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E-mail: bjsir07@gmail.com

Impact of vehicle fleet characteristics on ambient PM concentrations during rainy season at Farm Gate (CAMS-2) in Dhaka

B. A. Begum[1], A. Hossain[2], G. Saroar[3], N. Nahar[2] and M. Nasiruddin[3]

[1]Chemistry Division, Atomic Energy Centre, P.O. Box 164, Dhaka-1000
[2]Chemistry Department, Jahangirnagar University
[3]Clean Air & Sustainable Environment project, DoE, Dhaka

Abstract

The impact of vehicle fleet characteristics on ambient particulate matters (both $PM_{2.5}$ and PM_{10}) concentrations during the rainy season was investigation. Sampling was corriedout at the continuous air monitoring station (CAMS-2) at the Farm Gate site, a location near a major traffic intersection. It was observed from the analysis, that the $PM_{2.5}$ concentrations were not varying so much between day and night time. This might be due to the rainfall and high humidity during these days. As the $PM_{2.5}$ is less, so $BC/PM_{2.5}$ becomes high compared to winter season. Therefore $PM_{2.5}/PM_{10}$ ratio is also less compared to winter time, as $PM_{2.5}$ is the part of PM_{10}. The black carbon (BC) value is less during this period compared to winter due to both local and meteorological effect. It was also found that although there was heavy rainfall on 13 July 2010, the PM concentration is also high. It may be due to the contribution of sea salt to PM.

Keywords: $PM_{2.5}$, PM_{10}, CAMS-2

Introduction

Dhaka is the eighth largest city in the world. Rapid urban population growth is projected to reach approximately 20 million by the year 2020. Vehicular emissions are one of the major sources of pollution in Dhaka where the vehicle fleet characteristics are different in the day and nighttime. To understand impact of fleet characteristics on particulate matter (PM) concentration, sampling was conducted (both PM_{10} and $PM_{2.5}$ fractions) from 5 - 19 July, 2010 at the continuous air monitoring station (CAMS-2) at the Farm Gate site, a location near a major traffic intersection. In recent years, high circulations of commercial vehicles (primarily buses and cars) and small industries (primarily brick kilns) have contributed to increase levels of air pollution, especially PM, in and around cities of Bangladesh. Fine particulate matter with aerodynamic diameter less than 2.5 m is a widespread air pollution problem. In Dhaka, Bangladesh, the daily average of $PM_{2.5}$ levels usually exceeds the Bangladesh National Ambient Air Quality Standard (NAAQS) of 65 $\mu g/m^3$ in winter although they meet the requirements during the monsoon season. As a result, the annual average can never comply with the National Standard of 15 μ g/m^3. Previous studies of Dhaka air quality showed major fractions of the $PM_{2.5}$ is Black Carbon (BC) (Begum *et. al*., 2010a, Begum *et. al*., 2004). There are no coal- or oil-fired power plants in and around Dhaka. Therefore, the emission of BC and sulfur comes from diesel (heavy duty vehicles), household solid fuel combustion, and brick kilns where coal is used as fuel. Public buses, private cars, and 3-wheeled taxis, which mainly run during daytime, are operated on compressed natural gas (CNG). Heavy-duty diesel vehicles ply the roads primarily during the night (10 PM to 8 AM) because of restrictions imposed to reduce traffic congestion. It has been found that about 85% of total vehicle fleet (Begum *et. al.*, 2012) during the daytime in Dhaka is private cars. The densities of cars are high on weekdays. On the other hand about 18% of total vehicles are trucks that run through this area at night. Because of frequent power failures, diesel-run generators are used extensively to meet the electricity demand. These diesel-run generators, heavy-duty vehicles and brick kilns emit carbonaceous particles, which are important contributors to ambient $PM_{2.5}$ concentrations. On the other hand, due to the geographical position, there are also transboundary impact (both natural and anthropogenic source)(Begum *et. al.*, 2011b) during the dry season when wind mainly comes from the north and northwest direction.

*Corresponding author. e-mail: bilkisab@dhaka.net

Bangladesh has a climate of tropical monsoon, mild winter (October to February), hot, humid summer (March to May) and humid warm rainy monsoon (June to October).

It rains mostly during June to October. In the present study the sampling were done during July 5-19, 2010. The aim of this study was to understand the pollution characteristics and to the compare the results with those reported during dry season.

