldwin, M., Pilger, C., Dugandzic, R. and Brauer, M. (2005). Small-scale spatial variability of particle concentrations and traffic levels in Montreal: a pilot study. Science of the Total Environment, 338, 243–251.

United National Development Program (UNDP), (2011). Improving kiln efficiency in the brick making industry. GEF-United National Development Program, Dhaka.

United Nations Human Settlements Programme (UN HABITAT), (2008). State of the world's cities 2008/2009—harmoniouscities. Nairobi.

Van der Wal, J. T. and Janssen, L. H. J. M. (2000). Analysis of spatial and temporal variations of PM_{10} concentrations in Netherlands using kalman filtering. Atmos. Environ., 34, 3675–3687.

Van der Wal, J. T. and Janssen, L. H. J. M. (1996). How contribute emission of PM_{10} and meteorology to concentrations of fine particles in the Netherlands. J. Aerosol Sci., 27, S681–S682.

WHO , (2011). Outdoor air pollution in the world cities. World Health Organization, Geneva.

World Bank, (2007). Small study on air quality of impacts of the North Dhaka brickfield cluster by modeling of emissions and suggestions for mitigation measures including financing models. Consultant report prepared by Bangladesh University of Engineering and Technology for the World Bank, Washington DC.

World Health Organization (WHO) air quality guidelines, (2005). A working Group meeting, Bonn, Germany, 18–20 October, 2005, Copenhagen, WHO Regional office for Europe. Available online at http://www.euro.who.int/Document/E87950.pdf, accessed in April 2010.