International Journal
of
Integrated Sciences & Technology (IJIST)

http://www.cuet.ac.bd/IJIST/index.html

International Journal of Integrated Sciences & Technology 2 (2016) 1-6

An Approach for Quantitative Estimation of Long Range Transport of Fine Particulate Matter Entering Bangladesh

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Abstract

Particulate air pollution is a major environmental concern in Bangladesh during winter season. In this view fine particulate matter ($PM_{2.5}$) sampling was done in consecutive three winter seasons, December 2010 to February 2011, December 2011 to February 2012 and December 2012 to February 2013. The sampling stations were Continuous Air Monitoring Stations (CAMS) located at Farm Gate in Dhaka, Sapura in Rajshahi, Baira in Khulna and Male Declaration Station Shamnagar, Khulna. PM sampling was performed using dichotomous samplers, which collect samples in two sizes: $PM_{2.5}$ and $PM_{2.5\text{-}10}$ during the first two years and the stations are Farm Gate in Dhaka, Sapura in Rajshahi, and Baira in Khulna. During third year, PM sampling was performed using an Air Metrics sampler that collects one fraction, either $PM_{2.5}$ or PM_{10} at a time from Farm Gate in Dhaka, Sapura in Rajshahi, and Male Declaration Station Shamnagar, Khulna. All of the samples were analyzed for fine mass and black carbon (BC). It was found that the mean $PM_{2.5}$ value in Rajshahi was higher to than that Dhaka and Khulna cities although anthropogenic activities were higher in Dhaka than the other two cities. It was also observed that during the monsoon season, the daily average of $PM_{2.5}$ comply with the national ambient air quality standard (NAAQS) in Dhaka and Khulna cities, but in Rajshahi, $PM_{2.5}$ values exceed the NAAQS. A source for these higher values may be long range transport of PM from agricultural burning in upwind regions and/or from natural dust storms that occur around the mid/end of February in the Arabian Peninsula almost every year. A threshold value (2*STD+MEAN) was set for three sites in order to reduce the influence of local pollutants. It was found that threshold value for Rajshahi was 385 $\mu g/m^3$ and for other two sites, it was 208 $\mu g/m^3$ (Average value). Hence, it may be concluded that a potential 177 $\mu g/m^3$ comes from long range transport during the winter season.

Key words: $PM_{2.5}$, NAAQS, Long range transport

1. Introduction

Transboundary air pollution is a particular problem for pollutants that do not readily react in the atmosphere or wet or dry deposit. These cross boundary pollutants can be generated in one country and produce impacts in others. Control of these pollutants requires international action and collaboration to control their formation and effects. Transboundary air pollutants can survive for periods of days to weeks and can be transported thousands of kilometers and affect the air quality, soils, rivers, lakes and/or our food. Transboundary air pollutants can include particles and ground level ozone. Particulate matter pollution is a major concern in Bangladesh [1].

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Prior studies [2] found that during monsoon or post monsoon season when the wind comes from south or south-eastern directions, the concentration of fine PM complies with the Bangladesh National Ambient Air Quality Standard (BNAAQS). During the winter season, wind comes from north or north-west direction and concentration of fine PM goes up to 3 to 4 times higher compare to monsoon season. From source apportionment studies, Begum et al. [3-4] found that the sources of pollutants are motor vehicles, diesel generators, biomass and wood burning, brick kilns, Zn from galvanizing factory and fugitive Pb from battery industries and Pb recycling.

Given its geographical location, there are four seasons in Bangladesh; winter (December to February), pre-monsoon (March-May), monsoon (June-September), and post-monsoon (October-November). During

ISSN : 2411-9997

winter, cold winds blow from the north-west. This cold air carries continental fine air masses[5]. As a result, local pollutants mix with transported material that was hanged along the lower levels of the Himalayas. The visible impact of air pollution is the haze, a layer of pollutants and particles from biomass burning and industrial emissions. This polluted Atmospheric Brown Cloud has a brownish color and this brown cloud phenomenon is a common feature of industrial and rural regions around the world[6]. Because of long range transport of air pollutants, the mostly urban emissions (fossil fuel related) and/or rural emissions (biomass burning and brick kiln related) are transformed into a regional haze (or cloud) that can span large areas. It is now becoming clear that the brown cloud may have huge impacts on agriculture, health, climate and the water budget of the planet[6-7]. This haze is the result of forest fires, the burning of agricultural wastes, dramatic increases in the burning of fossil fuels in vehicles, industries and power stations and emissions from millions of inefficient cookers burning wood, cow dung and other biofuels.

