Air Quality Assessment and the Health Effects of Air Pollution in Dhaka City through Impact-Pathway Model

by

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

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DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

September, 2010

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Sheikh Mokhlesur Rahman

Dedicated

To

My Mother

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ABSTRACT

Dhaka, the capital city of Bangladesh, with a population density of around 20,000 per square kilometer is at the risk of experiencing significant health impacts from poor air quality, especially during the dry season. The economic cost associated with urban air pollution is estimated to be around 1.1% of national GDP.

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

Currently, the institutions lack an integrated policy analysis tool to help the decision makers evaluate alternate air pollution management strategies and analyze costs and benefits. This research aims to fill this gap, by developing a policy analysis tool for Dhaka to better understand the impact of various abatement measures and potential for environmental benefits. The tool is designed to follow the impact pathway approach linking the changes in emissions with changes in ambient concentration, especially particulate matter (PM) and related health impacts - mortality effects and the associated monetized benefits.

A grid based source-receptor matrix over Dhaka has been developed using an atmospheric dispersion model, considering temporal variations in emissions and weather parameters round the year. The contributions from major sources (vehicles, and brick kilns) have been considered in determining the ambient PM concentrations; both spatial and temporal variations of PM have been estimated. In the Dhaka city the PM_{10} concentrations in dry season has been estimated to be less than 50 $\mu g/m^3$ to about 150 $\mu g/m^3$. The range of $PM_{2.5}$ concentration in the city has been estimated in between 25 $\mu g/m^3$ and about 65 $\mu g/m^3$. Near the National Parliament Building, where CAMS (air quality monitoring station) is located, brick kiln has been found to be 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 at that specific site. However, the source-receptor matrix could be easily utilized to obtain ambient concentrations as new sources are added/removed from the domain.

Particulate related health impacts have been evaluated utilizing established concentration-response functions for mortality due to pollution exposure. Moreover, the monetary value of these health impacts due to traffic and brick kiln emissions are estimated. Finally, the study presents case studies under “what-if” scenarios for multiple policy alternatives using the developed policy assessment tool for Dhaka. It has been found that significant health and economic benefits could be achieved with policy interventions aimed at improving air quality.

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CHAPTER ONE
INTRODUCTION

1.1 Background

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

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

Air quality (AQ) in Dhaka is monitored systematically only at one Continuous Air Monitoring Station (CAMS) since April 2002. 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 indicate long-term trends in the AQ of the city, but can provide indications of trends. PM concentrations (as PM_{10} and $PM_{2.5}$) on an annual basis in Dhaka indicate 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 µg/m^3) and $PM_{2.5}$ (15 µg/m^3) by a factor of over two.

A number of studies have assessed the impacts of air pollution on the health of people in Bangladesh, primarily focusing Dhaka. Air pollution is estimated to be responsible for approximately 3,580 premature deaths, 10 million restricted activity days and 87 million respiratory symptom days per annum (ADB and CAI-Asia, 2006). An estimated 15,000 premature deaths, as well as several million cases of pulmonary, respiratory and neurological illness are attributed to poor air quality in Dhaka, according to the Air Quality Management Project (AQMP), funded by the government and the World Bank. The World Health Organization (WHO) says vehicular air pollution is a major cause of respiratory distress in urban Bangladesh (IRIN, 2009). 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).

As the air quality of Dhaka is deteriorating rapidly, kind attention in this matter is very vital. In order to control the deterioration, some abatement measures need to be taken. There are a number of alternatives that could be taken to control the air pollution. Recently, the Government introduced a number of initiatives such as banning of two-stroke engine vehicles, promoting the use of alternative fuels like CNG, banning of old vehicles from plying on streets, in order to curb the growing air pollution problem. These policy decisions are taken on ad-hoc basis, yet some improvements have been observed. But there is a lack of benefit modeling to support these decisions due to limited monitoring and limited analysis of the options.

Extensive studies on cost-benefit analyses of the alternatives are required to support the policy implementation. The decision may fail if the benefit resulted from the policy implementation exceeds the cost associated with the executions of the alternatives. This renders the need of an Impact Pathway Modeling. But there is no such Impact Pathway Model which may help in analyzing the policy alternatives. Thus a necessity of policy analysis tool which will help to take necessary actions to reduce the effect of air pollution arises. The present study has been conducted with a view to develop such a policy analysis tool through Impact Pathway Approach, which might help the decision makers to take some abatement measures to reduce or control the effect of air pollution.

1.2 Objective of the Study

The overall objective of the present study is to develop a policy analysis and planning tool for assessing the effect of air quality management options in Dhaka city. Specific objective of this study include:

i) Assessment of air quality and emission of pollutants in Dhaka city.
ii) Identifying and estimating meteorological and dispersion parameters needed for air quality modeling of Dhaka city.
iii) Developing a source-receptor air quality model for Dhaka city.
iv) Generating the ambient concentration of different pollutants, especially particulate matter in Dhaka city using the developed model source-receptor model and predetermined emission inventory.
v) Estimation health effects and corresponding air pollution related health costs/benefits for different policy scenario.
vi) Estimation of monetary value of health impact of the pollutant concentration.

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 on the data available from different source e.g. AQMP, DoE, BAEC. Pollutant emissions from different sources also will be assessed. Furthermore a grid-based emission inventory will be constructed to use in the air quality model.

Identifying meteorological and dispersion parameters:

Dispersion of pollutants in atmosphere largely depends upon the meteorological and atmospheric dispersion parameters (wind speed, direction, mixing depth). These parameters vary both locally and temporally. Relevant parameters and there spatial and temporal variations will be assessed and appropriate values for these parameters will be selected for use in the air quality model.

Developing a source-receptor model (SRM) for the Dhaka city:

In order to develop a source-receptor model for the Dhaka city, the city will be will be divided into a number of grids. Source-receptor matrix defines the incremental change in concentration in any cell for a unit change in emissions in any one cell. A grid-based model will be used to develop the SR matrix.

Generate ambient concentration of different pollutants in Dhaka city:

The ambient concentration will be found by multiplying the source receptor matrix and the emission inventory matrix following Guttikunda and Harshadeep (2009). In determining the concentration of the pollutants, effects of both primary and secondary pollutants have been considered. For example, in case of particulate matter concentration secondary particulate matter formed from the NO_x and SO_x in the atmosphere will be considered as well as the primary particulate matter generated from the different sources.

Estimation of monetary value of health impact of the pollutant concentration:

Health impacts of air pollution are important for air quality planning for a city. After getting the concentration of the pollutants, an assessment of human exposure to pollution will be conducted. Then the health impacts of air pollution will be estimated from the concentration-response relationships found in the literature. Monetary values of the health impacts/ benefits will be estimated with calculations depending upon the type of impact. The value of statistical life (VSL) approach will be adopted in the monetary valuation of the health impacts.

Estimation of health effects and corresponding air pollution related health benefits/costs for different policy scenario:

Using the model developed, a few policy approaches to reduce air pollution will be investigated as case-studies.

1.4 Organization of the Thesis

The thesis is presented in six chapters. The first chapter (Chapter 1) presents the background of the study, objectives and outline of the methodologies of the study.

Chapter 2 reviews the basic information of air pollution and its impacts. This chapter provides summary of some of the earlier studies on air quality modeling and health impact evaluation.

Chapter 3 describes the methodologies adopted in the present study. It describes the Impact Pathway Approach to determine the health impact of air pollution. This Chapter also presents the setting up of the air quality model, emission inventory and population estimation.

Chapter 4 presents the particulate matter concentration in Dhaka city due to emissions from road traffic and brick kilns. Both the spatial and temporal distributions of the particulates are described in this Chapter.

Chapter 5 illustrates the health impact of the particulate ($PM_{2.5}$) pollution in Dhaka. Some policy alternatives and their consequences are also depicted in this Chapter.

Finally Chapter 6 draws the conclusion of the study. It also contains the limitations of the present study and the recommendations for future studies.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Air pollution is one of the major manmade environmental in Bangladesh. Exposure to air pollution is a major environmental threat to human health in large cities such as city, Dhaka. 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. But it is not feasible to measure the air quality of all over the area. Furthermore, sometimes forecasting of future air quality is essential. So in order to help in these regards air quality modeling has been developed. This chapter deals with not only the air pollution and its impact but also describes the air quality modeling to visualize the air quality of an area. This chapter also summarizes some of the studies on source apportionment of air pollution and also the evaluation of air pollution related health effects.

2.2 Air Pollution and its Impact

Before describing the air quality of the Dhaka city, the information on air pollution and the impact of air pollutants are elementary necessities. The subsequent articles discuss the air pollution concept and its impact.

2.2.1 Air pollution

Air pollution may be defined as any atmospheric condition in which substances (gases, liquid drops or solid particles) are present at concentrations above their normal ambient levels, produce a “measurable adverse effect” on human, animal, vegetations or materials. Figure 2.1 shows the typical air pollution system of an area. The figure illustrates the common sources of air pollution, transportation and transformation of pollutants in the atmosphere and their effect on some of the resources of the environment. Air pollution affects the soil, water, natural resources, human health and even different types of materials.

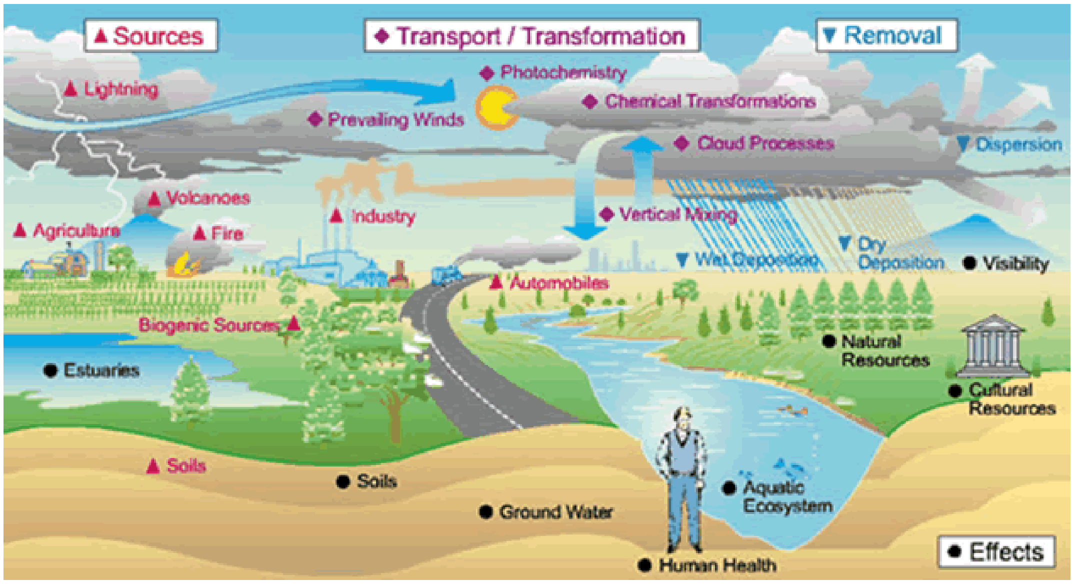


Figure 2.1: Air pollution: sources and effects (National Park Service, 2010)

2.2.1.1 Local pollution

Local air pollution is resulted from the local emissions of pollutants e.g., emissions from industry, vehicle etc. Air pollution in the nineteenth and early twentieth centuries was generally local, and concentrated in or around industrial centers and big cities. Even the infamous environmental catastrophes in the area of Liege in the 1930s, the first recorded occurrence of death by air pollution, or in London in the 1950s, were essentially local phenomena (Slanina, 2010).

2.2.1.2 Regional pollution

Only in the second half of the 20th century were the effects of air pollution detected on regional (>500 km), continental, and global scales. Smog episodes in U.S. cities, such as Los Angeles, were reported during that period. Reactions of volatile organic compounds (VOCs) and nitrogen oxides (NO_x) produced high concentrations of ozone and peroxides that are harmful to human and ecosystem health. Around the same period, the first high oxidant concentrations (the complex mixture of ozone, peroxides and other products of the reactions of organics and nitrogen oxides are called oxidants) were more and more frequently occurring in Europe during stagnant meteorological conditions (Slanina, 2010).

2.2.1.3 Global pollution

The next scale of air pollution is its effect on global dimensions, such as the destruction of stratospheric ozone due to emissions of CFC's (chlorofluorocarbon compounds). This issue was given a lot of attention in the period 1985–1995, as it was revealed that the destruction of stratospheric ozone leads to higher UV-light intensities and a higher incidence of skin cancer (Slanina, 2010). Presently, the increase in the concentrations of radioactive substances (compounds which alter the radioactive balance of the Earth; greenhouse gases; but also aerosols, and water in liquid form, as clouds) and the connected climatic consequences brought about new dimension in air pollution.

2.2.2 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):

i. *Transportation/ mobile sources:* Motor vehicles, rails, ships, aircrafts etc
ii. *Stationary sources:* Fuel combustion in power plant, heating plant, etc.
iii. *Industrial processes:* Chemical, metallurgical, paper-pulp industries, petroleum refineries.
iv. *Incineration or burning of wastes:* Household and commercial wastes, agricultural burning, industrial and hazardous waste incineration
v. *Miscellaneous sources:* Re-suspension from roads, Domestic fuel/wood burning, Forest fire, volcanic eruption, pollen grains etc (natural sources)

2.2.3 Classification of pollutants

There are various air pollutants. They can be classified into different groups from different aspects. The classification of air pollutants is discussed in the following articles.

2.2.3.1 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.

a) *Primary Pollutants:*

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

b) *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.

2.2.3.2 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)

2.2.3.3 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

2.2.3.4 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.

2.2.4 Air pollutants

The most common air pollutants in urban and industrial areas are particulate matter, CO, NO_x, SO_x and O_3 (Masters, 2004). In addition, there could be a wide range of other pollutants (e.g. organic compounds, toxic chemicals, asbestos, etc.) present in air in certain areas depending on the land use and activity pattern in that area.

Criteria pollutants

Among the major air pollutants, six are identified as causing harmful health effects. As they are causing the adverse impact on human health ambient air quality guidelines have been established for these pollutants. These six pollutants are CO, Pb, NO_2, SO_2, O_3 and Particulate Matter. They are combinedly known as “Criteria Pollutants”.

2.2.5 Effects of air pollutants

Effects of air pollutants can be categorized as effects:

- on atmospheric properties
- on materials
- on vegetation
- on human health

But recent studies have established that the major adverse effect of air pollution is on human health (USEPA, 2007). Hence mainly the health impact of air pollutants are discussed in the following subsections.

2.2.5.1 Particulate matter

Any dispersed substance, except pure water, that exists as a liquid or solid in the atmosphere under normal conditions and is of microscopic or submicroscopic size, but larger than molecular dimension (about 2 Å) are termed as particulate matter. Once the particulates are in the atmosphere, their size, number and chemical composition are changed by several mechanisms until they are ultimately removed by natural processes. Major natural sources of particulate matters are soil and rock erosion, forest fire, sea spray, volcanoes etc. Among the anthropogenic sources industrial processes, transportation, fugitive emission from industries, fugitive emission from non- industries (e.g., road dust, construction debris etc) are the common.

About 90% of all respirable particles in the earth's atmosphere are natural. About 10 % are anthropogenic (Masters, 2004). However, most natural particles are relatively harmless, e.g., soil, sea-spray, biological materials etc. Particles of anthropogenic origin, on the other hand, are often toxic. Non-uniform distribution of anthropogenic particle sizes makes them even more dangerous.

Size distribution of particulates

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. Particles with aerodynamic diameter not more than 2.5 μm are termed as "Fine Particles" and the particles larger than 2.5 μm are known as "Coarse Particles". Figure 2.2 shows the particles size distribution that are ideally found in the atmosphere. From the figure it is seen that the anthropogenic particles are of smaller sizes, hence they reached the respiratory tract easily.

Based on the size particulates are divided into two major groups:

PM_{10} – Particulate Matter of size ≤ 10 μm.

$PM_{2.5}$ – Particulate Matter of size ≤ 2.5 μm.

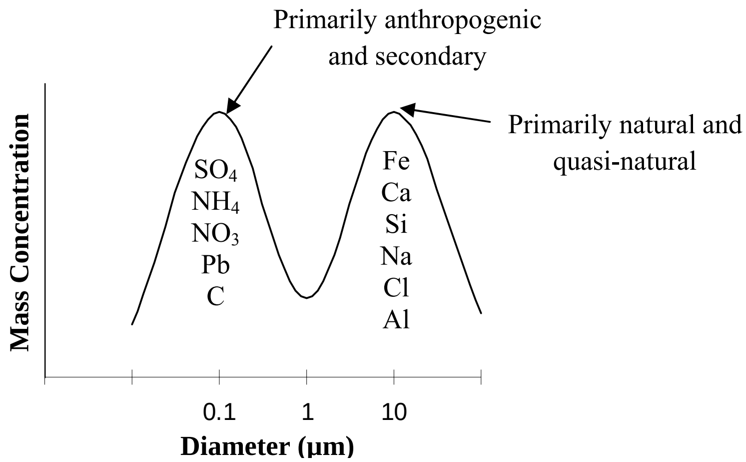


Figure 2.2: Idealized mass distribution of particulates showing a typical segmentation of chemical species into fine and coarse fraction (Seinfeld, 1985)

Health effects of particulates

When a particle enters into the human body, it goes under a number of removal processes. Nostril hair filters out larger (>10µm) particles (e.g., coarse dust, fly ash etc.) in the head region. Smaller size (2 to 10 µm) particles (e.g., fume, dust, smoke) can be removed by sweeping action of cilia in the tracheo-bronchial region. Much smaller particles (< 0.5 µm) penetrate to the lungs and reach the alveoli. Some particles retained in the alveoli are absorbed in the blood stream.

Extent of the effect of particulates depends on concentration, presence of other contaminants (e.g., SO_x) and length of exposure. Exposure to particulate matter is associated with increased incidence of respiratory illness, chronic bronchitis, broncho-constriction, decrement in pulmonary function and increased mortality rates. Adverse effects associated with short-term exposure to particulate matter include increase in the rate of asthma attack. Health impacts of particulate matter are discussed in more details in the article 2.6.

2.2.5.2 Carbon monoxide (CO)

Incomplete combustion of carbon or carbon-containing compounds is responsible for the generation of carbon mono-oxide in atmosphere:

$$2C + O_2 \longrightarrow 2CO$$

$$2CO + O_2 \longrightarrow 2CO_2$$

The 1st reaction is about 10 times faster than the 2nd reaction. Thus CO is an intermediate product in the overall combustion reaction and can show up as an end product if insufficient O_2 is present to complete the 2nd reaction. CO may be produced, even in presence of sufficient O_2, if the fuel and air are poorly mixed.

High temperature reaction between CO_2 and carbon containing materials can also produce Carbon Monoxide. During this process the following reaction takes place:

$$CO_2 + C \longrightarrow 2CO$$

CO produced in this way is necessary in certain applications, as in blast furnace. However, some CO may escape into the atmosphere and act as pollutant.

The effects of CO exposure are reflected in the O_2 carrying capacity of blood. In normal functioning hemoglobin (Hb) molecules carry oxygen which is exchanged for CO_2 in the capillaries connecting arteries and veins. CO diffuses through the alveolar wall and competes with O_2 for one of the 4 iron sites in hemoglobin molecule. Affinity of the iron site for CO is about 210 times greater than O_2. When a hemoglobin molecule acquires a CO molecule it is called carboxyhemoglobin.

Formation of COHb causes two problems:

1) Less sites available for O_2
2) Greater amount of energy binding the rest 3 O_2 molecules to Hb, so that they cannot be released easily (to be exchanged for CO_2).

Symptoms of CO poisoning depend on the amount of hemoglobin combined with CO. Figure 2.3 describes the health effect of carbon monoxide.

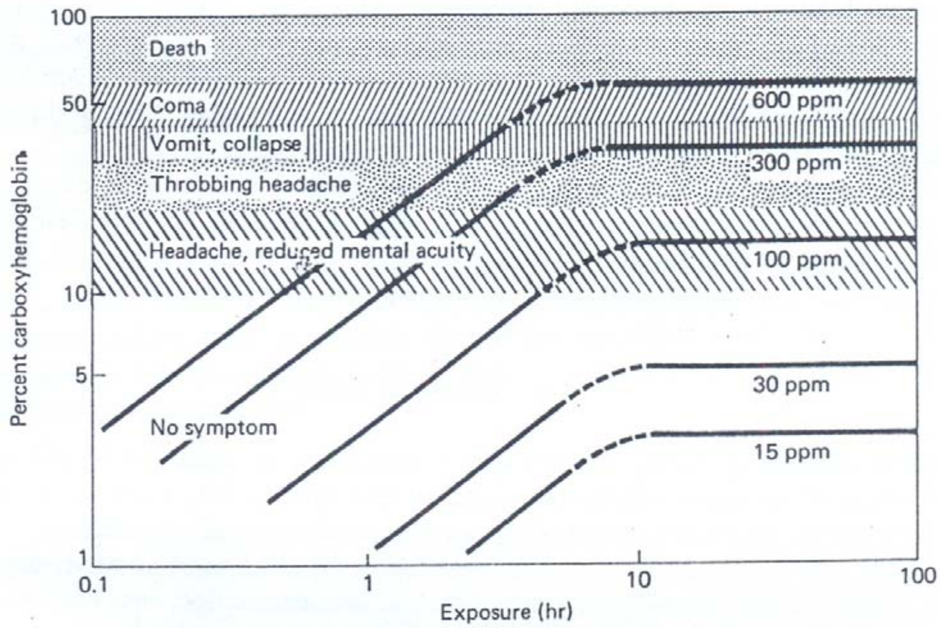


Figure 2.3: Effects of exposure to CO on human health (Seinfeld, 1985)

2.2.5.3 Oxides of sulfur (SO_x)

Oxides of sulfur consist primarily of two colorless gaseous compounds: sulfur dioxide, SO_2 and sulfur trioxide, SO_3. Collectively these two are referred as SO_x. The combustion of any sulfur containing material will produce both sulfur oxides. Oil and coal generally contain appreciable quantities of sulfur (~ 0.5 to 6 %), either in the form of inorganic sulfides or as organic sulfur. When the fuel is burned, sulfur is released mostly as SO_2, but also with small amount of SO_3.

$$S + O_2 \qquad SO_2$$

$$2\ SO_2 + O_2 \qquad 2\ SO_3$$

SO_2 once released can convert to SO_3 in a series of reactions involving free radical such as OH^-. SO_3 reacts quickly with H_2O to form H_2SO_4, which is the principal cause of "acid rain". Sulfuric acid molecules rapidly become particle by either condensing on existing particles in the air or by merging with water vapor to form H_2O-H_2SO_4 droplets (acid rain).

$$SO_2 + OH^- \qquad H_2SO_2^-$$

$$H_2SO_2^- + O_2 \qquad SO_3 + HO_2^-$$

$$SO_3 + H_2O \qquad H_2SO_4$$

Often a significant fraction of particulate matter in the atmosphere consists of sulfate aerosols. Most sulfate particles in urban air have an effective size less than 2µm with most of them being in the range of 0.2 to 09 µm. Their size is comparable to the wavelengths of visible light and their presence greatly affects visibility. Their size also allows them to penetrate into the deeper part of the respiratory system. Figure 2.4 describes the health effects of exposure to SO_2. Shaded area in the figure represents the range of exposures where excess deaths have been reported. Speckled area represents the range of exposures where health effects are suspected.

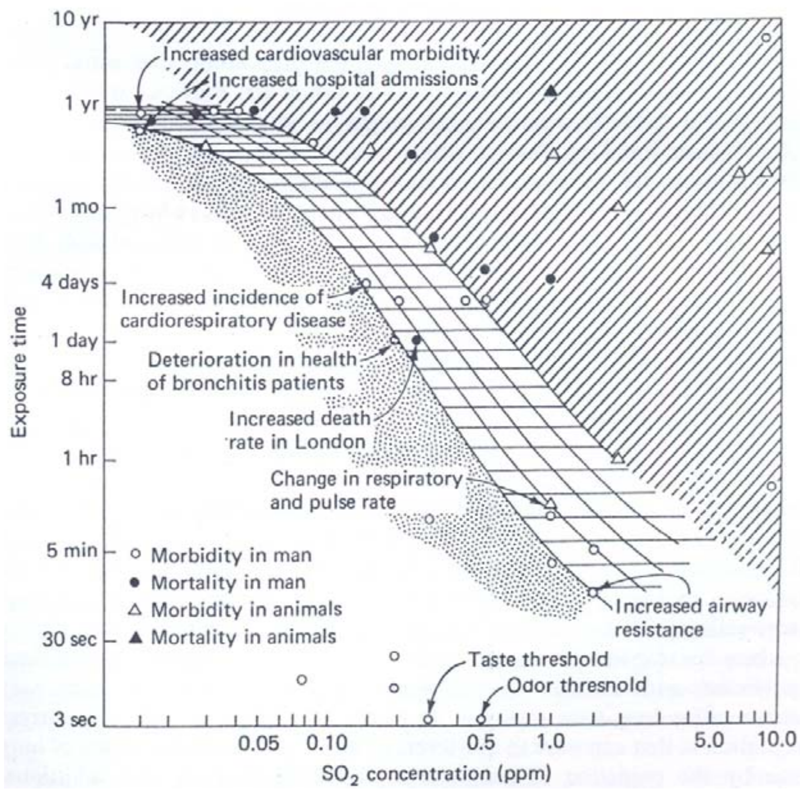


Figure 2.4: Health effects due to various exposures to SO_2 (Seinfeld, 1985)

In dusty atmosphere, SO_x is particularly harmful, because both SO_2 and H_2SO_4 paralyze the hair-like cilia that line the respiratory tract. Without regular sweeping action of cilia, particulates may penetrate to the lung and settle there. These particulates usually carry absorbed/adsorbed SO_2, thus brings this irritant into direct prolonged contact with delicate lung tissues. The SO_2-particulate combination has been cited as cause of death in several air pollution tragedies.

2.2.5.4 Oxides of nitrogen (NO_x)

Nitric oxide (NO) and Nitrogen dioxide (NO_2) are of primary concern in atmospheric pollution. These two are collectively termed as NO_x. Sources of NO_x can be divided in different categories. Among them two basic sources of NO_x involve combustion of fossil fuel (Seinfeld, 1985):

i. *Thermal NO_x*: Created when N and O in the combustion air are heated to high temperature (>1000 K) to oxidize N.
ii. *Fuel NO_x:* Result from oxidation of nitrogen compounds that are chemically bound in the fuel molecules themselves. (Coal has about 3% N by weight, whereas natural gas has almost none). Fuel NO_x is usually the dominant source.

Almost all NO_x emissions are in the form of NO, which has no known adverse health effects at concentration found in atmosphere (< 1.0 ppm). However, NO can be oxidized to NO_2, which may react with hydrocarbon in the presence of sunlight to form photochemical smog, which is injurious to health. NO_2 also reacts with hydroxyl radical in the atmosphere to form nitric acid (HNO_3), which is washed out of the atmosphere as acid rain. In addition, NO_2 irritates lungs. Persistent low level concentration of NO_2 increases respiratory illness.

2.2.5.5 Lead (Pb)

Most lead emissions come from vehicles burning gasoline containing the antiknock additive, tetraethyl lead $(C_2H_5)_4Pb$. Lead is emitted to the atmosphere primarily in the form of inorganic particulates. Human exposure to air borne lead primarily result from inhalation. It can also be ingested after lead has deposited onto food stuff. About one-third of lead particles inhaled are deposited in the respiratory system, and about half of those are absorbed into bloodstream.

Adverse effects of lead poisoning include aggressive, hostile and destructive behavioral changes, learning disabilities, seizures, severe and permanent brain damage, and even death. Children and pregnant women are the most vulnerable group.

2.2.5.6 Photochemical smog and ozone

When NO_x, various hydrocarbons and sunlight come together, they can initiate a complex set of reactions to produce a number of secondary pollutants known as “photochemical oxidant”.

$$\text{Hydrocarbons} + NO_x + \text{Sunlight} \longrightarrow \text{Photochemical Smog}$$

Constituents of photochemical smog include Ozone (most abundant), Formaldehyde, Peroxy benzoyl nitrite (PBzN), Peroxy acetyl nitrite (PAN), Acrolein, etc. Photochemical smog mainly occurs in highly motorized areas in large metropolitan cities, where the meteorology also favors the formation of the smog.

Photochemical smog is extremely toxic to animal and plant life, and damages paint, rubber, and plastics. Eye irritation, the most common human complaint about smog, is caused by the other components of smog listed above, especially formaldehyde (HCHO), Acrolein (CH_2CHCHO) and PAN. Ozone (O_3) is desirable in the upper atmosphere (stratosphere) but causes damage to plant and animal tissues when present at even low levels in the lower atmosphere (troposphere). Ozone (O_3) is primarily responsible for chest constriction, irritation of mucus membrane, cracking of rubber, damage of vegetation, etc. Recent study of National Academy of Sciences (National Research Council, 2010) has found that O_3 increases premature mortality of human. The study shows that total mortality increase by 0.82% per 10 ppb of Ozone. Cardiovascular and Respiratory mortality rate is increased by 0.64% for increase in ozone concentration of 10 ppb.

2.3 Air quality of Dhaka

From the above discussion it can be inferred that human being suffers from air pollution related health impact most often. The people of Dhaka city have no different issues. This leads to the necessity of air quality data of the city. In Dhaka monitoring of air quality data has a relatively short history. Only in 2002 continuous air quality monitoring was commenced through the establishment of Continuous Air quality Monitoring Station (CAMS) by Department of Environment (DoE) under the world bank financed Air Quality Management Project (AQMP). Before that, some uncoordinated efforts were undertaken by different authorities on intermittent or project basis. 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. Works on installation of two more CAMS in Dhaka by DoE are underway.

2.3.1 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). 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.

Table 2.1: Air Quality Standards

Pollutant	Averaging Period	Bangladesh[a] Standard	WHO[b] Guideline Values	US EPA Standards[c]
		μg/m³ (ppm)	μg/m³	μg/m³
CO	8 - hr	10,000 (9)	10000	10000
	1 - hr	40,000 (35)	30000	40000
Pb	Annual	0.5	0.5	-
NO_x	Annual	100 (0.053)	40	100
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

Source: [a]S.R.O. No: 220-Law, DoE, 2005; [b]WHO, 2005; and [c]US EPA, 2005.

2.3.2 Air quality data of CAMS

The air quality data for Dhaka city from CAMS is available from 2002 only. Hence it is not possible to analyze the long term trends of air pollution. But it still gives the opportunity to assess the variation in AQ due to the seasonal changes. Figure 2.5 shows the yearly average values of PM_{10} and $PM_{2.5}$. 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).

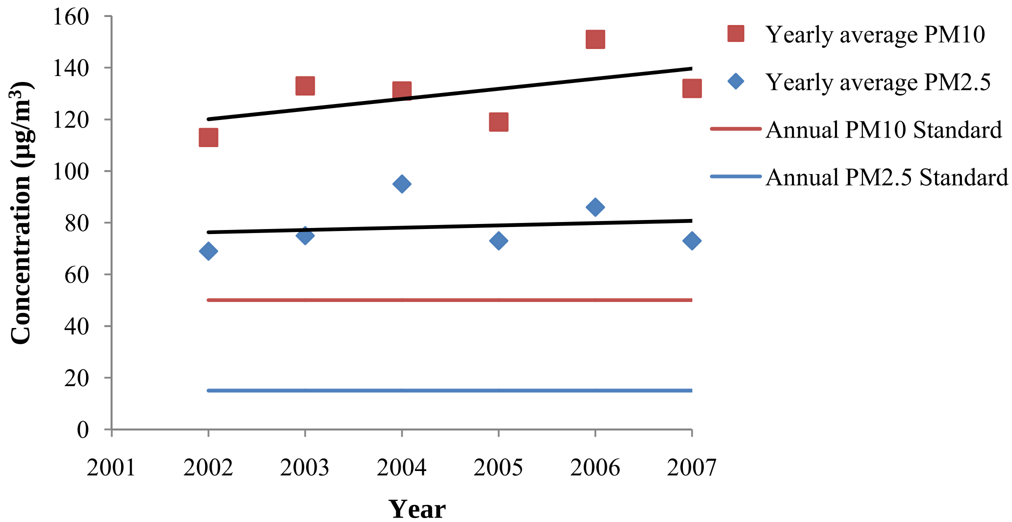


Figure 2.5: Variation of yearly average PM_{10} and $PM_{2.5}$ (AQMP, 2007)

Figure 2.6 to Figure 2.11 shows the air quality recorded at the CAMS in Dhaka. From these graph it is seen that mainly PM_{10} and $PM_{2.5}$ values are well above the standard set by the DoE, Bangladesh during the dry season (November to March). During the wet season (April to October) ambient PM concentration comfortably meets the standard. These seasonal variations are seen in almost all the years for which data are available.

In addition, 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_2) 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.

