Particulate Matter and Black Carbon Monitoring at Urban Environment in Bangladesh

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Abstract

Four major cities, Rajshahi, Dhaka, Khulna and Chittagong, in Bangladesh have been suffering under severe impact of air pollution for many years particularly by particulate matter (PM). PM samples were collected within the period from September 2010 to July 2012 at four continuous air monitoring stations (CAMS) located at Farm Gate in Dhaka, Sapura in Rajshahi, Baira in Khulna and a TV station, Khulshi in Chittagong. PM sampling was performed using dichotomous samplers, collecting samples in two sizes: $PM_{2.5}$ and $PM_{2.5\text{-}10}$. Samples were collected on 37 mm Teflon filters. These filters were weighed for PM mass, analyzed for BC by transmissometry and elements by XRF. Data revealed that the pollution from particulate matter varied greatly with climatic conditions. It was found that the PM and BC concentrations in Rajshahi were higher than those in other three cities such as Dhaka, Khulna and Chittagong. A major cause might be transboundary transport of pollutants from agricultural burning in upwind regions. It was observed that the number of brick kilns and vehicles in Dhaka was the highest of all of these cities. The industrial emissions in Chittagong were expected to be high. However, the mean concentrations in Rajshahi were higher than the other major cities. The highest $PM_{2.5}$ concentration was found in Rajshahi and this value was detected when transboundary pollutant transport were expected to be high.

Keywords: PM10, PM2.5, BC and transboundary transport

1. Introduction

In Bangladesh, particulate matter pollution is more severe than gaseous pollution. The concentrations of trace gases, including key primary pollutants and ozone monitored in ambient air in Dhaka were found to comply with the National Ambient Air Quality Standard [1]. The high level of particulate air pollution demands a comprehensive air quality management plan to improve the air quality in urban areas. An urban air quality management plan usually consists of four important components including air quality monitoring, development of emission inventories, air quality modeling to assess the impacts of the pollutants sources, and control strategy development. An effective air quality management approach for any urban area can only be successful through a comprehensive study, built upon the above mentioned key factors.

Particulate air pollution is a mixture of particles varying in number, size, surface area, chemical composition, solubility and origin. Several studies have shown that PM2.5 has significant negative impact on human health [2-4]. PM_{10} derived from suspension and resuspension of solid particles contributes greatly to the mass of the total suspended particles in urban environments. In contrast, the prior work in Dhaka, Bangladesh has shown that fine particles contribute about 60% to the PM10 mass [5]. Subsequent studies have found that 63% of $PM_{2.5}$ is PM_1 [6]. Hence most of the PM_1 particles are in the accumulation mode. It is also found that BC concentration is higher in $PM_{2.5}$. The main sources of $PM_{2.5}$ were identified as motor vehicles, brick kilns, Zn sources, smelters and soil dust [7-8]. Several studies have shown that there is also transboundary contribution during the wintertime when wind blows from north and northwest directions [9].

The Department of Environment (DOE) has been conducting an air quality monitoring program at continuous air monitoring stations (CAMS) in four major cities, namely Rajshahi, Dhaka, Khulna and Chittagong since September 2010. In this study the PM samples were collected from the stations in four different cities using dichotomous samplers to measure $PM_{2.5}$ and $PM_{2.5\text{-}10}$ respectively. The objectives of this work are to find out the seasonal variation of particulate matter and BC concentrations, distribution of PM in different cities to find out the quantitative level of transported fine PM in Bangladesh.

2. Materials and Methods

2.1 Sampling

Air particulate matter was collected from four stations located in Dhaka, Chittagong, Rajshahi and Khulna (Fig. 1). Samples were collected on 37 mm diameter Teflon filters using Thermo Andersen dichotomous samplers, programmed to sample at 16.7 lpm for proper size fractionation. The sampler in each station was positioned with the intake upward and located in an unobstructed place at least 30 cm from any obstacle to air flow with the sampler inlet at a height of 10 m above ground level. Appropriate QA/QC protocol was followed during sampling and mass measurements. Quality assurance of the sampling was ensured by using appropriate laboratory and field blanks. According to protocol, samples were collected every third day of the week from September 2010 to July 2012 at essentially all sites. After sampling, the filters were brought to the conditioned weighing room of DoE directly

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from the sampling site for equilibration and PM mass measurement. Care was taken in transporting the exposed filters to avoid PM loss.

