

Sources of Carbonaceous Materials in the Airborne Particulate Matter of Dhaka

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ABSTRACT

To explore the sources of carbonaceous material in the airborne particulate matter (PM), comprehensive PM sampling was performed (3 to 14 January 2010) at a traffic hot spot site (HS), Farm Gate, Dhaka using several samplers: AirMetrics MiniVol (for PM₁₀ and PM_{2.5}) and MOUDI (for size fractionated submicron PM). Long-term PM data (April 2000 to March 2006 and April 2000 to March 2010 in two size fractions (PM_{2.2} and PM_{2.2-10}) obtained from two air quality-monitoring stations, one at Farm Gate (HS) and another at a semi-residential (SR) area (Atomic Energy Centre, Dhaka Campus, (AECD)), respectively were also analyzed. The long-term PM trend shows that fine particulate matter concentrations have decreased over time as a result of government policy interventions even with increasing vehicles on the road. The ratio of PM_{2.5}/PM₁₀ showed that the average PM_{2.5} mass was about 78% of the PM₁₀ mass. It was also found that about 63% of PM_{2.5} mass is PM₁. The total contribution of BC to PM_{2.5} is about 16% and showed a decreasing trend over the years. It was observed that PM₁ fractions contained the major amount of carbonaceous materials, which mainly originated from high temperature combustion process in the PM_{2.5}. From the IMPROVE TOR protocol carbon fraction analysis, it was observed that emissions from gasoline vehicles contributed to PM₁ given the high abundance of EC1 and OC2 and the contribution of diesel to PM₁ is minimal as indicated by the low abundance of OC1 and EC2. Source apportionment results also show that vehicular exhaust is the largest contributors to PM in Dhaka. There is also transported PM_{2.2} from regional sources. With the increasing economic activities and recent GDP growth, the number of vehicles and brick kilns has significantly increased in and around Dhaka. Further action will

be required to further reduce PM-related air pollution in Dhaka.

Key words: Particulate matter, Dhaka, Source apportionment, PMF, Size distribution

1. INTRODUCTION

Black carbon (BC) and elemental carbon (EC) originate from the incomplete combustion of carbonaceous fuel. They are used to describe aspects of ambient particulate matter. However, these two terms are actually based on its measurement technique namely, thermo-optical and optical techniques (Poschl, 2005). BC has received increasing attention in recent years because of its potential to contribute to global warming, carries carcinogenic compounds, and causes serious health risks (Ramanathan and Carmichael, 2008; Koelmans *et al.*, 2006; Hansen and Nazarenko, 2004; Jacobson, 2001). Positive aerosol radiative forcing arises from absorption of solar radiation by black carbon. The significant impact of light absorbing particles such as BC and dust involves the vertical redistribution of the solar radiation between the surface and the lower atmosphere, quantitatively resembling the nuclear winter forcing (UNEP and C4, 2002). Black carbon (BC) can act in two ways. First as a direct absorber of visible light that provides direct warming in the lower atmosphere. Secondly, the deposition of black carbon on ice or snow such as on Himalayan glaciers (Kehrwald *et al.*, 2008) is part of what is causing them to rapidly melt. BC may also influence climate indirectly on a regional scale by altering the monsoon circulation and hydrological cycle. Thus, there are good reasons to understand the extent and sources of BC.

BC in indoor environments is largely due to cooking with biofuels such as wood, dung, and crop residue. In

the ambient atmosphere, it is due to fossil fuel combustion (diesel and coal), open biomass burning (associated with deforestation and crop residue burning and cooking with biofuels (Andreae and Crutzen, 1997).

Among the suite of air pollutants, particulate matter (PM) is thought to be the most important pollutant in Dhaka with respect to health effects and reduced urban visibility. In a previous study, Biswas *et al.* (2001) found that approximately 40% of fine PM ($< 2.5 \mu\text{m}$) is BC. The important sources of PM in Dhaka were identified as diesel-powered vehicles, two-stroke engine gasoline vehicles, and brick kilns (Begum *et al.*, 2006a, 2005a, 2004; Salam *et al.*, 2003). These studies have suggested that motorized transport vehicles were the single largest contributor to particulate air pollution especially to fine particulate matter concentrations in Dhaka. Policy interventions including the conversion of vehicles to compressed natural gas (CNG) has reduced the vehicular contributions (Begum *et al.*, 2008). Among other policy actions, gasoline-powered two-stroke, three-wheel vehicles were banned leading to reduced black smoke (Begum *et al.*, 2008). Buses older than 20 years have also been banned and mechanic training programs have been implemented to improve vehicle maintenance.

Although the growth in the number of motorized vehicles in Dhaka has been about 10% year for last several years, the contribution from vehicles has not increased linearly with vehicular numbers (Begum *et al.*, 2011a). The majority of private cars that ran on gasoline have been converted to CNG. Additionally, some diesel buses and trucks have also been converted to CNG largely because of the fuel price differential. However, because of electrical power problems, there are many diesel powered generators.