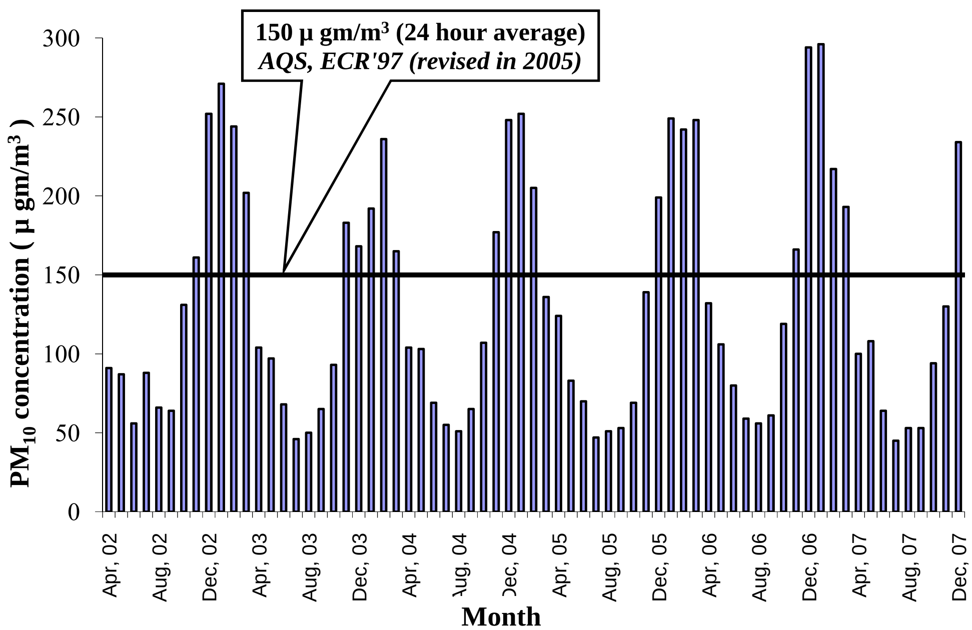


Figure 2.6: Monthly 24-hour average value of PM_{10} concentration (AQMP, 2007)

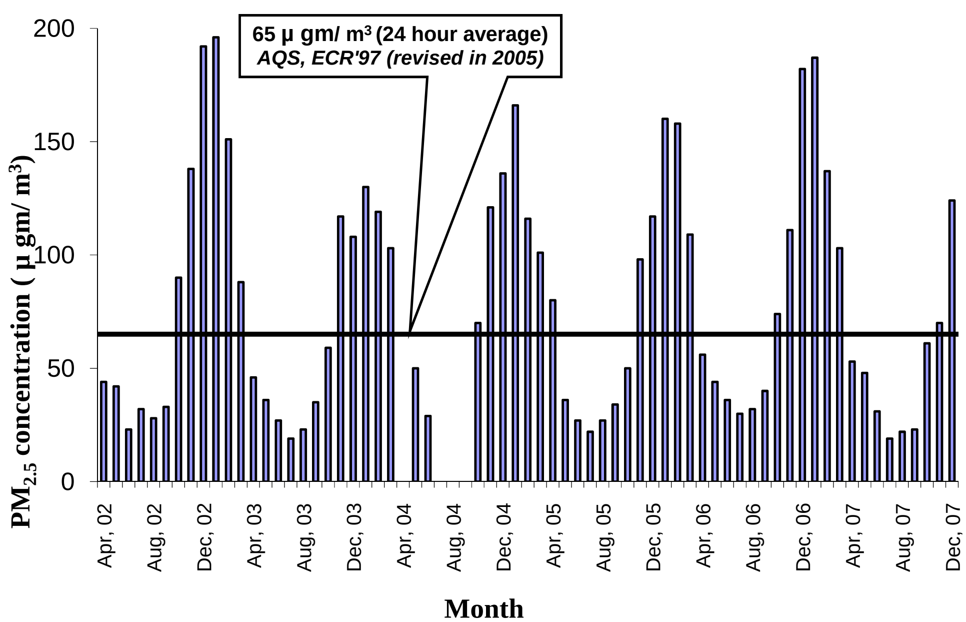


Figure 2.7: Monthly 24-hour average value of $PM_{2.5}$ concentration (AQMP, 2007)

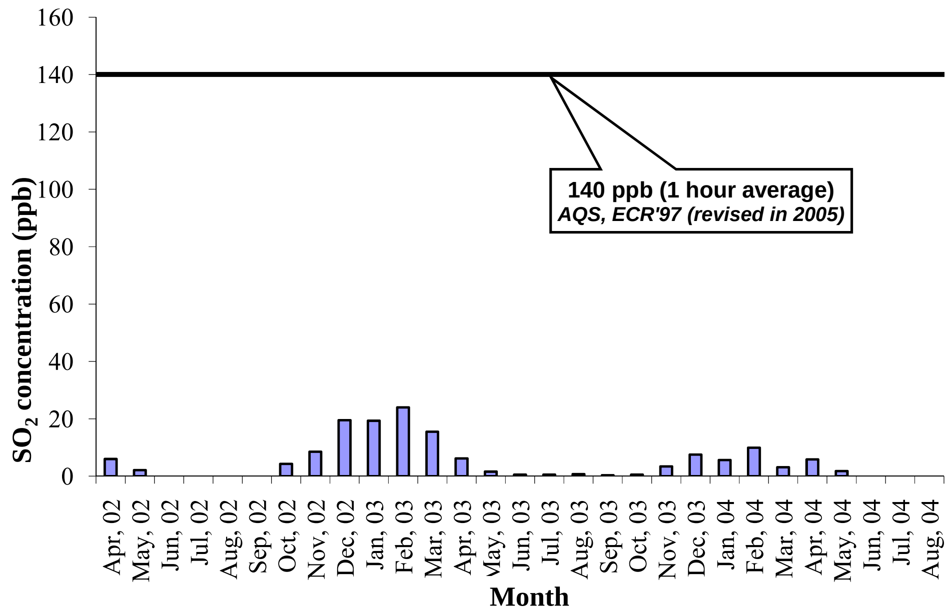


Figure 2.8: Monthly 24-hour average value of SO_2 concentration (AQMP, 2007)

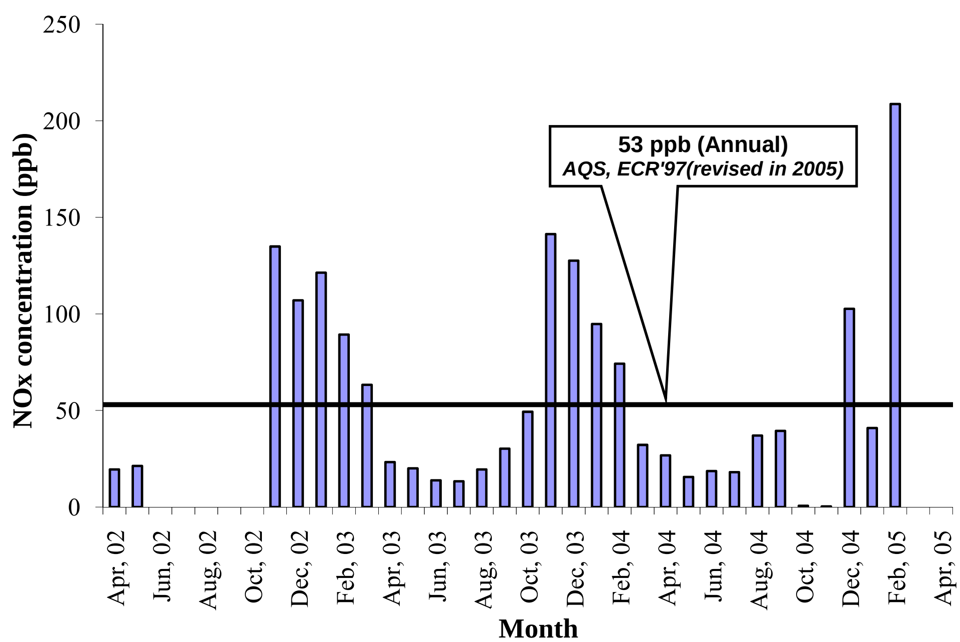


Figure 2.9: Monthly 24-hour average value of NO_x concentration (AQMP, 2007)

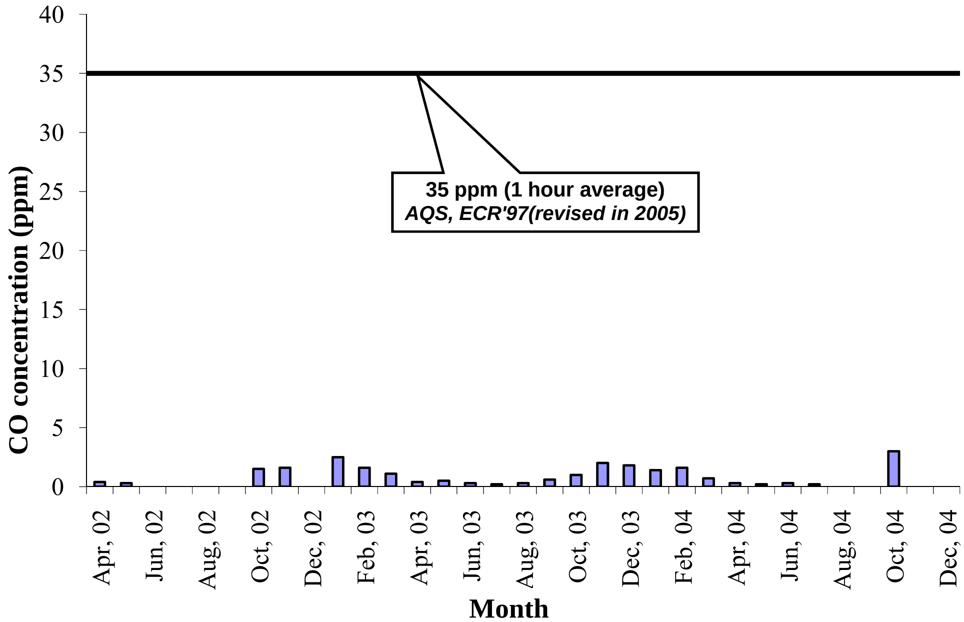


Figure 2.10: Monthly 1-hour average value of CO concentration (AQMP, 2007)

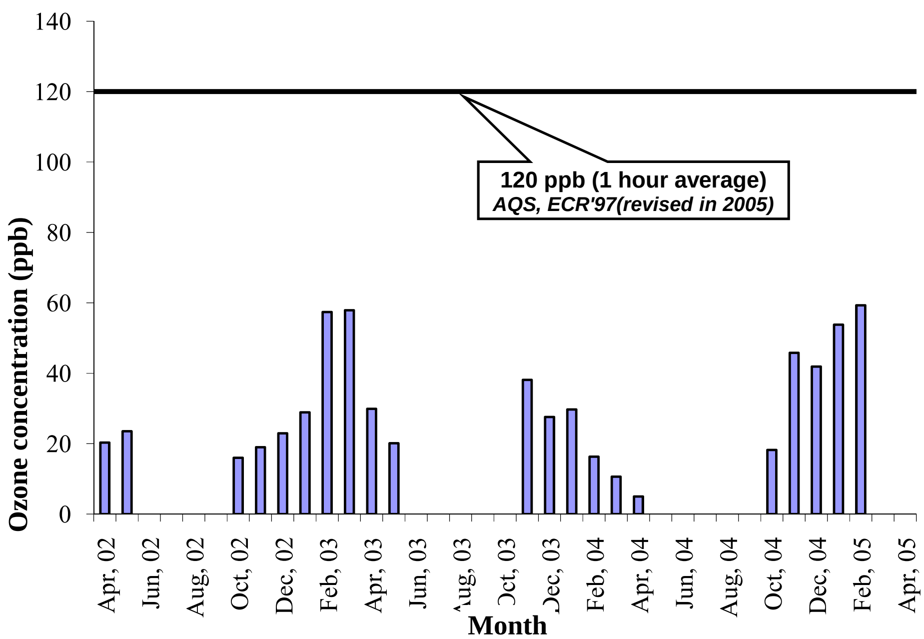


Figure 2.11: Monthly 1-hour average value of O_3 concentration (AQMP, 2007)

2.4 Source Apportionment of Particulate Matter

Since particulate matter emission is of prime concern among the air pollutants in Dhaka, it is important to identify the sources of particulate pollution. For policy making purpose the knowledge about the sources of the pollutants is essential. A number of studies have been conducted for the source apportionment of the particulate matter. Table 2.2 presents the result of the study conducted by Biswas et al. (2001). From the table it is clear 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 2.2: Average percentage mass contribution for each source to the urban APM (Biswas et. al., 2001)

Source type	Percentage Contribution to APM	
	Coarse (PM10)	Fine (PM2.5)
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 $PM_{2.5-10}$ 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.

Figure 2.12 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.

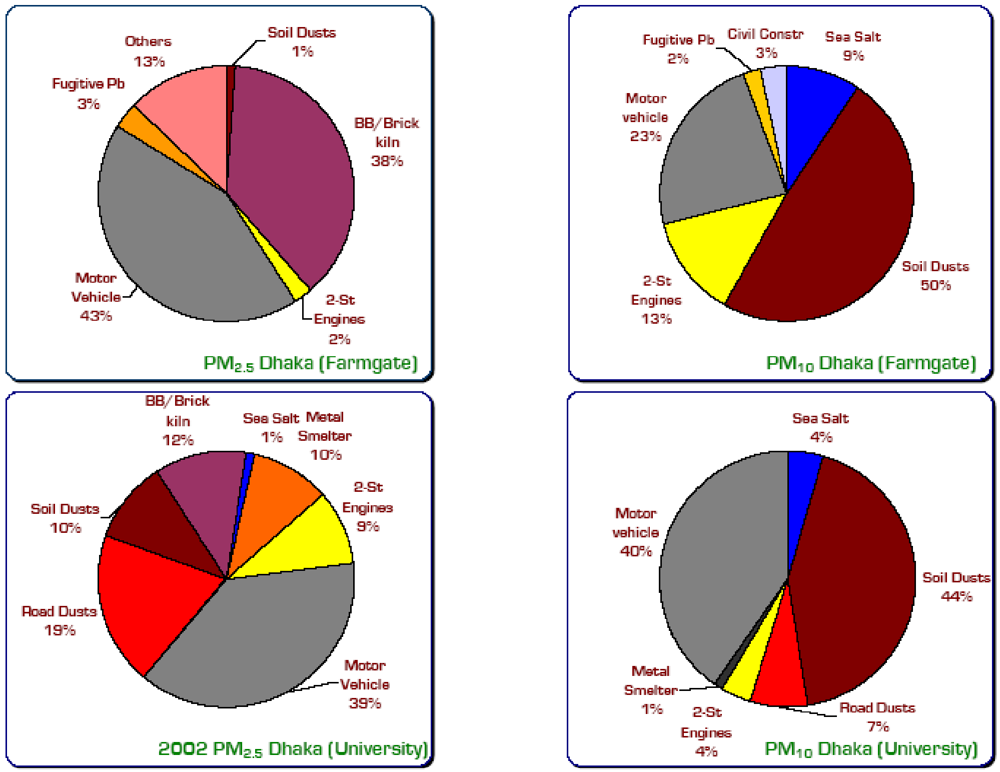


Figure 2.12: Source apportionment results for Dhaka city (Begum et al., 2005)

2.5 Air Quality Models

In order to assess the air pollution impact over a region and to forecast the future air quality air quality model is necessary. Air quality (AQ) models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on inputs of meteorological data and source information like emission rates and stack height, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and, in some cases, secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere. These models are important to air quality management system because they are widely used by agencies tasked with controlling air pollution to both identify source contributions to air quality problems and assist in the design of effective strategies to reduce harmful air pollutants. For example; air quality models can be used during the permitting process to verify that a new source will not exceed ambient air quality standards or, if necessary, determine appropriate additional control requirements. In addition, AQ models can also be used to predict future pollutant concentrations from multiple sources after the implementation of a new regulatory program, in order to estimate the effectiveness of the program in reducing harmful exposures to humans and the environment (USEPA, 2007).

2.5.1 Purpose of air quality modeling

In general air quality model is a tool for:

a) Establishing emission control legislation, i.e. determining the maximum allowable emission rates that will meet fixed air quality standards.
b) Evaluating proposed emission control techniques and strategies, i.e., evaluating the impacts of future control
c) Selecting locations of future sources of pollutants, in order to minimize their environmental impacts
d) Planning the control of air pollution episodes, i.e., defining immediate intervention strategies, (i.e., warning systems and real-time short-term emission reduction strategies) to avoid severe air pollution episodes in a certain region.
e) Assessing responsibility for existing air pollution levels, i.e., evaluating present source-receptor relationships

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.

Impact assessment

There will always be a need for both measurements and models. In some cases, an AQ model is actually broader than measurements. Measurements are usually not representative for a broader area, and their quality is sometimes questionable. An AQ model can provide estimates of concentrations in areas where one does not have measurements. For health impact assessment including exposure evaluations the use of AQ models of some kind is essential. (NILU, 2010)

Forecasts

Air quality models are also necessary for forecasting and planning purposes. AQ models have been developed combining meteorological forecast models with air pollution dispersion models to enable air quality forecasts in urban areas of the developed world. (NILU, 2010)

2.5.2. Factors to be considered in air quality modeling

Air pollution models quantitatively simulate factors affecting the fate of pollutants in the atmosphere. In air pollution dispersion modeling there are five major physical processes that are to be simulated:

1) Pollutant advection (transport),
2) Diffusion,
3) Deposition,
4) Chemical reactions (transformation) and
5) Emission.

Besides, plume rise and aerodynamic effects of terrain are also important factors to be modeled. Models input data include:

a. Source characteristics and emission data with spatial and temporal variations,
b. Area characteristics (surface roughness, topography etc.),
c. Measurement data (measurement type, heights etc.),
d. Meteorological data (wind, stability, mixing height, temperatures etc.),
e. Dispersion coefficients (type to be used and parameters),
f. Location of receptor points (distances or grid specifications).

Important processes to be simulated depend on transport scales of air pollution phenomena. A preliminary distinction between the transport scales can be made as follows:

a. Near-field phenomena (<1 km from the source), e.g., downwash effects of plume caused by building aerodynamics
b. Short-range transport (<10 km from the source), e.g., the area in which the maximum ground-level impact of primary pollutants from an elevated source is generally found

c. Intermediate transport (between 10 km and 100 km) e.g., the area in which chemical reactions become important and must be taken into account

d. Long-range (or regional or interstate) transport (>100 km), e.g., the area in which large-scale meteorological effects and deposition and transformation rates play key roles.

e. Global effects, i.e. phenomena affecting the entire earth atmosphere such as CO_2 accumulation.

2.5.3 Types of air quality model

The science of modeling of air quality and specific constituents is extremely sophisticated, particularly where adequate input data on meteorological, topographical and chemistry constituent is available. The most commonly used air quality models include the following (Zanetti, 1990):

i) Dispersion modeling

Dispersion modeling uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source. Only the physical processes are considered in this type of model. Based on emissions and meteorological inputs, a dispersion model can be used to predict concentrations at selected downwind receptor locations.

ii) Photochemical modeling

Photochemical air quality models have become widely recognized and routinely utilized tools for regulatory analysis and attainment demonstrations by assessing the effectiveness of control strategies. These photochemical models are large-scale air quality models that simulate the changes of pollutant concentrations in the atmosphere using a set of mathematical equations characterizing the chemical and physical processes in the atmosphere. These models are applied at multiple spatial scales from local, regional, national, to global.

iii) Receptor modeling

Receptor models are mathematical or statistical procedures for identifying and quantifying the sources of air pollutants at a receptor location. Unlike photochemical and dispersion air quality models, receptor models do not use pollutant emissions, meteorological data and chemical transformation mechanisms to estimate the contribution of sources to receptor concentrations. Instead, receptor models use the chemical and physical characteristics of gases and particles measured at source and receptor to both identify the presence of and to quantify source contributions to receptor concentrations.

2.5.3.1 Simulation approaches

In the modeling of air quality two main numerical simulation approaches are undertaken (Masters, 2004):

- Eulerian Approaches/ Models, and
- Lagrangian Approaches/Model

The basic difference between the two simulation techniques is located in the reference systems/coordinates. The origin for a coordinate system x, y, z can be fixed at any point in space, however, most commonly it is fixed at the source or the receptor. It can also move with the plume/puff, for example it can be fixed at the center of a puff. The Eulerian models use fixed reference system (with respect to the Earth) while the Lagrangian models use the reference/co-ordinate system, which follows the average atmospheric motion.

2.5.3.2 Types of Eulerian models

i) Single box model

Box models are the simplest form of the atmospheric dispersion models which can be used to estimate pollutant concentration from an area source. It is based on the mass conservation of pollutants inside an Eulerain box, which generally represents a large city. The "box" represents the volume of air over the area of interest. Pollutants within the box are assumed to be mixed fast and completely so that concentrations are uniform within the box. The single box models are used for both inert and reactive pollutants. For later case a chemistry module has to be incorporated to account for complex photochemistry. In general the box model can be used to obtain order-of-magnitude estimates of ambient pollution levels. However, the model can not account for changes of wind with height. Besides, the simplifying assumptions, such as uniform concentration of pollutants within the box of the fixed height, lead to almost non-existent situation of real atmospheric transport and diffusion.

ii) Slug models

Due to the fact that single box models have a great inertia and can not properly handle rapid temporary change of emission or wind speed, the slug model is used as an improvement of the single box models, especially during stagnation episodes. The slug model allows concentration to vary along-wind direction and vertical direction, but assumes that concentration does not change in Y direction.

iii) Multi-box models

Single box concept has been extended to multi-box simulations. In this model the variation of the average concentration in a box during time is determined by pollutant flux through sides of the box and the pollutant emission from all sources inside the box. The major limitations of this multi-box approach are its neglect of horizontal diffusion and the assumption of instantaneous mixing throughout the box (especially in the vertical). It is, however, computationally fast and in several cases, may provide satisfactory, cost-effective answers, especially in regions where detailed meteorological and emission information are not available.

iv) Advanced Eulerian models

The Eulerian approach plays a major role in air pollution simulations, especially when non-linear chemistry is required (as for the evaluation of O_3 impacts). Errors introduced by this method should not overweigh those produced by Gaussian plume model.

Advanced Eulerian models are being developed to provide better simulation of air pollution phenomena. Advanced models use complex Eulerian formulations for simulating atmospheric diffusion instead of the K-theory. Therefore they avoid the shortcomings of the K-theory. Among them two are most popular: second-order closure modeling and large eddy simulation techniques.

2.5.3.3 Types of Lagrangian models

i) Lagrangian box models

The Lagrangian box is advected horizontally according to the local time-varying average wind speed and direction. The Lagrangian box models are often used for photochemical modeling. Photochemical air pollution is formed as a result of complex interaction between sunlight, meteorology and primary emission of nitrogen oxides and reactive hydrocarbons. Photochemical models have been used in urban areas bounded with smog. These models must account for the chemical reactions including chemical depletion and deposition. In this case, the models provide average time-varying concentration estimates along the box trajectory. The major shortcoming of the approach is the assumption that wind speed and direction are constant throughout the PBL (Planetary Boundary Layer). As compared to the Eulerian box models the Lagrangian box models can save computational cost as they perform computations of chemical and photochemical reactions on a smaller number of moving cells instead of at each fixed grid cell of Eulerian models.

ii) Gaussian plume models

It considers the assumption that the time averaged pollutant concentration downwind from a source can be modeled using a normal or Gaussian distribution curve. The basic Gaussian dispersion model applies to a single point source such as smokestack, but it can be modified to account for line sources (such as emission from motor vehicle.), or area sources.

The highest concentration of pollutant would be along plume centerline, with lower and lower values as we get further and further away. The Gaussian plume model assumes that pollutant concentration follows a normal distribution in both the vertical planes and in the horizontal direction. It also treats emission as if coming from a virtual point source along the plume centerline, at an effective stack height (Masters, 2004).

Following assumptions are incorporated into the analysis:

- Pollutant material takes on Gaussian distribution in both horizontal and vertical directions

- No diffusion in along the wind direction
- The rate of emission from the source is constant, uniform & continuous
- Homogeneous horizontal wind field. The wind speed is constant both time and with elevation.
- Steady state condition
- Ideal gas
- The pollutant is conservative
- The terrain is relatively flat, open country.

iii) Particle models

This is a most recent and powerful computational tool for the numerical discretization of a physical system. Particles have the Lagrangian nature since they follow the main flow. Therefore they are often named Lagrangian particles. In a "particle" model for atmospheric dispersion a set of "tracers" (or fictitious computational particles) are used to describe the dynamics of the atmosphere. If realistic air parcel trajectories can be computed the simple calculation of the density of the trajectory points provides an estimate of concentration.

2.5.4 Previous studies in air quality modeling

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, 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.

2.6 Evaluation of Health Impacts of Particulate Matter

Air pollution directly affects the human health. High level of air pollution causes serious damage to health. It creates many of the respiratory related problems, as well can cause death. Premature deaths have been attributed to air pollution in many urban regions all over the world. Long term exposure to air pollution can lead to premature death by increasing the rate at which lung tissue ages, by contributing to chronic obstructive lung disease, and by exacerbating cardiovascular disease. Sudden rise of pollution level (acute exposure), on the other hand, can cause the people who have history of cardiopulmonary diseases or simply weak or susceptible to die prematurely. This is known as the short-term or acute effect. In addition to the increase in the mortality rate of a community, air pollution can add to the morbidity effect of human as well. Among the different morbidity effects Adult Chronic Bronchitis, Child Acute Bronchitis, Respiratory Hospital Admission, Cardiac Hospital Admission, Emergency Room Visit, Asthma Attacks, Restricted Activity Days, Respiratory Symptom Days etc. are the most common (Guttikunda, 2008).

2.6.1 Mortality related health effects

For the quantitative assessment of health effects, $PM_{2.5}$ and PM_{10} are selected because these exposure metrics have been used in epidemiological studies throughout the world. In addition, over the past two decades, epidemiological studies spanning five continents have demonstrated an association between mortality and morbidity, and daily, multi-day or long-term (a period of more than a year) exposures to concentrations of pollutants, including PM. The estimated mortality impacts are likely to occur predominantly among elderly people with pre-existing cardiovascular and respiratory disease, and among infants. The effect of the air pollution upon the human mortality can be for several health outcomes including: adult cardiovascular mortality and lung cancer associated with long-term exposure to $PM_{2.5}$, all-cause mortality for all ages associated with short-term exposure to PM_{10}, and infant and childhood mortality from respiratory diseases associated with PM_{10} exposure.

2.6.1.1 Mortality related to short-term exposure

The earliest and most methodologically simple studies that evaluated short-term changes in exposure to air pollution focused on severe air pollution episodes. Death counts for several days or weeks were compared before, during, and after the episodes. By the early 1990s, the results of several daily time series studies were reported e.g., Schwartz and Marcus (1990), Fairley (1990), Schwartz and Dockery (1992), Pope et al. (1992), Dockery et al. (1992). These studies did not rely on extreme pollution episodes but evaluated changes in daily mortality counts associated with daily changes in air pollution at relatively low, more common levels of pollution. Another methodological innovation, the case-crossover study design (Maclure, 1991) has been applied to studying mortality effects of daily changes in particulate air pollution. This method was used by Pope in 1999 to find out the short term mortality effect of air pollution. Rather than using time series analysis, the case-crossover design is an adaptation of the common retrospective case-control design. Basically, exposures at the time of death (case period) are matched with one or more periods when the death did not occur (control periods), and potential excess risks are estimated using conditional logistic regression. By carefully and strategically choosing control periods, this approach restructures the analysis such that day of week, seasonality, and long-term time trends are controlled for by design rather than by statistical modeling. Because this approach focuses on individual deaths rather than death counts in a population, this approach facilitates evaluation of individual-level effect modification or susceptibility. Table 2.3 summarizes the different studies on short-term mortality rate based on Pope and Dockery, 2006.

Table 2.3: Comparison of pooled estimated percentage increase (and 95% confidence or posterior interval, CI, or *t* value) in relative risk of mortality estimated across meta-analyses and multicity studies of short-term (daily) changes in exposure (Pope and Dockery 2006)

			Percent Increases in Relative Risk of Mortality (95% CI)		
Study	**Primary Sources**	**Exposure Increment**	**All Cause**	**Cardiovascular**	**Respiratory**
Meta-analysis of 29 studies	Levy et al. 2000[134]	20 μg/m³ PM_{10}	1.5 (1.2, 1.75)[a]	–	–
Meta-analysis: GAM-based studies	Stieb et al. 2002, 2003[135,136]	20 μg/m³ PM_{10}	1.4 (1.0, 1.8)[a]	–	–
Non GAM-based studies			0.8 (0.5, 1.2)	–	–
Metaestimate from single-city studies,	Anderson et al. 2005[137]	20 μg/m³ PM_{10}	1.2 (1.0, 1.4)[a]	–	–
adjusted for publication bias			1.0 (0.8, 1.2)[a]	–	–
Metaestimates from COMEAP report to the	COMEAP 2006[138]	20 μg/m³ PM_{10}	–	1.8 (1.4, 2.4)	
U.K. Department of Health on		10 μg/m³ $PM_{2.5}$	–	1.4 (0.7, 2.2)	–
Cardiovascular Disease and Air Pollution					
U.S. 6 cities	Klemm and Mason 2003[142]	10 μg/m³ $PM_{2.5}$	1.2 (0.8, 1.6)	1.3 (0.3, 2.4)[b]	0.6 (−2.9, 4.2)[c]
Canadian 8 cities	Burnett and Goldberg 2003[144]	10 μg/m³ $PM_{2.5}$	1.1 (t = 3.4)	–	–
Californian 9 cities	Ostro et al. 2006[145]	10 μg/m³ $PM_{2.5}$	0.6 (0.2, 1.0)	0.6 (0.0, 1.1)	2.2 (0.6, 3.9)
U.S. 10 cities	Schwartz 2000, 2003[146,148]	20 μg/m³ PM_{10}	1.3 (1.0, 1.6)	–	–
U.S. 14-city case-crossover	Schwartz 2004[149]	20 μg/m³ PM_{10}	0.7 (0.4, 1.0)	–	–
NMMAPS 20–100 U.S. cities	Dominici et al. 2003[153]	20 μg/m³ PM_{10}	0.4 (0.2, 0.8)	0.6 (0.3, 1.0)[d]	–
APHEA-2 15–29 European cities	Katsouyanni et al. 2003[162]	20 μg/m³ PM_{10}	1.2 (0.8, 1.4)	–	–
APHEA-2 29 European cities	Analitis et al. 2006[163]	20 μg/m³ PM_{10}	–	1.5 (0.9, 2.1)	1.2 (0.4, 1.9)
Australia 3-cities	Simpson et al. 2005[165]	10 μg/m³ $PM_{2.5}$	0.9 (−0.7, 2.5)	–	–
French 9 cities	Le Tertre et al. 2002[164]	20 μg/m³ BS	1.2 (0.5, 1.8)[a]	1.2 (0.2, 2.2)[a]	1.1 (−1.4, 3.2)[a]
Korean 7 cities	Lee et al. 2000[166]	40 μg/m³ TSP	0.9 (0.5, 1.2)[a]	–	–
Japanese 13-cities, age >65 yr	Omori et al. 2003[167]	20 μg/m³ SPM	1.0 (.8, 1.3)	1.1 (0.7, 1.5)	1.4 (0.9, 2.1)

[a]Includes GAM-based analyses with potentially inadequate convergence; [b]Ischemic heart disease deaths; [c]Chronic obstructive pulmonary disease deaths; [d]Cardiovascular and respiratory deaths combined.

It seems unlikely that relatively small elevations in exposure to particulate air pollution over short periods of only 1 or a few days could be responsible for very large increases in death. In fact, these studies of mortality and short-term daily changes in PM are observing small effects. For example, assume that a short-term elevation of $PM_{2.5}$ of 10 μg/m^3 results in an approximately 1% increase in mortality (Pope and Dockery, 2006). Pope and Dockery also summarized that, on any given day, the number of people dying because of PM exposure in a population is small.

2.6.1.2 Mortality related to long-term exposure

Although daily time series studies of acute exposures continue to suggest short-term acute PM effects, they provide little information about the degree of life shortening, pollution effects on longer-term mortality rates, or the role of pollution in inducing or accelerating the progress of chronic disease (McMichael et al., 1999). These population-based cross-sectional mortality rate studies were largely discounted by 1997 because of concern that they could not control for individual risk factors, such as cigarette smoking, which could potentially confound the air pollution effects (Pope and Dockery, 2006). With regard to the mortality effects of long-term PM exposure, recent emphasis has been on prospective cohort studies (Brunekreef, 2003) that can control for individual differences in age, sex, smoking history, and other risk factors. However, because these studies require collecting information on large numbers of people and following them prospectively for long periods of time, they are costly, time consuming, and, therefore, much less common.

A brief summary of results from these studies is presented in Table 2.4. As can be seen in Table 2.4, for both the Harvard Six Cities and the ACS prospective cohort studies, the estimated effects for all-cause and cardiopulmonary mortality were relatively stable across different analyses. The Harvard Six Cities estimates, however, were approximately twice as large as the ACS estimates. Two main factors may explain these differences in estimated PM-mortality effects. First, both the reanalysis and extended analyses have found that persons with higher educational attainment had lower relative risk of PM-related mortality. The ACS cohort overrepresented relatively well-educated individuals relative to the Harvard Six Cities study. Second, the geographical areas that defined the communities studied in the Harvard Six Cities study were, on average, substantially smaller than the metropolitan areas included in the ACS study. Indeed, an analysis of the Los Angeles metropolitan area ACS participants showed that interpolated $PM_{2.5}$ air pollution concentrations resulted in effect estimates comparable with estimates from the Harvard Six Cities Study. Similarly, in the Netherlands study, when local sources of particulate pollution exposure in addition to community-wide background concentrations were modeled, the elevated relative risk estimates also approximately doubled. These results suggest that PM-mortality effect estimates based on analysis that only uses metropolitan-wide average background concentrations may underestimate the true pollution-related health burden and suggests the importance of analyses with more focused spatial resolution.