2.2 Site description and measurement period

Being the capital city of the country, Dhaka is congested along with a large number of public and private motor vehicles. Many small factories are also located in and around the city. The CAMS-2 site is at Farm Gate in Dhaka (latitude: 23.76°N; longitude: 90.39°E). Farm Gate is characterized as a hot spot site due to the proximity of several major roadways, intersections and large numbers of vehicles plying through the area [10]. The site is surrounded by commercial and semi industrial area. It was found from the source apportionment study that the main pollutant sources are road dust, soil dust, sea salt, Zn source, motor vehicle and brick kiln in this site [11].

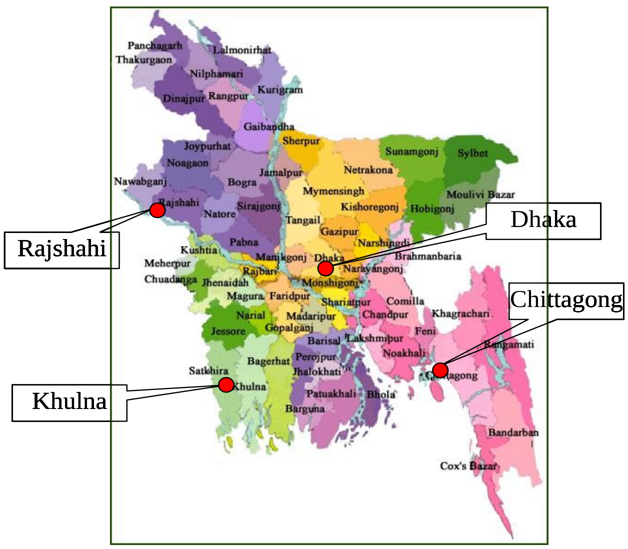

Fig. 1. Map of sampling locations in Bangladesh

Chittagong (latitude 22.22°N, longitude 91.47°E) has the largest sea port in Bangladesh and has heavy traffic, especially through the central city area covering about 10 km^2. The main road network in the city runs from the port area northward towards the industrial areas. These roads are also heavily trafficked, with persistent traffic jams most of the day. Trucks carrying goods from the port to the industrial areas constitute a significant part of the traffic, and the of the hilly nature of the area, the stop and start mode of the congested traffic and heavy loading of most of the trucks cause large emissions of black smoke. A continuous air monitoring station (CAMS) is operated in Chittagong to measure criteria pollutants. The location of the CAMS-3 is in the Chittagong Television Station Campus on a hilltop at Khulshi, about 2.5 km northwest of the Chittagong downtown area and about 100 meters above the surrounding area. The location is hardly affected by nearby air pollution sources, and is considered pollution free zone of the city. The major sources were biomass burning/brick kiln, soil dust, road dust, Zn source (including two-stroke motorcycles), motor vehicle, CNG vehicle, and sea salt in the Chittagong aerosol [12].

Rajshahi, a metropolitan city, is situated in the northern region of Bangladesh (latitude 24.37°N, longitude 88.70°E) and near the border with India. The location of the CAMS-4 is at the Divisional Forest Office of Rajshahi at Sapura. There are few small industries surrounding the sampling site. The climatic conditions are very similar to Dhaka. As there is a low number of industries, apart from brick kilns in Rajshahi city, it has been found that the contribution of biomass burning at this site is the highest [13]**.** This biomass burning contribution may originate from both brick industry, domestic burning/residential combustion (cooking with low grade fuels) or from transboundary transport.

Khulna, the third largest city of the country, is situated in the southern region of Bangladesh (latitude 22.48°N, longitude 89.53°E) and near the Bay of Bengal. Being located in a large river delta, it is the second port area of Bangladesh. The CAMS-5 is located at Samagic Bonayan Nursery and Training Center in Baira is about 3 km north of Khulna main town. There are many small factories near the sampling site (on both western and southern sides), which are producing Touchwood, a special type of fuel, made with rice husk and used as fuel for cooking.

About 211, 185, 145 and 114 pairs of $PM_{2.5\text{-}10}$ and $PM_{2.5}$ samples were collected on 37 mm diameter Teflon filters from Rajshahi, Dhaka, Khulna and Chittagong CAMS, respectively under clean air and sustainable environment (CASE), staff. These samples were collected within the period from September 2010 to July 2012 depending on the cities (Table 1). Quality assurance of the sampling was ensured by using appropriate laboratory and field blanks [14].

