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Identification of Sources of Fine and Coarse Particulate Matter in Dhaka, Bangladesh

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ABSTRACT

In Bangladesh, the ambient air within Dhaka city is highly polluted by motor vehicle and brick kiln emissions. In addition, meteorological conditions during the winter cause increases in the fine particulate matter concentrations by factors of 4 to 5 fold compared to the rainy season. To understand the contribution of possible pollution sources, compositional data for both the coarse and fine fractions samples collected between May 2001 and March 2005 have been analyzed using Positive Matrix Factorization (PMF). The results were compared with the previous source apportionment results. Conditional Probability Function (CPF) plots were developed for each source using local wind data to explore the directionality of local sources. Back trajectory ensemble methods were used to identify potential source regions and pathways of transboundary transport of $PM_{2.2}$ apportioned sources. The Potential Source Contribution Function (PSCF) domain extended around the receptor site in Dhaka (23.77°N, 90.38°E) over the range from 1.5° to 42.5°N and 56.5° to 110.5°E. The PSCF results are compared to the conditional probability function (CPF) analyses that use 3 hour average local wind directional data to determine the likely directions for the sources. Both PSCF and CPF help to identify the potential source locations, but on different distance scales. These analyses demonstrate that coarse particles are dominated by local sources. However, local and regional source contributed to the elevated fine PM levels in Dhaka. Thus, regional control efforts will be required in addition to local initiatives to improve the air quality in mega cities in this region like Dhaka.

Keywords: PMF; PSCF; CPF; Back trajectory.

INTRODUCTION

Atmospheric pollution from anthropogenic activities is not only a local issue but it is also a regional as well as global problem. During the last decade, a greater awareness has been created in the general public and governments as to the impact of pollutants on the quality of human life and in general the ecosystems. As a result, rapid progress is being made in different regions of the industrialized world to develop a better understanding on the issues related to various aspects of the environment and its pollution including air pollution. Urban air pollution and its effects are also becoming an issue of great concern for developing countries. To address the air pollution issues, it important to know the possible sources and their strengths so actions can be taken that can effectively improve air quality. Local sources can be controlled by local initiatives, but regional as well as transboundary issues would require intergovernmental interventions.

Particles can have either a cooling effect on the atmosphere through scattering of shortwave radiation (sulfate and organic carbon particles) or a warming effect through absorption of shorter wave radiation (black carbon particles) (Ramanathan and Carmichael, 2008). 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. Thus, there are good reasons to understand the extent and sources of BC.

Moreover, Asian dust particles could lead to both cooling by scattering sunlight back to space and warming by absorbing solar and infrared radiation that makes the Asian aerosol situation more complicated. Clarke *et al.* (2004) and Kim *et al.* (2004) showed that Asian dusts flowing from the source regions in Northern China could evolve into darker dusts during their movement to the east where they can mix with soot particles. Diesel and compressed natural gas burning emit particulate matter consists of fine particles with high number of ultrafine

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particles and are respirable particles with large surface area where organics adsorb easily and can cause acute irritation and other diseases (Wichmann, 2007).

Previously source apportionment studies were performed for Dhaka city air pollution using data from June 2001 to June 2002 (Begum *et al.*, 2004, 2005). These source apportionment studies found that vehicles normally produced about 50% of fine particles ($PM_{2.2}$ particles) in Dhaka. Coarse particles ($PM_{2.2\text{-}10}$ particles) mainly originate from mechanical processes (Begum *et al.*, 2006). During this period, gasoline and diesel were mainly used as fuel to run motorized vehicles. The Bangladesh government has enacted a number of policies to reduce the concentration of ambient particulate matter. Source apportionment based on the PM data can be used to examine the effect on these policy implementations.

Therefore, in this study, data from 2001 to 2005 was analyzed for source apportionment to examine if there were significant changes in the source characteristics arising from the policy interventions taken during this period. Moreover, to understand the possible contribution of regional/transboundary sources to the local pollution, especially during wintertime, efforts have been made to identify possible potential source regions and pathways of transboundary transport using back trajectory ensemble methods. In our previous study, it was observed that there could be a role of transported $PM_{2.2}$ from regional sources to the elevated PM pollution levels in the Dhaka atmosphere (Begum *et al.*, 2008; Kehrwald *et al.*, 2008)

MATERIAL AND METHODS

Receptor Site

A size-fractionating aerosol sampler, the Gent stacked filter unit (SFU) (Hopke *et al.*, 1997) was used to collect aerosol particles from the semi-residential area in Dhaka that is situated inside the Atomic Energy Centre, Dhaka campus. Particulate matter (PM) samples were collected in two size fractions, coarse (d = 10–2.2 µm) and fine (d < 2.2 µm). Sequential polycarbonate filters with 8 and 0.4 µm pores (Nuclepore, supplied by Costar Corp. Cambridge, MA, USA) were used for PM size separation and collection. The sampling station is located within Dhaka University Campus about 1 km from a busy road with significantly high traffic and details are given by Begum *et al.* (2004).