Table 2.4: Comparison of percentage increase (and 95% CI) in relative risk of mortality associated with long-term particulate exposure (Pope and Dockery 2006)

			Percent Increases in Relative Risk of Mortality (95% CI)		
Study	**Primary Sources**	**Exposure Increment**	**All Cause**	**Cardiopulmonary**	**Lung Cancer**
Harvard Six Cities, original	Dockery et al. 1993[26]	10 $\mu g/m^3$ $PM_{2.5}$	13 (4.2, 23)	18 (6.0, 32)	18 (−11, 57)
Harvard Six Cities, HEI reanalysis	Krewski et al. 2000[177]	10 $\mu g/m^3$ $PM_{2.5}$	14 (5.4, 23)	19 (6.5, 33)	21 (−8.4, 60)
Harvard Six Cities, extended analysis	Laden et al. 2006[184]	10 $\mu g/m^3$ $PM_{2.5}$	16 (7, 26)	28 (13, 44)[a]	27 (−4, 69)
ACS, original	Pope et al. 1995[27]	10 $\mu g/m^3$ $PM_{2.5}$	6.6 (3.5, 9.8)	12 (6.7,17)	1.2 (−8.7, 12)
ACS, HEI reanalysis	Krewski et al. 2000[177]	10 $\mu g/m^3$ $PM_{2.5}$	7.0 (3.9, 10)	12 (7.4, 17)	0.8 (−8.7, 11)
ACS, extended analysis	Pope et al. 2002[179] Pope et al. 2004[180]	10 $\mu g/m^3$ $PM_{2.5}$	6.2 (1.6, 11)	9.3 (3.3, 16) 12 (8, 15)[a]	13.5 (4.4, 23)
ACS adjusted using various education weighting schemes	Dockery et al. 1993[26] Pope et al. 2002[179] Krewski et al. 2000[177]	10 $\mu g/m^3$ $PM_{2.5}$	8–11	12–14	3–24
ACS intrametro Los Angeles	Jerrett et al. 2005[181]	10 $\mu g/m^3$ $PM_{2.5}$	17 (5, 30)	12 (−3, 30)	44 (−2, 211)
Postneonatal infant mortality, U.S.	Woodruff et al. 1997[185]	20 $\mu g/m^3$ PM_{10}	8.0 (4, 14)	–	–
Postneonatal infant mortality, CA	Woodruff et al. 2006[186]	10 $\mu g/m^3$ $PM_{2.5}$	7.0 (−7, 24)	113 (12, 305)[c]	–
AHSMOG[b]	Abbey et al. 1999[187]	20 $\mu g/m^3$ PM_{10}	2.1 (−4.5, 9.2)	0.6 (−7.8, 10)	81 (14, 186)
AHSMOG, males only	McDonnell et al. 2000[188]	10 $\mu g/m^3$ $PM_{2.5}$	8.5 (−2.3, 21)	23 (−3, 55)	39 (−21, 150)
AHSMOG, females only	Chen et al. 2005[189]	10 $\mu g/m^3$ $PM_{2.5}$	–	42 (6, 90)[a]	–
Women's Health Initiative	Miller et al. 2004[190]	10 $\mu g/m^3$ $PM_{2.5}$	–	32 (1, 73)[a]	
VA, preliminary	Lipfert et al. 2000, 2003[190,192]	10 $\mu g/m^3$ $PM_{2.5}$	0.3 (NS)[d]	–	–
VA, extended	Lipfert et al. 2006[193]	10 $\mu g/m^3$ $PM_{2.5}$	15 (5, 26)[e]	–	–
11 CA counties, elderly	Enstrom 2005[194]	10 $\mu g/m^3$ $PM_{2.5}$	1 (−0.6, 2.6)	–	–
Netherlands	Hoek et al. 2002[195]	10 $\mu g/m^3$ BS	17 (−24, 78)	34 (−32, 164)	–
Netherlands	Hoek et al. 2002[195]	Near major road	41 (−6, 112)	95 (9, 251)	–
Hamilton, Ontario, Canada	Finkelstein et al. 2004[197]	Near major road	18 (2, 38)	–	–
French PAARC	Filleul et al. 2005[198]	10 $\mu g/m^3$ BS	7 (3, 10)[f]	5 (−2,12)[f]	3 (−8,15)[f]
Cystic fibrosis	Goss et al. 2004[200]	10 $\mu g/m^3$ $PM_{2.5}$	32 (−9, 93)	–	–

[a]Cardiovascular only; [b]Pooled estimates for males and females; pollution associations were observed primarily in males and not females; [c]Respiratory only; [d]Reported to be nonsignificant by author; overall, effect estimates to various measure of particulate air pollution were highly unstable and not robust to selection of model and time windows; [e]Estimates from the single pollutant model and for 1989–1996 follow-up; effect estimates are much smaller and statistically insignificant in an analysis restricted to counties with nitrogen dioxide data and for the 1997–2001 follow-up; furthermore, county-level traffic density is a strong predictor of survival and stronger than $PM_{2.5}$ when included with $PM_{2.5}$ in joint regressions; [f]Estimates when six monitors that were heavily influenced by local traffic sources were excluded; when data from all 24 monitors in all areas were used, no statistically significant associations between mortality and pollution were observed.

With regard to the infant mortality findings (Woodruff et al., 2006), although the analyses are based on cross-sectional or long-term differences in air pollution, the time frame of exposure for the infants was clearly shorter than for adults (a few months vs. years). The relevant time scales of exposure for different age groups, levels of susceptibility, and causes of death need further exploration.

2.6.1.3 Time scales of exposure

The PM-mortality effect estimates from the long-term prospective studies (Table 2.4) are substantially larger than those from the daily time series and case-crossover studies (Table 2.3). If the pollution- related excess deaths are only because of deaths of the very frail who have heightened susceptibility and who would have died within a few days anyway, then the appropriate time scale of exposure would be only a few days, and impacts on long-term mortality rates would be minimal. Much of the difference in PM-mortality associations observed between the daily time series and the prospective cohort studies may be because of the dramatically different time scales of exposure (a few days vs. decades). Effective dose, in terms of impact on risk of adverse health effects, is almost certainly dependent on both exposure concentrations and length of exposure. It is reasonable to expect that effect estimates could be different for different time scales of exposure. Long-term repeated exposures could have larger, more persistent effects than short-term transient exposures, and that long-term average exposures could be different from the cumulative effect of short-term transient exposures.

These results from (Table 2.3 and 2.4) do not provide the complete picture, but they suggest that the short-term, daily time series air pollution studies are not observing only harvesting or mortality displacement. These results also suggest that daily time series studies capture only a small amount of the overall health effects of long-term repeated exposure to particulate air pollution. Because the adverse health effects of particulate air pollution are likely dependent on both exposure concentrations and length of exposure, it is expected that long-term repeated exposures would have larger, more persistent cumulative effects than short-term transient exposures. PM-mortality effect estimates for intermediate time intervals provide evidence that the difference in PM-mortality associations observed between the daily time series and the prospective cohort studies are at least partially because of the substantially different time scales of exposure.

Concentration-Response (CR) functions of short-term exposure are available for long time, while the effect of long-term exposure is still need some more study. But still the effect of long-term exposure gets more interests than short-term exposure (Wadud and Khan, 2010). From Table 2.3 and 2.4 it can be conclude that, CR functions for increases in premature deaths due to a continued exposure to $PM_{2.5}$ are almost an order of magnitude higher than those for short term exposure. This study utilizes the CR functions for long term exposure since the different policy alternatives are expected to lead to a long term reduction in $PM_{2.5}$ exposure.

2.6.2 Morbidity related health effects

Several dozen epidemiological studies have reported associations between various measures of PM and a range of morbidity outcomes, including:

- Chronic Bronchitis
- Respiratory Hospital Admission
- Asthma Attack
- Emergency Room Visits
- Restricted day activities
- Lower respiratory illness
- Respiratory symptoms
- School absenteeism
- Decreased lung function

Most of the studies have been conducted in cities in North America, with a few conducted in Europe and very few outside of these two areas (World Bank, 2006). Therefore, compared to the mortality findings, there is a greater degree of uncertainty when morbidity findings are extrapolated to developing countries, since estimation requires both a concentration-response function and a baseline incidence rate. However, the additional regional evidences about these effects are more readily available now-a-days. Consequently, these estimates can be applied to other economically developing regions, outside of North American and Western Europe, with some modifications.

2.6.3 Valuation methods of health impacts

There are various approaches to valuing health effects resulted from air pollution. The simplest is the use of Value of Statistical Life (VSL). This approach values every life lost as equal, irrespective of whether the remaining life expectancy of the people dying is a few weeks or many years. This is the approach used by USEPA in its recent Regulatory Impact Analyses (USEPA 2005a, 2007, 2008). Clearly, the VSL approach builds on the assumption that 'attributable deaths' can be calculated from the CR functions directly. The advantage of the model is its simplicity and rather well studied estimates of VSL. The disadvantage is that it is, at best, an approximation and generally an overestimation, especially for the mortality risk (Wadud, 2008).

A different stream of literature (mainly in Europe), however, follows the Loss of Life Expectancy (LLE) approach. For long term exposure (cohort studies), the age-specific mortality risks are adjusted using the CR functions and changes in concentration of the pollutant. These adjusted mortality rates are applied to a life-table and survival years are compared between a base case and a changed concentration (as a result of policy intervention) case. The differences give the average LLE in the population, which when multiplied by the Value of a Life Year (VOLY) gives the health costs due to long term exposure. This approach requires extensive amount of explicit data regarding different health end point including age at the time of death for each personnel (Wadud, 2008).

Another method used for valuation of health impacts is human capital approach. This method estimates the impact of an individual's illness or premature death on society by measuring the discounted value of his/her productivity loss (labor earnings) due to morbidity or premature mortality. The approach is considered a lower bound value since it uses foregone future incomes as the valuation vehicle, but does not include the subjective value people assign to life (in terms of consumption, leisure, etc.) (Gaioli et al., 2002).

Cost of Illness (COI) method is also used to estimate the economic values of health effects of air pollution. This method includes medical costs of treatment (medicine, physician, medical tests and hospitalization) and indirect costs (loss of wages due to illness, opportunity lost due to absence from school, etc) (Torres et al., 2004).

2.6.4 Previous studies on health impact estimation

A number of studies have been performed to find out the different impacts of particulate air pollution upon human health all over the world. 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 in Dhaka city (ADB & CAI-Asia, 2006). 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 Dhaka 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).

Wadud and Khan (2010) have estimated the health benefits achieved by introducing the CNG- fuel in Dhaka city. It shows that in 2007 around 5,200 premature deaths have been avoided in Dhaka city only due to the introduction of CNG as fuel, which accounts for a savings of US\$ 0.99 billion annually (1.4% of the total GDP). Torres et al. (2004) have conducted a study on health effects of air pollution in Metro Manila, Philippines. It summarized the different health effects in the Metro Manila due to air pollution. It was estimated that there were more than 10,000 excess cases of acute bronchitis, almost 300 excess cases of asthma and 9 excess cases of chronic bronchitis attributable to the air pollution with the PM_{10} level above $50 \mu g/m^3$ in Metro Manila in 2002. For hospital admissions, there were 200 excess respiratory and 40 excess cardiovascular admissions. From the same study, mortality was found to be substantial as it was estimated that the excess deaths due to cardiovascular causes attributable to the PM_{10} level above $50 \mu g/m^3$ were 40-200 persons and 300-330 persons for excess respiratory deaths for all of Metro Manila in 2002.

A study is conducted by Srivastava and Kumar (2001) to assess the health impact of air pollution in Mumbai, India in 2001. The study results show that the avoidance cost related to air pollution can be as much as 29% of the total health damage cost of the city. A study on the Jakarta shows that premature mortality can be reduced by 1,200 if the particulate concentration is within the Indonesian Standards (CAI-Asia, 2009). According to Guttikunda (2008) premature mortality in Hyderabad, India due to particulate matter above the threshold value selected on the basis of WHO guidelines can be 2,790 persons in 2006. The total cost regarding the health impact is US\$ 260 million, 46% of which is due to the morbidity effects. Ostro (2004) has compiled a study for environmental burden of disease at national and local levels due to outdoor air pollution as a part of Environmental Burden of Disease study by WHO. This study has focused on different effects of outdoor air pollution and results are published for different countries, both in health effect and monetary terms.

2.7 Concluding Remarks

Air quality of Dhaka is a threat to its inhabitants. 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. Source apportionment studies indicate that apart from the soil dust, motor vehicles and brick kilns are the most dominant source of particulate pollution. Contribution of different sources to ambient particulate concentrations needs to be studied in further details. This chapter also summarizes different air quality modeling studies carried out so far as well as the studies involving the health impact of air pollution. It shows that no significant modeling study has so far been carried out for predicting air quality throughout the city by considering major pollution sources including motor vehicles and brick kilns. This leads to the requirement of the present study as this will consider both the sources to model and predict the air quality, which eventually could help in valuation of the health related effects on residents of Dhaka. 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

The primary objective of the present study is to estimate the effect of air pollution upon human health. This chapter presents the methodologies that have been followed in achieving the objectives of the study. The study is based on the Impact Pathway Approach. This chapter describes the modeling approach adopted to find out the source receptor relationships which is the first step of the impact pathway approach. Then the procedure for obtaining ambient concentration from the source receptor relationships and the emissions is described. Afterwards health impact evaluation methods are presented. Finally, the valuation of different health damages to determine the monetary values of the effects is described.

3.2 Impact Pathway Approach

Air pollution accounts for a large share of the total environmental costs in a country. To quantify the environmental costs due to air pollution the Impact Pathway Approach is adopted by many organizations. European Commission first adopted this approach (Bickel et al., 2001). Impact pathway approach can help in quantification of both marginal costs and total costs. In determining the costs of environmental impacts due to air pollution, it is important to relate the emissions from different sources to a well defined damage end point (e.g. $PM_{2.5}$ related respiratory illness) and associated costs. A sequence of events is necessary to model the valuation of environmental impacts. This can be best explained by the impact-pathway approach, described graphically in Figure 3.1 (ExternE, 2005). Impact pathway assessment is a bottom-up-approach in which environmental benefits and costs are estimated by following the pathway from source emissions via quality changes of air, soil and water to physical impacts, before being expressed in monetary benefits and costs. Each sequence of this model can be treated as individual module and requires extensive mathematical and statistical input. Consequently, each segment of the approach can be associated with a certain amount of error. Thus, the later module of the model is expected to have error of more intensity than the earlier ones.

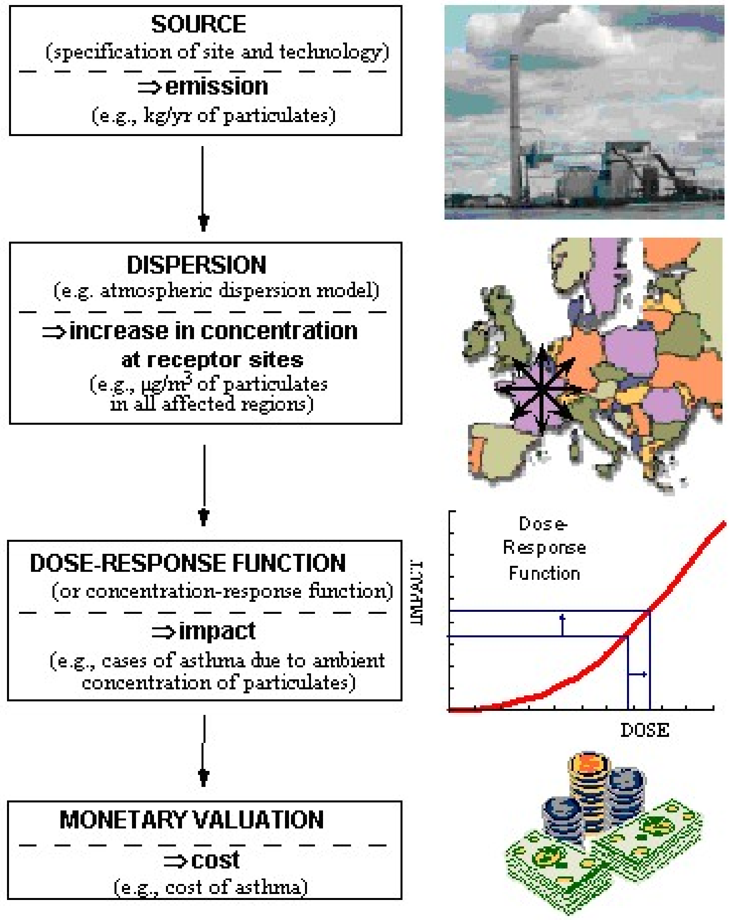


Figure 3.1: Impact Pathway Approach Methodologies (ExternE, 2005)

The first step of the Impact Pathway Approach is the emission generation from the source. Emission can be estimated through any technical model or sometimes it can be the monitoring data. The next step involves dispersion modeling, which estimates the increase in concentration. The third step defines the relationship between exposure and a damage valuation end point e.g., respiratory problem due to $PM_{2.5}$ concentration. Often Dose-Response functions, also known as Concentration-Response (CR) or Exposure-Response functions are used to convert the exposure to a damage end point. Two emission scenarios are needed for each calculation, one reference scenario and one case scenario. The estimated difference in the simulated air quality situation between the case and the reference situation is combined with exposure response functions to derive differences in physical impacts on public health, crops and building material etc. the last step of the pathway approach is the evaluation of physical impacts in monetary terms. This step could be straight forward as for property damages, yet it could be more difficult, and sometimes controversial, e.g. when valuing the premature mortality effects of emissions due to respiratory illness from the vehicle emissions.

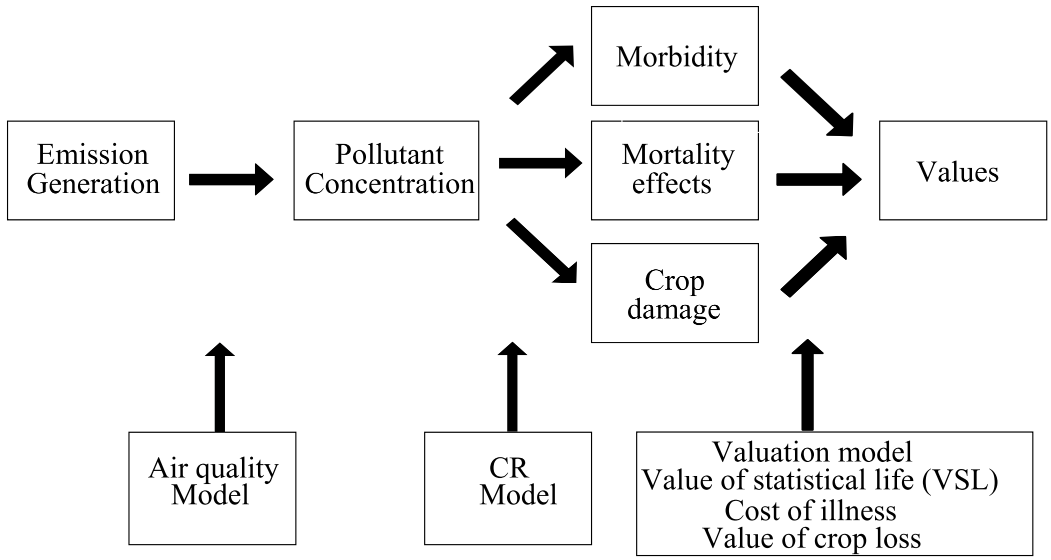


Figure 3.2: Impact pathway for air quality (Wadud, 2008)

Within the impact-pathway chain, there could be different end points for valuation, e.g. air pollutants can have different effects on health, e.g. increased premature mortality, increased morbidity or damage crops and materials (Figure 3.2). To generate the total impact, the monetary values of all the end points need to be added together. While damage valuation could be straight forward for some end point, (e.g. property values can be obtained from housing data directly), value of some of the end points (e.g. premature mortality) cannot be obtained from market data directly and need to be modeled using, primarily, econometric techniques. This study is mainly focused on the second, third and fourth steps of the Impact Pathway Approach i.e., to find out ambient pollutant concentration, damage prediction and finally valuation of the damage end point. This study uses the emission inventory developed in the study of Arjumand (2010), with some modifications, as input in the air quality model. Then the ambient concentrations of particulate matter have been predicted by adopting source-receptor model.

3.3 Source-Receptor Model

The Source-Receptor (S-R) model is the indication of 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). 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:

$$C = mQ \quad \text{(3.1)}$$

where, C = ambient concentration of pollutant,

m = constant,

Q = total emissions

In equation 3.1, 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.).

3.3.1 Dispersion modeling versus S-R model

Dispersion models, which are described in the previous chapter, are used to determine the ambient concentration in a region. It uses the emission, meteorology and all the necessary data to fit into the main model in each case. But once transfer matrix is obtained, S-R model requires only the emission within the domain. Thus if domain and meteorology are remain constants, it does not require to run the whole modeling process for the change in emission in S-R modeling. Hence, for the scenario analysis in urban cases, when the only variable changing is emissions, this methodology helps with the rapid assessment.

Dispersion modeling:

- data intensive
- time consuming
- needs a lot of training and experience
- needs full-fledged meteorological data
- requires plenty of local input
- A variety of models exist

SR Matrices:

- Still require some level of dispersion modeling to develop these relationships – it is done once for multiple scenario analysis
- Help conducting quick analysis of pollution sources
- Waiting period for results is less – given some limitations on accuracy
- Results obtained still need to be calibrated and authenticated before actual use

Figure 3.3 shows the comparison between these two major types of air quality modeling. From the figure it can be easily visualized that dispersion modeling consumes much more time than S-R modeling in case of scenario analyses, where only variable is emissions.

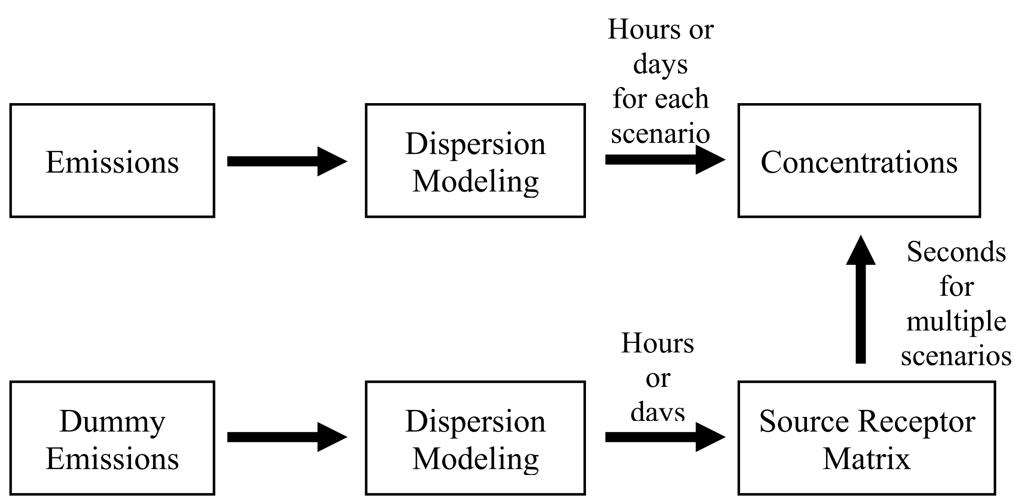


Figure 3.3: Comparison of concentrations computation (Guttikunda, 2010)

3.3.2 Linear or non-linear S-R model

The S-R model can be linear or even non-linear. In the nonlinear case, it is defined by the partial derivative $\partial y/\partial x$ at a given state of the system. But standard Lagrangian particle dispersion models cannot simulate nonlinear chemical reactions. However, all the other processes occurring during the atmospheric transport of pollutant substances are linear: advection, diffusion, convective mixing, dry deposition, wet deposition and radioactive decay. Transformations of primary pollutants to the secondary pollutants involve some chemical reactions which can be represented as first-order reactions. First-order chemical reactions are also linear.

3.3.3 Elements of source receptor matrix

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 presents in the domain, which contribute to the concentration of a certain portion of that domain, the concentration can be obtained using the following equation 3.2.

$$C_j = \sum_i m_{ij} Q_i \quad \text{(3.2)}$$

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,

$$C = MQ \quad \text{(3.3)}$$

Where, C = Concentration vector

M = Source-Receptor Matrix (SRM)

Q = Emission vector

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

$$m_{ij} = \frac{\partial c_j}{\partial q_i} \quad \text{(3.4)}$$

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}.

$$m_{ij} = \frac{c_j}{q_i} \qquad (3.5)$$

To generate the SRM an air quality model is required. It can be generated using box model, puff model, plume model, Eulerian or Lagrangian models as discussed in section 3.3.4. 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. The SRM obtained from the dispersion modeling need to be calibrated and validated. But the basic challenge in case of the S-R matrix is the determination of it through the dispersion modeling.

3.3.4 Dispersion modeling for SRM generation

Air pollution dispersion models are computerized representations of the atmospheric processes, such as physical and chemical transformation of a mix of pollutants at urban, regional, and global level. This model can simulate the atmospheric concentration to a various degree of accuracy. It can mathematically represent the pollutant emissions, background concentration, chemical reactions for the primary to secondary pollutant transformation and even the local meteorology such as sunlight, wind, temperature, precipitation etc (Guttikunda and Calori, 2009).

The physical transformation may include advection of the pollutants, depending on the local terrain and meteorological conditions, and dry and wet deposition of the pollutants. The deposition schemes vary for the pollutants depending on the chemical composition. The chemical transformation depends on the intensity and mix of the emissions, local meteorology affecting the mix of the pollutants via advection. For example, secondary particulate matter is formed as a result of reaction between primary pollutants, e.g., Nitrogen Oxides (NO_x), Sulfur Oxides (SO_x), Ammonia (NH_3) and Sulfate (SO_4^{2-}).

Particulate Matter (PM) is the most important ambient pollutant in the urban context especially in Dhaka. The mix of PM pollution is also complex, with contribution from the primary emissions, such as black carbon, soil dust, and sea salt, and the secondary. The secondary PM contribution is a result of chemical transformation of the primary emissions, such as sulfates from sulfur dioxide (SO_2), nitrates from NO_x, and secondary organic aerosols due to oxidation of VOCs. The dispersion model can help study these physical and chemical transformations of pollutant, which is very essential for understanding the contribution from different sources to control the PM related air pollution. The mathematical representation of the dispersion models varies depending on the depth of information available for modeling and computational facilities. The models range from easy to use simplified Box models to complex three-dimensional (3D) Eulerian models with full fledged chemical mechanisms. A comparative description of the dispersion models is provided in Table 3.1.

Table 3.1: Comparative description of the dispersion models (Guttikunda and Calori, 2009)

	Box	Plume	Eulerian
Complexity	*	**	****
Data requirement	*	**	****
Pollutant chemistry	*	**	****
Advection of pollutants	*	**	****
Ease of operations	****	**	*
Computational requirements	*	**	****
Results – level of detail	*	**	****

There are benefits for using any of the available models, depending on the model output requirements. For example,

- Where rapid assessment of the emissions and chemical mechanism is required the Box Models can be advantageous.

- To evaluate the impact of point sources (e.g., industrial stacks) the Gaussian plume models have been used.
- Data and computationally intensive Eulerian models are known to provide modeling flexibilities at urban, regional, and global scales

3.3.4.1 Criteria for model selection

Given the complexities of the models available, the selection of a dispersion model primarily depends on the following parameters (Guttikunda and Calori, 2009):

- Information: The models vary on the intensity of data requirements and it is important to understand the level of information available. The confidence levels and the accuracy of the models depend entirely on the input information and it is important that a model is chosen to support the information available.

- Computational Facilities: The intensity of the modeling varies from the box models to Eulerian models. The Box models can simulated even in a MS Excel format, while the 3D Eulerian models are data intensive and require Linux or UNIX operating environment for ease of data manipulation. The latter are also time consuming – for the preparation of the input fields and computational times. So, depending on the technical expertise and computational facilities available, a model is chosen to support necessary modeling objectives.

- Modeling Objectives: Each of the models available is capable of performing a set of similar calculations, but the levels of details vary. A model should be chosen depending on the objective. For example, if the objective is to evaluate point sources and not the interactions of pollutants, and then a Gaussian plume model will suffice. However, for the later an Eulerian model is better suited.

An output from a dispersion model is advantageous in many ways. The output can be used to study the spatial distribution of the pollution over a city or region; to better understand the pollution hot spots and assist in the allocation of monitoring networks; to study the influences of the local terrain and meteorological conditions on pollution chemistry; and to evaluate the possible pollution scenarios for the future.

For this study, a modified version of The Atmospheric Transport Modeling System (ATMoS), ATMoS-4.0 is selected which is a Lagrangian Puff-transport model. This model is suitable for urban context. It requires meteorological input of one station only. The transfer coefficients of different pollutants can easily be achieved be using this model.

3.3.4.2 Advantages of ATMoS-4.0

The main advantages of the model ATMoS-4.0 are:

- Since the model uses the puff transport methodology, illustrated later in the Figure 3.5, this allows for segregated analysis of the pollutant concentrations by grid or by sector, depending on the input details.
- The modeling can be conducted for individual grids or all grids combined.
- The model has flexibility in grid size resolution and the number of grids (domain size to be modeled). However, for the simplifications to suite urban analysis, the maximum domain size is fixed in this version.
- All the modeling calculations are conducted on a Linux or UNIX platform and the outputs are formatted for direct input in MS Excel worksheet or GIS platforms for further analysis.
- The ATMoS-4.0 has been simplified, especially for the meteorological pre-processors, to reduce computational time and input requirements (details in the next section).
- The output format is fixed for monthly and yearly time frames.

3.3.5 ATMoS-4.0 model description

The dispersion model used for the present study 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 3.4 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. The next sections describe the salient features of the ATMoS-4.0 AQ model.

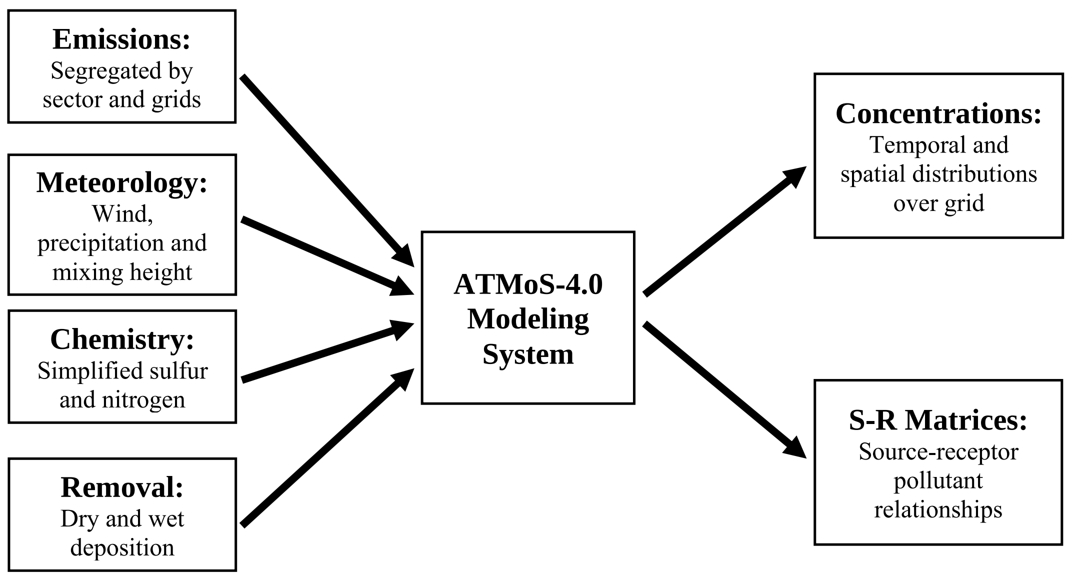


Figure 3.4: Input and output schematics of ATMoS-4.0 (Guttikunda and Calori, 2009)

3.3.5.1 Puff transport

The model uses the puff transport methodology as illustrated in Figure 3.5. It assumes that the pollutants are emitted as puffs. Then the puffs released in the atmosphere undergo different physical and chemical mechanisms and the mass of the puffs are reduced. The puffs are also divided into segments. These segments of puffs are tracked until they are small enough to have no substantial impact on the atmospheric concentration.

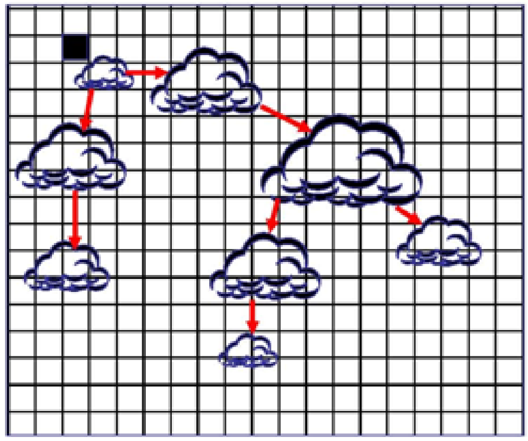


Figure 3.5: Lagrangian puff transport of the pollutants in ATMoS-4.0(Guttikunda and Calori, 2009)

The puffs are assumed to get released in every 3 or 6 hours. Then each of the puff is assigned a mass value which is corresponding to source strength. The puff is also assumed to mix uniformly in each vertical layer and diffused along horizontal direction following a Gaussian distribution (Figure 3.5). The puffs are tracked for 5 days or until there mass falls below 0.1% of their original mass or they fall out of the domain. Puffs transported beyond the modeling domain are no longer tracked.

3.3.5.2 Spatial and temporal scales

The grids in the ATMoS-4.0 are defined in degrees of latitudes and longitudes. Maximum number of grids is limited to 25 x 25 for both longitudes and latitudes. This limitation is due to the ease of operations. The maximum grid resolution is 0.1° for both latitudes and longitudes. Since the model is modified for urban domain with uniform wind pattern only, these limitations are adopted.

The temporal and the spatial resolutions have a certain level of flexibility. The model can run for grid resolution of hundredth of a degree to tenth of a degree. The temporal resolution can be month, season or year.

3.3.5.3 Meteorological data

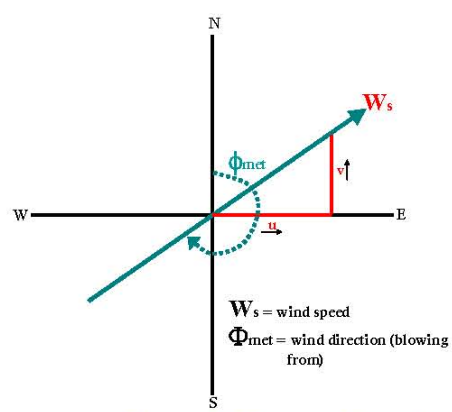
The actual ATMoS model utilized 2.5° by 2.5° reanalysis meteorological data from the NCEP/NCAR. Meteorological input data included six hourly precipitation, mixing height, and wind vector information (speed and direction). The modified version ATMoS-4.0, though uses the same meteorological parameters, the input is simplified to a single meteorology data for the city (Guttikunda and Calori, 2009). This is valid as long as the assumption that anywhere in the city domain, defined by the user, the meteorological conditions are similar.