Table 1. The summary of PM and BC concentrations (μg/m3) during the sampling periods.

Parameter	Rajshahi			Dhaka			Khulna			Chittagong		
	PM10	PM2.5	BC	PM10	PM2.5	BC	PM10	PM2.5	BC	PM10	PM2.5	BC
Min	24.3	14.9	3.07	21.1	14.3	1.05	10.3	6.20	1.44	13.2	9.34	0.84
Max	1526	842	46.1	419	212	17.2	579	371	23.0	345	211	11.4
Mean	244	155	131	130	65.1	7.20	112	64.7	5.84	117	73.3	4.32
STD	172	112	7.05	74.2	41.2	3.31	88.4	56.8	3.58	78.5	50.7	2.67
Median	204	121	10.8	119	56.0	7.40	95.6	52.0	5.2	111	74.2	3.32
Sample size	211			185			145			114		
Sampling period	01/09/2010 to 31/07/2012			23/08/2010 to 01/07/2012			16/09/2010 to 23/02/2012			03/12/2010 to 29/02/2012		

2.3 PM mass and BC analysis

The $PM_{2.5}$ masses were determined by weighing the filters before and after exposure using a microbalance [15]. The filters were equilibrated for 24 h at a constant humidity of 50% and a constant temperature (22°C) in the balance room before every weighing. A Po-210 (alpha emitter) electrostatic charge eliminator was used to eliminate the static charge accumulated on the filters before each weighing. The difference in weights for each filter was calculated and the mass concentrations for each $PM_{2.5}$ and $PM_{2.5\text{-}10}$ samples were determined.

Black carbon (BC) measurement were conducted with a two-wavelength transmissometer (model OT-21, Magee Scientific, Berkeley, CA). The two-wavelength transmissometer measures the optical absorption of the ambient PM sample at 880 nm (BC) and 370 nm (UVBC) [16]. Certain organic aerosol components of wood combustion particles have enhanced optical absorption at 370 nm relative to 880 nm. A calculated variable, Delta-C signal (UVBC (370nm)- BC (880nm)), has been suggested as an indicator of wood combustion particles, but is not a direct quantitative measurement of their mass concentrations [17-18].

2.4 Meteorological Conditions

In Bangladesh, the climate is characterized by high temperatures and high humidity for most of the year, with distinctly marked seasonal variations in precipitation. According to meteorological conditions, the year can be divided into four seasons, pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February) [19]. The winter season is characterized by dry soil conditions, low relative humidity, scanty rainfall, and low northwesterly prevailing winds. The rainfall and wind speeds become moderately strong and relative humidity increases in the pre-monsoon season when the prevailing direction changes to southwesterly (marine). During the monsoon season, the wind speed further increases and the air mass is purely marine in nature. In the post-monsoon season, the rainfall and relative humidity decreases, as does the wind speed. The wind direction starts shifting back to northeasterly [20]. The meteorological data used in this study were obtained from a local meteorological station, located about 2 kilometers north of the CAMS in Dhaka.

2.5 Back Trajectory Calculation

Using models of atmospheric transport, a trajectory model calculates the position of the air being sampled backward in time from the receptor site from various starting times throughout the sampling interval. The trajectories are presented as a sequence of latitude and longitude values for the endpoints of each segment representing each specific time interval being modeled. The vertical motion of air parcels is considered during this model. The NOAA Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT-4) [21] model was used to calculate the air mass backward trajectories for those days when fine particles were sampled. Archived REANALYSIS meteorological data were used as input. The latitude/longitude was used depending on the site of location of four countries and trajectories were computed backward in time up to 120 hours (5 days). Tick marks on the trajectory plots indicate 6-hour movement locations.

3. Results and Discussion

3.1 Daily average value of PM10 and PM2.5

Figs. 2, 3 and 4 show the annual variation of daily averaged PM_{10}, $PM_{2.5}$ and BC concentrations. From Figs. 2 and 3, it can be seen that the 24-hr average PM concentrations followed a systematic cycle throughout the