In addition, increasing economic activity has generated a high demand for construction materials including fired bricks. To meet this enhanced demand, there has been an increased number of brick kilns around Dhaka. The majority of brick making technology used fixed chimney kilns. These kilns use high sulfur coal and wood. Wood combustion is less energy efficient resulting in significant air pollution in Dhaka.

The carbonaceous fraction of PM in Dhaka has been less comprehensively studied than the inorganic components. To reduce carbonaceous PM, the emission sources must be known. Source identification and apportionment can be obtained through the analysis of the chemical characteristics of BC containing particulate matter.

Understanding characteristics of BC in submicron particles (PM_1 ; $D_p < 1 \mu\text{m}$) is important because the leading removal mechanism of ultrafine particles ($< 100 \text{nm}$) is agglomeration to form fine particles.

Thus, measuring size distributions and analyzing BC fractions can be useful in determining the sources of those particles (Kim *et al.*, 2011).

In previous studies (Begum *et al.*, 2011a, 2005, 2004) on Dhaka fine particles, elemental compositions have been analyzed to identify potential sources of such particles. Only a few studies are conducted on carbonaceous particles. The present study combines measurement of BC fractions in fine PM and ultrafine PM along with the available information on size resolve PM sources. Although this study focuses mainly on the concentrations of OC and EC in $\text{PM}_{2.5}$ and PM_1 to better understand the BC emission sources, general trends of PM and BC concentrations as well as their possible sources are discussed. The objectives of this study are 1) to measure the concentration of OC and BC in fine and ultrafine particles at traffic intensive urban area in Dhaka, 2) to observe the relationship between the OC, EC concentrations of fine and ultrafine particles 3) to identify the sources of OC and EC in UFPs and FPs and 4) trends and sources of PM pollution in an urban environment in Dhaka. The present results are discussed in the context of the previous source apportionment studies, especially of combustion sources, to relate the particulate air quality status with different policy interventions previously undertaken by the Government to reduce air pollution.

2. MATERIALS AND METHODS

2.1 Sampling

Fig. 1 shows the location of two sampling sites and the meteorological station in Dhaka, where long term PM samples have been collected over past decade. The hot spot site in Dhaka (HS) is a high traffic area located at Farm Gate adjacent to the intersection of several main roads typically carrying high volumes of traffic (Latitude: 23.76°N ; Longitude: 90.39°E). The semi-residential area (SR) (Latitude: 23.77°N ; Longitude 90.38°E) in Dhaka is located in the Atomic Energy Centre, Dhaka (AECD) campus building with moderate traffic. Long term sampling (April 2000 to March 2006 at HS site and April 2000 to March 2010 at SR site) at both the sites were performed using a 'Gent' stacked filter sampler (Hopke *et al.*, 1997) capable of collecting air particulate samples in coarse (2.2 to $10 \mu\text{m}$) and fine ($2.2 \mu\text{m}$) size fractions. The sampling protocol was described by Begum *et al.* (2011a).

For the ultrafine particulate sampling campaign, two MOUDI and three AirMetrics MiniVol samplers were used. The samplers were placed on the flat roof of the guardhouse of the Bangladesh Agricultural Research Council (BARC) at Farm Gate.

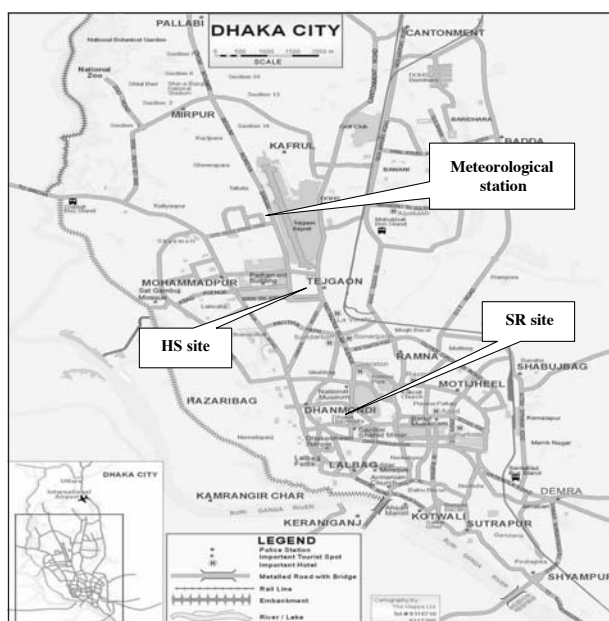


Fig. 1. Map of Dhaka, Bangladesh showing the locations of the two sampling sites (HS site and SR site).

