Session: EI Preparation for Modeling

Development of a Grid-Based Emission Inventory and a Source-Receptor Model for Dhaka City

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ABSTRACT

Dhaka, the capital of Bangladesh, has a population density of around 20,000 per square kilometer and faces the risk of large adverse health impacts due to poor air quality, particularly high particulate matter (PM) concentration. Government decisions aimed at curbing air pollution are usually taken on ad-hoc basis, primarily due to limited capacity for analysis of options. To assess the impact of a particular pollution control strategy, it is important to predict pollutant concentration in response to the control strategy. The present study focuses on development of a grid-based emission inventory for Dhaka considering major emission sources including vehicles, brick kiln as an industrial source, and road dust; and subsequently using the emission inventory to predict PM concentration, using a grid-based source-receptor model (SRM). The SRM has been developed using an atmospheric dispersion model ATMoS-4.0. The grid-based emission inventory has been developed considering spatial and temporal (e.g., brick kilns operating only during dry season) variations in emissions. The emission inventory and SRM are being used to estimate contribution of the major sources to ambient PM. Model predictions show that brick kilns, road dust and traffic emissions – all contribute significantly to ambient PM_{10} and $PM_{2.5}$ in Dhaka. Comparison of predicted PM with the monitored PM at a CAMS location in Dhaka provides some confidence in the developed emission inventory and S-R model. Such a model, when fully developed and calibrated, could become a very useful policy analysis tool for air quality management.

INTRODUCTION

Dhaka is the capital and the largest city of Bangladesh. It is the center of all administrative, economic and cultural activities of the country. With an area of about 2000 km^2 and over twelve million people, Dhaka is one of the most densely populated cities in the world and has a population density of about 20,000 people per km^2 (BBS, 2008). The city contributes almost 40% of the national GDP (ADB and CAI-Asia, 2006). It is projected that by 2015 Dhaka will have a population of approximately 22 million, and rank as the fourth largest city in the world.

The growth of Dhaka comes at a high environmental cost. Air pollution, river pollution, soil pollution, noise pollution are the major problems that this city is facing. The Bangladesh country environmental analysis undertaken jointly by the World Bank and Government of Bangladesh (World Bank, 2006), estimated that economic cost associated with environmental degradation is about 4.3% of GDP, with urban air pollution accounting for almost one-fourth of that. In Dhaka alone, this translates to health costs of almost US$500 million per year. The World Bank has estimated that the economic costs of sickness and deaths associated with air pollution in Dhaka City are approximately US$ 200-800 million per year. Other physical impacts of air pollution include damage to ecosystems, infrastructure and materials. Thus air pollution inhibits the sustainable development of Dhaka as well as Bangladesh.

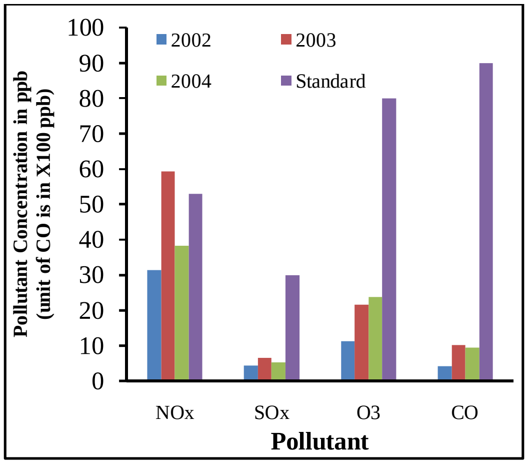


Figure 1: Yearly average Concentration of NO_x, SO_x, O_3 and CO (AQMP, 2011)

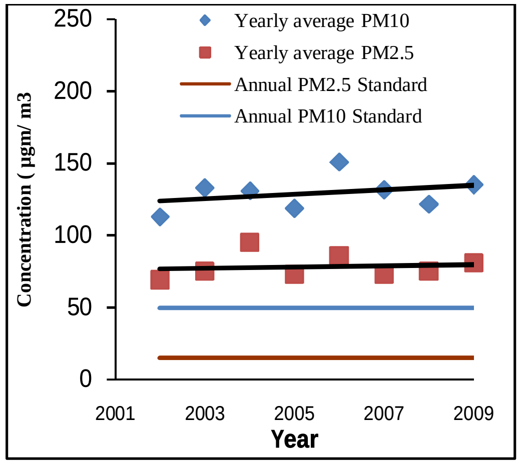


Figure 2: Variation of yearly average PM10 and PM2.5 (AQMP, 2011)

Air quality (AQ) in Dhaka is monitored systematically at two Continuous Air Monitoring Station (CAMS); at the Shangshad Bhaban CAMS since April 2002 and at the BARC CAMS since June 2008. However, data on gaseous pollutants could not be recorded at Shangshad Bhaban CAMS since 2005. Some additional data on particulate matter (PM) concentration in different areas of Dhaka city are also available (Biswas et al., 2000, Begum et al., 2004). These data are insufficient to assess long-term trends in the AQ of the city, but can provide indications of trends. Figures 1 and 2 show the yearly average concentration of different criteria pollutants (NO2, SO2, O3, CO, PM10 and PM2.5) recorded at the Shangshad Bhaban CAMS. It shows that concentrations of PM2.5 and PM10 exceed the national limits (15 µg/m3 and 50 µg/m3, respectively) by a factor over two. Figure 2 also shows slightly increasing trend for ambient PM concentration. A similar pattern was also observed from the air quality data of the BARC CAMS, with NOx, SO_2, O_3, CO below the standard level and PM concentrations above the Bangladesh standard.