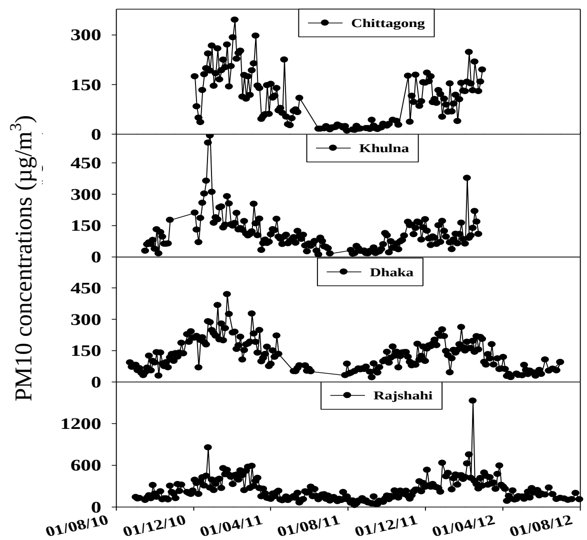

Fig. 2. Variation of PM10 concentrations with time in different cities

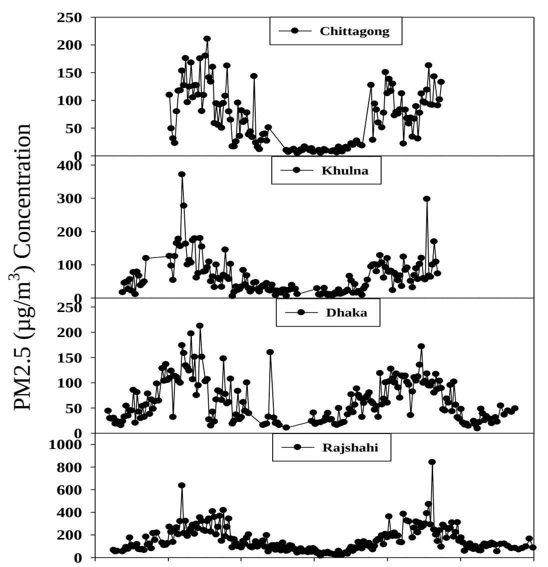

Fig. 3. Variation of PM2.5 concentrations with time in different cities

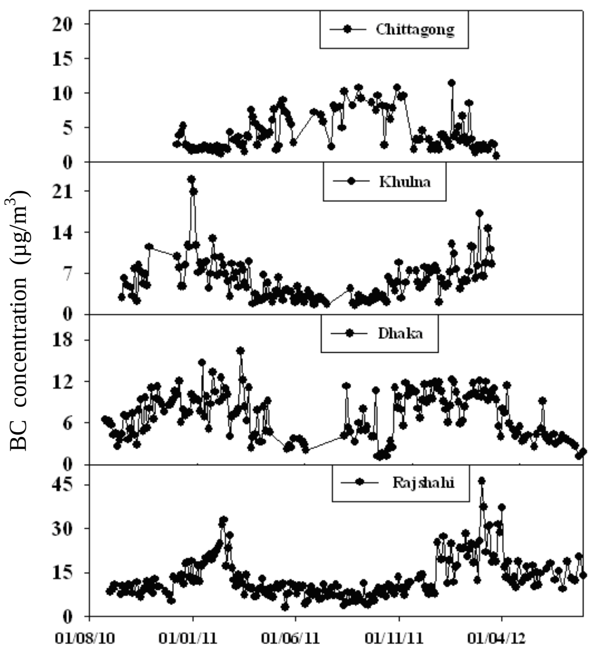

Fig. 4. Variation of BC concentrations with time in different cities

whole monitoring period. During the winter season, the PM concentrations exceeded the 24 hr (The value of PM10 and PM2.5 is 150 μg/m^3 and 65 μg/m^3 respectively) Bangladesh national air quality standards (BNAAQS) almost every day. The PM concentrations started to increase in November and decrease in March when rainfall starts. In the monsoon season, the daily PM became less than the BNAAQS, particularly in August and September. During the winter, the day-to-day variations of PM concentrations were higher than during the monsoon time.

3.2 Monthly variation and annual average of PM10, PM2.5 and BC

Fig. 5 shows the monthly average PM_{10}, $PM_{2.5}$ and BC concentrations with their standard deviations during the sampling periods in these cities. It can be seen that in case of Rajshahi city, the PM concentrations exceed the annual average standards (PM_{10} = 50 μg/m^3 and $PM_{2.5}$ = 15 μg/m^3) in every month of the year. The other three cities have concentrations near to the BNAAQS from June to August.