The 10-stage micro-orifice uniform deposit impactors (MOUDIs, MSP Corp., Model 100) were operated in parallel for consecutive 24 hour periods from 4 January to 13 January 2010 to collect a total of 10 samples. The cut points for the 10 stages are 18, 10, 5.6, 3.2, 1.8, 1.0, 0.56, 0.32, 0.18, 0.1 and 0.056- μm . However, an AIHL-design cyclone separator (John and Reischl, 1980) was connected upstream to each MOUDI to remove large particles having a 50% aerodynamic cutoff diameter at 1.8 μm before the air passed through the MOUDI impactors at a flowrate of 30 L/min. The cyclone was used to prevent particle bounce in the upper stages of the MOUDI since our interest in the study was to quantify mostly $\text{PM}_{1.0}$ and smaller size ranges. The AIHL cyclone was used to suppress particle bounce from the upper stages of the impactors. Particles in the aerodynamic diameter size range of 0.056 to 1.8 μm were collected in impaction stages 5 through 10 of the impactors. All 10 stages of the impactors were in place during the experiment but only the lower 6 stages collected meaningful samples because of the cyclone separator upstream of the impactors. The flow rate, and start and end time were recorded to allow the total volumes and mass concentrations to be calculated.

One impactor was loaded with aluminum foil substrates (MSP Corp., 47 mm diameter) and a 47 mm diameter quartz fiber backup filter. The second impactor was operated with PTFE impaction substrates and a backup filter (47 mm diameter, Teflo filters (Pall Corp.), 2.0 μm pore size). The foil impaction substrates and

quartz fiber filters were baked before use in order to lower their carbon blank values, since these materials were dedicated to the analysis of carbonaceous aerosol species; foil substrates were baked for 48 hours at 500°C, and quartz fiber filters were baked for 12 hours at 500°C. To avoid contamination by organic compounds, no grease or oil was applied to the impaction substrates. Following sample collection, filter samples and samples on impaction substrates were placed in petri dishes, and then frozen immediately until subsequent analysis.

Two AirMetrics MiniVol samplers were used to collect PM_{10} and $\text{PM}_{2.5}$ on Teflon filters and a third MiniVol sampler was used to collect $\text{PM}_{2.5}$ on quartz filters for subsequent compositional analysis parallel to the MOUDI sampling.

2.2 PM Mass, BC and Carbon Fraction Analysis

The masses of the samples were determined by weighing the Teflon filters before and after their exposure. A ^{210}Po (alpha emitter) electrostatic charge eliminator (STATICMASTER) was used to eliminate the static charge accumulated on the filters before each weighing. Elemental analyses were performed on the Teflon filters using PIXE (Cohen *et al.*, 1996), and XRF methods in GNS Science, New Zealand and Clarkson University, NY, USA, respectively. These methods are described in detail by Landsberger and Creatchman (1998).

Carbonaceous materials collected on the $\text{PM}_{2.5}$ quartz filters were analyzed via IMPROVE/TOR protocol (Chow *et al.*, 2008, 2004, 1993) for eight temperature resolved carbon fractions (Atmoslytic model DRI2100A). This protocol provides concentrations of carbon in four organic carbon fractions (OC1, OC2, OC3, OC3), three elemental carbon fractions (EC1, EC2, EC3) and pyrolyzed carbon (OP). The samples which were collected on Teflon filters in $\text{PM}_{2.5}$ were analyzed by an EEL-type Smoke Stain Reflectometer (Diffusion Systems, Ltd) to measure BC. Secondary standards of known black carbon concentrations were used to calibrate the reflectometer (Biswas *et al.*, 2003). The aluminum foil substrates (MOUDI sampler) were analyzed via IMPROVE/TOR protocol (Chow *et al.*, 2008, 2004, 1993) for eight temperature resolved carbon fractions.

3. RESULTS AND DISCUSSION

3.1 Meteorological Condition

In Bangladesh, the climate is characterized by high temperatures and high humidity for most of the year,

and distinctly marked seasonal variations in precipitation. Based on the meteorology, the year can be divided into four seasons, pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February) (Salam *et al.*, 2003). The winter season is characterized by dry soil conditions, lower relative humidity, scanty rainfall and low northwesterly winds. The meteorological data used in this study was obtained from a local meteorological station that is located about 2 and 5 kilometers north of the hot spot (HS) and semi-residential (SR) sites, respectively.

Dhaka has a sub-tropical climate and is under the influence of the strong southwest or summer monsoon and weak northeast or winter monsoon. It has been understood from last few years of air quality monitoring, the air quality level of the city greatly influenced by the Asian monsoon. The air quality characteristics in Dhaka shows distinct seasonal variations, with high pollution episodes observed during the winter, while summer has relatively cleaner ambient air. During the dry winter and part of the post-monsoon season, the strength of north and northwesterly winds coming from India, Nepal and Southeastern China to the Bay of Bengal through Bangladesh can transport pollutants to the city. Moreover, during this season, wind speeds are low so that locally emitted pollutants are not well dispersed into the downwind area. Mixing heights of the boundary layer are important factors influencing the dispersion of pollutants.