Figure 3 shows the monthly 24-hour average concentration of PM10 and PM2.5 during 2002 to 2010 at Sangshad Bhaban CAMS. It shows that both PM10 and PM2.5 values are well above the national standard during the dry season (November to March), while during the wet season (April to October) these concentrations comfortably meet the standards.

These seasonal variations are mainly attributed to precipitation during wet season, and emission from brick kilns during the dry season. Emissions from the brick kilns around Dhaka, which remain operational during the dry season, have been identified as a major source of PM in Dhaka in a number of studies (Begum et al., 2005; Biswas et al., 2001; Guttikunda, 2009); however, these studies differ significantly with respect to contribution of PM from different sources. It is obvious that particulate pollution is the primary air pollution hazard in Dhaka and the sources and distribution of particulates need to be studied further.

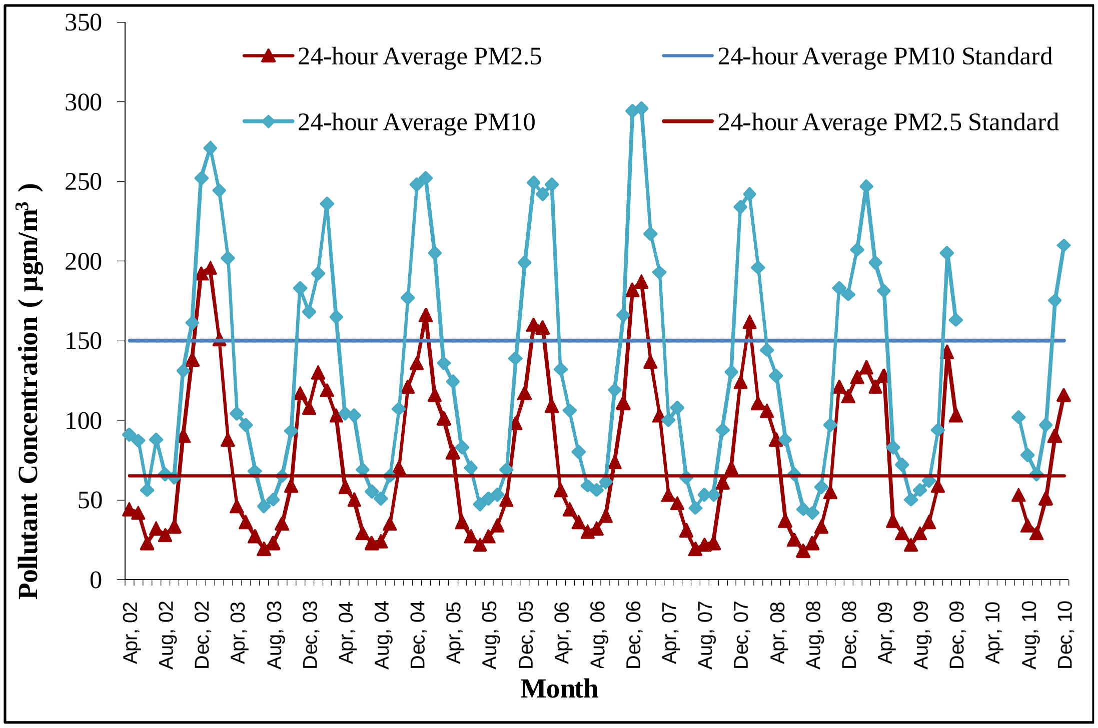


Figure 3: Monthly 24-hour average concentration of $PM_{2.5}$ and PM_{10} (Source : DoE)

In Dhaka, there are significant emissions from motor vehicles and other anthropogenic activities. Re-suspended road dust is also considered as an important source (Begum et al., 2005; Biswas et al., 2001; Guttikunda, 2009); according to the US Environmental Protection Agency, road dust is a major source of particulate matter in the atmosphere (second largest source of- PM 2.5, largest source of PM 10). This re-suspended dust includes (a) wind-blown dust which settles on the road (b) wear and tear of tires and (c) dry deposits of other pollutants.

The Government has introduced a number of initiatives such as banning of two-stroke engine vehicles, promoting the use of alternative fuels like CNG, banning of old vehicles from plying on streets, in order to curb the growing air pollution problem. Although these policy decisions have largely been taken on ad-hoc basis, yet some improvements have been observed. But there is a lack of benefit modeling to support these decisions due to limited monitoring and limited analysis of the options.

In order to select the better air pollution mitigation strategies from a number of alternatives, it is necessary to rank the alternatives in terms of benefits. For such analysis, a policy analysis tool could be very useful. And for any such tool, a detailed spatially disaggregated "Emission Inventory" is necessary (Wadud et al., 2003). It is therefore important to develop a sound emission inventory and subsequent concentration of pollutants for Dhaka city which could be updated periodically as situation changes.

