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Developing source receptor model (SRM) to estimate the grid-based particulate matter concentration in Dhaka

S. M. Rahman, Z. Wadud & M. A. Ali
Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

S. Guttikunda
Urban Emissions Info, New Delhi, India

ABSTRACT: Dhaka city with a population density of around 20,000 per square kilometer faces the risk of large adverse health impacts due to poor air quality. Government decisions aimed at curbing air pollution are usually taken on ad-hoc basis, primarily due to limited monitoring and limited capacity for analysis of options. There are currently only two continuous air monitoring stations (CAMS) in Dhaka. However, in order to assess the impact of a particular pollution control strategy, it is important to predict pollutant concentration over the entire city in response to the control strategy. This study presents an source-receptor model (SRM) for prediction of particulate matters (PM) in the atmosphere of Dhaka. The grid-based SRM has been developed using an established atmospheric dispersion model, considering weather parameters round the year. The developed SRM has been used to estimate the contribution of vehicles and brick kilns to ambient PM concentrations, using a grid-based emission inventory that considers temporal variations in emissions. Over Dhaka, the PM_{10} in dry season has been estimated to vary from less than 50 µg/m^3 to about 150 µg/m^3; $PM_{2.5}$ varied from 25 µg/m^3 and 65 µg/m^3. Near the National Parliament Building, where one of the CAMS is located, brick kiln has been found to account for 29% of PM_{10} and 17% of $PM_{2.5}$; traffic pollution accounts for 7% to PM_{10} and 11% to $PM_{2.5}$. The developed SRM could be easily utilized to predict ambient PM concentrations as new sources are added/ removed from the domain. Results of a few case studies have been reported in the paper to show the impact of emission redistribution on ambient concentration. The model still has a large uncertainty, and future efforts to fine-tune the model should primarily focus on reducing the uncertainties around the emissions inventory.

1 INTRODUCTION

Dhaka is the capital and the largest city of Bangladesh. With an area of about 2000 km^2, Dhaka is one of the most densely populated cities in the world and has a population density of about 20,000 per km^2 (BBS, 2009). 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 city contributes almost 40% of the national GDP (ADB & CAI-Asia, 2006). The growth 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 are 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.

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 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 (NO_2, SO_2, O_3, CO, PM_{10} and $PM_{2.5}$) recorded at the Shangshad Bhaban CAMS. Figure 1 shows that the yearly average concentrations of NO_x, SO_2, O_3 and CO are below the Bangladesh air quality standard (except for NOx in 2003,). But concentrations of $PM_{2.5}$ and PM_{10} exceed the national limits (15 µg/m^3 and 50 µg/m^3, 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 NO_x, SO_2, O_3, CO below the standard level and the particulates concentrations above the Bangladesh standard.

Figure 3 shows the monthly 24-hour average concentration of PM_{10} and $PM_{2.5}$ during 2002 to 2010 at Sangshad Bhaban CAMS. It shows that both PM_{10} and $PM_{2.5}$ 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.

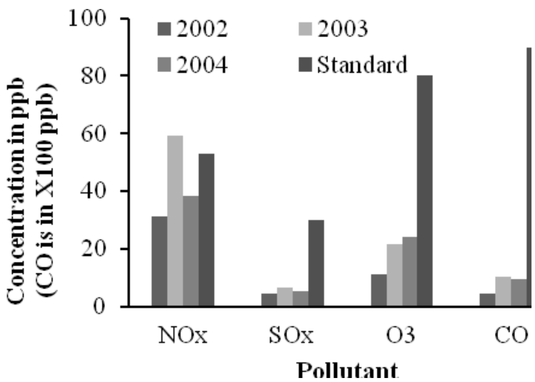


Figure 1. Yearly average Concentration of NO_x, SO_x, O_3 and CO (AQMP, 2011)

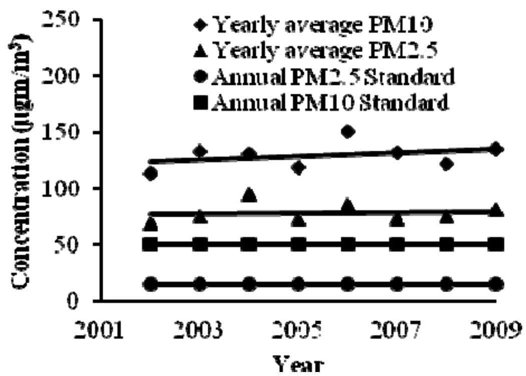


Figure 2. Variation of yearly average PM_{10} and $PM_{2.5}$ (AQMP, 2011)