Materials and methods

Sampling

The Air Metrics MiniVol sampler developed jointly by the U.S. Environmental Protection Agency (EPA) and the Lane Regional Air Pollution Authority was used for both PM_{10} and $PM_{2.5}$ sampling (Baldauf *et. al.,* 2001) from Farm Gate site (Fig. 1) in Dhaka city. Farm Gate is a hot spot site due to the proximity of several major roadways intersection and large numbers of vehicles plying through the area (Begum *et. al.,* 2005). The site is surrounded by commercial and semi industrial areas.

The samplers were placed on the flat roof of the guardhouse of Bangladesh Agricultural Research Council (BARC). This location also houses the second continuous air monitoring station (CAMS) in Dhaka. The MiniVols were programmed to sample at 5 lpm through PM_{10} and $PM_{2.5}$ particle size separators (impactors) and then through 2 m pore Teflon filters. The actual flow rate should be 5 lpm at ambient conditions for proper size fractionation. To ensure a constant flow of 5 lpm through the size separator at different air temperatures

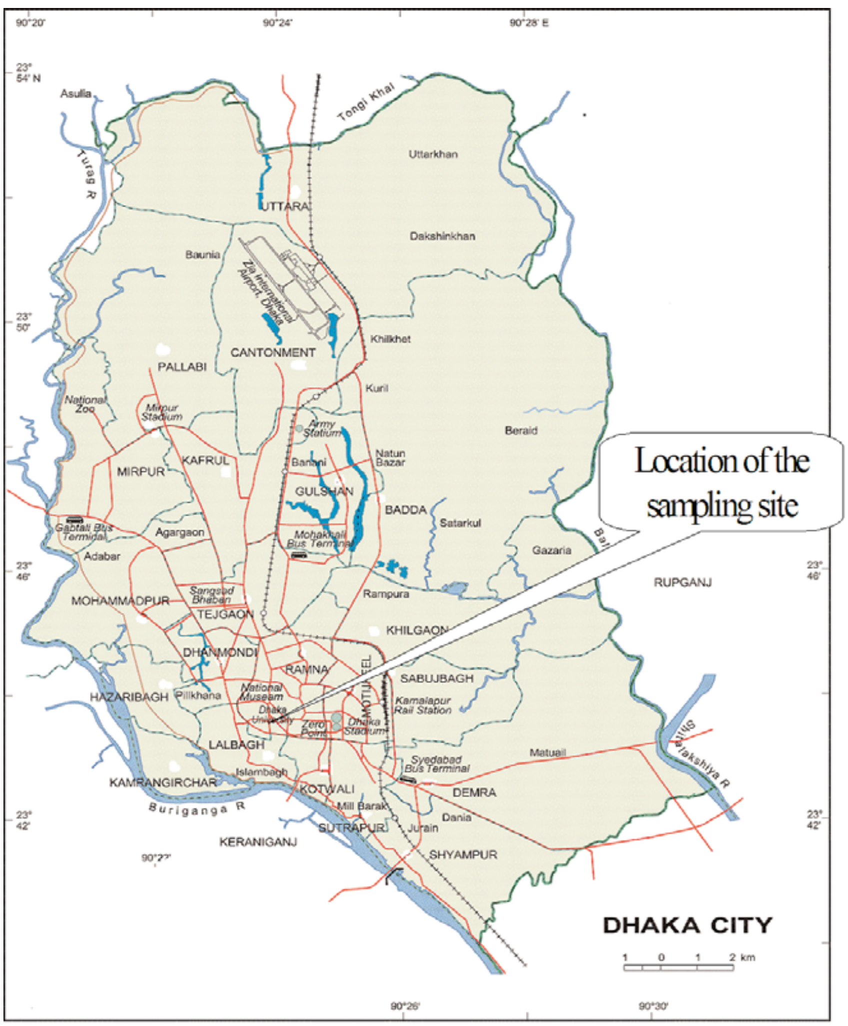

Fig. 1. Map of sampling location

and ambient pressures, the sampler flow rates were adjusted for the ambient conditions at the sampling site. The MiniVol sampler was positioned with the intake upward and located in an unobstructed area at least 30 cm from any obstacle to air flow and the sampler inlet was placed at a height of 10 m above ground level for the Farm Gate area. The intake nozzle of the sampler at the Farm Gate location was about 5 m away from the main road. PM_{10} and $PM_{2.5}$ were collected simultaneously from 8 am to 6 pm and 8 pm to 6 am with two MiniVol samplers. The inlets of the samplers were kept 45 cm apart from each other.