The main focus of this study is to develop an emissions inventory which could be fed into an air quality model for predicting ambient concentrations; which could subsequently be used for additional (e.g., health impacts) analysis. The grid-based emission inventory developed in this study has been used for generating ambient concentration (PM_{10}, $PM_{2.5}$) utilizing the SR matrix.

METHODOLOGY

The grid-based emission inventory developed in this study has been used for the generation of ambient concentration (PM10, PM2.5) utilizing the Source-Receptor (SR) matrix. The ambient PM concentrations have been predicted by multiplying the SR matrix developed by Rahman (2010) with the emission matrix developed n this study.

Model Domain

The brick kiln clusters, which are considered major contributor to air pollution in Dhaka, are located to the north and south of Dhaka city. Hence, in choosing the model domain, the positions of the brick kilns have been carefully examined. Figure 4 shows the modeling domain. The modeling domain is between 23°30’0” to 24°6’0” N and 90°18’0” to 90°48’0” E. The model area is divided into 200 grids of 0.03° × 0.03°, which is approximately 3 km × 3 km. Figure 5 presents the grid division of the model domain. If the grid size is larger, the change in emission in a particular cell can have very little effect on the other cells. While smaller grids can improve the efficiency, but the time requirement will be higher compared to the degree of accuracy and accuracy of input data might not be adequate.

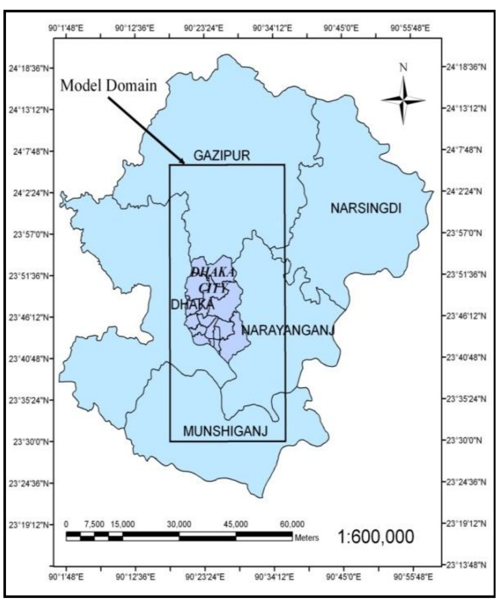


Figure 4: Model domain for the study

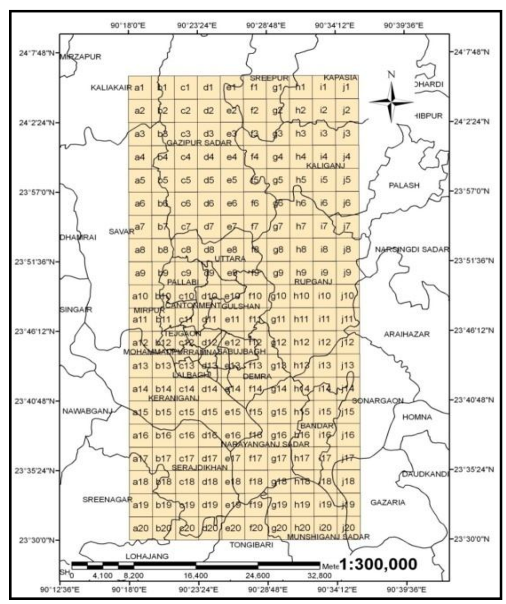


Figure 5: Division of the model domain into grids

For the development of the vehicular and road dust emission inventory, the year 2010 has been selected as the base year, considering the time-frame of the available data. On the other hand, for industrial emission inventory (brick kiln) 2009 has been selected as base year, as the collected primary data is for that period.

Development of Emission Inventory

In Dhaka city, the major sources of air pollutants are motor vehicles, road dust and industries i.e. brick kilns, cement factories (Biswas et al., 2001; Begum et al., 2005). In the present study, the emissions from the motor vehicles/ traffic, road dust and brick kilns have been considered; efforts are underway to include other industrial emissions in the emission inventory. Emission from each of these source groups has been estimated separately and finally they have been summed up to estimate the total emission.

Traffic emission

Traffic has been considered as an area source. Total emission from different vehicle modes has been estimated for each grid separately. The emission of each grid has been estimated according to formula given below,

$\sum$ Emission $E_i = \sum_j \sum_k [EF_{ijk} * A_{jk}]$

where,

i = Type of a pollutant like PM_{10}
j = Fuel usages like CNG, Gasoline
k = Vehicle type like Car
$Emission_i$ = Emissions from pollutant for each grid cell
EF = Emission Factor for each pollutant sector
A =Activity level for each pollutant source.