Sampling Period

The PM samples providing the data for this study were obtained between May 2001 and March 2005. Twenty-four hour representative samples were collected at the site twice a week but only on weekdays (no weekend days) using a GENT air sampler (Hopke *et al.*, 1997). Approximately 100 sample pairs (each sample pair comprises one fine and one coarse fraction sample) were collected each year at this sampling station. By using a controller to turn the sampler off and on, the effective sampling interval was varied between 6 and 20 h (depending on season) distributed uniformly over 24 h a day to avoid filter clogging and so that the flow rate remains within the prescribed limits to maintain the sampler's aerodynamic characteristics. This ensured proper size fractionation and collection efficiency. Intercomparison of GENT data with continuous 24 h AirMetrics MiniVol data by collocated sampling suggested (Begum and Biswas, 2005) that the data generated using such time-sliced sampling procedure provides reasonably accurate average PM mass data.

PM mass and BC determination

The masses of the coarse and fine fraction samples were determined by weighing the filters before and after the exposure. A Po-210 (alpha emitter) electrostatic charge eliminator (STATICMASTER) was used to eliminate the static charge accumulated on the filters before each weighing.

The concentration of black carbon (BC) in the fine fraction of the samples is determined by reflectance measurement using an EEL (Evans Electroselenium Limited) -type Smoke Stain Reflectometer. Secondary standards of known black carbon concentrations are used to calibrate the Reflectometer (Biswas *et al.*, 2003).

Multielemental Analysis

Multielemental analyses of the samples collected during the above cited time intervals were made using proton induced X-ray emission (PIXE) at the Institute of Geological and Nuclear Science (GNS), New Zealand. The X-ray spectra obtained from PIXE measurements were analyzed using the computer code GUPIX (Maxwell *et al.*, 1989, 1995). Of the twenty six species determined including BC for each fraction of the 342 samples, ten elements (P, Sc, V, Ni, Ga, Ge, As, Se, Rb, and Sr) had missing or below detection limit values for more than 80% of the cases. These elements were eliminated from the data analyses. Concentration data for fifteen chemical species (Na, Al, Si, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Cu, Zn, Br and Pb, BC) and mass were available. The data quality of the available elemental concentration together with mass and BC were tested by a reconstructed mass (RCM) analysis comparing the computed RCM values with the gravimetric weight of the filters (Begum *et al.*, 2006). The least squares fit to the data gave RCM = 0.45 × mass with an R^2 = 0.72 for coarse mass and RCM = 0.84 × mass with an R^2 = 0.69 in case of fine mass. The reconstructed mass could only account for about 45% of the gravimetric coarse mass in this study. It is likely that much of the missing mass was organic carbon. In case of fine aerosol, a surrogate was used for organic carbon where OC = 0.67 × EC (Begum *et al.*, 2009) was used for calculation of organic carbon and to check the data quality and the reconstructed mass could account for 84% of the gravimetric mass but this organic carbon mass was not used in PMF analysis.

Positive Matrix Factorization Modeling

PMF is a source-receptor model that solves the equation:

$$x_{ij} = \sum_{i=1}^{p} g_{ik} f_{kj} + e_{ij} \qquad (1)$$

where x is the matrix of ambient data collected at the receptor site, consisting of the species in columns and dates in rows, g is the matrix of source contributions, where each source k contributes to each sample i, and f is the mass of each element j in each source k (Paatero and Tapper, 1993, 1994; Paatero, 1997). A 340 × 17 [(rows) × (columns)] input data matrix and uncertainties matrix were used as input of the PMF2 program which is developed by Paatero (Paatero and Tapper, 1993, 1994; Paatero, 1997). PMF tries to minimize the sum of squares:

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{n} (e_{ij} / s_{ij})^2 \quad (2)$$