Table 1 presents a summary of annual PM_{10}, $PM_{2.5}$, and BC concentrations at Rajshahi, Dhaka, Khulna, and Chittagong from September 2010 to July 2012. It can be seen from the Table 1 that the standard deviations of PM_{10}, $PM_{2.5}$ mass and BC concentrations are very large because of significant day-to-day variations. Variations in emissions and meteorological conditions like wind speed and wind direction drive this variability. The meteorology is responsible for dispersion and dilution of the pollutants in the atmosphere. Anthropogenic activities in Dhaka or Chittagong are much higher than Rajshahi. However, the PM and BC concentrations are much higher in Rajshahi.

Tables 1, 2, 3, 4, and 5 show the seasonal variations of PM and BC in the four major cities. PM concentrations are seen to be higher in all 4 cities than the annual average BNAAQS and in winter these values are higher than in other seasons. It is found that in winter, the $PM_{2.5}/PM_{10}$ is high due to high $PM_{2.5}$. Alternatively, the ratio of $BC/PM_{2.5}$ becomes high in monsoon season due to low $PM_{2.5}$ relative to more constant BC values. Except for Rajshahi, the PM concentrations are almost the same in all cities within uncertainties. Although anthropogenic activities in Dhaka are much higher than in the other cities, it was found that the average fine PM concentration of Rajshahi city was twice that of the other cities. Examining the meteorological conditions, it is seen that during winter, the wind mainly comes from the north and northwest [22]. It can be observed that with the change of the season, the $PM_{2.5}$ mass also changes. Low humidity also plays an important role in this respect.

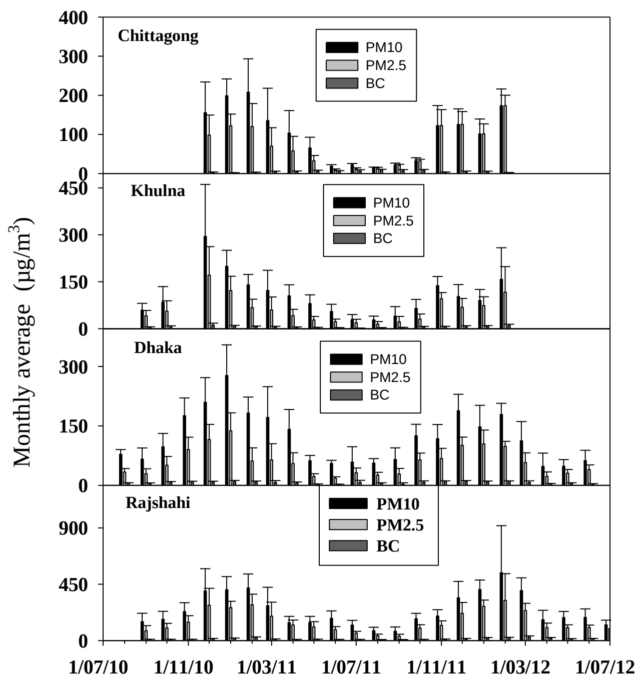

Fig. 5. Variation of monthly average with time in different cities

The high peaks during the winter are not only caused by seasonal fluctuations of the emissions, but also by meteorological effects. The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT 4) model [21] was used to calculate the air mass backward trajectories for days with high impacts of fine particles that are shown in Fig. 6. Backward trajectories starting at height of 500 m above ground level were computed using the vertical mixing model. The contributions on 22 December 2010 and 12 February 2012 as shown in Fig. 5 were likely due to trasport from the north and northwesterly directions. These results indicate that PM concentrations in winter are influenced by transboundary air pollution.

Table 2. Seasonal variation of PM10, PM2.5 and BC concentrations (μg/m^3) at Rajshahi

Year	Season	PM10		PM2.5		PM2.5/PM10		BC		BC/PM2.5	
		Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
2010-2011	Post-monsoon	208	95.4	127	66.4	0.60	0.08	9.86	2.24	0.09	0.04
	Winter	408	131	277	94.0	0.69	0.09	18.45	5.68	0.07	0.02
2011-2012	Pre-monsoon	188	112	143	79.6	0.80	0.17	9.56	2.42	0.08	0.03
	Monsoon	114	58.0	55.4	26.5	0.50	0.09	7.27	2.18	0.15	0.05
	Post-monsoon	184	46.0	109	31.84	0.59	0.04	9.45	1.78	0.09	0.03
	Winter	431	245	271	140	0.63	0.08	17.63	6.66	0.07	0.05
2012	Pre-monsoon	253	132	151	77.5	0.61	0.12	19.73	9.49	0.14	0.04
	Monsoon	150	56.7	100	28.2	0.70	0.14	14.96	3.42	0.16	0.05

