DEVELOPMENT OF A GRID-BASED EMISSION INVENTORY AND AN AIR QUALITY MODEL FOR DHAKA CITY

A Thesis submitted

By

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October, 2012

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A thesis submitted to the Department of Civil Engineering of Bangladesh University of Engineering and Technology, Dhaka, in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING (ENVIRONMENTAL)

DEPARTMENT OF CIVIL ENGINEERING

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

October, 2012

CERTIFICATE OF APPROVAL

The thesis titled **"Development of a grid-based emission inventory and an air quality model for Dhaka city"** submitted by Tanjina Afrin, Student No: 1009042136 (P), Session: October 2009 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of M.Sc. Engineering (Civil and Environmental) on 9th October, 2012.

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It is hereby declared that the thesis on "**Development of a grid-based emission inventory and an air quality model for Dhaka city"** has been performed by me and any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Tanjina Afrin

Dedicated

To

My Parents

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful

From the depth of my heart, I express my deep sincere gratitude to the Almighty for the Blessings He had bestowed upon me to do this work.

Foremost, I would like to gratefully and sincerely thank my supervisor Dr. M. Ashraf Ali, Professor, Department of Civil Engineering, BUET, for the continuous support of my M.Sc. research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my M.Sc. study. He encouraged me to not only grow as an experimentalist but also as an independent thinker.

I would like to convey my heartiest thanks especially to Sheikh Mokhlesur Rahman, Assistant Professor of Department of Civil Engineering, BUET, Shamarokh Arjumand, Tanzila Khan and Faizuna Warda for their endless help and support during my research period. Special Thanks goes to Dr. Zia Wadud, Associate Professor of Department of Civil Engineering, BUET for his generous support.

My deepest gratitude goes to my beloved parents and also to my other family members for their endless love, unceasing prayers and encouragement. Without their unconditional support, it was impossible to complete this work.

I would like to thank my husband for his continuous support, encouragement, quiet patience and unwavering love. Sincere thanks to all my friends for their kindness and moral support during my study.

I would like to express my deepest gratitude to the Department of Civil Engineering, BUET, The Head of the Department of Civil Engineering and all the members of BPGS committee to give me such a great opportunity of doing my M.Sc. and this contemporary research work.

Finally, I thank all those who have helped me directly or indirectly in the successful completion of my thesis. Anyone missed in this acknowledgement are also thanked.

ABSTRACT

Dhaka, the capital city of Bangladesh, is at the risk of experiencing major health impacts resulting from poor air quality. Reliable emission inventory and air quality model are essential prerequisites for assessment of health impacts and analysis of possible options for air quality management. In this study, a GIS based spatially disaggregated emission inventory has been developed for five air pollutants, namely, PM_{10}, $PM_{2.5}$, CO, NOx and SOx, considering three major sources i.e. motor vehicles, road dust and bricks kilns in and around the Dhaka city. The developed emission inventory has been used as input in an air quality model (ATMoS) to predict ambient concentrations of particulate matter (PM).

The model domain considered for developing emission inventory and air quality model is about 1,800 sq. km. covering areas surrounding Dhaka city, including the brick kiln clusters around the city. The model area has been divided into 200 grids of 0.03° × 0.03°, which is approximately 3 km × 3 km. Since the brick kilns operate only during the dry season (November to mid-April), the emission inventory has a district seasonal variation, with brick kilns dominating the dry season emission, while road dust dominating the wet season emission. The north-western and western parts of Dhaka (representing Savar, Gazipur and Dhamrai areas) account for a large portion of brick kiln emissions during the dry season. Brick kilns located to the eastern periphery of the city (Kaliganj and Rupganj) and to the south of the city (Narayanganj, bandar and Sirajdikhan) are also responsible for significant emission. Vehicular and road dust emissions are significant along major roads and intersections. Average total monthly emission of PM_{10} for dry months (24,606 tons/month) is about ten times higher than that for a wet season (2,584 tons/month). During dry season, emission from brick kiln accounts for about 87 percent of PM_{10} emission, followed by road dust (11.2 percent) and vehicle (2 percent). During wet period, road dust becomes dominant contributor of PM emission, accounting for over 80 percent of PM_{10} emissions, and 64 percent of $PM_{2.5}$ emissions. Diesel driven vehicles (i.e., buses and trucks) are responsible for majority of PM_{10}, $PM_{2.5}$, SOx, and NOx emissions. Together, buses and trucks account of about 81 percent of vehicular PM_{10} emissions, 88 percent of vehicular $PM_{2.5}$ emissions, 94 percent of vehicular SOx emissions, and 83 percent of vehicular NOx emissions.

The predicted ambient PM concentrations within and around Dhaka city has been found to vary widely, depending on the presence of emission sources (brick kilns, major roads) and meteorology (primarily wind direction and precipitation). The areas to the north-east of the Dhaka city i.e., Kaliganj, Sreepur are less polluted, primarily because they are not located down-wind of the major brick kiln clusters. During wet season (April to October), predicted PM concentration are relatively low throughout the model domain, but they are much lower for the boundary areas of Dhaka City (e.g., Kapasia, Savar, Keraniganj), compared to the city-centre areas. For some months, e.g., February and March, the predicted values matched well the values recorded at the CAMS, but in general, the predicted values are lower than those recorded at the CAMS. Inclusion of industrial emissions is likely to improve the model predictions. Although brick kilns are the dominant emission source during the dry season, source apportionment exercise suggest that vehicular emission and road dust account for major fractions of ambient PM concentration within city areas. For example, at the CAMS location near Shangshad Bhaban, vehicular emission, road dust and brick kilns account for about 36 percent, 29 percent, and 17 percent, respectively of ambient $PM_{2.5}$ concentration in March.

The developed emission inventory model is flexible such that it can take as input user defined parameters such as emissions factors, activity rates (e.g., AADT for vehicles), fuel use by different vehicle types, etc. Thus the inventory model can be easily updated as new information about the parameters becomes available. The air quality model together with the emission inventory, when fully developed and calibrated, could become a very useful policy analysis tool for air quality management.

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CHAPTER ONE: INTRODUCTION

1.1 GENERAL

Dhaka, the capital city of Bangladesh, with a population 11.9 million (BBS, 2011) is at the risk of experiencing major health impacts resulting from poor air quality. 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 in Dhaka is monitored at two Continuous Air Monitoring Stations (CAMS); at the Shangshad Bhaban CAMS since April, 2002 and at the BARC CAMS since June, 2008. However, there are significant discontinuities in the monitoring data; for example, data on gaseous pollutants could not be measured 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). Like many urban areas, particulate matter (PM) is the principal air pollutant of concern in Dhaka. PM concentrations (PM_{10} and $PM_{2.5}$) on an annual basis in Dhaka show a slightly increasing tendency from April 2002 to July 2006 (ADB and CAI-Asia, 2006). Both PM_{10} and $PM_{2.5}$ concentrations exhibit levels exceeding the World Health Organization (WHO) guidelines; they also exceed the national standards of annual PM_{10} (50 $\mu g/m^3$) and $PM_{2.5}$ (15 $\mu g/m^3$) by a factor of over two.

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. 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. Development of a good emission inventory and air quality model for Dhaka city is a prerequisite for development of such a tool.

A number of source-apportionment studies have been carried out identifying sources of particulates in Dhaka (e.g., Begum, 2004; 2005); a few air quality modeling studies have also been carried out (e.g., Guttikunda, 2009; Rahman, 2010). According the source apportionment studies, vehicles, brick kilns surrounding Dhaka city, and road/ soil dust are the major sources of particulates in the city. Depending on the location, contribution of vehicular emission to $PM_{2.5}$ has been estimated to vary from 39 t0 43 percent, while that of brick kilns varied from 12 to 38 percent. According to these studies, re-suspension of road dust accounted for at least 50% of the coarse PM. Guttikunda (2009) carried out air quality modeling of Dhaka city focusing only on brick kiln emission. Rahman (2010) carried out air quality modeling considering emissions from vehicles and brick kilns. The results from these modeling studies differed significantly with those of the source apportionment studies, highlighting the need for more comprehensive assessment of air quality sources and modeling studies. Rahman (2010) carried out air quality modeling of Dhaka city using the emission inventory developed by Arjumand (2010). Apart from the fact that the emission inventory considered only vehicular and brick kiln emissions, the grid system used by Arjumand (2010) and Rahman (2010) differed significantly.

The present study focuses on development of a grid-based emission inventory for Dhaka city considering the major emission sources, and subsequently using the emission inventory for development of an air quality model for Dhaka city.

1.2 OBJECTIVES OF THE STUDY

The major objectives of the present study are development of a spatially disaggregated, grid-based emission inventory for Dhaka city considering the major emission sources, and subsequently using the emission inventory for development of an air quality model for Dhaka city. The specific objectives include the following:

a) Assessment of air quality characteristics and major emission sources for Dhaka city;
b) Development of a spatially disaggregated and grid wise emission inventory for Dhaka city in GIS format, considering major emission sources, for subsequent interfacing with an air quality model;

c) Upgradation of the existing source-receptor matrix of Rahman (2010) using the new emission inventory;
d) Prediction of ambient concentration of particulate matter (PM_{10} and $PM_{2.5}$) in Dhaka city for both dry and wet seasons, and calibration of the model using measured data at the CAMS in Dhaka;
e) Estimation of contribution of major sources to ambient PM concentration, and identification of most vulnerable zones of the city with respect to air pollution;

The major output of the proposed study would be a spatially disaggregated, grid-based emission inventory for Dhaka city that could be updated periodically (incorporating new/ changing sources), and an air quality model that could also be updated with new data on emissions and meteorology. The developed emission inventory and air quality model could be used for analysis of different policy options for control and management of air quality, e.g., by liking it with a health impact model.

1.3 OUTLINE OF METHODOLOGY

Assessment of air quality and emission of pollutants in the context of Dhaka city:

Air quality of Dhaka city will be assessed based primarily on the data available from the two CAMS located in Dhaka city. The available data will be used for assessment of temporal variation of air quality (including daily, seasonal and yearly) over Dhaka city. Efforts will be made to collect air quality data recorded at other locations of Dhaka city for assessment of spatial distribution of pollutants.

Model domain and grid for emission inventory and air quality model

At first a geographical boundary line will be selected that represents the study area. The model boundary will include the entire Dhaka city as well areas surrounding Dhaka city where the brick kilns are located (e.g., Dhamrai, Savar, Gazipur, Kaliganj and Rupganj). The modeling domain used by Rahman (2010) will be used in this study, which is between 23°30’0” to 24°6’0” N and 90°18’0” to 90°48’0” E. The same model domain and model grid system will be used for emission inventory and air quality modeling.

Estimation the emission from various emitting sectors

The emission inventory will be developed considering the major sources of emissions including vehicular emission, brick kiln and road dust. In transportation sector, only road traffic will be considered. Emissions from each these source groups (traffic, road dust and brick kiln) will be estimated separately in a grid-wise fashion using different methodological approaches and finally they would be summed up to estimate the total emission.

Emission factors (EF) (e.g., gm/km for transportation, ton/unit time for other sectors) and activity data (e.g., km/day for transportation, kg/ton for other sectors) will be used for estimating emission from different sources. Total emission from different sources will be estimated for each grid separately.

Prediction of Ambient Air Pollutant's Concentrations of Dhaka city:

The ambient concentration of pollutants (PM_{10} and $PM_{2.5}$) will be predicted by multiplying the Source Receptor Matrix (SRM) developed by Rahman (2010) and the emission matrix (to be developed as a part of this study) of the city following the method used by Guttikunda and Harshadeep (2009) and Rahman (2010). The predictions will be made as monthly average concentrations and compared with available data at the CAMS. Contribution of the different major sources, especially to PM pollution will be estimated and compared with the available modeling and source apportionment studies.

1.4 ORGANIZATION OF THE THESIS

The thesis is presented in six chapters. The first chapter (Chapter One) presents the background of the study, objectives, and outline of the methodology followed in the study.

Chapter Two (Literature Review) reviews the basic information on air pollution and its impacts. This Chapter also provides an overview of air quality of Dhaka city, and previous studies on emission inventory and air quality modeling

Chapter Three describes the methodologies adopted in the present study. It describes the selection of study area and its subdivision into grids, selection of emission inventory parameters and methods for estimation of emission from different sources. Data source for emission factors and activity levels and the formula used for emission estimation have been presented and discussed. This Chapter also describes the methods followed for prediction of the ambient particulate matter concentration by multiplying the SR matrix developed by Rahman (2010) with the emission inventory developed in this study.

Chapter Four presents the emission inventory developed in this study considering road traffic, road dust and industrial sources i.e. brick kiln. This Chapter presents the spatial distribution of emission over the Dhaka city in GIS maps.

Chapter Five presents spatial and temporal distribution of particulate matter concentration in study area due traffic emission, road dust and brick kiln emission. It also presents contribution of different sources to ambient PM concentration in different seasons. Assessment of a few policy options on ambient air quality has also been presented.

Finally, Chapter Six summarizes the major conclusions of the present study. It also discusses the limitations of the present study and the recommendations for future studies.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

Air pollution is one of a variety of manmade environmental disasters that are currently taking place all over the world. Air quality has deteriorated both due to human activities, and natural phenomenon such as windblown dust particles etc. Recently, air pollution has received priority among environmental issues in Asia, as well as in other parts of the world. Exposure to air pollution is the main environmental threat to human health in many towns and cities. Particulate emission is mainly responsible for increased death rate and respiratory problems for the urban population. This problem is acute in Dhaka being the capital of the country and also the hub of commercial activity. Hence estimation and understanding of the status and level of air pollution is necessary. A comprehensive study on air pollution and its impact need to be undertaken to find out the degree of air pollution. The effect of air pollution can be estimated only when the quality of air of the region is available. In order to understand the air quality of an area, measurements of air quality parameters are required. So in order to help in these regards air quality modeling has been developed. The Chapter presents an overview of the air quality of Dhaka, emission inventory and its characteristics and uses, major sources of pollution, and the air quality modeling to visualize the air quality of an area. This chapter also summarizes emission inventory conducted by various organizations of Bangladesh and some of the studies on source apportionment of air pollution

2.2 AIR POLLUTION

Air pollution may be defined as an atmospheric condition in which various substances are present at concentrations high enough above their normal ambient levels to produce a measurable effect on people, animals, vegetation, or materials. ‘Substances’ refers to any natural or manmade chemical elements or compounds capable of being airborne. These may exist in the atmosphere as gases, liquid drops, or solid particles. It includes any substance whether noxious or benign; however, the term ‘measurable effect’ generally restricts attention to those substances that cause undesirable effects. This section describes the effect of air pollution, sources and apportionment of sources for air pollution, types of air pollutants and present state of air quality of Dhaka City.

2.2.1 Sources of air pollution

The use of fossil fuel for heating and cooling, for transportation, for industrial processes and energy conservation; incineration of various forms of industrial, municipal and private wastes – all contribute to the atmospheric pollution. Major air pollution sources may be categorized as follows (Seinfeld and Pandis, 1998):

1. *Transportation/ mobile sources:* Motor vehicles, rails, ships, aircrafts etc. In most urban areas, motor vehicles are major contributors of emissions of Total Organic Gas, SOx, NOx, CO, and PM (PM_{10} and $PM_{2.5}$).
2. *Stationary sources/Point Sources:* Fuel combustion in power plant, heating plant, power generation, heating plant, petroleum refineries, brick kilns, cement factories and other industries are taken as point source. The brick kilns are responsible for emission of SOx, NOx, CO_2, and PM (PM_{10} and $PM_{2.5}$). Cement factories also contribute in particle matter, SOx, NOx and CO emissions
3. *Industrial processes:* Chemical, metallurgical, paper-pulp industries, petroleum refineries.
4. *Incineration or burning of wastes:* Household and commercial wastes, agricultural burning, industrial and hazardous waste incineration
5. *Miscellaneous sources:* Re-suspension from roads, Domestic fuel/wood burning, Forest fire, volcanic eruption, emissions from soil, pollen grains etc (natural sources).

2.2.2 Classification of pollutants

In general, an air pollutant may be defined as any substance released to the atmosphere that alters the air's natural composition and may result in adverse effects to the human, animals, vegetations, or materials. Air pollutants can be classified into different groups from different aspects. The classification of air pollutants is discussed in the following articles.

According to the origin

The air pollutants can be classified as primary or secondary (Masters, 2004). This classification is based on how the pollutants are originated in the atmosphere.

1. *Primary Pollutants:*

   These pollutants are emitted directly into the atmosphere from an identifiable source. Examples include carbon monoxide and sulfur dioxide.

2. *Secondary Pollutants:*

   These types of pollutants are produced in the atmosphere by chemical and physical processes from primary pollutants and natural constituents. For example, ozone is produced by hydrocarbons and oxides of nitrogen (both of which may be produced by car emissions) and sunlight.

According to the state of matter

Air pollutants can be found in different state e.g., gas, liquid and solid (Masters, 2004). The classification based on the state of matter is as follows:

a) *Gaseous:*

   -CO, SOx, NOx (inorganic)

   -Benzene, Methane (organic)

b) *Particulates/ Aerosols:*

   -Dust, smoke, fume, fly ash (solid state)

   -Mist, spray (liquid state)

   -Pollen, bacteria, virus (natural particulates)

According to the chemical composition

Air pollutants can be of various chemical compositions (Masters, 2004). They are:

a) *Organic:* e.g., Hydrocarbons (HC), Aldehydes and Ketones
b) *Inorganic:* e.g., SO_x, NO_x, CO, HCl, NH_3, H_2S

Air pollutants are also classified according to major groups of compounds as follows (Seinfeld, 1985):

i) Sulfur – containing compounds
ii) Nitrogen – containing compounds

iii) Carbon – containing compounds
iv) Halogen – containing compounds
v) Toxic Substances (may include components of other classes)
vi) Radioactive compounds

According to the types of releases

Sources of air pollutants can be divided into three categories according to their release (Seinfeld, 1985).

a) *Point Sources* - such as smokestack
    i) Continuous: the pollutant emits continuously as like a plume
    ii) Puff releases: the pollutants are released intermittently
b) *Line Sources* - such as emissions from motor vehicle along a highway.
c) *Area Sources* - e.g. wildfires, evaporated vapors from a large spill of volatile liquid.

The Clean Air Act requires US EPA to set National Ambient Air Quality Standards for six common air pollutants. These air pollutants are known as "criteria pollutants". They are particle pollution (often referred to as particulate matter), ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. These pollutants can harm people's health and the environment, and cause property damage. Of the six pollutants, particle pollution and ground-level ozone are the most widespread health threats. EPA calls these pollutants "criteria" air pollutants because it regulates them by developing human health-based and/or environmentally-based criteria (science-based guidelines) for setting permissible levels. These six pollutants are most common air pollutants in urban and industrial areas. The following subsections describe briefly about these criteria pollutants.

Particulate Matter

"Particulate matter," also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles.

Although particles may have irregular shapes, their size is described by an equivalent "Aerodynamic Diameter". Aerodynamic diameter is determined by comparing them with perfect spheres having same settling velocity. It is defined as the diameter of the perfect sphere having the same velocity as the particulate has. The size of particles is directly linked to their potential for causing health problems. EPA is concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects. EPA groups particle pollution into two categories:

a. *Inhalable coarse particles (PM_{10})*: Such as those found near roadways and dusty industries, are larger than 2.5 micrometers and smaller than 10 micrometers in diameter.

b *Fine particles ($PM_{2.5}$)*: Such as those found in smoke and haze, are 2.5 micrometers in diameter and smaller. These particles can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries and automobiles react in the air.

Particle pollution - especially fine particles - contains microscopic solids or liquid droplets that are so small that they can get deep into the lungs and cause serious health problems. Numerous scientific studies have linked particle pollution exposure to a variety of problems, including:

- premature death in people with heart or lung disease,
- nonfatal heart attacks,
- irregular heartbeat,
- aggravated asthma,
- decreased lung function, and
- increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing.

People with heart or lung diseases, children and older adults are the most likely to be affected by particle pollution exposure.

Besides health impacts, there are some other significant effects of PM. Fine particles ($PM_{2.5}$) are the main cause of reduced visibility (haze) , including many treasured national parks and wilderness areas. Particles can be carried over long distances by wind and then settle on ground or water. The effects of this settling include: making lakes and streams acidic;

changing the nutrient balance in coastal waters and large river basins; depleting the nutrients in soil; damaging sensitive forests and farm crops; and affecting the diversity of ecosystems. Particle pollution can stain and damage stone and other materials, including culturally important objects such as statues and monuments. (http://www.epa.gov)

Ground –level Ozone

Ozone is found in two regions of the Earth's atmosphere – at ground level and in the upper regions of the atmosphere. Both types of ozone have the same chemical composition (O_3). While upper atmospheric ozone protects the earth from the sun's harmful rays, ground level ozone is the main component of smog.

Tropospheric, or ground level ozone, is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC). Ozone is likely to reach unhealthy levels on hot sunny days in urban environments. Ozone can also be transported long distances by wind. For this reason, even rural areas can experience high ozone levels.

Children are at greatest risk from exposure to ozone because their lungs are still developing and they are more likely to be active outdoors when ozone levels are high, which increases their exposure. Children are also more likely than adults to have asthma.

Ozone also affects sensitive vegetation and ecosystems, including forests, parks, wildlife refuges and wilderness areas. In particular, ozone harms sensitive vegetation, including trees and plants during the growing season.

Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NOx and VOC. (http://www.epa.gov)

Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless gas emitted from combustion processes. Nationally and, particularly in urban areas, the majority of CO emissions to ambient air come from mobile sources. CO can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, CO can cause death. CO can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, CO can cause death.

Exposure to CO can reduce the oxygen-carrying capacity of the blood. People with several types of heart disease already have a reduced capacity for pumping oxygenated blood to the heart, which can cause them to experience myocardial ischemia (reduced oxygen to the heart), often accompanied by chest pain (angina), when exercising or under increased stress. For these people, short-term CO exposure further affects their body's already compromised ability to respond to the increased oxygen demands of exercise or exertion. (http://www.epa.gov)

Sulfur Oxides

Sulfur dioxide (SO_2) is one of a group of highly reactive gasses known as "oxides of sulfur." The largest sources of SO_2 emissions are from fossil fuel combustion at power plants (73%) and other industrial facilities (20%). Smaller sources of SO_2 emissions include industrial processes such as extracting metal from ore, and the burning of high sulfur containing fuels by locomotives, large ships, and non-road equipment. SO_2 is linked with a number of adverse effects on the respiratory system.

SO_2 is the component of greatest concern and is used as the indicator for the larger group of gaseous sulfur oxides (SOx). Other gaseous sulfur oxides (e.g. SO_3) are found in the atmosphere at concentrations much lower than SO_2.

Emissions that lead to high concentrations of SO_2 generally also lead to the formation of other SOx. Control measures that reduce SO_2 can generally be expected to reduce people's exposures to all gaseous SOx. This may have the important co-benefit of reducing the formation of fine sulfate particles, which pose significant public health threats.

SOx can react with other compounds in the atmosphere to form small particles. These particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory disease, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and premature death. (http://www.epa.gov)

Nitrogen Oxides

The sum of nitric oxide (NO) and NO_2 is commonly called nitrogen oxides or NOx. Other oxides of nitrogen including nitrous acid and nitric acid are part of the nitrogen oxide family. While EPA's National Ambient Air Quality Standard covers this entire group of NOx, NO_2 is the component of greatest interest and the indicator for the larger group of nitrogen oxides. NO_2 forms quickly from emissions from cars, trucks and buses, power plants, and off-road equipment. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO_2 is linked with a number of adverse effects on the respiratory system. NOx react with ammonia, moisture, and other compounds to form small particles. These small particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory disease, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and premature death. (http://www.epa.gov)

Lead

Lead (Pb) is a metal found naturally in the environment as well as in manufactured products. The major sources of lead emissions have historically been from fuels in on-road motor vehicles (such as cars and trucks) and industrial sources.

In addition to exposure to lead in air, other major exposure pathways include ingestion of lead in drinking water and lead-contaminated food as well as incidental ingestion of lead-contaminated soil and dust. Lead-based paint remains a major exposure pathway in older homes. Once taken into the body, lead distributes throughout the body in the blood and is accumulated in the bones. Depending on the level of exposure, lead can adversely affect the nervous system, kidney function, immune system, reproductive and developmental systems and the cardiovascular system. Lead exposure also affects the oxygen carrying capacity of the blood. The lead effects most commonly encountered in current populations are neurological effects in children and cardiovascular effects (e.g., high blood pressure and heart disease) in adults. Infants and young children are especially sensitive to even low levels of lead, which may contribute to behavioral problems, learning deficits and lowered IQ. (http://www.epa.gov)

2.2.3 Air quality standards

In order to analyze the air quality data of a city it is necessary to compare these values with already established standard. Table 2.1 lists the air quality standards of Bangladesh, United States Environment Protection Agency (USEPA), and the World Health Organization (WHO).

Table 2.1: Air Quality Standards ([a]S.R.O. No: 220-Law, DoE, 2005; [b]WHO, 2006; and [c]US EPA, 2005.)

Pollutant	Averaging Period	Bangladesh[a] Standard	WHO[b] Guideline Values	US EPA Standards[c]
		μg/m^3 (ppm)	μg/m^3	μg/m^3
CO	8 - hr	10,000 (9)	10000	10000
	1 - hr	40,000 (35)	30000	40000
Pb	Annual	0.5	0.5	0.15
NO_x	Annual	100 (0.053)	40	100 ppb
SPM	8 - hr	200	-	-
PM_{10}	Annual	50	20	Revoked
	24 - hr	150	50	150
$PM_{2.5}$	Annual	15	10	15
	24 - hr	65	25	35
O_3	1 – hr	235 (0.12)	-	235
	8 - hr	157 (0.08)	100	157
SO_2	Annual	80 (0.03)	-	78
	24 - hr	365 (0.14)	20	365

From this it could be seen that Bangladesh standards are more or less same as those of the USEPA. The standards for the different pollutants are set considering the different averaging period, since health effect of air pollutants are directly related to exposure time.

2.2.4 Air quality of Dhaka

In Dhaka monitoring of air quality data has a relatively short history. Air quality (AQ) in Dhaka is monitored systematically at two Continuous Air Monitoring Station (CAMS) by Department of Environment (DoE) under the world bank financed Air Quality Management Project (AQMP).; at the Shangshad Bhaban CAMS since April 2002 and at the BARC CAMS since June 2008. After the installation of CAMS at the premises of National Parliament it is now possible to have a better idea of the trends of air pollution in Dhaka city. It also gives the opportunity to assess the variation in AQ due to the seasonal changes. 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. Table 2.2 shows the concentrations of pollutants in 2003, one year after installing the CAMS.

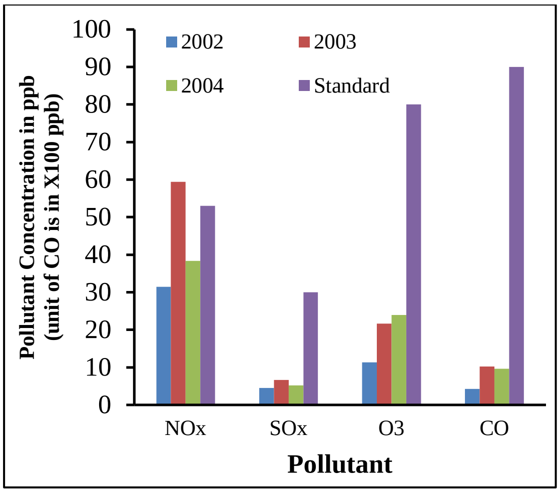
Table 2.2: Average values for criteria pollutants measured at CAMS, Dhaka during 2003 along with Bangladesh Standard (AQMP, 2002-2004)

Pollutants	Averaging Time	Who Guidelines	Bangladesh Standards	Annual average Concentration during 2003
CO	1 hour	30 mg/m^3	40 mg/m^3 (35 ppm)	---
	8 hour	10 mg/m^3	10 mg/m^3 (9 ppm)	1.0 ± 0.8ppm
SO_2	24 hour	125 mg/m^3	365 mg/m^3 (140 ppb)	----
	Annual	50 mg/m^3	80 mg/m^3 (30 ppb)	7±8 ppb
NO_2	24 hour	---	---	---
	Annual	40 mg/m^3	100 mg/m^3 (53 ppb)	59±58 ppb
Ozone	1 hour	---	235 mg/m^3 (120 ppb)	
	8 hour	120 mg/m^3	157 mg/m^3 (80 ppb)	28±20 ppb
PM_{10}	24 hour	---	150 mg/m^3	
	Annual	---	50 mg/m^3	133 ± 78mg/m^3
$PM_{2.5}$	24 hour	---	65 mg/m^3	---
	Annual	---	15 mg/m^3	76 ± 57mg/m^3

Figures 2.1 and 2.2 show the yearly average concentration of different criteria pollutants (NOx, SOx, O3, CO, PM_{10} and $PM_{2.5}$) recorded at the Shangshad Bhaban CAMS.

It is seen from the graph that, yearly average values for PM_{10} shows an increasing trend. But $PM_{2.5}$ concentrations show a trend which is slightly increasing. These imply that air pollution level in Dhaka city is increasing. It is also observed that these values are well above the World Health Organization (WHO) guidelines as well as exceed more the national standards of annual PM_{10} (50µg/m^3) and $PM_{2.5}$ (15µg/m^3).

It also shows that concentrations of $PM_{2.5}$ and PM_{10} exceed the national limits (1 µg/m^3 and 50 µg/m^3, respectively) by a factor over two. 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.



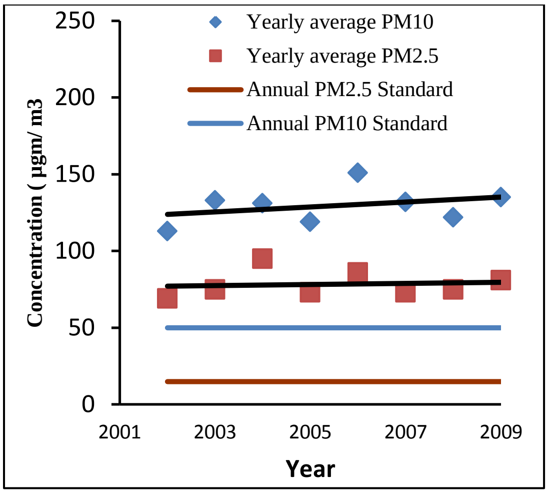


Figure 2.1: Yearly average Concentration of NO_x, SO_x, O_3 and CO (AQMP, 2011)

Figure 2.2: Variation of yearly average PM_{10} and $PM_{2.5}$ (AQMP, 2011)

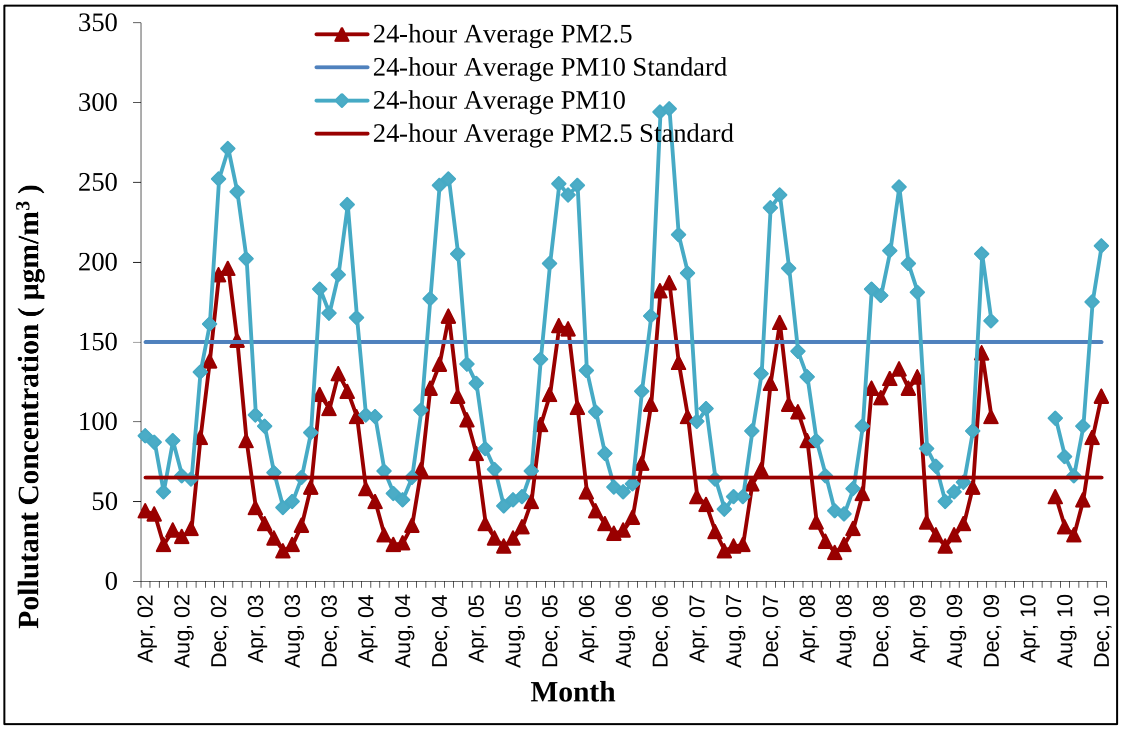


Figure 2.3: Monthly 24-hour average concentration of $PM_{2.5}$ and PM_{10} (Source : DoE)

Figure 2.3 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 seen in almost all the years for which data are available.

In addition, Figure 2.4 to 2.7 in some cases the concentration of Nitrogen oxides (NO_x) has crossed the limit set by the ECR, 2005 (DoE, 2005). But the concentrations of Carbon Mono-oxide (CO), Sulfer Di-oxide (SO_x) and Ozone (O_3) are well below the standard values. But these values also show the seasonal variation.

These seasonal variations are mainly due to the fact that, during the rainy days the wet depositions of different pollutants are effective. Especially the particulate matters are deposited to the ground, which results in lowering their ambient concentration. Also during the entire dry season, the brick kilns around Dhaka remain operational, which increase the emission of pollutants and subsequently increases the ambient concentration in Dhaka city. These pollution charts show that the particulate pollution is the primary air pollution hazard in Dhaka city and the sources and distribution of particulates need to be studied further.

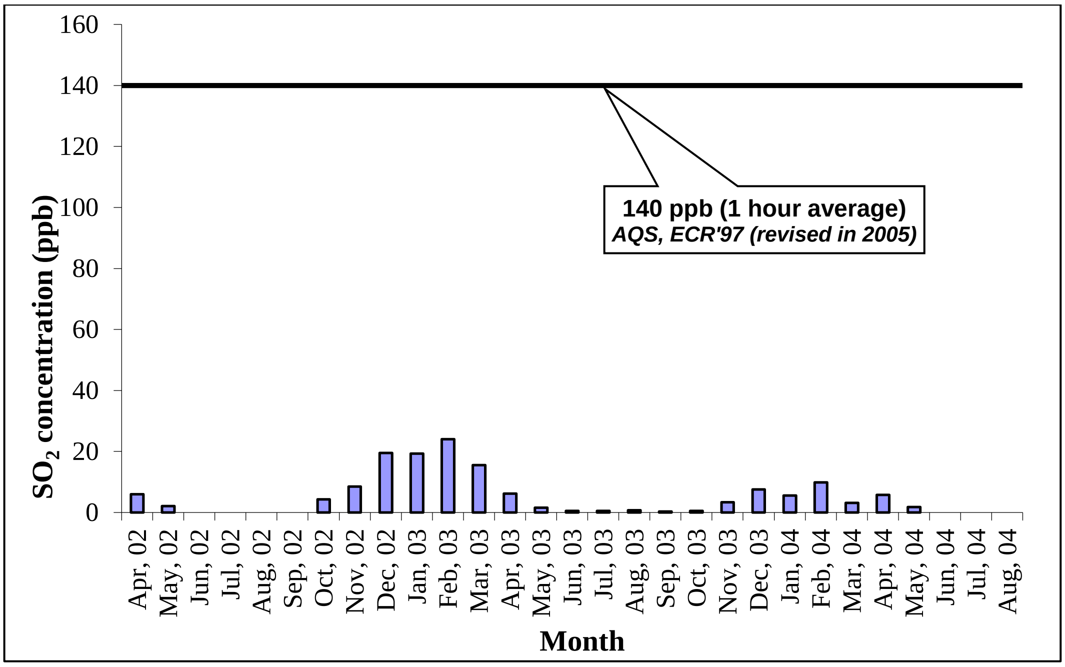


Figure 2.4: Monthly 24-hour average value of SO_2 concentration (AQMP, 2007)

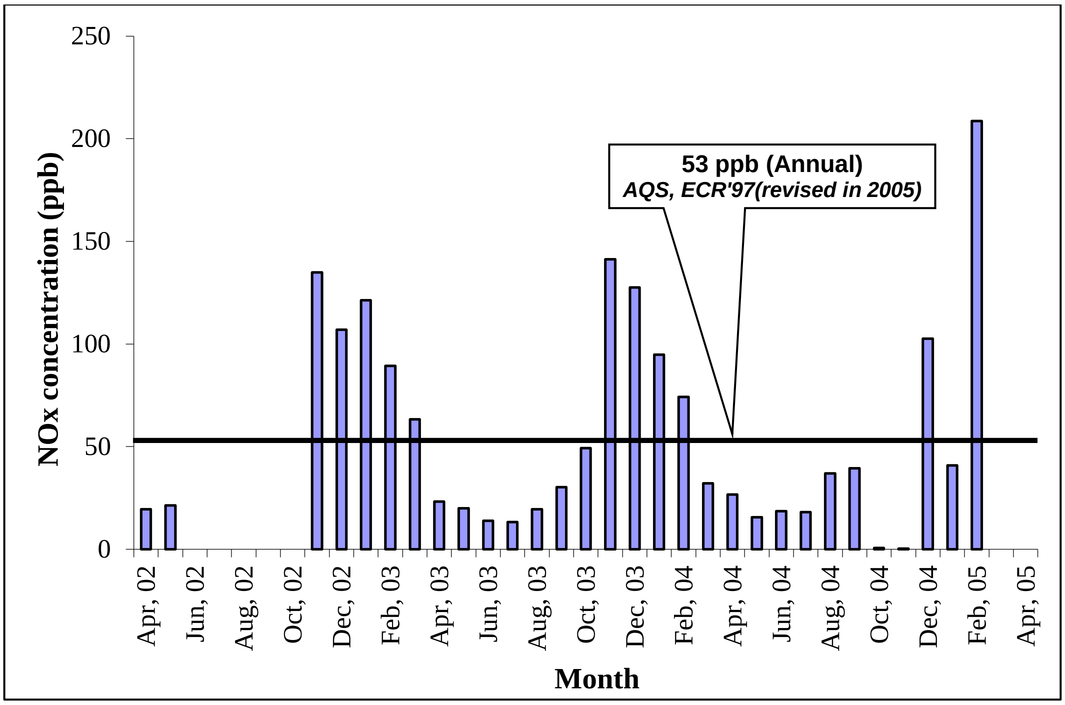


Figure 2.5: Monthly 24-hour average value of NO_x concentration (AQMP, 2007)

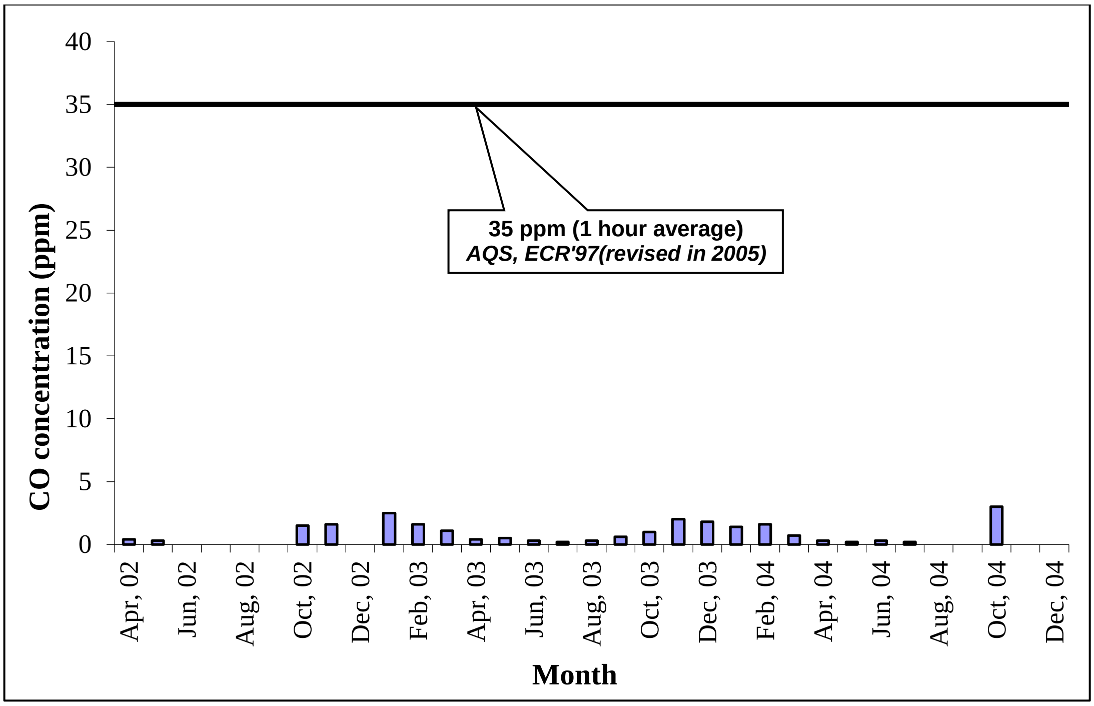


Figure 2.6: Monthly 1-hour average value of CO concentration (AQMP, 2007)

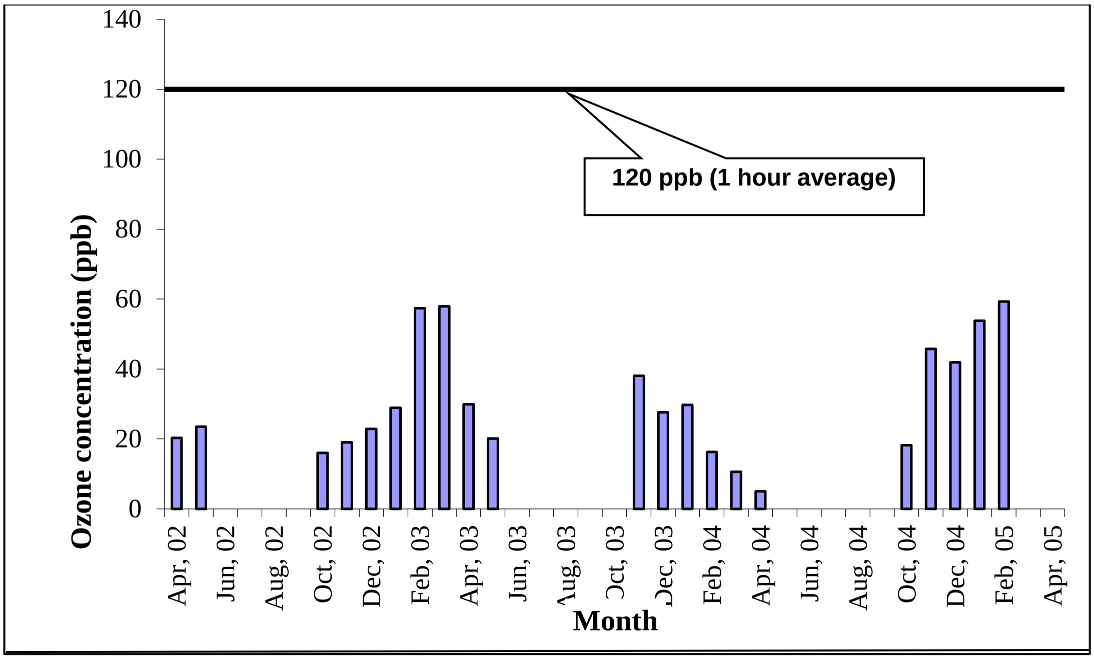


Figure 2.7: Monthly 1-hour average value of O_3 concentration (AQMP, 2007)

2.2.5 Effects of Air Pollution

Air pollutants have effects on atmospheric properties, on materials, on vegetations, and on human health etc .But recent studies have established that the major adverse effect of air pollution is on human health (USEPA, 2007). Previous sections describe the effects of pollutants. This section describes the effects in terms of morbidity and health cost for Dhaka City.