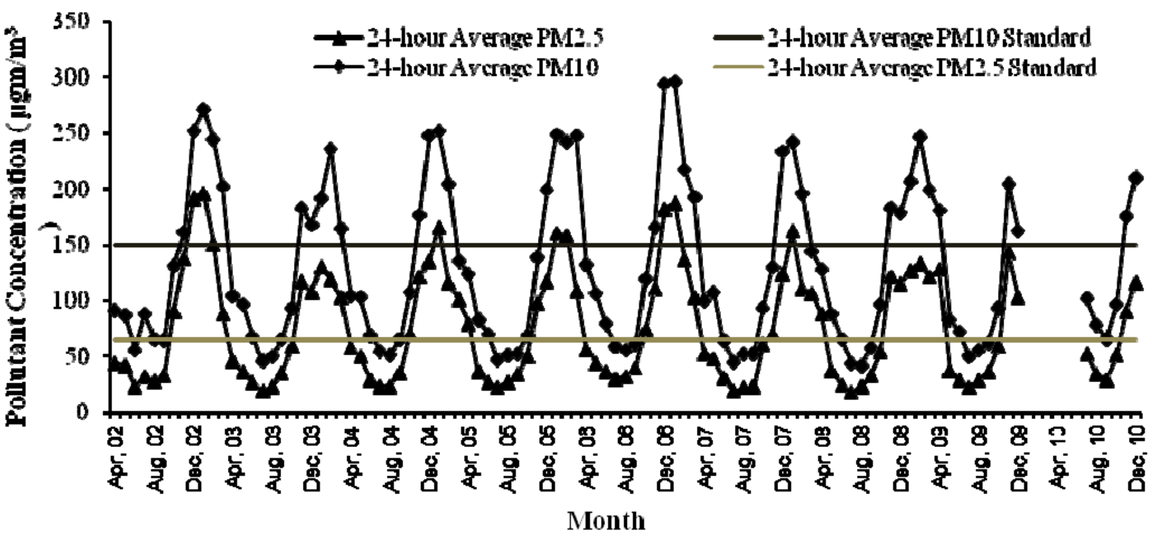


Figure 3. Monthly 24-hour average concentration of $PM_{2.5}$ and PM_{10} (AQMP, 2011)

Long term exposure to air pollution can lead to premature death by increasing the rate at which lung tissue ages, by contributing to chronic obstructive lung disease, and by exacerbating cardiovascular disease. Sudden rise of pollution level (acute exposure), on the other hand, can cause the people, who have history of cardiopulmonary diseases or simply weak or susceptible, to die prematurely. This is known as the short-term or acute effect. Among the different morbidity effects Adult Chronic Bronchitis, Child Acute Bronchitis, Respiratory Hospital Admission, Cardiac Hospital Admission, Emergency Room Visit, Asthma Attacks, Restricted Activity Days, Respiratory Symptom Days etc. are the most common (Guttikunda, 2008).

Air pollution is estimated to be responsible for approximately 3,580 premature deaths, 10 million restricted activity days and 87 million respiratory symptom days per annum (ADB and CAI-Asia, 2006). An estimated

15,000 premature deaths, as well as several million cases of pulmonary, respiratory and neurological illness are attributed to poor air quality in Dhaka, according to the Air Quality Management Project (AQMP), funded by the government and the World Bank (IRIN, 2009). The yearly economic loss associated with these health problems could range from a low estimate of $60 million to a high estimate of $270 million, equivalent to 1.7 to 7.5% of the city's gross product (Xie et al. 1998).

In order to control the deterioration, abatement measures need to be taken on an urgent basis. In the past, the Government 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. Extensive studies on cost-benefit analyses of the alternatives are required to support the policy implementation. 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. This study is a step towards developing such a tool, as it develops a Source-Receptor Model to predict grid-wise particulate concentrations in Dhaka. The study also aims to compare different policy alternatives in reducing the particulate concentration in the city.

2 METHODOLOGY

2.1 *Impact Pathway Approach*

In order to quantify the environmental costs due to air pollution European Commission first adopted the Impact Pathway Approach (Bickel et al., 2001). Impact pathway approach can help in quantification of both marginal costs and total costs. In determining the costs of environmental impacts due to air pollution, it is important to relate the emissions from different sources to a well defined damage end point (e.g. $PM_{2.5}$ related respiratory illness) and associated costs. A sequence of events is necessary to model the valuation of environmental impacts. This has been explained by the impact-pathway approach, in various literatures (e.g., ExternE, 2005). Each sequence of this model can be treated as individual module and requires extensive mathematical and statistical input. Consequently, each segment of the approach can be associated with a certain amount of error. Thus, the later module of the model is expected to have error of more intensity than the earlier ones. The first step of the Impact Pathway Approach is the emission generation from the source. The next step involves dispersion modeling, which estimates the increase in concentration. The third step defines the relationship between exposure and a damage valuation end point e.g., respiratory problem due to $PM_{2.5}$ concentration. Often Dose-Response functions, also known as Concentration-Response or Exposure-Response functions are used to convert the exposure to a damage end point. The estimated difference in the simulated air quality situation between the case and the reference situation is combined with exposure response functions to derive differences in physical impacts on public health, crops and building material etc. the last step of the pathway approach is the evaluation of physical impacts in monetary terms.

This study is mainly focused on the first and second steps of the Impact Pathway Approach i.e., generation of pollutants and estimating the ambient pollutant concentration.