For vehicular emission inventory, the relevant emission factors (in gm/km units) for pollutants such as PM_{10}, $PM_{2.5}$, NOx, and SOx have been collected from available literature. The main data sources are SIM-air, Dhaka City State of Environment, the World Bank (2006), VAPIS, CAI-Asia and Malé emission inventory. Since there are significant uncertainties in the emission factors, an uncertainty analysis is carried out to get the most likely emission. Vehicular emission inventory also requires estimation of the number of vehicles and/or traffic activity. Annual Average Daily Traffic (AADT) of major roads measured by JICA (2010) has been used. AADT of minor roads have been assumed based on estimated population residing in a particular grid. Based on the length of road in a particular grid and the reported AADT, the activity level for each pollutant source (i.e., vehicle type) for each grid was then calculated as follows:

A or VKT = L x AADT

where,

A = Activity level for each pollutant source for each grid (km/day)
VKT = Vehicle Kilometers Traveled (km/day).
L = Road length (km) in every grid
AADT = Annual Average Daily Traffic (traffic volume/day)

Road Dust

Road Dust has been considered as an area source of emission of PM. The quantity of particulate emissions from re-suspension of loose materials on the road surface due to vehicle travel on a dry paved road may be estimated using the following empirical expression (USEPA AP-42, Section 13.2.1):

E= (k*(sL/2)0.65*(W/3)1.5)-C)*(1-P/4N)

where,

E=PM10 emission factor units matching units of k
k=particle size multiplier = 4.6 gram/vehicle km traveled/day
sL=silt loading = 30 grams per square meter for Dhaka City
C= EF for brake and tire wear = 0.1317 gram/vehicle km traveled/day for PM_{10}
W=average weight (tons) of each type of vehicles on the road
P= number of wet days with precipitation > 0.01 in or 0.254mm=5 for March
N=number of days in averaging period = 30 for this analysis

By using a fixed ratio between $PM_{2.5}$ and PM_{10} for each type of vehicle, $PM_{2.5}$ has been calculated. For this analysis, it is assumed that 100% roads are paved.

Brick kiln emission

Brick kiln has been considered as point source. The brick kiln emission inventory for PM_{10} and $PM_{2.5}$ developed by Arjumand (2010) has been used in the present study. The inventory was developed for the year 2009, and the operating period for the brick kiln was considered to be 165 days per year (November to Mid-April). The locations of brick kiln are shown in Figure 6.

The total emission from brick kilns for each grid, Emission I, has been estimated as follows (Arjumand, 2010):

$$Emission_i = EF_i \times AL \times N$$

where,

i = Type of a pollutant, e.g., PM10
N=Number of brick kilns in every grid
EF = Emission Factor for each pollutant
AL =Duration of brick manufacture

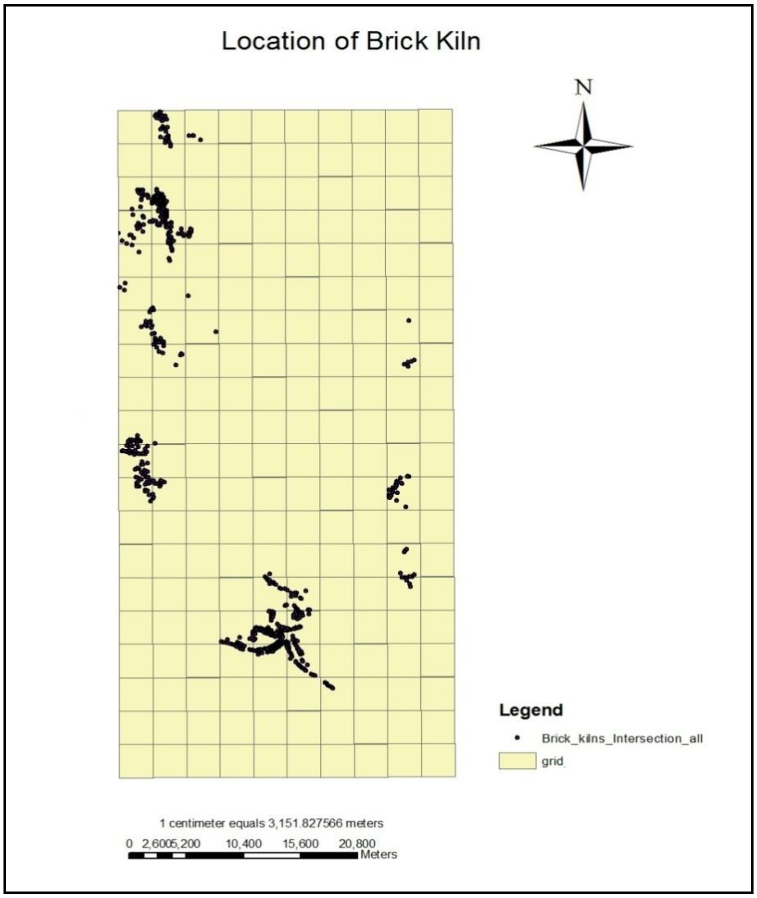


Figure 6: Location of Brick Kiln

Prediction of Ambient Concentration of Air Pollutants

The Source-Receptor (SR) matrix developed by Rahman (2010) using a modified version of the Atmospheric Transport Modeling System (ATMoS) has been used to determine the ambient concentration of air pollutants. This paper presents ambient PM concentrations for March, a dry period when air quality in the city deteriorates significantly.