Air pollution seriously affects the respiratory tract and causes irritation, headache, asthma, high blood pressure, heart ailments and even cancer. If this trend of air pollution continued, those living in major cities including the metropolis, will become exposed to these ailments and also other complications. The mental faculty of children will be adversely affected by lead pollution, which can also affect the central nervous system and cause renal damage and hypertension. 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. The economic loss associated with these health problems could range from a low estimate of $60 million to a high estimate of $270 million, equivalent to 1.7 to 7.5% of the city’s gross product. If added with traffic congestion, global warming, soiling of materials, and aesthetic degradation, the total cost of air pollution would be substantially larger (Xie et al. 1998). For Dhaka City Corporation (DCC) area, 15,327 premature deaths could be attributed to traffic and brick kiln pollution. This figure increases to 19,890, when the greater Dhaka area has been considered. The mortality effect of traffic and brick kiln pollution is equivalent to about 2,912 million US$ in DCC area and 3,779 million US$ in greater Dhaka. This means around 1.21% to 1.56% of country's total GDP is lost due to air pollution in the Dhaka city (Rahman, 2010).

2.3 EMISSION INVENTORY AND AIR QUALITY MODELS

Emission inventories are which provide quantitative estimates for pollution loads in a given geographic area have long been fundamental tools for air quality management (Khaliquzzaman, 2006). This means that; emission inventory is an analysis to calculate the amount of pollutants discharged into the atmosphere.

An emission inventory usually contains the total emissions for one or more specific greenhouse gases or air pollutants, originating from all source categories in a certain geographical area and within a specified time span, usually a specific year.

From epidemiological studies it is seen that in industrial and developing countries ambient particle matter (PM) levels is a major threat to mortality and morbidity. Besides, due to air pollution children suffer from acute respiratory infections, adults suffer from chronic bronchitis. "Uncontrolled emissions from motor vehicles and other economic activities like industries give rise to air and other forms of pollution" (IRIN, 2009). Information on emissions therefore is an important requirement in understanding environmental problems and in monitoring progress towards solving these. Emission inventories provide this type of information. In determining the benefits of a policy intervention to improve the local air quality, it is important to relate the reduction in emissions to well defined improvements in damage end points and associated benefits. There is a sequence of events in a model to value environmental externalities which can be best explained by the impact-pathway approach, described graphically in Figure 2.8 (Wadud, 2008).

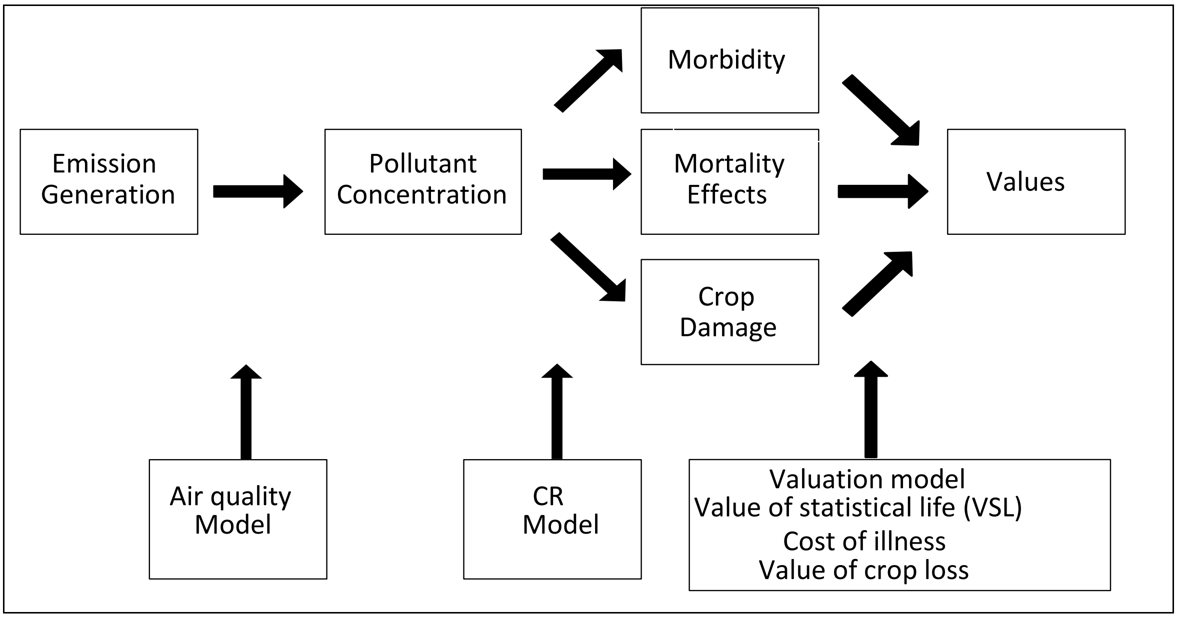


Figure 2.8: Impact pathway for air quality (Wadud, 2008)

It is clear for the impact-pathway approach that in order to estimate the pollutant concentration; at the very beginning emission information is required.

The Government of Bangladesh 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. 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. Development of a good emission inventory and subsequently feeding the emission inventory into air quality model for determining the concentration for Dhaka city is a prerequisite for development of such a tool.

An air pollution model mainly performs two activities:

- Predict how an emission will be transmitted to a receiver
- Predict the concentration of the contamination when it reaches the receiver (receptor)

Air quality modeling is used to determine and visualize the significance and impact of emissions to the atmosphere. They are especially useful for the policy-makers to take effective abatement measure in managing air pollution.

2.4 PREVIOUS STUDY ON AIR QUALITY IN BANGLADESH

In Dhaka there are significant emissions from motor vehicles and other anthropogenic activities resulting in severe air and other forms of pollution. Airborne particulate matter (APM) is considered to be one of the important pollutants (Azad et.al., 1998) .The identification of various sources of airborne particulate matter (PM) and the assessment of the impact on the aerosol composition of an air shed has been done by the Atomic Energy Center of Bangladesh in 2006. Table 2.3 presents the source apportionment of particulate matter in Dhaka city in percentage. Study shows that major sources of PM_{10} are re-suspended soil or road dust and motor vehicle, while motor vehicles account for the most of the $PM_{2.5}$. But the study apparently did not consider the emission of the brick kilns, which is also a major source. Table 2.3 shows average mass contribution to particulate pollution.

Table 2.3: Average Mass Contribution (in percentage) to Particulate Pollution in Dhaka, 1993-94 (Biswas et.al. 2000)

Source type	Percentage Contribution to Particulate Matter	
	Coarse (PM_{10})	Fine ($PM_{2.5}$)
Re-suspended Soil	54.7±2.4	8.88±5.04
Two-stroke engine	6.07±1.8	2.03±3.24
Construction. Work	7.09±3.36	---
Motor vehicle	31.2±6.1	29.1±4.6
Sea Salt	0.22±3.69	4.11±2.48
Refuse burning	0.74±5.96	---
Natural gas/diesel	---	45.7±8.3
Metal Smelting	---	10.2±8.1

Begum et al. (2004) has studied for the apportionment of source through the Positive Matrix Factorization (PMF) method in Dhaka and Rajshahi. They estimated that a large fraction of about more than 50% of the PM mass at both sites comes from soil dust and road dust. While in Dhaka 23% of coarser particles (PM_{10}) come from motor vehicles. They also estimated that motor vehicles contribute about 48% of the $PM_{2.5}$ in semi-residential area Dhaka. On the other hand, the biomass-burning factor contributes about 50% of the $PM_{2.5}$ mass in Rajshahi. Interestingly, for Dhaka no contribution of brick kiln is seen. From some other source apportionment studies conducted for Dhaka city (Begum et al. 2004, 2005), it is found that fine fraction i.e., $PM_{2.5}$ is dominated by vehicle emission and coarse fraction i.e. PM_{10} is dominated by re-suspension of road dusts. It was observed that vehicles normally produce about 50% of fine particles ($PM_{2.5}$ particles).

Figure 2.9 shows the source apportionment results reported by Begum et al. (2005). According to the study brick kilns contribute almost 38% of $PM_{2.5}$ concentration at Farmgate and 12% at Dhaka University area. Again, motor vehicles contribute about 40% at both the sites. For PM_{10} soil dust and motor vehicles are the major contributors at both the sites.

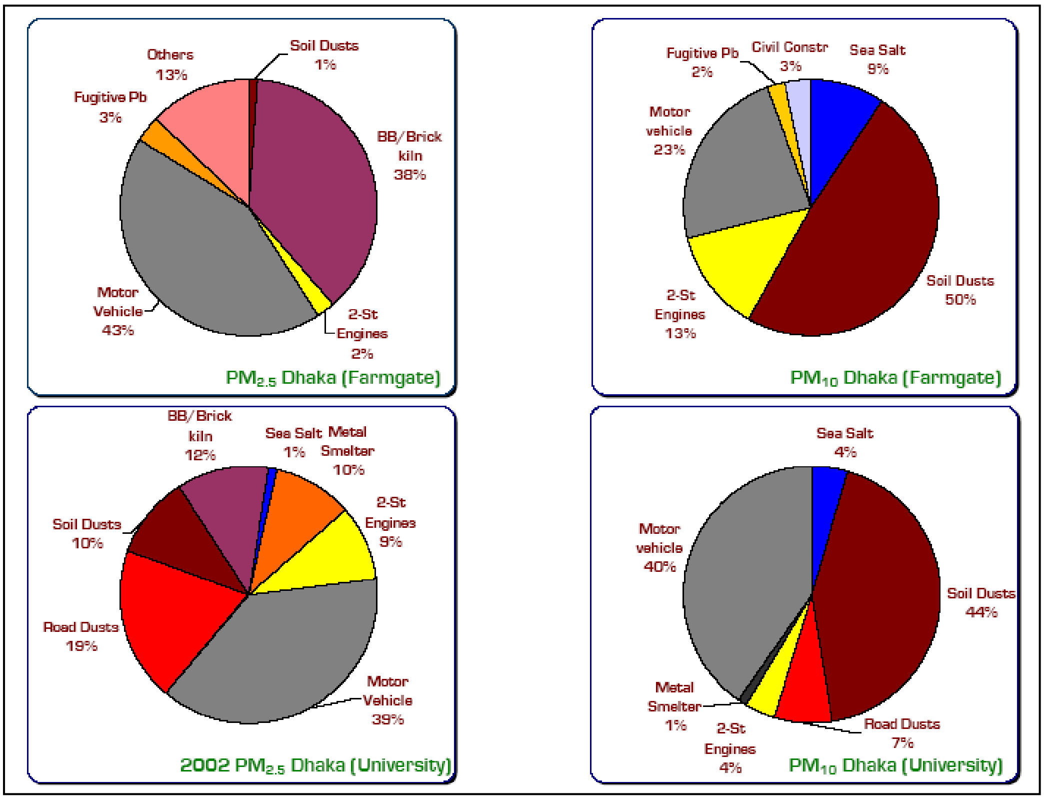


Figure 2.9: Source apportionment results for Dhaka city (Begum et al., 2005)

The Emission Inventory for Vehicular Emission has been prepared by Khaliquzzaman (2006) and Arjumand (2010) and by are presented below in Table 2.4 and Table 2.6, respectively.

Table 2.4: Dhaka Vehicular Emission Inventory in 2006 (ton/year) by Khaliquzzaman (2006)

Sl. No.	Vehicle Type	km/day	Number (2006)*	Emission (Tons/year)				
				CO	NOX	SO_2	HC	PM_{10}
1	Cars	40	158,301	57,779.7	3,466.8	184.9	9,244.8	231.1
2	Taxis-CNG	130	12,000	2,847.0	854.1	0.0	1,138.8	17.1
3	3W Taxis-CNG	130	15,500	3,677.4	1,103.2	0.0	1,471.0	22.1
4	LD Diesel	60	31,004	3,394.9	5,771.4	271.6	1,358.0	543.2
5	Buses	130	14,968	7,102.2	12,073.7	568.2	2,840.9	1,136.3
6	Trucks	60	23,361	5,116.2	8,697.5	409.3	2,046.5	818.6
7	Motorcycles	30	140,747	7,705.9	462.4	30.8	6,164.7	154.1
	Total			87,623.3	32,429.0	1,464.8	24,264.5	2,922.5

* Projected from BRTA figures for 2003. Inter-district buses have not been considered in calculating the inventory.

Table 2.5: Vehicular Emission in 2004 (in percentage) in Dhaka (Khaliquzzaman, 2006)

Sl.	Vehicle Type	Emission (%)				
		CO	NOX	SO_2	HC	PM-10
1	Cars	66.5	10.8	12.6	38.6	7.9
2	Taxis-CNG	2.8	2.3	0.0	4.1	0.5
3	3W Taxis-CNG	3.8	3.1	0.0	5.5	0.7
4	LD Diesel	3.9	17.9	18.5	5.7	18.6
5	Buses	8.2	37.5	38.8	11.9	38.9
6	Trucks	5.9	27.0	27.9	8.5	28.1
7	Motorcycles	8.9	1.4	2.1	25.7	5.3
	Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Results found from Nasiruddin (2006) are given in Figure 2.10.

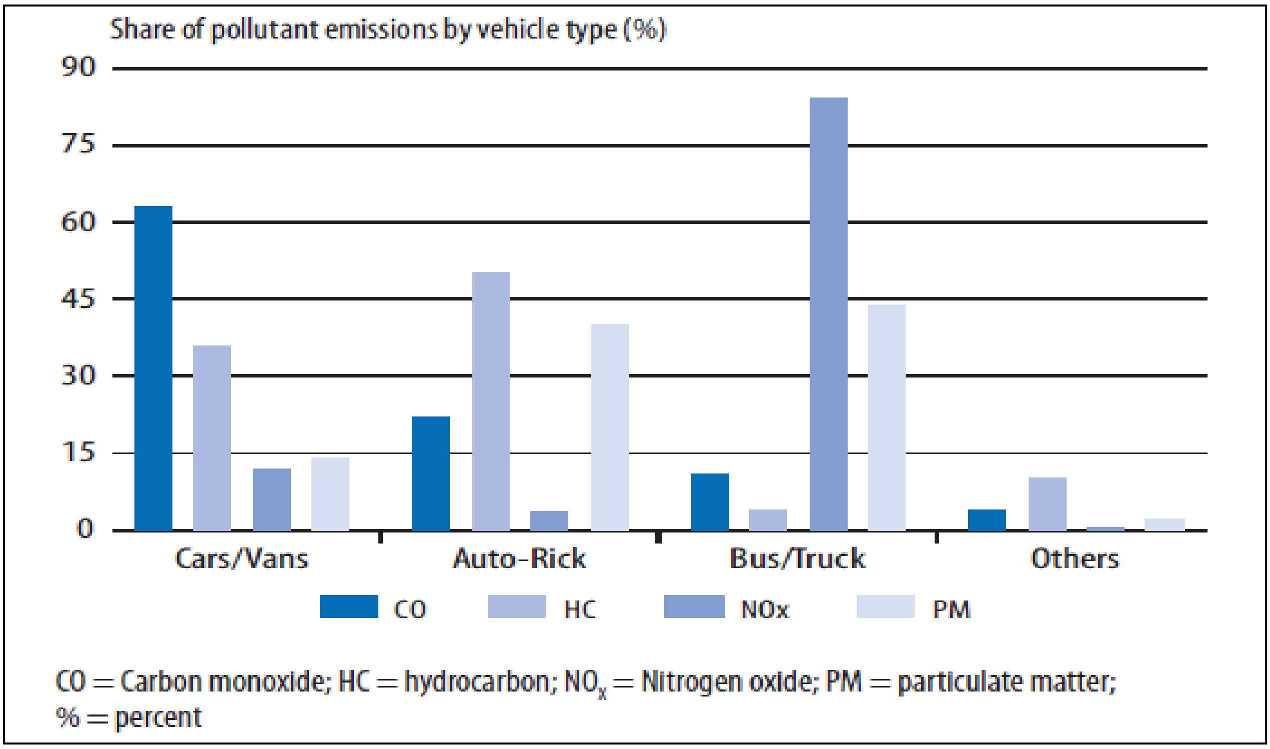


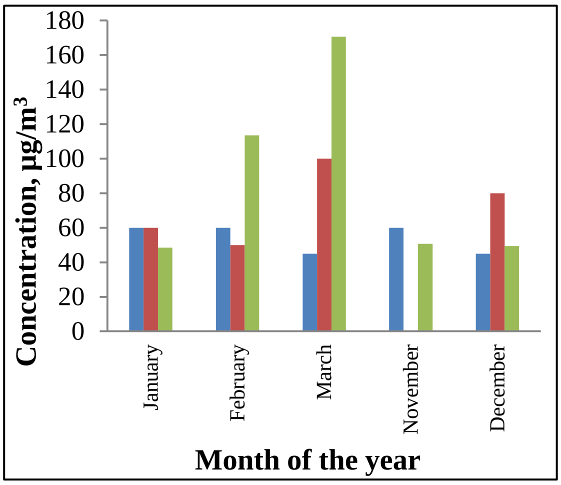
Figure 2.10: Share of pollutant emissions by vehicle type (%)

Table 2.6: Vehicular (on road) Emission Inventory for Bangladesh in (ton/year) by Arjumand (2010)

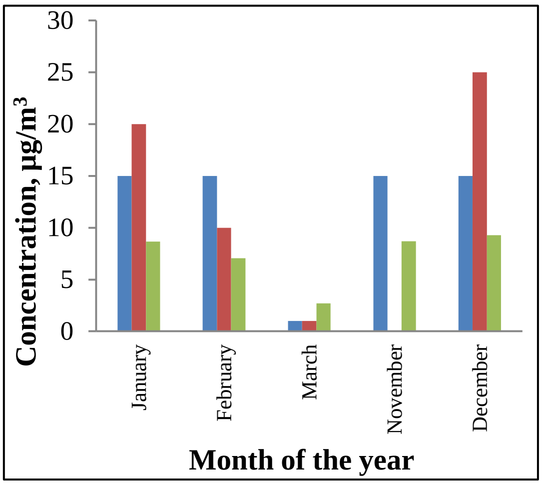
	Emission (ton/year)				
Vehicle Type	PM_{10}	$PM_{2.5}$	SOx	NOx	CO
Car	141.6	86.4	75.5	1689.2	9823.9
Taxi	73.6	24.6	23.5	399.9	2027.4
Bus	951.9	772.3	730.4	14536.1	3094.9
Truck	609.6	355.9	722.5	9552.8	2204.9
Auto rickshaw	106.2	63.1	130.8	678.6	8229.7
Tempo	38.6	87.8	8.7	131.6	1211.6
Motor Cycle	122.5	40.3	34.6	136.5	1296.7
Total	2044.0	1430.4	1726.0	27124.7	27889.2

The emissions analysis and data on the physical location of the brick kiln clusters was reported in a study carried out by Bangladesh University of Engineering and Technology. At the brick kilns, measured emission rate was found to be 44 gm/sec of TSP (Total Suspended Particles) from a single stack. This is assumed same for all size of stack heights. The TSP emission rates were converted to PM_{10} (using a ratio of 0.3 to TSP) and to $PM_{2.5}$ (using a ratio of 0.3 to PM_{10}). This amounts to a total of 108 ktons of PM_{10} during 180 days of operation of 530 brick kilns (Guttikunda, 2009).

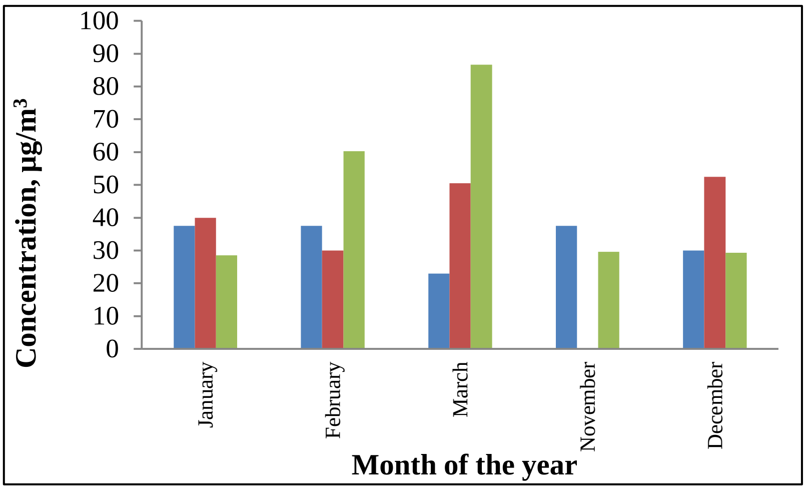
Arjumand (2010) shows that the brick clusters located in north-west direction of the study area are mainly responsible for particulate matter emission in Dhaka city as the wind direction during brick manufacturing season is north-west (170 degree clock wise from north direction) and during dry season the emission of PM_{10} and $PM_{2.5}$ is mostly generated form brick kilns. Figure 2.11 shows the comparison among different studies on brick kiln in Dhaka City.



(a) Maximum $PM_{2.5}$ concentration



(b) Minimum $PM_{2.5}$ concentration



(c) Average $PM_{2.5}$ concentrations

Figure 2.11: Comparison $PM_{2.5}$ concentration in DCC area among Rahman (2010) (green color) Guttikunda (2009) (blue color) and Choudhury (2009)(red color)

From the result of Rahman (2010), it is seen that the in the Dhaka city, the ambient concentration of both $PM_{2.5}$ and PM_{10} due to vehicular and the brick kiln pollution crosses the WHO Guideline values (2005) and the Bangladesh Standard (DoE, ECR, 2005). The dry season (November to Mid April) is the most critical period of the year. During this period, the operation of the brick kilns and lack of rainfall lead to the higher concentration. Particulate matter concentration during the wet season has found to be very low (primarily due to wet deposition and absence of contribution from brick kilns), with the maximum concentration well below the standards.

The source apportionment calculation at the CAMS site shows that Brick kiln is the major source of particulate pollution with 43% contribution to PM_{10} concentration and 21% contribution to $PM_{2.5}$ concentration. Traffic pollution contributes 10% to PM_{10} concentration and 13% to $PM_{2.5}$ concentration (Rahman, 2010).

Re-suspended road dust is considered as an important source (Begum et al., 2005; Biswas et al., 2001; Guttikunda, 2009); according to the US Environmental Protection Agency (US EPA) , 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.

Fugitive dust constitutes nearly two-thirds of the primary PM_{10} emissions according to the US National Emissions Trends inventory for 1997.

Road dust is 54.7±2.4 % and 8.88±5.04 responsible for PM_{10} and $PM_{2.5}$ respectively for Bangladesh. (Biswas, 2001).

Air Quality Model

Air quality models, such as Gaussian plume model, urban air shed model, box model and other trajectory and mesoscale models are being worldwide for many years. Dispersion model is being used to determine the location of an unknown emission source (Ahmed and Hossain, 2008). Concentrations of different pollutants in different seasons are also being estimated by using urban scale Gaussian dispersion model (Ahmed and Hossain, 2008). Industrial Source Complex Short Term (ISCST-3) model can be utilized to facilitate the study of emission source contributions to ambient concentrations of different pollutants. In India and Nepal, air pollution modeling has been used for different purposes (Ahmed and Hossain, 2008).

The World Bank has provided funding for studies in air quality management in Asia. As a part of those studies, air quality management strategy reports for different cities of Asia have been published. Among the cities Kathmunda, Jakarta, Metro Manila and Greater Mumbai are worth mentioning (World Bank Technical Paper, 1997). These studies have used the "KILDER" Dispersion Modeling System to estimate the ambient concentrations of particulate matter.

Guttikunda (2008) carried out a cost-benefit analysis of air pollution and GHG emissions for Hyderabad, India. In this study he used the air quality model "Atmospheric Transport Modeling System (ATMoS)" to find out the concentration of particulate matter.

Though air quality modeling is a very effective tool to predict ambient pollution level and is used worldwide, it has not been widely used in Bangladesh. Some air quality modeling works have been carried out in discrete or project basis to a smaller scale. Ahmed and Hossain (2008) have applied air quality modeling to find out the intensity of air pollution from the brick kiln. The study was based on the air quality model Industrial Source Complex (ISC3). Guttikunda (2009) describes the modeling study to assess the impact of brick kilns around the Dhaka city on its air quality. This study has been carried out using the model Atmospheric Transport Modeling System (ATMoS). A similar type of study has been carried out by the Chemical Engineering Department, Bangladesh University of Engineering and Technology. But this study used the Industrial Source Complex (ISC3) model (Choudhury, 2009). No modeling study has been conducted incorporating major air pollution sources such as transportation, road dust, industries, etc. A study has been conducted for evaluating the benefits achieved due to fuel conversion of motor vehicles from gasoline to CNG (Wadud and Khan, 2010) using a simple box model. Rahman (2010) has used ATMoS for determining the concentrations due to brick kiln and traffic emissions, and for different policy analysis.

2.5 SUMMARY

Air quality of Dhaka is a deteriorating day by day and it is a great threat to its inhabitants. Health impact of air pollution is very high. According to available data, high concentrations of particulate matter (both PM_{10} and $PM_{2.5}$) especially during the dry season are the most serious air pollution problem of Dhaka city. This chapter summarizes different studies conducted in Dhaka City considering traffic and brick kiln emission. Source apportionment studies indicate that road dust, motor vehicles and brick kilns are the most dominant source of particulate pollution, though there is no study available considering all of three sources. Contribution of different sources to ambient particulate concentrations needs to be studied in further details. This leads to the requirement of the present study as this will consider all three major sources to model and predict the air quality, which eventually could help in assessment of different policies taken for improving the air quality of Dhaka City. With a view to this objective the next chapter will explain the methodology that has been adopted for the present study.

CHAPTER THREE: METHODOLOGY

3.1 INTRODUCTION

This Chapter describes the methodology followed in the present study for developing a spatially disaggregated, grid-based emission inventory for Dhaka city considering the major emission sources, and subsequently using the emission inventory for development of an air quality model for Dhaka city.

Sections 3.2-3.4describe the methodology and logic followed in the selection of emission inventory parameter, including base year, study area and its division into grids, pollutants and emission sources. Section 3.5 describes the methodology followed for developing the emission inventory. Finally, Section 3.6 describes prediction of the ambient PM concentrations by multiplying the SR matrix developed by Rahman (2010) with the emission inventory developed in this study.

3.2 MODEL DOMAIN

The present study focuses on air quality of Dhaka city. But the areas outside the Dhaka city also contribute to the air pollutant concentrations of Dhaka. For this reason, the modeling domain covers the surrounding areas of Dhaka city, which may have impact on Dhaka city's air pollution. The major sources are identified as road dust, brick kilns and the motor vehicles. The brick kiln clusters 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 and the domain is extended in both north and south of Dhaka city.

Figure 3.1 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 3.2 presents the grid division of the model domain. This technique has a number of advantages, including easier updating of the inventory in the future. During updating, emissions in only those grids need to be updated where new sources have been added or removed. 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.

The same model domain and model grid system have been used for emission inventory and air quality modeling.

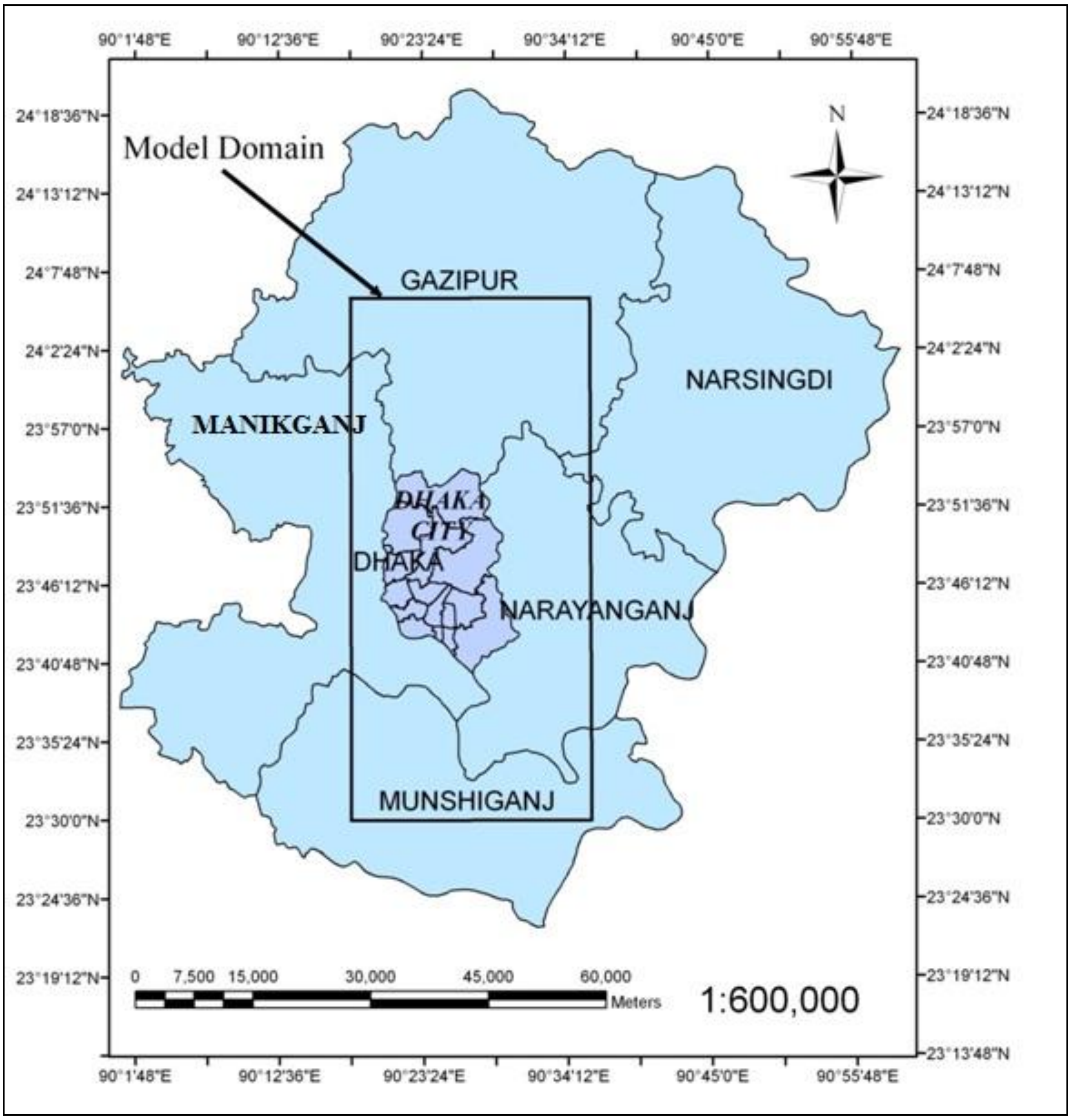


Figure 3.1: Model domain for the study

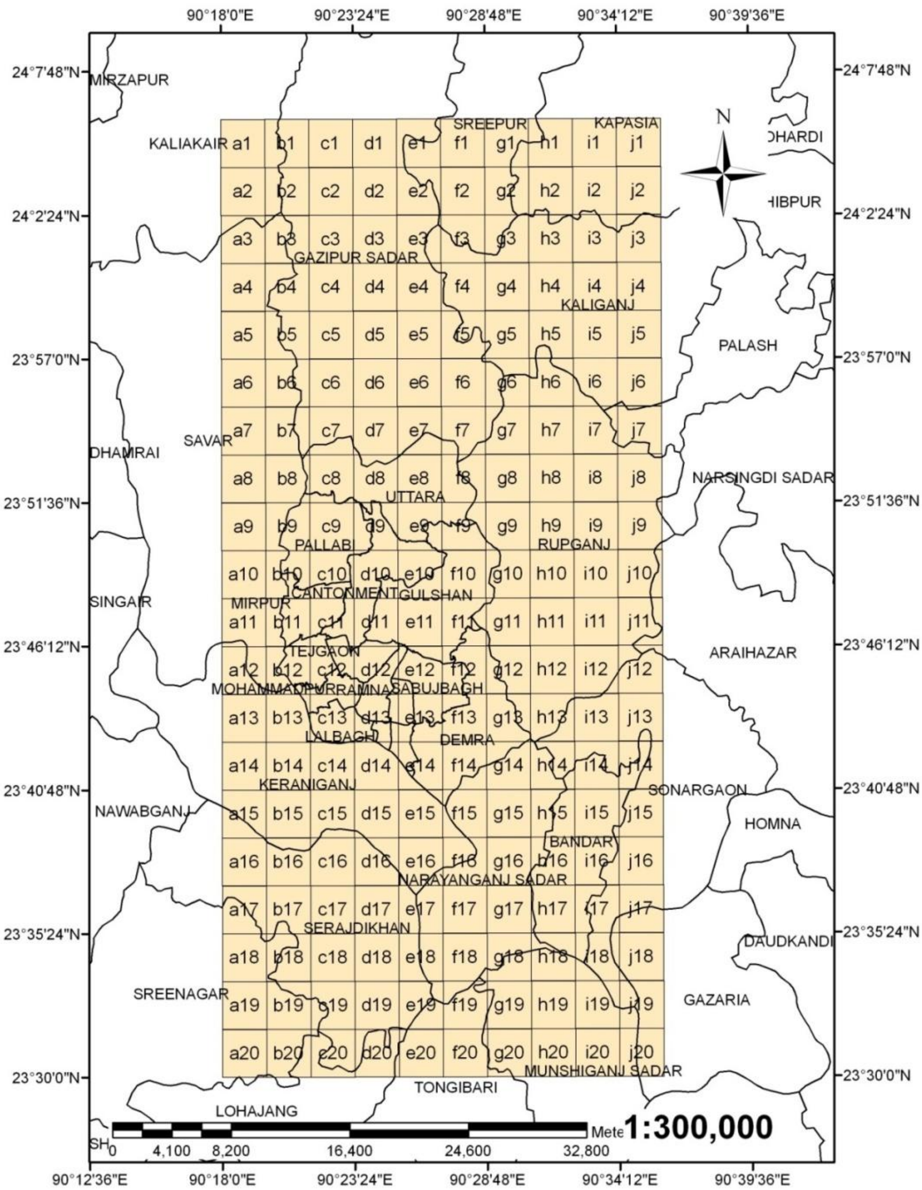


Figure 3.2: Division of the model domain into grids

3.3 SELECTION OF BASE YEAR

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 the base year, as the collected primary data is for that period.

3.4 SELECTION OF POLLUTANTS

In this study, 4 criteria pollutants have been selected for developing emission inventory. These are particulate matter (PM_{10} and $PM_{2.5}$), Carbon Monoxide (CO), Oxides of Nitrogen (NOx) and Oxides of Sulfur (SOx). Among the criteria pollutants, lead (Pb) has not been included because of lack of data, and Ozone (O_3), being a secondary pollutant, has not been considered.

3.5 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. Other emission sources have not been considered because of lack of data for the study area. Here, the locations of point sources (i.e., brick kilns) have been identified in the gridded study area by taking their GPS coordinates. For estimating vehicular emissions, the road networks within the study area have been identified in the gridded map. Emission from each of these source groups has been estimated separately and finally they have been summed up to estimate the total emission.

3.5.1 Traffic Emission

Among the many air pollution sources, the transport sector is the fastest growing contributor and one of the main culprits causing air pollution in the urban centers of the developed and developing countries (Guttikunda, 2009). The capital city of Bangladesh, Dhaka is congested with a large number of motor vehicles, including both public and private transportation. The vehicles are believed to be the main contributor of air pollution (Begum et.al., 2004). It has been reported that motor vehicles are responsible for almost 40% of total coarse particles and 55% of total fine particles (Begum et.al., 2007).

The motor vehicle emission inventory is an accounting of pollutants emitted from both on-road and off-road mobile sources. The on-road emission inventory data has two components: emissions-related data and activity-related data. The emission-related data include vehicle testing information and the latest vehicle registration data. The activity-related data include estimates of the daily vehicle miles of travel, the distribution of travel by speed, and the number of starts per vehicle per day by year. The off-road emissions inventory is an estimate of the population, activity, and emissions estimate of the varied types of off-road equipment. This study has been carried out considering only on-road emission inventory as there is no statistics to estimate off-road emissions inventory.

Traffic has been considered as an area source. This dissertation only considers road traffic. Rail and air traffic have not been considered in this study because of lack of information for estimating emission from these sources.

Based on available information on emission factors (Appendix A) and survey data for calculating traffic volume (Appendix B), the vehicular fleet has been categorized into eight groups. Table 3.1 shows the vehicle categories.

Table 3.1: Type of Transportation Modes

Serial Number	Vehicle Categories
1	Bus (Large Bus, Large Staff Bus, Large School Bus, Minibus, Mini Staff Bus & Mini School Bus)
2	Car (Micro Bus, Micro Staff Bus, Micro School Bus, Private Car, Station Wagon, Jeep)
3	Truck (Truck Trailer, Medium truck, Tanker/ tank Lorry)
4	Pick Up/Small Van
5	Taxi
6	Auto-tempo, Laguna/maxi
7	Motor Cycle
8	Auto-Rickshaw/CNG/Mishuk

Figure 3.3 shows a GIS road map of Dhaka city. In the Figure, the major roads are shown in red color and the upazila boundary in green color. This map gives better visualization of road network of the Dhaka city.

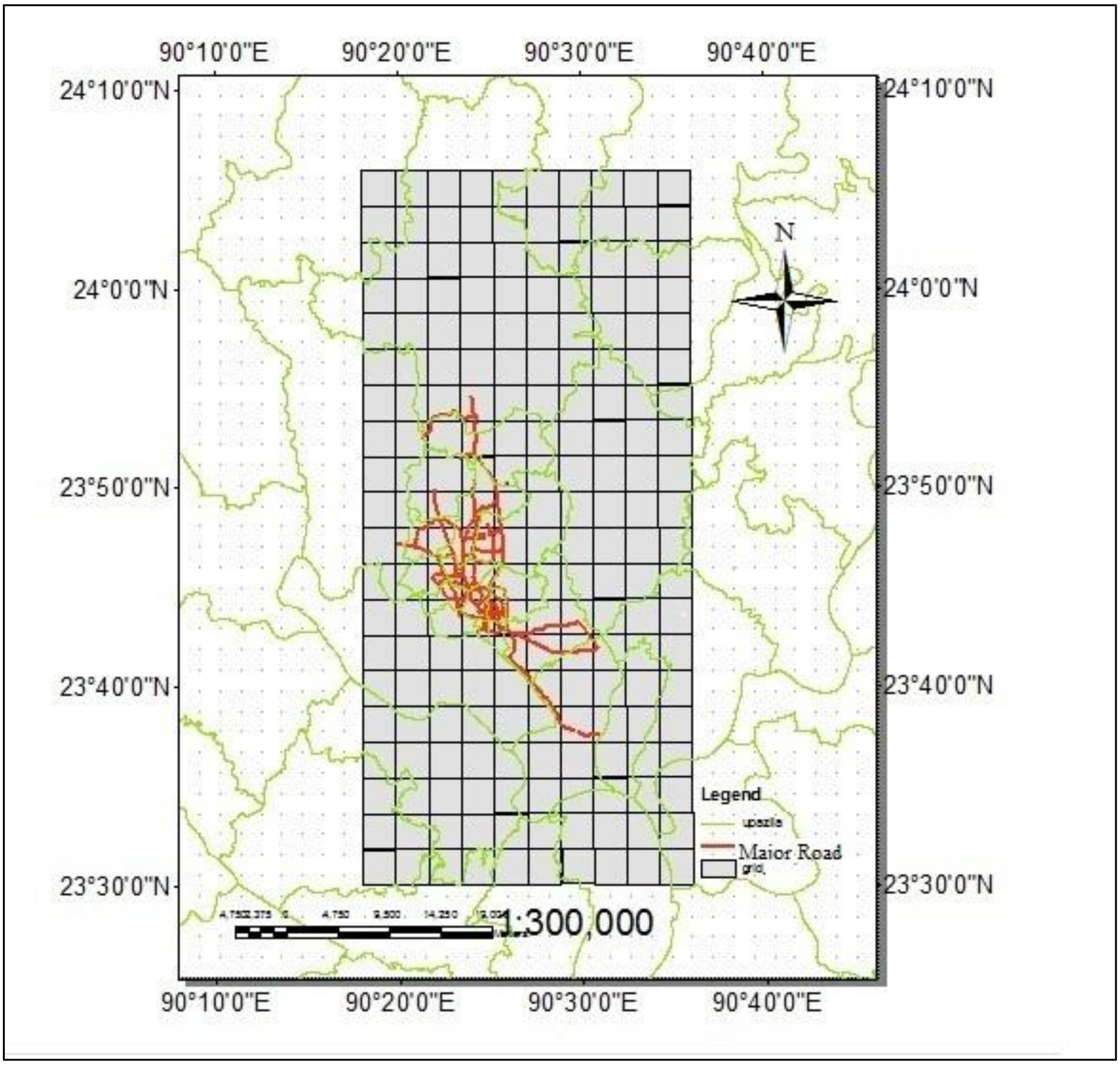


Figure 3.3: GIS Map Presenting Major Road of Dhaka City

Emission Factor and Vehicle Activity

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 (Simple Interactive Model for Better Air Quality), the World Bank, Dhaka City State of Environment (2006), VAPIS, URBAIR, CAI-Asia, Malé Declaration, where important sets of emission factors have been reported for vehicles plying on the roads of Dhaka and other cities of South Asian region. These emission factors are listed in Appendix A. Since it is difficult to assess which set of emission factor would be more appropriate in context of Bangladesh, all the reported sets of emission factors have been considered in this study. Later an uncertainty analysis has been carried out to address the large variations in reported emission factors and to get the most likely emission. For uncertainty analysis, Monte Carlo Simulation has been used. The uncertainty distribution for emission factors has been considered to be uniform distribution. The number of iteration is taken 5000 to generate the probability functions of the outcomes. In Monte Carlo analysis the 95% confidence interval of emissions factor of pollutants PM_{10}, $PM_{2.5}$, SOx, NOx, and CO were estimated.