The sampling protocol was continued for fifteen consecutive days starting from July 05 to July 19, 2010. The conditioned clean filters were loaded to respective filter holder assembly at the CAMS-2 conditioning room and were brought to sampling site in separate clean polyethylene bags at each effective sampling day. After sampling, the filter holder assemblies (keeping the exposed filters inside) were brought to the conditioning room of AECD directly from the sampling site for conditioning and PM retrieval. Care was taken in transporting the exposed filter holder assemblies, so that there should be no PM loss.

Traffic volume at the sampling site

A traffic survey was conducted by manual counting of vehicles in the Farm Gate corridor in front of the sampling site on selected days during the present study to understand correlation between PM concentration and traffic volume. It was observed that the private cars are the main motorized vehicles (80% of the total vehicles) plying along this corridor. Some buses (large and medium) are also run through the roadways. Table I summarizes the day time traffic counts and Table II summarizes the night time traffic counts. Tables I and II show that heavy duty diesel trucks operate 17 times more frequently at night than during the day. Among the bus and minibuses, only a few buses run on CNG and most of the buses and minibuses have diesel engines.

Meteorological conditions

In Bangladesh, the climate is characterized by high temperatures, high humidity most of the year and distinctly marked seasonal variation of precipitation. According to meteorological condition, the year can be divided into four seasons, premonsoon (March-May), monsoon (June-September), postmonsoon (October-November) and winter (December-February) (Salam *et. al*., 2003). As the dispersion of PM strongly depends on the wind speed and direction the meteorological data for dates of samples collection was collected from the nearby meteorological station, which is located about 2 kilometers east of the sampling sites. The sampling was done in early pre-monsoon period.

Measurement of PM mass and black carbon (BC)

PM mass was measured in the Chemistry Lab of the Atomic Energy Centre, Dhaka (AECD). The PM_{10} and $PM_{2.5}$ samples were determined by weighing the filters before and after exposure using a microbalance (Begum *et. al.,* 2006). The filters

Table I. Average number of different motor vehicles plying at Farm Gate during daytime

Date	Bus & Minibus	Private car &CNG	Motor Cycle	Truck
02/17/2010	2912	63345	6105	540
02/18/2010	2898	64350	5998	612
02/19/2010	2962	43534	3876	804
02/20/2010	2789	43790	4586	693
02/21/2010	2898	50180	6233	854
02/22/2010	3080	66712	6192	520
02/23/2010	2848	65958	6630	912
02/24/2010	2880	63145	6232	550
02/25/2010	3007	62151	6130	584
02/26/2010	2919	41237	3979	650
02/27/2010	2990	44321	5110	852
02/28/2010	3123	62328	6980	673
03/01/2010	2960	61710	7210	830
03/02/2010	3452	62130	7584	678
03/03/2010	3323	61130	7019	590

Table II. Average number of different motor vehicles plying at Farm Gate during night time

Date	Bus & Minibus	Private car &CNG	Motor Cycle	Truck
02/17/2010	850	12345	876	2890
02/18/2010	1007	11987	987	3060
02/19/2010	865	11230	905	3790
02/20/2010	890	10980	926	3346
02/21/2010	896	11675	878	3416
02/22/2010	953	15120	698	3468
02/23/2010	904	11580	1400	2886
02/24/2010	839	9879	1123	2918
02/25/2010	870	13980	819	3012
02/26/2010	890	14546	907	3310
02/27/2010	911	13345	784	4260
02/28/2010	895	14789	980	3980
03/01/2010	885	12398	1073	2978
03/02/2010	947	12650	1350	2243
03/03/2010	879	11349	935	2197

were equilibrated for 24h at constant humidity of 50% and temperature (22^{o}C) in the balance room before each 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_{10} or $PM_{2.5}$ samples were determined.