Model Parameters and Meteorology

ATMoS-4.0 is a three dimensional multi-layered Lagrangian Puff-transport model capable of estimating ambient concentrations at urban scale using meteorological input of one station only. The model considers both primary and secondary pollutants (e.g., secondary PM formed from NOx and SOx). The model inputs comprise of emissions, meteorology, physical and chemical transportation parameters. The meteorological data for Dhaka has been extracted from the ECMWF 40 Years re-analysis data server (ECMWF, 2010). The output can be in terms of either concentrations or S-R matrices. The default values for physical and chemical transportation parameters (dry and wet deposition rates; reaction rates for primary to secondary transformation) in the ATMoS model have been used in the present study, since locally measured values are not available (Rahman, 2010).

Source Receptor (S-R) Matrix

The S-R matrix, also known as transfer coefficient/matrix, defines incremental change in concentration in any cell/grid in model domain for a unit change in emissions in any one cell (Guttikunda, 2010). If there is a series of sources present in the domain, which contribute to the concentration in a certain portion of that domain, the concentration can be obtained from:

$$C_j = \sum_i m_{ij} Q_i$$

where,

Cj = Ambient concentrations in area j,
mij = Transfer matrix that determines the proportion of net emissions from area i transported to area j, and
Qi = emissions from area i.

The above equation can be re-written in a matrix form as,

Concentration Vector, $C = MQ$

where,

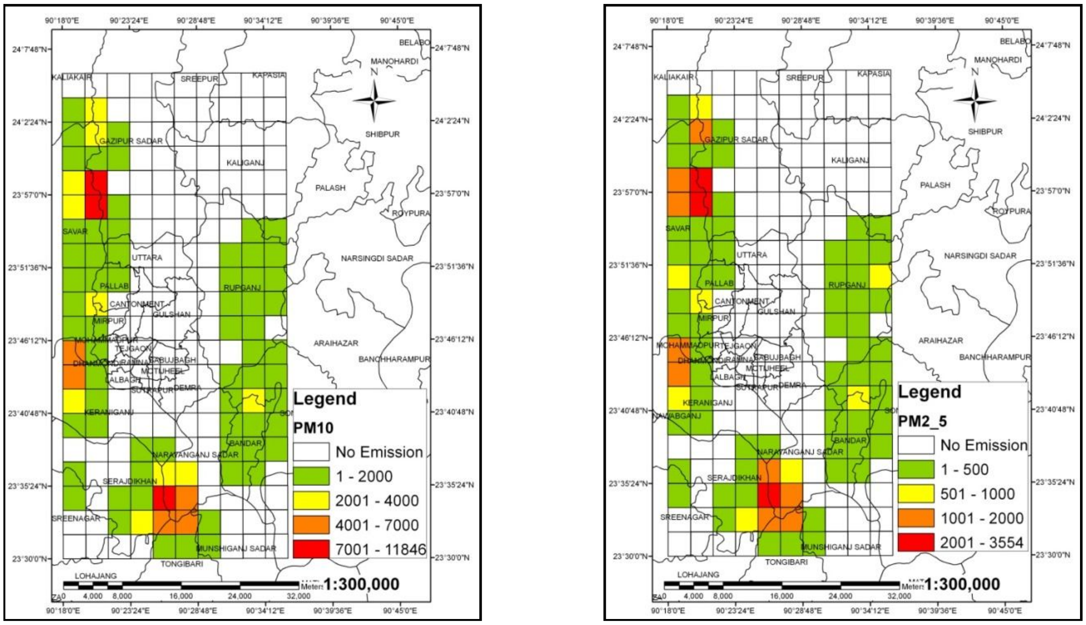
M = Source-Receptor Matrix (SRM)
Q = Emission vector

RESULTS AND DISCUSSION

Emission Inventory

The estimated yearly brick kiln emissions are shown in Figure 7. The brick kiln emissions take place outside the main city, but the emission load is very high in comparison to the traffic emissions (Figure 8).

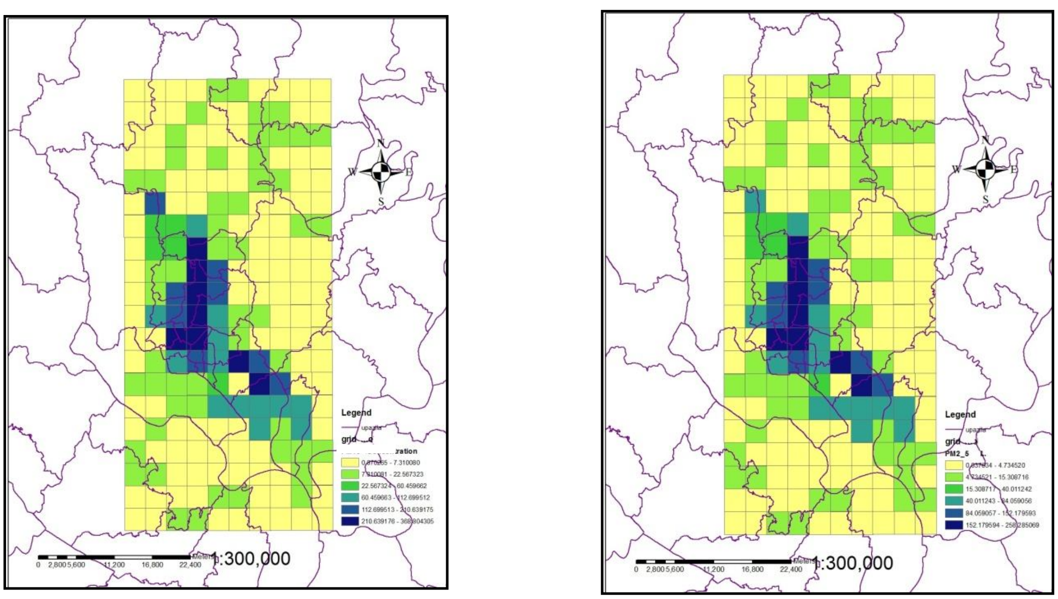
It should be noted that monthly emissions from brick kilns, which operates from November to mid-April, have also been estimated for prediction of the monthly average PM concentration due to brick kiln emissions. Figure 8 presents the yearly traffic emissions in the model domain.