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, which are listed in Appendix B.

To estimate traffic activity rate, we need to know the fuel usages for each category of vehicle listed in Table 3.1. In Bangladesh, both gasoline and CNG are used by vehicles of all categories except buses and trucks; while diesel and CNG are used by buses and trucks. Table 3.2 shows the percentage fuel used in each vehicle that have been considered in this study.

Table 3.2: Percentage of Fuel Usage of different Vehicle category (Arjumand, 2010)

Transport Mode	Fuel	% of Fuel Usages	% of Fuel Usages (Used in this study)
Bus	Diesel	75-85	80
	CNG	15-25	20
Car	Gasoline	20-30	25
	CNG	70-80	75
Truck	Diesel	100	100
Pick Up/Small Van	Gasoline	80-90	85
	CNG	10-20	15
Taxi	CNG	100	100
Auto-tempo, Laguna/maxi	Gasoline	80-90	85
	CNG	10-20	15
Motor Cycle	Gasoline	100	100
Auto-Rickshaw/CNG/Mishuk	Gasoline	10-20	15
	CNG	80-90	85

The reported ranges of fuel usage by different categories of vehicles have been estimated by Arjumand (2010) based on discussion with concerned people.

Grid Wise Emission Estimation from Vehicles

For vehicular sources, an emission inventory must be compiled using activity data and emission factors for a wide range of vehicle types. The following three steps have been followed to develop a gridded vehicular emission inventory.

Step 1:

The first step involves the selection of a set of emission factors, which represents the emission rate of emission per unit of activity. In Bangladesh no regular testing of vehicles is carried out to determine the emission factors and the emission factor estimates are largely subjective. Therefore, emission factors that have been used by neighboring developing countries and the factors which are declared by some organizations for Bangladesh to develop emission inventory have been used in the present study. These emission factors are reported in Appendix A.

Step 2:

The second step in the process involves the determination of an estimate of traffic activity. For this study, activity data for every grid has been calculated by multiplying road length (km) of every grid with Annual Average Daily Traffic (AADT). For this study, recent AADT data have been collected from Japan International Cooperation Agency (JICA). These AADT are reported in Appendix B. Table 3.3 represents Annual Average Daily Traffic of different Vehicle categories of Kazi Nazrul Islam Avenue. For minor road, there is no available AADT. For this study, AADT of minor road has been assumed based on number and characteristics of people i.e. financial condition, and, length and condition of road in particular grid.

In addition to estimating grid wise activity level, the road length for each grid has been calculated. In Appendix C the spatial distribution of some major roads has been given. In Figure 3.4, an example is given to understand the spatial distribution of a road.

Table 3.3: Annual Average Daily Traffic of different Vehicle categories (JICA, 2010) (Road Name: Kazi Nazrul Islam Avenue)

Vehicle Type	AADT
Large Bus	2942
Large Staff Bus	393
Large School Bus	82
Mini Bus	9018
Mini Staff Bus	229
Mini School Bus	58
Micro Bus	8471
Micro Staff Bus	566
Micro School Bus	122
Truck 3 Axle	98
Tank Lorry	108
Truck 2 Axle	2498
Car/ Station Wagon	33036
Taxi	5923
Jeep	3894
Auto-Tempo	21
Laguna /Maxi	517

Figure 3.4 shows the New Airport Road (the line in blue color) passes through five grids named D9, D10, D11, E9 and E10. The road length (both major and minor) in each grid has been calculated. The calculation has been carried out by Arc GIS software. For estimating the length of highway near the boundary of Dhaka City, Google Earth has been used. Table 3.4 shows the grid wise road length.

Table 3.4: Spatial distribution of New Airport Road

Grid Name	Length(meter)	
	Major Road	**Minor Road**
D9	2906	4729
D10	4213	13,527
D11	2979	13456
E9	2932	5032
E10	1964	1441

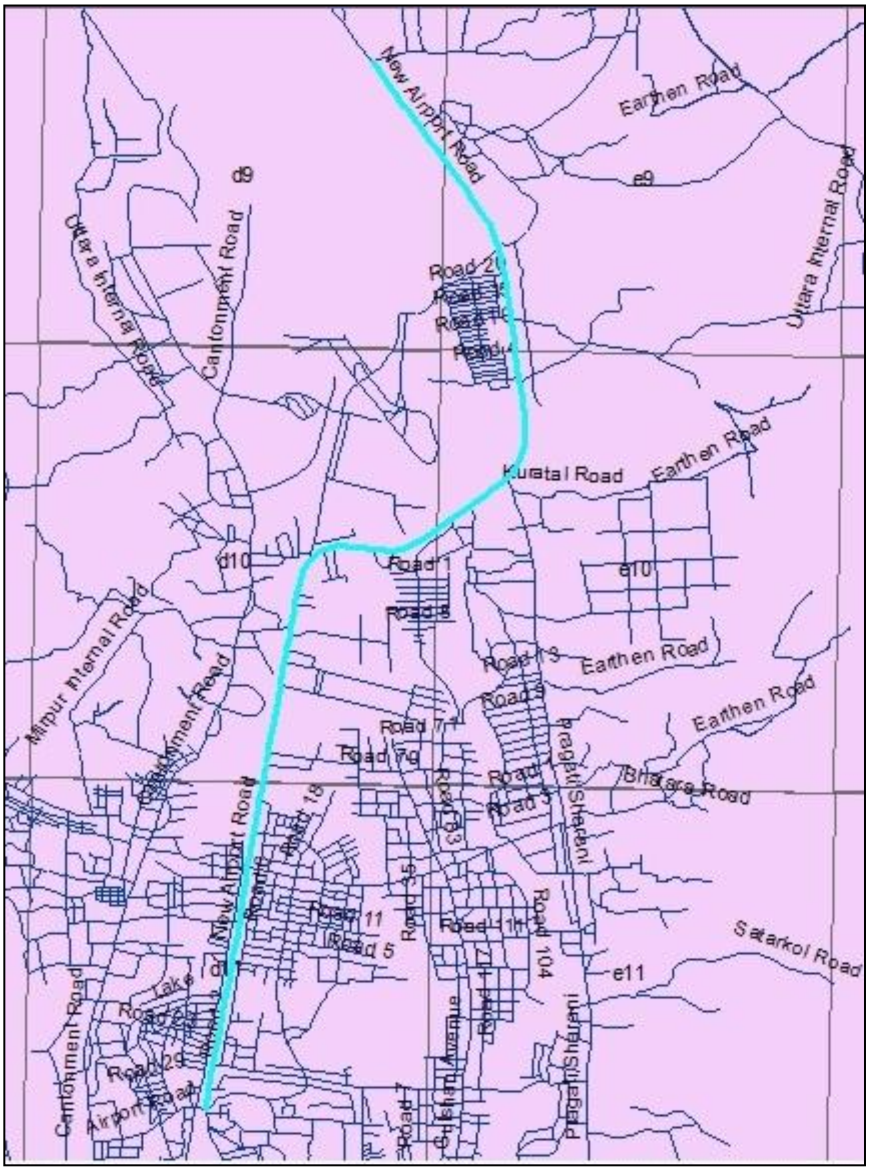


Figure 3.4: Grid wise spatial distribution of New Airport Road (Including Minor Road)

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…………………………………………………………………….(3.1)

where,

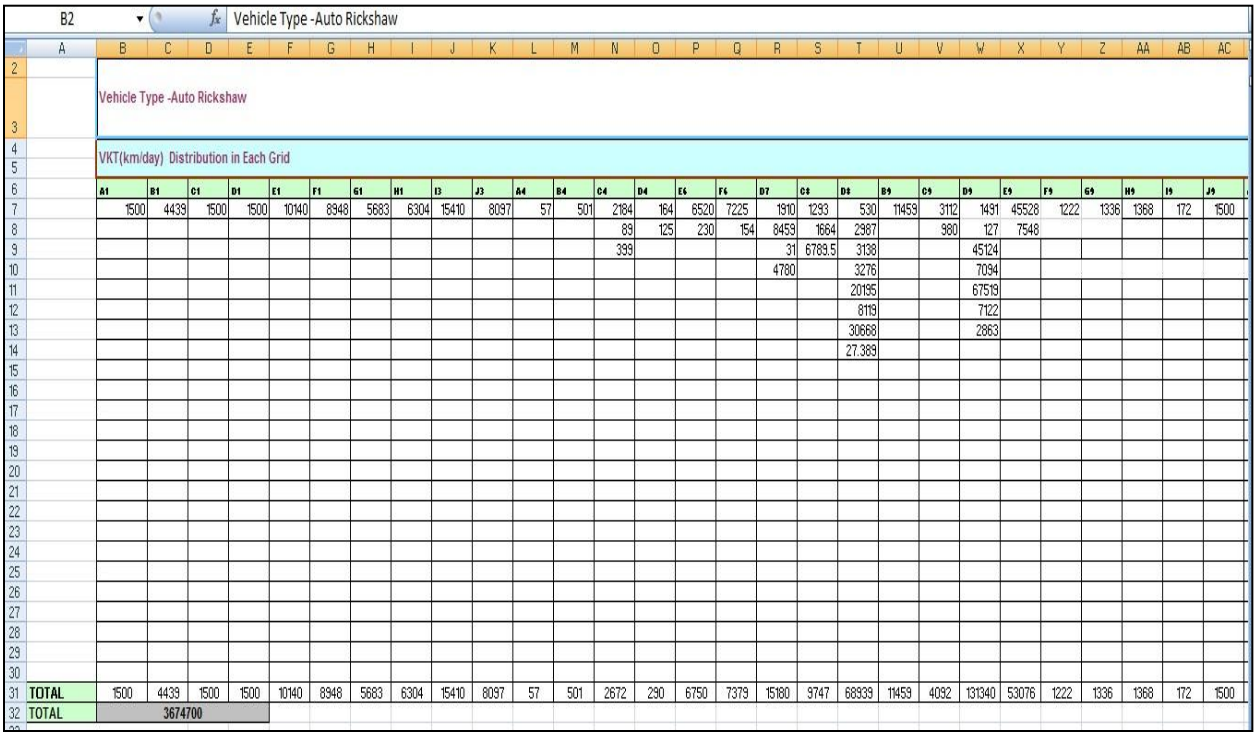
A = Activity level for each pollutant source for each grid (km/day)

VKT = Vehicle Kilometers Traveled (km/day).

L = Road length (km) in every grid

AADT = Annual Average Daily Traffic (traffic volume/day)

Since a grid can contain more than one road, so the VKT for a particular type of vehicle for a particular grid is the summation of VKT for all roads within that particular grid. After calculation of grid-wise VKT for each road, grid wise total VKT of all roads passing a particular grid should be calculated. Figure 3.5 shows an example to understand the calculation of total VKT of each grid of the study area.



	A1	B1	C1	D1	E1	F1	G1	H1	I3	J3	A4	B4	C4
7	1500	4439	1500	1500	10140	8948	5683	6304	15410	8097	57	501	2184
8													89
9													399
31 TOTAL	1500	4439	1500	1500	10140	8948	5683	6304	15410	8097	57	501	2672
32 TOTAL	3674700												

	D4	E6	F6	D7	C8	D8	B9	C9	D9	E9	F9	G9	H9	I9	J9
7	164	6520	7225	1910	1293	530	11459	3112	1491	45528	1222	1336	1368	172	1500
8	125	230	154	8459	1664	2987		980	127	7548					
9				31	6789.5	3138			45124						
10				4780		3276			7094						
11						20195			67519						
12						8119			7122						
13						30668			2863						
14						27.389									
31 TOTAL	290	6750	7379	15180	9747	68939	11459	4092	131340	53076	1222	1336	1368	172	1500

Figure 3.5: Snap shot of worksheets of estimation Grid wise VKT of Auto-rickshaw (km/day).

The total activity for a particular type of vehicle for the entire study area is the summation of activity of all grids of the study area (i.e., grid A1 to grid J20).

Step 3:

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 $E_i = \sum_j \sum_k [EF_{ijk} \quad *A_{jk}]$……………………………………………………(3.2)

where,

i = Type of a pollutant like PM_{10}

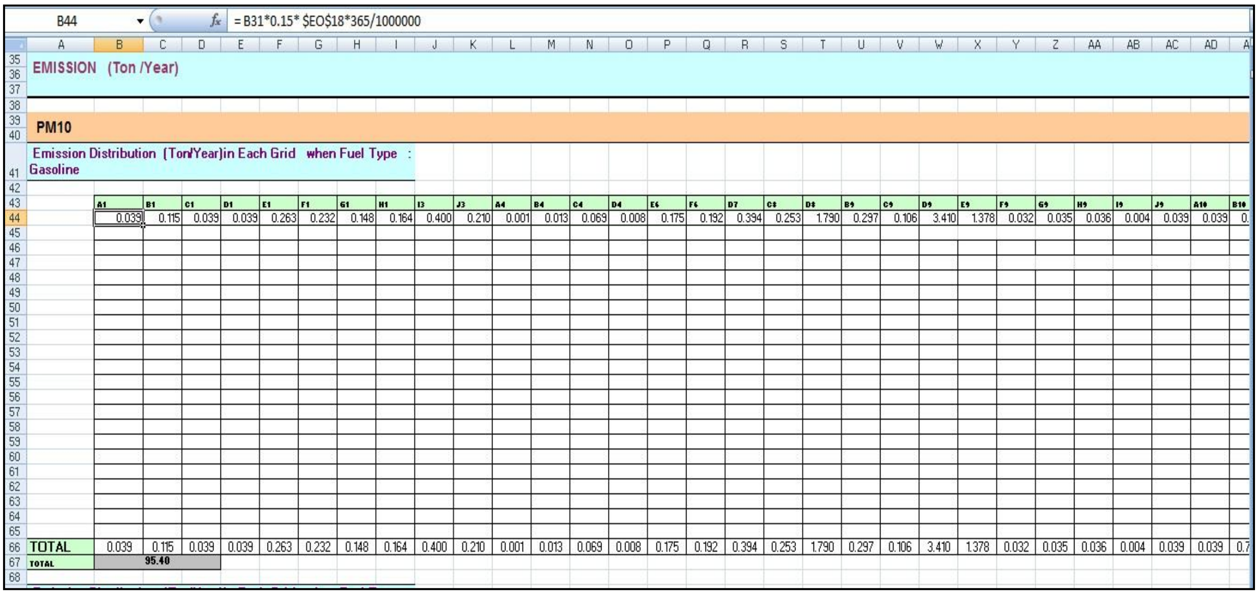
j = Fuel usages like CNG, Gasoline

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.


B44 = B31*0.15* EO18*365/1000000

EMISSION (Ton /Year)

PM10

Emission Distribution (Ton/Year)in Each Grid when Fuel Type : Gasoline

	A1	B1	C1	D1	E1	F1	G1	H1	I3	J3	A4	B4	C4	D4	E6
44	0.039	0.115	0.039	0.039	0.263	0.232	0.148	0.164	0.400	0.210	0.001	0.013	0.069	0.008	0.175
TOTAL	0.039	0.115	0.039	0.039	0.263	0.232	0.148	0.164	0.400	0.210	0.001	0.013	0.069	0.008	0.175

	F6	D7	C8	D8	B9	C9	D9	E9	F9	G9	H9	I9	J9	A10	B10
44	0.192	0.394	0.253	1.790	0.297	0.106	3.410	1.378	0.032	0.035	0.036	0.004	0.039	0.039	0.
TOTAL	0.192	0.394	0.253	1.790	0.297	0.106	3.410	1.378	0.032	0.035	0.036	0.004	0.039	0.039	0.7

TOTAL 95.40

Figure 3.6: Snap shot of spreadsheet of estimation of emission of auto rickshaw for each grid (ton/year) where fuel type is gasoline and pollutant type is PM_{10}

Figure 3.6 provides an example of estimation of emission for a grid. It shows a part of the worksheet used for estimation of grid wise emission (ton/year) from Auto rickshaw. Here the calculation of PM_{10} (ton/year) emission from grid A1 has been shown, where fuel type is Gasoline; emission factor is taken from uncertainty analysis and fuel usage is 15% (i.e., 15% of vehicles use gasoline).

3.5.2 Road Dust

Road Dust has been considered as an area source of PM emission. 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 formula.

$$\text{Emission} = \text{VKT} \times \text{Emission Factor E for PM10} \times \text{\% of Paved Traffic} \quad \ldots\ldots\ldots\ldots\ldots(3.4)$$

Emission factor E for PM_{10} can be estimated using the following empirical expression prescribed by USEPA at AP-42, Section 13.2.1.

$$E=(k*(sL/2)^{0.65}*(W/3)^{1.5})-C)*(1-P/4N) \quad \text{..}(3.3)$$

where,

E=PM_{10} 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}

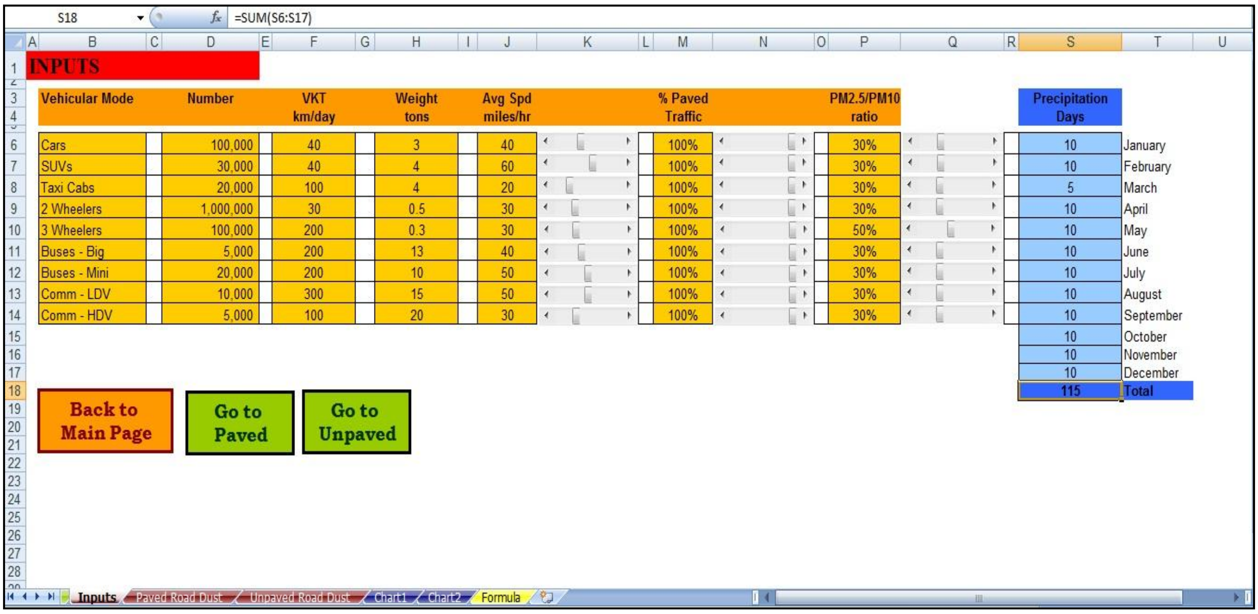
W=average weight (tons) of each type of vehicles on the road

P= number of wet days with precipitation > 0.01 in or 0.254mm

N=number of days in averaging period = 30 and 365 for monthly and yearly analysis respectively.

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. For calculation of emission from road dust, the software generated by Dr. Sarath Guttikunda of SIM-Air (www.sim-air.org) named *Vehicular Fugitive Dust Calculator version 1.01* has been used.

Figures 3.7 and 3.8 show the snapshot of calculating the emission from road dust using *Vehicular Fugitive Dust Calculator version 1.01*.


INPUTS

Vehicular Mode	Number	VKT km/day	Weight tons	Avg Spd miles/hr	% Paved Traffic	PM2.5/PM10 ratio	Precipitation Days	
Cars	100,000	40	3	40	100%	30%	10	January
SUVs	30,000	40	4	60	100%	30%	10	February
Taxi Cabs	20,000	100	4	20	100%	30%	5	March
2 Wheelers	1,000,000	30	0.5	30	100%	30%	10	April
3 Wheelers	100,000	200	0.3	30	100%	50%	10	May
Buses - Big	5,000	200	13	40	100%	30%	10	June
Buses - Mini	20,000	200	10	50	100%	30%	10	July
Comm - LDV	10,000	300	15	50	100%	30%	10	August
Comm - HDV	5,000	100	20	30	100%	30%	10	September
							10	October
							10	November
							10	December
							115	Total

Figure 3.7: Inputs of Vehicular Fugitive Calculator for Emission

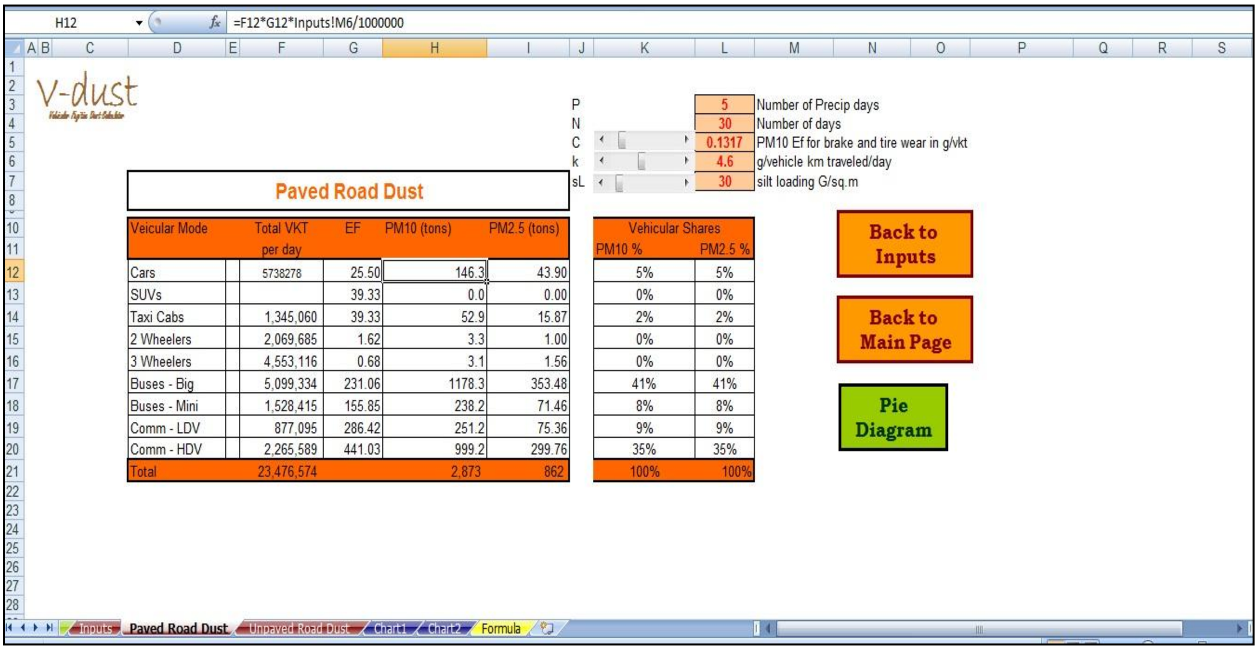


Figure 3.8: Emission from road dust for March

3.5.3 Brick kiln emission

There are many industries located in and around the Dhaka city. Air pollution is dominated by a limited number of industries, e.g., cement industry, and brick fields, paper mills, steel mills, fertilizer factories. Most of the brick fields around Dhaka city are situated at Gazipur, Savar, Kaliganj,Rupganj,Narayanganj and Serajdikhan.

It is difficult to estimate the emissions from different types of other industries within and around Dhaka city, including many small-scale industries because of lack of information on location, raw material and production data, and other information for estimation of emission factor. Therefore, only brick kiln has been considered in this study as industrial point source.

The brick kiln emission inventory for $PM_{2.5}$ and PM_{10} 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 kilns are shown in Figure 3.9.

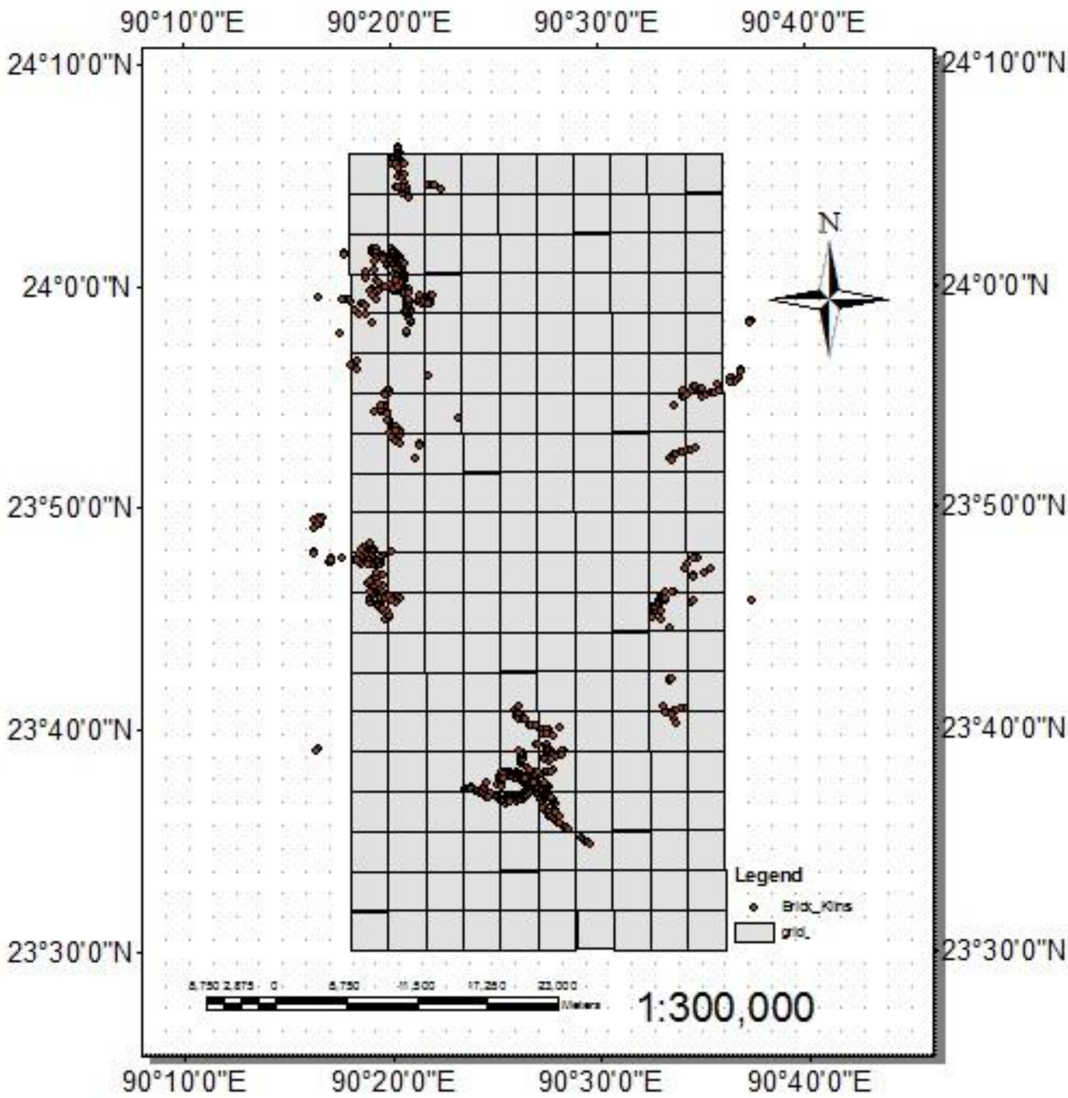


Figure 3.9: Location of Brick Kiln

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

$$Emission_i = EF_i \times AL \times N \quad \ldots\ldots(3.5)$$

where,

i = Type of a pollutant, e.g., PM_{10}

N=Number of brick kilns in every grid

EF = Emission Factor for each pollutant

AL =Duration of brick manufacture

However, we recognize that it is important to identify the other types of industries within and around Dhaka city and quantify emission from these sources.

3.6 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. The model has been described briefly in this Section. Additional details have been reported in Rahman (2010).

Source Receptor (S-R) Matrix

The Source-Receptor (S-R) model generates the relationship between the source of emission and the receptor (person, building etc.). S-R model 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). S-R relationship is an important concept in air quality modeling. It describes the sensitivity of a “receptor” element y to a “source” x. The receptor could be, for example, the average concentration of a certain atmospheric trace substance in a given grid cell during a given time interval. It could also be a deposition value, and instead of a grid volume average it could be the value at a measurement station. The source could be a point, area or volume source acting during a specified time interval in a specific location (Peng et al., 2002). The S-R matrix, also known as transfer coefficient/matrix, plays a important role in calculation of ambient air concentration provided emission loads are given and vice-versa.

A typical air quality (AQ) model for a single source can be defined as the product of total emissions and transfer coefficients:

$$C = mQ \quad \text{……(3.6)}$$

where,

C = ambient concentration of pollutant,

m = constant,

Q = total emissions

In equation 3.6, *m* is the transfer coefficient and depends on model domain, source type, pollutant types and meteorological parameters (which include wind speed and direction, precipitation, maximum mixing depth, atmospheric stability, etc.).

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 of a certain portion of that domain, the concentration can be obtained using equation 3.7.

$$C_j = \sum_i m_{ij} Q_i \quad (3.7)$$

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*.

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

$$C = MQ \quad (3.8)$$

Where,

C = Concentration vector

M = Source-Receptor Matrix (SRM)

Q = Emission vector

Mathematically, the source-receptor relationship m_{ij} is defined as

$$m_{ij} = \frac{\partial c_j}{\partial q_i} \quad (3.9)$$

where,

q = source emission occupying a certain three-dimensional space and time interval

c = receptor concentration

In a linear source-receptor relationship, which is characterized by steady state condition, m_{ij} can be referred 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}.

$$m_{ij} = \frac{c_j}{q_i} \quad (3.10)$$

To generate the SRM an air quality model is required. A grid-based simulation model is run with a base case and concentrations in each cell are checked. 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. The important factor that governs the generation of transfer matrix is the meteorological data (such as wind speed, class, direction, etc.). Thus one SRM does not fit all of the conditions. Hence, the SRM should be generated for each city using the local meteorological condition. In this study, ATMoS-4.0 model has been used.

Description of ATMoS-4.0 model

The dispersion model used for the generatin of the S-R matrix is ATMoS-4.0. This is a modified version of The Atmospheric Transport Modeling System (ATMoS), which 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). ATMoS is a three dimensional multi-layered Lagrangian model capable of estimating ambient concentrations at urban scale. The software developed and distributed by the International Institute of Applied Systems Analysis (IIASA), Laxenburg, Austria was later updated to support PM and Nitrate pollution. This is a software package developed to trace the causes and consequences of air pollution across 23 countries and 94 sub-regions in Asia (Shah et al., 2000).

Though the ATMoS-4.0 model is the modified form of the original format of ATMoS, it keeps the physical and chemical mechanisms intact to predict the pollutant deposition and concentrations at urban scale. Figure 3.10 shows a schematic of the input and output of the ATMoS-4.0. 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.

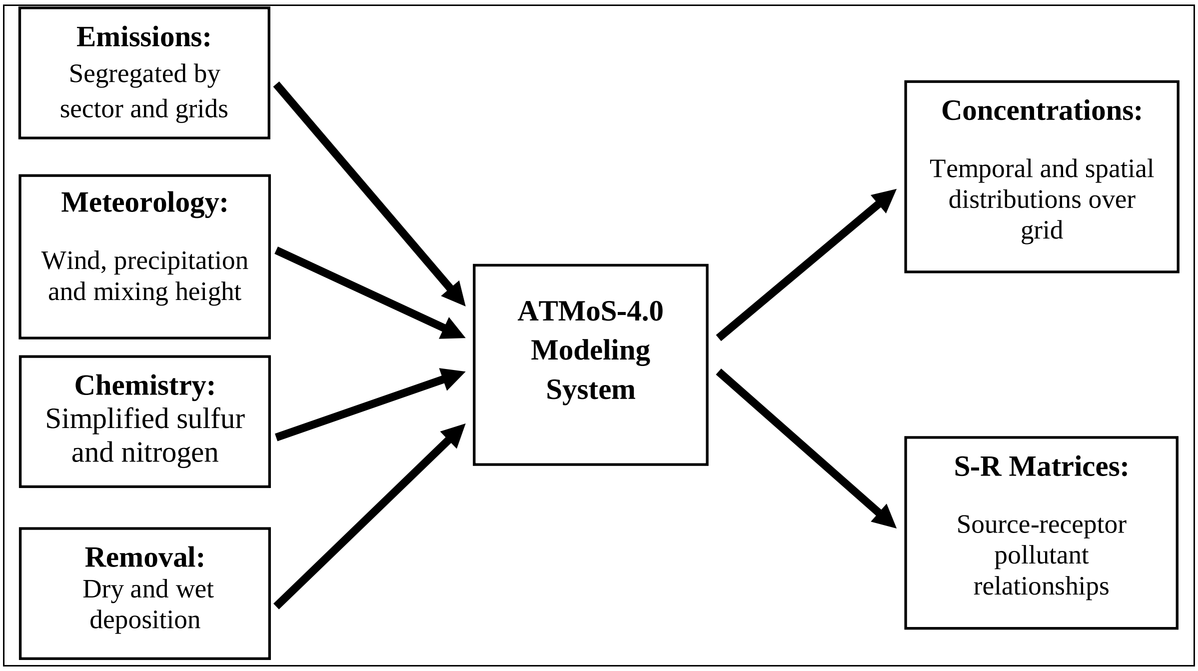


Figure 3.10: Input and output schematics of ATMoS-4.0 (Guttikunda and Calori, 2009)

Multi-pollutant processing of Model

The PM pollution, which is critical for the urban areas, is a result of contributions of multiple sources and multiple pollutants. The ATMoS model allows for multi-pollutant analysis for PM in which each of the primary emissions are modeled separately and aggregated at the end. This includes conversion of SO_2 to sulfates and NO_x to nitrates. This model does not include black carbon and organic carbon. The chemical transformation to sulfates and nitrates is simplified using linear reactions. The reactions are considered to follow the first order reaction, thus only parameter related to chemical transformation is the reaction rate. No chemical transformation is applied to direct PM emissions.

Modeling each of the sub-fractions (i.e., conversion of SO_2 to sulfates, NO_x to nitrates etc.) is very important due to the differences in physical and chemical differences in PM_{10} and $PM_{2.5}$. In the model, besides the sub-fractions, the direct PM emissions are also simulated in two bins – distinguished as PM with aerodynamic diameters between 2.5 and 10 micron meters (the ‘coarse fraction’) and particles between 0 and 2.5 micron meters (the ‘fine fraction’). At the end of the simulations, the total PM_{10} concentrations comprise of all the sub-fractions (PM_{coarse}+PM_{fine}+SO_4+NO_3) while the total $PM_{2.5}$ comprise of the finer sub-fractions (PM_{fine}+SO_4+NO_3), thus providing a multi-pollutant aspect to the PM pollution.

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 meteorological input file consists of wind vector (wind speed and direction), precipitation and mixing height. 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).

3.7 SUMMARY

This Chapter presents the approach and methodologies followed in the present study. The grid-based emission inventory developed in this study has been used for the generation of ambient concentration (PM_{10}, $PM_{2.5}$) 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 inventory developed in this study. The next two Chapters (Chapter 4 and Chapter 5) present the results of the study. Chapter 4 illustrates the emission inventory for the study area. Chapter 5 presents spatial and temporal distribution of particulate matter concentration in study area due traffic emission, road dust and brick kiln emission.

CHAPTER FOUR: DEVELOMENT OF EMISSION INVENTORY

4.1 INTRODUCTION

A reliable emission inventory is a prerequisite for air quality modeling and for development of policy options for managing air pollution and its adverse impacts. For development of grid based emission inventory for Dhaka City and its surroundings, emission from three major sources i.e. vehicle, brick kiln and re-suspended road dust have been considered. It should be noted that none of the previous studies on emission inventory have considered re-suspended road dust, which is a major source for PM not only for Dhaka, but also for most major cities of the world. The methodology for developing the emission inventory is described in Chapter Three. This Chapter presents detailed results found from the present study. Section 4.2 presents GIS maps showing spatial distribution of the emission of the selected pollutants, including PM_{10}, $PM_{2.5}$, CO, NOx, and SOx due to the three major sources within the study domain for both dry and wet seasons, tabular value of total emission, and comparison among different studies on vehicular emission inventory. Section 4.3 presents emissions from different categories of vehicles. Finally, Section 4.4 summarizes the major findings regarding the emission inventory.

4.2 EMISSION INVENTORY

In Section 3.5 of Chapter Three, the method to develop the grid based emission inventory for the study area has been described. This section graphically presents the grid-based emission inventory for the study area utilizing Arc GIS software. As noted in Chapter 3, since the brick kilns are operated only during the dry months of the year (November to mid-April), the emission inventory for the selected pollutants was developed on a monthly basis. Figure 4.1 to Figure 4.8 and Figure 4.9 to Figure 4.12 represent the GIS maps of spatial distributions of the pollutants PM_{10}, $PM_{2.5}$, SOx, and NOx of a dry month (March) and a wet month (August) of the year, respectively. Since the emission due to traffic has been considered same for all months of the year, the traffic emissions for both dry and wet seasons are identical; traffic emission inventory for only a dry month is therefore presented here. Emissions for other months are listed in Appendix D.

Figure 4.1 shows the distribution of PM_{10} emission due to traffic for a month (March) during the dry season in different grids of study domain. The darker colors indicate grids with higher PM_{10} emission. Scale in the map presents the value range of each color. From the map it is clear that PM_{10} emission is higher for the grids with the major roads and intersection; these include the grids D8, D9, D10, D11, C12, D12, F13, G14, etc. These grids are located in Uttara, Cantonment, Tejgaon, Gulshan , Mirpur and Dhanmondi.

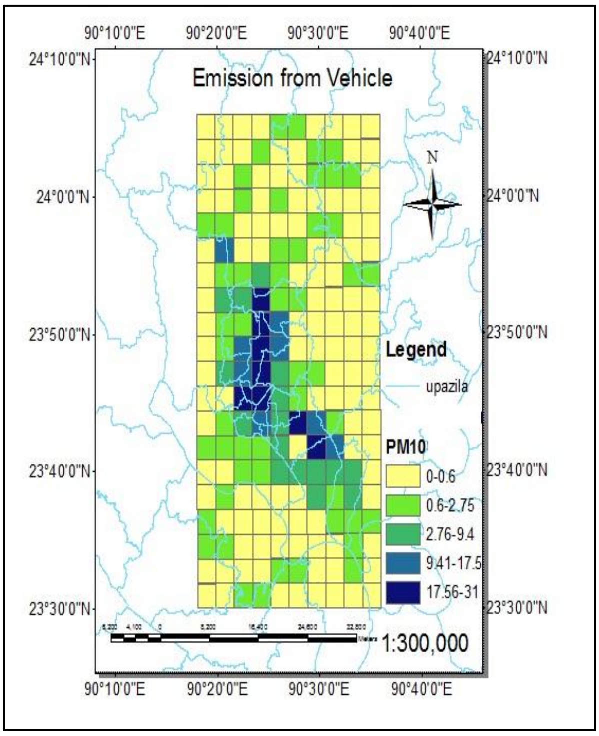


Figure 4.1: Spatial Distribution of PM_{10} emission in ton due to traffic for March (Dry Season)

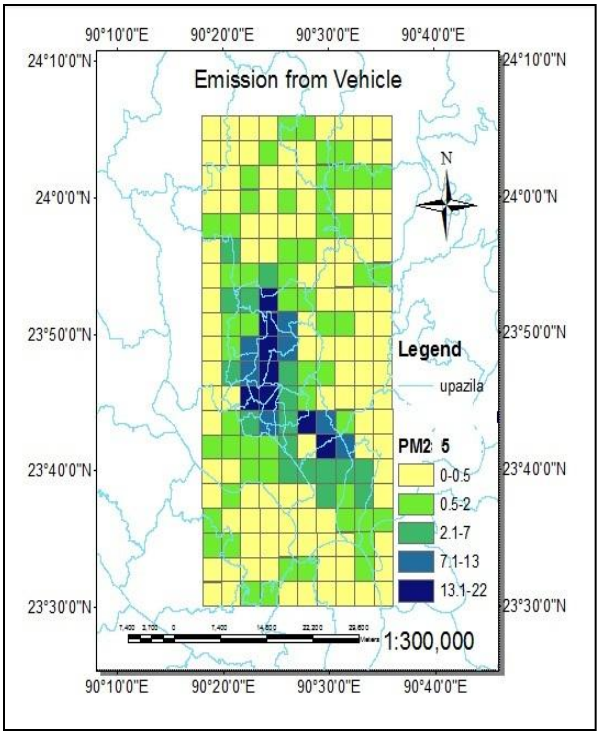


Figure 4.2: Spatial Distribution of $PM_{2.5}$ emission in ton due to traffic for March (Dry Season)

Figure 4.2 shows the distribution of $PM_{2.5}$ emission in different grids of study domain. Like PM_{10}, higher $PM_{2.5}$ emissions occur in Uttara, Cantonment, Tejgaon, Gulshan, Mirpur and Dhanmondi.

Figure 4.3 shows the distribution of SOx emission in different grids of study domain. Here, the darker colors indicate grids with higher SOx emission and the lighter color indicates grids with lower SOx emission. SOx emission is high in D8, D9.D10, D11, F12 and G13 which include Demra, Uttara, Cantonment, Tejgaon, Gulshan, Mirpur and Dhanmondi.

Figure 4.4 shows the distribution of NOx emission in different grids of study domain. It shows a pattern similar to that of SOx.