2.2 *Source Receptor Model*

The Source Receptor Model (SRM) presents the incremental change in concentrations due to an incremental change in emissions. It can be defined as change in concentrations in a receptor grid per unit change in emissions in the source grid (Guttikunda, 2010). Source-Receptor (S-R) relationship describes the sensitivity of a "receptor" to a "source". The S-R matrix, also known as transfer coefficient/matrix, plays an important role in calculation of ambient air concentration provided emission loads are given and vice-versa.

The transfer coefficient indicates the incremental change in concentration in a cell for a unit change in emissions in each of the other cells. It defines the relationship between the source and the receptor. 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 using the following equation 1.

$$C_j = \sum_i m_{ij} Q_i \qquad (1)$$

where, C_j = Ambient concentrations in area j, m_{ij} = Transfer matrix that determines the proportion of net emissions from area i transported to area j, and Q_i = emissions from area i.

Equation 1 can be re-written in a matrix form as, $C = MQ$ (2)

where, C = Concentration vector, M = Source-Receptor Matrix (SRM) and Q = Emission vector

Source-receptor relationship, $m_{ij} = \frac{\partial c_j}{\partial q_i}$ (3)

where, q = source emission occupying a three-dimensional space and time interval and c = concentration

In a linear source-receptor relationship, which is characterized by steady state condition, m_{ij} can be treated to be a constant and $\frac{\partial c_j}{\partial q_i}$ can be replaced by $\frac{c_j}{q_i}$. Hence, a source-receptor matrix (SRM), M is generated with elements m_{ij}, where $m_{ij} = \frac{c_j}{q_i}$ (4)

In order to generate the SRM, an air quality model is required. A grid-based air quality model is run with a base case and concentrations in each cell are calculated. Then the emissions are increased in one cell by one unit, and changes in the concentrations in the rest of the cells are noted. The difference in concentrations would yield one row of the transfer matrix. This process when repeated and results summed up on a cumulative basis for all the grids, results in a transfer matrix. Meteorological data (such as wind speed, stability class, direction, etc.) and a range of other parameters are needed for the generation of transfer matrix (Rahman, 2010). The SRM obtained from the model need to be calibrated and validated.

2.3 *Model domain*

The principal objective of the present study was to analyze the air pollution of Dhaka city. But Brick kiln clusters located to the north and south of the city are considered as major contributor to air pollution in Dhaka; hence the modeling domain used in this study covers the surrounding areas of Dhaka city. 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 grids of 0.03° × 0.03°, which is approximately 3 km × 3 km (Figure 5). 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.

2.4 *Meteorology*

The meteorological input file consists of wind vector (wind speed and direction), precipitation and mixing height. The meteorological data (wind speed and direction, precipitation and mixing height) for Dhaka has been extracted from the ECMWF 40 Years re-analysis data server of European Centre for Medium-Range Weather Forecasts (ECMWF, 2010). The latest available data of Dhaka city was for the year 2001. A time series analysis of meteorological parameters from the year 1999, 2000 and 2001 has been conducted. The analysis shows that there are little discrepancies among the data of different years.

2.5 *Emission inventory*

From the available literature (Biswas et al., 2001; Begum et al., 2005), it can be concluded that the major sources of air pollutants in Dhaka city are brick kilns, motor vehicles and the road dust. In the present study, the emissions from the motor vehicles/ traffic and brick kilns have been considered. A grid-based emission inventory for Dhaka city has been developed by Arjumand (2010), which has been used in the present study with some modifications.

2.5.1 *Traffic emission*

Traffic (vehicular) Emission inventories are prepared for PM_{10}, $PM_{2.5}$, SOx and NO_x. Arjumand (2010) has established the inventories for the year 2005. These inventories are then forecasted to get the inventory for 2009. The forecasting is done by comparing the result of Arjumand (2010) with the results Wadud and Khan (2010), which has carried out an inventory for 2009. It is seen that the traffic emissions are usually higher in the Dhaka city area but outside the city the emission load is very small (Rahman, 2010).

2.5.2 *Brick kiln emission*

Arjumand (2010) has also established an emission inventory for brick kiln emissions. Only the PM_{10} and $PM_{2.5}$ has been considered as the major pollutants emitted from the brick kilns in that study. The inventory was made for the year 2009 and the operating period for the brick kiln was considered to be 165 days per year (November to Mid-April). In the present study, the emission inventory has been used with no alteration. The brick kiln emissions take place outside the main city, but the emission load is very high in comparison to the traffic emissions.