3.2 PM, BC, and EC Concentrations from 1-14 January 2010

Samples were collected by three AirMetrics MiniVol samplers and the two MOUDI samplers. During the study period, the daily $PM_{2.5}$ and PM_{10} values (Table 1) were higher than the 24 h average Bangladesh National Ambient Air Quality Standard (BNAQS), which were set at $65 \mu\text{g}/\text{m}^3$ and $150 \mu\text{g}/\text{m}^3$, respectively. The

ratios of $EC/PM_{2.5}$ concentrations for the intensive study and for the same period in previous years were calculated and compared (Fig. 2). It was observed that the ratios have decreased after 2002. Although there is evidence that BC comes from the transboundary sources, especially during winter (Begum *et al.*, 2011a, b, 2008; Ramanathan and Carmichael, 2008), it has significant local sources. BC concentrations were observed to vary from month to month depending on the meteorological conditions. It has been found that the concentration has decreased relative to previous years as a result of policies adopted by the government (Begum, 2006a).

PM and BC concentrations in the AirMetrics and MOUDI samples were compared. Fig. 3 shows mass ratios for different fractions of PM during the period of 4 January to 13 January 2010. From the average mass ratios of different PM fractions, it was observed that about 78% of PM_{10} is $PM_{2.5}$ and about 63% of $PM_{2.5}$ is PM_1 . It can be seen that the BC and EC masses are concentrated mainly in the PM_1 fractions (Fig. 3). Thus, most of the BC mass was in the accumulation mode ($0.1-1 \mu\text{m}$ diameter). Prior studies (Begum *et al.*, 2006a, b; Salam, 2003) suggested that high EC

Table 1. Mass concentrations ($\mu\text{g}/\text{m}^3$) in different fractions of PM during 4 to 13 January 2010.

Date	Air metrics		MOUDI
	PM_{10}	$PM_{2.5}$	PM_1
01/04/2010	339	267	177
01/05/2010	294	252	161
01/06/2010	359	330	166
01/07/2010	303	234	150
01/08/2010	328	227	132
01/09/2010	255	183	126
01/10/2010	267	207	141
01/11/2010	271	211	147
01/12/2010	269	208	126
01/13/2010	327	248	159

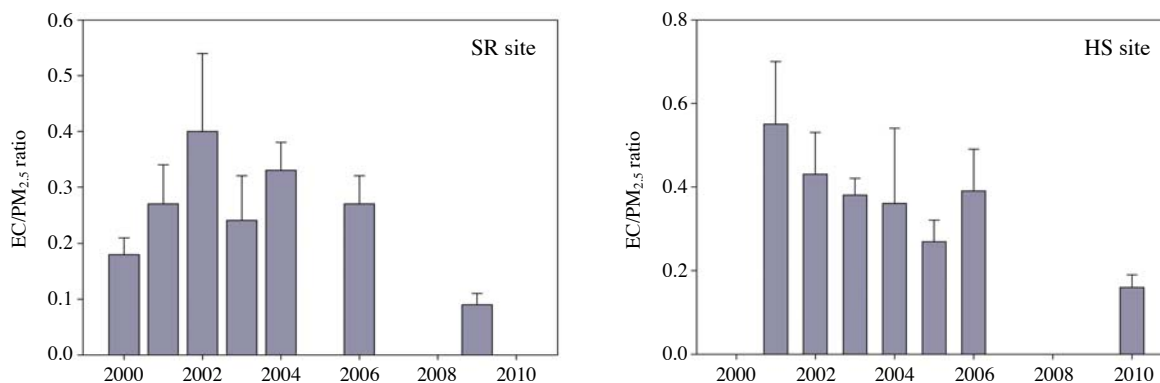


Fig. 2. Variation of $EC/PM_{2.5}$ ratio in different years from 1 to 14 January.