The model utilizes-

- Horizontal x-wind component (u)
- Horizontal y-wind component (v)
- Mixing layer height (MH)
- Precipitation (p)

Most often the meteorological data is available in the form of wind speed and wind direction. The equation used to convert the wind speed and wind direction into u and v parameters are shown in Figure 3.6. Hence, the model meteorological input fields include:

- Wind speed (m/sec)
- Wind direction (origin, as shown in Figure 3.6) (degree)
- MH, mixing layer height (m)
- Precipitation (mm/hr)



$$u = -W_s * \sin(\frac{\pi}{180} * \varphi_{met})$$

$$v = -W_s * \cos(\frac{\pi}{180} * \varphi_{met})$$

φ_{met} is in degrees

Figure 3.6: Sign convention and conversion of wind field parameters (Guttikunda and Calori, 2009)

3.3.5.4 Emission processing

There is no input required for the emissions. A dummy emission value of 3,000 tons/year for each pollutant is set from each grid point as area and point source (separately) to build the source receptor transfer matrix. The dummy emissions value is selected arbitrarily. The result will not change if this value is changed. All the emissions are treated as puffs and advected utilizing the meteorological data (as illustrated in Figure 3.5).

The ATMoS-4.0 model separates the vertical dimension into two layers (boundary layer and upper layer) during the day and three layers (surface layer, boundary layer, and upper layer) at night, as determined by the vertical temperature profile. The model allocates emissions in different layers according to the source type and the hour of the day. Area emission sources (small industries, residential and mobile sources) are released into the boundary layer during the day and into the surface layer at night. Elevated sources such as high stack emissions are also released into the boundary layer all the time. Further details are documented in (Guttikunda and Calori, 2009) and CGRER (2001).

The puff released during daytime or nighttime expands and follows its own trajectory. However, during day to night and night to day transitions, the puff branches into multiple puffs (Figure 3.7). This action simulates the vertical wind shearing of the puff. Up to 32 branches of the original puff may be tracked simultaneously after which branching ceases.

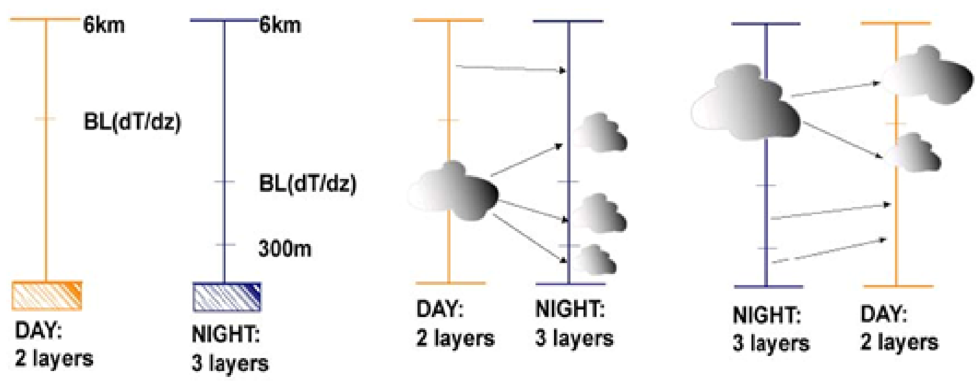


Figure 3.7: Branching mechanism of puff during vertical advection (CGRER, 2001)

During a day to night transition a puff in boundary layer will branch into three layers, while a puff in the upper layer will stay in the same layer during nighttime. During night to day transition, a puff in the surface layer will go to boundary layer, a puff in the boundary layer will stay in the same layer during daytime, and the growing boundary layer will cause a puff in the upper layer to branch into the two layers. This continues for 5 days (120 hours) or until the trajectories leave the modeling domain as discussed earlier.

3.3.5.5 Multi-pollutant processing

The PM pollution, which is critical for the urban areas, is a result of contributions of multiple sources and multiple pollutants. In Chapter 2 the chemical species for PM is discussed. 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 doesnot 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.

3.3.5.6 Removal process

While the chemical transformation of the species provides a form of removal of the emissions, two physical processes are included - dry deposition and wet deposition. The wet deposition scheme is activated only during the precipitation period. A net removal rate at the surface due to dry deposition is calculated using the equation

$$R_d = \frac{V_d}{z} \quad (3.6)$$

Where, R_d is the dry removal rate (per sec), V_d is the dry deposition velocity (m/sec), and z is the surface layer height (m). Constant dry deposition rates are prescribed in the model. Similarly, net removal rate at the surface due to wet deposition is calculated using the equation:

$$R_w = S_p * p \quad \text{(3.7)}$$

Where, R_w is the wet removal rate (per sec), S_p is the precipitation scavenging coefficient and p is the precipitation rate (mm/hr).

3.3.6 Model set up

At the beginning of the development of S-R relationship for the present study, the Model ATMOS-4.0 has to set up for run. The following articles describe the model setup steps sequentially.

3.3.6.1 Model domain

Selection of the spatial domain for the model is the first step in AQ modeling. The principal objective of the present study was to analyze the air pollution 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 brick kilns and the motor vehicles. Hence in choosing the domain, the positions of the brick kilns have been carefully examined. Figure 3.8 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 domain is extended in both north and south of Dhaka city. Most of the Brick kilns are situated outside the city. To consider the effect of them on the air quality of Dhaka the domain is so extended. The model area is divided into grids of 0.03° × 0.03°, which is approximately 3 km × 3 km.

Figure 3.9 presents the grid division of the model domain. The resolution of grid domain is usually adopted for the urban region. If the grid size is larger, the change in emission in a particular cell can have very little effect on the other cells. While smaller grids can improve the efficiency, but the time requirement will be higher compared to the degree of accuracy and accuracy of input data might not be adequate.

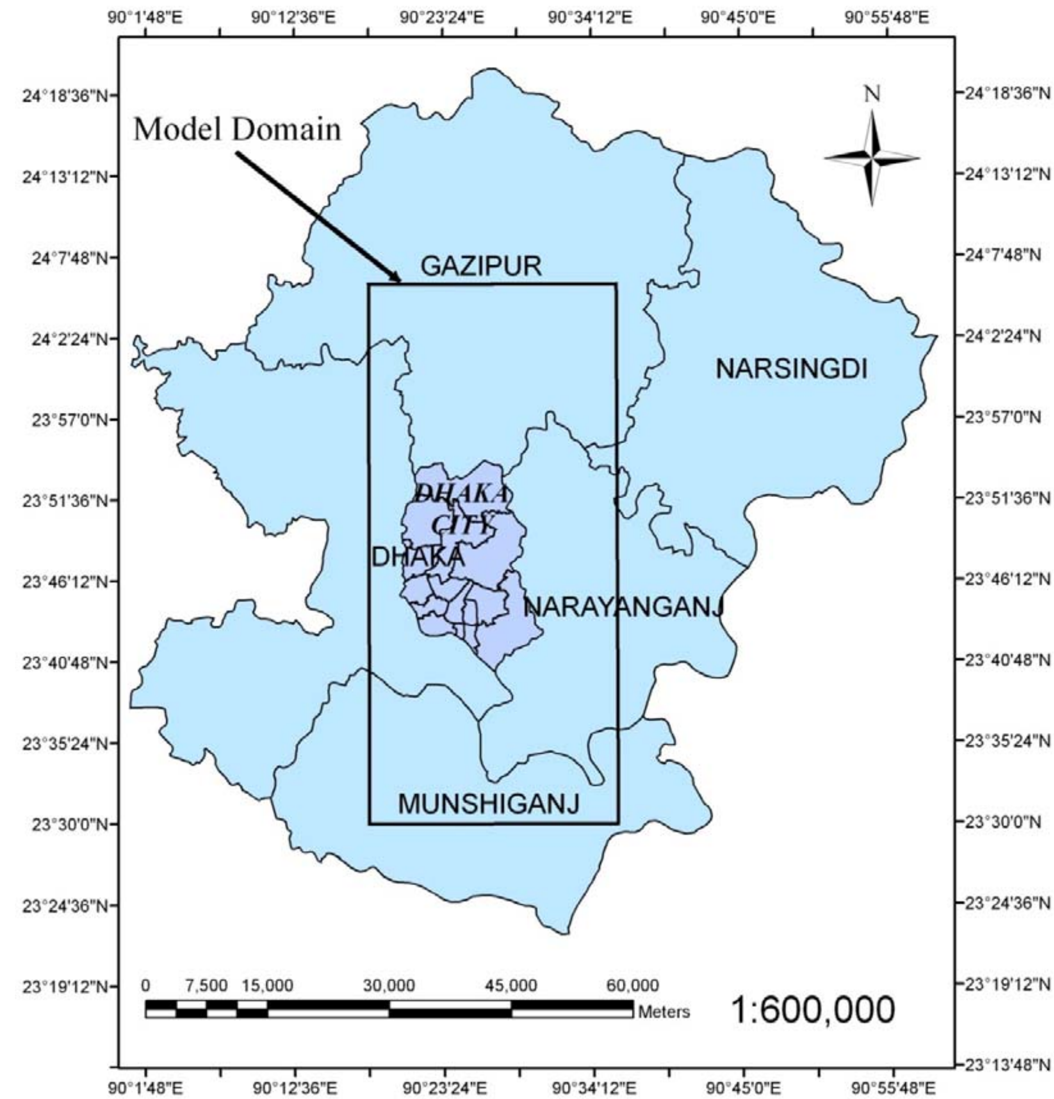


Figure 3.8: Model domain for the study

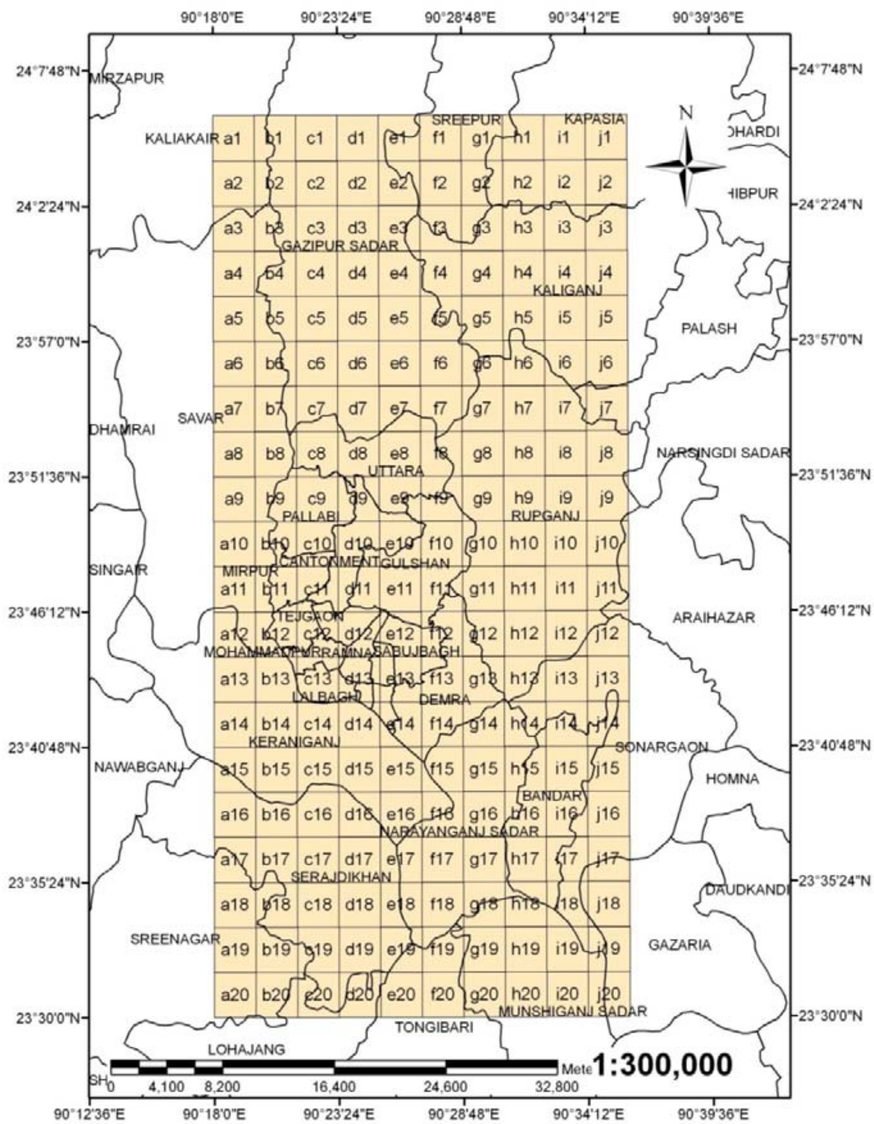


Figure 3.9: Division of the model domain into grids

3.3.6.2 Meteorology

The meteorological input file consists of wind vector (wind speed and direction), precipitation and mixing height. The meteorological data for Dhaka has been extracted from the ECMWF 40 Years re-analysis data server of European Centre for Medium-Range Weather Forecasts (ECMWF, 2010).

The latest available data of Dhaka city was for the year 2001. A time series analysis of meteorological parameters from the year 1999, 2000 and 2001 has been conducted. The analysis shows that there are little discrepancies among the data of different years. The following Table 3.2 summarizes the outcome of the above mentioned analysis. Hence in modeling the meteorological data of 2001 have been used as the input.

Table 3.2: Summary table of time series analysis of meteorological parameters

Meteorological Parameters	Statistical Indicator	1999	2000	2001
Wind Speed (m/s)	Standard Deviation	0.90	0.93	0.93
	Mean	2.07	1.93	1.87
	Median	2.02	1.82	1.77
Precipitation (mm/hr)	Standard Deviation	0.057048	0.057454	0.057917
	Mean	0.032808	0.034562	0.036285
	Median	0.000098	0.000065	0.000165
Mixing Height (m)	Standard Deviation	471	490	485
	Mean	477	484	491
	Median	307	298	295

3.3.6.3 Emission inventory

Emission sources

From the discussion presented in Chapter 2, it can be concluded that the major sources of air pollutants in Dhaka city are brick kilns, motor vehicles and the road dust. In the present study the emissions from the motor vehicles/ traffic and brick kilns have been considered. A grid-based emission inventory for Dhaka city has been developed by Arjumand (2010), which has been used in the present study with some modifications.

Emission conversion

Since Arjumand (2010) was developed independently some discrepancies arises in spatial grid locations, which create some difficulties e.g., differences in study domain, shifting of grid lines and inconsistency of base year. Due to the input format of the ATMoS-4.0 model, the model boundary is selected to be 90.3° to 90.6° E and 23.5° to

24.1° N and the grid lines were at the resolution of 0.03°. But the domain used for the emission inventory was 23°32’38” to 24°6’56” N and 90°16’14” to 90°37’26” E. Figure 3.10 shows these deviations of grids. As the emissions were treated as area sources, the emissions have distributed in the modeling domain in proportion to the area that crosses that of the emission inventory domain.

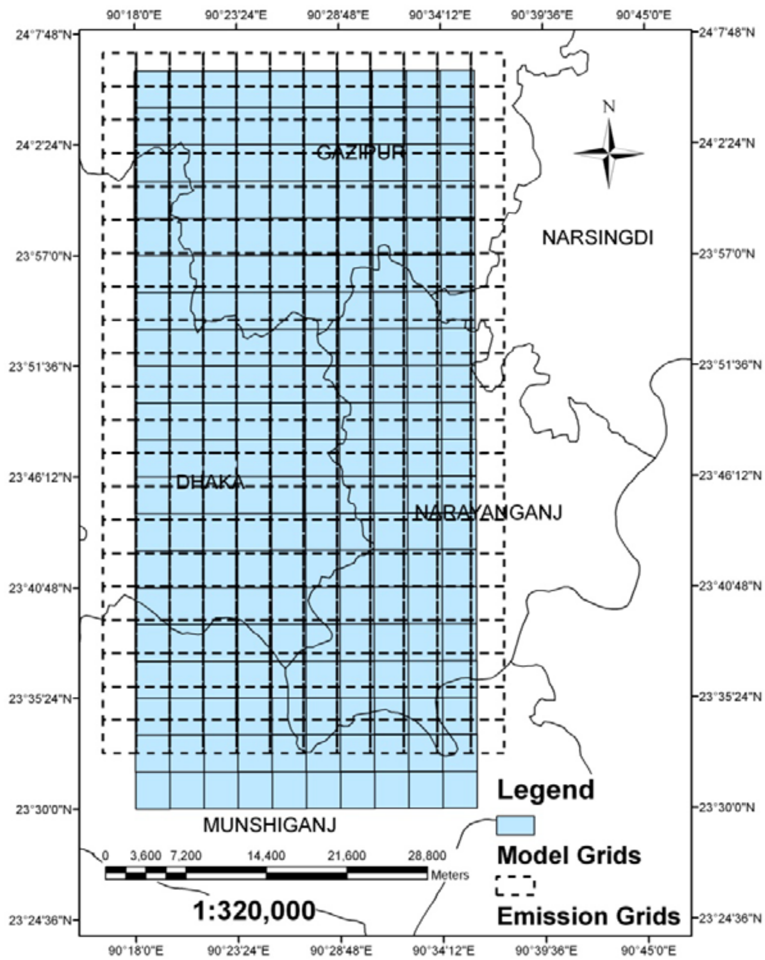
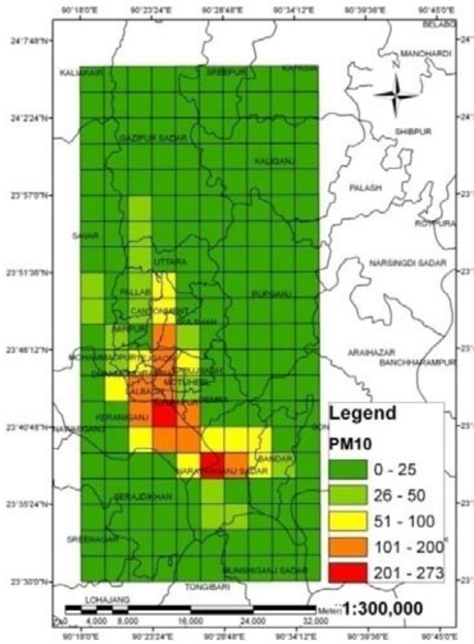


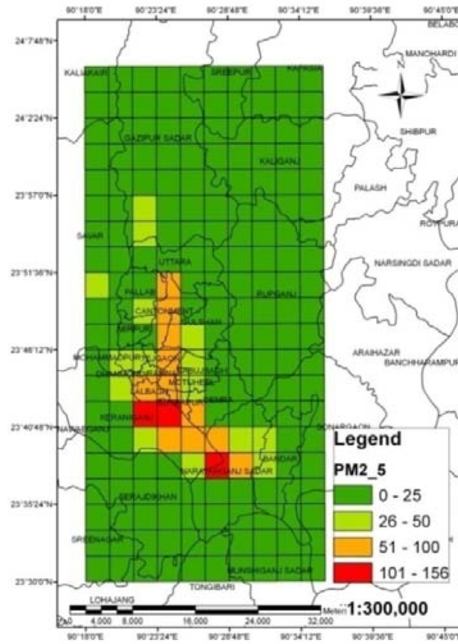
Figure 3.10: Shifting of grids in models from the emission grids

Traffic emission

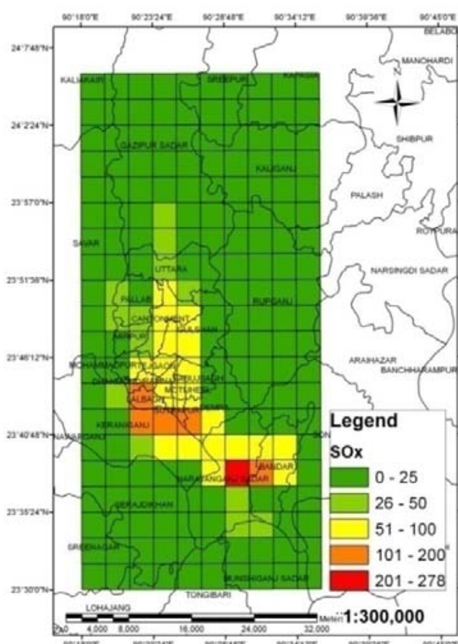
Figure 3.11 presents the traffic emissions in the model domain. Emission inventories are prepared for PM_{10}, $PM_{2.5}$, SOx and NO_x. Arjumand (2010) has established the inventories for the year 2005. These inventories are then forecasted to get the inventory for 2009. The forecasting is done by comparing the result of Arjumand (2010) with the results Wadud and Khan (2010), which has carried out an inventory for 2009. From the figure it is seen that the traffic emissions are usually higher in the Dhaka city area. Outside the city the emission load is very small.



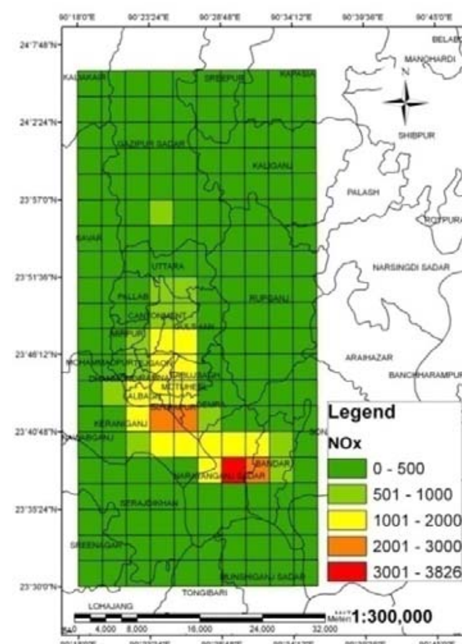
(a) PM_{10} emissions in tons/year



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



(c) SO_x emissions in tons/year

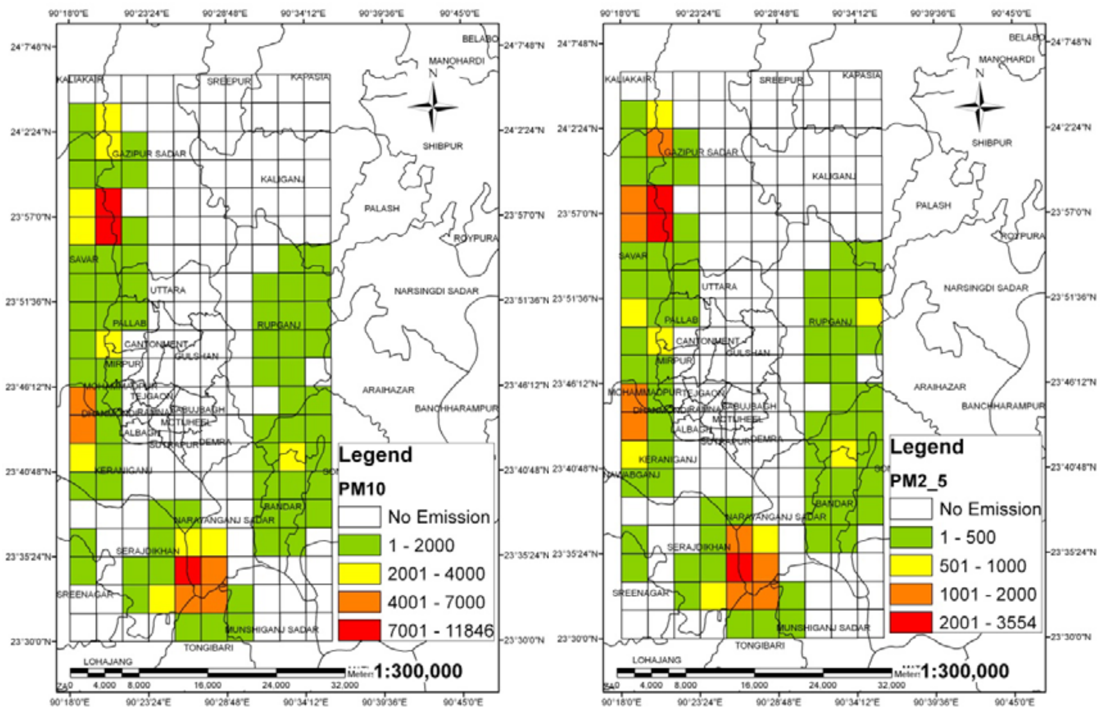


(d) NO_x emissions in tons/year

Figure 3.11: Traffic Emission (Base year: 2009)

Brick kiln emission

Arumand, 2010 has established an emission inventory for brick kiln emissions. Only the PM_{10} and $PM_{2.5}$ has been considered as the chief polluting agent emitted from the brick kilns in that study. The inventory was made for the year 2009 and the running period for the brick kiln was considered to be 165 days per year (November to Mid-April). In the present study the same is used with no alteration. The emissions are shown in figure 3.12. The brick kiln emissions are usually outside the main city. But the emission load is very high in comparison to the traffic emissions.



(a) PM_{10} emissions in tons/year **(b)** $PM_{2.5}$ emissions in tons/year

Figure 3.12: Brick Emission (Base year: 2009, Brick Burning Period: 165 days/yr)

3.3.6.3 Model parameters

In the modeling input file, some parameter values are to be set. The values of some of these parameters have been selected on trial and error basis. The ATMoS-4.0 has some default values. For Dhaka city, locally measured values are not available. But it has been found that that the default values give reasonable output, as the simulation results match some of the earlier studies. Hence the default values have been kept for the model simulations. These parameters include dry deposition rates, wet deposition rates and reaction rates for primary to secondary transformation. Table 3.3 shows the parameter values that are used in the study.

Table 3.3: Deposition and reaction rates of different pollutants (Guttikunda and Calori, 2009)

Pollutants	Dry Deposition Rates	Wet Deposition Rates	Reaction Rates
PM_{10} Coarse	0.003	0.001	--
$PM_{2.5}$ Fine	0.001	0.0001	--
SO_2	0.001	0.0001	0.00001
SO_4	0.0005	0.0003	--
NO_x	0.001	0.0001	0.000001
NO_3	0.0005	0.0005	--

3.4 Health Impact Evaluation

The third step of the Impact Pathway approach is to analyze the effect of the air pollution upon environment. The effects could be on human health, vegetation and even on the materials used for daily life. This study is limited to the impacts on human. Effects on human health can be in the form of increase in mortality rate or even in terms of morbidity. The change in concentration due to different policy alternatives along with the population under threat are coupled with epidemiological concentration response (CR) functions to estimate the heath impacts of various types. Each of these health cases is valued using the costs associated with the avoided incidents or the willingness-to-pay to avoid the incidents. The same air pollutants can have different effects on health, *e.g.* they can increase the mortality rate or increase morbidity of different types (asthma, respiratory trouble, eye irritation, sore throats, hospitalization for cardiovascular and respiratory disease, emergency room and physician office visits, asthma exacerbation, respiratory symptoms, loss of schooling, restrictions in activity, and acute and chronic bronchitis etc.), giving rise to different branches within the impact pathway chain (Wadud and Khan, 2010). Epidemiological studies (e.g. USEPA, 2004, IEc, 2006, Pope and Dockery, 2006, Dockery et al., 1993, Pope et al., 2002, Krewski et al., 2000, Laden et al., 2006) have been conducted to determine the different CR functions of these health end points. More details of these studies have been discussed in Chapter 2. In order to generate the total impact, each of the health end points for each of the harmful pollutants is modeled within the impact pathway approach. Finally, the monetary values of all the end points are added together (Wadud and Khan, 2010).

The health impact estimates are based on average urban concentrations of PM_{10} and $PM_{2.5}$ as markers for air pollution. Traditionally, monitoring of PM has been conducted to determine the concentration of pollutants in regional and background population exposures. As such, the estimates incorporated some of the larger urban sources of pollution such as traffic, industrial boilers, brick burning, road dust and incineration. On the other hand, since the monitors were fixed-site, these estimations do not take into account pollution "hot spots" that may have affected segments of the population, without affecting the overall urban average (Ostro, 2004). But this study considers the air pollution exposure of the segmented regions that are modeled by dividing the whole city into a number of grids.

As discussed in Chapter 2, $PM_{2.5}$ is believed to be a greater health threat than PM_{10} since the smaller particles are more likely to be deposited deep into the lung. In addition, studies have shown that particles this small will penetrate into the indoor, home environment (Ostro, 2004). The effect of $PM_{2.5}$ exposure has been considered in the present study.

3.4.1 Relationships for quantifying mortality effect

Based on the available study Ostro (2004) recommend a log-linear exposure formula for relative risk determination for measuring mortality. The formula is

$$RR = \frac{e^{\alpha+\beta \ln(X+1)}}{e^{\alpha+\beta \ln(X_o+1)}} \quad \text{.......} \quad (3.8)$$

where, ß = the co-efficient depending on the CR function of particular type of health end point

X = the annual mean concentration of $PM_{2.5}$

X_o = target or threshold concentration of $PM_{2.5}$

The equation 3.8 can be simplified as the ratio of the relative concentrations (of the current versus the target) raised to the power of ß:

$$RR = \left[\frac{X+1}{X_o+1}\right]^{\beta} \quad \text{.......} \quad (3.9)$$

The background level is the non-anthropomorphic concentration – that is, what would exist without any man-made air pollution. Typically, this level could be determined by examining monitors at very rural or coastal locations that are not impacted or minimally impacted by pollution sources.

Alternative relationships

To illustrate the effects of making a different assumption about the shape of the CR function, assume that mortality is linearly related to concentration (rather than a log-linear function). The RR would then be:

$$RR = \frac{e^{\alpha+\beta X}}{e^{\alpha+\beta X_o}} \quad (3.10)$$

$$RR = e^{\beta(X-X_o)} \quad (3.11)$$

Table 3.4 summarizes the ß co-efficient which are based on CR functions of Pope, 2002.

Table 3.4: ß coefficients for both the models for estimating relative risk associated with long-term exposure to $PM_{2.5}$ (Ostro, 2004)

Outcome	ß coefficient (lower and upper bound)
Cardiopulmonary mortality (log–linear exposure)	0.15515 (0.0562, 0.2541)
Cardiopulmonary mortality (linear exposure)	0.00893 (0.00322, 0.01464)
Lung cancer mortality (log–linear exposure)	0.23218 (0.08563, 0.37873)
Lung cancer mortality (linear exposure)	0.01267 (0.00432, 0.02102)

Since in this study improvement due to policy alternatives are analyzed, linear relationship of CR function is used. Log-linear requires exact concentration levels, which is not available in this study as all the sources have not considered. But linear relationship requires only the difference in concentrations due to the policy alternatives.

Once the relative risks have all been determined, the Attributable fraction, AF (or impact fraction, IF) of health effects from air pollution for the exposed population can be calculated. The “Attributable Fraction” is the decline in disease or injury that could be achieved in a given population by reducing the risk. The proportional reduction in the number of health problems or deaths as a result of reducing the risk factor is known as the "Attributable Fraction". In other words, it is the proportion of all health problems or deaths in the community that can be attributed to the risk factor. AF can be found from the following equation:

$$AF = \frac{RR-1}{RR} \quad \ldots\ldots (3.12)$$

To calculate the expected number of mortality cases due to air pollution (E), the AF is applied to the total number of deaths:

$$E = AF \times B \times P \quad \ldots\ldots (3.13)$$

Where, E = the expected number of deaths due to air pollution

B = the population incidence of the given health effect (i.e. deaths per 1000 people)

P = the relevant exposed population for the health effect

3.4.2 Estimation of morbidity effects

Exposure to the PM_{10} concentration is adopted to estimate the morbidity related health effects (World Bank, 2006). Health impacts are calculated from the following relation:

$$\Delta H_i = b_{ij} \times (X - X_o) \times P \quad \ldots\ldots (3.14)$$

Where, ΔH_i = change in the number of health impact of type i

b_{ij} = the slope of the concentration response function of health effect of type i for exposure to pollutant j

Concentration-response function for different morbidity case is adopted from the report of Bangladesh: Country Environment Analysis (World Bank, 2006) and are presented below in Table 3.5. Among the various morbidity effects, CR of lower respiratory illness is based on the child population i.e., population below 15 years. CR of restricted day activities and chronic bronchitis are based on the population above 15 years. While CR of respiratory hospital admission and emergency room visits are based on the total population, that of asthma attack is based on the asthmatic population.

Table 3.5: Concentration response-function slope (b_{ij}) per µg/m^3 change in the Annual average PM_{10} concentration (World Bank, 2006)

Health Effects	Units	Concentration response function per µg/m^3 PM_{10}
Chronic bronchitis	Per 100,000 adults	6.12
Respiratory hospital admission	Per 100,000 population	1.2
Asthma attack	Per 100,000 asthmatics	3,260
Emergency room visits	Per 100,000 population	23.54
Restricted day activities	Per 100,000 adults	5,700
Lower respiratory illness	Per 100,000 children	169
Respiratory symptoms	Per 100,000 adults	18,300

3.4.3 Valuation of mortality impact

After assessing the number of premature deaths avoided due to different policy alternatives induced air quality improvement, the monetary evaluation of the policy is demanded. To evaluate the monetary benefits from the policy, monetary value is assigned to the avoided deaths. The most common approach is to use a Value of Statistical Life (VSL). Wadud and Khan (2010) define VSL as the amount that the people are willing to pay to reduce or accept to increase the mortality risks (probability of death), they face. More technically, VSL is the marginal rate of substitution between an individual's wealth and mortality risk (Hammit 2008). VSL is a controversial concept, especially in the developing countries, but economic value of a statistical life is now an accepted methodology in economics (Viscusi 2004) and is used widely for policy analysis. Health benefits therefore are calculated as:

$$Health\ benefits = Deaths\ avoided\ \times VSL \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.14)$$

This approach values every life saved as equal, irrespective of whether the remaining life expectancy of the people dying is a few weeks or many years. This is the approach used by USEPA in its recent Regulatory Impact Analyses (USEPA 2005, 2007). The advantage of the model is its simplicity and the availability of numerous VSL estimates. The disadvantage is that it generally overestimates the benefits, especially for valuation of health risks from long term exposure. Loss of Life Expectancy (LLE) approach is more specialized approach and also estimates a lower value than VSL approach (DEFRA, 2007). This approach utilizes the age distribution and remaining life expectancy of people and applies Value of Life Year (VOLY) to each year of life prolonged by the policy intervention. But this approach is more data extensive; hence this study uses the simple VSL approach.