The concentrations of BC in the PM_{10} and $PM_{2.5}$ samples were determined by reflectance measurement in AECD laboratory using an Evans Electroselenium Limited (EEL) type Smoke Stain Reflectometer (Biswas *et. al.,* 2003). Secondary standards of known black carbon concentrations were used to calibrate the reflectometer. The concentrations are defined based on the amount of reflected light that is absorbed by the filter sample and an assumed mass absorption coefficient. It is related to the concentration of light absorbing carbon through standards of carbon with known areal density. Iron (Fe) has a moderate light absorption coefficient and can have some limited influence on the BC value measured by reflectance. The uncertainty associated with the BC measurement is rather high (4-9%), and therefore, the influence of variation in Fe concentration on BC measurement has been neglected.

Result and discussion

The time series variation of the meteorological parameters and PM are shown in Fig.'s 2 and 3 respectively. It would be found that with the increase of wind speed and with rainfall, the PM values decrease. Again high humidity also helps to increase in size of fine particles and then easily remove from the environment.

The basic statistics of the concentration level are also illustrated in Table III. The difference between arithmetic mean and geometric mean is small suggesting minimum day-to-day variations in the data and perhaps major pollutants contributing to the PM pollution are from local sources. The 10

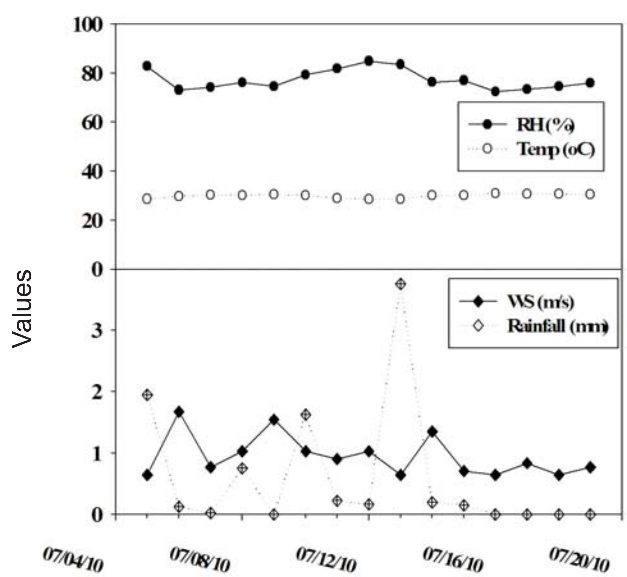

Fig. 2. Meteorological condition during the sampling time

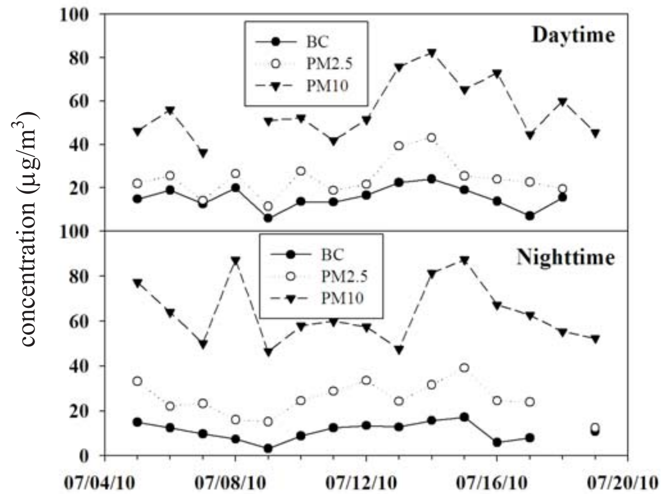

Fig. 3. Variation of PM_{10}, $PM_{2.5}$ and BC concentrations during the day and night time

hr average values for both PM_{10} and $PM_{2.5}$ masses (Table III) during day and night time are about 2.5 times less than the 24 hour average Bangladesh National Ambient Air Quality Standard as well as 1997 USEPA standards, which are set at 150 µg/m^3 and 65 µg/m^3 respectively.

It was found (Table IV) that the PM_{10} and $PM_{2.5}$ concentrations between night time and day time are not remarkably different. This could be due to rainfall, which lower PM concentrations. The higher PM_{10} and $PM_{2.5}$ concentrations observed at night may be attributed to heavy-duty diesel trucks that ply on the road, and the shopping markets, medical clinic and lot of small industries where the diesel generators run during the power failure in this area. Hence, the emissions from diesel vehicles and generators increase the $PM_{2.5}$ concentrations, which in turn increase PM_{10} concentration.