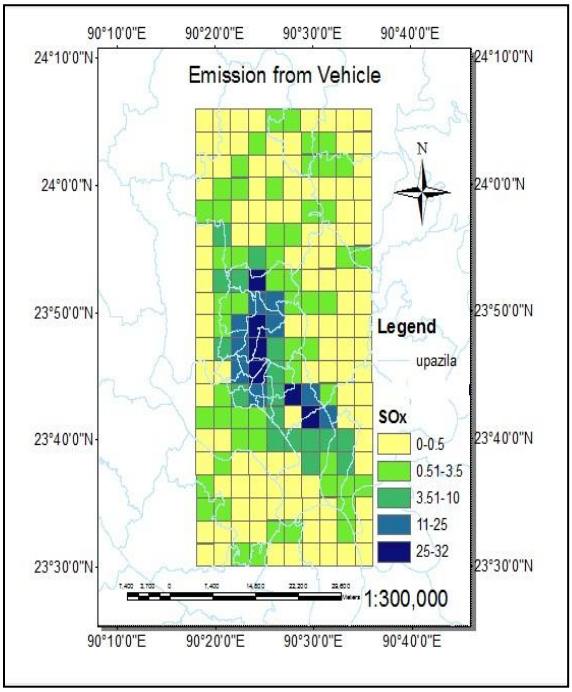


Figure 4.3: Spatial Distribution of SOx emission in ton due to traffic for March (Dry Season)

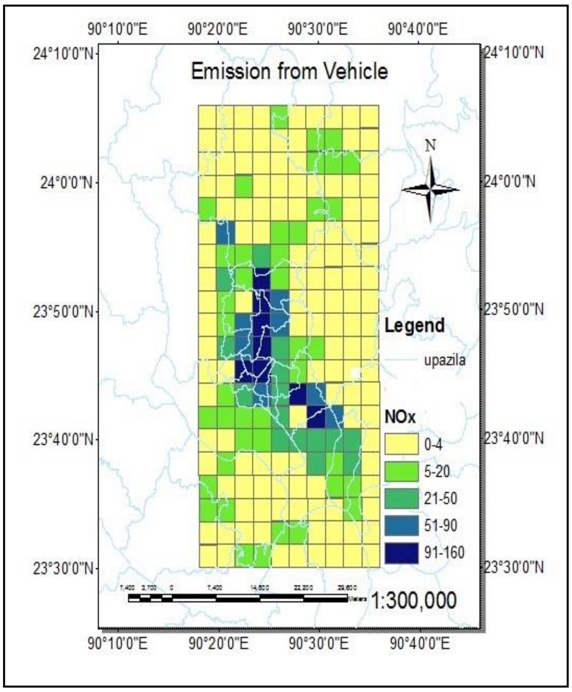


Figure 4.4: Spatial Distribution of NOx emission in ton due to traffic for March (Dry Season)

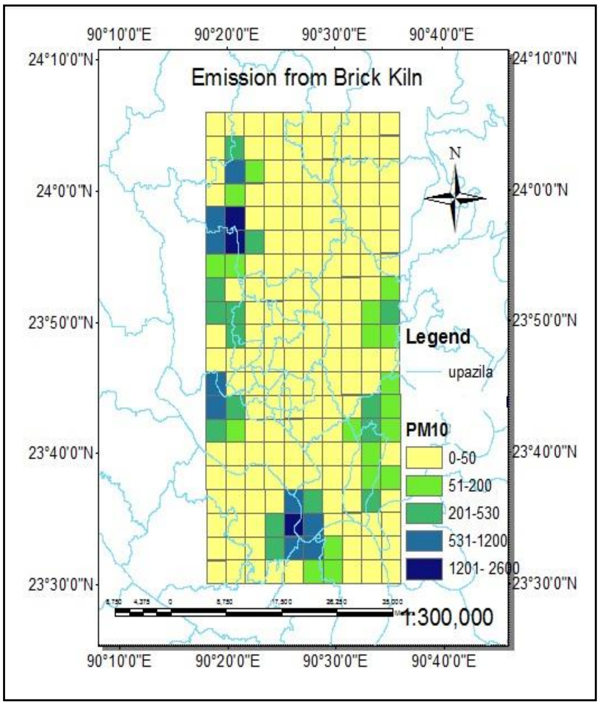


Figure 4.5: Spatial Distribution of PM_{10} emission in ton due to brick kiln for March (Dry Season)

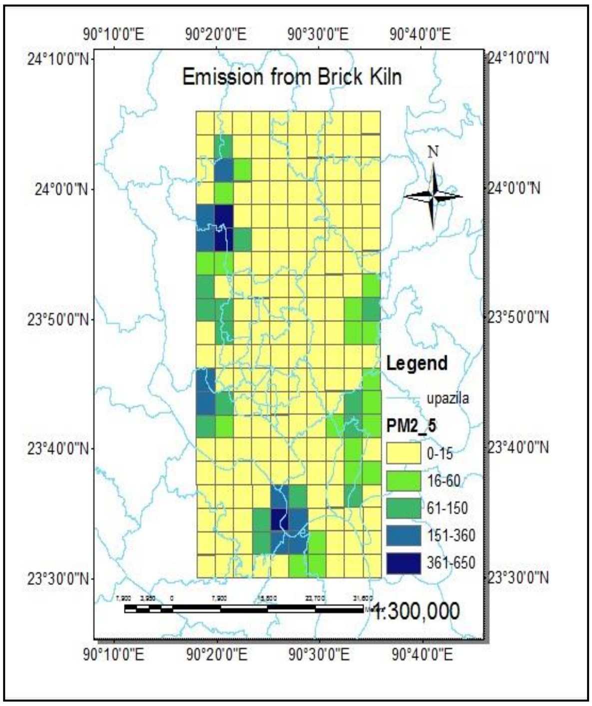


Figure 4.6: Spatial Distribution of $PM_{2.5}$ emission in ton due to brick kiln for March (Dry Season)

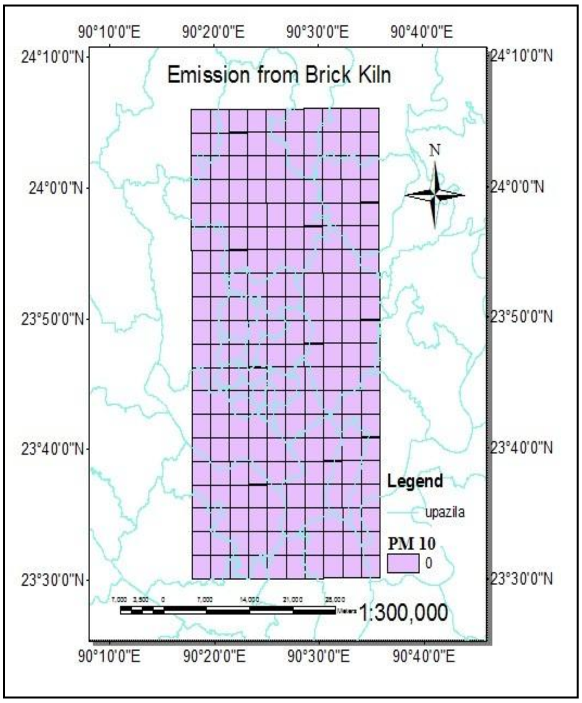


Figure 4.7: Spatial Distribution of PM_{10} emission in ton due to brick kiln for August (Wet Season)

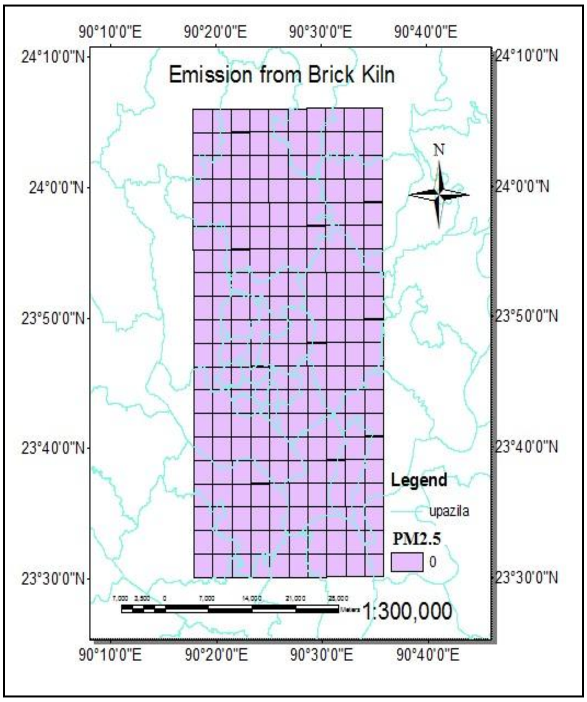


Figure 4.8: Spatial Distribution of $PM_{2.5}$ emission in ton due to brick kiln for August (Wet Season)

Figure 4.5 and Figure 4.6 present distribution of PM_{10} and $PM_{2.5}$ emission for dry season, respectively from brick kilns. It is seen that brick kiln emissions take place outside the main city, but the emission load is very high in comparison to the traffic emissions. The north-western and western parts of Dhaka (representing Savar, Gazipur and Dhamrai areas) account for a large portion of brick kiln emissions during the dry season. Brick kilns located to the eastern periphery of the city (Kaliganj and Rupganj) and to the south of the city (Narayanganj, bandar and Sirajdikhan) are also responsible for some emission. It should be noted that the brick kilns are not operated during the wet season (mid-April to October), and hence no emissions take place from brick kilns during this period (Figures 4.7 and 4.8).

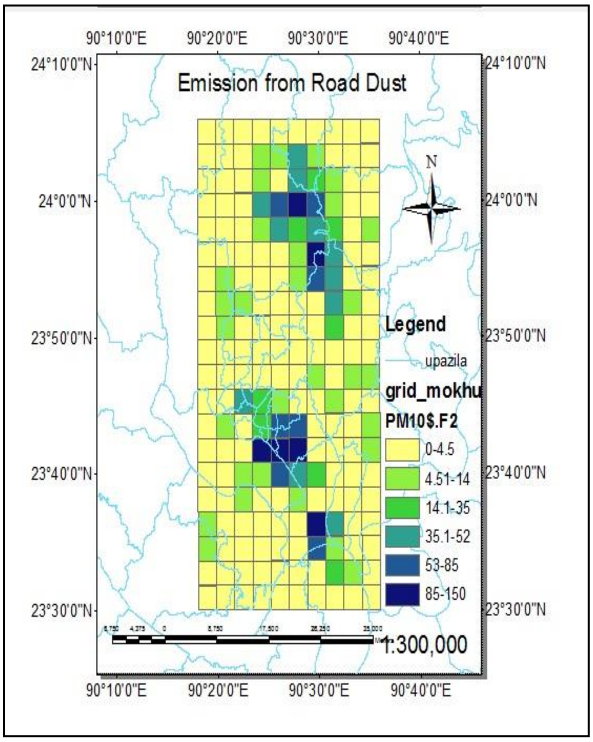


Figure 4.9: Spatial Distribution of PM_{10} emission in ton due to road dust for March (Dry Season)

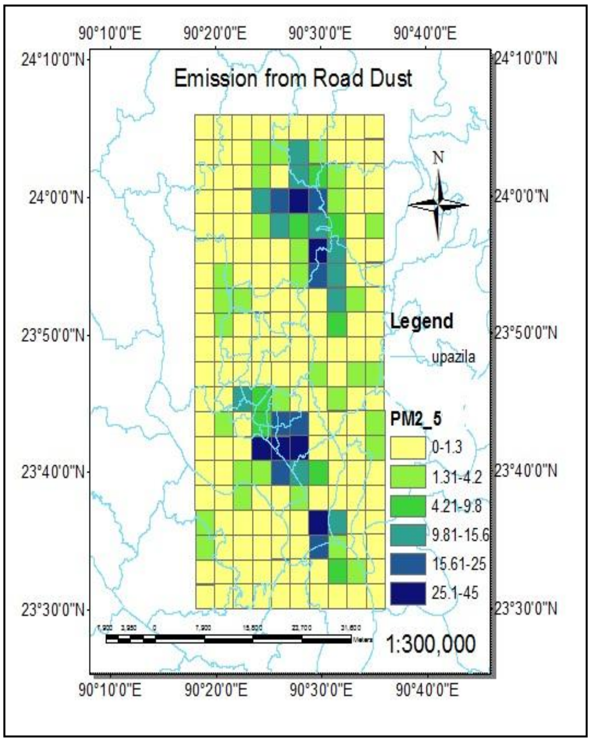


Figure 4.10: Spatial Distribution of $PM_{2.5}$ emission in ton due to road dust for March (Dry Season)

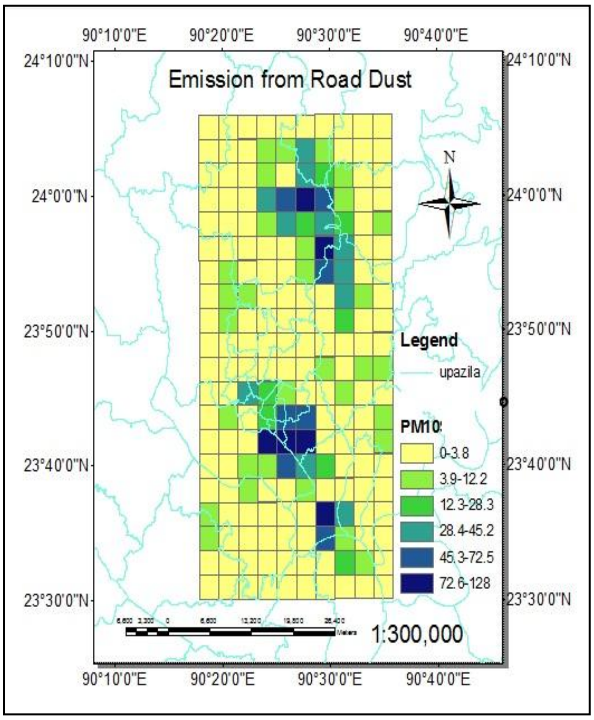


Figure 4.11: Spatial Distribution of PM_{10} emission in ton due to road dust for August (Wet Season)

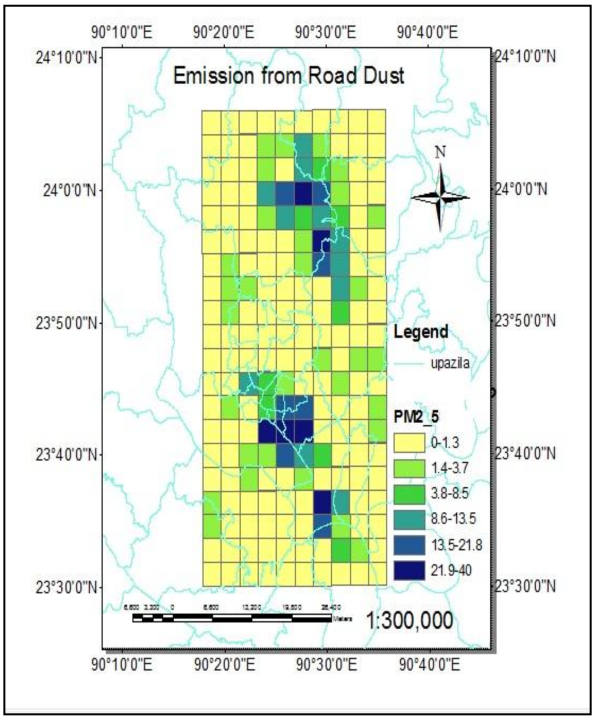


Figure 4.12: Spatial Distribution of $PM_{2.5}$ emission in ton due to road dust for August (Wet Season)

Figure 4.9 and Figure 4.10 present spatial distribution of PM_{10} and $PM_{2.5}$ emission due to road dust. As expected, both PM_{10} and $PM_{2.5}$ emissions from road dust are higher in grids containing major roads (e.g., grids E4, F4, G4, G6, G7, E13, F13, D14, E14, F15, G17 and G 18) in Uttara, Demra, Keraniganj, Sobujbag, etc.

Figure 4.11 and Figure 4.12 present spatial distribution of PM_{10} and $PM_{2.5}$ emission due to road dust for a month (August) during the wet season. The figures show similar pattern of emission during the wet season, but in lesser magnitude (compared to dry season) due to the effect of rain (precipitation).

Total PM_{10} and $PM_{2.5}$ Emission

Among the three major sources considered, only emission from brick kiln varies seasonally since brick kilns operate during November to mid-April. Hence total PM emissions have been calculated on a monthly basis, and also on a seasonal basis (i.e., dry season spanning from November to mid-April, and wet season covering the rest of the year).Figures 4.13 and 4.14 show the spatial distribution of total PM_{10} and $PM_{2.5}$ emissions (ton), respectively during the dry season (November to 15 April). During this time bricks are manufactured. So the emissions are larger for the grids where the brick kilns are located. From the present study, it is found that during dry season emissions of particulate matter (PM) from brick kilns are higher than those from vehicles and road dust. On the other, during wet season when brick kiln operation is closed, and there is precipitation, PM emission come primarily from vehicular source. The spatial distributions of PM_{10} and $PM_{2.5}$ emissions during wet season are presented in Figure 4.15 and 4.16, respectively. Table 4.1 shows total emissions from different sources during the dry season and wet season. It shows that emissions during dry season are much higher than in wet season. Section 4.3 describes distribution of emission from different sources.

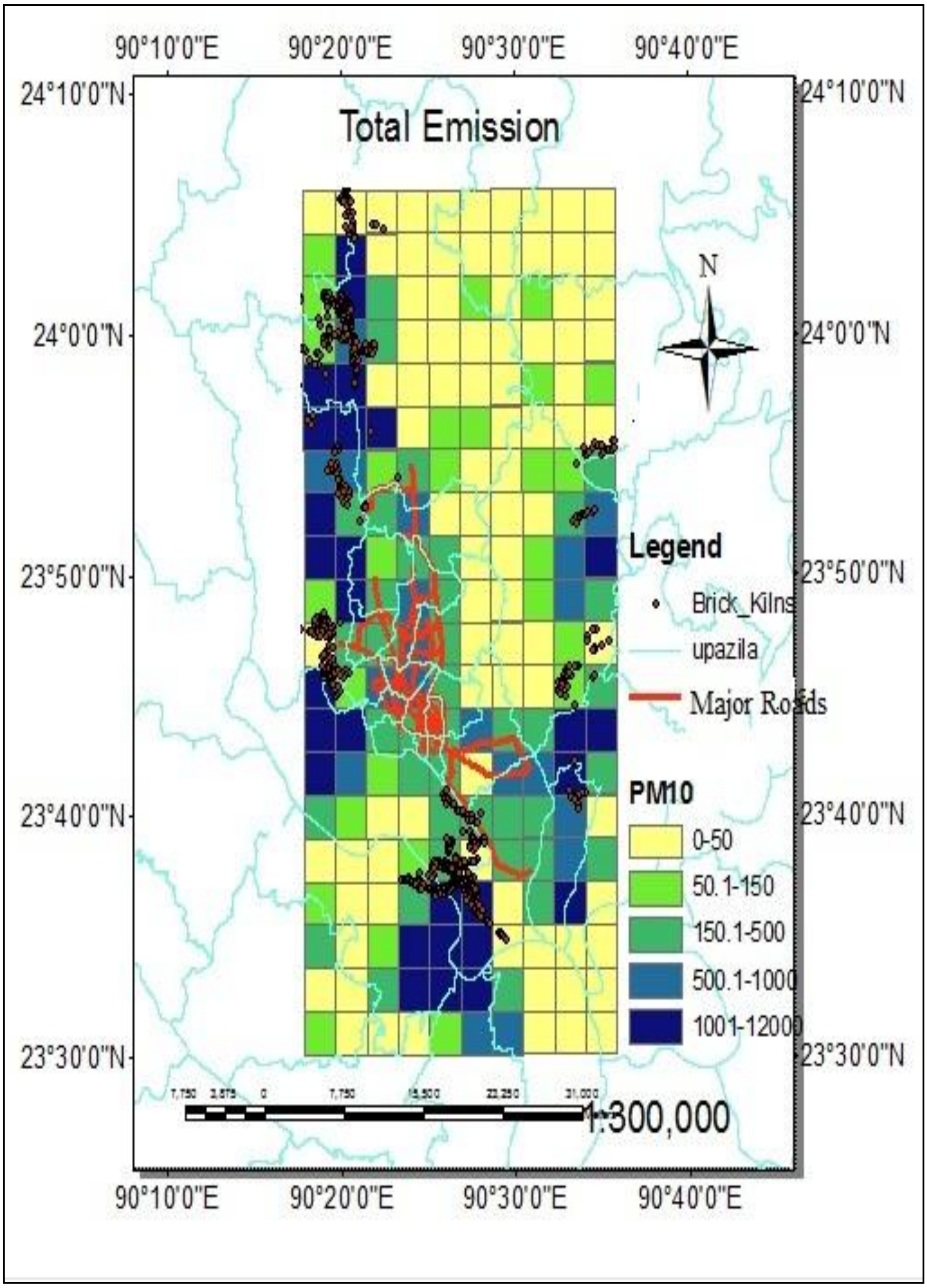


Figure 4.13: Spatial distribution of total PM_{10} emission (ton) for dry season (November to 15 April)

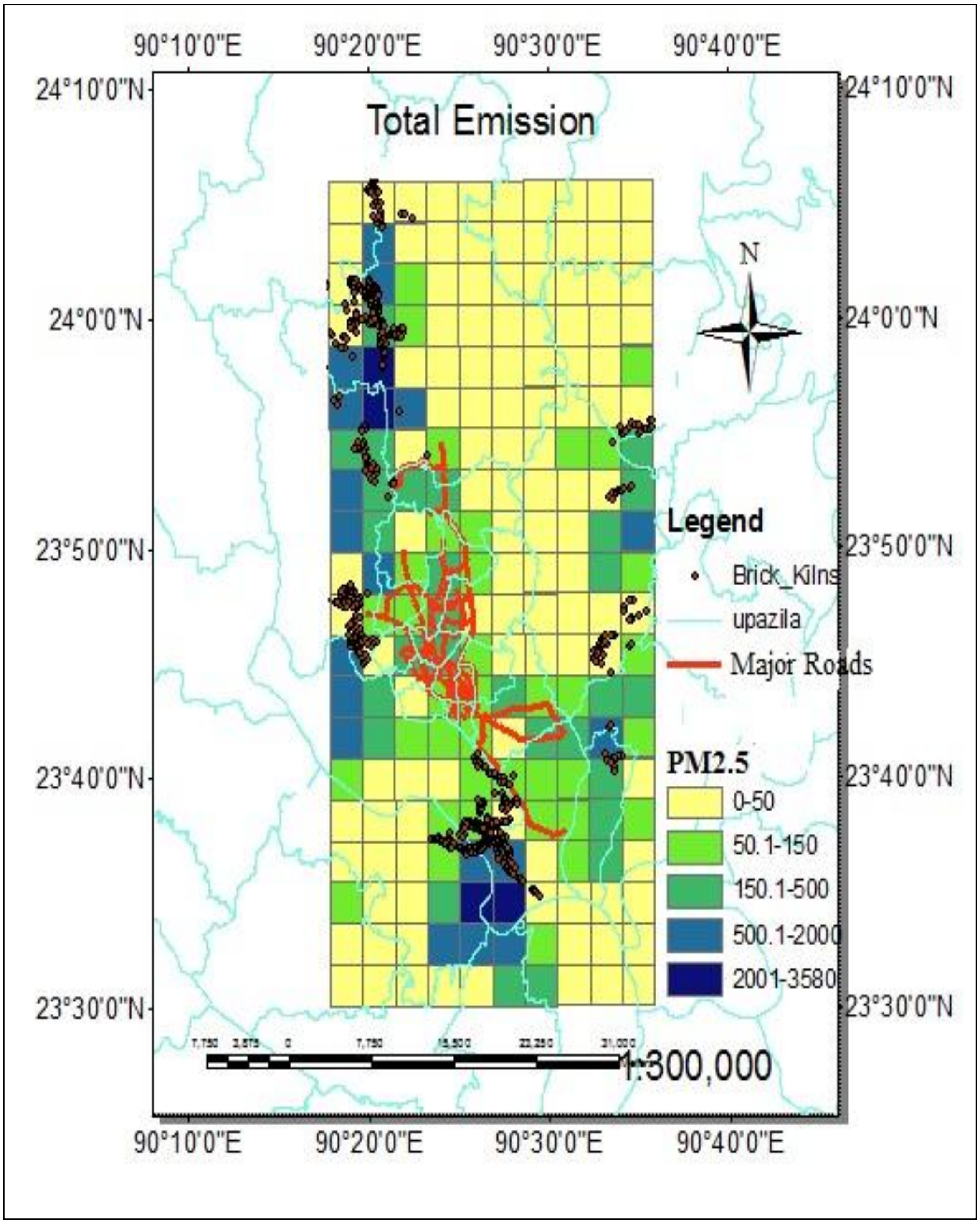


Figure 4.14: Spatial distribution of total $PM_{2.5}$ emission (ton) for dry season (November to 15 April)

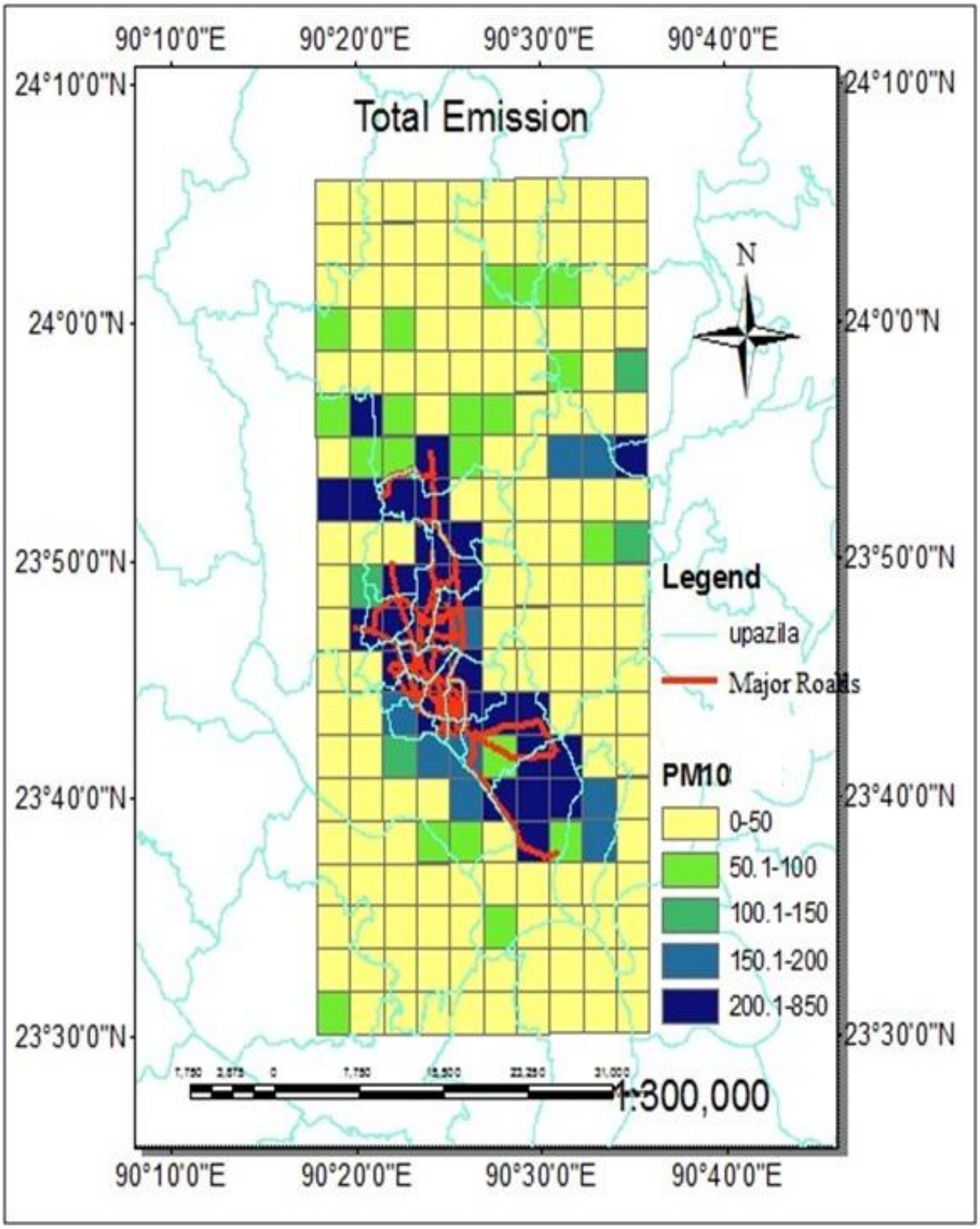


Figure 4.15: Spatial distribution of total PM_{10} emission (ton) for wet season (16 April to 31 October)

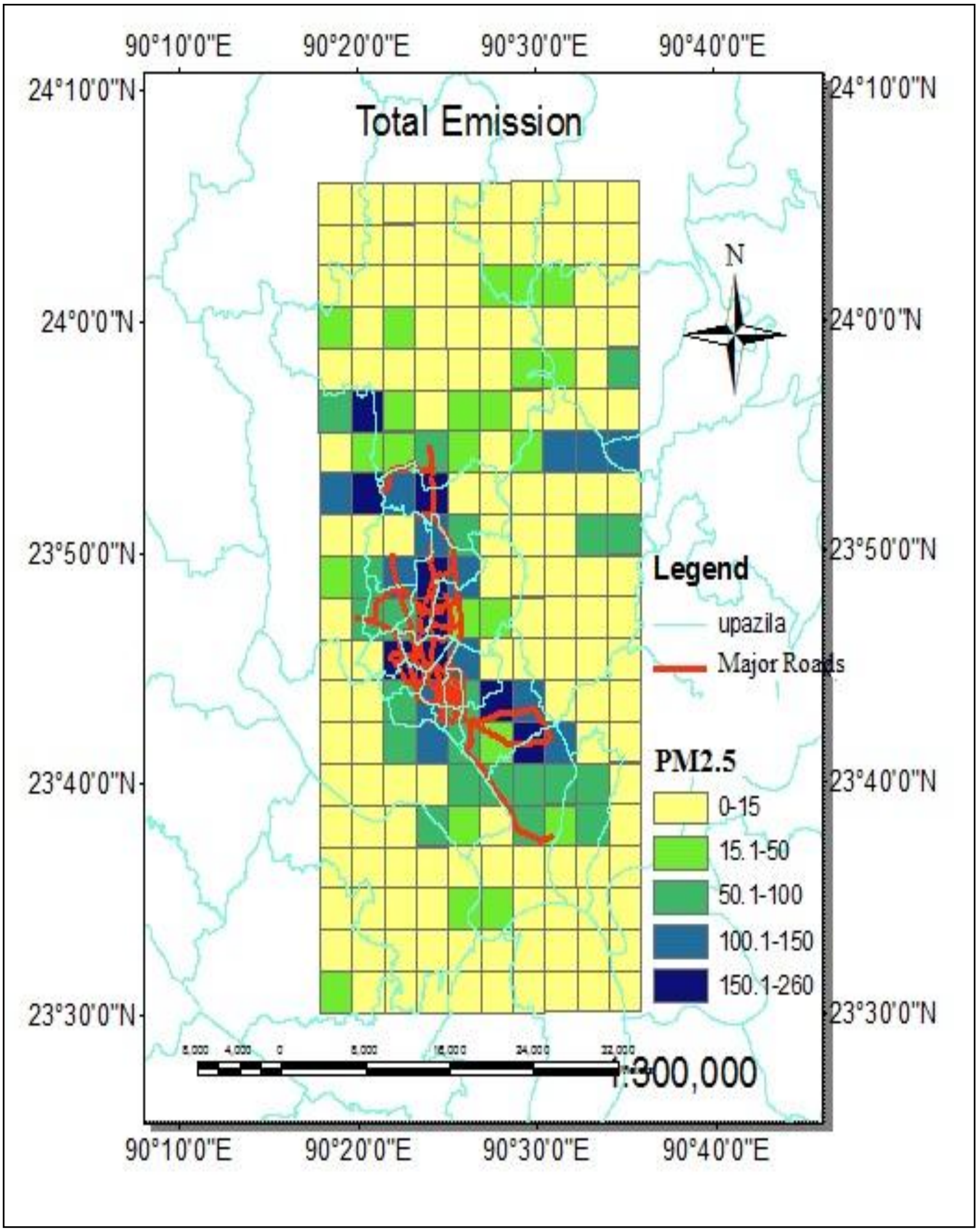


Figure 4.16: Spatial distribution of total $PM_{2.5}$ emission (ton) for wet season (16 April to 31 October)

Table 4.1: Estimated total PM emissions during dry and wet seasons in study area

Period	Emission	
	PM_{10}	$PM_{2.5}$
Dry Season (1 November to 15 April; 166 days)	1,35,332 tons	41,720 tons
Average Dry Season Emission per month (30 days)	24,606 ton per month	7,585 ton per month
Wet Season (16 April to 31 October; 198 days)	17,057 tons	6,515 tons
Average Wet Season Emission per month (30 days)	2,584 ton per month	1002 ton per month

Table 4.2 shows the vehicular emission inventory for the pollutants PM_{10}, $PM_{2.5}$, SOx, NOx, and CO for all categories of vehicles. The estimated figure represents emission with 95% confidence interval value. An uncertainty analysis has been carried out to get these 95% confidence interval of emissions factor of pollutants. Section 3.5.1.1 describes the details about uncertainty analysis.

Table 4.2: Vehicular emission inventory for the study area

Vehicle Type	**Emission (Ton/year)**				
	PM_{10}	**$PM_{2.5}$**	**SOx**	**NOx**	**CO**
Auto Rickshaw	189.4	113.5	31.3	1221.2	8,006.4
Bus	3,516.0	2,737.6	4,220.1	16,806.4	10,859.4
Car	276.1	182.7	266.9	3,029.1	7,514.8
Motor Cycle	308.2	101.2	76.0	119.4	2,550.3
Pick up	92.5	35.3	22.0	220.3	1,233.8
Taxi	92.0	28.5	32.9	351.2	1,233.4
Tempo	127.2	21.4	13.4	668.3	2,143.6
Truck	1,433.0	1028.0	2,093.3	9,736.0	5,493.7
Total	6035.1	4,248.1	6,756.0	32,151.7	39,035.4

Table 4.2 shows that buses dominate the emissions from vehicular sources, followed by trucks. For example, buses account for about 58 percent of PM_{10} emissions and over 64

percent of $PM_{2.5}$ emissions from vehicular sources. On the other hand trucks account for about 24 percent of both PM_{10} and $PM_{2.5}$ emissions from vehicular sources. Buses and trucks are also dominant sources of SOx and NOx emission from vehicular sources. Thus, diesel driven buses and trucks are the dominant sources of emissions from vehicular sources. Other important vehicular sources include Auto rickshaw, Car and Motor Cycle.

Table 4.3 shows the comparison of estimated emissions of the present study with those of Khaliquzzaman (2006) and Arjumand (2010) for the pollutants between the previous studies and present study. Figure 4.17 shows the comparison graphically. It is worth noting that although the study area used in this study is the same as that used by Arjumand (2010), the emissions estimated in this study are much higher than those reported by Arjumand (2010). For example, PM_{10} and $PM_{2.5}$ emission estimated in this study are about 3 times higher than those reported by Arjumand (2010); while SOx emission is about 4 times higher. The primary reason for higher emissions estimated in this study is the traffic data (AADT) used for estimation of emission. Arjumand (2010) used AADT from Strategic Transport Plan (STP), 2004; while in this study a more recent database from Japan International Cooperation Agency (JICA), 2010 has been used.

Table 4.3: Vehicular emission inventory for Dhaka City

	Emission (Ton/year)				
	PM_{10}	**$PM_{2.5}$**	**SOx**	**NOx**	**CO**
Present Study (2012)	6,035	4,248	6,756.0	32,152	39,035
Arjumand (2010)	2,044	1,430	1,726	27,125	27,889
Khaliquzzaman (2006)	2,923	--	1,464	32,429	87,623

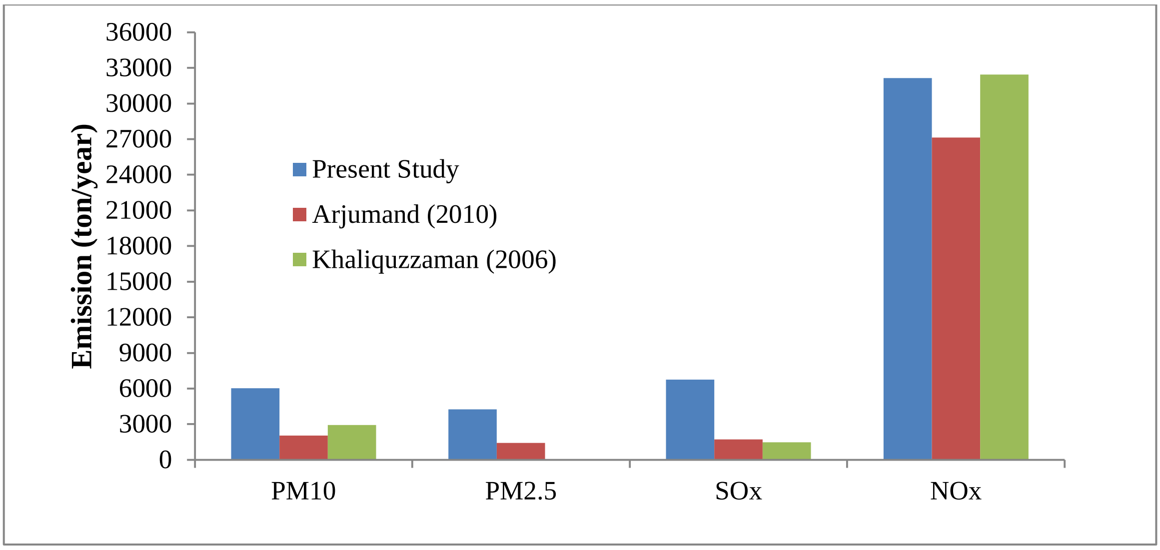


Figure 4.17: Comparison among different studies for vehicular emission inventory.

Table 4.4 represents comparison of some major road's AADT. Significant change in road length and consideration of minor road length are responsible for differences in emission. The present study also differs significantly with emission figures reported by Khaliquzzaman (2006). The reasons could be differences in study area, traffic data and emission factors used for estimation of emission.

Table 4.4: Comparison of AADT of some major roads in Study Area

AADT	Road Name	Bus	Car	Truck	Taxi	Motor-cycle	Auto-rickshaw/ CNG/ Mishuk
STP(2004)	New Airport Road	5,492	19,622	3,357	6,284	3,037	--
JICA (2010)		5,269	52,672	2,783	3,932	28,016	861
STP(2004)	Progati Sarani	7,930	19,805	0	7,596	1,595	9,614
JICA (2010)		4,782	19,227	5,793	2,423	2,288	7,371
STP(2004)	Atish Dipankar Road	4,536	3,634	4,824	2,835	1,264	5,049
JICA (2010)		4,812	9,909	7,107	2,188	1,996	8,461
STP(2004)	Dhaka-Mymensingh Road	2,295	2,202	2,153	261	461	927
JICA (2010)		13,657	54,789	6,434	6,086	4,296	14,537
STP(2004)	Tongi Diversion Road	4,931	37,733	3,460	11,466	4,275	35,445
JICA (2010)		5,885	32,747	2,702	3,545	7,427	28,373

It should be noted from Table 4.4 that large difference of AADT in diesel and gasoline driven vehicles make the difference in total emission.

Table 4.5 and table 4.6 show the emission inventory for the pollutants PM_{10} and $PM_{2.5}$ due to brick kiln and re-suspended road dust, respectively. Table 4.6 shows that similar to vehicular emissions, buses and trucks also dominate the road dust emissions. Together, buses and trucks account for about 80 percent of PM_{10} and $PM_{2.5}$ emission during both dry and wet seasons.

Table 4.5: Emission inventory due to brick kiln for the study area

	Emission (Ton)	
	PM_{10}	$PM_{2.5}$
January	21,612	6,484
February	21,612	6,484
March	21,612	6,484
April	10,806	3,242
May	0	0
June	0	0
July	0	0
August	0	0
September	0	0
October	0	0
November	21,612	6,484
December	21,612	6,484
Yearly	118,866	35,662

Table 4.6: Emission inventory due to re-suspended road dust for the study area

Vehicle Type	Emission (Ton)			
	Dry Season (January)		Wet Season(August)	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Auto Rickshaw	3.0	1.5	2.2	1.1
Bus	1,171.1	351.3	885.5	265.6
Car	145.2	43.6	109.8	32.9
Motor Cycle	3.1	0.9	2.4	0.7
Pick up	209.4	62.8	158.3	47.5
Taxi	52.8	15.9	40.0	12.0
Tempo	146.0	43.8	110.4	33.1
Truck	1,047.2	314.2	791.8	237.5
Total	2,777.9	834.0	2,100.3	630.5

4.3 RELATIVE CONTRIBUTION OF DIFFERENT SOURCES

This section describes relative contribution of major sources (vehicles, brick kilns, and road dust) to total PM_{10} and $PM_{2.5}$ emissions during both dry and wet seasons. . January and August have been chosen to represent the dry and wet season, respectively. This section also presents contribution of different vehicle modes and the contribution of diesel and non-diesel vehicles in the emission of selected pollutants.

PM_{10} Emission

Figure 4.18 and Figure 4.19 present the relative percentage of PM_{10} emission from the three major sources considered in this study for dry and wet season, respectively. From these figure, it can be seen that during dry season, emission from brick kiln is dominant (accounting for about 87 percent of PM_{10} emission), followed by road dust (11.2 percent) and vehicle (2 percent). On the other hand, during wet period, when it is the brick kilns are not operating, road dust becomes dominant contributor of PM_{10} emission, accounting for over 80 percent of PM_{10} emissions.