where s_{ij} are the error estimates for the elements in x described above. The value of Q should approach the number of degrees of freedom, n × m, or the number entries in the data matrix. PMF can accommodate data sets with missing data by assigning an average value to the concentration with a large uncertainty such that the missing data will not significantly weight the results. The important feature of PMF2 is FPEAK, which was used to control rotations. By setting the value of FPEAK, the routine is forced to subtract the F factors from each other, yielding more physically realistic solution (Paatero *et al.*, 2002). To reduce the rotational freedom, a new additional approach, called G space plotting for PMF modeling (Paatero *et al.*, 2005) is used to explore the rotational ambiguity. The G space plotting helps to identify the edges that show the factors that are 'independent' in the factor analysis. The rotation can then be controlled by FPEAK until an appropriate distribution of the edges is achieved. Limitation of the software is that there is no option for estimating the uncertainties in the G factors and thus it is not possible to estimate errors in the source contribution from a PMF analysis. The work is currently underway to develop a credible approach to error estimation. For the determination of number of factors in PMF, the primary consideration was the goodness of fit to the original data. It is helpful to examine the distributions of scaled residuals (e_{ij}/s_{ij}). In a well-fit model, the residuals e_{ij} and the error estimates s_{ij} should be about equal and the e_{ij}/s_{ij} ratios should fluctuate between ±2 (Paatero and Tapper, 1994). PMF could resolve 6 sources for coarse fraction and 7 sources for fine fraction samples. The profiles for the coarse and fine PM fractions are presented in Figs. 1 and 2, respectively. The detailed descriptions of these source profiles are presented elsewhere (Begum *et al.*, 2004). The PMF solution was evaluated by comparing the predicted mass of both coarse and fine fractions (sum of the contributions from resolved sources) with measured mass concentrations (Supplemental Fig. S1). The slopes and r^2 values are slope = 0.72, r^2 = 0.73 for the coarse fraction and slope = 0.67, r^2 = 0.36 for the fine fraction.

Conditional Probability Function

The conditional probability function (CPF) calculates the probability that a source is located within a particular wind direction sector, Δθ (Ashbaugh *et al.*, 1985)

$$CPF = \frac{m_{\Delta\theta}}{n_{\Delta\theta}} \quad (3)$$

where $n_{\Delta\theta}$ is the number of times that the wind passed through direction sector Δθ and $m_{\Delta\theta}$ is the number of times that the source contribution peaked while the wind passed

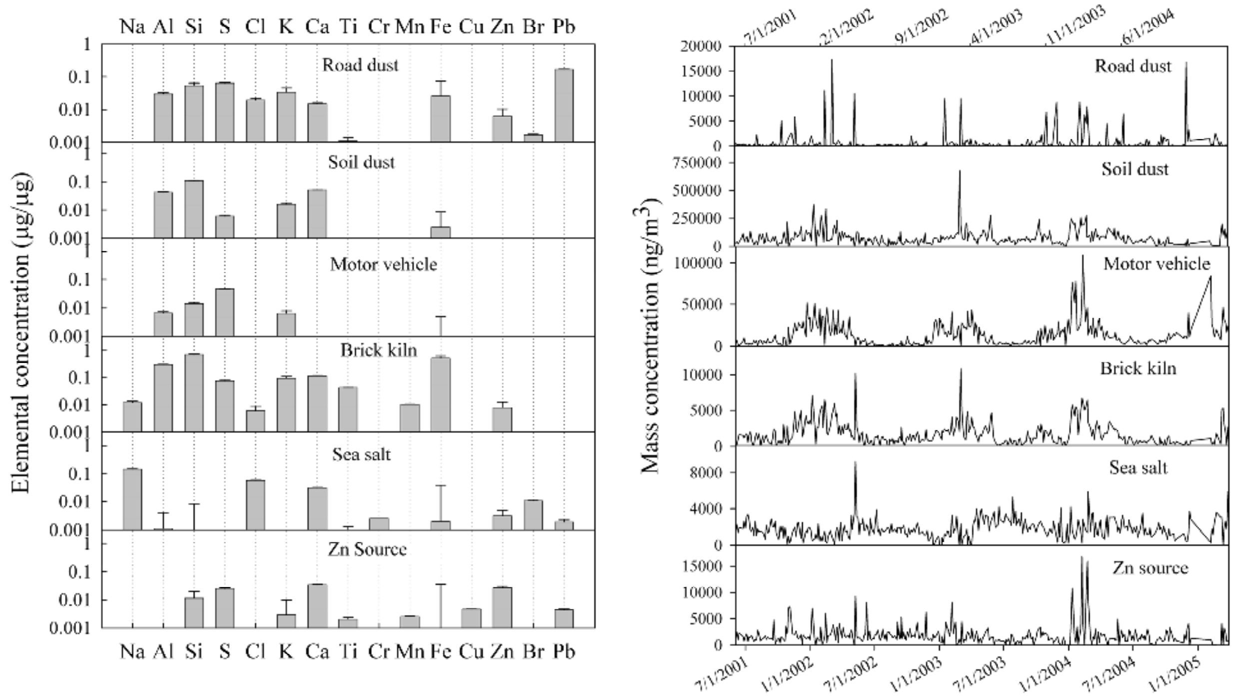

Fig. 1. Source composition profiles and time series of source contributions for coarse particulate matter.