Table III. The arithmetic mean and geometric mean of mass concentrations (µg/m^3) during the study period

Parameter	Day time			Night time		
	PM_{10}	$PM_{2.5}$	BC	PM_{10}	$PM_{2.5}$	BC
Average	55.8	24.4	15.6	63.6	25.2	10.9
95% confidence interval	48.5-63.2	11.8-37.0	12.9-18.3	56.5-70.7	21.0-29.4	8.85-13.0
Geomean	54.3	23.1	14.6	62.3	24.0	10.1
95% confidence interval	53.7-55.0	22.4-23.8	13.8-15.4	61.6-62.9	23.3-24.8	9.29-10.9
Max	82.5	43.1	24.1	87.3	39.1	17.2
Min	36.4	11.5	5.99	46.5	12.5	3.24

Table IV. The direction of wind pattern with respect to day and PM_{10} mass concentrations

Date	Wind Direction	$PM_{2.5}$ mass (µg/m^3)		PM_{10} mass (µg/m^3)	
		Day	Night	Day	Night
07/05/10	SE	22.0	33.1	46.2	77.3
07/06/10	S	25.6	22.1	56.0	64.0
07/07/10	S	14.1	23.3	36.4	50.0
07/08/10	S	26.4	16.1	87.3	
07/09/10	S	11.5	15.1	51.0	46.5
07/10/10	S	27.6	24.5	52.3	57.8
07/11/10	SSE	18.8	28.8	41.8	60.0
07/12/10	S	21.6	33.5	51.5	57.5
07/13/10	S	39.3	24.3	75.8	47.5
07/14/10	SE	43.1	31.6	82.5	81.3
07/15/10	SE	25.5	39.1	65.3	87.3
07/16/10	S	24.0	24.5	73.0	67.3
07/17/10	S	22.6	24.0	44.6	62.6
07/18/10	S	19.5	60.0	55.3	
07/19/10	S		12.5	45.5	52.3

Ratios of $BC/PM_{2.5}$ and $PM_{2.5}/PM_{10}$

Tables V and VI represent the variation of ratios of $BC/PM_{2.5}$ and $PM_{2.5}/PM_{10}$ during the winter and the rainy seasons. It was found that the concentration of $PM_{2.5}$ and PM_{10} is about 5 times lower than the winter time. This may be due to meteorology, wind direction and rainfall. On the other hand, brick kilns are not in operation during the rainy season. Therefore, it has been found that the decrease of $PM_{2.5}$ and PM_{10} is high compared to BC. The brick sector could not contribute to PM (high in BC), as the brick sector is not operated in rainy season. From source apportionment results (Begum *et. al.*, 2011a), it was found that the total mass concentration in wintertime is high and soil dust and road dust contribute about 60% of the total mass and in rainy season, it reduces to 33% of the total mass. Again as the wind mainly comes from south and southeast direction, therefore regional impact is less and there are sea salt contributions in the PM (both fine and coarse). The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT 4) model (Draxler and Rolph, 2003) was used to calculate the air mass backward trajectories for days with high impacts of fine particles as

Table V. Comparison of $BC/PM_{2.5}$ and $PM_{2.5}/PM_{10}$ ratios at day time

Date	$BC/PM_{2.5}$	$PM_{2.5}/PM_{10}$	Date	$BC/PM_{2.5}$	$PM_{2.5}/PM_{10}$
02/17/10	0.31	0.76	07/05/10	0.68	0.48
02/18/10	0.36	0.34	07/06/10	0.74	0.46
02/19/10	0.49	0.34	07/07/10	0.90	0.39
02/20/10	0.33	0.54	07/08/10	0.75	
02/21/10	0.30	0.64	07/09/10	0.52	0.22
02/22/10	0.26	0.64	07/10/10	0.49	0.53
02/23/10	0.25	0.66	07/11/10	0.71	0.45
02/24/10	0.19	0.65	07/12/10	0.77	0.42
02/25/10	0.32	0.75	07/13/10	0.57	0.52
02/26/10	0.27	0.67	07/14/10	0.56	0.52
02/27/10	0.25	0.71	07/15/10	0.75	0.39
02/28/10	0.30	0.58	07/16/10	0.57	0.33
03/01/10	0.28	0.50	07/17/10	0.31	0.51
03/02/10	0.21	0.49	07/18/10	0.80	0.32
03/03/10	0.25	0.44	07/19/10		