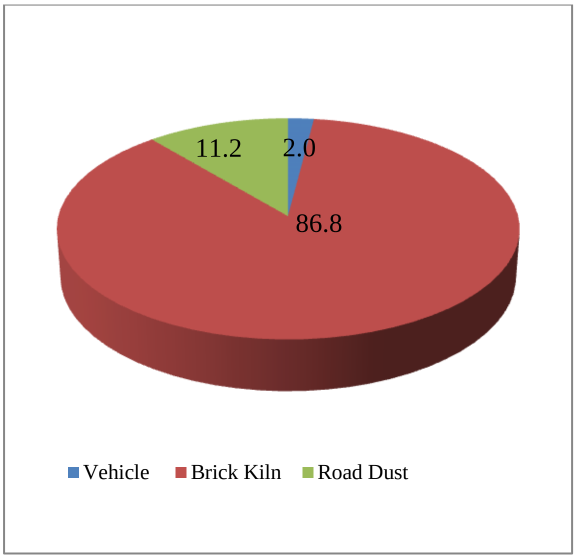


Figure 4.18: Contribution of major sources to PM_{10} emission during dry season (January)

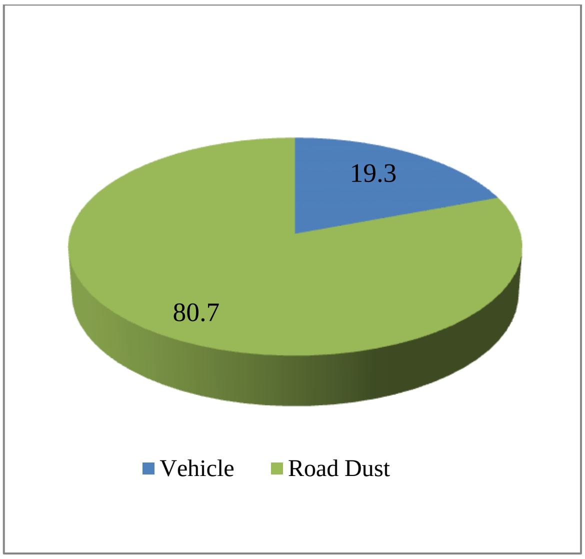


Figure 4.19: Contribution of major sources to PM_{10} emission during wet season (August)

Both in dry and wet season, a large portion of PM emission comes from different type of vehicles. Figure 4.20 and Figure 4.21 presents the relative contribution of different vehicle types to total PM_{10} from traffic and road dust emission respectively.

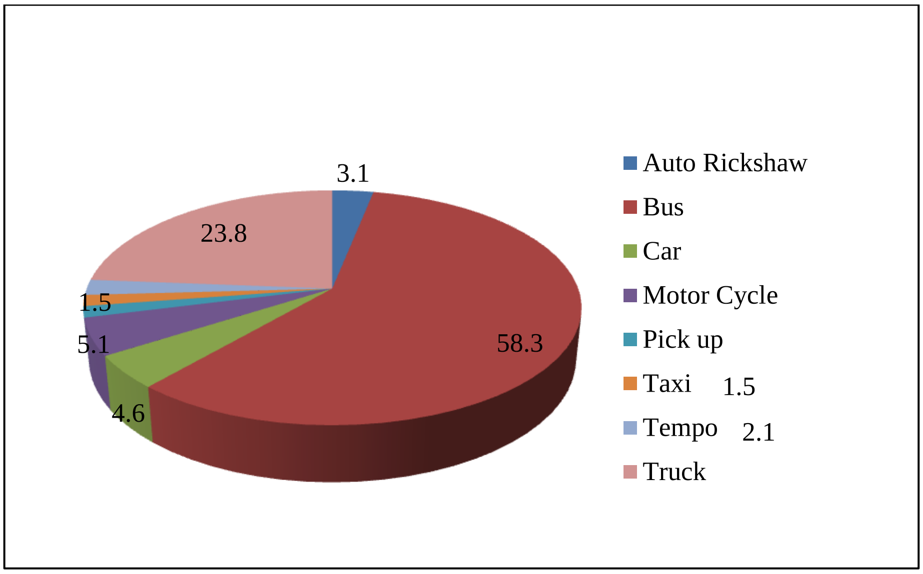


Figure 4.20: Contribution of different vehicular modes to monthly total vehicular PM_{10} emission.

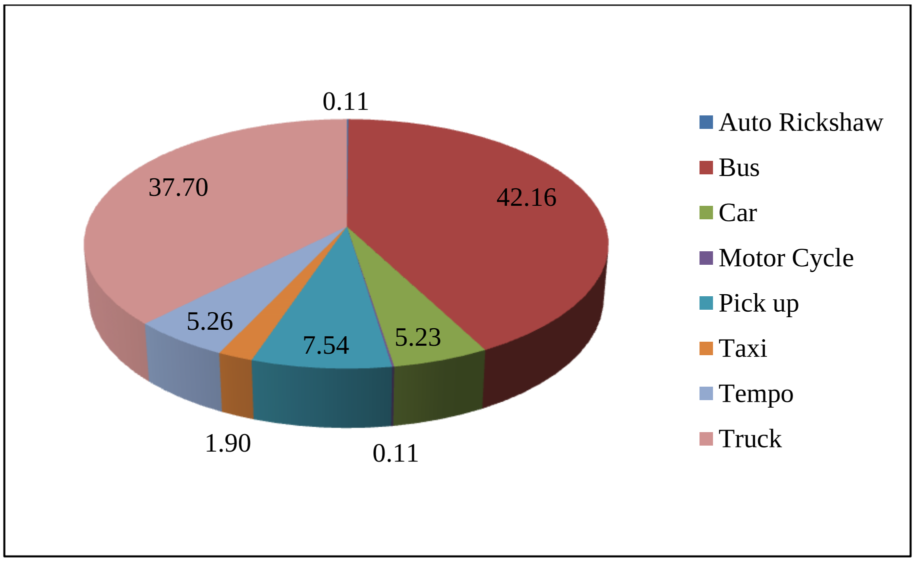


Figure 4.21: Contribution of different vehicular modes to monthly (January) total PM_{10} emission from road dust.

Here Figure 4.21 shows the relative contribution of different types of vehicle to the road dust emission for January month. Other months show almost similar pattern.

The figure clearly shows that the diesel driven vehicles (i.e., buses and trucks) are responsible for majority (about 82 percent) of PM_{10} emission. Buses account for over 58 percent of vehicular PM_{10} emissions and about 48 percent of road dust emission, while trucks account for about 23 percent and 38 percent of vehicular and road dust emission respectively. In this study, it has been assumed that 100% trucks and 80 % buses are diesel driven. The other types of vehicles like car, taxi, auto rickshaw, motorcycle and tempo together contribute a significant percent to total vehicular and road dust PM_{10} emission. It should be mentioned that buses and trucks are the only diesel driven vehicles on the streets.

$PM_{2.5}$ Emission

Figure 4.22 and Figure 4.23 show the relative contribution of major sources to total $PM_{2.5}$ emission during dry and wet season, respectively. Like PM_{10}, during dry season, emission from brick kiln is dominant while during wet period, road dust is mainly responsible for $PM_{2.5}$ emission.

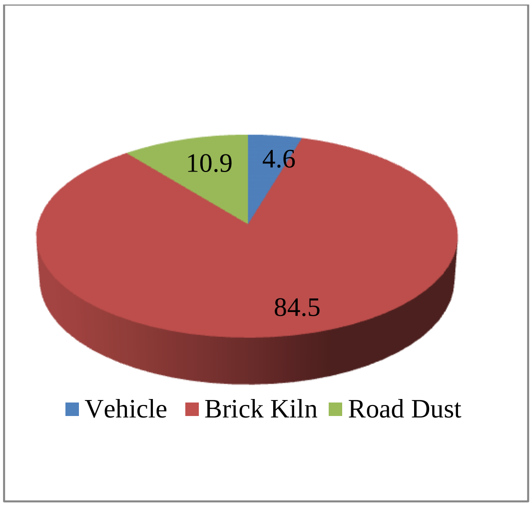


Figure 4.22: Contribution of major sources to $PM_{2.5}$ emission during dry season (January)

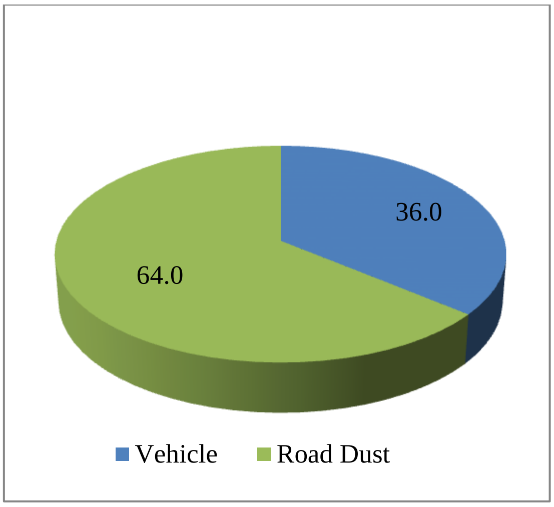


Figure 4.23: Contribution of major sources to $PM_{2.5}$ emission during wet season (August)

However, a comparison of relative contribution to vehicular emission to $PM_{2.5}$ is higher than that to PM_{10} emission; for example during wet season (when brick kilns are not operating), vehicular emission account for about 19.3 percent of PM_{10} emissions, while it accounts for about 36 percent of $PM_{2.5}$ emissions. This is because vehicular emissions contain finer PM compared to road dust.

Figure 4.24 and Figure 4.25 show relative contribution of different vehicular modes to total vehicular and road dust $PM_{2.5}$ emission. Similar to PM_{10} emission, diesel driven buses and trucks have been found to be mainly responsible for vehicular $PM_{2.5}$ emission. Since diesel driven vehicles emit more fine particles, their relative contribution to $PM_{2.5}$ emission is higher than that to PM_{10} emission. Buses account for 65 percent and 42 percent 6.4 percent of total $PM_{2.5}$ emission from traffic and road dust respectively, on the other hand, trucks are responsible for about 24.2 percent and 38 percent of total $PM_{2.5}$ from traffic and road dust respectively. Cars, auto rickshaw and motor cycle are responsible for about 9 percent of total vehicular $PM_{2.5}$ emission. Pick up, tempo and car contribute about 13% of total road dust $PM_{2.5}$ emission.

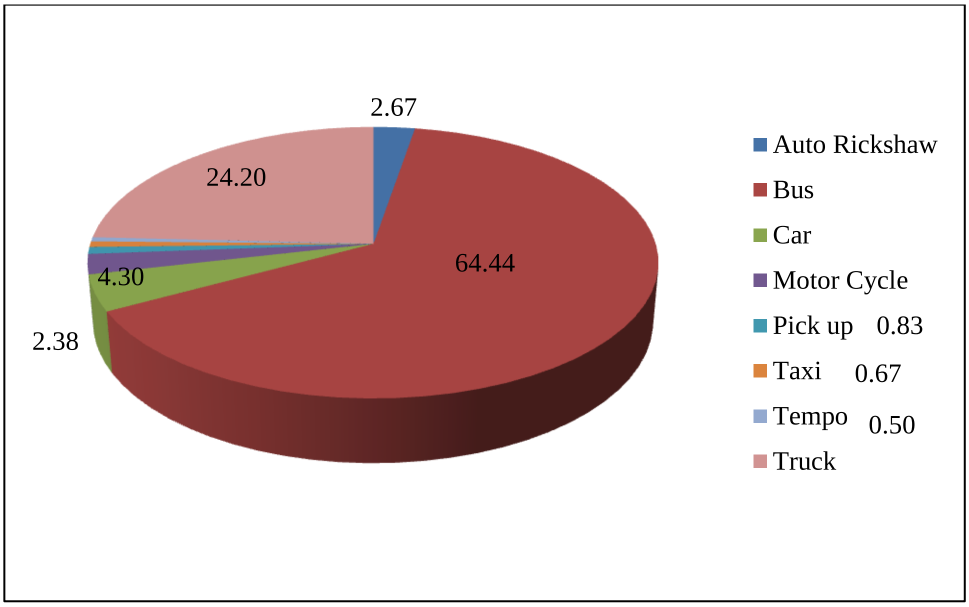


Figure 4.24: Contribution of different vehicular modes to monthly total vehicular $PM_{2.5}$ emission.

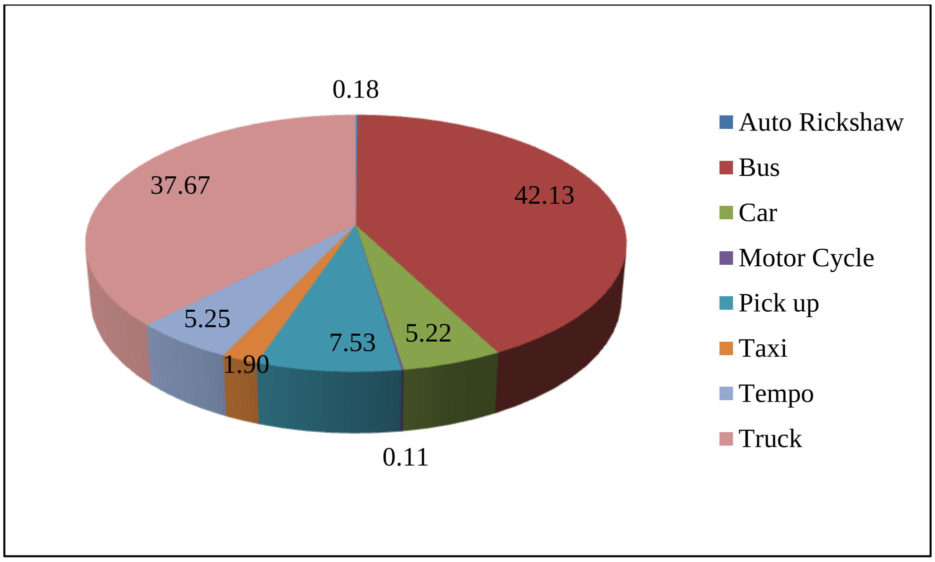


Figure 4.25: Contribution of different vehicular modes to monthly (January) total $PM_{2.5}$ emission from road dust.

SOx Emission

In this study, only vehicular emissions have been considered as sources of SOx NOx, and CO. Figure 4.26 shows relative contribution of different vehicular modes to total vehicular SOx emissions.

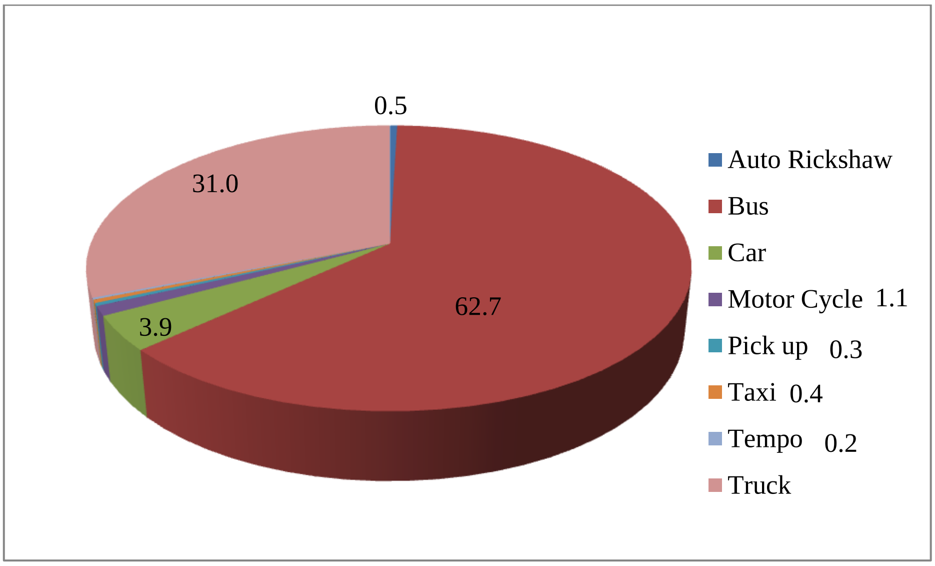


Figure 4.26: Percentage of SOx Emission from Different Vehicle Categories

It shows that that buses and trucks, which run on high-S diesel, are responsible for almost all (about 94 percent) SOx emissions. Buses and trucks account for 62.7% and 31% of total SOx emissions, respectively. Car ranks third, accounting for about 4% of total SOx emission.

It should be noted that conversion of significant number of cars to CNG (which contain no Sulfur) has contributed to reduce SOx emissions from cars.

NOx Emission

Figure 4.27 shows contribution of different vehicular modes to total NOx emission . It can be interpreted from the Figure 4.27, buses and trucks account for about 82.5 % of total NO_x emission; where bus alone is responsible for about 52 % of total emission. This is not surprising, because diesel driven vehicles usually emits higher NO_x because of higher engine temperature, which encourages higher production of thermal NO_x. Cars come as the third highest emitter, responsible for about 10% of total emission of NO_x.

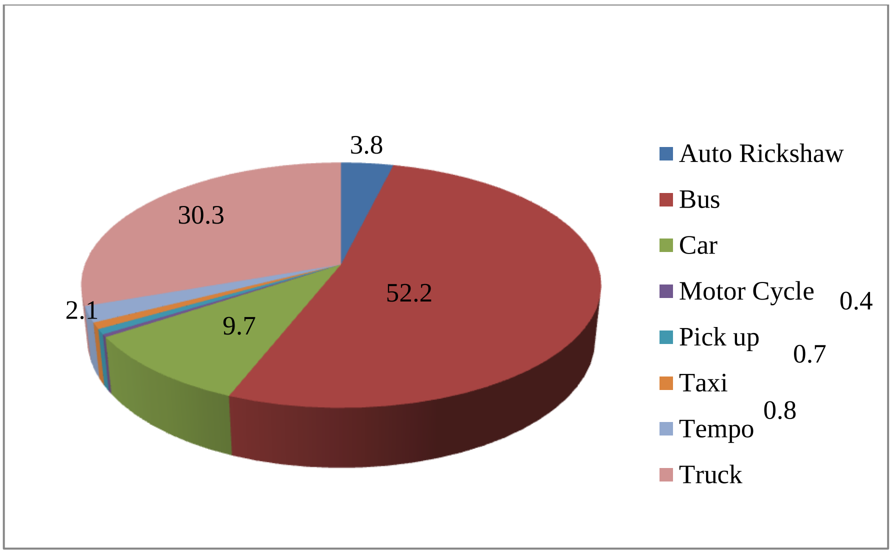


Figure 4.27: Percentage of NOx Emission from Different Vehicle Categories

CO Emission

Figure 4.28 shows contribution of different vehicular modes to total vehicular CO emission. It shows that cars and auto rickshaws account for 19% and 20% of total emission of CO, respectively.

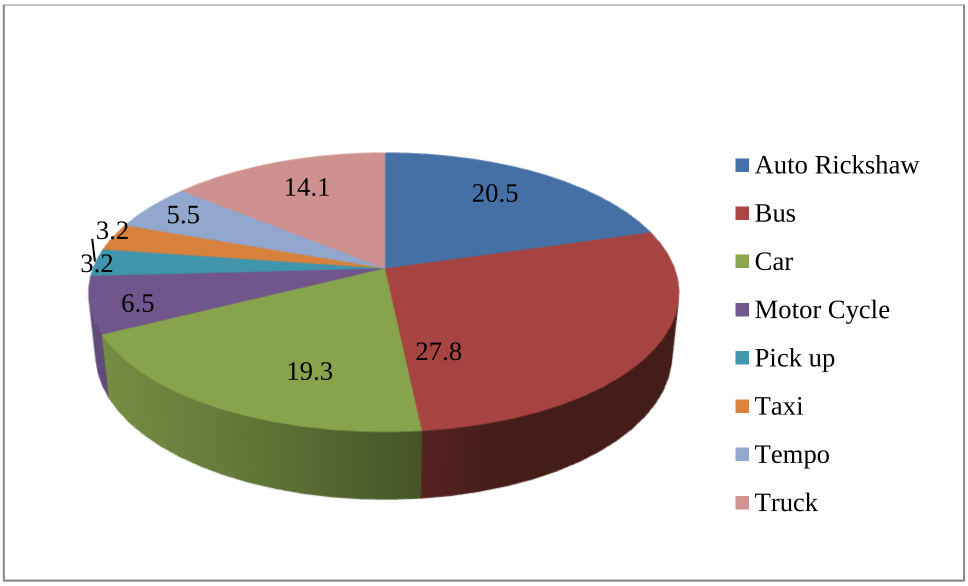


Figure 4.28: Percentage of CO Emission from Different Vehicle Categories

On the other hand, trucks and buses are responsible for about 40% of total emission of CO. It may be noted that diesel vehicles run on lean mixture (i.e., higher air to fuel ratio), and hence emission of both CO and Hydrocarbons are usually lower for diesel driven vehicles. Gasoline driven vehicles on the other hand emits more CO and Hydrocarbons.

From analysis of emission inventory, it is clear that during dry season, brick kiln emissions are dominant and large portion of emission occur near the area where brick kilns are located, i.e., the eastern, southern and south-western sides of Dhaka city.

On the other hand, during wet season, total emissions from PM_{10}, $PM_{2.5}$, SOx and NOx are higher in areas with major roads and intersection (Grids G4, G6, G7, D8, D9,D10, D11,D12, E10, E11, F13, G13, G14, H14) These grids/ areas include Tejgaon, Ramna, Motijheel, Uttara, Banani. The major roads including Kazi Nazrul Islam Avenue, Tongi Diversion Road, Old Airport Road, Panthapath Road, Sonargaon Road, New Eskaton Road, Kakrail Road are passes through these grids and vehicular emission dominate the total emissions.

4.4 SUMMARY

This Chapter presents the grid-based emission inventory for areas within and surrounding Dhaka city, and also presents spatial and temporal distribution of PM_{10}, $PM_{2.5}$, CO, NOx, SOx emissions due to vehicle, brick kiln and road dust. Analysis shows that during dry season, brick kilns located along the periphery of Dhaka city are the dominant sources of PM emission. The brick kilns about for about 87 percent of PM_{10} and 85 percent of $PM_{2.5}$ emissions during the dry season. On the other hand, during wet season when the brick kilns are not operating, road dust becomes the major source of PM emission, followed by vehicular emissions. Consequently higher emissions take place in city areas with major roads and intersections; these include Tejgaon, Ramna, Motijheel, Uttara, and Banani areas. Vehicular emission and road dust of some major roads including Kazi Nazrul Islam Avenue, Tongi Diversion Road, Old Airport Road, Panthapath Road, Sonargaon Road, New Eskaton Road, Kakrail Road are major contributor to emissions.

It is interesting to note that while vehicles are often considered to be the major source of pollution by many, results from this study reveal that they contribute a relatively smaller fraction to total PM emissions. However, contribution of vehicular emission to ambient PM concentrations is likely to be higher since they emit close to population (within city, along busy roads). This issue has been addressed in Chapter 5 through application of an air quality model.

Of the vehicular emission, it has been found that diesel-driven buses and trucks account for majority of emission of all major pollutants (PM_{10}, $PM_{2.5}$, SOx, NOx). Together buses and trucks account of about 81 percent of total vehicular and road dust PM_{10} emissions, 88 percent of total vehicular and road dust $PM_{2.5}$ emissions, 94 percent of vehicular SOx emissions, and 83 percent of vehicular NOx emissions.

CHAPTER FIVE: PREDICTION OF AMBIENT CONCENTRAION OF PARTICULATE MATTER

5.1 INTRODUCTION

A major objective of this study was to develop a grid based air-quality model for Dhaka City and its surroundings, and to run the model using the grid-based emission inventory developed as a part of this study. Methodology for predicting the ambient concentration of particulate matter (PM) has been described in Chapter Three. The ATMoS model has been used to generate the source-receptor matrices (Rahman, 2010) and the source-receptor transfer matrices have been obtained for both primary and secondary particulates. The source receptor matrices can be used to estimate the concentration within the model domain by multiplying them with the emission vectors. By feeding the emission inventory developed in this study and the transfer matrices into spreadsheet the ambient concentration at different grids for different months of the base year (2010) have been estimated.

The PM pollution, which is critical for the urban areas, is a result of contributions of multiple sources and multiple pollutants. The ATMoS model allows for multi-pollutant analysis for PM in which each of the primary emissions are modeled separately and aggregated at the end. This includes conversion of SO_2 to sulfate particles and NOx to nitrate particles. The chemical transformation to sulfates and nitrates is simplified using linear reactions. The reactions are considered to follow the first order reaction, thus only parameter related to chemical transformation is the reaction rate. No chemical transformation is applied to direct PM emissions.

Modeling each of the sub-fractions (i.e., conversion of SO_2 to sulfates, NOx to nitrates etc.) is very important due to the differences in physical and chemical differences in PM_{10} and $PM_{2.5}$. In the model, besides the sub-fractions, the direct PM emissions are also simulated in two bins – distinguished as PM with aerodynamic diameters between 2.5 and 10 micron meters (the 'coarse fraction') and particles between 0 and 2.5 micron meters (the 'fine fraction'). At the end of the simulations, the total PM_{10} concentrations comprise of all the sub-fractions (PM-coarse+PM-fine+SO_4+NO_3), while the total $PM_{2.5}$ comprise of the finer sub-fractions (PM-fine+SO_4+NO_3), thus providing a multi-pollutant description to the PM pollution.

This Chapter presents the spatial distribution and temporal variations of the particulate matter (both fine and coarse fractions) concentration within greater Dhaka city. It also presents the comparison among the simulated results, results found from Rahman (2010) and the monitored data of CAMS in Dhaka.

5.2 PREDICTED PM CONCENTRATION

The ATMoS model has been used to predict for the ambient particulate matter (both PM_{10} and $PM_{2.5}$) concentration using the emission inventory developed in this study. In the present study, the simulation has been carried out to estimate the monthly average concentration of the pollutants due to emissions from traffic, brick kilns and road dust. The following sections describe both spatial and temporal variation of particulate matter concentration.

Spatial Variation

Figure 5.1 to Figure 5.12 present the spatial variation of PM_{10} concentration for different months of the base year, 2010 and Figure 5.13 to Figure 5.24 show the $PM_{2.5}$ concentration. From the Figures 5.1 to 5.12, it is seen that the concentration of PM_{10} varies widely over the model domain. As expected, the model predicted higher PM concentrations for dry months of the year when brick kilns are in operation and virtually there is no precipitation. On the other hand, the predicted very low values of PM for the wet months. For the month of January (i.e., dry season), it varies from 0.74 µg/m^3 to 280 µg/m^3. In February and March these variations are even wider (from less than 1 µg/m^3 to greater than 1560 µg/m^3). During April to August, the concentrations are more or less similar and lie within a small range (0 to 20 µg/m^3). Maximum concentration for July is 1.06 µg/m^3, which is the lowest among all predicted values. In October, concentration is little bit higher than other wet months and maximum concentration in 45 µg/m^3. December the variations of concentration are higher than that of the November which is somewhat similar to that of the January.

The areas to the north-east of the Dhaka city i.e., Kaliganj, Sreepur are less polluted, primarily because they are not located down-wind of the major brick kiln clusters. During wet season (April to October), predicted PM_{10} concentration are relatively low throughout the model domain, but they are much lower for the boundary areas of Dhaka City (e.g., Kapasia, Savar, Keraniganj), compared to the city-center areas. Figure 5.12 reflects that in wet season, emission from vehicle and road dusts are responsible for PM concentration. On the other hand, predicted PM_{10} concentrations for the dry months (November to April) are much higher (by order of magnitude) due to emissions from brick kilns; wind direction (predominantly from north-west to south-east) also contributes to elevated PM concentrations down-wind of brick kiln clusters. Figure 5.12 shows spatial distribution of Pm concentration with major road network and brick kiln locations. The predicted PM_{10} concentration for the dry period (i.e., November to March) exceeds 50 µg/m^3, which is the national standard and WHO standard for annual average PM_{10} concentration. In some parts of the city, especially the bordering areas of Dhaka city where actually the brick kilns are located, it exceeds the 24-hour average standard (150 µg/m^3),

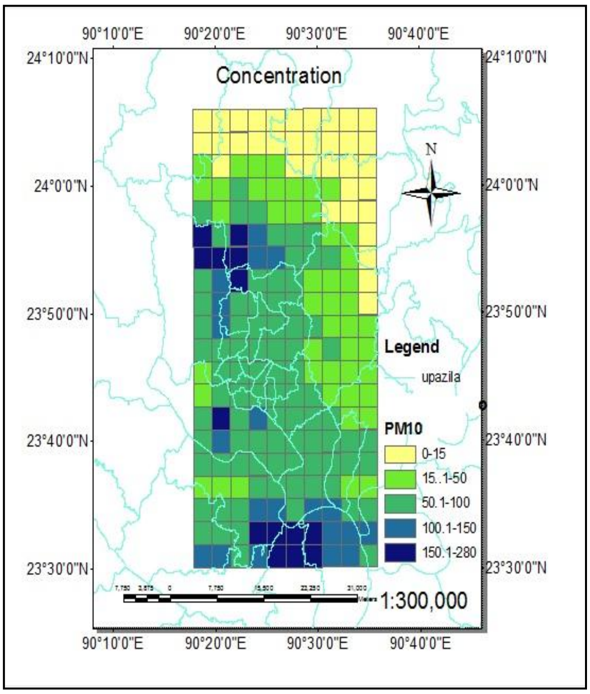


Figure 5.1: PM_{10} concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for January

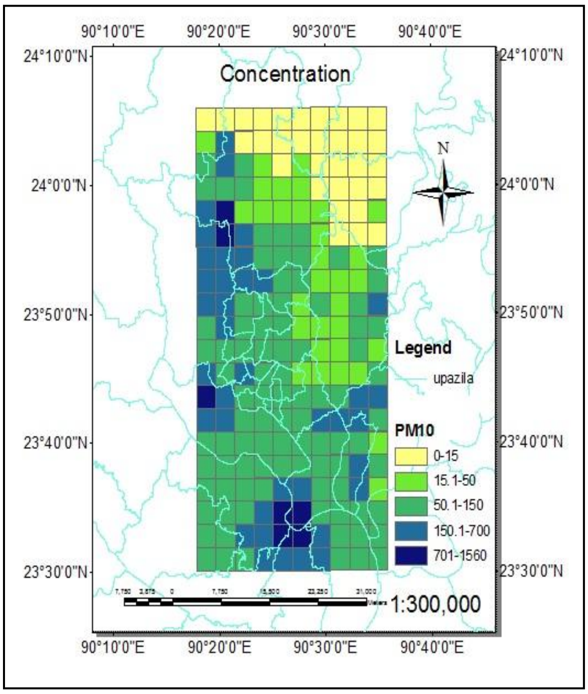


Figure 5.2: PM_{10} concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for February

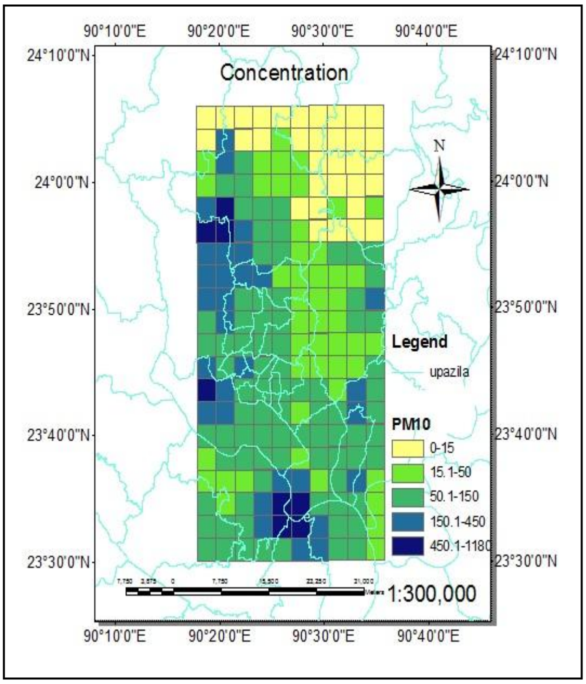


Figure 5.3: PM$_{10}$ concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for March

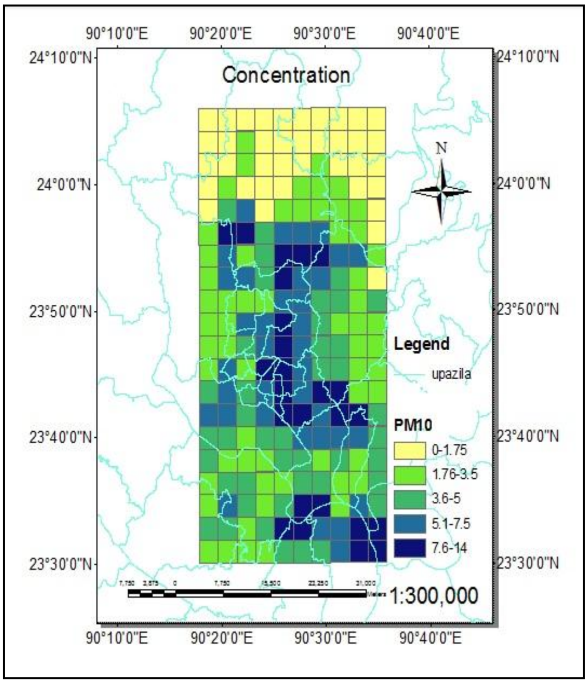


Figure 5.4: PM$_{10}$ concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for April

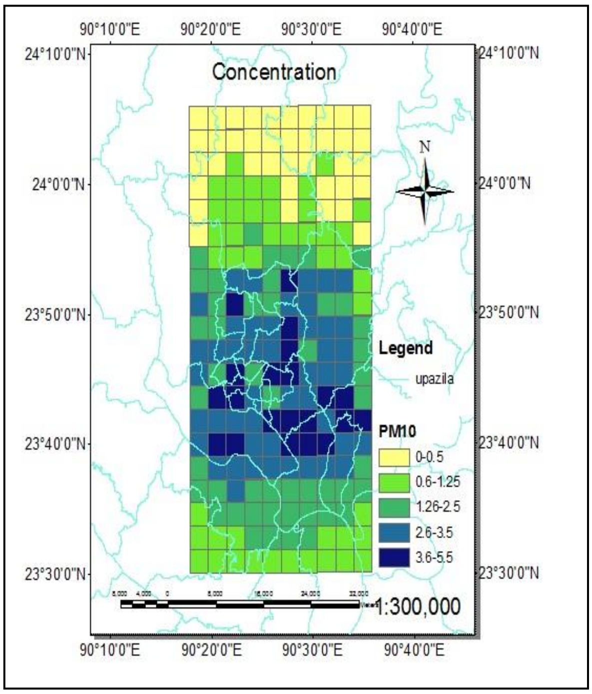


Figure 5.5: PM$_{10}$ concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for May

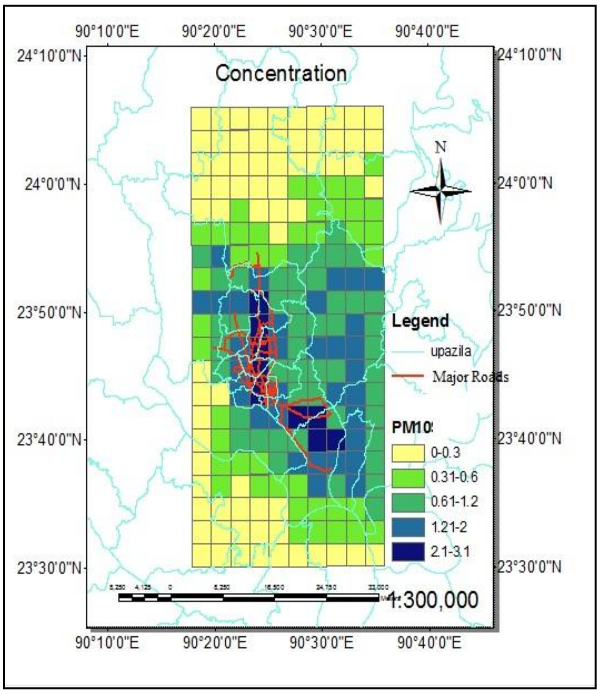


Figure 5.6: PM$_{10}$ concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for June

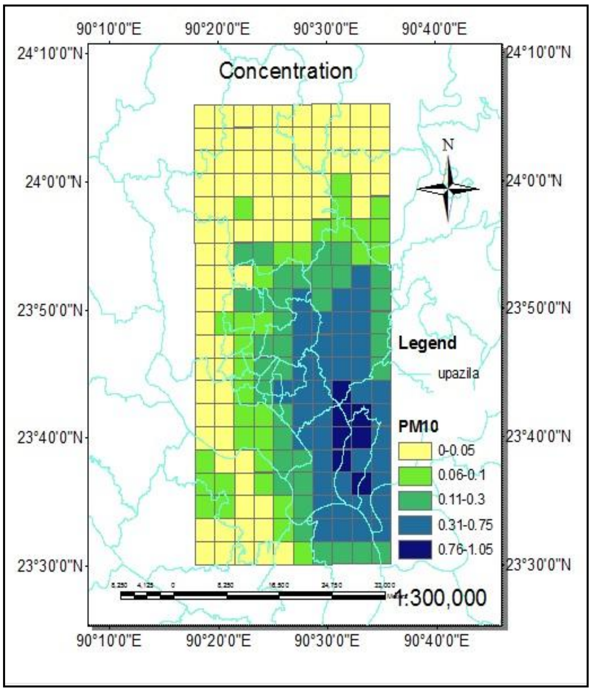


Figure 5.7: PM_{10} concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for July

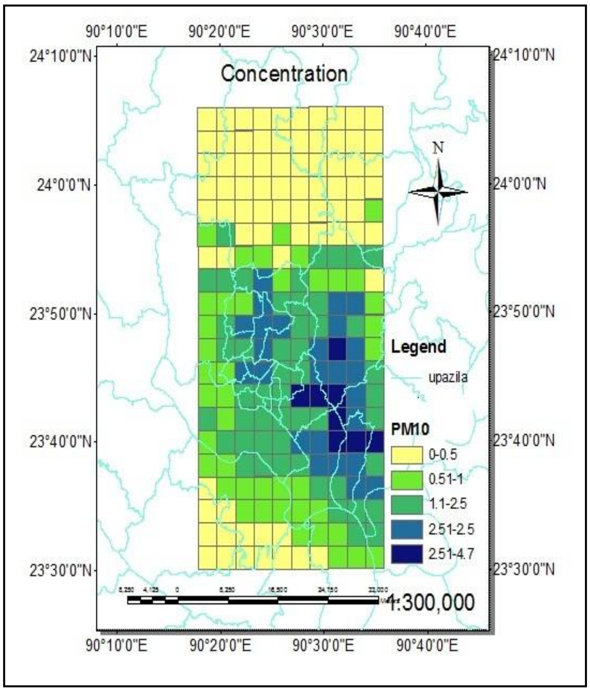


Figure 5.8: PM_{10} concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for August

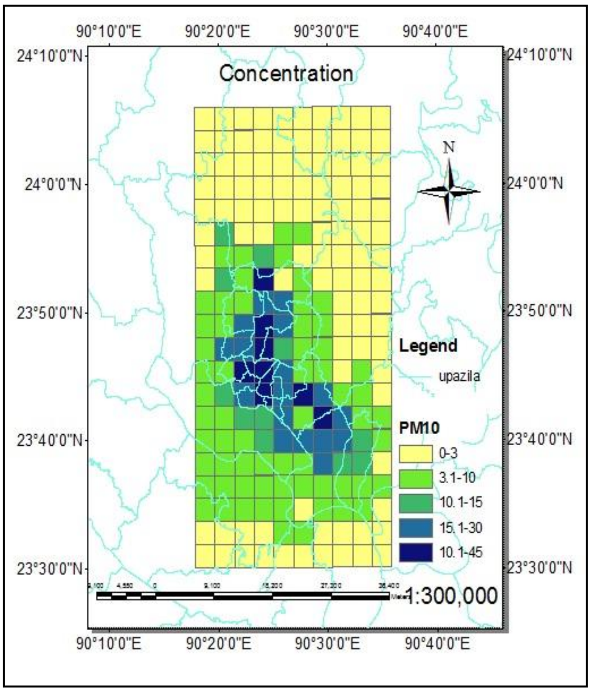


Figure 5.9: PM_{10} concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for September

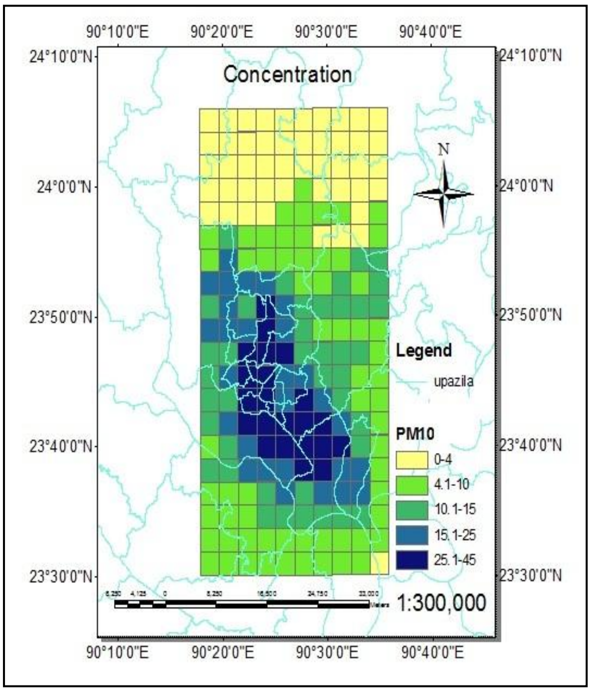


Figure 5.10: PM_{10} concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for October

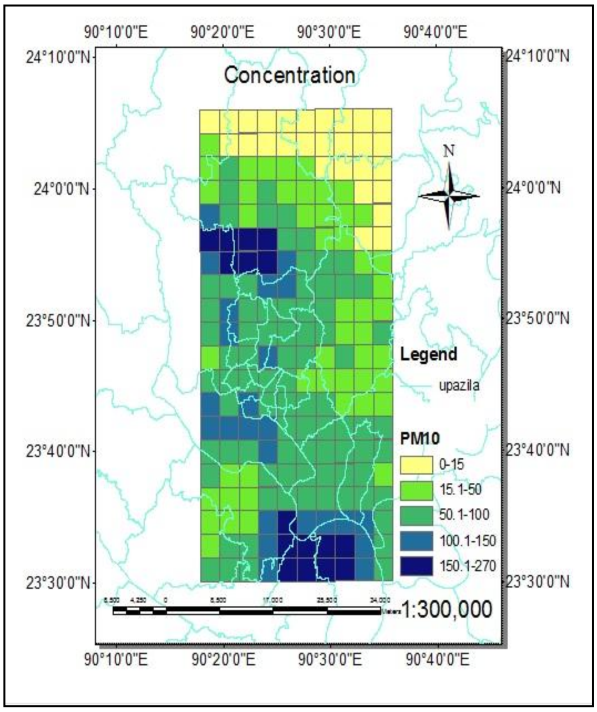


Figure 5.11: PM_{10} concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for November

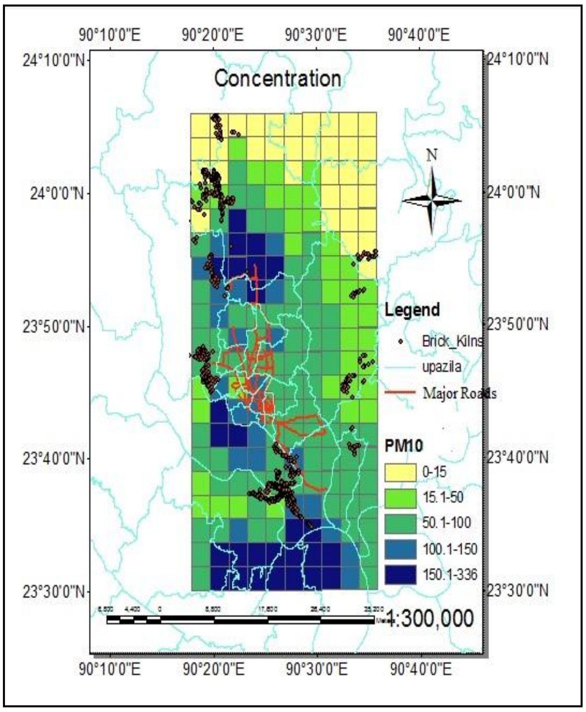


Figure 5.12: PM_{10} concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for December

Figures from 5.13 to 5.24 show similar spatial variation of concentration for $PM_{2.5}$. For the month of January it varies from 0.21 µg/m^3 to 91 µg/m^3 among the model grids. In February and March these variations are from 0.59 µg/m^3 to 820 µg/m^3. During April to August (i.e., wet season), the concentrations are more or less similar and lie within very small range (0 to 6 µg/m^3). As for the case of PM_{10}, the areas to the north-east of the Dhaka city i.e., Kaliganj, Sreepur are less polluted with respect to $PM_{2.5}$. However, due to brick kiln emissions, predicted $PM_{2.5}$ concentrations for the dry season are much higher, particularly in areas down-wind of brick kiln clusters; the concentration is greater than the annual average standard of 15 µg/m^3 in almost all parts of the Dhaka city. In some parts it even exceeds the 24-hour average standard (65µg/m^3)

Figure 5.17 and 5.24 represent spatial distribution of $PM_{2.5}$ concentration along with major road networks and brick kiln for wet and dry season respectively.