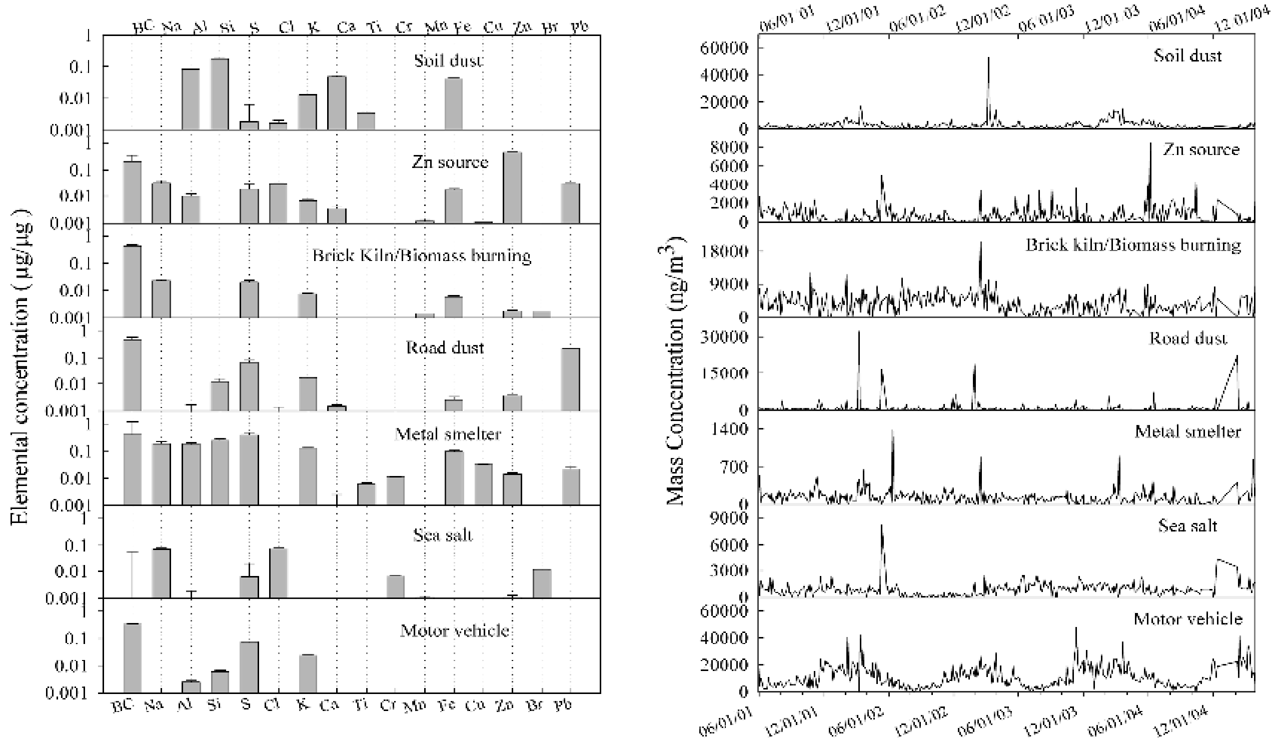

Fig. 2. Source composition profiles and time series of source contributions for fine particulate matter.

through sector $\Delta\theta$. To use CPF with the semi-residential site (AECD) data, the 24-hour averaged source contribution estimates have been used with the 3 hourly wind direction values measured at a meteorological station about 5 km north of the site.

Trajectory Model

The NOAA Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT-4) model (Draxler and Rolph, 2003) was used to calculate the air mass backward trajectories for those days when fine particles were sampled at both sites. The vertically mixed model starting at 500 m above the ground level was used to calculate the five-day backward trajectories arriving every six hours at the receptor site producing approximately 605 endpoints per sample. A starting height of 500 m has been used based on the results of Cheng *et al.* (1993). This height is approximately the height of the mixing layer and has generally found as useful height for such analyses (Zeng and Hopke, 1989; Lee and Hopke, 2006). This height was chosen to diminish the effects of surface friction and to represent winds in the lower boundary layer. Samples were generally collected twice a week. The geophysical region covered by the trajectories was divided into 9159 grid cells of 1° × 1° latitude and longitude so that there are approximately 206910 end points/9169 cells or 23 trajectory end points per cell on average.

Potential Source Contribution Function

The error associated with the trajectory segment increases as the distance from the receptor site increases. In a trajectory ensemble approach, the collective properties of a large number of end points are used to estimate a conditional probability field that represents the likely location of PM sources. If the errors in the endpoint locations are randomly distributed, then using a sufficient number of end points distributed over the region of interest should provide a reasonable estimate of the cell-by-cell probability values. Thus, the Potential Source Contribution Function (PSCF) model provides a means to map the source potentials of geographical areas. It does not apportion the contribution of the identified source area to the measured receptor data.