Though VSL is a widely researched area, very few studies are available for developing countries like Bangladesh. Even the estimated values vary a lot (Wadud and Khan, 2010). They summarize that USEPA (2007) uses a central value of US$ 5.5 million (1999 US$), with an order of magnitude difference between high and low estimated values (US$ 1- 10 million), DEFRA (2007) uses an implicit value of GBP 1.1 million (2002 GBP) while ExternE (2005) in Europe uses € 1 million (2000 €). Even in India estimates of VSL vary widely; e.g., Rs. 1 million (Bhattacharya et al. 2007), Rs. 14.5 million (Madheswaran 2007), Rs. 15 to 35 million (Simon et al. 1999) to Rs. 56 million (Shanmugam 2001). The lower values of VSL are generally found from Contingent Valuation studies (where people are asked about their willingness to pay to reduce the risk of death), while the higher values are found from Revealed Preference studies (where existing wage differentials in job with different risks are analyzed to determine the risk premium). Krupnick et al. (2006), on the other hand, find that the willingness to pay to reduce health risks are around US$ 1 million for China, similar to those in developed country when estimated using the same techniques and corrected for purchasing power parity (PPP).

One of the published estimates of VSL for Bangladesh by Miller (2000), suggests a value of US$ 40,000 (1997 US$) with a range of US$ 30,000-0.7 million. It is however, not clear if the value is purchasing power parity (PPP) adjusted or not. Mahmud (2005) estimates VSL for Bangladesh to be in the range of US$ 1,783 to US$ 2,922. But this estimation is very smaller compare to the previous study. Wadud and Khan (2010) transfer the central value of few of the above mentioned estimates to Bangladesh context. That study suggests US$ 190,000 (2007 US$) as the median VSL estimates for Bangladesh, while the lower and upper bound values are respectively US$ 53,000 and US$ 327,000. While the PPP adjusted GDP of Bangladesh is assumed to be 241.1 Billion US$ for 2009 (CIA, 2010).

3.4.4 Valuation of morbidity effects

In order to evaluation the monetary values of morbidity effects WTP based health effect costs is considered (World Bank, 2006). The values are shown in the table 3.6. The original literature reported the values for the US in 1990. These values are converted to the values for the base year 2009. The conversion is made considering the rate of change of the cost is same as the rate of change in GNI per capita. Then the Bangladesh specific values are obtained by multiplying the costs of the USA with the ratio of GNI per capita of Bangladesh to that of the USA.

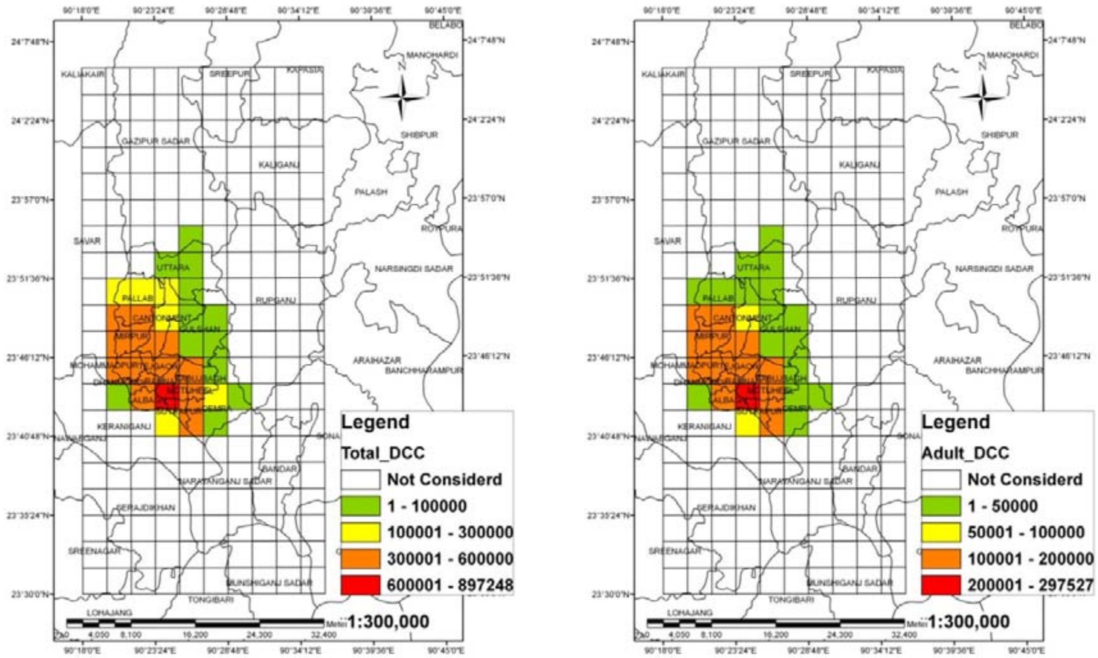
Table 3.6: Health costs per case in Bangladesh (World Bank, 2006)

Health Effects	WTP in USA (US$)		WTP in Bangladesh (US$)
	1990	2009	2009
Chronic bronchitis	195,000	383,013	12,489
Respiratory hospital admission	4,225	8,299	271
Asthma attack	63	124	4.04
Emergency room visits	126	247	8.07
Restricted day activities	53	104	3.39
Lower respiratory illness	44	86	2.82
Respiratory symptoms	44	86	2.82

3.4.5 Population and death rate

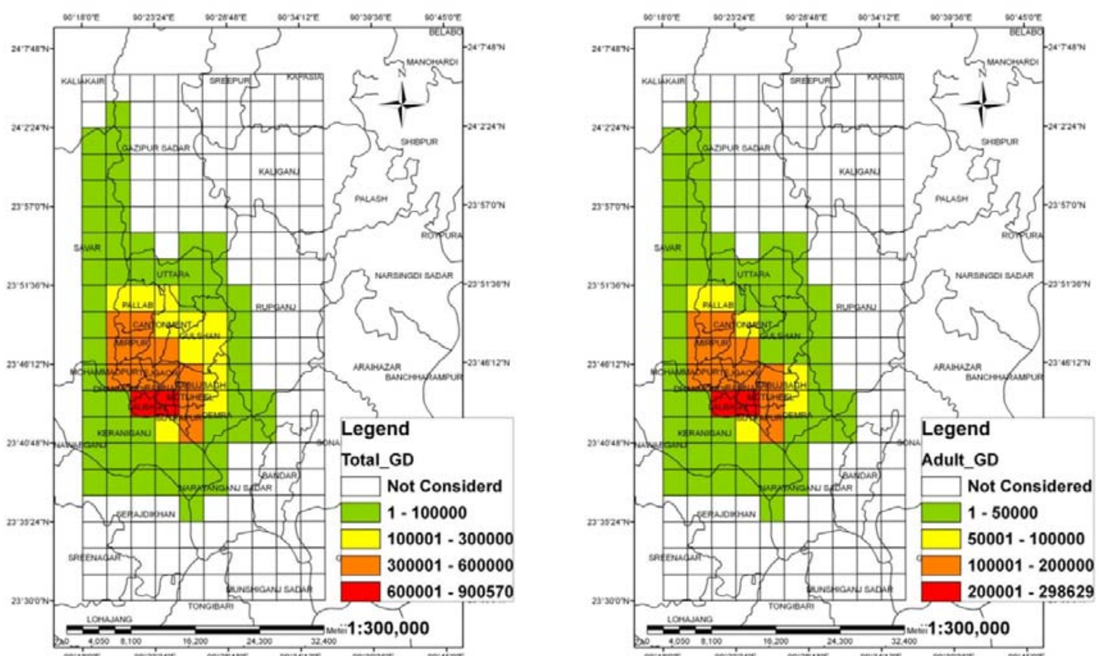
The population is estimated for the base year 2009 considering the available population from the 2001 census (BBS, 2008). The population of the census is extrapolated for 2009 using the growth rate of 4.08% (BBS, 2008). Thana based population of the literature (BBS, 2008) has been transformed to estimate the grid-based population. In estimating mortality related health impact due to long-term exposure, people above 30 years of age have been considered (Wadud and Khan, 2010). From the census data population above 30 years of age has been estimated to be 33.16% and population below 15 years has been found to be 30.4%. From this information, grid-wise population for the greater Dhaka and the Dhaka City Corporation area has been estimated. This population is summarized in the Figure 3.13 and 3.14. Figure 3.13 represents the population density in the Dhaka City Corporation (DCC) area. Figure 3.13 (a) shows the density of total population in different cells and Figure 3.13 (b) shows the adult population distribution in different cells.

On the other hand, Figure 3.14 represents the population density in the Greater Dhaka region which includes DCC area, part of Savar, part of Keraniganj and other thanas, part of which are under DCC area. Figure 3.14 (a) shows the density of total population in different cells and Figure 3.14 (b) shows the adult population distribution in different cells of greater Dhaka.



(a) Total Population **(b)** Adult Population (>30 years)

Figure 3.13: Grid-wise population in Dhaka City Corporation Area (Base year: 2009)



(a) Total Population **(b)** Adult Population (>30 years)

Figure 3.14: Grid-wise population in Greater Dhaka (Base year: 2009)

The precision of mortality risk statistics in Bangladesh is questionable. CIA (2009) estimates 9.23 deaths per thousand in 2009, the World Health Organization (WHO 2009) estimates a mortality rate of 8.15 per thousand in 2004, while Bangladesh Bureau of Statistics (BBS 2009b) suggests a death rate of 5.8 in 2004. Cause specific mortality statistics also differs. BBS (2009b) estimates cardiovascular and respiratory diseases to be responsible for 26.2% and 33.2% deaths nationally and in urban areas, respectively, while WHO (2009) reports 29% for cardiovascular (23.6%) and respiratory diseases (5.3%) nationally, rising to 38.6% when respiratory infectious diseases are included. This study uses the value from the study of Wadud and Khan (2010). They estimated that the mortality risks from cardiovascular and respiratory diseases among adults above 30 years are 5.36 and 3.40 per thousand, respectively.

3.6 Concluding Remarks

Impact Pathway Approach is one of the most effective methods of evaluating effect of air pollution upon human health. This chapter presents the approach and methodologies followed in the present study. At first, the study area has been divided into a number of grids; emission in each grid has been estimated; SR relationships have been developed using a dispersion model. Using the SR relationship and emissions, grid-wise ambient concentrations of PM_{10} and $PM_{2.5}$ have been determined. Population of study area in a grid-wise format has been estimated by extrapolating population of the last census and subsequently using the CR functions the health outcomes have been analyzed. The next two Chapters (Chapter 4 and Chapter 5) present the results of the study. Chapter 4 illustrates the spatial and temporal distribution of particulate matter concentration due traffic emission and brick kiln emission. Chapter 5 presents the health outcome and the monetary valuation of air pollution costs.

CHAPTER FOUR

PARTICULATE MATTER CONCENTRATION IN DHAKA CITY DUE TO TRAFFIC AND BRICK KILN POLLUTION

4.1 Introduction

The Impact Pathway Approach described in Chapter 3 helps to estimate the impact of air pollution upon human health. Prediction of ambient concentration of particulate matter (PM) is the first step in the health impact assessment. In this study the regional transport model ATMoS (CGRE, 2001) has been used for prediction of PM concentration over Dhaka city. This chapter presents the model validation, model calibration and model simulation results. A number of studies (e.g., Begum et al., 2005; Biswas et al., 2001) have identified two major sources of the particulate matter pollution in Dhaka city, road traffic and brick kilns. In this study only the vehicular pollution and the brick kiln pollutions have been considered. This chapter presents the spatial distribution and temporal variations of the particulate matter concentration within grater Dhaka city. It also presents the comparison of the simulated results and the monitored data of CAMS in Dhaka.

4.2 Model Calibration

In order to calibrate the model a simple simulation has been carried out, considering no wet and dry deposition. Even the secondary transformations have not been considered. The meteorology includes constant wind speed and direction all the year round. Then outcome of the ATMoS model is compared with the values obtained from the Gaussian Plume Model (solution of analytical equation). The comparison is presented in Figure 4.1. From the figure it is seen that the model results obtained are quite close to those calculated using Gaussian Plume equation.

4.3 Simulation Results and Discussion

After the setting up of the model, it has been simulated and the source-receptor transfer matrices have 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 and this statement is true until the model domain or grid resolution has been changed. In this study by feeding the emission inventory (Arjumand, 2010) and the transfer matrices into spreadsheet the ambient concentration at different grids for different months of the base year have been estimated. The emission inventory contains only two of the major sources- brick kiln emission and traffic emission. However, the results obtained are described in the following articles.

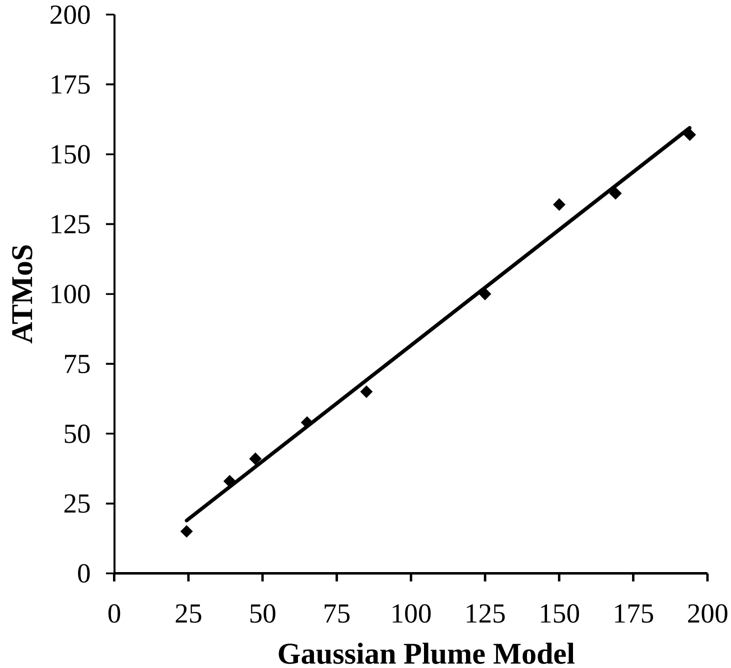


Figure 4.1: Comparison of PM_{10} concentration (µg/m^3)

4.3.1 Spatial variation of particulate matter

The model has been simulated for the ambient particulate matter (both PM_{10} and $PM_{2.5}$) concentration. The simulation has been carried out to estimate the monthly average concentration of the pollutants due to the traffic pollution and pollution from brick kilns. Figure 4.2 presents the PM_{10} concentration for different months of the base year, 2009 and Figure 4.3 shows the $PM_{2.5}$ concentration.

From the Figures 4.2(a) to 4.2(l), it is seen that the concentration of PM_{10} varies widely over the model domain. For the month of January it varies from less than 20 µg/m^3 to 271 µg/m^3. In February and March these variations are even wider (from less than 20 µg/m^3 to greater than 1000 µg/m^3). In November and December the variations are somewhat similar to that of the January. During April to October (i.e., wet season), the concentrations are more or less similar with very small range (0 to 14 µg/m^3).

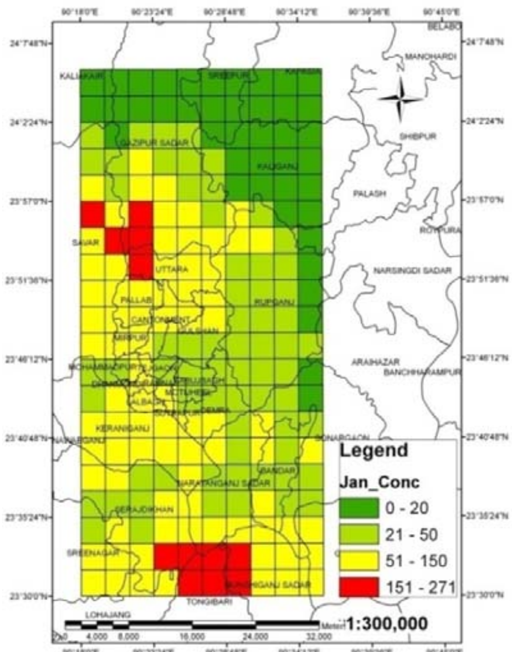


Figure 4.2(a): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of January

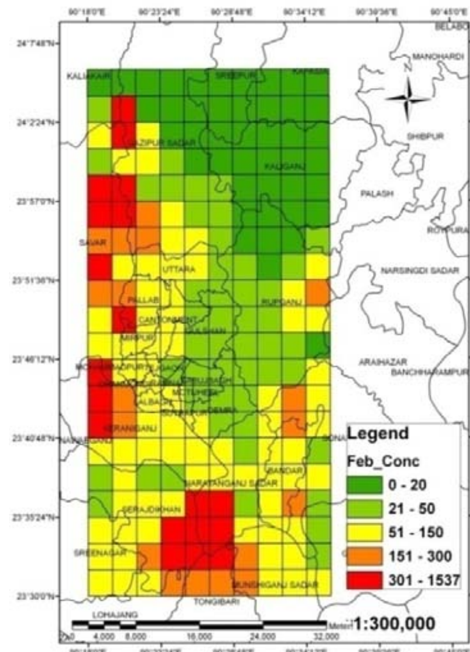


Figure 4.2(b): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of February

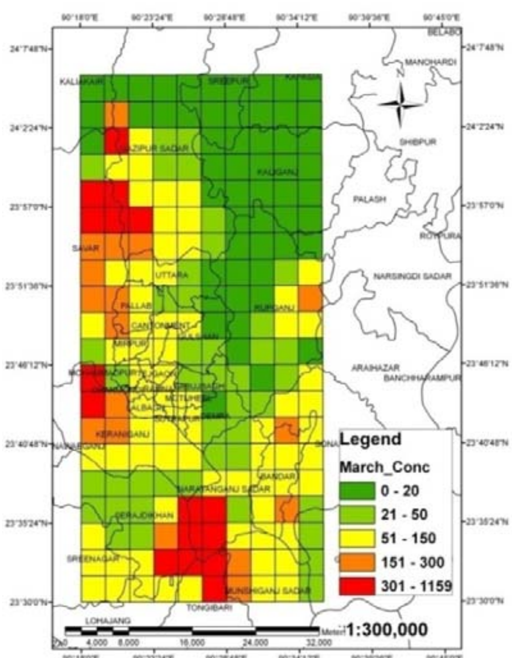


Figure 4.2(c): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of March

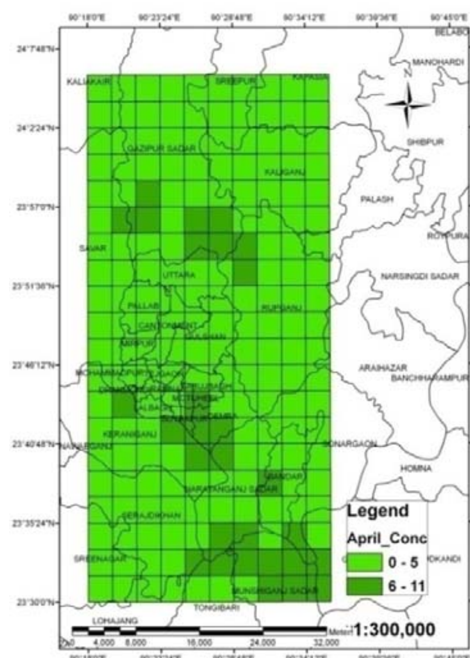


Figure 4.2(d): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of April

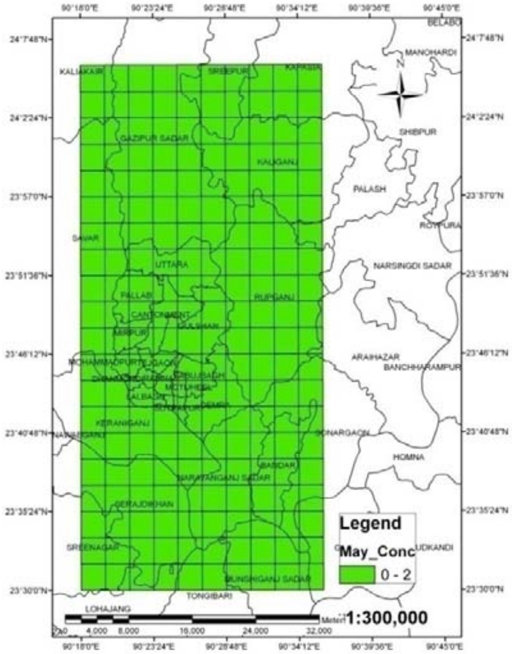


Figure 4.2(e): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of May

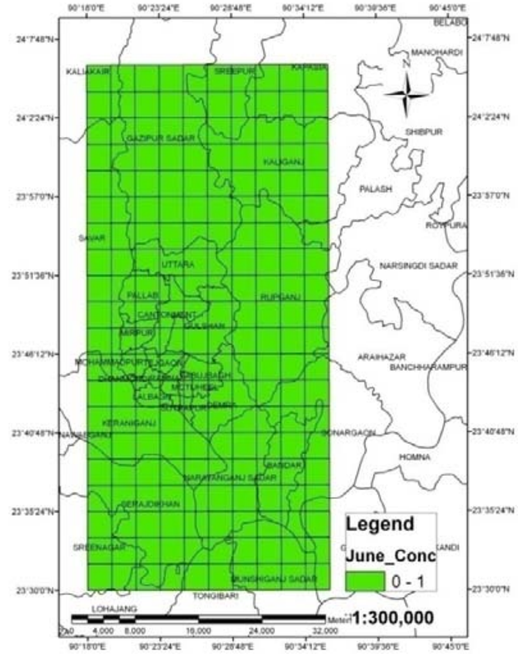


Figure 4.2(f): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of June

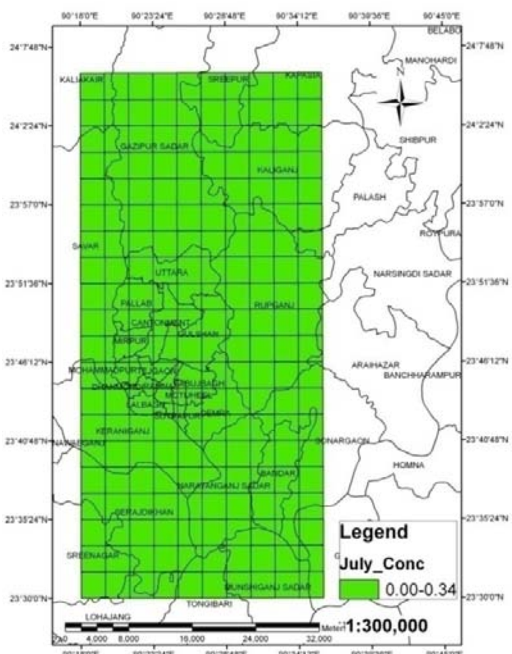


Figure 4.2(g): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of July

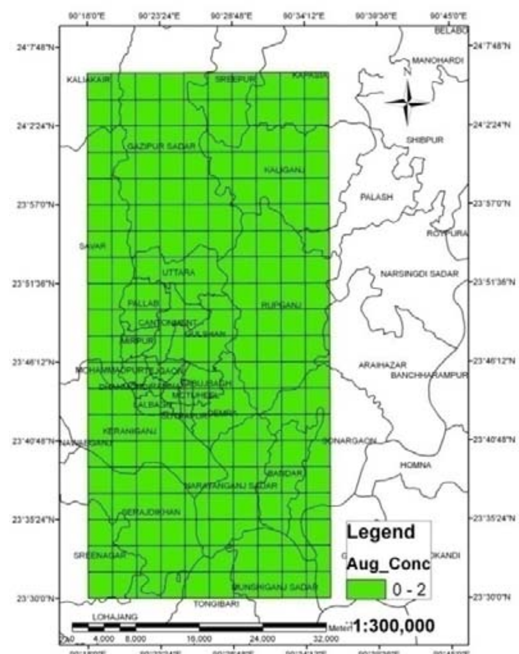


Figure 4.2(h): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of August

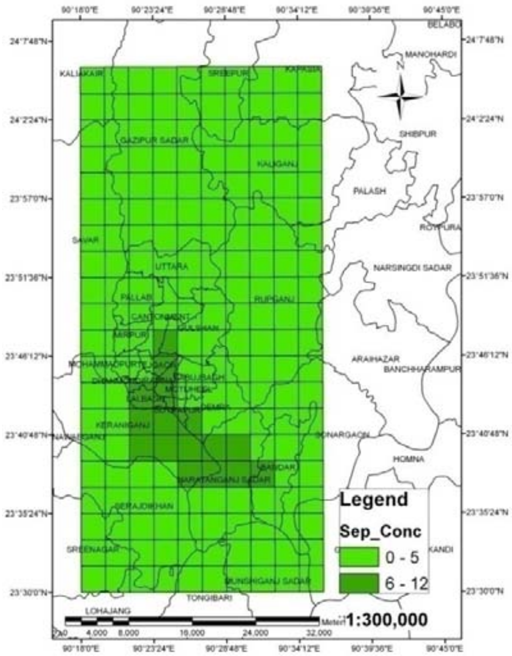


Figure 4.2(i): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of September

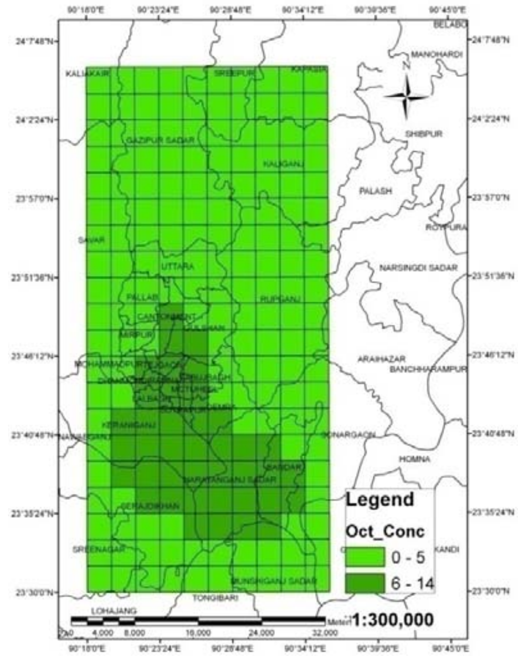


Figure 4.2(j): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of October

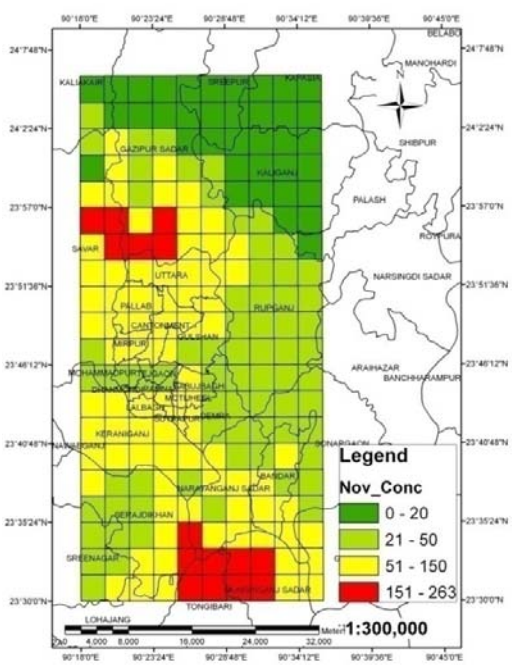


Figure 4.2(k): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of November

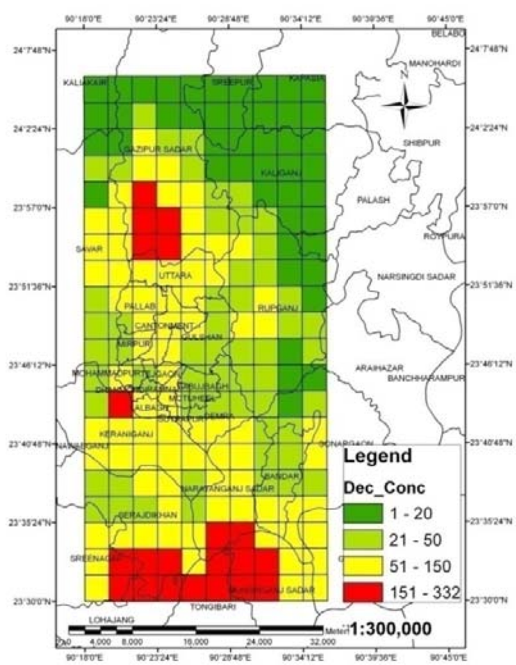


Figure 4.2(k): PM_{10} concentration in µg/m^3 due to traffic and brick kiln pollution for the month of November

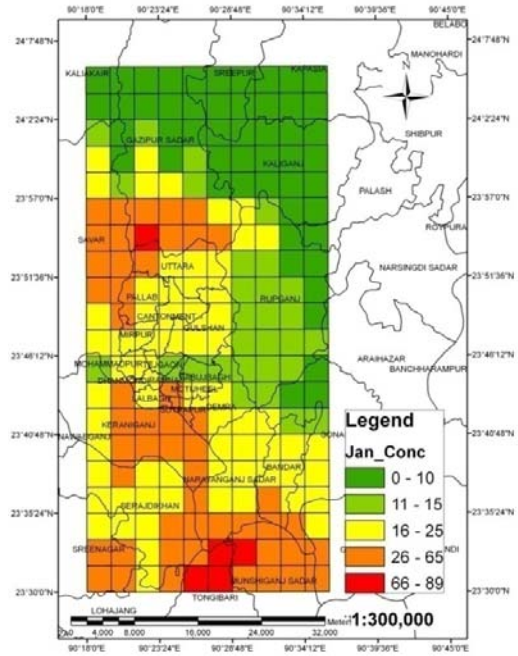


Figure 4.3(a): $PM_{2.5}$ concentration in $\mu g/m^3$ due to traffic and brick kiln pollution for the month of January

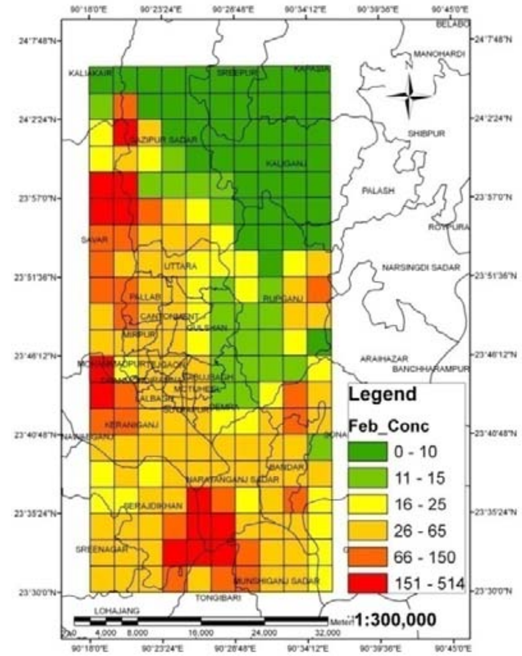


Figure 4.3(b): $PM_{2.5}$ concentration in $\mu g/m^3$ due to traffic and brick kiln pollution for the month of February

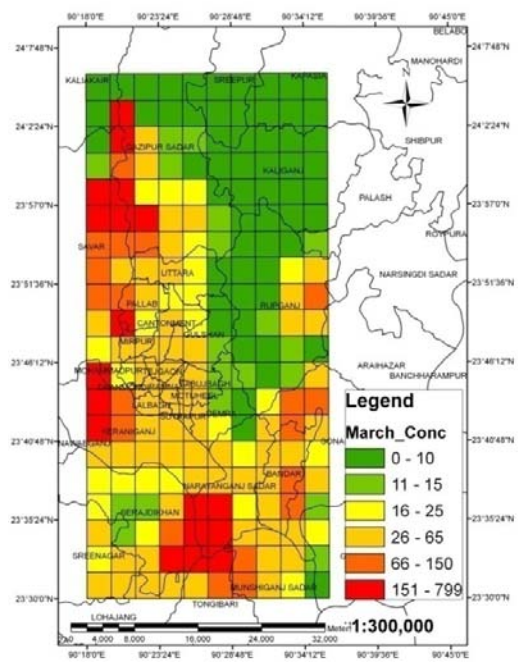


Figure 4.3(c): $PM_{2.5}$ concentration in $\mu g/m^3$ due to traffic and brick kiln pollution for the month of March

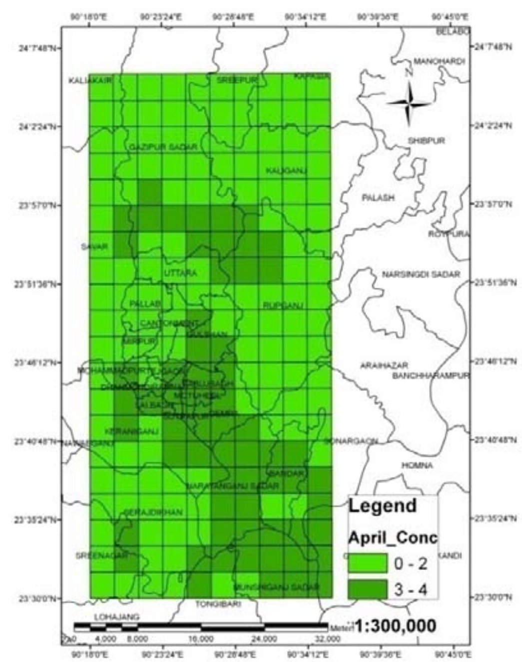


Figure 4.3(d): $PM_{2.5}$ concentration in $\mu g/m^3$ due to traffic and brick kiln pollution for the month of April

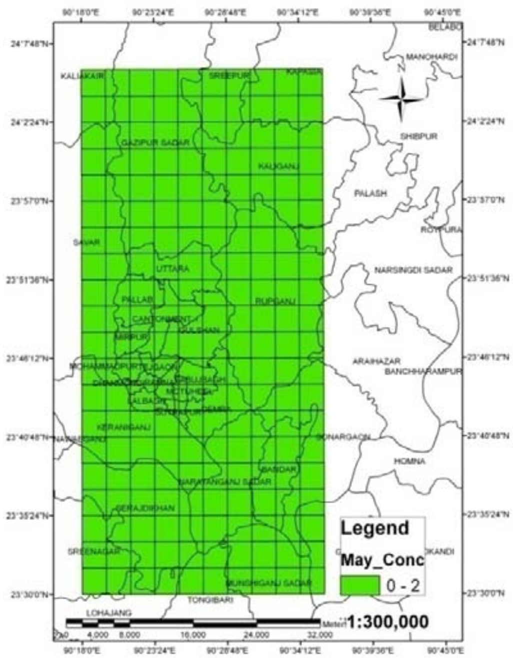


Figure 4.3(e): $PM_{2.5}$ concentration in µg/m^3 due to traffic and brick kiln pollution for the month of May