It is a well-recognized scientific fact that air pollutants spread easily across borders. In the 1970s, a Tran's boundary air pollution event promoted severe acidification in ecosystems in Europe. Northeast Asian regions including Japan, China, and Korea have also observed air pollutants crossing over borders from time to time. Japan and Korea, the countries most likely to be affected by air pollution because of their downwind locations. The targeted substances for restriction have changed over time, first with sulfur oxide (SOx) in the 1990s, yellow dust in the early 2000s, ozone (O_3), a cause of photochemical smog, in the late 2000s, and the most recently recognized problem of PM2.5 pollution. Although airborne particles are generally associated with global cooling effects, recent studies have shown that they can actually have a positive radiative forcing effect [8] particularly in certain regions such as the Himalayas [9]. In South Asia, many countries recognize air pollution as a major public health concern and have undertaken steps to control air pollution, but data provided by some of these countries indicate that in many cities, air quality still falls below world standards for acceptable air quality [10]. The fundamental cause embedded in the air pollution problem is that the current energy mix is dependent on fossil fuels and unsustainable development patterns which is a common issue among international communities and there is no instant solution. Transboundary air pollutants can survive for periods of days or even years and can be transported thousands of miles. Thus, an approach of quantitative estimation of transported fine PM is discussed in this study. Thus, in order to estimate the long range transport of fine air pollutants, airborne particulate matter (APM) sampling has conducted in three cities, Rajshahi, Dhaka, and Khulna during the winter seasons. The objective of this work is to estimate the transported of fine air pollutants that increase the local airborne pollutant concentrations during the winter season.

2. Materials and Method

2.1 Sampling

Samples were collected on 37 mm diameter Teflon filters using Thermo Andersen dichotomous samplers, which were programmed to sample at 16.7 lpm for proper size fractionation. The samplers at each station (Fig. 1) were positioned with the intake upward and located in an unobstructed area at least 1m from any obstacle to air flow and the sampler inlet was placed at a height of 10 m above ground level. The sampling protocol was every third day starting from September 2010 and continuing to July 28, 2012 at essentially all sites. After sampling, the filters were brought to Department of Environment (DOE).

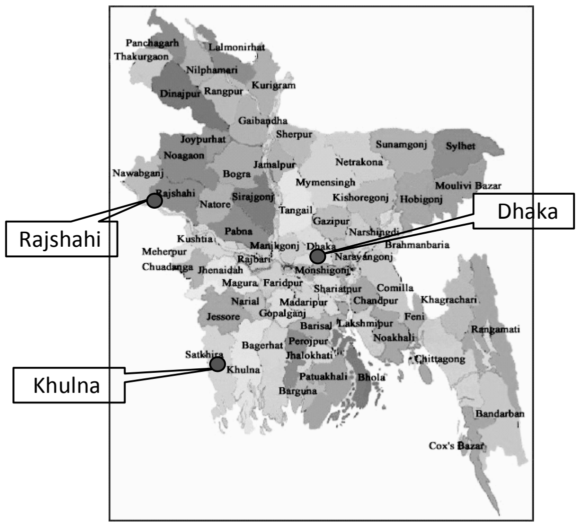

Fig. 1 Locations of sampling sites in Bangladesh

Similarly, the samples of fine fraction ($PM_{2.5}$) were collected using Air Metrics sampler at three sites, Rajshahi CAMS, Dhaka CAMS and Male Declaration air quality monitoring station at Shyamnagar in the Shatkhira district of Khulna from 01 December, 2012 to 07 March, 2013. After sampling, the filters were brought to the Atomic Energy Centre Dhaka (AECD) Laboratory directly from the sampling site for equilibration and PM mass measurement.

2.2 Site description and measurement period

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 [11].

Rajshahi 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 in Sapura at the Divisional Forest Office. 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 is highest contributor to the measured PM mass concentrations [12].

Khulna, the third largest city of the country, is situated in the southern region of Bangladesh (latitude 22.48°N, longitude 89.53°E) near the Bay of Bengal. Being located in a large river delta, it is the second largest port of Bangladesh. The CAM station, CAMS-5, is located at Samagic Bonayan Nursery and Training Centre in Baira about 3 km north of main art of Khulna. A Male Declaration air quality monitoring station is situated at Shyamnagar (Shatkhira) in Khulna. The site (rural area) was 12 km away from main road and situated near Indian border. The samples were collected from all cities from September 2010 to July 2012 by the stuff of DOE and from December 2012 to February 2013 by the stuff of AECD.