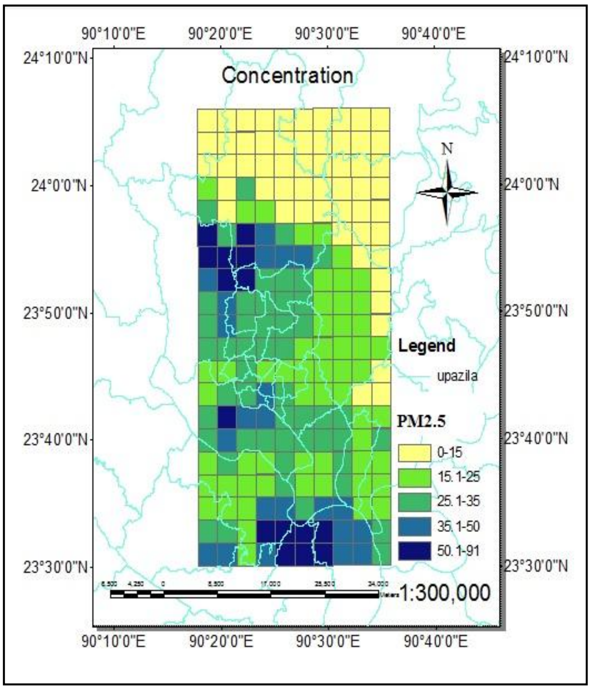


Figure 5.13: PM$_{2.5}$ concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for January

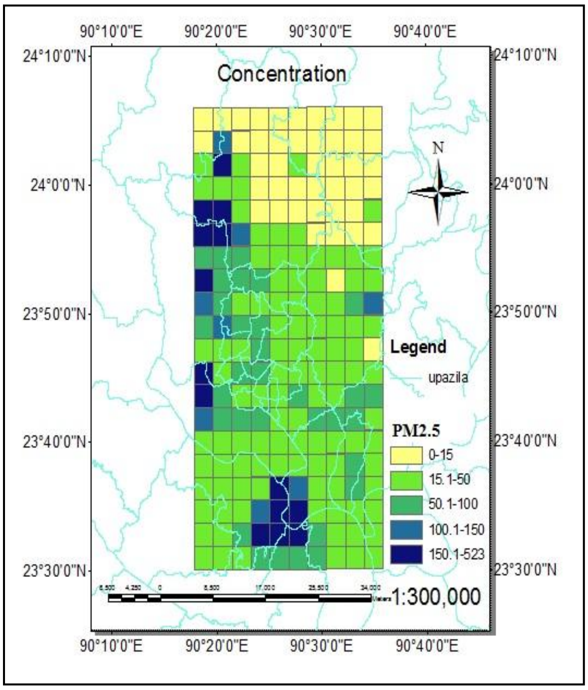


Figure 5.14: PM$_{2.5}$ concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for February

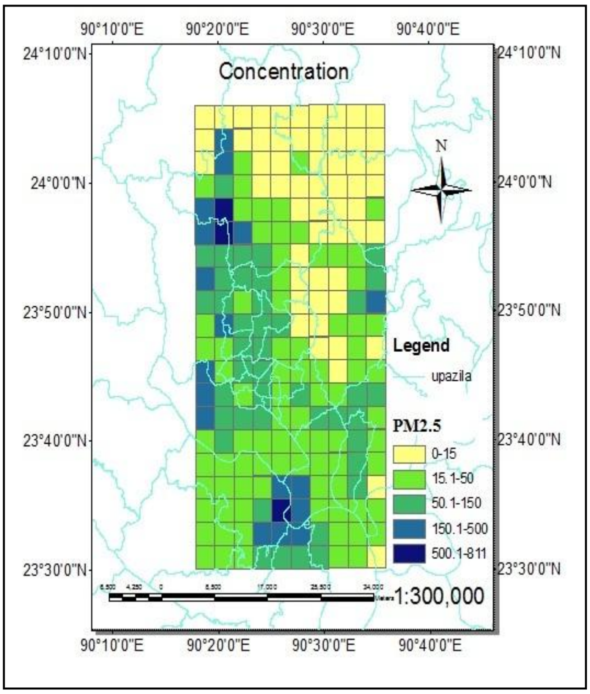


Figure 5.15: PM$_{2.5}$ concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for March

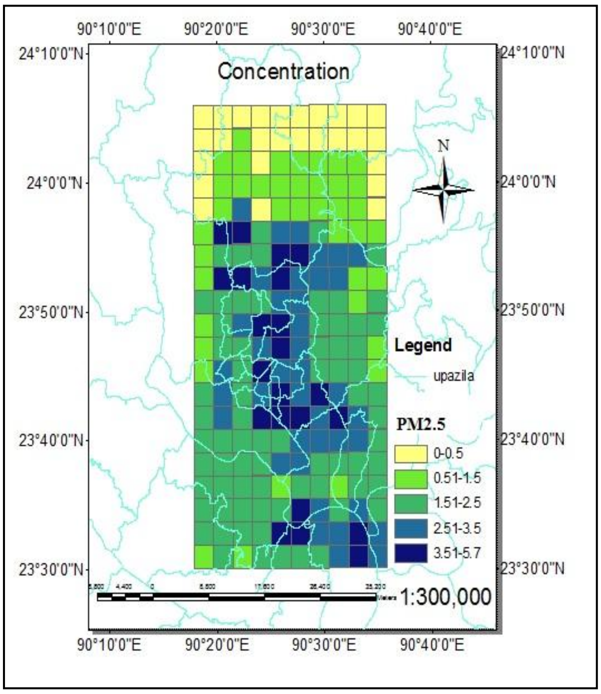


Figure 5.16: PM$_{2.5}$ concentration in µg/m^3 due to traffic, road dust and brick kiln emissions for April

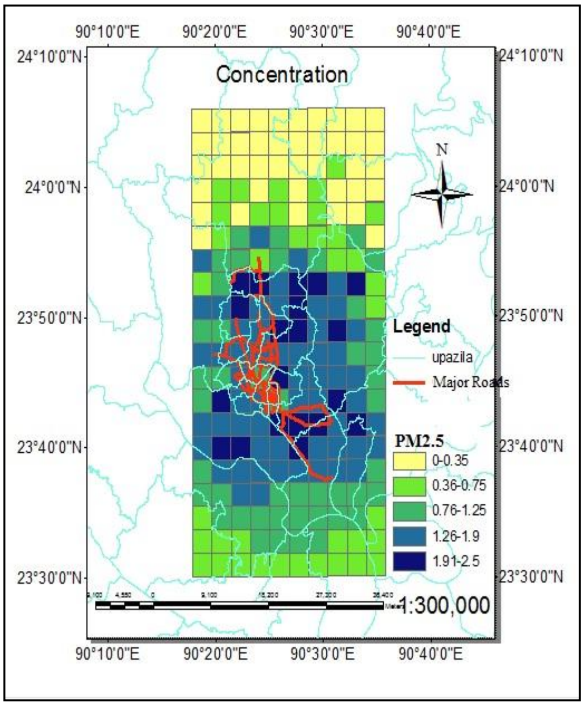


Figure 5.17: $PM_{2.5}$ concentration in μg/m^3 due to traffic, road dust and brick kiln emissions for May

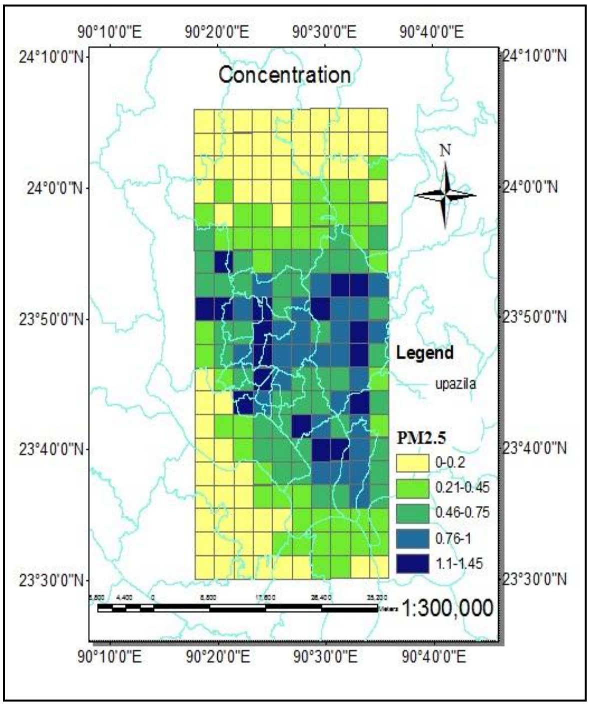


Figure 5.18: $PM_{2.5}$ concentration in μg/m^3 due to traffic, road dust and brick kiln emissions for June

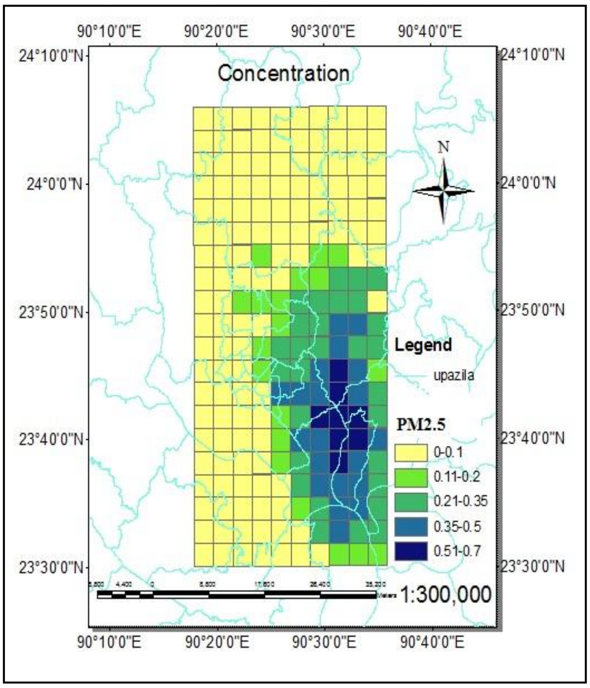


Figure 5.19: $PM_{2.5}$ concentration in μg/m^3 due to traffic, road dust and brick kiln emissions for July

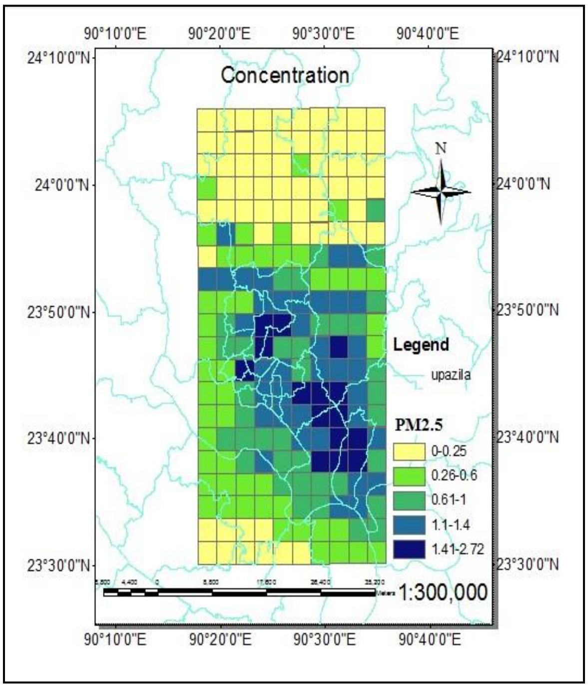


Figure 5.20: $PM_{2.5}$ concentration in μg/m^3 due to traffic, road dust and brick kiln emissions for August

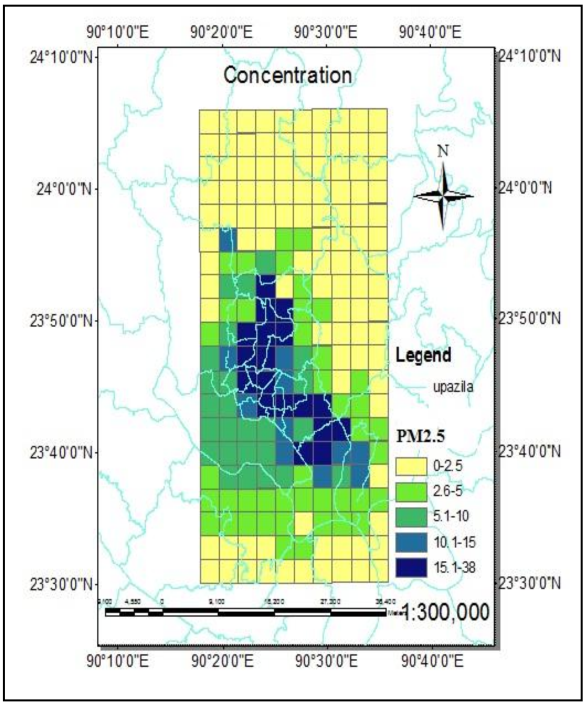


Figure 5.21: $PM_{2.5}$ concentration in μg/m^3 due to traffic, road dust and brick kiln emissions for September

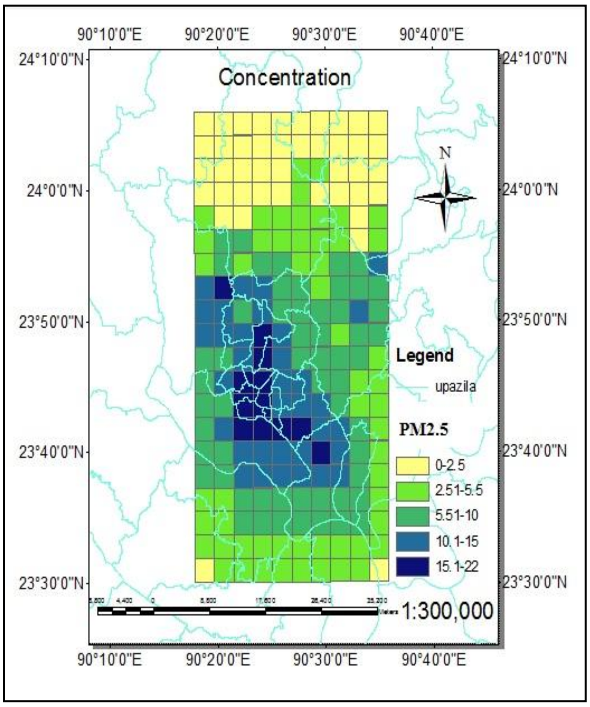


Figure 5.22: $PM_{2.5}$ concentration in μg/m^3 due to traffic, road dust and brick kiln emissions for October

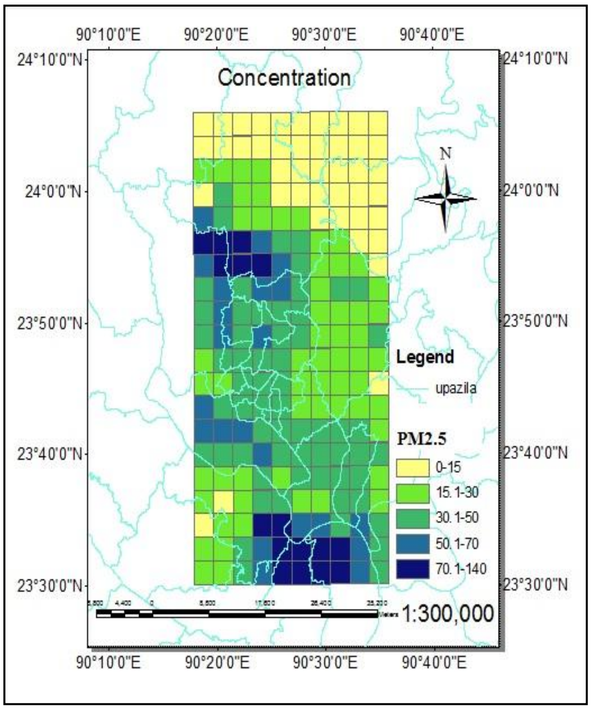


Figure 5.23: $PM_{2.5}$ concentration in μg/m^3 due to traffic, road dust and brick kiln emissions for November

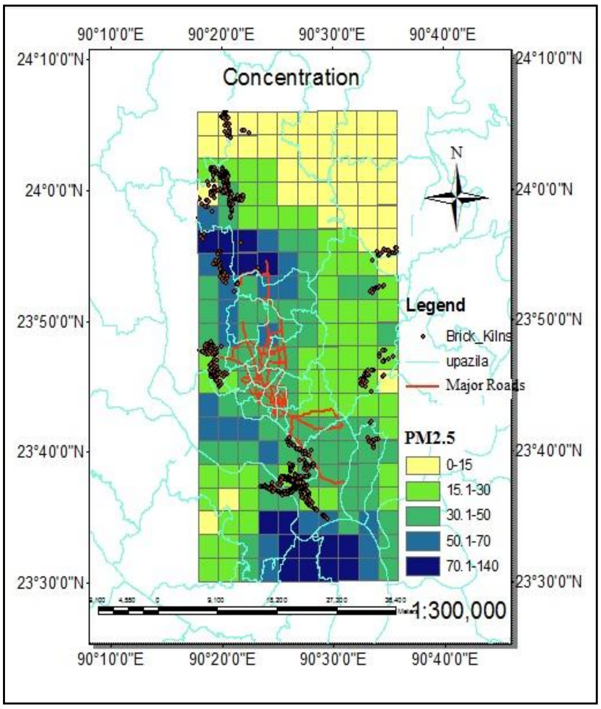


Figure 5.24: $PM_{2.5}$ concentration in μg/m^3 due to traffic, road dust and brick kiln emissions for December

Temporal Variation

Temporal variation in predicted ambient PM concentrations result from temporal variation in emission sources and also meteorology (particularly wind direction and precipitation). From the Figures 5.1 to 5.24, it is seen that the concentration of PM has very strong seasonal variation. Figure 5.25 and 5.26 show monthly average PM_{10} and $PM_{2.5}$ concentrations, respectively for the entire model domain. For PM_{10}, monthly average varies from a low of about 0.2 μg/m^3 to a high of 139 μg/m^3 in February. For $PM_{2.5}$, monthly average concentrations vary from a low of about 0.1 μg/m^3 in July to about 66 μg/m^3 in March. Figure 5.27 and 5.28 show maximum predicted concentrations of PM_{10} and $PM_{2.5}$, respectively for the dry months of the year. Maximum PM_{10} concentration of 1554 μg/m^3 has been predicted for the month of February, while maximum $PM_{2.5}$ concentration of 810 μg/m^3 has been predicted for the month of March.

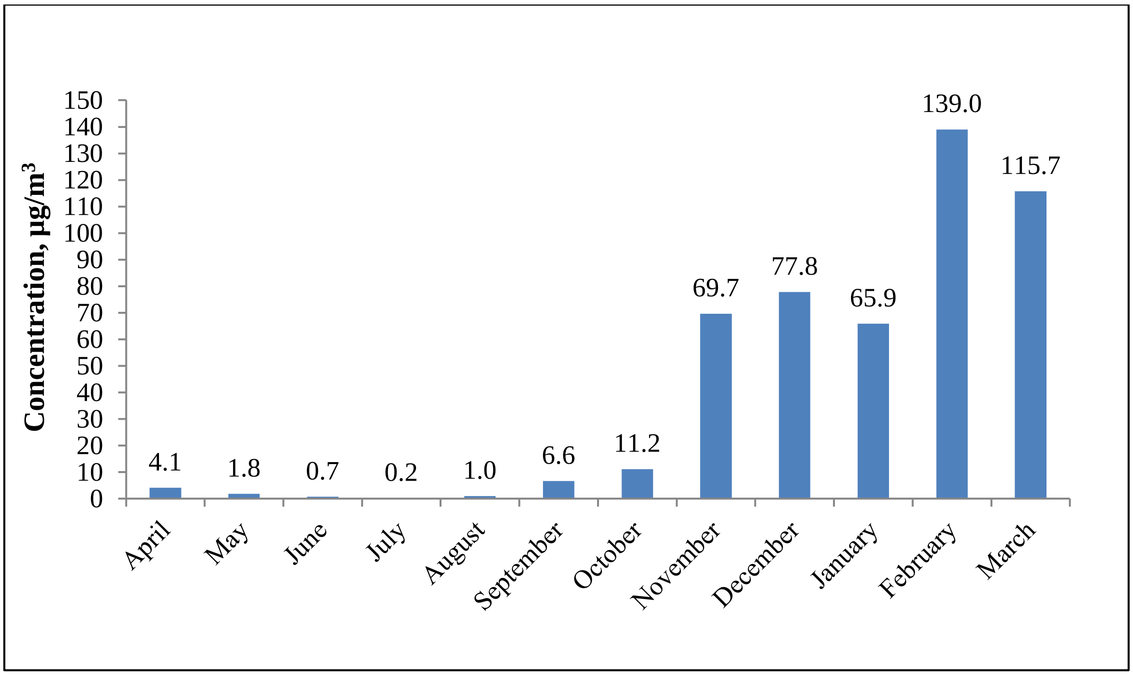


Figure 5.25: Monthly average of PM_{10} concentration for the entire model domain in μg/m^3 due to traffic, road dust and brick kiln emission.

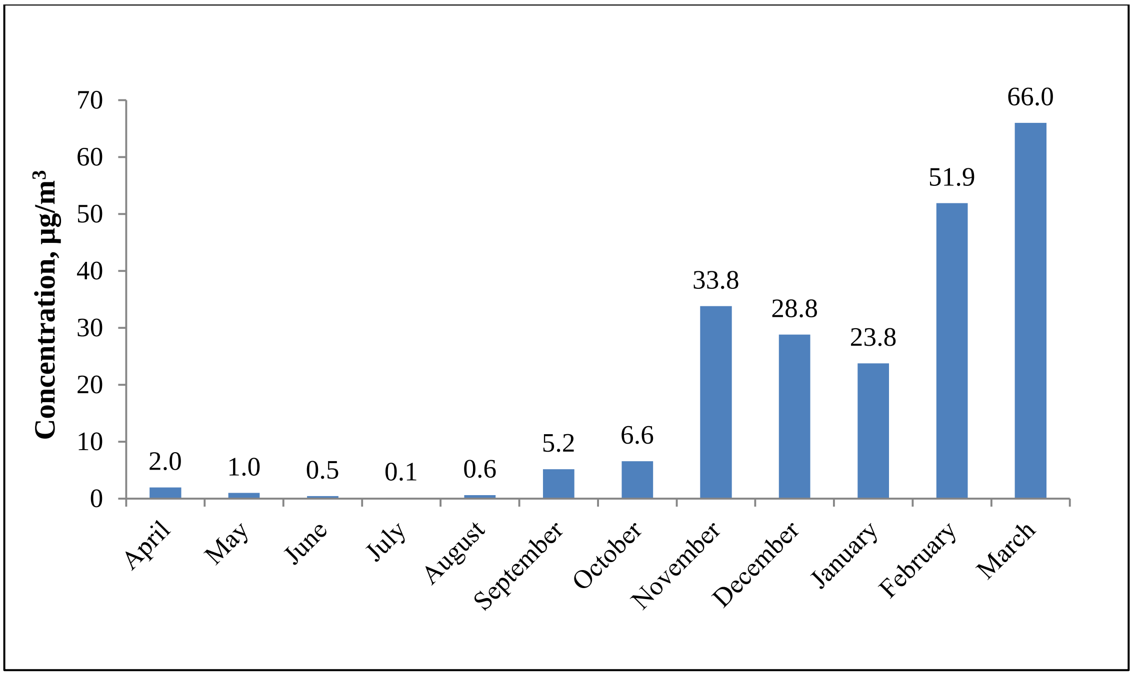


Figure 5.26: Monthly average of $PM_{2.5}$ concentration for the entire model domain in µg/m^3 due to traffic, road dust and brick kiln pollution.

Figure 5.27 and 5.28 represent the maximum PM_{10} and $PM_{2.5}$ concentration for dry season.

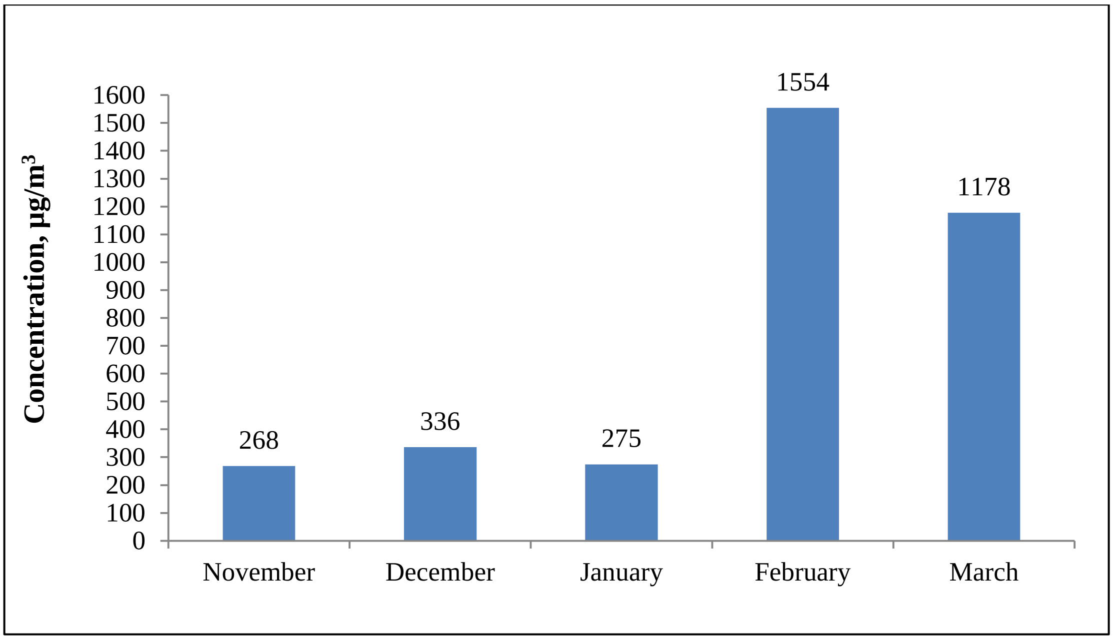


Figure 5.27: Monthly maximum of PM_{10} concentration in µg/m^3 due to traffic, road dust and brick kiln pollution for dry season.

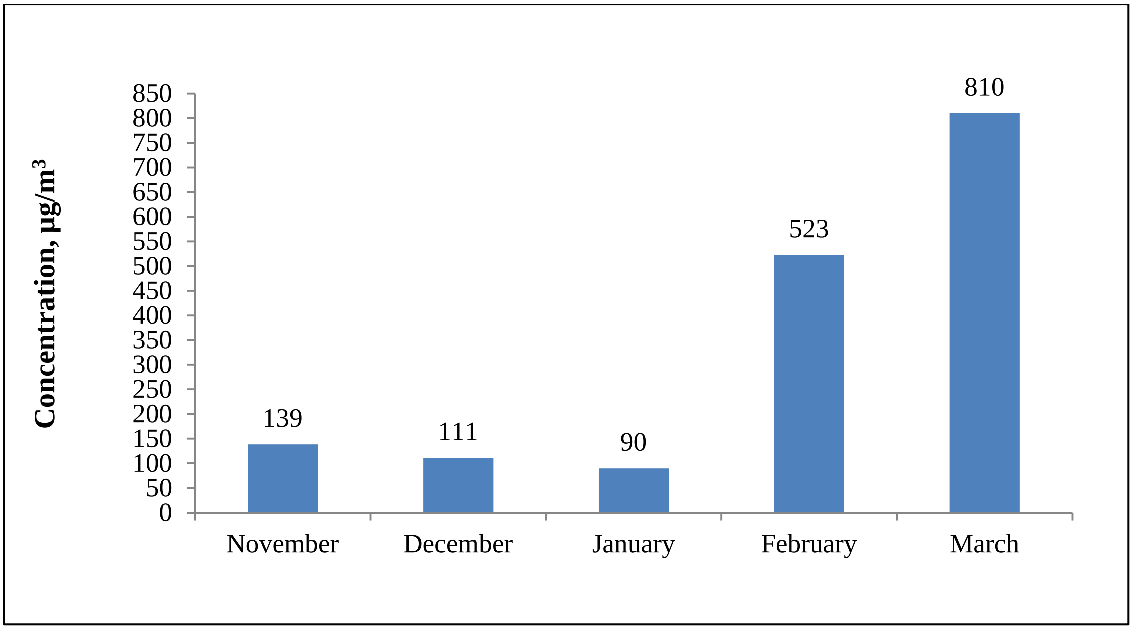


Figure 5.28: Monthly maximum of $PM_{2.5}$ concentration in µg/m^3 due to traffic, road dust and brick kiln pollution for dry season.

5.3 COMPARISON OF PREDICTED CONCENTRATION WITH "CAMS" DATA

The Department of Environment (DoE) has established a Continuous air quality Monitoring Station (CAMS) at the premises of National Parliament building in 2002. This location is within the cell no "c12" of the modeling domain. Rahman (2010) had predicted ambient concentration within the model domain considering the emission from traffic and brick kiln. In this study, road dust, a very important source of air emission has been incorporated. Figures 5.29 and 5.30 show a comparison among simulated monthly average concentrations found from the present study and Rahman (2010), and the monitored data from CAMS for both PM_{10} and $PM_{2.5}$. Though the present study has predicted the concentration for 2010, due to unavailability of data of 2010 from January to July at the CAMS, it has been compared with 2009 CAMS data.

From the figures it is seen that the concentration of both PM_{10} and $PM_{2.5}$ found from this study are higher than that of Rahman (2010) and less than the monitored data. For some months, e.g., February and March, the predicted values matched well the values recorded at the CAMS. Thus, it appears that inclusion of "road dust" in the emission inventory has improved model prediction, but still predicted values are lower than the recorded values at the CAMS, particularly from the wet months and some dry months. This could be due to the fact that industrial sources have not been considered in this study due to non-availability of relevant data (particularly locations, and emissions). Major industries that could contribute to air pollution include cement industries, power plants, steel industries, incineration, construction of structure, refuse burning, etc. Besides, it has been assumed that brick kilns do not operate in wet season from mid-April to October, which may not be entirely true; some brick kilns have been observed to remain operational beyond mid-April. In addition, there are also uncertainties in meteorological data and other model parameters (e.g., mixing depths, dry and wet deposition rates).

However, the predicted results show seasonal variation as observed in the monitored data. The concentration of both PM_{10} and $PM_{2.5}$ shows higher values in dry season and very small value in the wet season.

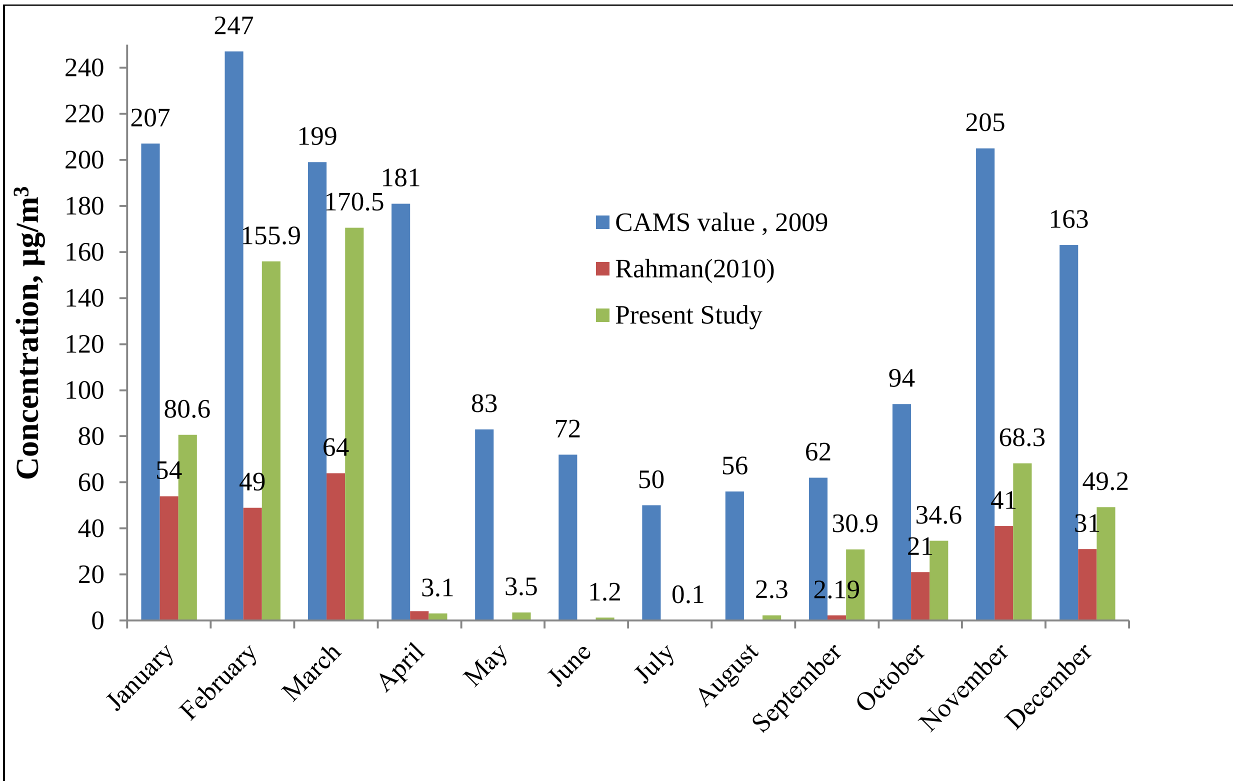


Figure 5.29: Comparison of predicted PM_{10} concentration and data recorded at the CAMS at Shangshad Bhaban

Comparison between data has given some confidence about the acceptability of the model.

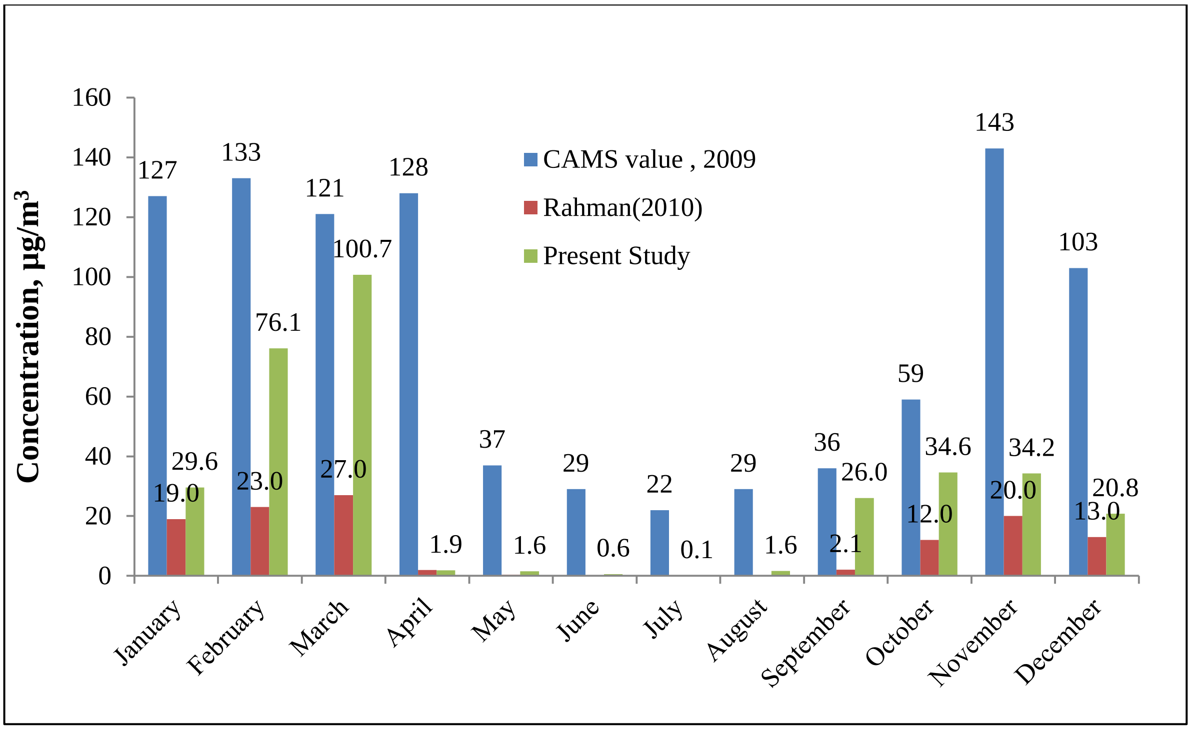


Figure 5.30: Comparison of predicted $PM_{2.5}$ concentration and data recorded at the CAMS at Shangshad Bhaban

5.4 SOURCE APPORTIONMENT

Through the analysis of the simulation results and actual measurement of ambient concentration (e.g., at CAMS), the contribution of the three different sources considered in this study could be estimated. In present study, this has been done at the CAMS location for the months of dry season i.e. for November to March. Figures 5.31 and 5.32 show the estimated contribution of different sources for the month of November and March. The mismatch of predicted and recorded concentration (shown in Figure 5.29 and Figure 5.30) is reflected in Figure 5.31 ; it shows that unknown sources (not considered in this study) accounted for about 67 percent PM_{10} concentration and 76 percent $PM_{2.5}$ concentration. On the other hand, the close match between predicted and measured concentration for March month (shown in Figure 5.33) is reflected in Figure 5.32, which shows relatively small fraction of unaccounted for sources.