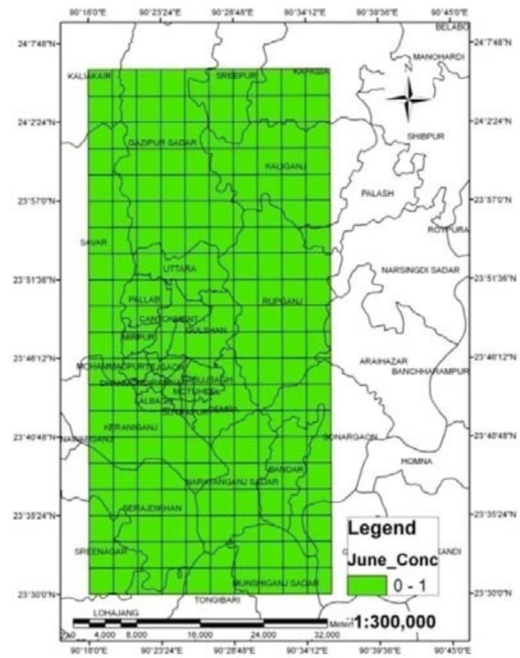


Figure 4.3(f): $PM_{2.5}$ concentration in µg/m^3 due to traffic and brick kiln pollution for the month of June

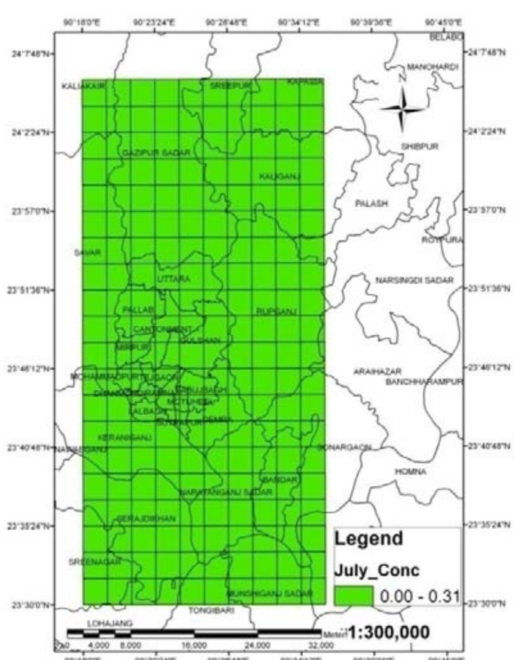


Figure 4.3(g): $PM_{2.5}$ concentration in µg/m^3 due to traffic and brick kiln pollution for the month of July

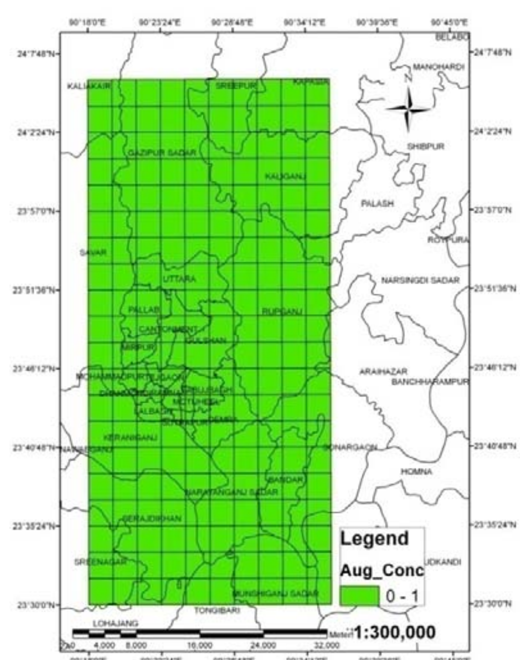


Figure 4.3(h): $PM_{2.5}$ concentration in µg/m^3 due to traffic and brick kiln pollution for the month of August

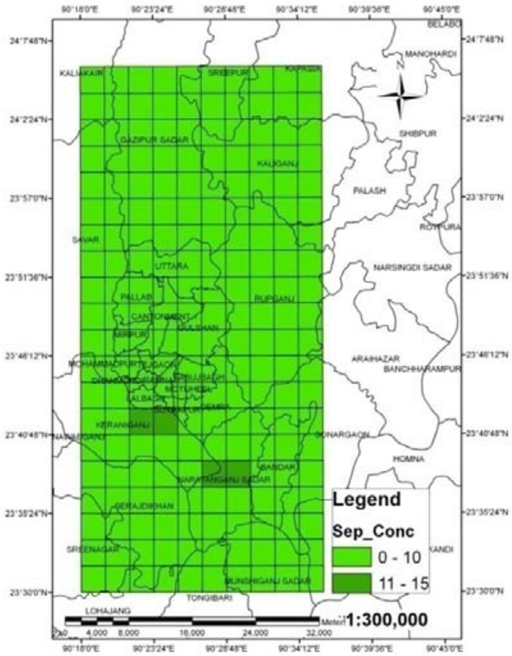


Figure 4.3(i): $PM_{2.5}$ concentration in $\mu g/m^3$ due to traffic and brick kiln pollution for the month of September

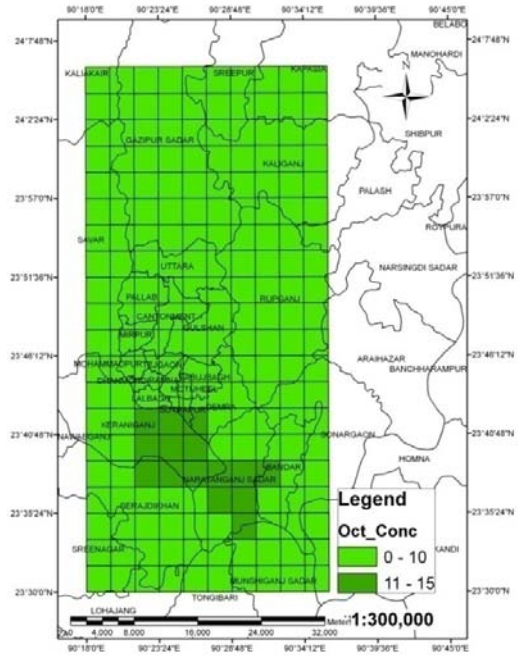


Figure 4.3(j): $PM_{2.5}$ concentration in $\mu g/m^3$ due to traffic and brick kiln pollution for the month of October

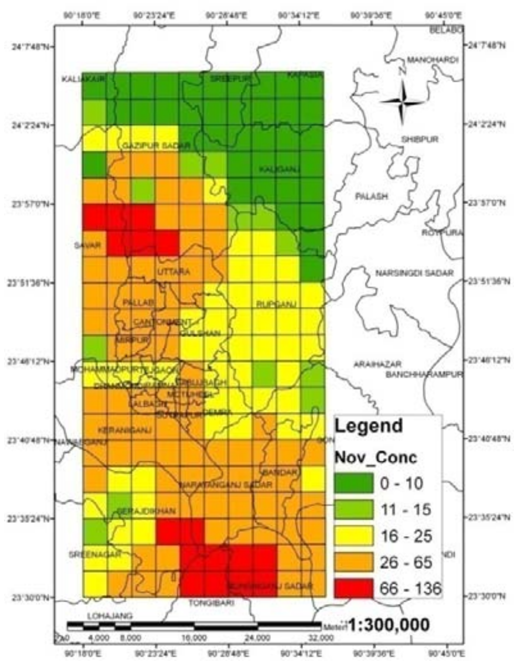


Figure 4.3(k): $PM_{2.5}$ concentration in $\mu g/m^3$ due to traffic and brick kiln pollution for the month of November

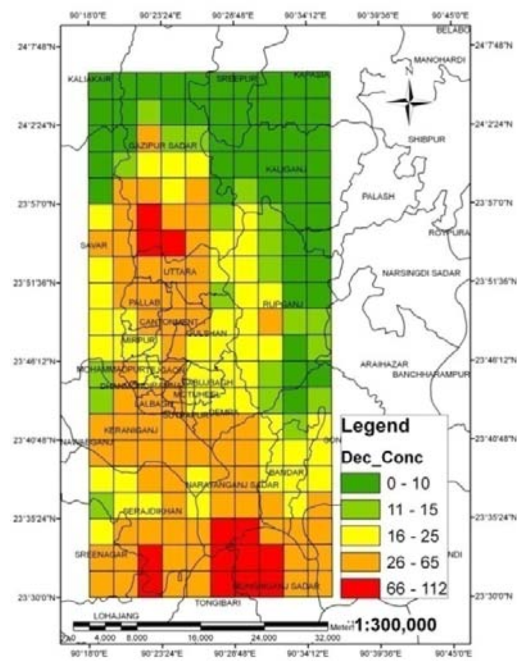


Figure 4.3(l): $PM_{2.5}$ concentration in $\mu g/m^3$ due to traffic and brick kiln pollution for the month of December

The areas north-east of the Dhaka city i.e., Kaliganj, Sreepur are less polluted from the traffic and brick kiln pollution. But within the Dhaka city for the dry period (i.e., November to March) the concentration exceeds 50 μg/m^3, which is the national standard for annual average PM_{10} concentration. Even in some parts of the city it exceeds the 24-hour average concentration (150 μg/m^3), especially the bordering areas of Dhaka city where actually the brick kilns are located.

Figures 4.3(a) to 4.3(l) show the variation of $PM_{2.5}$ concentration over the model region. The variations shown are quite similar to that of the PM_{10} variation. In January it varies from less than 10 μg/m^3 to 89 μg/m^3. In February and March these variations are even wider (from less than 10 μg/m^3 to greater than 500 μg/m^3). In November and December it varies from less than 10 μg/m^3 to less than 150 μg/m^3. During April to October (i.e., wet season), the concentrations are more or less similar and remains within a very small range (0 to less than 15 μg/m^3). The areas north-east of the Dhaka city i.e., Kaliganj, Sreepur are less polluted with respect to $PM_{2.5}$ as they are in terms of PM_{10} concentration. But in dry season, the concentration is greater than the annual average standard value of 15 μg/m^3 in almost all part of the Dhaka city. Even in some parts it exceeds the 24-hour average concentration (65 μg/m^3).

By comparing the Figures 4.2 and 4.3 with the Figures 3.11 and 3.12 it can be inferred that the predicted ambient concentration are higher in cells with higher emissions loads, especially from the brick kilns.

4.3.2 Temporal variation of particulate matter

From the Figures 4.2 and 4.3 it is seen that the concentration of both the pollutants varies seasonally. In the wet season (April to October) the concentration is smaller compared to those during the dry season (November to March). For example, PM_{10} concentration in the wet period is less than 15 μg/m^3, while in the dry season it is much higher. The similar pattern is also seen in the case of $PM_{2.5}$ concentration. These variations are due to the fact that the particles are deposited to the ground by incorporation into the rain-droplets. The seasonal variations of particulate matter concentration are shown in Figures 4.4 to 4.7.

Figure 4.4 shows the variation of average PM_{10} concentration in the Dhaka City Corporation (DCC) area. It is seen that the average concentration is 72 µg/m^3 in February which is the maximum among all months and the minimum monthly average value (59 µg/m^3) in dry season exceeds 50 µg/m^3. While in the wet season the PM_{10} concentration is less than 10 µg/m^3. Figure 4.5 shows the similar pattern for the $PM_{2.5}$ concentration. In the wet season the average concentration is less than 5 µg/m^3. But in the dry season concentration is always greater than 20 µg/m^3, with a maximum value of 35 µg/m^3 in March.

Figure 4.6 and 4.7 shows the temporal variation of the pollutants over the Greater Dhaka, which includes the DCC area, the upazilas and union parishads of the Dhaka districts that are within the model domain. As expected, these figures show similar temporal variations as observed for Dhaka city. From Figure 4.6 and 4.7 it is observed that the average concentrations in Greater Dhaka are higher than that of DCC area. This is because this includes the surrounding areas of Dhaka city, where most of the brick fields are located.

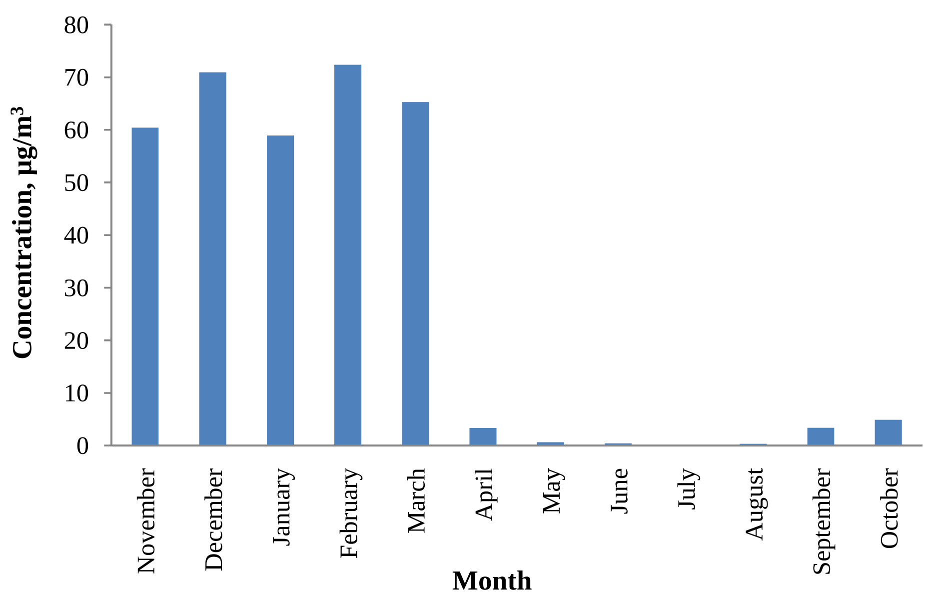


Figure 4.4: Average PM_{10} concentration in the Dhaka city corporation area

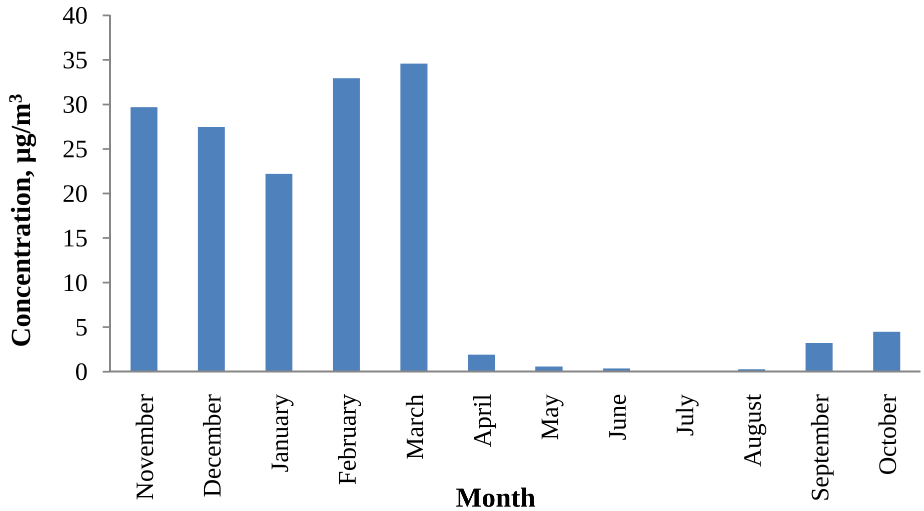


Figure 4.5: Average $PM_{2.5}$ concentration in the Dhaka city corporation area

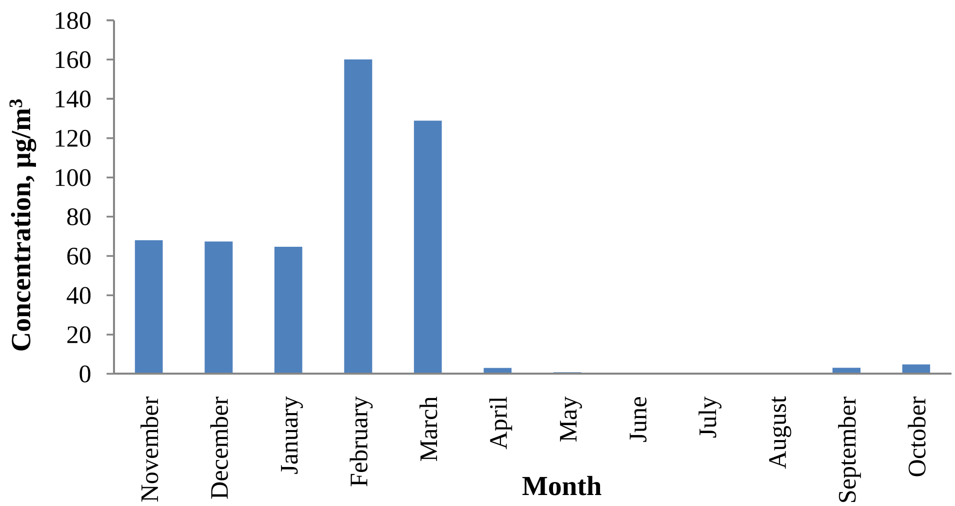


Figure 4.6: Average PM_{10} concentration in the greater Dhaka area

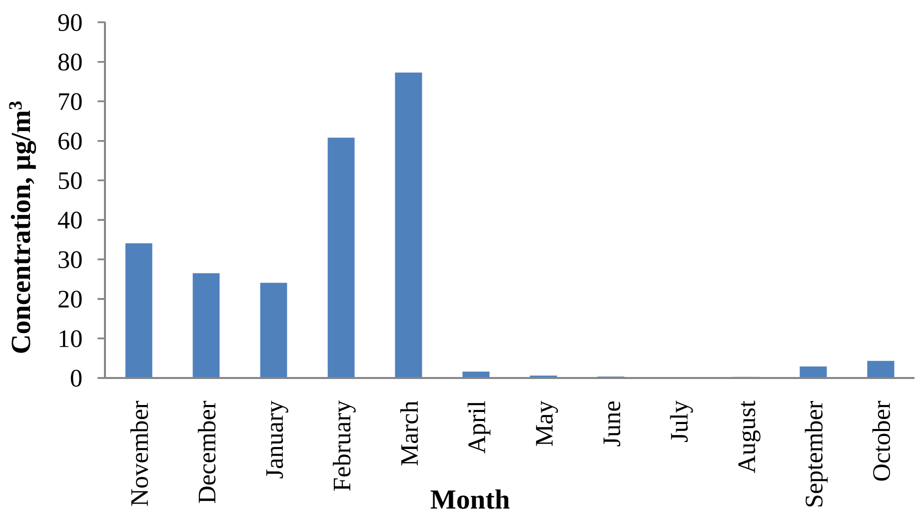


Figure 4.7: Average $PM_{2.5}$ concentration in the greater Dhaka area

4.3.3 Comparison with data at CAMS

The DoE has established a continuous monitoring station in Dhaka city. It is situated near the National Parliament building. This location is within the cell no "c12" of the modeling domain (Figure 3.9). Figures 4.8 and figure 4.9 show a comparison of the simulated monthly average concentrations and the monitored data for both PM_{10} and $PM_{2.5}$. From the figures it is seen that the concentration of both PM_{10} and $PM_{2.5}$ are less than the monitored data, which is expected since only the vehicular and brick kiln emissions have been considered in the present study. Road dust, the other major source of particulates could not be considered in the present study due to lack of data availability regarding its load in the air. Other sources such as, cement industries, power plant, incineration, refuse burning, etc. could not be incorporated in the study also due to the lack of data availability. 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. The maximum concentration is estimated in the month of March.

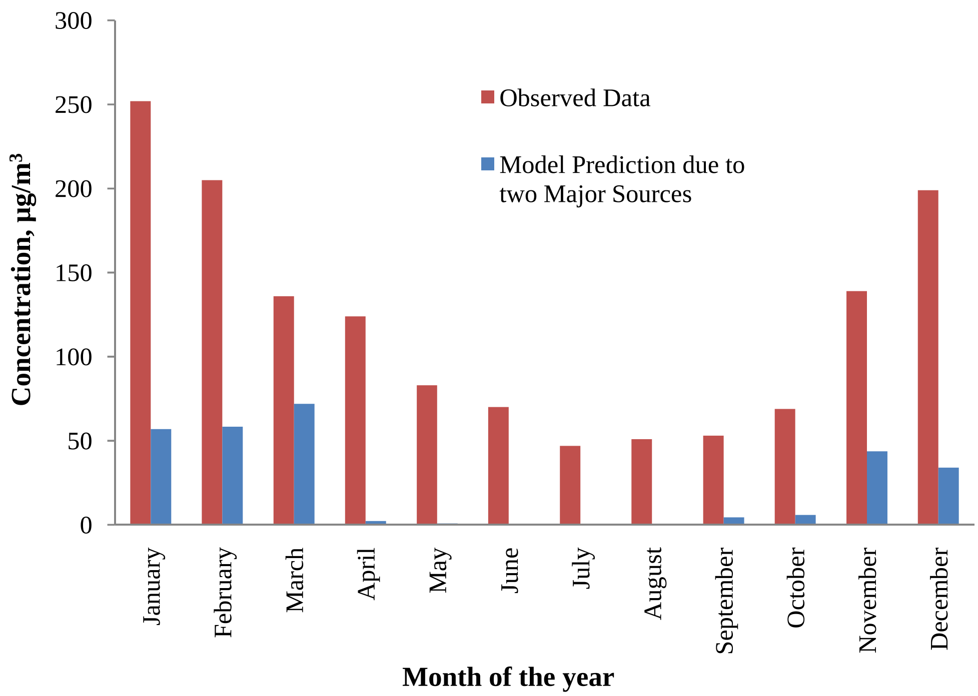


Figure 4.8: Comparison of PM_{10} concentration at the CAMS point

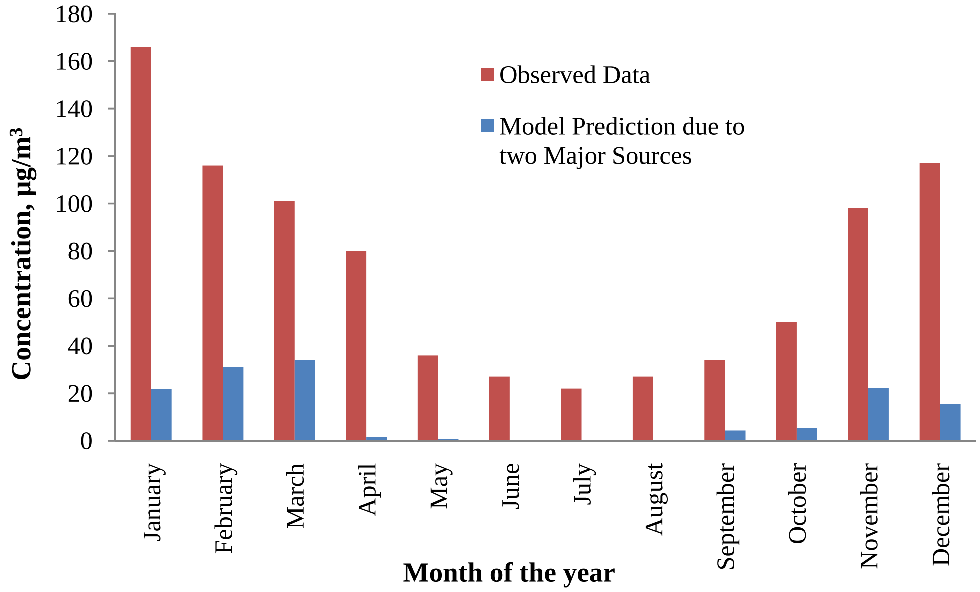
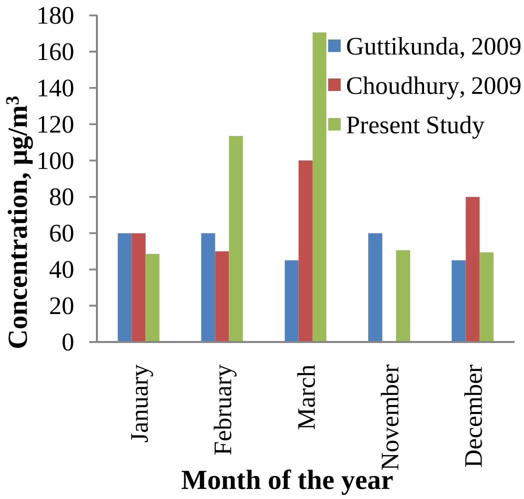


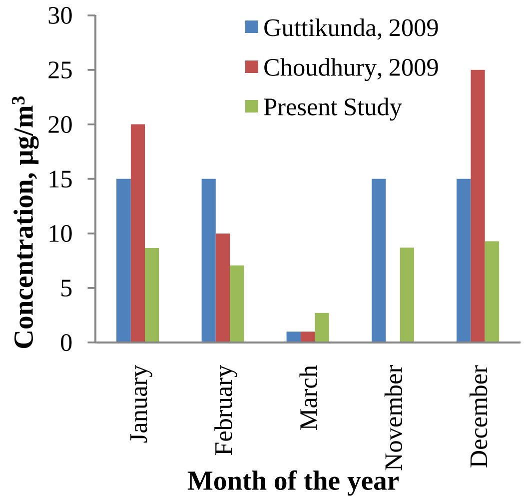
Figure 4.9: Comparison of $PM_{2.5}$ concentration at the CAMS point

4.3.4 Comparison of brick kiln effect with other studies

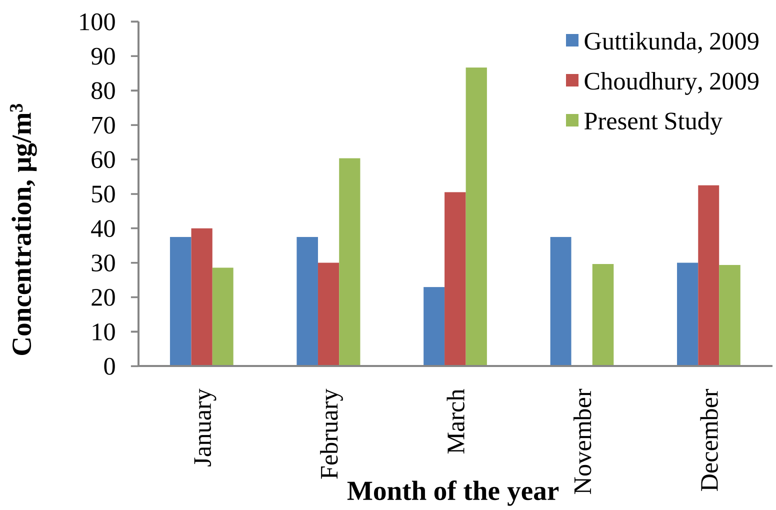
There two studies (Guttikunda, 2009 and Choudhury, 2009) available which estimate the effect of brick kiln emission on air quality of Dhaka city. The studies are described in the article 2.5.4. The outcome of the present study has been compared with the results of those studies. Figure 4.10 presents the comparison of maximum and minimum $PM_{2.5}$ concentration in DCC area. From the figure 4.10(a) it is seen that for the month of January, November and December the maximum $PM_{2.5}$ concentrations are close to the previous studies. But for the month of February and March the current study estimates a higher value than the previous studies. But the minimum $PM_{2.5}$ concentrations in DCC area are estimated lower than the previous studies for each of the month (Figure 4.10(b)). The average $PM_{2.5}$ concentration over the DCC area, shown in Figure 4.10(c) shows the pattern similar to that of maximum $PM_{2.5}$ concentrations. The average concentrations are estimated to be closer to the outcome of the previous studies for the month of January, November and December. For the month of February and March the current study estimates a higher value. However Choudhury (2009) estimates higher values than the other studies for December.



(a) Maximum $PM_{2.5}$ concentration



(b) Minimum $PM_{2.5}$ concentration



(c) Average PM2.5 concentrations

Figure 4.10: Comparison $PM_{2.5}$ concentration in DCC area of present study with Guttikunda, 2009 and Choudhury, 2009

4.3.5 Comparison of contributions from different sources

Through the analysis of the simulation results and actual measurement of ambient concentration (e.g., at CAMS), the pollutant contribution from the different sources could be estimated. This has been done at the CAMS location for the month of March, which is the most critical for air pollution. The results are shown in the Figure 4.11 and Figure 4.12. It is seen from Figure 4.11, Brick kiln accounts for the 43% of the PM_{10} pollution at the CAMS site and traffic contributes 10% of the total PM_{10} pollution. The rest 47% comes from the other sources, which may include road dusts, cement factories, steel furnaces, power plants and even the diesel generators in the households.

Figure 4.12 indicates that 21% of $PM_{2.5}$ concentration results from the brick kilns and 13% is due to traffic pollution. In the case of $PM_{2.5}$ the contribution of brick kiln is less than compared to that for PM_{10}. It is because usually the coarser particles are released from the brick kilns. The vehicular emissions are mostly in the form of the finer particles. Hence the contribution of traffic pollution to $PM_{2.5}$ concentration is higher than that for PM_{10} concentration. In the case of $PM_{2.5}$, contribution of other sources is about 66%.

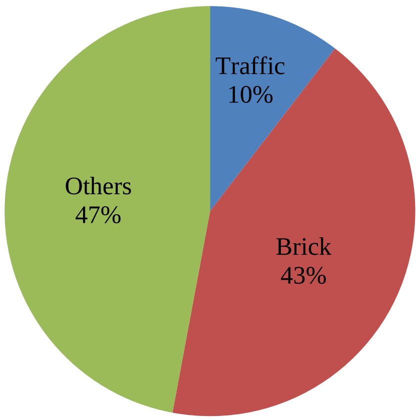


Figure 4.11: Source contribution for PM_{10}

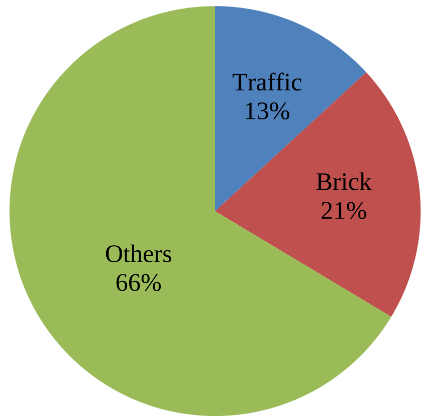


Figure 4.12: Source contribution for $PM_{2.5}$

These results are somewhat different from those of Begum et al. (2004) discussed in Chapter 2. The contribution of brick kilns comes out to be higher relative to the traffic contribution in the present study. There may be two possible reasons for this deviation. Firstly, the brick kiln emissions may have been over-estimated. All the brick kilns have been assumed to release pollutants 24 hours a day at the same rate, which may not be true. Also the productions of all the brick kilns have been considered to be the same, which may also lead to over estimation. It may be noted that the emission rate from brick kilns used in the study is based on a single measurement in another study (Choudhury, 2009); no other values are available in the literature for brick kiln emissions. Secondly, the traffic emissions might have been under-estimated. This could be possible by ignoring some of the minor roads in the model domain. Also the emission factors are also a great source of error.

4.4 Concluding Remarks

The particulate matter pollution is the major air quality problem in Dhaka city. From the simulation results 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 (ECR, 2005). The dry season (November to March) 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. After finding out the ambient concentration, health impact of the pollution can be evaluated. The next chapter presents the effect of particulate pollution and the impact of different policy scenarios.

CHAPTER FIVE

HEALTH IMPACT OF PARTICULATE MATTER

5.1 Introduction

In Chapter 4, the particulate matter concentration in greater Dhaka city due to the traffic and brick kiln pollution has been presented and discussed. From the discussion it is obvious that high level of particulate pollution during the dry season is a significant threat to human health. This Chapter presents an assessment of the health impact of particulate matter. Both the long-term mortality effect due to finer particles i.e., $PM_{2.5}$ and morbidity effect have been considered in this study. The Chapter ends with an assessment of policy alternatives and their effects.

5.2 Health Risk Estimation

Human health risk of particulates pollution is estimated through determination of the long-term effect of $PM_{2.5}$ on human mortality rate as well as effect of PM_{10} on morbidity health incidences. Estimation of health risk estimation from major pollution sources is discussed below.

5.2.1 Health risk from traffic pollution

Traffic pollution is one of the major sources of air pollution in Dhaka city. Population exposure to this type of pollution is very high. Hence, even the small amount of increase in it can result in significant health impact. The effects of traffic pollution on human health are discussed in the following sections.

5.2.1.1 Particulate concentration due to traffic pollution

In order to estimate the effect on human mortality due to traffic pollution, at first the yearly average concentration of $PM_{2.5}$ is determined. The $PM_{2.5}$ concentration for the base year 2009 is shown in the Figure 5.1. From the figure it is clear that in some parts of Dhaka city its concentration exceeds the Bangladesh yearly average standard of 65 $\mu g/m^3$. Especially Tejgaon, Ramna, Motijheel, Lalbag, parts of Dhanmondi are the areas where the concentrations exceed that level. Yearly average concentration of $PM_{2.5}$ resulting from traffic pollution exceeds the guideline value of 25 $\mu g/m^3$ set by WHO for almost all areas of the city. The concentration in Gazipur, Kaliganj, Rupganj and some parts of Savar are below the WHO guideline value and well below the Bangladesh standard.

Figure 5.2 shows the yearly average PM_{10} concentration due to traffic emission. The figure shows that concentrations in most of the areas of Dhaka city cross the WHO guideline value (50 µg/m^3). But they are below the Bangladesh standard (150 µg/m^3). Only a single grid, which is outside Dhaka, crosses the Bangladesh standard.