Air parcel backward trajectories were related to the composition of collected material by matching the time of arrival of each trajectory at the receptor site. The movement of an air parcel is described as series of segment end points defined by their latitude and longitude. The backward trajectories were calculated for each sample collected during the period of May 2001 to March 2005. PSCF values for each grid cell were calculated by counting the trajectory segment endpoints that terminate within the grid cells. The number of endpoints that fall in the ij^{th} cell is $n(i, j)$. The number of endpoints for the same cell when the corresponding samples show concentrations higher than an arbitrarily criterion value is defined to be $m(i, j)$. The PSCF value for the ij^{th} cell is defined as

$$PSCF(i,j) = m(i,j)/n(i,j) \tag{4}$$

In the PSCF analysis, it is likely that the small values of n_{ij} produce high PSCF values with high uncertainties. In order to minimize this problem, an empirical weight function $W(n_{ij})$ proposed by Han *et al.* (2004) was applied when the number of the end points per a particular cell was less than about three times the average values of the end points per cell.

$$W(n_{ij}) = \begin{cases} 1.0 & n_{ij} > 46 \\ 0.75 & 23 < n_{ij} \le 46 \\ 0.5 & 11 < n_{ij} \le 23 \\ 0.15 & 0 < n_{ij} \le 11 \end{cases} \quad (5)$$

RESULT AND DISCUSSION

PMF Modeling

All of the samples used in the present analysis were collected on weekdays. Table 1 shows the average elemental concentrations, standard deviation and median values of fine particulate mass (FPM) and coarse particulate mass (CPM) collected at semi-residential area (SR) in Dhaka.

The results of the source apportionment are given in Table 2 along with the previous PMF analysis results at the same location for a smaller data set covering the period 2001–2002 (Begum *et al.*, 2004). It is found that the pollution contributions from the brick kiln increased over the years. Bangladesh is a developing country, and there has been high growth in the industrial sector surrounding the Dhaka (Begum *et al.*, 2008). Because of the increasing economic activities mainly around the Dhaka city, there has been a significant population growth, which created extra demand on transportation and infrastructures. The building boom has lead to establishment of additional brick kilns. Currently, over 1,000 brick kilns are operating around Dhaka, and primarily use coal as fuel. The Government is considering adopting policies specifically to reduce the emissions from brick kilns.

The contribution from motor vehicle (petrol, diesel and CNG) increased about 5% compared to the previous results (Table 2). During the past few years, several policy interventions have been taken by the Government to reduce air pollutions from vehicular emissions, especially for Dhaka (Biswas *et al.*, 2003; Begum *et al.*, 2006). Even though the number of vehicles has increased significantly

Table 1. Summary fine and coarse particulate mass concentrations (ng/m^3) used for PMF modeling.

Parameter	Fine Particulate Mass			Coarse Particulate Mass		
	Mean	STD	Median	Mean	STD	Median
Mass	26217	16878	22065	44846	34639	34979
BC	8339	5743	6984	–	–	–
Na	368	370	254	724	704	467
Al	331	393	224	1361	1112	1051
Si	685	702	495	3279	2602	2537
S	1200	793	1028	961	839	672
Cl	148	150	115	692	796	414
K	360	225	298	578	471	421
Ca	155	205	104	1102	846	906
Ti	13.5	15.4	4.56	90.5	74.6	68.7
Cr	6.37	5.51	5.31	14.2	11.7	10.9
Mn	7.92	5.69	7.15	24.4	19.8	19.2
Fe	195	167	154	1057	847	825
Cu	4.61	4.86	3.48	11.2	9.52	8.58
Zn	335	402	199	449	628	240
Br	15.4	23.7	11.2	29.7	15.2	26.4
Pb	182	580	63.0	218	439	74.9

Table 2. Average source contributions derived from the PMF modeling.

Parameter	Coarse Fraction (μg/m^3)		Fine Fraction (μg/m^3)	
	2001–2002	2001–2005	2001–2002	2001–2005
Road dust	7.30	2.21	19.4	3.56
Soil dust	43.0	43.8	10.2	14.8
Motor vehicle	40.2	38.6	38.2	54.4
Metal Smelter	–	–	–	0.70
Sea salt	4.45	5.26	1.00	4.34
Zn source	3.78	5.20	9.36	3.53
Brick kiln	–	4.97	11.9	18.7
Cement	1.21	–	9.96	–

during this period (Begum and Biswas, 2005), pollution contribution has not been increased in that magnitude. Moreover, the adoption of compressed natural gas-powered vehicles in Dhaka has contributed to the slower increase in $PM_{2.2}$ concentrations. Although the two-stroke engine taxi was banned in 2003, there are still significant Zn emissions. Zn in fine PM comes in part from the remaining two-stroke motor vehicles plying peri-urban areas of Dhaka and from the galvanizing industry. Thus, the relatively limited rise in concentrations in fine size fraction indicates that the control actions have helped to balance the increases in pollution that would have been anticipated to parallel the growth in population, economic activity, and vehicles.