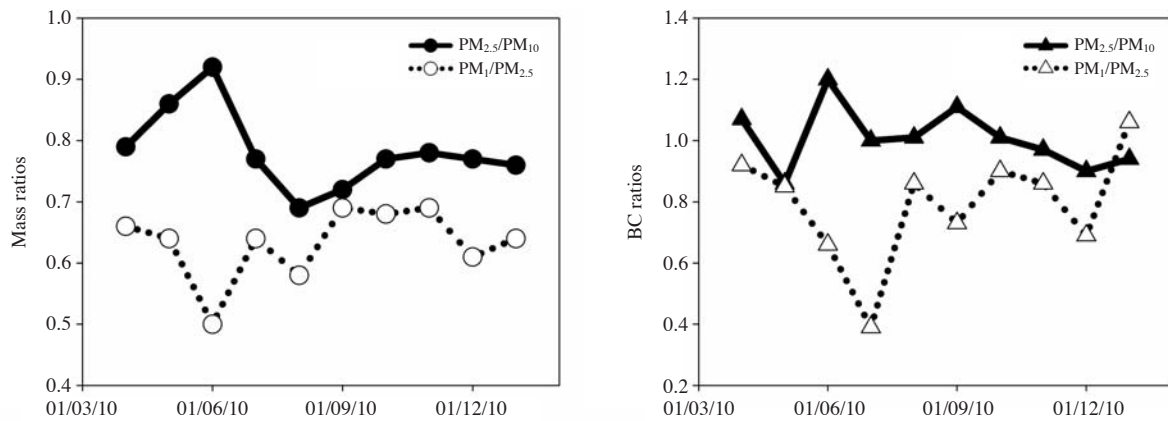


Fig. 3. Mass ratios for different fractions of PM during the January 2010.

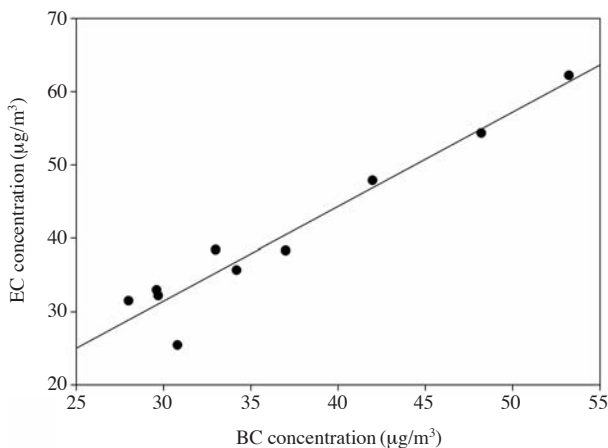


Fig. 4. Relation between EC and BC during January 2010.

contributions come mainly from the diesel trucks, petrol vehicle, two-stroke motorcycles, diesel-powered generators, open burning incinerators, and brick kilns.

3.3 OC, EC, and TC Components for Identification of Sources

Black carbon (BC) and elemental carbon (EC) in airborne particulate matter originate from the incomplete combustion of carbonaceous fuel. These terms are used to describe aspects of ambient particulate matter. However, they are not interchangeable because they are each defined by the way they are measured. Salako *et al.* (2011) report the variability of EC and BC in a number of locations across Asia and the South Pacific region. It was found that the BC concentrations were comparable with the EC values (slope=1.1, $r^2=0.91$) (Fig. 4). The mass absorption coefficient that is used for BC calculation was $10.98 \text{ m}^2/\text{g}$ (Biswas *et al.*, 2003). The two major classes of sources for EC and OC, fos-

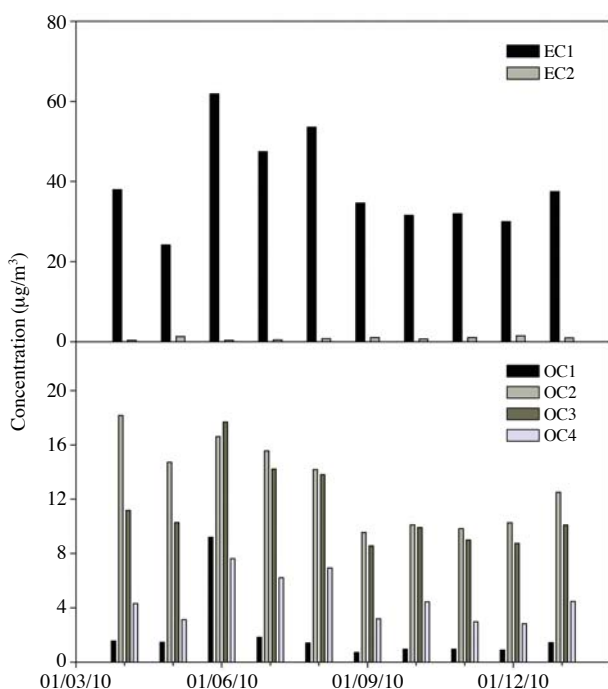
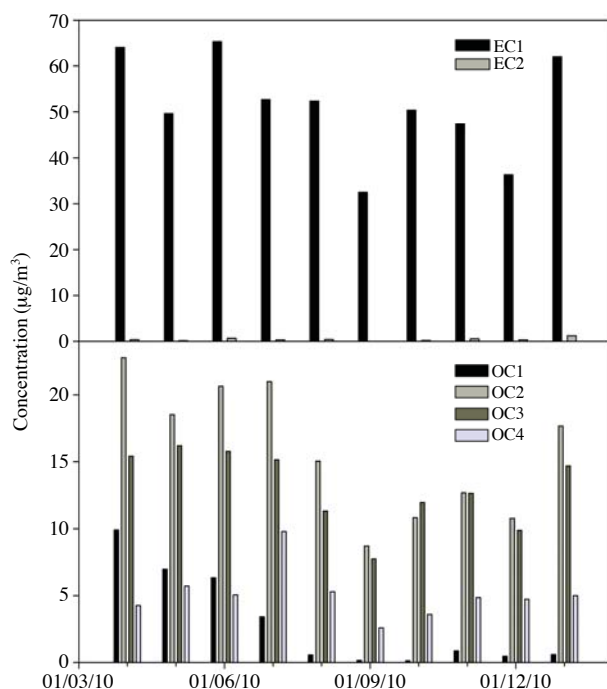
sil fuels and biomass based fuels exhibit distinctly different EC/TC and K/EC ratios allowing for source contributions to be estimated for EC and OC in the aerosol. Emissions from diesel engines as well as from oil- and coal-fired stationary sources exhibit EC/TC ratios in the range of 0.6-0.7 (Rau, 1989; Williams *et al.*, 1989; Cass *et al.*, 1982). It was found that K/EC ratio is 0.1 (Salam *et al.*, 2003) for $\text{PM}_{2.5}$, that indicate little influence from biofuel sources (Table 2). In smoke from biomass fires, the K/BC ratio is characteristically higher than for the other sources of EC. This K/EC ratio (rural sites) varies from 0.22 to 1.4 depending on the kitchen environment and the fuel types (Samir, 2007; Venkaraman *et al.*, 2002; Maenhaut *et al.*, 1996). Hence, it can be concluded that biomass fuel combustion is not a major source of EC in Dhaka urban atmosphere.