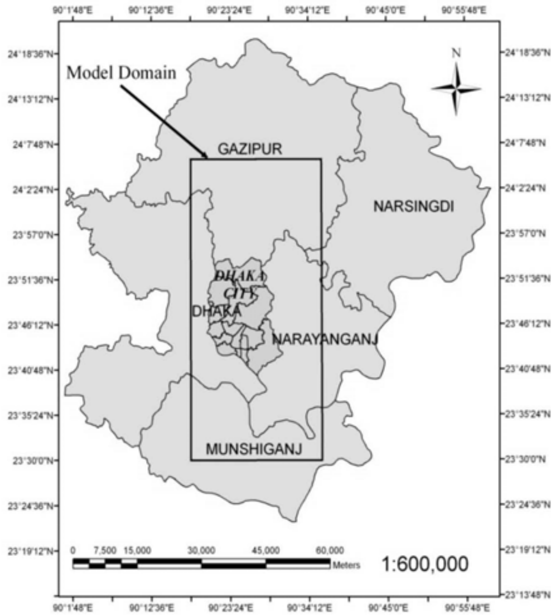


Figure 4. Model domain for the study

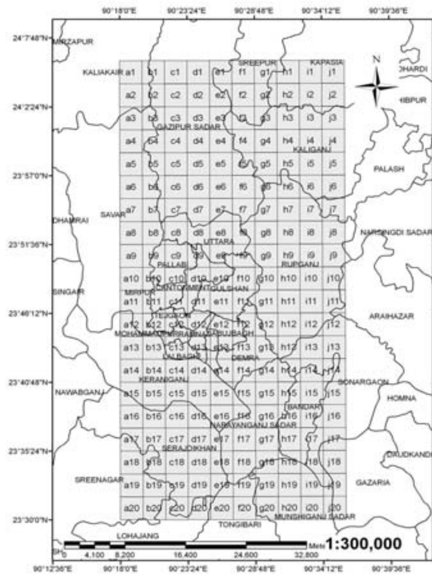


Figure 5. Division of the model domain into grids

2.6 *Model Parameters*

In the study, a modified version of The Atmospheric Transport Modeling System (ATMoS), ATMoS-4.0, a Lagrangian Puff-transport model, has been selected to establish the SRM. This model is suitable for urban context. It requires meteorological input of one station only. ATMoS was primarily developed for sulfur pollution dispersion modeling as part of the Regional Air Pollution Information System for Asia (RAINS-Asia) (Arndt and Carmichael, 1995; Arndt et al., 1998). It is a three dimensional multi-layered Lagrangian model capable of estimating ambient concentrations at urban scale. The inputs of the model comprise of emissions, meteorology, physical and chemical transportation parameters. The output can be in terms of either concentrations or S-R matrices, depending on the requirements and choices of the users. 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. It has been found that that the default values give reasonable output (Rahman, 2010).

3 RESULTS AND DISCUSSION

After the setting up of the dispersion model, it has been simulated and the source-receptor matrices have been obtained for both primary and secondary particulates. The source receptor matrices have been used to estimate the concentration within the model domain by multiplying them with the emission vectors. These source receptor matrices can be used repeatedly with new emission inventories as long as the model domain and grid resolution remain the same. In this study by feeding the emission inventory data described earlier and the transfer matrices into spreadsheet the ambient concentration at different grids for different months of the base year have been estimated.

3.1 *Variation of Particulate Matter Concentration*

The concentration of PM_{10} has been found to vary widely over the model domain. For January (dry season) it varies from less than 20 µg/m^3 to 271 µg/m^3. In February and March these variations are even wider (from less than 20 µg/m^3 to greater than 1000 µg/m^3). Similar variations have also been observed for the dry season months of November and December. During April to October (i.e., wet season), the concentrations are more or less similar and varies over a small range (0 to 14 µg/m^3).

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 for the dry period (i.e., November to March) the concentration of PM10 exceeds 50 µg/m3, which is the national annual average standard. In some parts of the city it even exceeds the 24-hour average standard (i.e., 150 µg/m3), especially in the bordering areas of Dhaka city where the brick kilns are located.

The variation of $PM_{2.5}$ follows a similar pattern. Relatively high values have been predicted for the dry season (November to March). In January $PM_{2.5}$ varies from less than 10 µg/m^3 to 89 µg/m^3; in February and March these variations are even wider,from less than 10 µg/m^3 to greater than 500 µg/m^3.. During April to October (i.e., wet season), $PM_{2.5}$ concentrations are more or less similar and remains within a very small range (0 to less than 15 µg/m^3). As before, the areas north-east of the Dhaka city i.e., Kaliganj, Sreepur are less polluted. But in dry season, the concentration exceeds the annual average standard of 15 µg/m^3 in almost all part of the Dhaka city. In some parts it even exceeds the 24-hour average standard (65 µg/m^3).

As expected, the predicted ambient concentrations show significant seasonal variation for both PM_{10} and $PM_{2.5}$. For example, PM_{10} concentration in the wet period is less than 15 µg/m^3, while in the dry season it is much higher; similar pattern is also seen for $PM_{2.5}$. These variations are most likely due to wet precipitation during wet season and operation of the brick kilns during the dry season. The seasonal variations of particulate matter concentration are shown in Figures 6 to 9.

Figure 6 shows the variation of average PM_{10} concentration in the Dhaka City Corporation (DCC) area. It is seen that the average concentration is 72 µg/m^3 in February which is the maximum among all months and the minimum monthly average value (59 µg/m^3) in dry season exceeds 50 µg/m^3. While in the wet season the PM_{10} concentration is less than 10 µg/m^3. Figure 7 shows the similar pattern for the $PM_{2.5}$ concentration. In the wet season the average concentration is less than 5 µg/m^3. But in the dry season concentration is always greater than 20 µg/m^3, with a maximum value of 35 µg/m^3 in March.