Comparing the present source apportionment results with the data set was from 2001–2002 (Begum *et al.*, 2004) and the ratio of $BC/PM_{2.2}$ values it is seen that the contribution from brick kilns has increased by about 6%. But the source contribution of coarse fraction does not change remarkably than the previous result. Therefore, due to the increased source contribution of the fine fraction the overall PM_{10} concentrations have increased (Begum *et al.*, 2008).

RESULTS AND DISCUSSION

The wind direction in Bangladesh depends on the seasonal climate. According to meteorological conditions, the year can be divided into four distinct 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, low relative humidity, scanty rainfall and low northwesterly prevailing winds. Rainfall and wind speed become moderately strong and relative humidity increases in the pre-monsoon season when the prevailing winds become southwesterly (marine). During the monsoon season, the wind speed further increases and the air mass is highly marine in nature. In the post-monsoon season, the rainfall and relative humidity decreases, as does the wind speed. The direction starts to shift back to northeasterly.

Because of the geographical position of Bangladesh, the wind directions are primarily from the northwest, southwest, south and southeast. Fig. 3 shows the PSCF plot for fine soil source apportioned by PMF analysis. In order to minimize the local contribution, only data values above the 75^{th} percentile were used to prepare the PSCF plot. These plots suggest there could be some influence of long-range transport of fine soil at the receptor site. To explore potential transboundary episodes, the highest soil contribution was found on March 5, 2003. The raw fine data set also showed that the concentration of Si is also very high for that sample. Thus, backward trajectories (10 days) for this day (Supplemental Fig. S2) were calculated. These trajectories show that the air parcels come from Iran and Pakistan. The corresponding satellite image shows two thick plumes of desert dust blowing over Oman and across the Gulf of Oman toward Iran and Pakistan on February 18, 2003 (Supplemental Fig. S3). Therefore, it can be concluded that the highest fine soil contribution was, in part, the result of long-range transport of the desert dust.

Fig. 4 shows the PSCF plot of the biomass burning/brick kiln source apportioned by PMF analysis. The elemental signature of brick kiln emission/biomass burning source includes BC, S, and K. However, S and BC can also be considered to be the signature of fossil fuels combustion that may come from both local sources and long-range transport of fine PM. The highest concentration of the biomass burning source was on February 9, 2003. It has also found that BC contribution of this day is also high. Therefore, to explore the possibility of long-range transport, backward trajectories (7 days) on this day were calculated (Supplemental Fig. S4). It is observed that air parcels traveled through the central and northern part of India. On January 10, 2003, there was a low-lying cloud blanketing much of the region south of the Himalayas (Supplemental Fig. S5) and this episode extended until February 14, 2003. The particulate pollution over the region was trapped by the mountains leading to this visible cloud. These layers of haze and cloud may be contributing to the unusually cold conditions being experienced those days in Bangladesh. The haze lingered near the base of the mountains because of a temperature inversion. Under normal conditions, the air near the ground is warmer than the air above it and pollution from biomass burning is diluted by vertical dispersion.

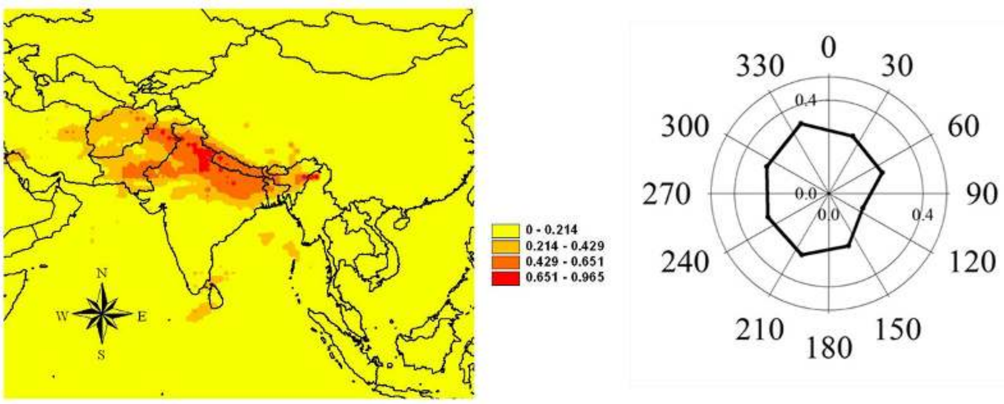

Fig. 3. PSCF and CPF plots for the Fine Soil Dust contributions.