2.3 PM mass and BC analysis

PM mass was measured in the laboratory of the Department of Environment which were collected from September, 2010 to July, 2012 period and at the AECD which were collected from December, 2012 to March, 2013. The $PM_{2.5}$ masses were determined by weighing the filters before and after exposure using a microbalance [13]. 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 $PM_{2.5}$ samples were determined.

Black carbon (BC) measurement was made 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) [14]. Certain organic aerosol components of wood combustion particles have enhanced optical absorption at 370nm 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 [15-16].

2.4 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) [17] 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 three cities and trajectories were computed backward in time up to 120 hours (5 days).

3. Results and Discussion

Estimation of transported fine PM

To exclude low local source contributions, the daily events with concentrations that are two standard deviations above the mean value for a measured species were considered. Table 1 shows the mean, standard deviation, and the threshold values (2*STD+Mean) for fine PM and BC concentrations in three sites. The meteorological conditions during winter lead to prevailing northerly and northwesterly winds. There are then possible transboundary events [18] affecting local air quality. The fine PM concentrations are always high at Rajshahi site and the distribution pattern of PM concentrations (Table 2) is similar at all of the sites. It can be seen that about 60% of PM_{10} is $PM_{2.5}$. The percentage of

BC in $PM_{2.5}$ (Table 2) has been increasing every year. From source apportionment study[19], it has found that the BC contribution from motor vehicle is minimum but main contribution comes from coal and wood/biomass (signature is S, K and Cl). During monsoon season, the daily fine PM concentrations at the Dhaka and Khulna sites are lower than Rajshahi site (Table 3). Hence, it may conclude that there is influence of long range transport during winter and the pathway is through north-west direction (Rajshahi). The numbers Industries (garments and brick manufacturing) and vehicle are higher in Dhaka rather than Rajshahi although the particulate matter concentration is high in Rajshahi. The start time and ending time for all sampling stations was held quite constant.

Table 1: Basic statistics of fine PM and BC concentrations (μg/m³) during winter season

Parameter	Rajshahi (24.38°N, 88.61°E)		Dhaka (23.76°N, 90.39°E)		Khulna (22.48°N, 89.53°E)	
	2010-2011					
	Fine PM	BC	Fine PM	BC	Fine PM	BC
Min	135	11.0	14.7	4.01	32.1	2.96
Max	407	32.9	212	14.7	371	23.0
Mean	265	18.5	104	8.89	120	8.76
STD	66.5	5.78	49.8	2.38	72.9	4.30
Median	258	17.9	106	9.05	103	8.16
Threshold	398	30.0	203	13.7	266	17.4
2011-2012						
Min	93.4	7.43	35.3	5.83	23.1	2.03
Max	471	28.1	171	12.2	297	17.2
Mean	251	17.4	102	9.83	84.6	7.97
STD	88.6	6.71	24.3	1.76	52.6	3.34
Median	242	17.8	102	9.85	73.0	7.31
Threshold	428	30.9	150	13.4	190	14.7
2012-2013						
Min	74.6	12.9	52.3	20.5	43.1	11.3
Max	356	48.5	299	47.0	183	30.2
Mean	186	31.3	159	31.7	88.8	17.5
STD	71.2	9.35	62.7	6.57	33.1	4.83
Median	164	32.6	164	31.1	84.3	16.8
Threshold	328	50.0	284	44.9	155	27.1

Table 2: Ratios of $PM_{2.5}/PM_{10}$ and $BC/PM_{2.5}$ during winter season

Year	Rajshahi		Dhaka		Khulna	
	$PM_{2.5}/PM_{10}$	$BC/PM_{2.5}$	$PM_{2.5}/PM_{10}$	$BC/PM_{2.5}$	$PM_{2.5}/PM_{10}$	$BC/PM_{2.5}$
2010-2011	0.68±0.09	0.07±0.02	0.45±0.13	0.12±0.14	0.56±0.12	0.08±0.02
2011-2012	0.62±0.12	0.12±0.06	0.62±0.11	0.10±0.02	0.74±0.14	0.10±0.03
2012-2013	0.76±0.16	0.17±0.05	0.74±0.14	0.22±0.07	0.67±0.10	0.20±0.06

Table 3: Basic statistics of fine PM and BC concentrations ((μg/m³) during monsoon season

Year	Rajshahi		Dhaka		Khulna	
	Mean	STD	Mean	STD	Mean	STD
2011	55.4	26.5	26.8	10.5	19.6	11.8
2012	100	28.2	41.3	11.1		
BNAAQS(24h)	65					