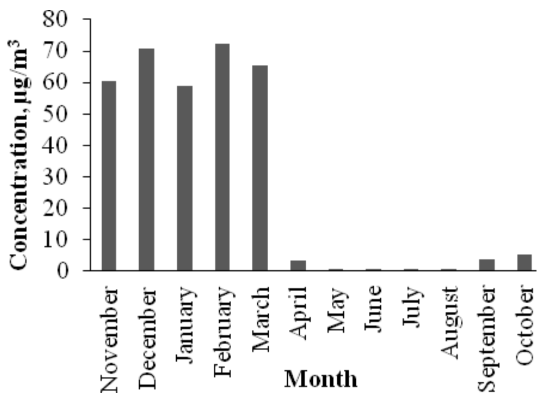


Figure 6. Average PM10 concentration in the DCC area

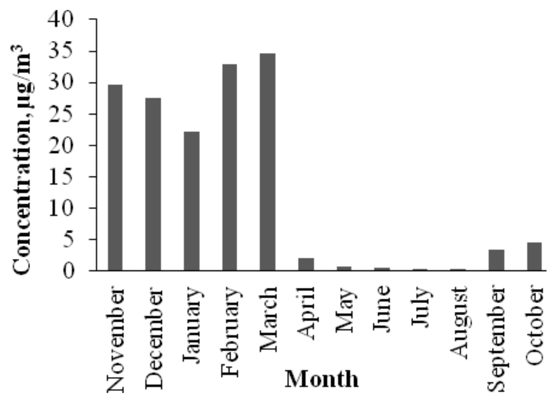


Figure 7. Average PM2.5 concentration in the DCC area

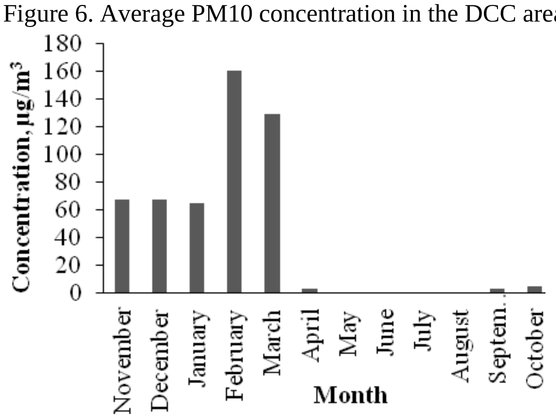


Figure 8. Average PM_{10} concentration in greater Dhaka area

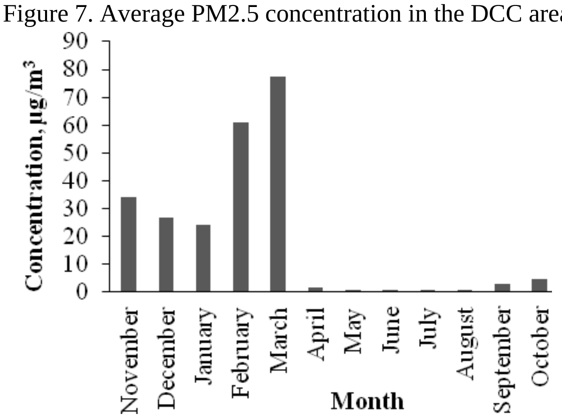


Figure 9. Average $PM_{2.5}$ concentration in greater Dhaka area

Figures 8 and 9 show the temporal variation of the pollutants over the Greater Dhaka, which includes the DCC area, the upazilas and union parishads of the Dhaka districts that are within the model domain. As expected, these figures show similar temporal variations as observed for Dhaka city. From Figures 8 and 9 it is observed that the average concentrations in Greater Dhaka are higher than that of DCC area. This is because this includes the surrounding areas of Dhaka city, where most of the brick fields are located.

3.2 *Comparison with data at Shangshad Bhaban CAMS*

The Shangshad Bhaban CAMS is located within the cell no "c12" of the modeling domain (Figure 5). Figures 10 and 11 show a comparison of the simulated monthly average concentrations and the data recorded at Shangshad Bhaban CAMS for both PM_{10} and $PM_{2.5}$. The figures show that the predicted concentrations of both PM_{10} and $PM_{2.5}$ are less than the recorded data, which is expected since only the vehicular and brick kiln emissions have been considered in the present study, while road dust has not been considered. Also, other sources such as, cement industries, power plant, incineration, refuse burning, etc. could not be incorporated in the study also due to the lack of available data. However, the predicted results show the seasonal variation as observed in the CAMS data.