Table VI. Comparison of $BC/PM_{2.5}$ and $PM_{2.5}/PM_{10}$ ratios at night time

Date	$BC/PM_{2.5}$	$PM_{2.5}/PM_{10}$	Date	$BC/PM_{2.5}$	$PM_{2.5}/PM_{10}$
02/17/10	0.29	0.84	07/05/10	0.45	0.43
02/18/10	0.40	0.57	07/06/10	0.57	0.35
02/19/10	0.33	0.62	07/07/10	0.42	0.47
02/20/10	0.37	0.69	07/08/10	0.46	0.18
02/21/10	0.38	0.65	07/09/10	0.21	0.33
02/22/10	0.36	0.72	07/10/10	0.36	0.42
02/23/10	0.26	0.80	07/11/10	0.43	0.48
02/24/10	0.35	0.99	07/12/10	0.40	0.58
02/25/10	0.26	0.56	07/13/10	0.53	0.51
02/26/10	0.26	0.55	07/14/10	0.50	0.39
02/27/10	0.24	0.82	07/15/10	0.44	0.45
02/28/10	0.25	0.62	07/16/10	0.25	0.36
03/01/10	0.28	0.55	07/17/10	0.33	0.38
03/02/10	0.27	0.51	07/18/10		
03/03/10	0.24	0.63	07/19/10	0.86	0.24

shown in Fig. 4. Backward trajectories starting at height of 500 m above the ground level were computed using the vertical mixing model. Fig. 4 shows the contribution on 13 and 14 July 2010 was likely due to contribution from southerly wind. The results indicate that PM concentrations in wet season are also influenced by southerly wind (Fig. 4). Therefore, we get sea salt contribution in PM samples. From Table IV, it can be found that most of the wind comes from South.

From Tables V and VI it may conclude that the background $PM_{2.5}$ and PM_{10} concentrations in the urban ambient air in Dhaka city will be 24.8 and 59.7 μ g/m^3 (20h average) respectively. Hence the ambient air quality is much better in

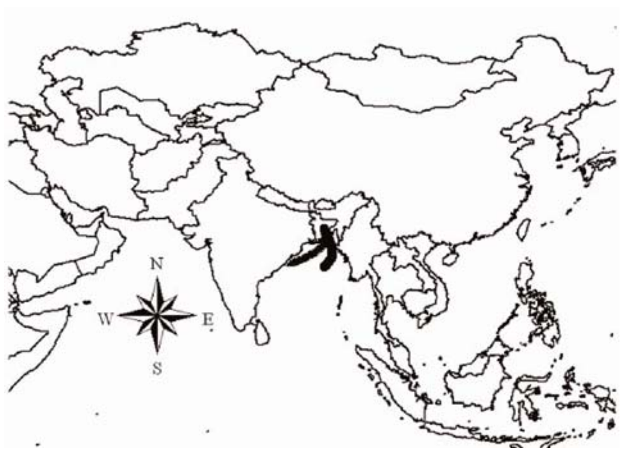

Fig. 4. Backward trajectories arriving Dhaka on 13 and 14 July 2010 computed at the NOAA Air Resources Laboratory HYSPLIT site

Dhaka during the wet season than the dry season when the rainfall and wind speed is minimal.

Conclusion

Bangladesh is a developing country and due to relatively faster economic growth, the numbers of industries especially around Dhaka city are increasing at a rapid pace. The population density is also increasing. To meet the growing transport demand, the numbers of vehicles are also increasing. The rate of increase is higher in and around Dhaka city and consequently has increased impact on the air quality. This impact is also reflected in the source apportionment results although majority of the vehicles currently running in Dhaka use compressed natural gas. There are also a large number of brick kilns operating surrounding the Dhaka city to meet the demand of the economic growth and the pollution from the brick kilns also increases day by day. From the present study, it is observed that the main criteria pollutant is particulate matter (PM) and the concentration of PM is compatible to the National Ambient Air Quality Standard (BNAAQS), Bangladesh. Although local sources of air pollution in Dhaka city are quite high in winter time, PM concentrations in wet season is about 2.5 times less than the daily ambient air quality standard.

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