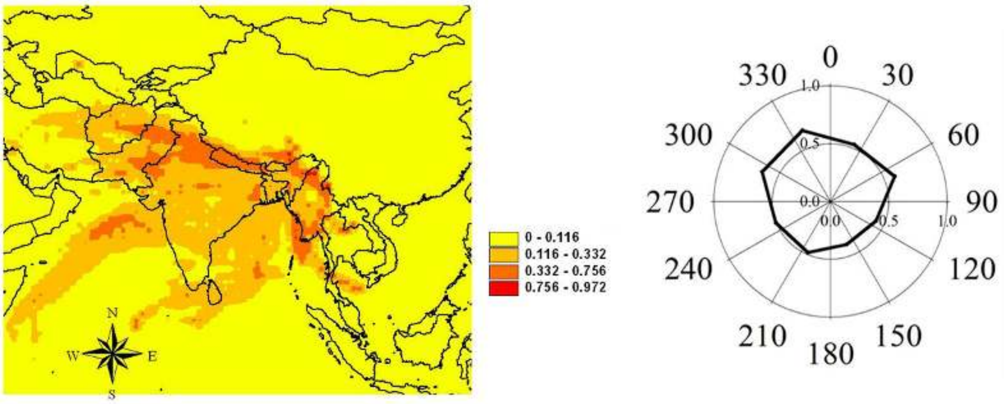

Fig. 4. PSCF and CPF Plots for the Biomass Burning/ Brick Kiln contributions.

The signature of smoke source is *K* and by definition of smoke, *K* is

$$K_{Smoke} = [K] - 0.036 \times [Na] - 0.6 \times [Fe] \tag{6}$$

In Eq. (6), bracket [ ] denotes the concentration of the element. Fig. 5 shows the time series of the smoke contributions. In order to minimize the local contribution values of smoke, those samples having concentrations greater than twice the standard deviation plus the mean value (600 ng/m^3) were considered as possibly influence by long-range transport contributions. From the data time series, the peak K concentration was found on November 10, 2003 and equaled 1.1 µg/m^3. The BC concentration on that day was 25.4 µg/m^3. Examination of the back trajectories (7 days) for this day (Supplemental Fig. S6) showed the potential source area is northwestern part of India. Supplemental Fig. S7 shows the haze as seen in a satellite image occurred as a result of smoke from agricultural fires in northern India starting on November 3, 2003 and then stagnating along the Himalayan Mountains until November 6, 2003.

Fig. 6 shows the PSCF plot for the motor vehicle source (includes both diesel and gasoline) apportioned by PMF analysis prepared using the 75th percentile contribution value as the criterion. In order to minimize the local

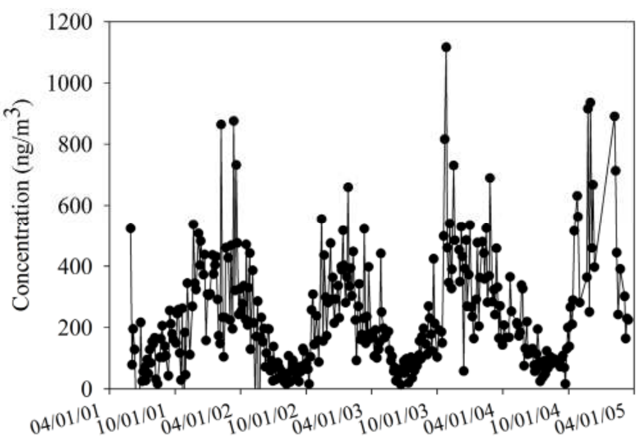

Fig. 5. Time series plot of the smoke contributions (ng/m^3).

contribution, the highest values (above 27,000 ng/m^3) were used explored as well. There are several high concentrations and the highest concentration value (41,000 ng/m^3) was found on February 06, 2005. The back trajectories (7 days) for this day are shown in Supplemental Fig. S8. The satellite view on this day (Supplemental Fig. S9) shows haze across southern Afghanistan, India and Pakistan resulting from a mixture of different particle types. This haze is likely to be anthropogenic particle pollution from vehicles, energy production, and household heating and cooking fires. An atmospheric inversion trapped them in the region. This pollution and fog were mixed at the base of the Himalayas in India in late December 2005. Such phenomena are common in this region between December and February.

The directional pattern found in CPF plot is consistent with the direction of heaviest truck traffic. The diesel used in Bangladesh contains about 0.7% sulfur. Burning high sulfur coal emits organic matter, black carbon particles, and SO_2 that is converted to secondary sulfate aerosols. Lower temperature combustion would also permit emission of SO_3. Therefore, sulfur and BC are common signature species of both heavy duty motor vehicles and coal burning and cannot always be separated. In India, about 77% of energy comes from fossil fuel combustion (CARMA, 2009). There are a number of coal fired power plant in Durgapur, Birat Nagar, Patna, Kanpur, Kolkata and New Delhi areas and could be potential source of fine sulfate as well as carbonaceous aerosol. Because of longer transport time, these fine particles are expected to travel long distances and contribute to the Dhaka aerosol.