Table 3. Seasonal variation of PM10, PM2.5 and BC concentrations (μg/m^3) at Dhaka

Year	Season	PM10		PM2.5		PM2.5/PM10		BC		BC/PM2.5	
		Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
2010-2011	Monsoon	69.0	25.5	30.3	11.6	0.44	0.08	5.10	1.44	0.18	0.04
	Post-monsoon	133	55.3	68.6	32.7	0.51	0.08	7.98	2.29	0.13	0.05
	Winter	221	71.2	104	49.8	0.45	0.13	8.89	2.38	0.12	0.14
2011-2012	Pre-monsoon	133	74.3	50.0	35.5	0.36	0.08	5.90	3.80	0.12	0.02
	Monsoon	60.0	21.6	26.8	10.5	0.46	0.13	4.40	2.89	0.17	0.08
	Post-monsoon	122	32.0	65.8	21.4	0.54	0.07	8.92	2.65	0.14	0.05
	Winter	172	44.9	101	23.6	0.61	0.11	9.85	1.72	0.10	0.02
2012	Pre-monsoon	73.6	47.8	39.1	23.1	0.56	0.09	5.45	3.20	0.15	0.05
	Monsoon	67.7	26.6	41.3	11.1	0.63	0.11	2.77	1.15	0.08	0.06

Table 4. Seasonal variation of PM10, PM2.5 and BC concentrations (μg/m^3) at Khulna

Year	Season	PM10		PM2.5		PM2.5/PM10		BC		BC/PM2.5	
		Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
2010-2011	Post-monsoon	76.5	44.2	51.3	29.3	0.67	0.06	5.81	2.53	0.13	0.04
	Winter	211	118	120	72.9	0.56	0.12	8.76	4.30	0.08	0.02
2011-2012	Pre-monsoon	102	46.1	42.5	28.9	0.40	0.11	4.05	1.94	0.11	0.05
	Monsoon	40.6	24.6	19.6	11.8	0.53	0.18	2.69	0.99	0.16	0.07
	Post-monsoon	101	47.0	63.1	37.8	0.59	0.15	5.97	1.65	0.15	0.12
	Winter	115	67.0	84.6	52.6	0.74	0.14	7.97	3.34	0.10	0.03

Table 5. Seasonal variation of PM10, PM2.5 and BC concentrations (μg/m^3) at Chittagong

Year	Season	PM10		PM2.5		PM2.5/PM10		BC		BC/PM2.5	
		Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
2010-2011	Winter	187	72.2	113	47.4	0.60	0.06	2.44	0.98	0.04	0.05
2011-2012	Pre-monsoon	107	67.6	56.6	39.4	0.51	0.08	4.81	2.14	0.17	0.19
	Monsoon	20.0	4.73	11.7	2.32	0.60	0.10	7.43	2.32	0.66	0.24
	Post-monsoon	85.1	59.9	60.5	45.9	0.72	0.17	5.43	3.21	0.20	0.20
	Winter	130	48.4	91.7	33.7	0.71	0.11	3.36	2.19	0.06	0.11

3.3 Long range transport of Fine $PM_{2.5}$

In order to identify transboundary influences, the effect of local contributions was minimized using a threshold value to define high values set as $2*std\ dev+mean$ in case of measured fine PM. Table 6 shows the mean, standard deviation, and the threshold values for $PM_{2.5}$ and black carbon concentrations have been shown in Table 6. There is then the possibility of transboundary events [23] affecting local air quality. The maximum fine PM concentrations in Dhaka, Khulna and Chittagong are 147, 178, and 175 $\mu g/m^3$, respectively. Bangladesh is a flat area, and the concentrations should be similar in all areas with variation due to local sources. Hence the expected maximum concentration can be estimated as 184 $\mu g/m^3$ (Mean+2STD). However, the actual maximum measured concentration in Rajshahi is 842 $\mu g/m^3$. Thus, it can be concluded that the $PM_{2.5}$ concentrations more than 184 $\mu g/m^3$ may come from the transboundary transport and the value is 195 $\mu g/m^3$.