It was found that the days with the peak PM and BC concentrations in Dhaka are the same as in Rajshahi. It was not possible to operate the Shamnagar site with the sampling protocol as Dhaka and Rashahi during the period of December 2012 to February 2013. The backwards trajectories during the days which have concentrations above the threshold values at Rajshahi are shown in Fig. 2. Fig. 2 shows the backwards trajectories of air parcels which carries high fine Pmcontribution. The average of threshold value at Rajshahi was 385 µg/m^3 and average of threshold values of other two sites is 208 and by subtracting second value from first, it would be 177 g/m^3. It means that the long range transport of $PM_{2.5}$ is about 177 µg/m^3 for during winter season. Similarly for BC, threshold value for Rajshahi in 34.9 µg/m^3 and the other two sites was 22.2 µg/m^3[5]. Hence, long range transport of BC is about 12.7 µg/m^3. From source apportionment study [3] and NASA satellite image (http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=47742), it was found that from November to January, anthropogenic activities is responsible for high fine PM mass but in February and March, the high fine PM is for natural dust storm.

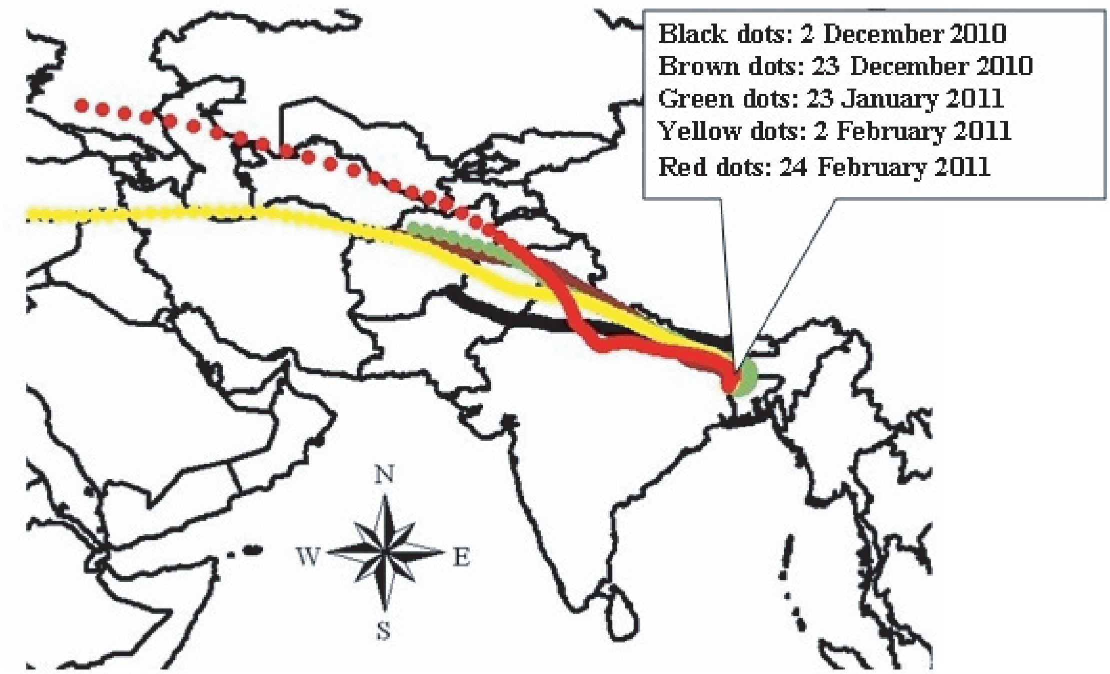

Fig. 2 Backwards trajectories of air parcel movement and arriving at Rajshahi in 2010 to 2011

4. Conclusion

It was found that the mean $PM_{2.5}$ value in Rajshahi was higher than for the Dhaka and Khulna sites although anthropogenic activities were higher in Dhaka than the other two cities. It was also observed that during the monsoon season, the daily average of $PM_{2.5}$ comply with the national ambient air quality standard (NAAQS) in Dhaka and Khulna sites, but in Rajshahi, $PM_{2.5}$ values exceed the NAAQS. A source for these higher values may be long range transport of PM from agricultural burning in upwind regions and/or from natural dust storms that occur around the mid/end of February.

Acknowledgement

We thankfully acknowledge the Department of Environment to give us permission for PM sampling during December 2012 to February 2013 period using their CAMS sites (Dhaka and Rajshahi city).

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