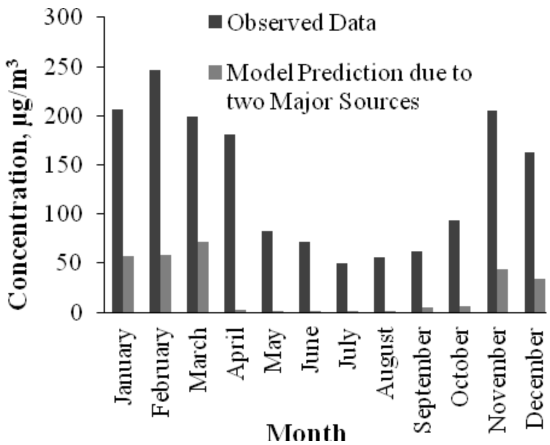


Figure 10. Comparison of PM_{10} concentration at the Shangshad Bhaban CAMS point

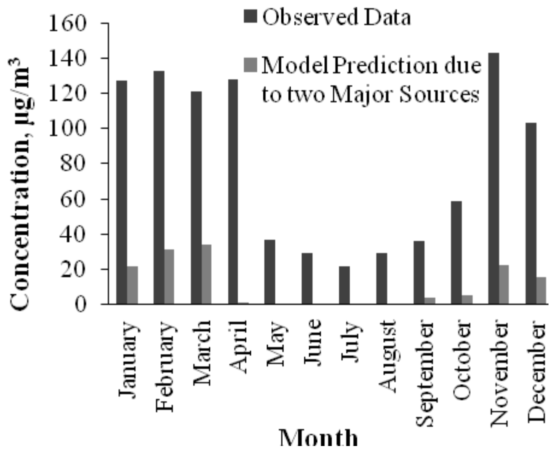


Figure 11. Comparison of PM2.5 concentration at the Shangshad Bhaban CAMS point

3.3 *Comparison of contributions from different sources*

Through the analysis of the simulation results and actual measurement of ambient concentration (e.g., at Shangshad Bhaban CAMS), the contribution of different sources to ambient PM could be estimated. This has been done at the Shangshad Bhaban CAMS location for the month of March, which is the most critical for air pollution. The results show that brick kiln accounts for 29% and traffic for 7% of the total PM_{10} pollution at the CAMS site. The rest 64% comes from the other sources, which may include road dusts, industrial sources and even the diesel generators in households.

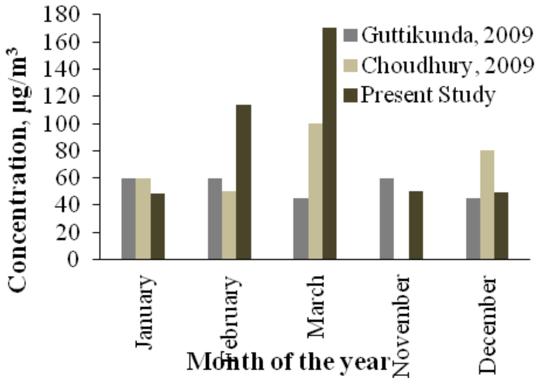
It is also found that, 17% of $PM_{2.5}$ concentration results from the brick kilns and 11% are due to traffic pollution. In the case of $PM_{2.5}$ the contribution of brick kiln is lower than that for PM_{10}. It is because coarser particles are primarily released from the brick kilns. The vehicular emissions are mostly in the form of the finer particles. Hence the contribution of traffic emission to $PM_{2.5}$ is higher than that for PM_{10}. In the case of $PM_{2.5}$, estimated contribution of other sources is about 72%.

These results are somewhat different from a few of the earlier studies (e.g., Begum et al., 2004). In the present study the contribution of brick kilns comes out to be higher relative to the traffic contribution. There may be two possible reasons for this deviation. Firstly, the brick kiln emissions may have been over-estimated. All the brick kilns have been assumed to release pollutants 24 hours a day at the same rate, which may not be true. Also the productions of all the brick kilns have been considered to be the same, which may also lead to over estimation. It may be noted that the emission rate from brick kilns used in the study is based on a single measurement in another study (Choudhury, 2009); no other values are available in the literature for brick kiln emissions. Secondly, the traffic emissions might have been under-estimated. This could be due to ignoring some of the minor roads in the model domain. Also in conducting the emission inventory, emission factors for vehicular emissions are assumed based on the available data for other countries. This may lead to the addition of further error in the estimation of the concentration.

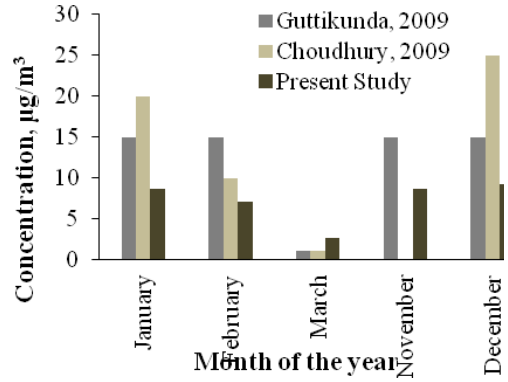
3.4 *Comparison of brick kiln effect with other studies*