EC has different sources such as diesel engine emissions, fossil fuel combustion at low burning efficiency and biomass burning. Figs. 5 and 6 show the fraction of total carbon contributed by each of the six carbon fractions for each sample ($\text{EC}_3=0$) collected with the AirMetrics and MOUDI samplers, respectively. The abundance of EC_1 is generally higher in gasoline vehicles than in diesel vehicles (Watson *et al.*, 1994). Similarly the OC_1 abundance is higher in the diesel fueled relative to gasoline fueled and OC_2 would be higher in gasoline emissions compared to diesel. In the present study, it was found that the contribution of gasoline is much higher than diesel. This finding could be due to banning of heavy duty diesel trucks in Dhaka city during daytime and use of gasoline during starting of CNG converted engines. The contribution of EC from compressed natural gas (CNG) would be much less.

The population of motorized vehicles in Dhaka is more than 560,000 up to 2010 and average annual

Table 2. Ratios of EC/TC and K/EC in PM_{2.5} and PM₁ fractions during the study period.

Date	Air metrics					MOUDI				
	EC	K	OC	EC/TC	K/EC	EC	K	OC	EC/TC	K/EC
	μg/m ³					μg/m ³				
01/04/2010	38.3	3.43	35.2	0.52	0.09	34.0	2.60	27.6	0.55	0.08
01/05/2010	25.4	3.42	29.6	0.46	0.13	26.3	2.43	25.0	0.51	0.09
01/06/2010	62.2	4.79	51.1	0.55	0.08	34.9	3.17	25.2	0.58	0.09
01/07/2010	47.9	4.82	37.8	0.56	0.10	16.5	2.83	17.2	0.49	0.17
01/08/2010	54.3	4.32	36.4	0.60	0.08	41.2	2.37	25.2	0.62	0.06
01/09/2010	35.7	3.02	22.0	0.62	0.08	24.9	2.76	13.4	0.65	0.11
01/10/2010	32.2	3.66	25.4	0.56	0.11	26.7	2.42	14.0	0.66	0.09
01/11/2010	33.0	2.91	22.8	0.59	0.09	25.3	2.13	16.4	0.61	0.08
01/12/2010	31.5	2.64	22.8	0.58	0.08	19.4	1.92	13.6	0.59	0.10
01/13/2010	38.4	3.40	28.5	0.57	0.09	35.0	2.19	20.9	0.63	0.06

**Fig. 5.** Fractions of OC1, OC2, OC3, OC4, EC1, and EC2 in PM_{2.5} mass during the January 2010.**Fig. 6.** Fractions of OC1, OC2, OC3, OC4, EC1, and EC2 in PM₁ mass during January 2010.

growth is about 10% (Fig. 7). Motorcycles, which are mainly gasoline fueled vehicles, are the largest fleet and comprise about 35% of the total vehicle population. Motor cars and jeep/station wagon/microbus are the next largest fleet component (about 34%). Because of government policy, a large number of vehicles especially cars, taxis, and three wheelers are now operated on CNG (as of January 2011 over 0.12 million vehicles were converted to CNG). The remaining vehicles are using either diesel or gasoline (BRTA, 2010). Heavy duty commercial vehicles comprising 19% of the total fleet are expected to be causing air pollution.