(a) PM10 emissions in tons/year

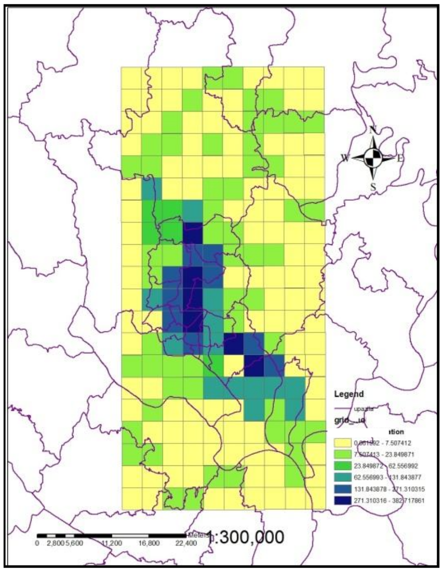
(b) PM2.5 emissions in tons/year

Figure 7: Brick Emission (Base year: 2009, Brick Burning Period: 165 days/yr)

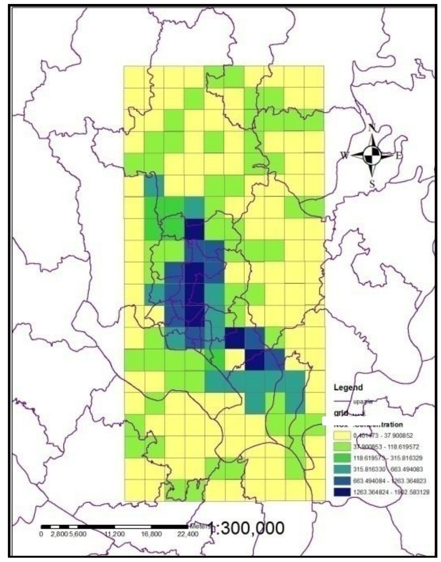


(a) PM_{10} emissions in tons/year

(b) $PM_{2.5}$ emissions in tons/year



(c) SOx emissions in tons/year



(d) NO_x emissions in tons/year

Figure 8: Traffic Emission (Base year: 2010)

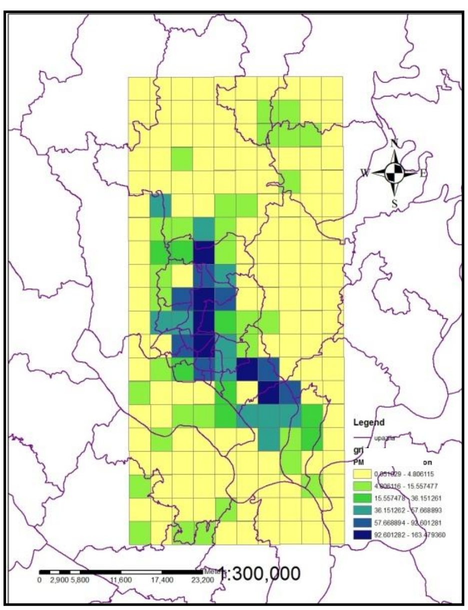


Figure 9 (a) : PM_{10} emissions from re-suspended road dust in tons/year

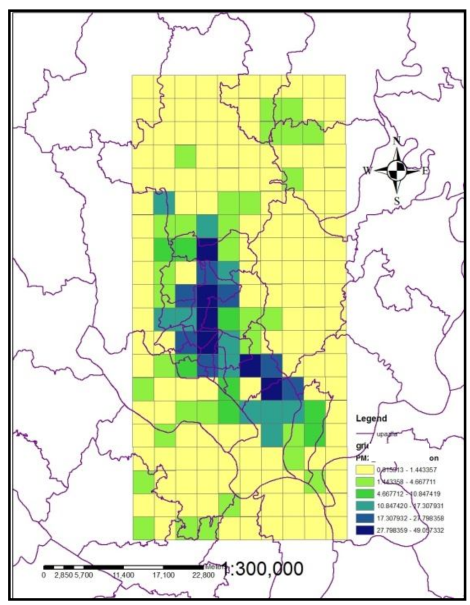


Figure 9 (b) : $PM_{2.5}$ emissions from re-suspended road dust in tons/year

Emission inventories are prepared for PM10, PM2.5, SOx and NOx. From the figure it is seen that the traffic emissions are higher in the Dhaka city area. Outside the city the emission load is relatively small. Figure 9 shows the yearly emissions of PM10 and PM2.5 from re-suspended road dust. It shows that the contribution of road dust is relatively higher than that of vehicular emission. Monthly emissions for both traffic and road dust have also been estimated for estimating corresponding monthly average ambient concentrations.