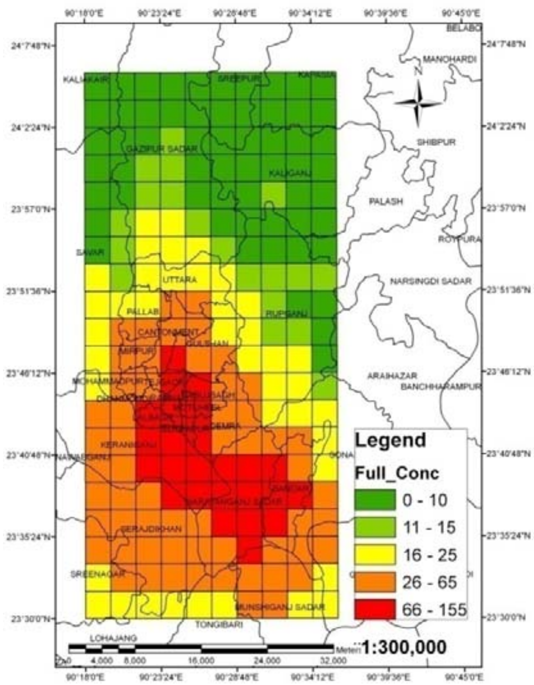


Figure 5.1: Yearly Average concentration of $PM_{2.5}$ in µg/m^3 due to traffic pollution

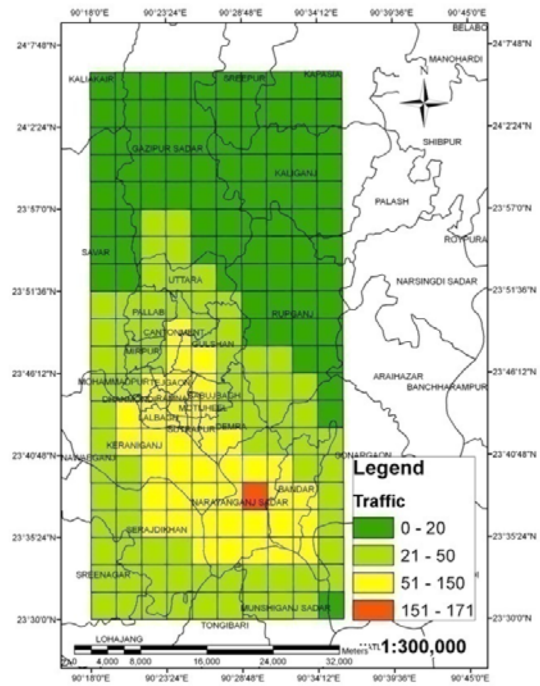


Figure 5.2: Yearly Average concentration of PM_{10} in µg/m^3 due to traffic pollution

5.2.1.2 Mortality effect of traffic pollution

In order to determine mortality effect of particulate pollution, long-term effect of $PM_{2.5}$ has been considered. Table 5.1 summarizes the estimation of mortality effect. It shows that a total of 9,757 premature deaths in the Dhaka City Corporation (DCC) area are attributed to particulate pollution. This is equivalent to a monetary cost of 1,854 million US$, which is approximately 0.77% of country's GDP in 2009. This value could be in the range of 517 to 3,191 million US$. When Greater Dhaka is considered, the premature death attributable of particulate pollution is increased to 12,104 persons, and monetary costing reaches 2,300 million US$ with lower bound and upper bound values of 642 and 3,958 million US$ respectively. The cost was approximately 0.95% of GDP.

Table 5.1: Summary of mortality effect in 2009 due to traffic pollution

	Greater Dhaka	**Dhaka City Corporation**
Total Population	9,719,577	7,405,607
Population above 30 years	3,223,015	2,455,702
Cardio-vascular death, person	6,709	5,411
Respiratory death, person	5,395	4,346
Total death, person	12,104	9,757
Monetary Cost*****, million US$	2,300 (642; 3,958)	1,854 (517; 3,191)
Percentage of GDP*****	0.95 (0.27; 1.64)	0.77 (0.21; 1.33)

***** The lower bound and upper bound values are shown in the parenthesis

5.2.1.3 Morbidity effect of traffic pollution

The morbidity effects have been estimated with respect to the yearly average PM_{10} concentration. Different types of morbidity effects of traffic pollution are shown in the Table 5.2. Total monetary costs associated with the morbidity are about 651 million US$ in Greater Dhaka and in DCC area it is about 527 million US$. In greater Dhaka the cost is 0.27% of national GDP and in DCC area about 0.22% of GDP. Table 5.1 and 5.2 indicate that the mortality related cost is much higher, though the numbers of morbidity incidences are higher.

Table 5.2: Summary of morbidity effect in 2009 due to traffic pollution

Morbidity Effects	**No of incidence**		**Monetary costs**	
	Greater Dhaka	**DCC**	**Greater Dhaka**	**DCC**
Chronic Bronchitis	26,676	21,600	333.2	269.8
Respiratory Hospital Admission	7,519	6,084	2.0	1.6
Asthma Attack	1,020,986	826,481	4.1	3.3
Emergency Room Visits	147,446	119,357	1.2	1.0
Restricted day activities	24,849,467	20,115,392	84.4	68.3
Lower respiratory illness	321,806	260,495	0.9	0.7
Respiratory symptoms	79,779,859	64,580,996	224.8	182.0
Total	-	-	651.0	527.0
As a ratio of GDP	-	-	0.27%	0.22%

5.2.2 Health risk from brick kiln pollution

Brick kiln is another major source of air pollution in Dhaka city. In general, the concentrations of particulates during dry season due to brick kilns are higher than that of traffic emissions. But the population exposed to brick kiln pollution is smaller than those exposed to traffic pollution. The effects of brick kiln pollution on human health are discussed in the following sections.

5.2.2.1 Particulate concentration due to brick kiln pollution

Figure 5.3 shows the yearly average concentration of $PM_{2.5}$ in the modeling domain resulting from the brick kiln emission. From the figure it is seen that in most of the DCC area, this concentration is within the Bangladesh Standard. But it exceeds the national standard in the region where there are brick kilns. Many of the brick kilns are located in Savar, Keraniganj and Narayanganj. From the figure it is also apparent that the $PM_{2.5}$ concentration is high in these regions. In most places it exceeds the standard by a small margin. But in some of the areas concentration higher than 150 $\mu g/m^3$ are observed, with a peak of 403 $\mu g/m^3$.

Figure 5.4 shows the yearly average concentration of PM_{10}. The concentrations in some parts of the city exceed the WHO guideline value but they are below the national standard. Concentration in the areas near the brick kilns are higher and in some cases exceed the national standard for brick kiln emission only.

5.2.2.2 Mortality effect of brick kiln pollution

Table 5.3 summarizes the brick kiln related health impact. From the Table it is seen that in DCC area about 5,570 premature deaths are attributed to brick kiln pollution in 2009. The cost associated with this is equivalent to about 1,058 million US$ with lower bound value of 295 and upper bound value of 1,821 million US$. The amount is about 0.44% of GDP on an average, with a range of 0.12% to 0.76%. In case of Greater Dhaka, the number is increased to about 7,786 persons. Resulting cost is 1,479 million US$, which is 0.61% of country’s GDP. In this case the lower and upper bound values are 413 and 2,545 million US$, respectively.

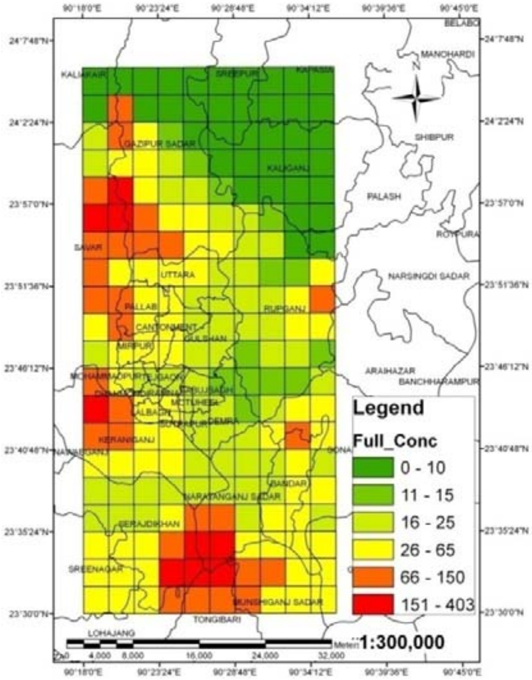


Figure 5.3: Yearly Average concentration of $PM_{2.5}$ in $\mu g/m^3$ due to brick kiln pollution

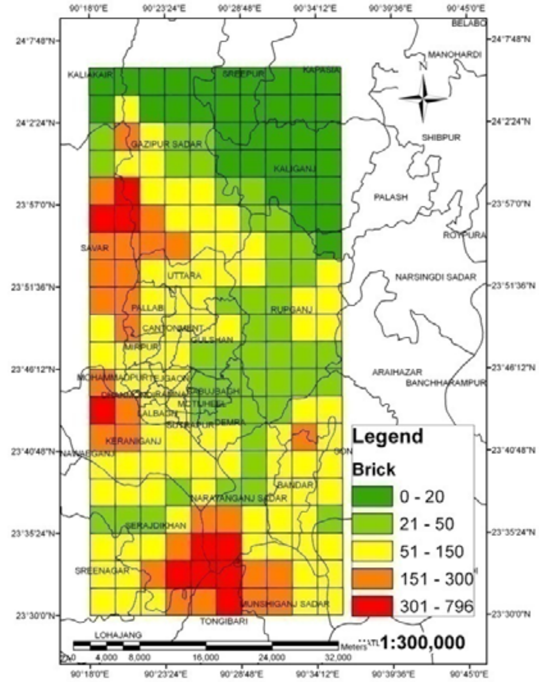


Figure 5.4: Yearly Average concentration of PM_{10} in $\mu g/m^3$ due to brick kiln pollution

Table 5.3: Summary of mortality effect in 2009 due to brick kiln pollution

	Greater Dhaka	**Dhaka City Corporation**
Total Population	9,719,577	7,405,607
Population above 30 years	3,223,015	2,455,702
Cardio-vascular death, person	4,246	3,019
Respiratory death, person	3,540	2,551
Total death, person	7,786	5,570
Monetary Cost*****, million US$	1479 (413; 2,545)	1058 (295; 1,821)
Percentage of GDP*****	0.61 (0.17,1.05)	0.44 (0.12,0.76)

***** The lower bound and upper bound values are shown in the parenthesis

5.2.2.3 Morbidity effect of brick kiln pollution

Table 5.4 summarizes the morbidity effects of brick kiln pollutions in 2009. The morbidity related cost is found to be 835 million US$ in the Greater Dhaka, which is about 0.35% of national GDP. The cost is 569 million US$ in DCC area, which is 0.24% of national GDP. Mortality related cost of brick kiln pollution is almost double than the morbidity costs.

Table 5.4: Summary of morbidity effect in 2009 due to brick kiln pollution

Morbidity Effects	No of incidence		Monetary costs	
	Greater Dhaka	DCC	Greater Dhaka	DCC
Chronic Bronchitis	34,245	23,330	427.7	291.4
Respiratory Hospital Admission	9,647	6,573	2.6	1.8
Asthma Attack	1,310,519	892,737	5.3	3.6
Emergency Room Visits	189,265	128,925	1.5	1.0
Restricted day activities	31,896,290	21,727,974	108.3	73.8
Lower respiratory illness	413,063	281,383	1.2	0.8
Respiratory symptoms	102,403,871	69,758,222	288.6	196.6
Total	-	-	835.0	569.0
As a ratio of GDP	-	-	0.35%	0.24%

5.3 Impact of Different Policy Alternatives

From the above discussion it can be inferred that both traffic and brick kiln pollution have significant impact on public health. A total of 19,890 premature deaths are predicted due to particulate pollution in the greater Dhaka and in DCC area the number is about 15,327. So to mitigate or reduce the effect, abatement measures should be taken. With a view to this, a policy analysis tool has been developed. The tool is developed to identify the benefits of the policy implementations only. The costs associates with the policy need to be estimated also to conduct the cost-benefit analysis. However, this tool is capable to rank the different policy alternatives in terms of their benefits only. Some of the policy alternatives and their effect on reducing the impact are examined for illustration.

5.3.1 Description of the policy options

A total of five policy alternatives have been examined. They are listed in Table 5.5. The first alternative involves reducing the truck emission by restricting them from entering Dhaka. The alternative considers restricting 20% of truck. Second alternative involves reduction in brick kiln emission by 20%, this could be achieved through adoption of alternative technologies (e.g., green brick kiln) or moving brick kilns to other distant locations. The third option involves conversion of 50% of buses to CNG fuel. The fourth option considers doubling the numbers of buses run by CNG; that is 72% of total buses would be run by CNG, which s 36% at present. The last alternative is that 100% buses are run by CNG.

Table 5.5: Policy Alternatives

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

5.3.2 Impact on particulate concentration

In order to evaluate the impact of the policy alternatives, the particulates concentration due to policy implementation are estimated first. Figure 5.5 illustrates the current concentration of $PM_{2.5}$ due to traffic and brick kiln emission. Figures 5.6 to 5.10 show the distribution of the same for different policy alternatives. With the adoption of Policy Alternative 1, an average of 5.8% $PM_{2.5}$ concentration can be reduced. The maximum concentration comes down to 443 μg/m^3 from 450 μg/m^3. Policy Alternative 2 reduces the maximum concentration from 450 μg/m^3 to 369 μg/m^3, with an average reduction of about 10.8%. Policy Alternative 3 can result in average reduction of 3.1%, which also lowers the maximum $PM_{2.5}$ concentration to 446 μg/m^3. An 7.8% of average reduction in $PM_{2.5}$ concentration can be achieved if Policy Alternative 4 is adopted. It also lowers down the maximum $PM_{2.5}$ concentration to 441 μg/m^3. Policy Alternative 5 has the most significant effect on can $PM_{2.5}$ concentration. It reduces the $PM_{2.5}$ concentration by about 14.0% on an average. The maximum concentration reaches 434 μg/m^3.

Figure 5.11 presents the concentration of PM_{10} due to traffic and brick kiln emission and Figure 5.12 to Figure 5.16 show the concentration of the same after policy implementation. Implementation of Alternative 1 can reduce the maximum concentration to 841 μg/m^3 from 849 μg/m^3. The average reduction in this case has been found to be about 4%. Policy Alternative 2 lowered the concentration of PM_{10} to 689 μg/m^3, with average reduction of 13.7%. Among the five policy options this alternative has brought the maximum reduction in PM_{10} concentration. Policy Alternative 3 and Policy Alternative 4 help to lower the concentration by 2% and 5.2%, respectively. An average reduction of 9.2% has been observed by adopting the Alternative 5 as the abatement measure.

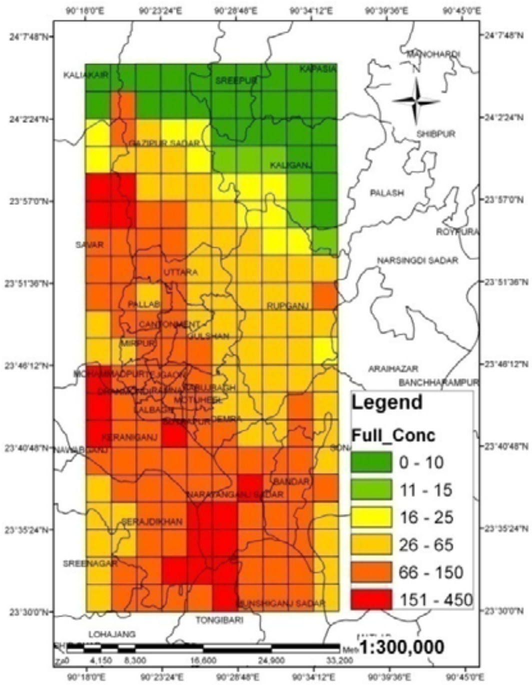


Figure 5.5: Yearly average concentration of $PM_{2.5}$ in $\mu g/m^3$ due to traffic and brick kiln pollution

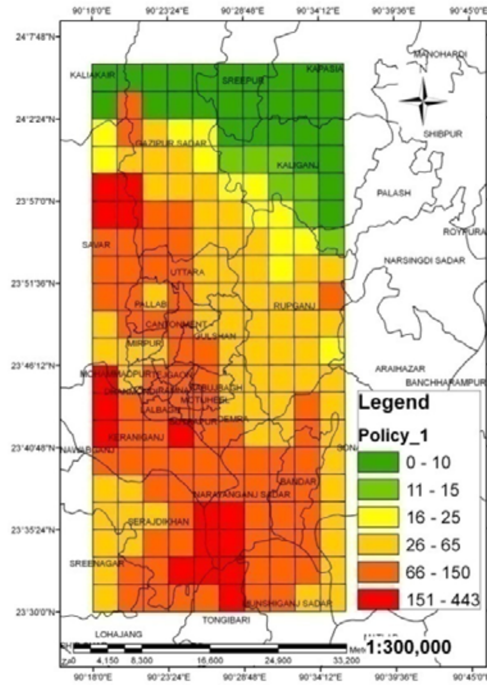


Figure 5.6: Yearly average concentration of $PM_{2.5}$ in $\mu g/m^3$ when Policy Alternative 1 has been considered

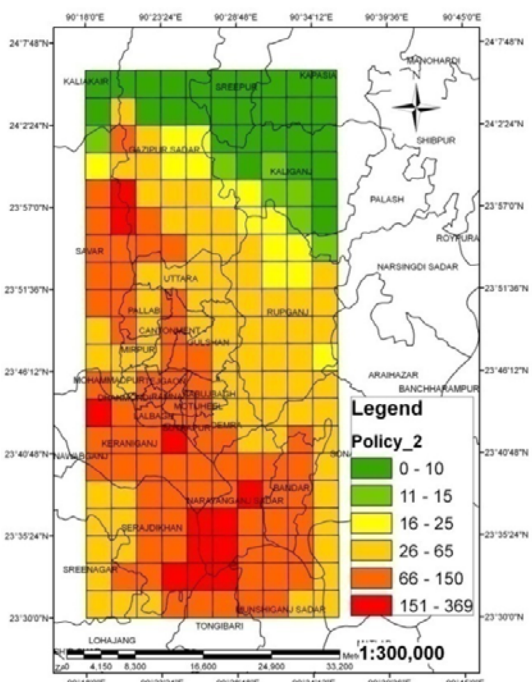


Figure 5.7: Yearly average concentration of $PM_{2.5}$ in $\mu g/m^3$ when Policy Alternative 2 has been considered

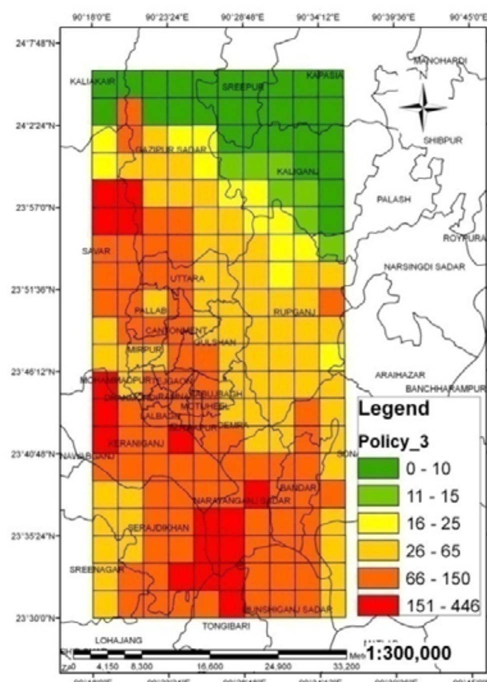


Figure 5.8: Yearly average concentration of $PM_{2.5}$ in $\mu g/m^3$ when Policy Alternative 3 has been considered

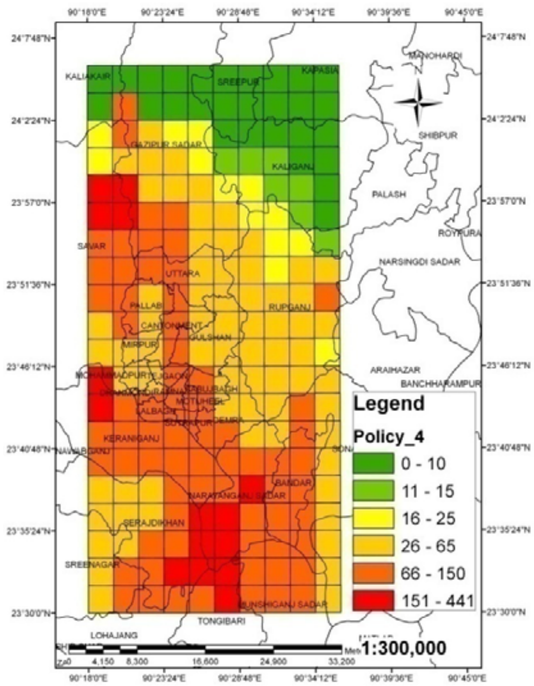


Figure 5.9: Yearly average concentration of $PM_{2.5}$ in $\mu g/m^3$ when Policy Alternative 4 has been considered

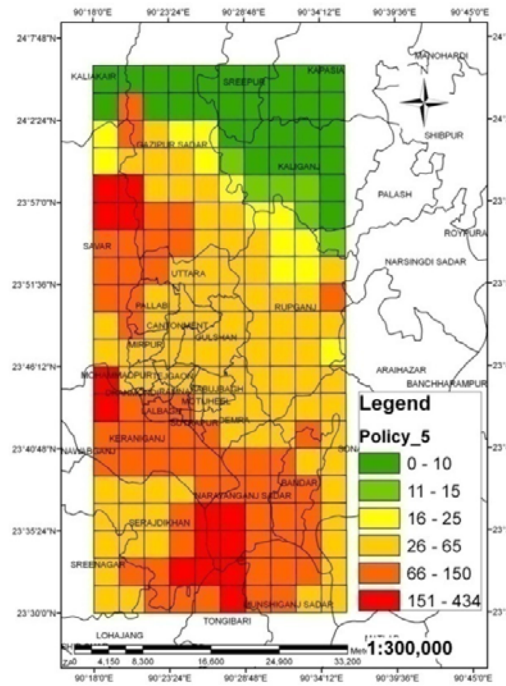


Figure 5.10: Yearly average concentration of $PM_{2.5}$ in $\mu g/m^3$ when Policy Alternative 5 has been considered

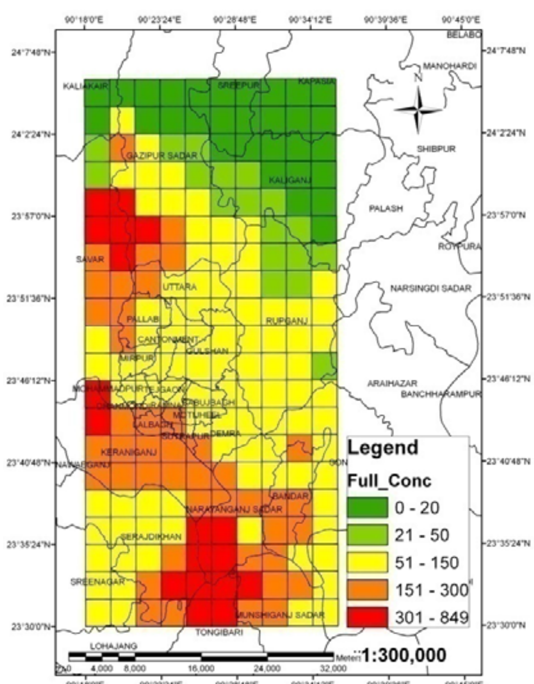


Figure 5.11: Yearly average concentration of PM_{10} in $\mu g/m^3$ due to traffic and brick kiln pollution

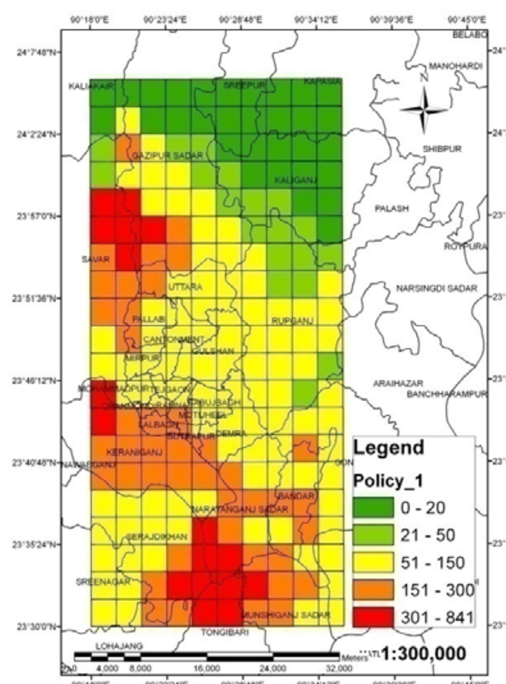


Figure 5.12: Yearly average concentration of PM_{10} in $\mu g/m^3$ when Policy Alternative 1 has been considered

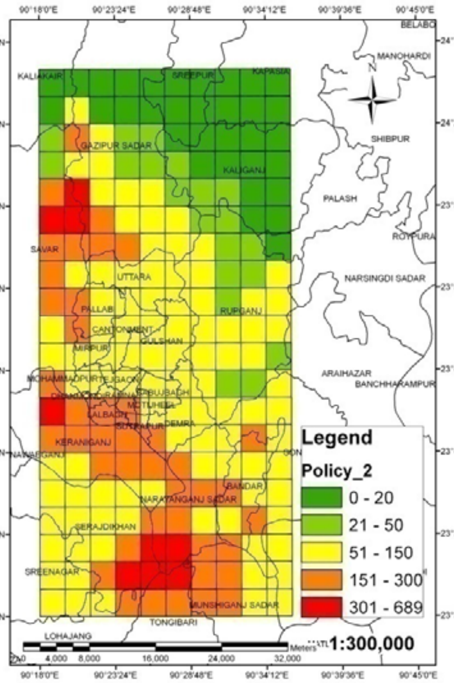


Figure 5.13: Yearly average concentration of PM_{10} in μg/m^3 when Policy Alternative 2 has been considered

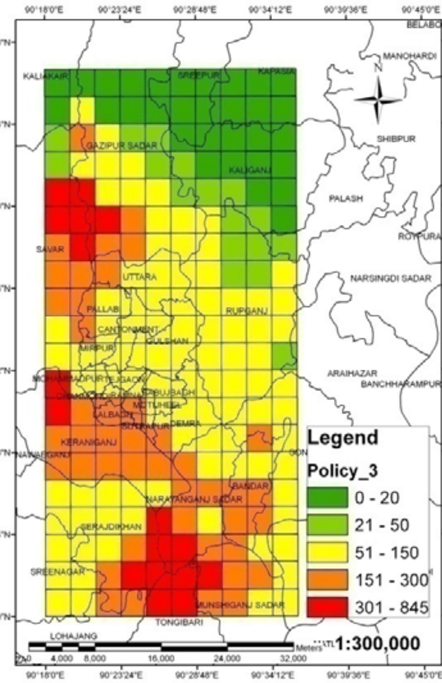


Figure 5.14: Yearly average concentration of PM_{10} in μg/m^3 when Policy Alternative 3 has been considered

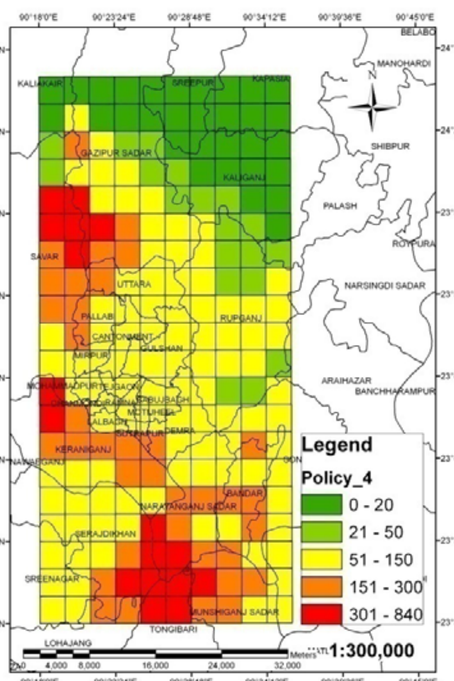


Figure 5.15: Yearly average concentration of PM_{10} in μg/m^3 when Policy Alternative 4 has been considered

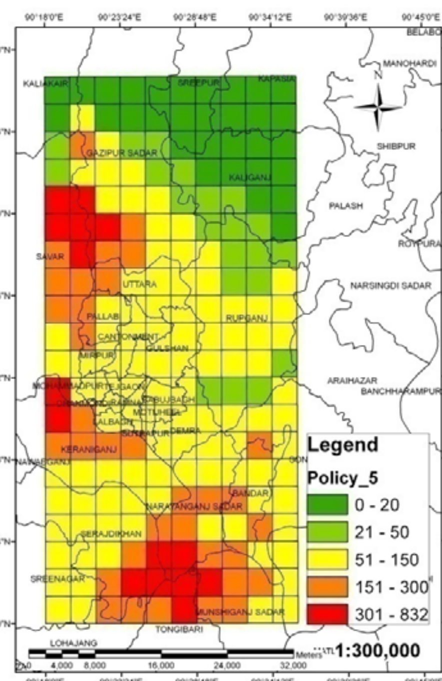


Figure 5.16: Yearly average concentration of PM_{10} in μg/m^3 when Policy Alternative 5 has been considered

5.3.3 Impact on human mortality

Impacts of policy alternatives on air quality are presented in the Table 5.6 and Table 5.7. Table 5.6 shows the impacts in the greater Dhaka. From Table 5.6 it is seen that by adopting the alternatives, total death avoidance could be in range from 1,232 to 6,406 per year. Monetary benefit achievable varies from around 230 million US$ to 1,200 million US$, which is equivalent to about 0.1% to 0.5% of country's GDP. In DCC area the policy alternatives save about 980 to 5,250 lives. The monetary benefit is about 186 to 998 million US$, which is 0.08% to 0.41% of total GDP. Table 5.7 presents the impact within the DCC area. The lower bound and upper bound values are also shown in the tables.

From Tables 5.6 and Table 5.7 it is observed that Alternative 5 is the most beneficial option among the alternatives analyzed in terms of mortality effect. Policy Alternative 4 is the second best option. But before implementation of a policy, the cost of implementation should be analyzed.

5.3.4 Impact on human morbidity

In addition to the impact on the human mortality, the policy alternatives can affect the human morbidity as well. Table 5.8 to Table 5.11 show the impact of policy implementation upon human morbidity. Table 5.8 presents the case reduction for different health effects due to policy implementation in the greater Dhaka region. From the figure it is seen that policy Alternative 5 has brought the maximum number case reduction for all of the health effects. Table 5.9 shows the similar results within the DCC area. Alternative 2 has reduced the second highest number of cases in the greater Dhaka region, but Alternative 3 has second highest impact within the DCC region. This is due to the fact that any reduction in brick kiln emission will improve the air quality surrounding the brick kilns. This results in higher reduction of morbidity case outside the DCC area than within the DCC area, when Alternative 2 has been considered.

Table 5.10 and Table 5.11 present the savings that could be achieved if the policy options can be implemented. Alternative 5 is found to have the best effect with total savings per year of 278 million US$ in greater Dhaka, which is about 0.115% of country's GDP. In DCC area the savings is 228 million US$. Alternative 4 could save up to 128 million US$ in the DCC area and 156 million US$ in Greater Dhaka.

Alternative 1 could result in a savings of 167 million US$ in greater Dhaka and 114 million US$ in DCC area. Thus, the second best alternative varies with the choice of area.