The contribution of sea salt source, characterized by Na and Cl, predominately comes from the southern direction. The PSCF plot (Fig. 7) was again prepared using the 75th percentile as the criterion value and shows that most of the hotspots are located in the Bay of Bengal. The value of peak concentration was on May 12, 2002 and was 8,280 ng/m^3. Back trajectories (7 days) for this day were calculated (Supplemental Fig. S10) to observe the air movement. Tropical Cyclone Kesiny (Supplemental Fig. S11) was seen over the Indian Ocean on May 6, 2002 and would likely be the cause of the high sea salt contributions on that day.

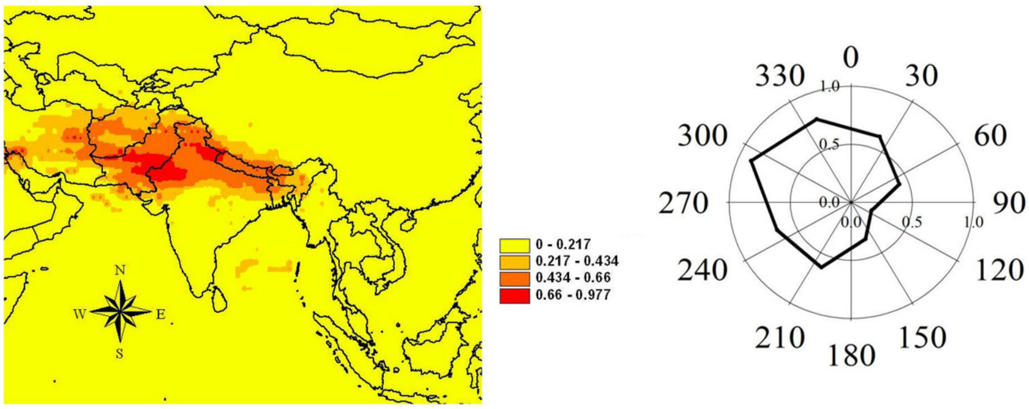

Fig. 6. PSCF and CPF plots for the Motor Vehicle contributions.

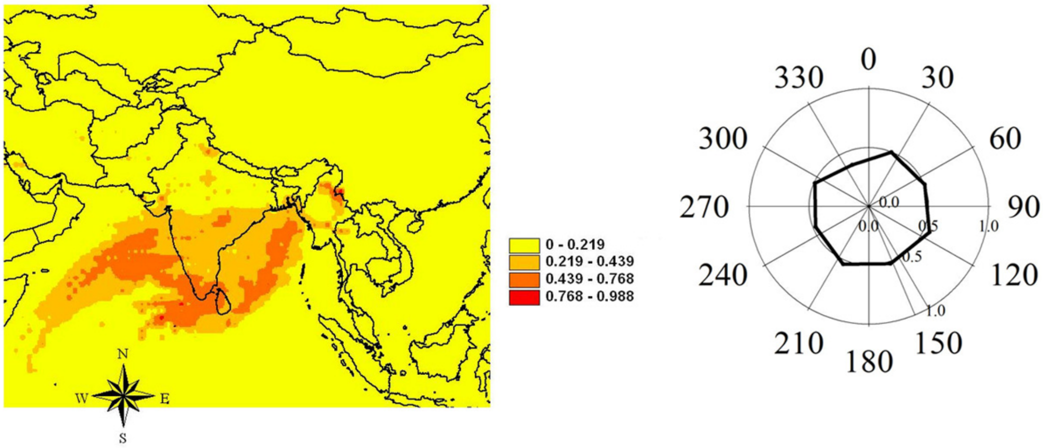

Fig. 7. PSCF and CPF plots for the Sea Salt contributions.

CONCLUSIONS

Bangladesh is a developing country and due to relatively faster economic growth, the numbers of industries especially around Dhaka city are increasing in a rapid pace. The population density is also increasing. To fulfill the growing transport demand, the number of vehicles is 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. The contributions from the vehicles increased reflecting the increasing number of vehicles. 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 contribution from the brick kilns also increases day by day. The Government is trying to control the emission from brick kilns through introducing green technologies for brick production. Although local sources of air pollution in Dhaka city are quite high, there are very high PM concentrations especially in dry days. These high concentrations might have some contribution from distance sources. It is seen from the PSCF analysis that apart from local contribution of pollution sources, there are regional influences on fine PM levels in Dhaka. Therefore, regional efforts will be necessary along with local control initiatives to improve the air quality.

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