Particulate Matter Concentration

As noted earlier, concentrations of PM over the model domain due to different sources have been estimated by multiplying the SR matrix with each emission inventory. The result for the month of March is presented in Fig. 10. It has been observed that the total concentration (due to all sources) of PM10 varies widely over the model domain for March. It varies from less than 20 µg/m3 to greater than 1100 µg/m3. Average concentration of PM10 has been found to be 118 µg/m3. The PM2.5 concentration varies from less than 5 µg/m3 to greater than 800 µg/m3, with an average of 67 µg/m3. Both average concentrations exceed the 24- hour average concentration of Bangladesh standards, which are 150 µg/m3 and 65 µg/m3 for PM10 and PM2.5, respectively.

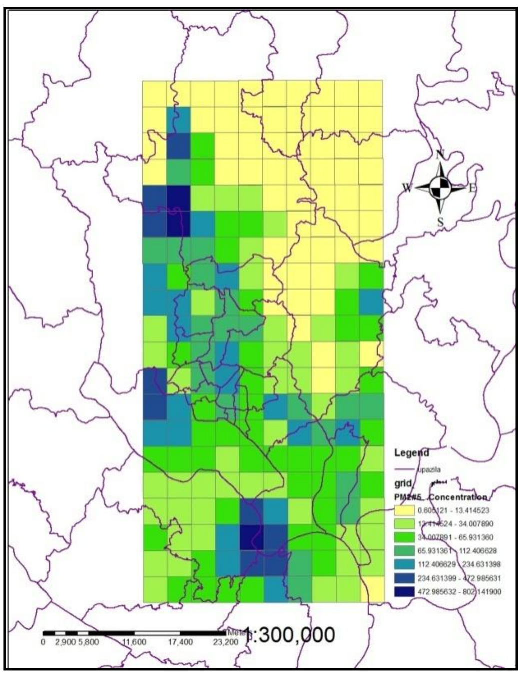


Figure 10 (a) : Total concentration for $PM_{2.5}$ in March

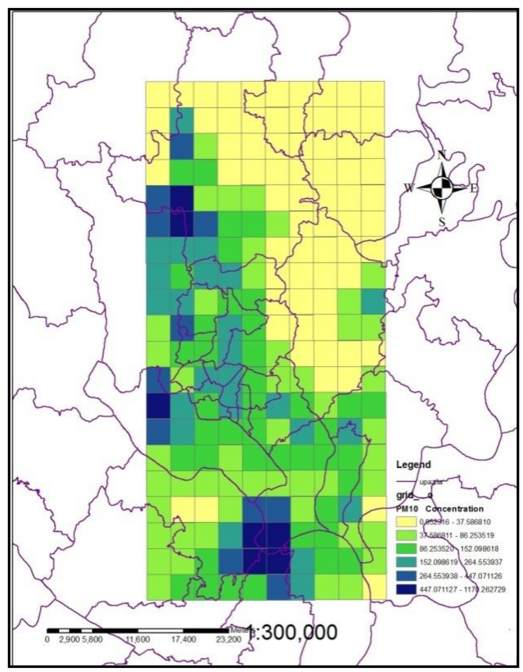


Figure 10 (b) : Total concentration for PM_{10} in March

The areas north-east of the Dhaka city i.e., Kaliganj, Sreepur are less polluted from the traffic and brick kiln pollution. But within the Dhaka city, in almost all grids, the concentration exceeds 50 µg/m3 and 15 µg/m3, which are the national standard for annual average PM10 concentration and PM2.5, respectively. It is also seen that, the ambient concentrations are higher in cells with higher emissions loads, especially from the brick kilns.

Comparison of contributions from different sources

Through the analysis of the simulation results, the contribution of different sources to ambient PM could be estimated. Figure 11 shows the contribution of the three major sources to PM10 and PM2.5 concentrations at the location of Sangshad Bhaban CAMS (Cell "c12") within Dhaka city. It shows that brick kilns account for about 20.5 percent of PM2.5 concentration, while road dust and traffic emissions account for 38.9 percent and 40.5 percent, respectively. Figure 11 also shows that brick kilns account for the 33.2 percent of the PM10, while road dust and traffic emissions account for 41.3 percent and 25.6 percent, respectively. While Rahman (2010) found very high contribution of brick kilns to both PM10 and PM2.5 concentrations, significantly higher contributions of both road dust and traffic emissions to ambient PM have been found in this study.