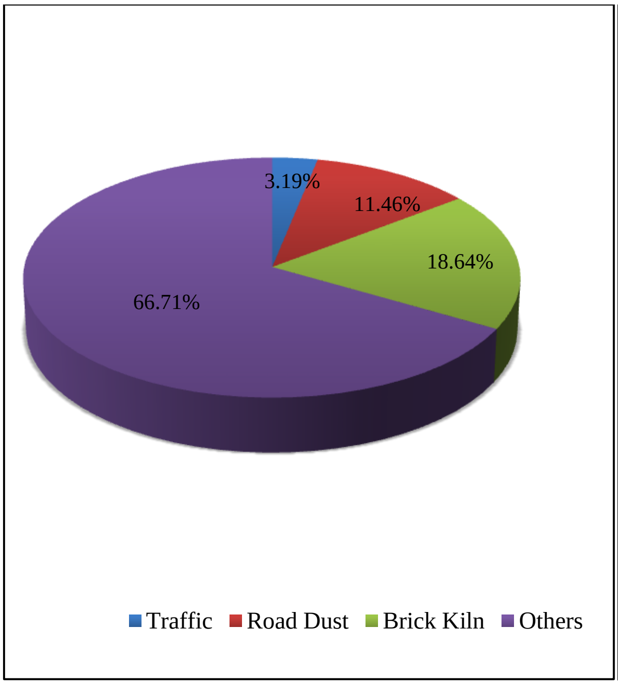


Figure 5.31(a): Percent contribution of different sources for PM_{10} in November

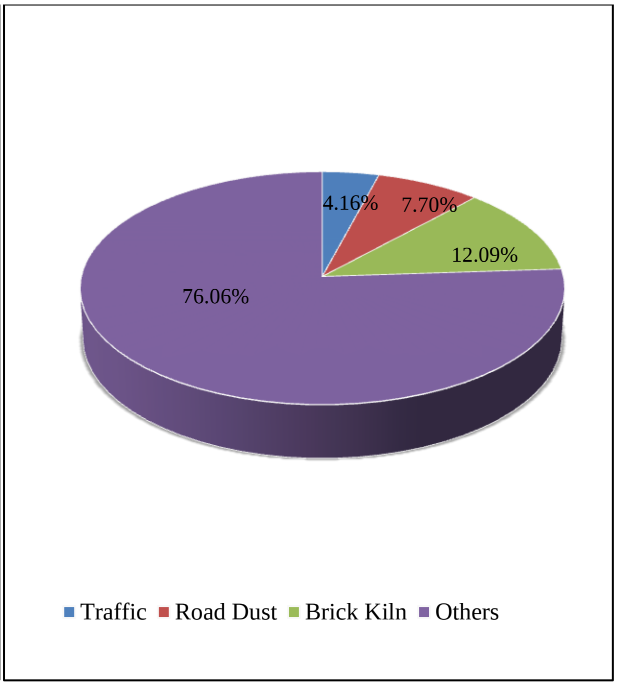


Figure 5.31(b): Percent contribution of different sources for $PM_{2.5}$ in November

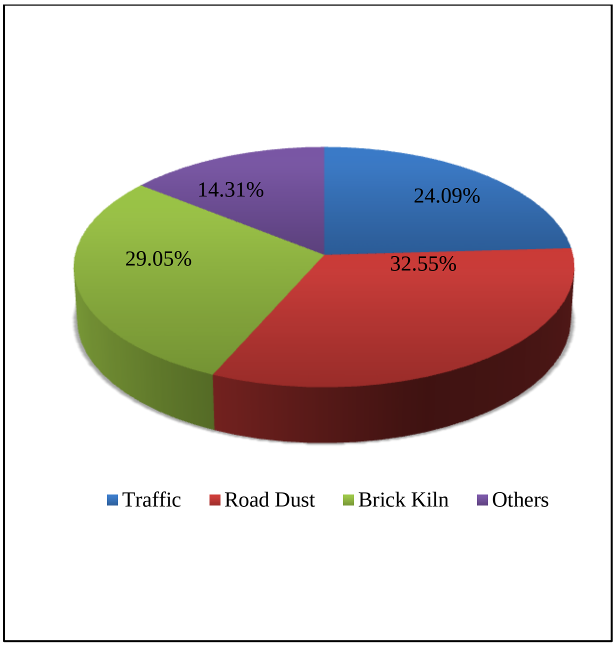


Figure 5.32(a): Percent contribution of different sources for PM_{10} in March

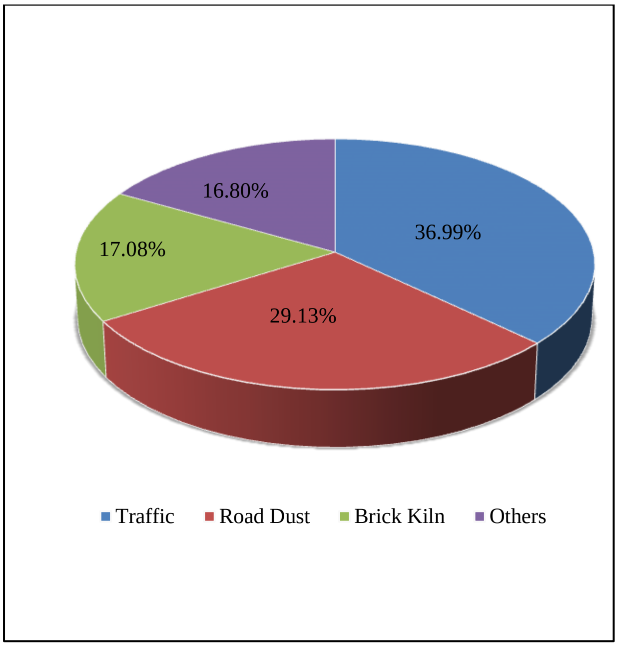


Figure 5.32 (b): Percent contribution of different sources for $PM_{2.5}$ in March

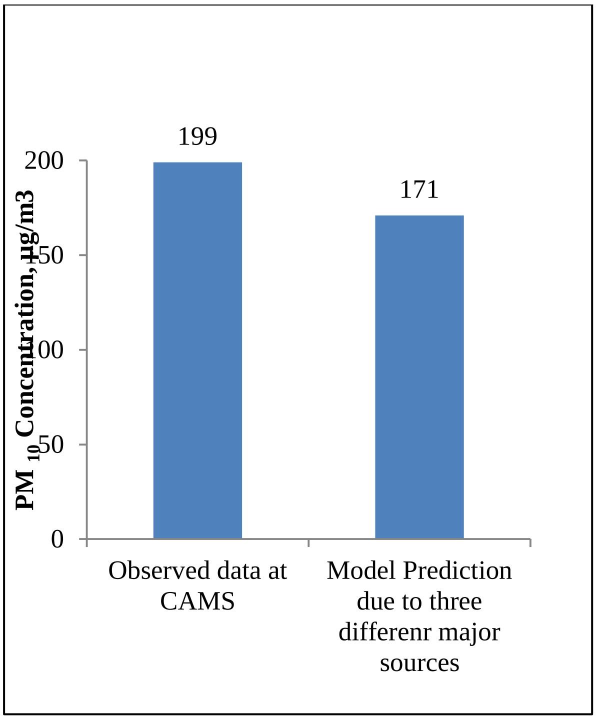


Figure 5.33(a): Comparison of predicted PM_{10} concentration and data recorded at the CAMS at Shangshad Bhaban in March

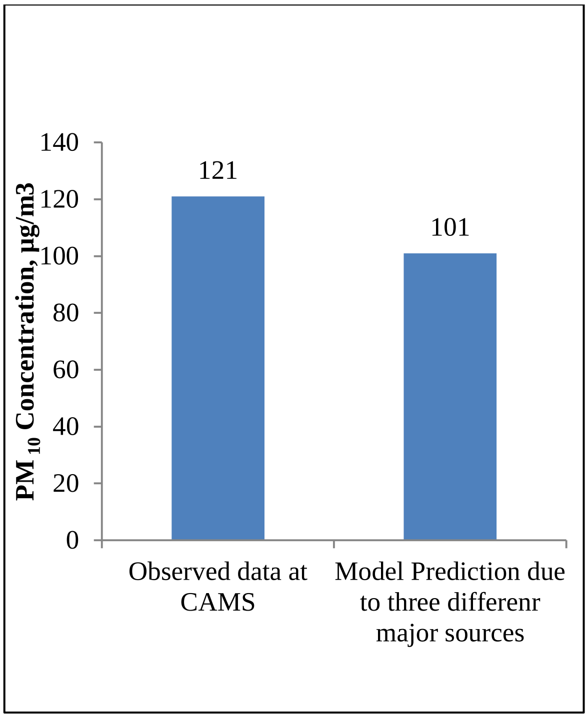


Figure 5.33 (b): Comparison of predicted $PM_{2.5}$ concentration and data recorded at the CAMS at Shangshad Bhaban in March

5.5 SUMMARY

The particulate matter pollution is the major air quality problem in Dhaka city. Within the Dhaka city for the dry period, in some parts of the city it exceeds the 24-hour average concentration, especially the bordering areas of Dhaka city where actually the brick kilns are located. Particulate matter concentration during the wet season has found to be very low, with the maximum concentration well below the standards. Study has concluded that concentrations in dry month are higher from that of wet month in a large scale.

Source apportionment at the CAMS location near Shangshad Bhaban reveals that vehicular emission, road dust and brick kilns account for about 36 percent, 29 percent, and 17 percent, respectively of ambient $PM_{2.5}$ concentration in March.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

The major objectives of the present study were to develop of a spatially disaggregated, grid-based emission inventory for Dhaka city considering three major emission sources i.e. vehicular emission, re-suspended road dust and brick kiln; and to develop of an air quality model for Dhaka city using the emission inventory. This Chapter summarizes the major findings of present study. It also presents recommendations for future study.

6.2 CONCLUSIONS

Emission Inventory

1. A GIS based spatially disaggregated emission inventory was developed for PM_{10}, $PM_{2.5}$, CO, NOx and SOx, considering three major sources i.e. motor vehicles, road dust, and bricks kilns located within and around the Dhaka city.

2. The developed emission inventory model is flexible such that it can take as input user defined parameters such as emissions factors, activity rates (e.g., AADT for vehicles), fuel use, etc; and can be easily updated as new information about the parameters become available.

3. Since brick kilns operate only during the dry season, the overall total emission is significantly high during the dry season, dominated by brick kiln emission; while wet season emission is dominated by road dust emissions. Average total monthly emission of PM_{10} for dry months (24,606 tons/month) is about ten times higher than that for a wet season (2,584 tons/month).

4. During dry season, emission from brick kiln accounts for about 87 percent of PM_{10} emission, followed by road dust (11.2 percent) and vehicle (2 percent). During wet period, road dust becomes dominant contributor of PM_{10} emission, accounting for over 80 percent of PM_{10} emissions.

5. Like PM_{10}, during dry season, emission from brick kiln is dominant while during wet period, road dust is mainly responsible for $PM_{2.5}$ emission. However, relative contribution of vehicular emission to $PM_{2.5}$ is higher than that to PM_{10} emission; during wet season, vehicular emission account for about 19.3 percent of PM_{10} emissions, while it accounts for about 36 percent of $PM_{2.5}$ emissions.

6. Diesel driven vehicles (i.e., buses and trucks) are responsible for majority of PM_{10}, $PM_{2.5}$, SOx, and NOx emissions. Together buses and trucks account for about 81 percent of vehicular PM_{10} emissions, 88 percent of vehicular $PM_{2.5}$ emissions, 94 percent of vehicular SOx emissions, and 83 percent of vehicular NOx emissions.

Prediction of Particulate Matter Concentration

1. The predicted PM concentrations within and around Dhaka city vary widely, depending on the presence of emission sources (brick kilns, major roads) and meteorology (wind direction and precipitation). The areas to the north-east of the Dhaka city i.e., Kaliganj, Sreepur are less polluted, because they are not located down-wind of the major brick kiln clusters. During wet season (April to October), predicted PM_{10} concentration are relatively low throughout the model domain, but they are much lower for the boundary areas of Dhaka City (e.g., Kapasia, Savar, Keraniganj), compared to the city-center areas.

2. For some months, e.g., February and March, the predicted values matched well the values recorded at the CAMS. But in general, the predicted values are lower than the recorded values at the CAMS. Inclusion of industrial sources (e.g., cement industries, power plants, steel industries, construction activities) in the emission inventory is likely to improve the model predictions. In addition, there are also uncertainties in meteorological data and other model parameters (e.g., mixing depths, dry and wet deposition rates).

3. Although brick kilns are the dominant emission source during the dry season, source apportionment exercise suggest that vehicular emission and road dust account for major fractions of ambient PM concentration within city areas. At the CAMS location near Shangshad Bhaban, vehicular emission, road dust and brick kilns account for about 36 percent, 29 percent, and 17 percent, respectively of ambient $PM_{2.5}$ concentration in March.

6.3 RECOMMENDATIONS FOR THE FUTURE STUDIES

The recommendations for future studies are listed below:

1. Three major sources i.e. traffic, road dust and brick kiln emissions have been considered in the present study. The effect of industrial sources (e.g., cement factories, power plants, open burning, construction site, etc.) should be considered in the emission inventory.

2. AADT for minor road and roads surrounding the Dhaka city should be measured.

3. The effect of mixing height for road dust should be considered. Important parameters for road dust emission i.e. silt loading, $PM_{2.5}/PM_{10}$ ratio, average speed should be determined through actual field measurements.

4. Uncertainty analysis of the present study could be carried out as there are significant uncertainties associated with the emission parameters. To reduce the uncertainty of the emission inventory, the input variables should be determined from field measurements.

5. The emission estimation from brick kilns should be carried out for pollutants of NOx, SO_2 and CO while updating the emission inventory.

6. Updated meteorological data should be used for generating SRM.

7. Unpaved road in the study area should be identified and emission from those roads should be incorporated properly with the current emission inventory.

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APPENDICES

Appendix A

Emission Factor of different types vehicle for developing Emission Inventory

Table A-1: Emission Factor for PM_{10} (gm/km) from different data sources

Vehicle Type	Fuel	Dhaka City State of Environment: 2005	The World Bank ,	VAPIS	SIM AIR	Bangkok		Draft mission Report, AQMP 1998	URBAIR Mumbai. 1997	CIASIA	UNEP	Malé
						Engine Category						
LDV	Gasoline	0.10	0.10					-	0.06			0.04
	CNG	0.03		0.02								
	Diesel	0.80	0.80	1.25								0.80
Taxis	CNG	0.03	0.03		0.10				0.01			0.01
	Gasoline				0.35						0.2	
	Diesel				0.90		0.20		0.84			0.84
Car/Jeep/Microbus/St.Wagon	Gasoline		0.10	0.10	0.39					0.18	0.2	0.06
	CNG		0.03	0.05	0.20							0.01
	Diesel		0.80	1.00	0.93		0.16				0.9	0.84
Pick- Up	Gasoline											
	NGV_Gasoline											
	NGV_Diesel					DDF	0.08					
	Diesel						0.16					
Van	Gasoline											
	NGV_Gasoline					MPI	0.00					
	NGV_Diesel					DDF	0.20					
	Diesel						0.20					
Autorickshaw/3W	CNG	0.03	0.03	0.10	0.10					0.75		
	Gasoline			0.20	0.20							0.35
	Diesel							0.75	0.50			0.04
Tem poo	Gasoline										0.21	
	Diesel										1.50	
Buses	CNG	1.60	1.60	0.02				0.10				0.01
	Diesel			1.50					2.00		3.0	3.00
Minibus										0.10	1.5	
Trucks	Diesel	1.60	1.60		2.50		0.66	0.45	2.00	0.45	3.0	1.50
HDT	Diesel			2.00								
Motorcycle/2w	Gasoline	0.10	0.10	0.10	0.10			0.75		0.05	0.5	0.23
												0.07

Table A-2: Emission Factor for $PM_{2.5}$ (gm/km) from different data sources

Vehicle Type/ Emission Categories	Fuel	VAPIS	Malé Emissions Inventory
LDV	CNG	0.01	
	Disel	0.50	0.80
Car	Gasoline	0.03	0.06
	CNG	0.20	0.01
	Disel	0.60	0.84
Three wheels	CNG	0.05	
	Disel		1.50
	Gasoline	0.08	0.35
Buses	CNG	0.01	0.01
	Disel	0.80	3.00
HDT	Disel	1.00	1.50
Two wheels	2-stroke	0.05	0.23
	4-stroke		0.07

Table A-3: Emission Factor for SOx (gm/km) from different data sources

Vehicle Type/ Emission Categories	Fuel	Dhaka City State of Environment: 2005	The World Bank , August, 2006	VAPIS	SIM AIR	Draft mission Report, AQMP 1998	CAI-ASIA	UNEP
LDV	Gasoline	0.08	0.08			0.05		
	CNG			0.00				
	Disel	0.40	0.40	0.30				
Taxis	CNG	0.00	0.00		0.10			
	Gasoline				0.12			0.13
	Disel				0.50			
Car/Jeep/Microbus/St.Wagon	CNG			0.00	0.08			
	Gasoline			0.07	0.08			0.13
	CNG							
	Disel			0.40	0.29		0.41	0.38
Autorickshaw/3W	CNG	0.00	0.00	0.00			0.20	
	Gasoline			0.02		0.03		
Tem poo	Gasoline							0.05
	Disel							0.39
Bus	CNG	0.80	0.80	0.00		0.40		
	Disel			1.00			3.14	1.75
Minibus	Disel						1.08	0.39
Trucks		0.80	0.80			1.13	4.27	1.75
HDT	Disel			1.00				
Motorcycle/2w	2-stroke	0.02	0.02			0.19		0.02
	4-stroke						0.22	

Table A-4: Emission Factor for NOx (gm/km) from different data sources

Vehicle Type/ Emission Categories	Fuel	Dhaka City State of Environment: 2005	The World Bank , August, 2006	VAPIS	SIM AIR	Bangkok		Draft mission Report, AQMP 1998	URBAIR Mumbai. 1997	CIASIA	UNEP
						Engine Category					
LDV	Gasoline	1.50	1.50					1.57	2.70		
	Disel	8.50	8.50	2.00							
	CNG			3.50							
Taxis	Gasoline				1.00	Fumi	0.50				2.7
	CNG	1.50	1.50		0.80	Fumi	1.65				
	Disel				1.50		1.05				1.4
Car/Jeep/ Microbus/ St.Wagon	Gasoline			0.20	0.98	Fumi	0.50				2.7
	CNG			0.20	0.79	Fumi	1.65				
	Disel			1.25	1.47		0.50		1.48		
Pick- Up	Gasoline						0.50				
	NGV_Gasoline					Fumi	0.50				
	NGV_Disel					DDF	0.61				
	Disel						0.50				
Van	Gasoline						0.50				
	NGV_Gasoline						.5,.3				
	NGV_Disel						0.91				
	Disel						1.05				
Autoricks haws /3W	Gasoline			0.10							
	CNG	1.50	1.50	0.35							
	Disel							0.03	0.13		
Tem poo	Gasoline										0.2
	Disel										13
Buses	CNG	17.00	17.00	2.50				2.50			
	Disel			10.00					22.5		13.0
Minibus	Disel								7.55		13.0
Trucks	Disel	17.00	17.00				8.83	6.48	22	22	13.0
HDT	Disel			10.00							
Motorcycl e/2w	2-stroke	0.30	0.30	0.15				0.02	0.11		0.07
	4-stroke										

Table A-5: Emission Factor for CO (gm/km) from different data sources

Vehicle Type/ Emission Categories	Fuel	Dhaka City State of Environment	Th eWorld Bank , August, 2006	VAPIS	SIM AIR	Bangkok		Draft mission Report	CAI-ASIA	Malé
						Engine Category				
LDV	Gasoline	25.00	25.00					28		
	CNG			3.50						
	Disel	5.00	5.00	2.50				24		8.70
Taxis	Gasoline					Fumi	6.00			
	CNG	5.00	5.00			OEM	2.00			4.00
	Disel						1.00			7.30
Car/Jeep/Microbus/St.Wagon	Gasoline			5.00		Fumi	6.00			9.80
	CNG			1.00		Fumi	1.34			4.00
	Disel			2.00			1.00			7.30
Pick- Up	Gasoline						2.80			
	NGV_Gasoline					Fumi	4.00			
	NGV_Disel					DDF	1.26			
	Disel						1.00			
Van	Gasoline						2.80			
	NGV_Gasoline					Fumi	4.00			
	NGV_Disel					DDF	4.91			
	Disel						1.00			
Autorickshaws /3W	CNG	5.00	5.00	3.50						
	Gasoline			8.00						14.00
	Disel									7.30
Buses	CNG			3.50						12.00
	Disel	10.00	10.00	3.50			9.01	1.30		5.50
Trucks	Disel	10.00	10.00				2.94	3.43		5.50
HDT	Disel			3.50						
Motorcycle/2w	2-stroke	5.00	5.00	2.50				26	2.20	6.50
	4-stroke									3.00

Appendix B

Annual Average Daily Traffic (AADT) for Dhaka City

Table B-1: Annual Average Daily Traffic (AADT) of Major Roads of Dhaka City (JICA, 2010)

North-South Screen Line									
SI. No.	**Road Name**	**Bus**	**Car**	**Truck**	**Pickup /Small Van**	**Taxi**	**Tampo+ laguna+ Maxi**	**Motor-cycle**	**Auto-rickshaw/ CNG/ Mishuk**
1	New Airport Road	5,269	52,672	2,783	4,030	3,932	11,806	28,016	861
2	New Eskaton Road	938	11,299	403	969	886	164	3,884	5,667
3	Hare Road	1,662	39,174	1,293	4,013	4,560	37	6,031	20,422
4	Bhashani Road (Shahbagh-Shegunbagicha)	13,518	14,241	2,770	1,050	1,118	14	3,844	7,649
5	Dhaka - Srinagor Road	2,662	2,903	1,349	1,983	403	1,642	1,515	1,839
6	Tongi-Ashura Road	2,048	4,614	1,984	1,222	747	1,909	471	1,049
7	Sonargaon Janapath	134	8,148	910	573	1,139	46	888	1,522
8	Rabindra Sarani	33	4,798	128	273	367	22	540	736
9	Jashimuddin Road	63	9,394	330	648	1,269	201	947	2,193
10	Shahid Yousuf Road	1,217	15,345	774	898	1,679	22	3,667	10,656
11	Panthapath	685	20,336	1,169	2,260	1,706	57	3,454	11,027
12	Shahid Shahidullah Kaiser Road	298	13,982	15	868	1,161	16	4,618	8,213
13	Sir Syed Ahmed Road	344	10,350	80	816	637	254	2,753	3,866
14	Zahir Raihan Sarani	1,339	3,487	407	820	257	4,234	1,572	1,229
15	Chalk Mughaltali Road	0	125	75	170	11	4	457	261
16	Uttara-Tongi Road	11,236	13,445	4,025	3,462	1,766	72	1,132	2,829

East-west screen line									
SI. No.	**Road Name**	**Bus**	**Car**	**Truck**	**Pickup /Small Van**	**Taxi**	**Tampo+ laguna+ Maxi**	**Motor-cycle**	**Auto-rickshaw/ CNG/ Mishuk**
1	Mirpur Road	10,899	40,449	3,309	2,363	4,522	598	7,527	18,716
2	Kazi Nazrul Islam Avenue	12,725	46,089	2,704	5,289	5,923	538	8,390	29,905
3	Tongi Diversion Road	5,885	32,747	2,702	4,197	3,545	1,215	7,427	28,373
4	DIT Road (Malibagh - Rumpura)	5,390	11,637	5,241	1,785	1,524	1,327	3,268	6,111
5	North - South Road	4,285	7,285	1,340	2,081	1,407	1,194	3,745	6,156
6	Atis Dipankar Road	4,812	9,909	7,107	2,764	2,188	107	1,996	8,461
7	Dhaka-Mymensingh Road	13,657	54,789	6,434	7,192	6,086	46	4,296	14,537
8	Progati Sarani	4,782	19,227	5,793	3,022	2,423	70	2,288	7,371
9	New Airport Road	11,533	42,895	2,713	5,422	5,259	79	4,508	15,528
10	Mirpur14-Mirpur10	947	12,252	772	960	2,029	1,578	3,628	8,425
11	Begum Rokeya Sarani	6,788	22,707	1,470	3,065	3,015	437	5,212	11,879
12	Mirpur Road (Shayamoli-Thecnival)	9,856	25,970	3,337	4,062	3,993	3,666	4,536	16,741
13	Sat Masjid Road	2,140	25,642	359	757	1,577	2,890	3,548	6,147
14	Jail Road (Nazimuddin Road)	3	878	369	520	97	1,595	859	753
15	Abul Hasnat Road	20	592	135	488	32	19	608	251
16	Azimpur - Lalbagh Road	3,061	2,308	55	162	204	448	1,524	1,384
17	Nawabpur Road	2,528	4,395	621	872	814	1,454	1,459	3,690
18	Narinda Road	10	1,597	344	516	148	9	1,061	1,079
19	Shahid Fazle Rabbi Road	8,603	14,220	1,590	3,004	2,674	2,056	3,202	11,576
20	Hathkhola Road	11,919	7,394	3,185	1,670	1,706	1,205	2,515	8,144
21	Dhakaswari Road	1,176	2,369	127	423	117	788	869	678
22	Gabtoli-Hazaribag Embankment Road	690	907	5,316	699	193	889	294	349
23	Mohammedpur-Hazaribag Embankment Road	614	1,185	2,965	668	159	621	459	475

24	Compani Ghat-Raj Narayan Dhar Embankment Road	491	259	1,846	507	55	827	342	274
25	Kazi Alauddin Road	2	475	117	199	77	0	1,268	1,276

Cordon line survey

SI. No.	Road Name	Bus	Car	Truck	Pickup /Small Van	Taxi	Tampo+ laguna+ Maxi	Motor-cycle	Auto-rickshaw/ CNG/ Mishuk
1	Dhaka - Comilla Road	5,552	5,236	10,732	2,832	492	1,254	735	4,462
2	Dhaka-Gazipur-Mymensingh Road	7,476	9,609	8,019	5,041	1,172	265	1,101	2,121
3	Dhaka-Manikganj Road	7,482	7,602	6,404	3,280	1,815	308	828	1,047
4	Dhaka-Mawa Road	1,239	1,270	2,691	568	158	30	1,084	9,565
5	Tongi-Ghorashal Road	736	1,816	1,528	861	305	5,325	577	1,195
6	Tongi-Ashulia Road	2,824	8,768	5,758	3,870	1,435	1,668	508	1,549
7	Mirpur-Ashulia (Western Embankment) Road	701	4,606	1,567	2,001	974	754	519	1,477
8	2nd Buriganga Bridge-Dohar Road	510	1,533	801	830	139	1,092	1,145	4,526
9	Dhaka-Munshiganj Road	677	793	1,128	211	165	2,632	317	1,473
10	Narayanganj-Kadamrasul Road	3,564	4,534	3,279	1,630	364	1,457	1,816	3,027
11	Dhaka Bypass Road	16	86	1,213	133	11	78	108	59
12	Jatrabari-Demra Road	1,560	1,024	2,779	646	190	2,746	321	1,377
13	Dhaka-2nd Buriganga Bridge	2,610	2,478	56	934	357	1,877	1,652	4,016

Additional screen line									
SI. No.	**Road Name**	**Bus**	**Car**	**Truck**	**Pickup /Small Van**	**Taxi**	**Tampo+ laguna+ Maxi**	**Motor-cycle**	**Auto-rickshaw/ CNG/ Mishuk**
1	Shaeed Tazuddin Road	8,234	22,486	2,593	3,811	2,516	100	3,906	17,206
2	Nabisco-Gulshan 1	510	27,641	684	1,924	1,399	3	3,049	8,586
3	Saidabad Road	3,554	13,270	5,288	1,684	1,632	55	3,331	7,791
4	New Circular Road	2,019	6,437	1,061	638	608	63	2,170	2,691
5	Kakrail VIP Road	5,130	27,246	1,783	2,350	3,042	59	4,875	23,381
6	Hatkhola Road	22,284	14,079	13,672	5,180	2,128	744	3,007	8,595
7	Mirpur 1 - Mirpur 10	4,692	10,954	2,688	1,762	2,020	1,119	3,962	6,162
8	Bijoy Sharani	2,083	42,671	2,464	3,281	4,312	1,101	6,291	25,747
9	Farmgate - Manikmia Avenue	7,829	15,541	811	1,465	1,218	1,959	3,351	6,391
10	Agargaon-PMO linkRoad	1,711	17,596	1,295	2,190	2,111	4,444	3,017	7,899

Table B-2: Annual Average Daily Traffic (AADT) of minor road for Dhaka City (Assumed based on number and characteristics of population and road length of a particular grid)

SI No.	Road Name	Population	Length (Km)	Thana	AADT (Assumed)						
					Bus	Car	Pickup /Small Van	Taxi	Tampo +laguna +Maxi	Motor -cycle	Auto-Ricksha w/ CNG/ Mishuk
1	Begum Rokeya Sarani	1651852	51.3	Uttara, Pallabi	100	5000	1000	500	150	1000	3000
2	Mirpur Road	1215354	72.4	Kafrul, Mohammad pur	250	8000	2000	750	200	1500	3000
3	Mazar road	1701358	0.98	Kafrul	20	800	250	50	20	200	200
4	Rabindra sarani	50968	6	Uttara	20	2500	200	250	25	200	500
5	DIT avenue	1393164	22	Khilgaon, Tejgaon	100	3000	500	50	20	500	2000
6	Banani - Gulshan-2	304694	9.6	Gulshan	25	1500	250	250	30	200	1500
7	Shahid Tajuddin Sarani Road	1205264	13	Gulshan, Tejgaon	35	2000	300	300	40	250	1700
8	Malibagh - Rampura Road	900570	3.1	Tejgaon	20	1000	150	250	25	200	1500
9	New Airport Road	416513	38.2	Cantonment	100	4000	500	50	20	500	1500
10	Atish Dipankar Road	967023	36.5	Tejgaon, Khilgaon	100	4000	500	50	20	500	2000
11	Azimpur - New Market Road	1562034	12	Kamrangir Char, Ramna	75	2500	816	637	254	2753	1000
12	Banga Bandhu Avenue	900570	0.8	Ramna	20	1000	250	50	20	200	200
13	Kazi Nazrul Islam Avenue	540189	2.6	Tejgaon	20	1500	150	250	25	200	1500
14	Bijoy Sarani	486583	1.1	Dhanmondi , Tejgaon	20	1000	250	50	20	200	250
15	Old Airport road	1823843	31.2	Ramna, Tejgaon	100	5000	500	50	20	500	2000
16	Sat masjid road	1148047	14.8	Dhanmondi	75	2500	816	637	254	2753	1000
17	Shahbag-Abdul Gani Road	900570	0.8	Ramna	20	1000	250	50	20	200	200

18	Mirpur-1 to Mirpur-10 Road	1208981	11.8	Mirpur	75	2500	816	637	254	2753	1000
19	Mirpur-10 to Mirpur-14 Road	540189	15.3	Cantonment, Mirpur	80	2500	816	637	254	2753	1000
20	New Eskaton Road	540189	4.1	Tejgaon	20	1500	150	250	25	200	1500
21	Green Road	1026772	3.6	Tejgaon	20	1500	150	250	25	200	1500

Appendix C

Table C-1: Spatial Distribution of some Major and Minor Roads of Dhaka City

Survey Road	Road Length (L) in meter									
Begum Rokeya Sarani	**Grid**	**C9**	**C10**	**C11**	**C12**	**B10**				
		262	3742	3732	1468					
	Minor		34,617	11,133	4,043	1,475				
Mirpur Road	**Grid**	**C11**	**B11**	**B12**						
		1281	854							
	Minor	49	601							
	1	1170	1596	124						
	2		2112							
	3		4165							
	4	1372	1361							
	5	547	269	43						
	6		114	940						
	7	772	1137							
	8		785	4416						
	9	274	24							
	10		630							
	11		4690							
	Total Minor	4184	17484	5523						
	Grid	**C11**			**C12**	**C13**				
	Major	436			3785	842				
	Minor									
	1	6772			15474					
	2				22921	3703				
Aricha road	**Grid**	**B11**								
		983								
Gabtoli - Technical road	**Grid**	**B10**	**B11**	**C10**	**C11**	**D11**				
		872	2251	2452	756					
	Minor				382	594				
Rabindra Sarani	**Grid**	**D8**								
		720								
	Minor	5,973								
DIT Avenue	**Grid**	**E12**	**D12**							
		1606	1098							
		13,905	7,995							

Banani - Gulshan-2	**Grid**	**D11**								
		1496								
	Minor	9,644								
Shahid Tajuddin Sarani Road	**Grid**	**D11**	**D12**							
		1097	2605							
	Minor	4,732	8,187							
Dhanmondi - Sonargaon Road	**Grid**	**C12**	**D12**							
		1229	1547							
Green Road	**Grid**	**D12**	**C12**							
		1089	1857							
	Minor	481	3,101							
Hatkhola Road	**Grid**	**E13**								
		2273								
Malibagh - Rampura Road (outer circular road to rail crossing/footpath)	**Grid**	**D12**								
		464								
	Minor	3,131								
Sonargaon-Mogbazar Road	**Grid**	**D12**								
		856								
Sheraton-Kakrail Road	**Grid**	**D13**	**E13**	**D12**						
		1656	394							
	Minor	769		1,212						
Malibagh - Moghbazar Road	**Grid**	**D12**	**E12**	**E13**						
		947	894	2264						
Kakrail - Shanti Nagar Road	**Grid**	**D12**	**D13**							
		748	339							
Jasimuddin Avenue	**Grid**	**C9**	**D8**	**D9**	**C8**					
		447	1431	680						
	Minor		6,552	254	2,586					
New Airport Road	**Grid**	**D9**	**E9**	**E10**	**D10**	**D11**				
		2906	2932	1964	4213	2979				
	Minor	4,729	5,032	1,441	13,527	13,456				
Progoti Sarani	**Grid**	**E10**	**E11**	**E12**						
		2831	3833	1089						
Atish Dipankar Road	**Grid**	**E13**	**D12**	**E12**						
		2683	1455	2271						
	Minor	14,403	4,966	17,138						
Azimpur - New Market Road	**Grid**	**C13**	**D13**							
		2694	919							
	Minor	10,451	1,557							
Banga Bandhu Avenue	**Grid**	**D13**								
		742								
	Minor	790								

Dar-us-Salam Road	**Grid**	**B11**	**C11**							
		2062								
	Minor	2,899	2,666							
Kazi Nazrul Islam Avenue	**Grid**	**D12**	**D13**							
		1360	163							
	Minor	2,629								
Bijoy Sharani	**Grid**	**C12**	**D12**							
		1590	970							
	Minor	1,138								
Old Airport Road	**Grid**	**D11**	**D12**	**C12**	**C11**					
		1699	2580							
	Minor	13,998	8,174	1,201	7,842					
Cantonment Road	**Grid**	**D9**	**D10**	**D11**						
		1464	4222	3798						
Sat Masjid Road	**Grid**	**C12**	**C13**							
		2552	207							
	Minor	14,805								
Shahbag-Abdul Gani Road	**Grid**	**D13**								
		840								
	Minor	762								
Shahid Fazle Rabbi Road	**Grid**	**D13**	**E13**							
		1014	533							
Shahid Yusuf Road (Shahid Yuauf Road)	**Grid**	**D11**								
		177								
Mirpur-1 to Mirpur-10 Road	**Grid**	**B10**	**B11**	**C10**						
		722	678	1260						
	Minor	7,242	2,167	2,436						
Mirpur-10 to Mirpur-14 Road	**Grid**	**C10**	**C11**	**D11**	**D10**					
		1981	1138	594						
	Minor	11,837	2,154	772	471					
Nawab Yusuf Road	**Grid**	**D13**								
		1769								
North South Road	**Grid**	**D13**								
		1626								
Minto Road	**Grid**	**D12**								
		994								
Narinda Road (rankin street to hatkhola road)	**Grid**	**E13**								
		765								
Dhaka - Comilla - Demra Road	**Grid**	**G14**	**F13**	**G13**	**H14**					
		22148	20693	11074	11074					

Dhaka - CTG-Comilla Road	**Grid**	**G15**	**H15**	**I15**	**I16**					
		8498	5537	5537	5537					
Dhaka - Narayanganj Road	**Grid**	**E13**	**E14**	**E15**	**F15**	**G16**				
		147	5689	17163	23306	19176				
Uttara Model Town	**Grid**	**D7**	**D8**	**D9**						
		362	3828	1350						
Zahir Raihan Road	**Grid**	**C13**	**D13**							
		726	2491							
Azimpur Lalbagh Road	**Grid**	**C13**	**D13**							
		3098	1782							
Dhaka - Manikganj - Aricha Road	**Grid**	**C13**								
		739								
Dhaka - Gazipur - Mymensingh Road (N3)	**Grid**	**D7**	**D8**	**D9**						
		3988	3828	1350						
Uttara Model Town (Uttara-tongi	**Grid**	**D8**								
		10839								
New Eskaton Road	**Grid**	**D12**								
		2042								
	Minor	4,056								
Bhashani Road (Shahbagh-Shegunbagicha)	**Grid**	**D13**								
		2888								
Tongi-Ashulia Road	**Grid**	**C7**	**C8**	**D7**						
		3258	1586	30						
Sonargaon Janapath	**Grid**	**C8**	**D8**							
		4462	18							
Sir Syed Ahmed Road	**Grid**	**C12**								
		993								
Jail Road (Nazimuddin Road)	**Grid**	**D13**								
		3765								
Abul Hasnat Road	**Grid**	**D13**								
		1228								
Nawabpur Road	**Grid**	**D13**								
		1347								
Dhakaswari Road	**Grid**	**D13**	**C13**							
		1924	316							
Kazi Alauddin Road	**Grid**	**D13**								
		1048								
Nabisco-Gulshan 1	**Grid**	**D11**								
		1148								
New Circular Road	**Grid**	**D12**	**D13**							
		1252	75							
	minor	3,981								

Dhaka-N.ganj district jail	**Grid**	**G16**								
		2030								
Dhaka-mawa	**Grid**	**A17**	**B15**	**B17**	**D14**	**E14**	**D15**	C15	B16	A18
		2652	1407	1544	457	4096	3371	3098	3649	2940
Dhaka-joydevpur-Mymensingh	**Grid**	**C3**	**D2**	**C4**	**D3**					
		2241	2369	2356	1165					
Dhaka-buriganga 2	**Grid**	**D13**	**D14**							
		521	102							
Dohar-buriganga 2	**Grid**	**A14**	**B14**	**D14**	**A15**	**C14**				
		3605	3083	2247	1689	3122				
Jatrabari-Demra	**Grid**	**E13**	**F13**	**E14**	**G13**					
		1215	1825	3153	23					
N.ganj-Kadamrasul	**Grid**	**H15**	**H17**	**I15**	**H16**	**I14**				
		6027	1854	57	3669	896				
Tongi-ghorashal	**Grid**	**d7**	**E7**	**G6**	**I6**	**E6**	**F6**	H6	J6	
		4000	6409	38	38	5456	6046	35.2	27	
Dhaka Bypass	**Grid**	**C4**	**D5**	**E6**	**F7**	**G8**	**C5**	D6	F6	G7
		1504	4275	3896	1897	1093	2201	764	2615	2163
Joydebpur - Tangail Road	**Grid**	**A3**	**B4**	**D4**	**A4**	**C4**				
		2907	3889	1278	442	3099				
Joydevpur bazar road	**Grid**	**D4**	**E4**							
		135	2248							
Purbachal	**Grid**	**E10**	**F9**	**H9**	**F10**	**G9**	**I9**			
		2892	3055	3421	311	3341	431			

Table C-2: Length (in meter) of Upazila Road in different grid of Dhaka City

All Upazila Road									
Grid	**A1**	**A2**		**A5**	**A6**	**A7**	**A8**	**A9**	**A10**
Length	3,000	8,670		20,398	13,409	3,000	3,000	3,000	3,000
Grid	**B1**	**B2**		**B5**	**B6**	**B7**	**B8**	**B9**	
Length	8,877	5,256		18,021	13,045	5,175	42,219	7,639	
Grid	**C1**	**C2**			**C6**				
Length	3,000	3,000			3,000				
Grid	**D1**								
Length	3,000								
Grid	**E1**	**E2**		**E5**			**E8**		
Length	20,280	12,866		3,000			24,250		
Grid	**F1**	**F2**	**F4**	**F5**			**F8**		
Length	17,896	12,156	3,000	3,000			17,402		
Grid	**G1**	**G2**	**G4**	**G5**					**G10**
Length	11,365	27,615	16,149	22,254					3,000
Grid	**H1**	**H2**	**H4**	**H5**		**H7**	**H8**		**H10**
Length	12,607	23,172	3,000	29,254		3,000	3,000		3,000
Grid	**I1**	**I2**	**I4**	**I5**		**I7**	**I8**		**I10**
Length	3,000	11,586	3,000	3,000		18,878	3,000		3,000
Grid	**J1**	**J2**	**J4**	**J5**		**J7**	**J8**	**J9**	**J10**
Length	3,000	3,000	3,000	3,000		18,432	6,228	3,000	9,273
All Upazila road									
Grid	**A11**	**A12**			**A16**			**A19**	**A20**
Length	12,035	12,035			3,290			3,000	9,523
Grid		**B12**					**B18**	**B19**	**B20**
Length		30,357					20,086	8,542	3,000
Grid					**C16**	**C17**	**C18**	**C19**	**C20**
Length					5,534	3,000	3,000	9,575	26,346
Grid					**D16**	**D17**	**D18**	**D19**	**D20**
Length					12,245	3,000	3,000	14,225	28,317
Grid					**E16**	**E17**	**E18**	**E19**	**E20**
Length					14,838	13,049	7,157	32,144	3,000
Grid	**F11**	**F12**	**F14**		**F16**	**F17**	**F18**	**F19**	**F20**
Length	32,602	22,917	3,000		3,000	3,000	12,387	22,118	4,817
Grid	**G11**	**G12**				**G17**	**G18**	**G19**	**G20**
Length	27,225	8,870				3,000	9,185	9,354	5,658
Grid	**H11**	**H12**					**H18**	**H19**	**H20**
Length	3,000	3,000					11,053	3,000	3,000
Grid	**I11**	**I12**			**I16**	**I17**	**I18**	**I19**	**I20**
Length	3,000	13,719			5,613	19,885	24,728	17,327	8,011
Grid	**J11**	**J12**	**J14**	**J15**	**J16**	**J17**	**J18**	**J19**	**J20**
Length	9,380	13,910	6,423	4,798	3,000	16,761	12,901	15,200	9,098

Appendix D

Grid wise Emission

Table D-1: Grid wise emission (95% confidences) in tons/year due to traffic and brick kiln emission for Dry Season (November-Mid April) and Wet Season (Mid April-October)

Grid Id	Traffic Emission				Brick Kiln Emission		Brick Kiln Emission	
	Dry and Wet Season				Dry Season		Wet Season	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
a1	0.12	0.08	0.12	0.37	0.0	0.0	0.0	0.0
a2	0.48	0.32	0.50	2.50	48.7	14.6	0.0	0.0
a3	0.35	0.23	0.37	1.84	75.2	22.6	0.0	0.0
a4	7.95	5.32	7.70	39.30	18.4	5.5	0.0	0.0
a5	0.12	0.08	0.12	0.62	3,640.2	1,092.1	0.0	0.0
a6	12.83	8.98	13.19	63.68	3,939.4	1,181.8	0.0	0.0
a7	0.12	0.08	0.12	0.62	638.3	191.5	0.0	0.0
a8	30.73	21.52	31.89	158.55	1,500.0	450.0	0.0	0.0
a9	0.81	0.53	0.83	4.21	1,760.0	528.0	0.0	0.0
a10	6.31	4.68	7.47	33.90	43.0	12.9	0.0	0.0
a11	0.71	0.47	0.74	3.72	1.9	0.6	0.0	0.0
a12	1.30	0.86	1.34	6.77	4,208.9	1,262.7	0.0	0.0
a13	0.45	0.30	0.47	2.36	6,162.0	1,848.6	0.0	0.0
a14	1.08	0.72	1.12	5.66	2,637.6	791.3	0.0	0.0
a15	0.50	0.33	0.52	2.62	278.8	83.6	0.0	0.0
a16	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
a17	0.12	0.08	0.12	0.62	41.0	12.3	0.0	0.0
a18	0.12	0.08	0.12	0.62	294.1	88.2	0.0	0.0
a19	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
a20	0.37	0.25	0.39	1.95	0.0	0.0	0.0	0.0
b1	0.34	0.23	0.36	1.80	0.0	0.0	0.0	0.0
b2	0.48	0.32	0.50	2.50	2,530.2	759.1	0.0	0.0
b3	0.21	0.14	0.22	1.09	3,930.3	1,179.1	0.0	0.0
b4	0.43	0.21	0.20	1.45	964.1	289.2	0.0	0.0
b5	0.12	0.08	0.12	0.62	9,302.1	2,790.6	0.0	0.0
b6	22.39	15.34	22.32	104.57	10,164.0	3,049.2	0.0	0.0
b7	0.70	0.49	0.82	3.94	822.8	246.8	0.0	0.0
b8	28.21	20.31	30.68	148.47	107.6	32.3	0.0	0.0
b9	0.51	0.34	0.53	2.67	1,354.0	406.2	0.0	0.0
b10	8.11	5.71	8.89	44.28	2,234.9	670.5	0.0	0.0
b11	0.48	0.32	0.50	2.53	97.3	29.2	0.0	0.0
b12	0.91	0.60	0.94	4.76	100.7	30.2	0.0	0.0
b13	1.10	0.73	1.14	5.74	1,355.7	406.7	0.0	0.0
b14	0.35	0.23	0.37	1.84	919.5	275.8	0.0	0.0
b15	0.92	0.61	0.95	4.81	90.6	27.2	0.0	0.0
b16	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
b17	0.46	0.31	0.48	2.41	0.0	0.0	0.0	0.0
b18	0.55	0.36	0.56	2.85	0.0	0.0	0.0	0.0
b19	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
b20	0.55	0.37	0.57	2.89	0.0	0.0	0.0	0.0
c1	0.44	0.29	0.53	2.60	0.0	0.0	0.0	0.0
c2	0.48	0.32	0.50	2.50	0.0	0.0	0.0	0.0
c3	0.34	0.23	0.35	1.78	447.6	134.3	0.0	0.0
c4	1.17	0.78	1.21	6.13	197.5	59.2	0.0	0.0
c5	0.66	0.46	0.78	3.72	0.0	0.0	0.0	0.0
c6	6.63	4.69	7.06	32.80	1,612.7	483.8	0.0	0.0
c7	0.34	0.24	0.40	1.94	16.5	4.9	0.0	0.0