Two studies (Guttikunda, 2009 and Choudhury, 2009) have estimated the effect of only brick kiln emission on air quality of Dhaka city. The contribution of brick kiln emission found from the present study has been compared with the results of those studies. Figure 12 presents the comparison of maximum and minimum $PM_{2.5}$ concentration in DCC area. From Figure 12(a) it is seen that for the months of January, November and

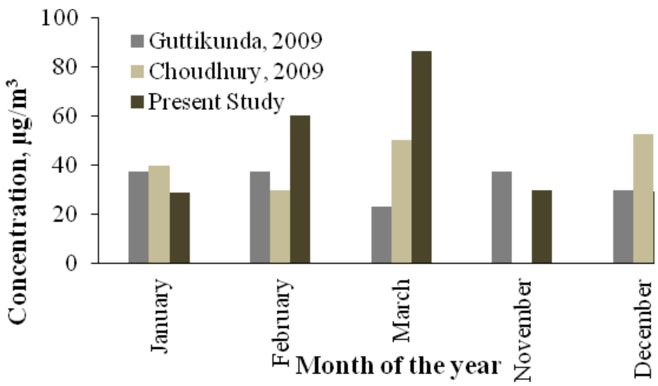
December the maximum $PM_{2.5}$ concentrations are close to the previous studies; for the months of February and March the current study estimates higher values than the previous studies. The minimum $PM_{2.5}$ concentrations in DCC area estimated in this study are lower than the previous studies for each of the month (Figure 12(b)). The average $PM_{2.5}$ concentration over the DCC area, shown in Figure 12(c) shows the pattern similar to that of maximum $PM_{2.5}$ concentrations. The average concentrations are estimated to be closer to the results of the previous studies for the month of January, November and December. For the month of February and March the current study estimates a higher average value.



(a) Maximum $PM_{2.5}$ concentration in DCC area



(b) Minimum $PM_{2.5}$ concentration in DCC area



(c) Average $PM_{2.5}$ concentrations in DCC area

Figure 12. Comparison $PM_{2.5}$ concentration due to brick kiln emission estimated in the present study with other available studies

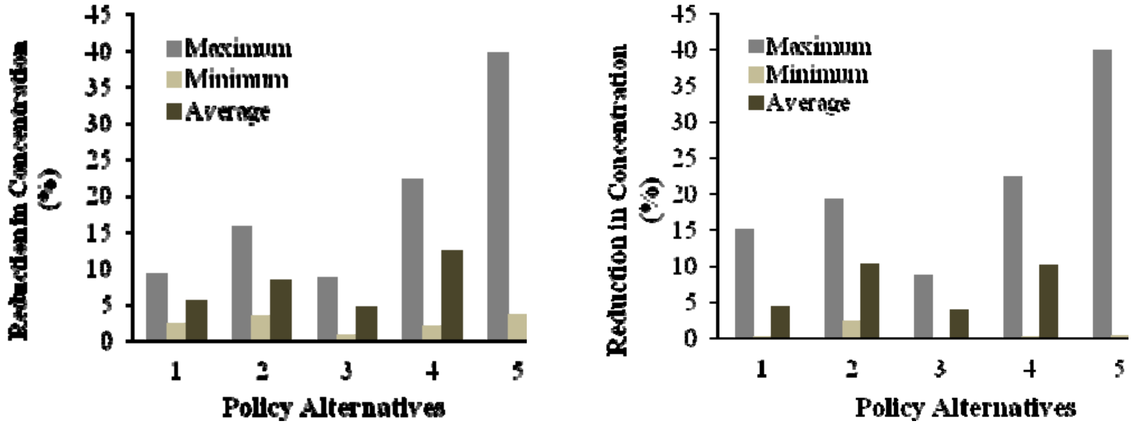
3.5 *Impact of Different Policy Alternatives*

From the earlier discussion it can be inferred that both traffic and brick kiln are two of the major sources of air pollution and can have significant impact on public health. So abatement measures should be taken to mitigate or reduce the effect. In order to evaluate alternative abatement measures, a policy analysis tool is required to be developed. However, the SRM developed in this study can help to estimate the particulate concentrations after the implementation of the policy alternatives. Subsequently, different policy alternatives can be ranked in terms of their effect on reducing the particulate concentration in the atmosphere. Some of the policy alternatives and their effect on particulate concentration are examined for illustration. A total of five policy alternatives have been examined. They are listed in Table 1.

Table 1. Policy Alternatives.