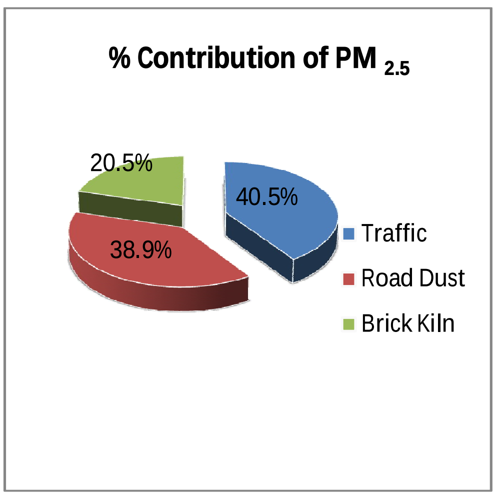


Figure 11(a): Source contribution for $PM_{2.5}$ at Sangshad Bhaban CAMS in March

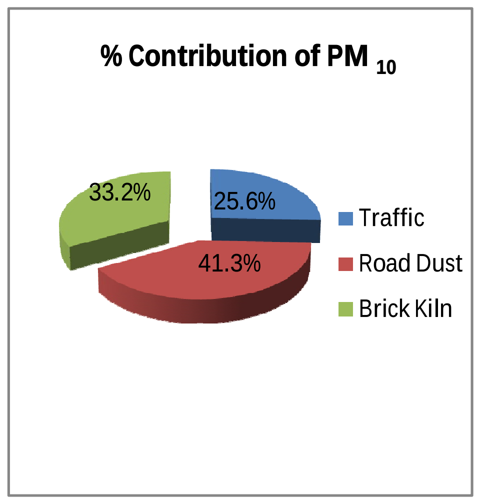


Figure 11(b): Source contribution for PM_{10} at Sangshad Bhaban CAMS in March

Comparison with data at CAMS

Figure 12 shows a comparison of the simulated monthly average concentrations and the monitored data for both PM10 and PM2.5 at the Sangshad Bhaban CAMS location (cell no "c12") in March. It shows that the predicted concentration of both PM10 and PM2.5 are somewhat lower than the monitored data. However, the predicted values are much closer to the monitored data compared to those found by Rahman (2010), where road dust was not considered. Inclusion of other sources such as such as, cement industries, power plant could improve the model predictions further.

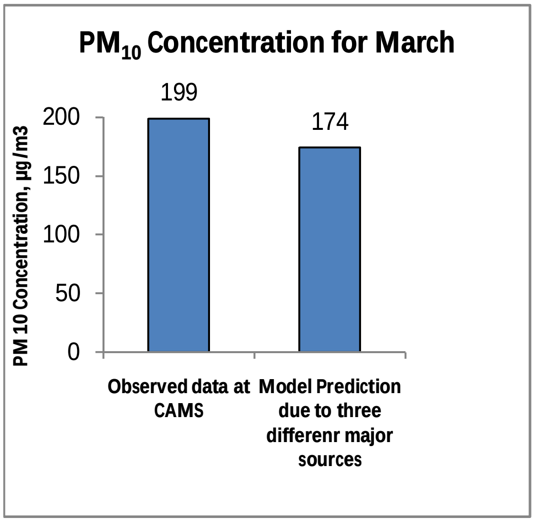


Figure 12 (a): Comparison of PM_{10} concentration at the CAMS point

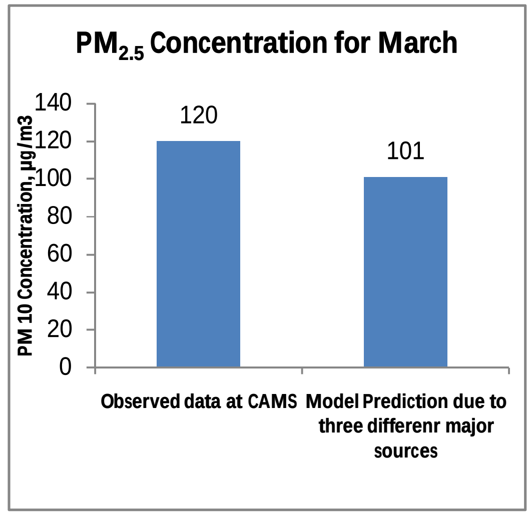


Figure 12 (b): Comparison of $PM_{2.5}$ concentration at the CAMS point

CONCLUSIONS

Air quality of Dhaka is major concern, especially during the dry season. For addressing the air quality problem, development of an emission inventory and subsequent prediction of ambient concentration is essential. A GIS based spatially disaggregated emission inventory has been developed for Dhaka city and its surrounding areas, incorporating major transportation and industrial sources. Using these emissions, concentrations for both PM10 and PM2.5 have been estimated using an S-R model. Model predictions show that brick kilns are the dominant sources of both PM10 and PM2.5 in Dhaka city, followed by road dust and traffic emissions. Comparison of predicted PM concentrations with the monitored PM data at a CAMS location in Dhaka provides some confidence in the developed emission inventory and S-R model. Such a model, when fully developed and calibrated (and possibly coupled with a health-impact model), could be very useful as a policy analysis tool for management of air quality. Works are currently underway on analysis of uncertainty of different parameters used in the simulations, predictions of ambient concentrations throughout the year and comparison with available data.

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KEY WORDS

Particulate matter
Emission Inventory
Road Dust
Source-Receptor Matrix
Concentration