3.4 Trends in Particulate Matter and Black Carbon Mass Concentrations

Long-term PM data (April 2000 to March 2006) and (April 2000 to March 2010) in two size fractions (PM_{2.2} and PM_{2.2-10}) obtained from two particulate air quality-monitoring stations, (HS and SR) were also analyzed to see the trend of air quality in Dhaka. The HS site is a heavily traffic-impacted site while the SR site is in a residential area. The sources of the observed PM for these sites have been extensively discussed in prior source apportionment studies (Begum *et al.*, 2010, 2008, 2006a, b, 2004).

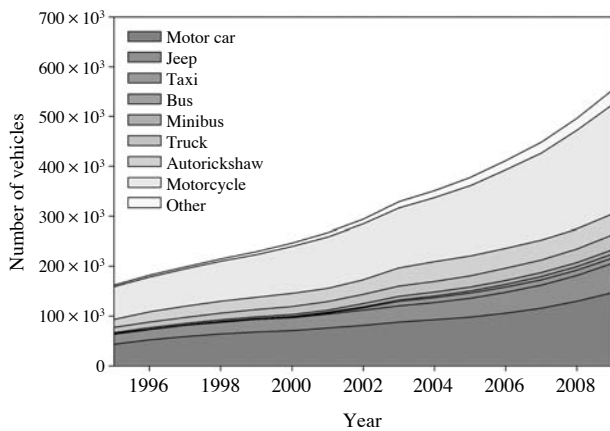


Fig. 7. Year-by-year registration of vehicles in Dhaka City (Source: Bangladesh Road Transport Authority, 2010).

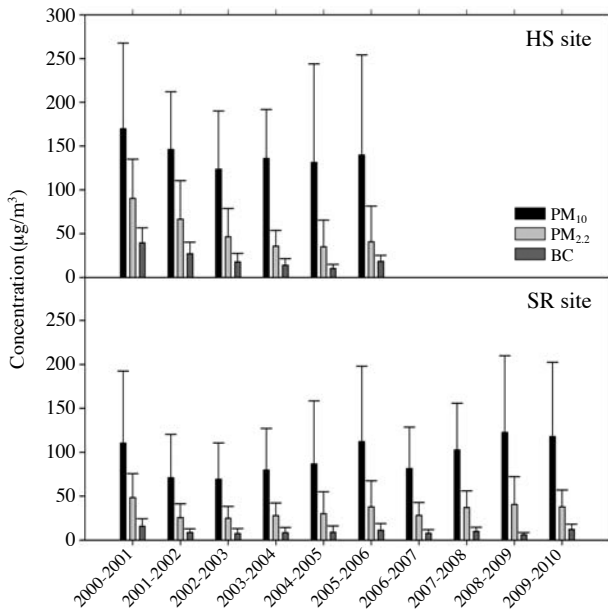


Fig. 8. The yearly average PM_{10} , $PM_{2.2}$ and BC mass concentrations from April 2000 to March 2006 and April 2000 to March 2010 at HS and SR sites respectively.

The year-by-year average values of PM_{10} , $PM_{2.2}$, and BC at mass concentrations obtained in these sites are presented in Fig. 8. From the figure, it can be observed that over the years, the $PM_{2.2}$ mass concentration has decreasing trend while PM_{10} has increased, which suggests that $PM_{2.2-10}$ fraction has been increasing. The decrease in fine particle mass is notable given the rise in the number of vehicles noted in Fig. 7. Thus, the policy approaches to reduce vehicular emissions have provided some of the improvements in the observed fine PM mass values.

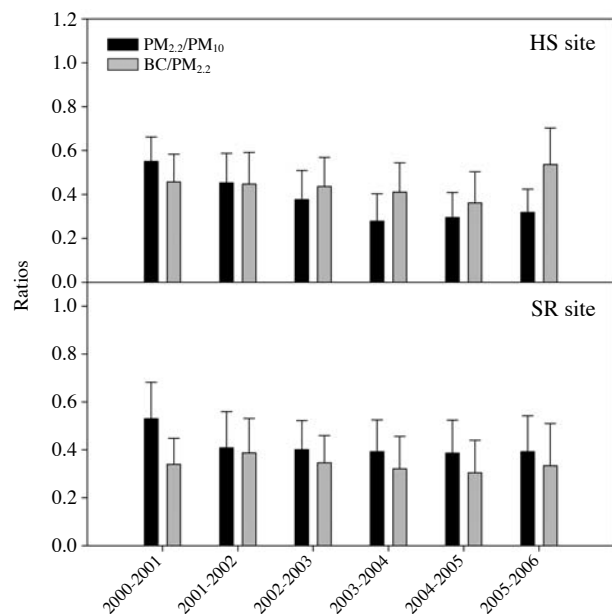


Fig. 9. Ratios of $PM_{2.2}/PM_{10}$ and $BC/PM_{2.2}$ over the collection periods from April 2000 to March 2006 and April 2000 to March 2010 at HS and SR sites respectively.