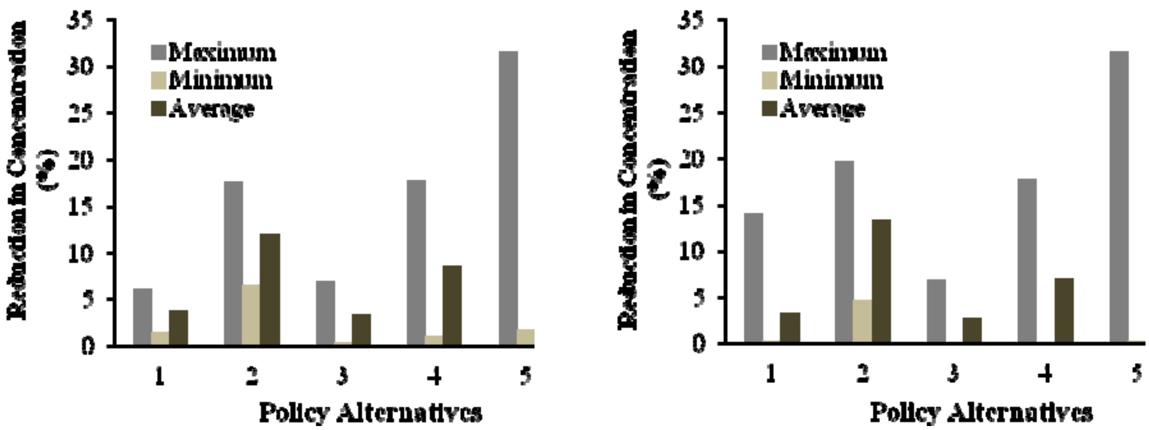
Serial No.	Policy Identification	Description
1	Policy Alternative 1	Truck entering Dhaka, reduced by 20%
2	Policy Alternative 2	Brick kiln emission is reduced by 20% by converting some of them into green brick kilns
3	Policy Alternative 3	50% of Buses are converted to CNG
4	Policy Alternative 4	Buses run by CNG are double from present i.e. 72% of the buses are converted to CNG
5	Policy Alternative 5	100% Buses are converted to CNG

In order to evaluate the impact of the policy alternatives, the particulates concentration due to policy implementation have been estimated. Adoption of Policy Alternative 1, reduces the maximum concentration to 443 µg/m^3 from 450 µg/m^3. Policy Alternative 2 reduces the maximum concentration from 450 µg/m^3 to 369 µg/m^3 while, Policy Alternative 3 can lower the maximum $PM_{2.5}$ concentration to 446 µg/m^3. Policy Alternative 4 lowers the maximum $PM_{2.5}$ concentration to 441 µg/m^3 and Policy Alternative 5 lowers it to 434 µg/m^3. Figure 13 and 14 illustrate the percentage reduction in particulate concentration from the base case due to the implementation of the policy options. However, the comparison is only due to traffic and brick kiln emission.



a) DCC Area b) Greater Dhaka Area

Figure 13. Impact of different policy alternatives upon concentration of $PM_{2.5}$



a) DCC Area b) Greater Dhaka Area

Figure 14. Impact of different policy alternatives upon concentration of PM_{10}

From Figure 13 it is seen that, maximum average reduction in $PM_{2.5}$ can be achieved through adoption of alternative 5 and it may yield 22% reduction in DCC area. Alternative 4 is the second best option considering the average $PM_{2.5}$ reduction in DCC area. But, when Greater Dhaka is considered alternative 2 has the higher reduction. Since, alternative 2 is related to the brick kiln pollution, its effect is higher in the surrounding area which is outside DCC. Similar ranking also can be made by comparing the reduction of PM_{10} concentration. Figure 14 shows the reduction in PM_{10} concentration. In terms of PM_{10} reduction Alternative 5 has the highest impact in DCC area. But, alternative 2 is seen to have the highest impact when the adjacent area is considered in addition to DCC area. From the above two figure, it may be predicted that brick kiln pollution has greater impact in the areas near the brick field than inside DCC area.

4 CONCLUSION

The present study has been conducted with an aim to develop a Source Receptor Model to estimate the particulate concentration of Dhaka city. The developed SRM could be used to predict the grid-wise particulate concentrations in Dhaka by updating the emission inventory and also to rank mitigation strategies in terms of concentration reduction. Using the tool ambient concentrations of both PM_{10} and $PM_{2.5}$ due to the traffic and brick kiln emissions have been estimated. The predicted ambient concentration of particulates in and around Dhaka city has been found to vary widely. The areas north-east to the city such as Kaliganj, Sreepur are found to be less compared to areas in the north-west, where the brick kilns are located. During the dry season (i.e., November to March) the ambient concentrations for both PM_{10} and $PM_{2.5}$ in most areas within the city exceed the Bangladesh standard. But during the wet season (April to October) they remain well below the standards. Brick kilns are found to be the major sources of particulate pollution. At the location of Shangshad Bhaban CAMS in Dhaka, it accounts for about 29% of PM_{10} and 17% of $PM_{2.5}$ concentration. Traffic emissions account for about 7% of PM_{10} concentration and 11% to $PM_{2.5}$ concentration at this location. Using the developed tool a number of policy alternatives have been analyzed to predict their impact on particulate concentration. The abatement measures could reduce the average PM_{10} concentration in DCC area from 3.3% to 15.2% and in Greater Dhaka the reduction can be within 2.7% to 12.5%. $PM_{2.5}$ reduction is found to be even more. In DCC area the range is 4.8% to 22.1% and in greater Dhaka this range is 4.0% to 18.4%. However, to rank the abatement measures completely, it is necessary to identify their benefit in terms of their effect on human health or any other physical benefits rather than concentration only.

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