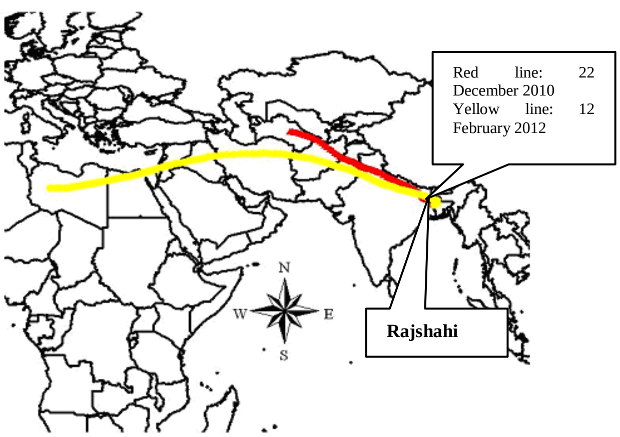

Fig. 6. Air parcel back trajectories showing the long range transport of fine PM on December 22, 2010 and February 12, 2012.

In Bangladesh, there are no thermal power plant or big industry that would emit pollutants. It was found from source apportionment study that about 50.4% of total fine PM came from biomass burning/brick kilns [10]. It was also found that concentrations of O_3, CO, SO_2 and NO_X were lower than the corresponding BNAAQS [1]. Figure 3 shows the time series plot for the fine PM concentrations in all 4 cities during the study period. It was found that there were two large peaks on 22 December 2010 and 12 February 2012 in case of Rajshahi with values of 635 $\mu g/m^3$ and 841 $\mu g/m^3$, respectively.

To explore the possibility of long-range transport of $PM_{2.5}$ to Rajshahi, Bangladesh, back trajectories were calculated starting at 500 m for 22 December 2010 and 12 February 2012 (5 days). Fig. 6 shows representative trajectories. From the NASA website [24] (Supplemental Fig. S1), it was found that haze hugged the southern face of the Himalaya in early December 2010. The haze resulted from a combination of agricultural fires and urban and industrial pollution, and a regional temperature inversion. In the wintertime, cold air frequently settles over northern India and Bangladesh, trapping warmer air underneath. The temperature inversion traps pollutants along with warm air at the surface, contributing to the buildup of haze.

Table 6. The mean, standard deviation and peak value of Fine PM and black carbon (BC) concentrations ($\mu g/m^3$) during the studying period.

Parameter	Statistics	Rajshahi	Dhaka	Khulna	Chittagong
Fine PM	Mean	155	65.1	64.7	73.3
	Median	121	56.0	52.0	74.2
	STD	112	41.2	56.8	50.7
	Threshold Value	379	147	178	175
BC	Mean	13.1	7.20	5.84	4.32
	Median	10.8	7.40	5.20	3.32
	STD	7.05	3.31	3.58	2.67
	Threshold Value	27.2	13.8	13	9.66

Fig. S1. Pollution and fog mixed at the base of the Himalayas in India, early December 2010

The high PM concentration in February 2012 might be due to dust storm. The satellite image for this date (Supplemental Fig. S2) shows a dust storm swapping across the Arabian Peninsula in early February 2012. This dust storm follows a familiar pattern for this region [25], with especially thick dust occurring in Saudi Arabia's southwest.

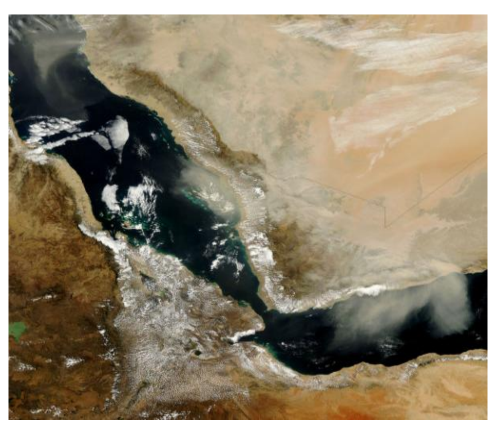

Fig. S2. Dust storm over the Arabian Peninsula

4. Conclusion

Air particulate matter sample has been collected from September 2010 to July 2012 from four divisional cities namely Dhaka, Rajshahi, Chittagong and Khulna. From data analysis, it is found that during rainy season, the PM concentrations are compliant with the BNAAQS and during winter, the concentrations become almost 3 to 4 times higher that the BNAAQS. There are two reasons for high concentration; one is for scarcity of rainfall during winter and the other is northwesterly winds which carries air dust and enhance the local air pollution.

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