The reduction in $PM_{2.2}$ fraction of the particulate pollution seems to be over compensated by increasing the coarse ($PM_{10-2.2}$) fraction and major portion of those particles are of natural origin. Increases in soil and road dust particles in the coarse fraction increase the PM_{10} mass concentration. About 60 to 70% of coarse mass is soil dust including road dust (Begum, 2011a) in the Dhaka air. BC concentrations also show a decreasing trend. Further policy interventions may also be required to reduce such coarse particles, which are mainly originated from soil, road dust and construction activities.

The yearly average $PM_{2.2}/PM_{10}$ and $BC/PM_{2.2}$ ratios are also shown in Fig. 9. It may be seen that after 2001/2003 the average $BC/PM_{2.2}$ ratio remained unchanged although major sources such as vehicles have significantly increased. During this period, different policies were implemented to reduce the ambient PM concentrations. These measures included a phased reduction of gasoline-powered, two-stroke, three-wheel taxis with their complete banning as of January 2003 (Begum *et al.*, 2006b), improved training of engine mechanics, and removal of trucks and buses that were more than 20 years old, and also electronic traffic signals.

It can be seen that the mean $PM_{2.5}$ values were much higher than the 2006 USEPA PM National Ambient Air Quality Standards as well as the Bangladesh National Ambient Air Quality Standard for $PM_{2.5}$. The PM_{10} concentrations are much higher than the WHO annual

Table 3. Average source contributions derived from the PMF modeling for the SR site.

Source	2001-2005				2005-2006			
	Fine sample		Coarse sample		Fine sample		Coarse sample	
	%	Mass (ng/m ³)	%	Mass (ng/m ³)	%	Mass (ng/m ³)	%	Mass (ng/m ³)
Soil dust	14.8	2934	43.8	15055	9.41	2735	48.9	26392
Zn source	3.53	701	5.20	1786	6.68	1943	2.03	1094
Brick kiln	18.7	3709			38.1	11085		
Road dust	3.56	707	2.21	758	17.7	5141	12	6483
Metal smelter	0.67	133	4.97	1708	6.68	1942	0.89	478
Sea salt	4.34	862	5.26	1807	2.07	602	9.87	5322
Motor vehicle	54.4	10797	38.6	13259	19.3	5622	26.3	14179
RM		19842		34373		29070		53947
MM		26217		44970		30514		56590

guideline 2005 mean of 20 µg/m³ and a 24-hour value of 50 µg/m³.

Source apportionments results obtained from previous Positive Matrix Factorization (PMF) analysis on both fine and coarse fractions in SR site were obtained are given in Table 3 (Begum *et al.*, 2011a, 2010). It was observed that the contributions of motor vehicles in fine PM fraction has decreased in 2005-2006 than the previous year, but the contribution from brick kilns increased. This decrease resulted from the conversion of about 50% of vehicles to CNG. The brick industry in Bangladesh produces 15 billion bricks per year with an annual growth of about 7-8% and contributes 1% of the GDP. It consumes 2.2 million tons of coal and 1.9 million tons of fire wood. Thus, the increased size of the brick industries has driven increases in PM emission. It is also seen that number of motor vehicles, which are believed to be a major combustion source for air pollution, have increased. However, the relative BC fraction in PM_{2.2} fraction has not increased over the years (Fig. 9) possibly resulting from significant reductions in the carbonaceous emissions by vehicular related sources.

4. CONCLUSIONS

In order to improve the ambient air quality of Dhaka, the government has implemented several policy interventions since 1999 including introducing unleaded gasoline, banning of two stroke auto-rickshaws and switching fuel to compressed natural gas (CNG). Although a large fraction of the automobiles, especially the smaller vehicles in Dhaka are now running on CNG, but CNG-converted engines use gasoline to start the engine. Moreover, long distance buses and trucks still operate using diesel. Therefore, the use of gasoline and diesel in transport sector has not been eliminated. Heavy-duty commercial vehicles and motor cycles

that constitute about 54% of the total fleet continue to contribute to the air pollution in Dhaka.

In this study, carbon analyses have shown the signature of gasoline-fueled vehicles. It is observed that a significant fraction (~63%) of PM_{2.5} is PM₁. It also seen that PM₁ fractions contain the majority of total carbonaceous materials in the PM_{2.5}. Carbon fraction analysis showed that the contribution of gasoline is much larger than from diesel with respect to carbonaceous material in the PM because of changes to vehicle characteristics in Dhaka city. Although carbonaceous materials in PM are likely to arise from combustion sources, the small number of samples does not permit the separation of their individual contributions. Further study will be necessary to determine the air quality impacts of the brick industry.

Source apportionment results showed that vehicular exhaust remain the single largest contributor to PM in Dhaka. Various government policy interventions have reduced PM pollution levels including carbonaceous materials that showed a decreasing trend over the years. With the increasing economic activities and GDP growth, the number of vehicles and brick kilns is increasing significantly in and around Dhaka. Further action will be required to further reduce the PM related air pollution in Dhaka.

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