Grid Id	Traffic Emission				Brick Kiln Emission		Brick Kiln Emission	
	Dry and Wet Season				Dry Season		Wet Season	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
c8	17.55	12.68	19.19	88.19	177.7	53.3	0.0	0.0
c9	0.13	0.09	0.14	0.70	128.4	38.5	0.0	0.0
c10	9.39	6.65	10.39	51.02	0.0	0.0	0.0	0.0
c11	0.47	0.31	0.49	2.46	0.0	0.0	0.0	0.0
c12	23.50	16.95	29.88	138.47	0.0	0.0	0.0	0.0
c13	1.23	0.81	1.27	6.43	0.0	0.0	0.0	0.0
c14	12.30	8.89	15.67	72.46	0.0	0.0	0.0	0.0
c15	0.92	0.61	0.95	4.81	0.0	0.0	0.0	0.0
c16	0.66	0.44	0.68	3.46	0.0	0.0	0.0	0.0
c17	1.23	0.81	1.27	6.40	0.0	0.0	0.0	0.0
c18	0.39	0.26	0.40	2.04	42.6	12.8	0.0	0.0
c19	0.64	0.43	0.67	3.36	147.1	44.1	0.0	0.0
c20	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
d1	0.07	0.04	0.08	0.39	0.0	0.0	0.0	0.0
d2	1.05	0.73	1.11	5.31	0.0	0.0	0.0	0.0
d3	0.59	0.39	0.70	3.47	0.0	0.0	0.0	0.0
d4	0.90	0.63	0.95	4.54	0.0	0.0	0.0	0.0
d5	1.27	0.87	1.52	7.37	0.0	0.0	0.0	0.0
d6	0.91	0.63	0.96	4.60	0.0	0.0	0.0	0.0
d7	0.23	0.16	0.28	1.37	0.0	0.0	0.0	0.0
d8	0.82	0.57	0.88	4.26	0.0	0.0	0.0	0.0
d9	0.66	0.46	0.78	3.74	0.0	0.0	0.0	0.0
d10	4.03	2.84	4.86	23.40	0.0	0.0	0.0	0.0
d11	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
d12	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
d13	0.64	0.43	0.66	3.36	0.0	0.0	0.0	0.0
d14	24.58	17.76	31.32	144.84	0.0	0.0	0.0	0.0
d15	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
d16	12.29	8.88	15.66	72.42	12.9	3.9	0.0	0.0
d17	0.12	0.08	0.12	0.62	257.1	77.1	0.0	0.0
d18	0.42	0.29	0.49	2.35	1,620.3	486.1	0.0	0.0
d19	0.12	0.08	0.12	0.62	2,913.3	874.0	0.0	0.0
d20	0.26	0.17	0.26	1.33	0.0	0.0	0.0	0.0
e1	0.81	0.54	0.84	4.24	0.0	0.0	0.0	0.0
e2	0.49	0.34	0.52	2.49	0.0	0.0	0.0	0.0
e3	0.72	0.47	0.74	3.74	0.0	0.0	0.0	0.0
e4	0.41	0.28	0.46	2.38	0.0	0.0	0.0	0.0
e5	0.15	0.11	0.21	1.00	0.0	0.0	0.0	0.0
e6	0.89	0.62	1.01	5.24	0.0	0.0	0.0	0.0
e7	0.30	0.21	0.41	1.95	0.0	0.0	0.0	0.0
e8	0.97	0.68	1.10	5.70	0.0	0.0	0.0	0.0
e9	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
e10	5.81	4.24	7.41	33.32	0.0	0.0	0.0	0.0
e11	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
e12	7.88	5.75	10.06	45.24	0.0	0.0	0.0	0.0
e13	0.89	0.59	0.92	4.62	0.0	0.0	0.0	0.0
e14	8.58	6.31	10.99	49.26	0.0	0.0	0.0	0.0
e15	1.16	0.77	1.20	6.08	0.0	0.0	0.0	0.0
e16	8.43	6.08	10.42	47.88	158.1	47.4	0.0	0.0
e17	0.12	0.08	0.12	0.62	3,445.7	1,033.7	0.0	0.0
e18	5.62	4.13	7.19	32.25	11,845.9	3,553.8	0.0	0.0
e19	0.12	0.08	0.12	0.62	6,118.0	1,835.4	0.0	0.0
e20	0.19	0.13	0.20	1.00	85.2	25.6	0.0	0.0
f1	0.53	0.35	0.55	2.79	0.0	0.0	0.0	0.0

Grid Id	Traffic Emission				Brick Kiln Emission		Brick Kiln Emission	
	Dry and Wet Season				Dry Season		Wet Season	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
f2	0.13	0.09	0.14	0.68	0.0	0.0	0.0	0.0
f3	10.58	7.00	10.95	55.29	0.0	0.0	0.0	0.0
f4	1.05	0.73	1.19	6.17	0.0	0.0	0.0	0.0
f5	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
f6	0.22	0.15	0.23	1.15	0.0	0.0	0.0	0.0
f7	0.27	0.19	0.38	1.77	0.0	0.0	0.0	0.0
f8	0.49	0.32	0.50	2.54	0.0	0.0	0.0	0.0
f9	1.45	0.82	1.41	8.53	0.0	0.0	0.0	0.0
f10	0.59	0.39	0.61	3.08	0.0	0.0	0.0	0.0
f11	1.49	0.83	1.40	8.68	0.0	0.0	0.0	0.0
f12	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
f13	0.01	0.00	0.01	0.05	0.0	0.0	0.0	0.0
f14	6.57	4.79	8.38	37.70	0.0	0.0	0.0	0.0
f15	0.01	0.00	0.01	0.04	0.0	0.0	0.0	0.0
f16	1.73	1.19	1.99	9.61	0.0	0.0	0.0	0.0
f17	0.01	0.00	0.01	0.05	2,843.6	853.1	0.0	0.0
f18	5.59	4.11	7.16	32.10	6,653.6	1,996.1	0.0	0.0
f19	0.01	0.00	0.01	0.03	4,559.7	1,367.9	0.0	0.0
f20	0.12	0.08	0.12	0.62	907.2	272.2	0.0	0.0
g1	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
g2	0.77	0.53	0.87	4.48	0.0	0.0	0.0	0.0
g3	2.76	1.83	2.86	14.42	0.0	0.0	0.0	0.0
g4	0.45	0.31	0.50	2.61	0.0	0.0	0.0	0.0
g5	2.60	1.88	3.20	15.06	0.0	0.0	0.0	0.0
g6	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
g7	6.54	4.63	7.72	36.39	0.0	0.0	0.0	0.0
g8	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
g9	1.39	0.74	1.22	7.94	0.0	0.0	0.0	0.0
g10	0.52	0.34	0.54	2.71	0.0	0.0	0.0	0.0
g11	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
g12	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
g13	0.15	0.10	0.21	0.98	0.0	0.0	0.0	0.0
g14	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
g15	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
g16	0.87	0.60	1.00	4.86	0.0	0.0	0.0	0.0
g17	0.75	0.50	0.78	3.92	0.0	0.0	0.0	0.0
g18	0.79	0.52	0.82	4.13	0.0	0.0	0.0	0.0
g19	0.73	0.49	0.76	3.83	339.7	101.9	0.0	0.0
g20	0.67	0.44	0.69	3.48	700.6	210.2	0.0	0.0
h1	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
h2	0.85	0.59	0.96	4.97	0.0	0.0	0.0	0.0
h3	5.04	3.33	5.21	26.32	0.0	0.0	0.0	0.0
h4	0.80	0.53	0.83	4.17	0.0	0.0	0.0	0.0
h5	3.97	2.93	4.69	21.39	0.0	0.0	0.0	0.0
h6	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
h7	24.98	18.41	29.63	134.88	0.0	0.0	0.0	0.0
h8	0.12	0.08	0.12	0.62	5.2	1.5	0.0	0.0
h9	0.96	0.64	1.00	5.04	51.1	15.3	0.0	0.0
h10	0.28	0.19	0.29	1.49	80.5	24.2	0.0	0.0
h11	0.69	0.46	0.72	3.62	15.0	4.5	0.0	0.0
h12	0.49	0.33	0.51	2.57	0.0	0.0	0.0	0.0
h13	0.08	0.05	0.11	0.50	198.8	59.6	0.0	0.0
h14	0.37	0.24	0.38	1.91	348.0	104.4	0.0	0.0
h15	0.12	0.08	0.12	0.62	60.4	18.1	0.0	0.0

Grid Id	Traffic Emission				Brick Kiln Emission		Brick Kiln Emission	
	Dry and Wet Season				Dry Season		Wet Season	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
h16	0.44	0.29	0.45	2.30	129.1	38.7	0.0	0.0
h17	0.12	0.08	0.12	0.62	247.8	74.3	0.0	0.0
h18	0.98	0.65	1.02	5.14	0.0	0.0	0.0	0.0
h19	0.25	0.16	0.26	1.29	0.0	0.0	0.0	0.0
h20	0.51	0.34	0.53	2.68	0.0	0.0	0.0	0.0
i1	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
i2	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
i3	0.91	0.60	0.94	4.76	0.0	0.0	0.0	0.0
i4	0.34	0.22	0.35	1.77	0.0	0.0	0.0	0.0
i5	0.74	0.55	0.83	3.76	0.0	0.0	0.0	0.0
i6	0.38	0.25	0.39	1.99	0.0	0.0	0.0	0.0
i7	20.91	14.86	22.61	105.28	2.9	0.9	0.0	0.0
i8	0.57	0.37	0.59	2.96	141.7	42.5	0.0	0.0
i9	13.85	9.80	14.69	67.01	670.8	201.2	0.0	0.0
i10	1.28	0.85	1.32	6.68	551.8	165.5	0.0	0.0
i11	0.54	0.39	0.71	3.23	84.2	25.3	0.0	0.0
i12	0.88	0.58	0.91	4.60	87.1	26.1	0.0	0.0
i13	0.59	0.43	0.77	3.53	1,335.8	400.8	0.0	0.0
i14	0.37	0.25	0.39	1.94	2,045.6	613.7	0.0	0.0
i15	0.61	0.44	0.79	3.61	345.0	103.5	0.0	0.0
i16	0.12	0.08	0.12	0.62	813.1	243.9	0.0	0.0
i17	0.08	0.05	0.10	0.46	1,393.9	418.2	0.0	0.0
i18	0.69	0.46	0.71	3.60	0.0	0.0	0.0	0.0
i19	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
i20	0.60	0.40	0.63	3.16	0.0	0.0	0.0	0.0
j1	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
j2	0.40	0.26	0.39	2.10	0.0	0.0	0.0	0.0
j3	1.88	1.28	1.90	9.88	0.0	0.0	0.0	0.0
j4	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
j5	14.23	9.70	14.04	68.93	0.0	0.0	0.0	0.0
j6	1.05	0.69	1.08	5.47	0.0	0.0	0.0	0.0
j7	28.02	19.63	29.23	140.42	141.3	42.4	0.0	0.0
j8	1.13	0.75	1.17	5.88	841.3	252.4	0.0	0.0
j9	14.37	10.35	15.97	72.45	1,899.2	569.8	0.0	0.0
j10	0.12	0.08	0.12	0.62	482.7	144.8	0.0	0.0
j11	0.06	0.04	0.07	0.33	0.0	0.0	0.0	0.0
j12	0.19	0.13	0.20	1.00	425.9	127.8	0.0	0.0
j13	0.12	0.08	0.12	0.62	1,087.4	326.2	0.0	0.0
j14	0.23	0.15	0.23	1.18	440.6	132.2	0.0	0.0
j15	0.12	0.08	0.12	0.62	25.6	7.7	0.0	0.0
j16	0.12	0.08	0.12	0.62	425.9	127.8	0.0	0.0
j17	0.12	0.08	0.12	0.62	0.0	0.0	0.0	0.0
j18	0.32	0.21	0.33	1.66	0.0	0.0	0.0	0.0
j19	0.37	0.24	0.38	1.93	0.0	0.0	0.0	0.0
j20	0.36	0.24	0.37	1.89	0.0	0.0	0.0	0.0

Table D-2: Grid wise emission (95% confidence) of PM_{10} in tons/year due to Road Dust

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
a1	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
a2	1.9	1.8	1.7	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.9
a3	3.5	3.2	3.0	2.8	2.7	2.7	2.6	2.6	2.6	2.7	2.8	3.4
a4	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
a5	4.6	4.1	4.0	3.6	3.5	3.5	3.4	3.4	3.4	3.5	3.6	4.4
a6	3.0	2.7	2.6	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.4	2.9
a7	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
a8	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
a9	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
a10	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
a11	2.7	2.4	2.3	2.1	2.1	2.1	2.0	2.0	2.0	2.1	2.1	2.6
a12	2.7	2.4	2.3	2.1	2.1	2.1	2.0	2.0	2.0	2.1	2.1	2.6
a13	2.7	2.4	2.3	2.1	2.1	2.1	2.0	2.0	2.0	2.1	2.1	2.6
a14	5.5	5.0	4.8	4.3	4.2	4.2	4.1	4.1	4.1	4.2	4.3	5.3
a15	2.6	2.3	2.2	2.0	2.0	2.0	1.9	1.9	1.9	2.0	2.0	2.5
a16	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
a17	4.6	4.2	4.0	3.6	3.5	3.5	3.5	3.5	3.5	3.5	3.6	4.4
a18	5.1	4.6	4.4	4.0	3.9	3.9	3.8	3.8	3.8	3.9	4.0	4.9
a19	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
a20	10.4	9.4	9.0	8.2	7.9	7.9	7.8	7.8	7.8	8.0	8.2	10.0
b1	2.0	1.8	1.7	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.9
b2	1.2	1.1	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.1
b3	1.9	1.7	1.7	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.9
b4	4.7	4.2	4.1	3.7	3.6	3.6	3.5	3.5	3.5	3.6	3.7	4.5
b5	4.0	3.7	3.5	3.2	3.1	3.1	3.0	3.0	3.0	3.1	3.2	3.9
b6	59.5	54.1	51.7	46.9	45.5	45.5	45.0	45.0	45.0	45.9	47.0	57.5
b7	15.5	14.1	13.5	12.2	11.9	11.9	11.7	11.7	11.7	12.0	12.2	15.0
b8	28.3	25.7	24.6	22.3	21.6	21.6	21.4	21.4	21.4	21.9	22.4	27.4
b9	5.1	4.7	4.5	4.0	3.9	3.9	3.9	3.9	3.9	4.0	4.0	5.0
b10	10.6	9.6	9.2	8.3	8.1	8.1	8.0	8.0	8.0	8.2	8.3	10.2
b11	41.5	37.7	36.1	32.7	31.7	31.7	31.4	31.4	31.4	32.1	32.8	40.2
b12	3.3	3.0	2.9	2.6	2.5	2.5	2.5	2.5	2.5	2.6	2.6	3.2
b13	6.6	6.0	5.7	5.2	5.0	5.0	5.0	5.0	5.0	5.1	5.2	6.4
b14	4.7	4.3	4.1	3.7	3.6	3.6	3.5	3.5	3.5	3.6	3.7	4.5
b15	2.4	2.2	2.1	1.9	1.9	1.9	1.8	1.8	1.8	1.9	1.9	2.4
b16	6.3	5.7	5.5	5.0	4.8	4.8	4.8	4.8	4.8	4.9	5.0	6.1
b17	2.7	2.4	2.3	2.1	2.0	2.0	2.0	2.0	2.0	2.1	2.1	2.6
b18	4.5	4.1	3.9	3.5	3.4	3.4	3.4	3.4	3.4	3.5	3.5	4.3
b19	1.9	1.7	1.7	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.8
b20	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
c1	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
c2	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
c3	4.5	4.1	4.0	3.6	3.5	3.5	3.4	3.4	3.4	3.5	3.6	4.4
c4	9.4	8.5	8.2	7.4	7.2	7.2	7.1	7.1	7.1	7.3	7.4	9.1
c5	1.3	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3
c6	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
c7	16.1	14.6	14.0	12.7	12.3	12.3	12.2	12.2	12.2	12.4	12.7	15.6
c8	20.0	18.2	17.4	15.8	15.3	15.3	15.1	15.1	15.1	15.4	15.8	19.3
c9	3.2	2.9	2.8	2.5	2.5	2.5	2.4	2.4	2.4	2.5	2.5	3.1
c10	68.1	61.9	59.3	53.7	52.1	52.1	51.5	51.5	51.5	52.6	53.8	65.9
c11	58.6	53.3	51.0	46.2	44.8	44.8	44.3	44.3	44.3	45.3	46.3	56.7
c12	80.9	73.6	70.4	63.8	61.8	61.9	61.2	61.2	61.2	62.5	63.9	78.3
c13	30.0	27.3	26.1	23.6	22.9	22.9	22.7	22.7	22.7	23.2	23.7	29.0

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
c14	4.7	4.3	4.1	3.7	3.6	3.6	3.6	3.6	3.6	3.7	3.7	4.6
c15	5.4	4.9	4.7	4.2	4.1	4.1	4.1	4.1	4.1	4.1	4.2	5.2
c16	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.2
c17	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
c18	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
c19	2.1	1.9	1.9	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.7	2.1
c20	5.9	5.4	5.1	4.6	4.5	4.5	4.5	4.5	4.5	4.5	4.7	5.7
d1	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
d2	4.8	4.4	4.2	3.8	3.7	3.7	3.6	3.6	3.6	3.7	3.8	4.6
d3	2.4	2.1	2.1	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.9	2.3
d4	1.8	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.7
d5	2.6	2.3	2.2	2.0	2.0	2.0	1.9	1.9	1.9	2.0	2.0	2.5
d6	2.3	2.1	2.0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	2.3
d7	42.7	38.8	37.2	33.7	32.6	32.7	32.3	32.3	32.3	33.0	33.7	41.3
d8	136.2	123.9	118.5	107.4	104.1	104.2	103.0	103.0	103.0	105.2	107.6	131.8
d9	95.8	87.1	83.4	75.6	73.2	73.3	72.5	72.5	72.5	74.0	75.7	92.7
d10	121.9	110.8	106.1	96.1	93.2	93.2	92.2	92.2	92.2	94.2	96.3	118.0
d11	135.7	123.4	118.1	107.0	103.7	103.8	102.6	102.6	102.6	104.8	107.2	131.3
d12	128.9	117.2	112.1	101.6	98.5	98.5	97.4	97.4	97.4	99.5	101.8	124.7
d13	80.8	73.4	70.3	63.7	61.7	61.7	61.1	61.1	61.1	62.4	63.8	78.1
d14	4.4	4.0	3.8	3.5	3.3	3.3	3.3	3.3	3.3	3.4	3.5	4.2
d15	5.8	5.3	5.1	4.6	4.5	4.5	4.4	4.4	4.4	4.5	4.6	5.6
d16	2.7	2.5	2.4	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.6
d17	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
d18	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
d19	3.2	2.9	2.8	2.5	2.4	2.4	2.4	2.4	2.4	2.5	2.5	3.1
d20	6.3	5.8	5.5	5.0	4.8	4.8	4.8	4.8	4.8	4.9	5.0	6.1
e1	4.5	4.1	3.9	3.6	3.5	3.5	3.4	3.4	3.4	3.5	3.6	4.4
e2	2.9	2.6	2.5	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.3	2.8
e3	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
e4	4.6	4.1	4.0	3.6	3.5	3.5	3.4	3.4	3.4	3.5	3.6	4.4
e5	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
e6	13.0	11.8	11.3	10.3	9.9	9.9	9.8	9.8	9.8	10.0	10.3	12.6
e7	12.5	11.4	10.9	9.9	9.6	9.6	9.5	9.5	9.5	9.7	9.9	12.1
e8	5.4	4.9	4.7	4.3	4.1	4.1	4.1	4.1	4.1	4.2	4.3	5.2
e9	59.7	54.3	51.9	47.1	45.6	45.6	45.1	45.1	45.1	46.1	47.1	57.7
e10	67.1	61.0	58.4	52.9	51.3	51.3	50.7	50.7	50.7	51.8	53.0	64.9
e11	32.4	29.4	28.1	25.5	24.7	24.7	24.5	24.5	24.5	25.0	25.5	31.3
e12	43.7	39.7	38.0	34.5	33.4	33.4	33.0	33.0	33.0	33.7	34.5	42.3
e13	49.6	45.1	43.1	39.1	37.9	37.9	37.5	37.5	37.5	38.3	39.1	48.0
e14	26.6	24.2	23.1	21.0	20.3	20.3	20.1	20.1	20.1	20.5	21.0	25.7
e15	37.4	34.0	32.6	29.5	28.6	28.6	28.3	28.3	28.3	28.9	29.5	36.2
e16	3.3	3.0	2.9	2.6	2.5	2.5	2.5	2.5	2.5	2.6	2.6	3.2
e17	2.9	2.7	2.5	2.3	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.8
e18	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.5
e19	7.2	6.5	6.3	5.7	5.5	5.5	5.4	5.4	5.4	5.5	5.7	7.0
e20	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
f1	4.0	3.6	3.5	3.2	3.1	3.1	3.0	3.0	3.0	3.1	3.2	3.9
f2	2.7	2.5	2.4	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.6
f3	2.6	2.4	2.3	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.1	2.6
f4	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
f5	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
f6	13.4	12.2	11.7	10.6	10.2	10.2	10.1	10.1	10.1	10.3	10.6	13.0
f7	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
f8	3.9	3.5	3.4	3.1	3.0	3.0	2.9	2.9	2.9	3.0	3.1	3.8
f9	3.7	3.4	3.2	2.9	2.8	2.8	2.8	2.8	2.8	2.9	2.9	3.6

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
f10	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
f11	7.3	6.6	6.3	5.7	5.6	5.6	5.5	5.5	5.5	5.6	5.8	7.1
f12	5.1	4.7	4.5	4.0	3.9	3.9	3.9	3.9	3.9	4.0	4.0	5.0
f13	162.2	147.4	141.1	127.9	124.0	124.0	122.6	122.6	122.6	125.3	128.1	156.9
f14	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
f15	50.8	46.2	44.2	40.1	38.8	38.8	38.4	38.4	38.4	39.2	40.1	49.2
f16	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
f17	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
f18	2.8	2.5	2.4	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.7
f19	4.9	4.5	4.3	3.9	3.8	3.8	3.7	3.7	3.7	3.8	3.9	4.8
f20	1.1	1.0	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9	1.0
g1	2.5	2.3	2.2	2.0	1.9	1.9	1.9	1.9	1.9	2.0	2.0	2.5
g2	6.2	5.6	5.4	4.9	4.7	4.7	4.7	4.7	4.7	4.8	4.9	6.0
g3	6.9	6.3	6.0	5.5	5.3	5.3	5.2	5.2	5.2	5.3	5.5	6.7
g4	3.6	3.3	3.1	2.8	2.8	2.8	2.7	2.7	2.7	2.8	2.9	3.5
g5	5.0	4.5	4.3	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.9	4.8
g6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
g7	1.3	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3
g8	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
g9	4.1	3.7	3.5	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.2	3.9
g10	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
g11	6.1	5.5	5.3	4.8	4.7	4.7	4.6	4.6	4.6	4.7	4.8	5.9
g12	2.0	1.8	1.7	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.9
g13	84.7	77.0	73.6	66.8	64.7	64.7	64.0	64.0	64.0	65.4	66.9	81.9
g14	169.2	153.8	147.2	133.4	129.3	129.4	127.9	127.9	127.9	130.7	133.6	163.7
g15	54.3	49.4	47.2	42.8	41.5	41.5	41.1	41.1	41.1	41.9	42.9	52.5
g16	42.4	38.5	36.8	33.4	32.4	32.4	32.0	32.0	32.0	32.7	33.4	41.0
g17	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
g18	2.1	1.9	1.8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	2.0
g19	2.1	1.9	1.8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.7	2.0
g20	1.3	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2
h1	2.8	2.6	2.5	2.2	2.2	2.2	2.1	2.1	2.1	2.2	2.2	2.7
h2	5.2	4.7	4.5	4.1	4.0	4.0	3.9	3.9	3.9	4.0	4.1	5.0
h3	5.2	4.7	4.5	4.1	4.0	4.0	3.9	3.9	3.9	4.0	4.1	5.0
h4	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
h5	6.5	5.9	5.7	5.2	5.0	5.0	4.9	4.9	4.9	5.1	5.2	6.3
h6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
h7	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
h8	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
h9	4.2	3.8	3.6	3.3	3.2	3.2	3.2	3.2	3.2	3.2	3.3	4.0
h10	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
h11	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
h12	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
h13	3.7	3.4	3.2	2.9	2.8	2.8	2.8	2.8	2.8	2.9	2.9	3.6
h14	84.6	76.9	73.6	66.7	64.7	64.7	64.0	64.0	64.0	65.3	66.8	81.9
h15	53.7	48.8	46.7	42.3	41.0	41.1	40.6	40.6	40.6	41.5	42.4	52.0
h16	11.1	10.1	9.7	8.8	8.5	8.5	8.4	8.4	8.4	8.6	8.8	10.8
h17	5.6	5.1	4.9	4.4	4.3	4.3	4.3	4.3	4.3	4.4	4.4	5.5
h18	2.5	2.2	2.1	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0	2.4
h19	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
h20	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
i1	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
i2	2.6	2.4	2.3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5
i3	6.9	6.3	6.0	5.4	5.3	5.3	5.2	5.2	5.2	5.3	5.4	6.7
i4	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
i5	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
i6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
i7	4.2	3.8	3.7	3.3	3.2	3.2	3.2	3.2	3.2	3.3	3.3	4.1
i8	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
i9	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
i10	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
i11	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
i12	3.1	2.8	2.7	2.4	2.3	2.3	2.3	2.3	2.3	2.4	2.4	3.0
i13	2.2	2.0	1.9	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	2.1
i14	2.7	2.5	2.4	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.6
i15	35.6	32.3	30.9	28.0	27.2	27.2	26.9	26.9	26.9	27.5	28.1	34.4
i16	35.4	32.2	30.8	27.9	27.0	27.1	26.8	26.8	26.8	27.3	27.9	34.2
i17	4.4	4.0	3.9	3.5	3.4	3.4	3.4	3.4	3.4	3.4	3.5	4.3
i18	5.5	5.0	4.8	4.4	4.2	4.2	4.2	4.2	4.2	4.3	4.4	5.3
i19	3.9	3.5	3.4	3.1	3.0	3.0	2.9	2.9	2.9	3.0	3.1	3.7
i20	1.8	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.7
j1	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
j2	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
j3	3.6	3.3	3.1	2.9	2.8	2.8	2.7	2.7	2.7	2.8	2.9	3.5
j4	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
j5	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
j6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
j7	4.1	3.7	3.6	3.2	3.1	3.1	3.1	3.1	3.1	3.2	3.3	4.0
j8	1.4	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.3
j9	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
j10	2.1	1.9	1.8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	2.0
j11	2.1	1.9	1.8	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.7	2.0
j12	3.1	2.8	2.7	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.5	3.0
j13	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
j14	1.4	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4
j15	1.1	1.0	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0
j16	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
j17	3.7	3.4	3.3	3.0	2.9	2.9	2.8	2.8	2.8	2.9	3.0	3.6
j18	2.9	2.6	2.5	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.3	2.8
j19	3.4	3.1	3.0	2.7	2.6	2.6	2.6	2.6	2.6	2.6	2.7	3.3
j20	2.0	1.8	1.8	1.6	1.6	1.6	1.5	1.5	1.5	1.6	1.6	2.0

Table D-3: Grid wise emission (95% confidence) of $PM_{2.5}$ in tons/year due to Road Dust

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
a1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
a2	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.6
a3	1.0	1.0	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0
a4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
a5	1.4	1.2	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.3
a6	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.9
a7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
a8	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
a9	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
a10	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
a11	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8
a12	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8
a13	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8
a14	1.6	1.5	1.4	1.3	1.3	1.3	1.2	1.2	1.2	1.3	1.3	1.6
a15	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
a16	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
a17	1.4	1.3	1.2	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.3
a18	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.5
a19	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
a20	3.1	2.8	2.7	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.5	3.0
b1	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
b2	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
b3	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.6
b4	1.4	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4
b5	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.2
b6	17.9	16.2	15.5	14.1	13.7	13.7	13.5	13.5	13.5	13.8	14.1	17.3
b7	4.7	4.2	4.1	3.7	3.6	3.6	3.5	3.5	3.5	3.6	3.7	4.5
b8	8.5	7.7	7.4	6.7	6.5	6.5	6.4	6.4	6.4	6.6	6.7	8.2
b9	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.5
b10	3.2	2.9	2.8	2.5	2.4	2.4	2.4	2.4	2.4	2.5	2.5	3.1
b11	12.5	11.3	10.9	9.8	9.5	9.5	9.4	9.4	9.4	9.6	9.9	12.1
b12	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0
b13	2.0	1.8	1.7	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.9
b14	1.4	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4
b15	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
b16	1.9	1.7	1.7	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.8
b17	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8
b18	1.3	1.2	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.3
b19	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.6
b20	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
c1	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
c2	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
c3	1.4	1.2	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.3
c4	2.8	2.6	2.5	2.2	2.2	2.2	2.1	2.1	2.1	2.2	2.2	2.7
c5	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
c6	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
c7	4.8	4.4	4.2	3.8	3.7	3.7	3.7	3.7	3.7	3.7	3.8	4.7
c8	6.0	5.5	5.2	4.7	4.6	4.6	4.5	4.5	4.5	4.6	4.7	5.8
c9	1.0	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.9
c10	20.5	18.6	17.8	16.1	15.6	15.6	15.5	15.5	15.5	15.8	16.2	19.8
c11	17.6	16.0	15.3	13.9	13.5	13.5	13.3	13.3	13.3	13.6	13.9	17.0
c12	24.3	22.1	21.1	19.2	18.6	18.6	18.4	18.4	18.4	18.8	19.2	23.5
c13	9.0	8.2	7.8	7.1	6.9	6.9	6.8	6.8	6.8	7.0	7.1	8.7

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
c14	1.4	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4
c15	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.6
c16	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
c17	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
c18	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
c19	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
c20	1.8	1.6	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.4	1.4	1.7
d1	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
d2	1.4	1.3	1.3	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4
d3	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.7
d4	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
d5	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
d6	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.7
d7	12.8	11.7	11.1	10.1	9.8	9.8	9.7	9.7	9.7	9.9	10.1	12.4
d8	40.9	37.2	35.6	32.2	31.2	31.3	30.9	30.9	30.9	31.6	32.3	39.6
d9	28.8	26.2	25.0	22.7	22.0	22.0	21.8	21.8	21.8	22.2	22.7	27.8
d10	36.6	33.3	31.9	28.9	28.0	28.0	27.7	27.7	27.7	28.3	28.9	35.4
d11	40.8	37.1	35.5	32.2	31.2	31.2	30.8	30.8	30.8	31.5	32.2	39.4
d12	38.7	35.2	33.7	30.5	29.6	29.6	29.3	29.3	29.3	29.9	30.6	37.5
d13	24.2	22.0	21.1	19.1	18.5	18.5	18.3	18.3	18.3	18.7	19.1	23.5
d14	1.3	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3
d15	1.8	1.6	1.5	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.7
d16	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8
d17	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
d18	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
d19	1.0	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.9
d20	1.9	1.7	1.7	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.8
e1	1.4	1.2	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.3
e2	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8
e3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
e4	1.4	1.2	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.3
e5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
e6	3.9	3.5	3.4	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.1	3.8
e7	3.8	3.4	3.3	3.0	2.9	2.9	2.8	2.8	2.8	2.9	3.0	3.6
e8	1.6	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6
e9	17.9	16.3	15.6	14.1	13.7	13.7	13.5	13.5	13.5	13.8	14.1	17.3
e10	20.1	18.3	17.5	15.9	15.4	15.4	15.2	15.2	15.2	15.6	15.9	19.5
e11	9.7	8.8	8.4	7.7	7.4	7.4	7.3	7.3	7.3	7.5	7.7	9.4
e12	13.1	11.9	11.4	10.3	10.0	10.0	9.9	9.9	9.9	10.1	10.4	12.7
e13	14.9	13.5	12.9	11.7	11.4	11.4	11.3	11.3	11.3	11.5	11.8	14.4
e14	8.0	7.3	6.9	6.3	6.1	6.1	6.0	6.0	6.0	6.2	6.3	7.7
e15	11.2	10.2	9.8	8.9	8.6	8.6	8.5	8.5	8.5	8.7	8.9	10.9
e16	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0
e17	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8
e18	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
e19	2.2	2.0	1.9	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.7	2.1
e20	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
f1	1.2	1.1	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.2
f2	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8
f3	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8
f4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
f5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
f6	4.0	3.7	3.5	3.2	3.1	3.1	3.0	3.0	3.0	3.1	3.2	3.9
f7	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
f8	1.2	1.1	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.1
f9	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	1.1

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
f10	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
f11	2.2	2.0	1.9	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	2.1
f12	1.5	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.5
f13	48.7	44.2	42.3	38.4	37.2	37.2	36.8	36.8	36.8	37.6	38.4	47.1
f14	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
f15	15.2	13.9	13.3	12.0	11.7	11.7	11.5	11.5	11.5	11.8	12.0	14.8
f16	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
f17	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
f18	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.8
f19	1.5	1.3	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.4
f20	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
g1	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
g2	1.9	1.7	1.6	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.5	1.8
g3	2.1	1.9	1.8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	2.0
g4	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.9	1.0
g5	1.5	1.4	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.4
g6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
g7	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
g8	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2
g9	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.2
g10	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
g11	1.8	1.7	1.6	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.8
g12	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
g13	25.4	23.1	22.1	20.0	19.4	19.4	19.2	19.2	19.2	19.6	20.1	24.6
g14	50.8	46.2	44.2	40.0	38.8	38.8	38.4	38.4	38.4	39.2	40.1	49.1
g15	16.3	14.8	14.2	12.8	12.5	12.5	12.3	12.3	12.3	12.6	12.9	15.8
g16	12.7	11.6	11.1	10.0	9.7	9.7	9.6	9.6	9.6	9.8	10.0	12.3
g17	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
g18	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
g19	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
g20	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
h1	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.8
h2	1.6	1.4	1.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.5
h3	1.6	1.4	1.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.5
h4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
h5	2.0	1.8	1.7	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.9
h6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
h7	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
h8	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
h9	1.3	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	1.0	1.0	1.2
h10	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
h11	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
h12	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
h13	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	1.1
h14	25.4	23.1	22.1	20.0	19.4	19.4	19.2	19.2	19.2	19.6	20.0	24.6
h15	16.1	14.6	14.0	12.7	12.3	12.3	12.2	12.2	12.2	12.4	12.7	15.6
h16	3.3	3.0	2.9	2.6	2.6	2.6	2.5	2.5	2.5	2.6	2.6	3.2
h17	1.7	1.5	1.5	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.6
h18	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
h19	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
h20	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
i1	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
i2	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8
i3	2.1	1.9	1.8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	2.0
i4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
i5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
i6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
i7	1.3	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2
i8	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
i9	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
i10	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
i11	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
i12	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.9
i13	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
i14	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8
i15	10.7	9.7	9.3	8.4	8.2	8.2	8.1	8.1	8.1	8.2	8.4	10.3
i16	10.6	9.7	9.2	8.4	8.1	8.1	8.0	8.0	8.0	8.2	8.4	10.3
i17	1.3	1.2	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.3
i18	1.7	1.5	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.6
i19	1.2	1.1	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.1
i20	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
j1	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
j2	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
j3	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.9	1.1
j4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
j5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
j6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
j7	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.2
j8	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
j9	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
j10	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
j11	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6
j12	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.9
j13	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
j14	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
j15	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
j16	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
j17	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.1
j18	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8
j19	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.0
j20	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6

Table D-4: Grid wise emission (95% confidence) of SOx and NOx in tons/year due to Traffic

Grid ID	SOx	NOx	Grid ID	SOx	NOx	Grid ID	SOx	NOx	Grid ID	SOx	NOx
a1	1.5	4.4	**d1**	1.0	4.7	**g1**	1.5	7.5	**j1**	1.5	7.5
a2	5.9	30.0	**d2**	13.3	63.7	**g2**	10.4	53.8	**j2**	4.7	25.1
a3	4.4	22.1	**d3**	8.4	41.7	**g3**	34.3	173.0	**j3**	22.8	118.6
a4	92.4	471.6	**d4**	11.4	54.5	**g4**	6.1	31.3	**j4**	1.5	7.5
a5	1.5	7.5	**d5**	18.3	88.4	**g5**	38.5	180.7	**j5**	168.4	827.2
a6	158.3	764.1	**d6**	11.5	55.2	**g6**	1.5	7.5	**j6**	13.0	65.7
a7	1.5	7.5	**d7**	3.3	16.4	**g7**	92.6	436.7	**j7**	350.7	1685.0
a8	382.7	1902.6	**d8**	10.5	51.2	**g8**	1.5	7.5	**j8**	14.0	70.6
a9	10.0	50.6	**d9**	9.4	44.8	**g9**	14.6	95.3	**j9**	191.7	869.4
a10	89.7	406.8	**d10**	58.4	280.8	**g10**	6.4	32.5	**j10**	1.5	7.5
a11	8.8	44.6	**d11**	1.5	7.5	**g11**	1.5	7.5	**j11**	0.9	3.9
a12	16.1	81.3	**d12**	1.5	7.5	**g12**	1.5	7.5	**j12**	2.4	12.0
a13	5.6	28.3	**d13**	8.0	40.3	**g13**	2.5	11.8	**j13**	1.5	7.5
a14	13.4	67.9	**d14**	375.8	1738.1	**g14**	1.5	7.5	**j14**	2.8	14.1
a15	6.2	31.4	**d15**	1.5	7.5	**g15**	1.5	7.5	**j15**	1.5	7.5
a16	1.5	7.5	**d16**	187.9	869.1	**g16**	12.1	58.3	**j16**	1.5	7.5
a17	1.5	7.5	**d17**	1.5	7.5	**g17**	9.3	47.1	**j17**	1.5	7.5
a18	1.5	7.5	**d18**	5.8	28.2	**g18**	9.8	49.6	**j18**	4.0	20.0
a19	1.5	7.5	**d19**	1.5	7.5	**g19**	9.1	46.0	**j19**	4.6	23.1
a20	4.6	23.4	**d20**	3.2	16.0	**g20**	8.3	41.8	**j20**	4.5	22.7
b1	4.3	21.6	**e1**	10.1	50.9	**h1**	1.5	7.5			
b2	5.9	30.0	**e2**	6.2	29.9	**h2**	11.5	59.6			
b3	2.6	13.1	**e3**	8.9	44.9	**h3**	62.6	315.8			
b4	2.4	17.4	**e4**	5.5	28.5	**h4**	9.9	50.1			
b5	1.5	7.5	**e5**	2.5	12.0	**h5**	56.3	256.7			
b6	267.8	1254.9	**e6**	12.2	62.8	**h6**	1.5	7.5			
b7	9.9	47.2	**e7**	4.9	23.4	**h7**	355.5	####			
b8	368.2	1781.7	**e8**	13.2	68.4	**h8**	1.5	7.5			
b9	6.4	32.1	**e9**	1.5	7.5	**h9**	12.0	60.5			
b10	106.7	531.4	**e10**	88.9	399.8	**h10**	3.5	17.8			
b11	6.0	30.3	**e11**	1.5	7.5	**h11**	8.6	43.4			
b12	11.3	57.1	**e12**	120.7	542.9	**h12**	6.1	30.9			
b13	13.6	68.9	**e13**	11.0	55.5	**h13**	1.3	6.0			
b14	4.4	22.1	**e14**	131.8	591.2	**h14**	4.5	22.9			
b15	11.4	57.8	**e15**	14.4	72.9	**h15**	1.5	7.5			
b16	1.5	7.5	**e16**	125.1	574.6	**h16**	5.5	27.6			
b17	5.7	28.9	**e17**	1.5	7.5	**h17**	1.5	7.5			
b18	6.8	34.2	**e18**	86.3	387.0	**h18**	12.2	61.7			
b19	1.5	7.5	**e19**	1.5	7.5	**h19**	3.1	15.5			
b20	6.9	34.7	**e20**	2.4	12.0	**h20**	6.4	32.2			

c1	6.3	31.2	**f1**	6.6	33.4	**i1**	1.5	7.5
c2	5.9	30.0	**f2**	1.6	8.2	**i2**	1.5	7.5
c3	4.2	21.3	**f3**	131.4	663.5	**i3**	11.3	57.1
c4	14.6	73.6	**f4**	14.3	74.0	**i4**	4.2	21.3
c5	9.3	44.7	**f5**	1.5	7.5	**i5**	10.0	45.1
c6	84.8	393.6	**f6**	2.7	13.8	**i6**	4.7	23.9
c7	4.8	23.2	**f7**	4.5	21.3	**i7**	271.3	####
c8	230.3	1058.3	**f8**	6.0	30.5	**i8**	7.0	35.5
c9	1.7	8.4	**f9**	16.9	102.4	**i9**	176.2	804.1
c10	124.6	612.2	**f10**	7.3	37.0	**i10**	15.9	80.2
c11	5.8	29.5	**f11**	16.8	104.2	**i11**	8.5	38.7
c12	358.5	1661.6	**f12**	1.5	7.5	**i12**	10.9	55.2
c13	15.3	77.1	**f13**	0.1	0.6	**i13**	9.3	42.3
c14	188.0	869.5	**f14**	100.5	452.4	**i14**	4.6	23.3
c15	11.4	57.8	**f15**	0.1	0.5	**i15**	9.5	43.4
c16	8.2	41.5	**f16**	23.8	115.3	**i16**	1.5	7.5
c17	15.2	76.8	**f17**	0.1	0.6	**i17**	1.2	5.5
c18	4.9	24.5	**f18**	85.9	385.2	**i18**	8.6	43.2
c19	8.0	40.4	**f19**	0.1	0.4	**i19**	1.5	7.5
c20	1.5	7.5	**f20**	1.5	7.5	**i20**	7.5	37.9