Table 5.6: Impacts of different policy alternatives upon mortality in the Greater Dhaka

ID	Death Avoided, person/year			Monetary Benefit*, million US$	% of GDP*
	Cardio-vascular	Respiratory	Total		
Policy Alternative 1	649	583	1,232	234 (65; 403)	0.1 (0.03; 0.17)
Policy Alternative 2	1,013	892	1,905	362 (101; 623)	0.15 (0.04; 0.26)
Policy Alternative 3	852	756	1,608	306 (85; 527)	0.13 (0.04; 0.22)
Policy Alternative 4	2,084	1,809	3,893	740 (206; 1,274)	0.31 (0.09; 0.53)
Policy Alternative 5	3,473	2,933	6,406	1,217 (339; 2,095)	0.5 (0.14; 0.86)

***** The lower bound and upper bound values are shown in the parenthesis

Table 5.7: Impact of different policy alternatives upon mortality in the Dhaka City Corporation area

ID	Death Avoided, person/year			Monetary Benefit*, million US$	% of GDP*
	Cardio-vascular	Respiratory	Total		
Policy Alternative 1	519	462	981	186 (52; 320)	0.08 (0.02; 0.14)
Policy Alternative 2	690	614	1,304	248 (69; 427)	0.1 (0.03; 0.17)
Policy Alternative 3	703	624	1,327	252 (70; 434)	0.1 (0.03; 0.17)
Policy Alternative 4	1,709	1,487	3,196	607 (169; 1,045)	0.25 (0.07; 0.43)
Policy Alternative 5	2,843	2,410	5,253	998 (278; 1,718)	0.41 (0.11; 0.71)

***** The lower bound and upper bound values are shown in the parenthesis

Table 5.8: Number of case reduction for morbidity per year in the Greater Dhaka

Morbidity Effects	Policy Alternative 1	Policy Alternative 2	Policy Alternative 3	Policy Alternative 4	Policy Alternative 5
Chronic Bronchitis	2,035	6,846	2,488	6,400	11,382
Respiratory Hospital Admission	573	1,929	701	1,803	3,207
Asthma Attack	77,926	262,091	95,286	245,046	435,613
Emergency Room Visits	11,254	37,848	13,757	35,385	62,911
Restricted day activities	1,896,577	6,378,903	2,319,101	5,963,999	10,602,259
Lower respiratory illness	24,559	82,605	30,035	77,239	137,307
Respiratory symptoms	6,089,014	20,479,645	7,445,530	19,147,566	34,038,824

Table 5.9: Number of case reduction for morbidity per year in the DCC area

Morbidity Effects	Policy Alternative 1	Policy Alternative 2	Policy Alternative 3	Policy Alternative 4	Policy Alternative 5
Chronic Bronchitis	1,613	4,666	2,042	5,254	9,336
Respiratory Hospital Admission	453	1,311	575	1,480	2,631
Asthma Attack	61,677	178,532	78,158	201,000	357,322
Emergency Room Visits	8,906	25,782	11,282	29,027	51,605
Restricted day activities	1,501,077	4,345,195	1,902,295	4,892,095	8,696,771
Lower respiratory illness	19,443	56,272	24,636	63,353	112,627
Respiratory symptoms	4,819,255	13,950,360	6,107,361	15,706,204	27,921,211

Table 5.10: Savings per year in health costs in million US$ for Greater Dhaka

Morbidity Effects	Policy Alternative 1	Policy Alternative 2	Policy Alternative 3	Policy Alternative 4	Policy Alternative 5
Chronic Bronchitis	25.42	85.50	31.07	79.93	142.16
Respiratory Hospital Admission	0.16	0.52	0.19	0.49	0.87
Asthma Attack	0.31	1.06	0.38	0.99	1.76
Emergency Room Visits	0.09	0.31	0.11	0.29	0.51
Restricted day activities	6.44	21.65	7.87	20.25	35.99
Lower respiratory illness	0.07	0.23	0.08	0.22	0.39
Respiratory symptoms	17.16	57.71	20.98	53.96	95.93
Total	50.00	167.00	61.00	156.00	278.00
Percentage of GDP	0.021	0.069	0.025	0.065	0.115

Table 5.11: Savings per year in health costs in million US$ for the DCC area

Morbidity Effects	Policy Alternative 1	Policy Alternative 2	Policy Alternative 3	Policy Alternative 4	Policy Alternative 5
Chronic Bronchitis	20.15	58.28	25.50	65.62	116.60
Respiratory Hospital Admission	0.12	0.35	0.16	0.40	0.71
Asthma Attack	0.25	0.72	0.32	0.81	1.44
Emergency Room Visits	0.07	0.21	0.09	0.23	0.42
Restricted day activities	5.10	14.75	6.46	16.61	29.52
Lower respiratory illness	0.05	0.16	0.07	0.18	0.32
Respiratory symptoms	13.58	39.31	17.21	44.26	78.69
Total	39.00	114.00	50.00	128.00	228.00
Percentage of GDP	0.016	0.047	0.021	0.053	0.095

5.4 Concluding Remarks

The mortality related health impact of $PM_{2.5}$ concentration contributed from traffic and brick kiln emissions has been estimated and presented in this Chapter. In the DCC area, 15,327 premature deaths have been estimated for the year 2009. This increases to 19,890 when the greater Dhaka region is considered. The monetary valuation of this is around 2,912 million US$ in DCC area and for greater Dhaka it is around 3,779 million US$. This means around 1.21% to 1.56% of country's total GDP is lost in the Dhaka city. Cost of morbidity is about 1,486 million US$ in Greater Dhaka and 1096 million US$ in DCC area. Some abatement policy alternatives are analyzed. The abatement measures analyzed could save up to 980 to 5,250 lives per year in DCC area and 1,232 to 6,400 lives in Greater Dhaka region. This results in savings of 234 to 1,200 million US$ per year in Greater Dhaka region, which is 0.1% to 0.5% of GDP. In DCC area this savings is about 186 to 998 million US$ per year, which equivalent to 0.08% to 0.41% of GDP. The savings in morbidity costs can vary from 39 to 228 million US$ in DCC area and from 50 to 278 million US$ in the Greater Dhaka area. Among the alternatives analyzed, the policy Alternative 5 yields the maximum benefit. It has been found that mortality related health costs are much higher than the morbidity related health costs.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 General

The main objective of this study was to develop a policy analysis tool through the impact pathway approach. The study aims to predict ambient concentration of particulate matter in Dhaka city using air quality modeling and estimate the health effects of particulate pollution. The major findings of the current study are described in the Chapter 4 and Chapter 5. This Chapter summarizes the key findings of the study. This chapter also lists some of the limitations of the study. Finally, it presents recommendations for future studies.

6.2 Summary of the Study

The major output and findings of this study are summarized below:

1. An impact pathway based policy analysis tool has been developed for Dhaka city. The developed tool could be used to predict the particulate concentrations and their health impact in Dhaka city by updating the emission inventory.
2. Using the tool ambient concentrations of both PM_{10} and $PM_{2.5}$ due to the traffic and brick kiln emissions and health effects of particulates are estimated.
3. The predicted ambient concentration of particulates in and around Dhaka city has been found to vary widely. The areas north-east to the city such as Kaliganj, Sreepur are found to be less compared to areas in the north-west, where the brick kilns are located.
4. During the dry season (i.e., November to March) the ambient concentrations for both PM_{10} and $PM_{2.5}$ in most areas within the city cross the Bangladesh standard. But during the wet season (April to October) they remain well below the standards.
5. Brick kiln is found to be the major source of particulate pollution. At the location of CAMS in Dhaka, it accounts for about 43% of PM_{10} and 21% of $PM_{2.5}$ concentration. Traffic emissions account for about 10% of PM_{10} concentration and 13% to $PM_{2.5}$ concentration at this location.

6. 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 within the model domain is considered.
7. 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.
8. Cost of morbidity due to traffic and brick kiln emission is about 1096 million US$ in DCC area and 1,486 million US$ in Greater Dhaka and 1096 million US$ in DCC area. This is equivalent to 0.46% to 0.62% of country's GDP.
9. Using the developed tool a number of policy alternatives have been analyzed and ranked according to their associated benefits.
10. The abatement measures analyzed could save up to 980 to 5,250 lives per year in DCC area and 1,232 to 6,400 lives in Greater Dhaka region, if implemented.
11. The policy alternatives could result in savings of 186 to 998 million US$ per year in DCC area, which is 0.08% to 0.41% of GDP by reducing the premature deaths. In Greater Dhaka region this savings is about 234 to 1,200 million US$ per year, which equivalent to 0.1% to 0.5% of GDP.
12. The savings in morbidity costs can vary from 39 to 228 million US$ in DCC area and from 50 to 278 million US$ in the Greater Dhaka area. These are equivalent to 0.02% to 0.12% of national GDP.

6.3 Limitations of the Study

The study conducted has set up a framework for policy analysis of air pollution in Dhaka city. The results, especially those related to health impacts, should be considered as indicative and should not be used directly for policy assessment until further refinement. The limitations of the study are listed below:

i. The emission inventory, developed in another study (Arjumand, 2010) has some uncertainties. Some of the inputs in the inventory were assumed due to lack of available data.
ii. Emission rate and production level of each of the brick kilns have been considered the same. This may lead to some error in estimation of emissions. Also the emission was considered to be continuous throughout the manufacturing period, which may not be true for all brick kilns.

iii. In estimating the traffic emission some of the minor roads have been ignored. Also the fuel usage of the vehicles and activity rate were assumed in some cases due to lack of data.

iv. Meteorological parameters extracted from the ECMWF were not recent.

v. Population of different areas of the city was estimated by forecasting the data of 2001 census using a constant growth rate. But the growth rate could be different in different areas of the city.

Efforts should be made to overcome these limitations in future studies.

6.4 Recommendations for Future Studies

The following recommendations are made for future studies relating to air pollution and its impact in Dhaka city:

1. Only traffic and brick kiln emissions have been considered in the present study. The effect of other sources e.g., road dust, cement factories, power plants, open burning, etc. should be considered in future modeling studies.
2. Site specific values of the deposition parameters (wet and dry deposition rates) could be estimated and used in air quality model.
3. The comparison of modeled value and monitored value was made only for a single site (e.g., CAMS site in Dhaka). Comparison with more of the monitored values (e.g., data from other CAMS that are currently being installed in Dhaka) should be performed.
4. Uncertainty analysis of the present study could be carried out as there are significant uncertainties associated with the emission factors, concentration-response function, VSL, etc.
5. Other dispersion models could be run to compare the results of the study.

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APPENDICES

Appendix A

Meteorological Data of Dhaka

Table A-1: Sample meteorological data of Dhaka for January, 2001 and July, 2001

Month	Day	Hour	Wind Speed (m/s)	Wind Direction (Degree)	Mixing Height (m)	Precipitation (mm/hr)
1	1	6	1.16	59.12	41.98	0
1	1	12	0.65	-80.04	1081.25	0
1	1	18	0.29	-82.27	143.41	0
1	1	24	1.74	-82.09	52.82	0
1	2	6	1.04	55.23	55.71	0
1	2	12	0.6	-5.77	1010.85	0
1	2	18	2.04	-15.82	126.82	0
1	2	24	1.64	-27.88	87.79	0
1	3	6	1.61	57.99	80.84	0
1	3	12	1.03	-79.17	1125.62	0
1	3	18	1.25	-34.52	255.83	0
1	3	24	2.34	-73.8	86.25	0
1	4	6	2.89	-60.74	179.06	0
1	4	12	1.7	-80.16	1044.52	0
1	4	18	1.8	-23.34	235.55	0
1	4	24	1.63	-44.26	210.89	0
1	5	6	1.28	-56.07	188.91	0
1	5	12	0.97	81.41	1151.94	0
1	5	18	1.66	-64.9	198.45	0
1	5	24	2.37	69.61	144.5	0
1	6	6	1.7	-49.9	130.96	0
1	6	12	1.84	-74.55	954.48	0
1	6	18	2.17	-54.52	141.33	0
1	6	24	2.04	-52.75	132.58	0
1	7	6	1.29	-46.82	106.21	0
1	7	12	1.03	45.75	994.16	0
1	7	18	2.1	-24.06	136.99	0
1	7	24	0.52	-67.67	120.55	0
1	8	6	1.44	59.76	107.75	0
1	8	12	0.48	35.14	1112.98	0
1	8	18	0.58	-53.34	157.03	0
1	8	24	0.42	75.25	89.01	0
1	9	6	0.95	4.64	67.15	0
1	9	12	1.21	-4.26	1142.13	0
1	9	18	1.11	53.7	118.97	0
1	9	24	1.87	59.23	101.23	0
1	10	6	1.84	69.92	66.29	0
1	10	12	1.42	-83.53	1420.83	0
1	10	18	1.83	-25.17	208.69	0
1	10	24	1.4	-61.98	145.49	0
1	11	6	1.47	78.71	131.38	0
1	11	12	1.04	-19.25	1210.4	0
1	11	18	1.63	-56.67	188.92	0
1	11	24	2.24	-86.14	135.99	0
1	12	6	2.12	70.2	122.26	0
1	12	12	1.28	88.35	998.65	0

Month	Day	Hour	Wind Speed (m/s)	Wind Direction (Degree)	Mixing Height (m)	Precipitation (mm/hr)
1	12	18	1.09	-59.49	144.11	0
1	12	24	1.71	83.03	80.28	0
1	13	6	1.45	71.06	70.92	0
1	13	12	0.56	-31.5	921.23	0
1	13	18	0.62	82.17	124.14	0
1	13	24	1.37	49.94	78.39	0
1	14	6	1.66	31.25	62.92	0
1	14	12	1.21	48.18	1000.17	0
1	14	18	2.63	-59.54	164.55	0
1	14	24	2.68	-87.1	68.86	0
1	15	6	2.42	-72.23	79.7	0
1	15	12	1.91	-80.46	1150.44	0
1	15	18	2.28	-44.65	141.32	0
1	15	24	2.98	-67.65	66.51	0
1	16	6	1.95	-62.6	62.86	0
1	16	12	1.54	81.55	1054.85	0
1	16	18	1.89	-17.67	126.49	0
1	16	24	2.63	-67.34	51.24	0
1	17	6	2.26	48.32	48.92	0
1	17	12	1.51	-76.39	1187.64	0
1	17	18	2.38	-47.31	126.07	0
1	17	24	1.94	-75.6	51.32	0
1	18	6	2	73.73	54.2	0
1	18	12	1.2	-43.27	1004.99	0
1	18	18	2.17	-37.74	133.83	0
1	18	24	1.77	-54.91	37.8	0
1	19	6	2.03	70.3	43.06	0
1	19	12	1.22	80.1	1006.54	0
1	19	18	2.46	-40.63	98.41	0
1	19	24	2.59	86.93	53.16	0
1	20	6	1.56	71.19	52.96	0
1	20	12	1.21	67.24	911.2	0
1	20	18	2.31	-15.85	112.5	0
1	20	24	1.2	-28.4	36.91	0
1	21	6	1.08	14.24	36.78	0
1	21	12	0.93	-57.3	1007.71	0
1	21	18	1.56	32.77	103.76	0
1	21	24	1.28	-8.12	38.06	0
1	22	6	1.16	9.23	39.8	0
1	22	12	0.23	-47.12	1098.68	0
1	22	18	1.41	57.89	44.04	0
1	22	24	1.69	-81.73	39.08	0
1	23	6	1.85	57.17	38.37	0
1	23	12	1.37	-82.66	1162.24	0
1	23	18	1.82	41.63	49.4	0
1	23	24	1.41	56.68	80.54	0.05731
1	24	6	1.57	5.44	65.23	0.054959
1	24	12	0.69	2.92	1584.28	0
1	24	18	1.94	-14.77	112.11	0
1	24	24	2.1	-84.18	53.2	0
1	25	6	1.2	-73.02	66.92	0
1	25	12	1.72	-46.45	1348.27	0
1	25	18	1.07	5.06	204.91	0
1	25	24	1.29	-58.77	102.27	0
1	26	6	1.41	26.13	106.64	0

Month	Day	Hour	Wind Speed (m/s)	Wind Direction (Degree)	Mixing Height (m)	Precipitation (mm/hr)
1	26	12	0.97	-77.09	1190.47	0
1	26	18	1.06	-4.32	187.76	0
1	26	24	1.37	64.89	131.54	0
1	27	6	1.02	72.16	85.16	0
1	27	12	0.47	47.82	1146.03	0
1	27	18	0.71	72.41	388.86	0
1	27	24	0.85	17.04	47.26	0
1	28	6	1.11	28.39	86.09	0
1	28	12	0.53	-27.8	1096.7	0
1	28	18	1.85	-45.28	157.1	0
1	28	24	1.83	76.77	128.77	0
1	29	6	1.23	63.4	67.07	0
1	29	12	1.11	-2.31	1125	0
1	29	18	1.78	-31.96	125.2	0
1	29	24	0.75	-77.69	32.43	0
1	30	6	0.88	-40.07	51.61	0
1	30	12	1.26	81.34	1068.42	0
1	30	18	1.47	74.38	100.97	0
1	30	24	1.26	-56.5	23.69	0
1	31	6	1.2	-52.77	45.33	0
1	31	12	2.29	-67.15	1062.04	0
1	31	18	1.38	88.04	53.94	0
1	31	24	2	-66.84	28.06	0
7	1	6	2.6	66.72	350.81	0.000137
7	1	12	2.57	77.93	760.76	0.000288
7	1	18	3.42	89.32	473.65	0.000189
7	1	24	3.17	-56.31	255.95	0.082939
7	2	6	2.79	73.52	298.23	0.119431
7	2	12	2.36	-84.43	858.49	0.139659
7	2	18	2.08	-79.64	632.49	0.053607
7	2	24	1.88	-73.25	227.89	0.000045
7	3	6	2.09	-19.38	232.15	0.087708
7	3	12	2.27	-33.34	962.04	0.045588
7	3	18	1.97	-72.7	677.1	0.045081
7	3	24	0.63	-74.05	191.16	0.064338
7	4	6	2.26	-48.04	195.61	0.02841
7	4	12	2.52	-34.69	948.54	0.000066
7	4	18	1.47	-72.54	601.9	0.097669
7	4	24	1.3	-68.6	225.17	0.027432
7	5	6	2.51	-35.04	227.14	0.154485
7	5	12	2.61	-66.8	731.39	0.000216
7	5	18	2.24	-75.05	569.88	0.000117
7	5	24	1.39	-65.38	333.42	0.095531
7	6	6	2.69	-26.37	305.66	0.223089
7	6	12	2.84	-50.37	878.81	0.121658
7	6	18	1.92	-39.42	501.75	0.060041
7	6	24	2.31	-53.1	355.92	0.058991
7	7	6	3.2	-3.86	397.6	0.180397
7	7	12	3.56	-38.75	911.1	0.076942
7	7	18	3.44	-47.05	600.89	0.000121
7	7	24	3.44	-28.4	369.58	0.039752
7	8	6	2.89	-30.51	430.66	0.081027
7	8	12	4.96	-48.9	1109.49	0.120575
7	8	18	4.79	-72.39	745.63	0.049565
7	8	24	1.63	-28.76	482.85	0.171583

Month	Day	Hour	Wind Speed (m/s)	Wind Direction (Degree)	Mixing Height (m)	Precipitation (mm/hr)
7	9	6	2.24	-83.74	480.93	0.000052
7	9	12	3.45	-46.26	972.48	0.172172
7	9	18	4.02	-73.72	727.51	0.037831
7	9	24	4.25	-46.64	556.91	0.089007
7	10	6	3.58	-62.37	424.73	0.000306
7	10	12	3.84	-68.41	680.16	0.000294
7	10	18	2.92	-70.4	536.02	0.053096
7	10	24	1.99	-65.69	454.74	0.16092
7	11	6	2.77	-73.21	423.88	0.00012
7	11	12	2.86	-51.29	794.58	0.112024
7	11	18	3.08	-78.09	497.21	0.000254
7	11	24	2.63	-41.56	315.96	0.039031
7	12	6	3.3	88.68	377.15	0.161004
7	12	12	3.78	-89.43	935.88	0.000138
7	12	18	2.81	71.42	514.14	0.000217
7	12	24	2.71	-62.29	305.83	0.000137
7	13	6	1.85	62.68	340.41	0.000082
7	13	12	3.72	82.96	1100.67	0.139511
7	13	18	3.54	64.88	666.73	0.135116
7	13	24	2.99	54.97	389.25	0.1286
7	14	6	2.19	72.97	366.25	0.094277
7	14	12	2.98	76.25	901.94	0.000086
7	14	18	2.08	89.64	661.23	0.085603
7	14	24	2.34	-67.99	423.78	0.000111
7	15	6	2.42	-61.45	381.67	0.000292
7	15	12	2.1	-72.29	767.66	0.200963
7	15	18	2.22	-63.77	504.49	0.087478
7	15	24	2.35	-55.79	288.32	0.050606
7	16	6	2.94	-29.3	335.27	0.263368
7	16	12	2.63	-36.26	814.02	0.000191
7	16	18	2.87	-64.76	586.91	0.113792
7	16	24	1.66	-39.36	447.2	0.121602
7	17	6	1.77	-28.92	404.37	0.057691
7	17	12	2.04	-57.13	1015.31	0.086271
7	17	18	2.88	-88.53	553.42	0.000209
7	17	24	2.51	-58.28	370.22	0.113287
7	18	6	2.54	-29.21	433.63	0.150358
7	18	12	3.01	-76.05	919.24	0.160036
7	18	18	2.68	-77.65	697.27	0.186858
7	18	24	2.78	-75.84	368.31	0.140661
7	19	6	2.19	-56.46	398.45	0.058714
7	19	12	3.78	-71.3	1036.41	0.023353
7	19	18	3.96	-64.58	672.43	0.000197
7	19	24	3.15	-59.32	543.29	0.387151
7	20	6	2.33	-78.05	452.47	0.142554
7	20	12	3.64	-77.43	922.71	0.000222
7	20	18	2.83	-83.55	580.28	0.000135
7	20	24	2.59	-89.67	306.13	0.09135
7	21	6	2.93	-82.17	322.71	0.041987
7	21	12	3.1	-74.13	845.05	0.030406
7	21	18	2.16	-85.19	500.42	0.000152
7	21	24	2.31	-55.11	260.6	0.042037
7	22	6	1.69	-48.77	254.8	0.082148
7	22	12	2.24	-72.97	787.07	0.000283
7	22	18	2.98	-87.86	383.97	0.000311

Month	Day	Hour	Wind Speed (m/s)	Wind Direction (Degree)	Mixing Height (m)	Precipitation (mm/hr)
7	22	24	2.23	79.41	239.12	0.07275
7	23	6	1.72	-74.22	259.51	0.109083
7	23	12	3.26	-78.58	790.12	0.000161
7	23	18	2.81	-78.17	635.13	0.036145
7	23	24	2.54	-81.55	368.75	0.318639
7	24	6	1.54	83.1	313.39	0.234031
7	24	12	3.24	89.95	808.31	0.00012
7	24	18	3.94	-84.02	627.66	0.19483
7	24	24	3.49	-75.22	355.08	0.060487
7	25	6	3.01	84.93	413.14	0.266912
7	25	12	3.74	86.15	810.29	0.081377
7	25	18	3.08	-86.07	590.13	0.212433
7	25	24	3.48	-89.78	444.97	0.134911
7	26	6	3.07	64.02	392.17	0.000156
7	26	12	3.42	83.41	883.76	0.00013
7	26	18	3.76	85.29	552.71	0.044969
7	26	24	3.4	-84.82	415.2	0.177747
7	27	6	3.26	77.62	424.23	0.097466
7	27	12	4.01	71.34	829.88	0.000123
7	27	18	4.38	76.01	655.37	0.000141
7	27	24	4.26	71.83	435.03	0.211448
7	28	6	4.66	67.46	440.42	0.088882
7	28	12	5.29	80.69	919.87	0.077218
7	28	18	5	81.69	639.05	0.000196
7	28	24	4.13	78.1	546.89	0.00018
7	29	6	3.76	83.55	482.83	0.000145
7	29	12	4.34	86.06	575.22	0.025381
7	29	18	3.68	67.92	519.74	0.062632
7	29	24	3.12	75.46	384.29	0.169039
7	30	6	3.53	52.58	357.69	0.120123
7	30	12	3.72	72.76	800.48	0.000247
7	30	18	3.65	58.99	438.81	0.000196
7	30	24	3.41	62.57	227.52	0.138263
7	31	6	2.41	51.62	220.9	0.000097
7	31	12	3.08	62.76	932.3	0.132173
7	31	18	3.61	52.22	408.77	0.000195
7	31	24	3.67	78.51	255.97	0.157564

Appendix B

Grid wise Emission

Table B-1: Grid wise emission in tons/year from traffic and brick kiln

Grid Id	Traffic Emission				Brick Emission	
	PM_{10}	$PM_{2.5}$	SOx	NOx	PM_{10}	$PM_{2.5}$
a1	0.0	0.0	0.0	0.0	0.0	0.0
a2	0.3	0.1	0.1	0.9	48.7	14.6
a3	0.6	0.3	0.2	1.7	75.2	22.6
a4	0.4	0.2	0.1	1.1	18.4	5.5
a5	10.1	5.8	14.6	203.4	3,640.2	1,092.1
a6	1.8	1.0	2.1	29.4	3,939.4	1,181.8
a7	15.0	8.5	5.0	75.6	638.3	191.5
a8	21.2	12.3	23.2	327.9	1,500.0	450.0
a9	43.1	25.9	10.0	182.1	1,760.0	528.0
a10	29.2	17.9	7.2	134.4	43.0	12.9
a11	16.2	9.9	4.0	74.1	1.9	0.6
a12	1.3	0.8	0.7	8.6	4,208.9	1,262.7
a13	10.9	6.3	2.5	40.0	6,162.0	1,848.6
a14	4.3	2.4	9.8	134.0	2,637.6	791.3
a15	0.3	0.1	12.1	161.7	278.8	83.6
a16	3.4	2.1	13.0	178.6	0.0	0.0
a17	0.4	0.2	14.4	191.9	41.0	12.3
a18	3.4	1.9	13.4	180.9	294.1	88.2
a19	16.6	9.7	16.0	229.2	0.0	0.0
a20	20.2	12.4	18.6	276.9	0.0	0.0
b1	0.0	0.0	0.0	0.0	0.0	0.0
b2	8.2	4.7	1.7	27.3	2,530.2	759.1
b3	15.3	8.7	3.2	50.8	3,930.3	1,179.1
b4	5.0	2.9	1.1	17.8	964.1	289.2
b5	1.1	0.6	8.7	116.7	9,302.1	2,790.6
b6	19.3	11.2	4.9	81.3	10,164.0	3,049.2
b7	2.0	1.1	12.3	165.6	822.8	246.8
b8	1.5	0.8	17.1	229.4	107.6	32.3
b9	3.3	2.1	35.1	475.3	1,354.0	406.2
b10	16.9	10.6	28.0	399.2	2,234.9	670.5
b11	29.4	18.0	20.3	308.9	97.3	29.2
b12	46.8	30.3	20.1	351.1	100.7	30.2
b13	53.1	35.8	35.7	591.9	1,355.7	406.7
b14	18.0	12.3	12.9	215.0	919.5	275.8
b15	2.1	1.3	1.2	19.8	90.6	27.2
b16	3.5	2.1	3.3	48.3	0.0	0.0
b17	4.1	2.6	1.5	26.5	0.0	0.0
b18	5.4	3.9	6.1	101.1	0.0	0.0
b19	3.9	2.8	14.7	210.6	0.0	0.0
b20	0.3	0.1	12.9	172.1	0.0	0.0
c1	0.0	0.0	0.0	0.0	0.0	0.0
c2	8.4	4.8	8.1	114.1	0.0	0.0
c3	15.5	8.9	15.1	211.8	447.6	134.3
c4	19.0	11.5	9.0	145.7	197.5	59.2
c5	20.4	12.6	6.7	120.5	0.0	0.0
c6	49.8	28.3	23.3	338.4	1,612.7	483.8
c7	43.8	26.1	11.9	206.6	16.5	4.9
c8	32.0	19.1	8.9	153.5	177.7	53.3
c9	30.0	18.5	10.7	186.0	128.4	38.5

Grid Id	Traffic Emission				Brick Emission	
	PM_{10}	$PM_{2.5}$	SOx	NOx	PM_{10}	$PM_{2.5}$
c10	48.8	31.3	29.1	480.8	0.0	0.0
c11	24.8	17.0	35.9	544.3	0.0	0.0
c12	51.9	36.5	59.4	938.9	0.0	0.0
c13	133.1	92.8	104.0	1,714.9	0.0	0.0
c14	183.1	126.1	108.1	1,896.9	0.0	0.0
c15	52.9	36.2	31.6	560.0	0.0	0.0
c16	5.4	3.4	4.6	70.6	0.0	0.0
c17	10.2	6.2	5.8	85.3	0.0	0.0
c18	0.3	0.1	1.1	14.1	42.6	12.8
c19	0.3	0.1	0.8	10.2	147.1	44.1
c20	0.3	0.1	0.1	0.9	0.0	0.0
d1	0.0	0.0	0.0	0.0	0.0	0.0
d2	11.1	6.8	9.9	148.8	0.0	0.0
d3	18.1	11.2	17.6	262.4	0.0	0.0
d4	4.9	3.0	15.3	210.9	0.0	0.0
d5	0.3	0.1	14.6	194.4	0.0	0.0
d6	13.5	7.7	47.3	642.1	0.0	0.0
d7	14.3	8.1	36.4	494.9	0.0	0.0
d8	20.2	12.0	29.0	409.2	0.0	0.0
d9	81.4	54.6	55.5	937.0	0.0	0.0
d10	81.4	54.6	55.5	937.0	0.0	0.0
d11	110.1	79.9	73.2	1,340.1	0.0	0.0
d12	107.9	74.0	60.7	1,081.0	0.0	0.0
d13	127.8	87.0	90.0	1,492.2	0.0	0.0
d14	205.6	143.5	154.5	2,439.5	0.0	0.0
d15	124.6	86.5	82.0	1,399.0	0.0	0.0
d16	14.9	9.7	9.8	154.1	12.9	3.9
d17	9.9	6.0	10.0	141.4	257.1	77.1
d18	0.3	0.1	0.1	0.9	1,620.3	486.1
d19	0.3	0.1	0.1	0.9	2,913.3	874.0
d20	0.3	0.1	0.1	0.9	0.0	0.0
e1	0.0	0.0	0.0	0.0	0.0	0.0
e2	4.4	2.7	9.2	129.2	0.0	0.0
e3	3.3	1.9	13.8	189.2	0.0	0.0
e4	0.3	0.1	3.4	44.8	0.0	0.0
e5	0.9	0.5	0.3	4.2	0.0	0.0
e6	7.0	4.3	12.6	178.7	0.0	0.0
e7	1.6	0.9	11.7	157.4	0.0	0.0
e8	13.8	8.5	18.8	269.4	0.0	0.0
e9	8.2	4.8	46.4	629.8	0.0	0.0
e10	0.3	0.1	69.0	924.2	0.0	0.0
e11	43.2	33.6	63.0	1,022.6	0.0	0.0
e12	59.9	46.6	80.9	1,330.0	0.0	0.0
e13	47.8	38.0	81.9	1,299.5	0.0	0.0
e14	133.4	91.7	126.3	2,022.7	0.0	0.0
e15	123.7	81.9	82.8	1,367.4	0.0	0.0
e16	61.0	36.7	19.3	324.8	158.1	47.4
e17	8.9	5.4	8.9	129.1	3,445.7	1,033.7
e18	2.9	1.7	0.8	12.8	11,845.9	3,553.8
e19	0.3	0.1	0.1	0.9	6,118.0	1,835.4
e20	0.3	0.1	0.1	0.9	85.2	25.6
f1	0.0	0.0	0.0	0.0	0.0	0.0
f2	4.4	2.7	4.4	65.6	0.0	0.0
f3	3.3	1.9	3.1	45.8	0.0	0.0
f4	0.3	0.1	0.1	0.9	0.0	0.0
f5	6.8	4.2	2.5	43.5	0.0	0.0

Grid Id	Traffic Emission				Brick Emission	
	PM_{10}	$PM_{2.5}$	SOx	NOx	PM_{10}	$PM_{2.5}$
f6	1.1	0.6	5.1	69.0	0.0	0.0
f7	1.2	0.6	1.3	17.9	0.0	0.0
f8	10.6	6.4	12.9	184.2	0.0	0.0
f9	10.8	6.6	8.8	132.4	0.0	0.0
f10	0.3	0.1	0.1	0.4	0.0	0.0
f11	5.0	2.9	6.2	85.8	0.0	0.0
f12	4.8	2.8	6.4	88.7	0.0	0.0
f13	0.3	0.1	0.4	4.7	0.0	0.0
f14	0.3	0.1	59.2	793.1	0.0	0.0
f15	92.0	57.2	92.5	1,375.3	0.0	0.0
f16	272.6	155.7	85.0	1,284.7	0.0	0.0
f17	36.6	22.2	16.2	260.5	2,843.6	853.1
f18	29.8	18.1	9.9	168.2	6,653.6	1,996.1
f19	1.6	1.0	0.6	9.7	4,559.7	1,367.9
f20	0.7	0.4	0.3	4.3	907.2	272.2
g1	0.0	0.0	0.0	0.0	0.0	0.0
g2	5.5	3.3	4.6	68.6	0.0	0.0
g3	5.2	3.1	3.5	51.5	0.0	0.0
g4	2.3	1.2	0.5	6.6	0.0	0.0
g5	8.8	5.3	7.1	106.0	0.0	0.0
g6	1.2	0.7	0.9	12.7	0.0	0.0
g7	0.5	0.2	0.8	10.3	0.0	0.0
g8	3.9	2.4	8.8	122.7	0.0	0.0
g9	9.4	5.8	10.5	152.3	0.0	0.0
g10	1.0	0.6	0.3	4.4	0.0	0.0
g11	6.0	3.5	5.3	75.8	0.0	0.0
g12	4.8	2.8	4.9	67.9	0.0	0.0
g13	0.3	0.1	0.1	0.9	0.0	0.0
g14	0.3	0.1	0.1	0.9	0.0	0.0
g15	64.8	40.3	86.5	1,255.0	0.0	0.0
g16	173.2	99.5	277.8	3,826.0	0.0	0.0
g17	10.0	6.1	30.2	417.9	0.0	0.0
g18	34.9	21.3	31.9	471.2	0.0	0.0
g19	11.9	7.6	5.2	89.0	339.7	101.9
g20	4.1	2.7	2.1	35.6	700.6	210.2
h1	0.0	0.0	0.0	0.0	0.0	0.0
h2	10.7	6.2	6.4	95.2	0.0	0.0
h3	15.6	9.0	7.0	105.0	0.0	0.0
h4	13.1	7.4	4.2	62.5	0.0	0.0
h5	19.6	11.5	10.8	161.8	0.0	0.0
h6	4.2	2.4	1.6	23.8	0.0	0.0
h7	3.5	2.0	0.9	13.2	0.0	0.0
h8	10.7	6.3	5.2	80.1	5.2	1.5
h9	0.3	0.1	6.8	90.5	51.1	15.3
h10	4.9	3.0	2.0	32.1	80.5	24.2
h11	12.6	7.6	8.0	120.9	15.0	4.5
h12	5.8	3.4	5.1	72.7	0.0	0.0
h13	2.4	1.4	0.7	11.7	198.8	59.6
h14	3.6	2.2	1.0	17.6	348.0	104.4
h15	69.4	43.2	68.0	1,011.8	60.4	18.1
h16	69.7	43.3	178.2	2,490.0	129.1	38.7
h17	1.9	1.1	7.6	103.2	247.8	74.3
h18	10.2	6.2	28.7	397.6	0.0	0.0
h19	8.0	4.9	9.6	139.8	0.0	0.0
h20	5.1	3.2	3.8	59.4	0.0	0.0
i1	0.0	0.0	0.0	0.0	0.0	0.0

Grid Id	Traffic Emission				Brick Emission	
	PM_{10}	**$PM_{2.5}$**	**SOx**	**NOx**	**PM_{10}**	**$PM_{2.5}$**
i2	0.2	0.1	8.2	108.9	0.0	0.0
i3	0.3	0.1	12.1	161.6	0.0	0.0
i4	0.3	0.1	10.3	137.4	0.0	0.0
i5	5.5	3.4	16.6	230.5	0.0	0.0
i6	12.2	7.0	5.6	82.0	0.0	0.0
i7	13.8	7.9	5.3	78.6	2.9	0.9
i8	19.6	11.4	12.0	175.4	141.7	42.5
i9	0.3	0.1	0.1	0.9	670.8	201.2
i10	0.3	0.1	3.5	45.8	551.8	165.5
i11	9.8	5.9	12.2	173.2	84.2	25.3
i12	11.0	6.6	7.3	109.3	87.1	26.1
i13	14.9	9.2	5.7	94.2	1,335.8	400.8
i14	21.2	13.1	8.4	138.9	2,045.6	613.7
i15	3.8	2.3	52.0	701.2	345.0	103.5
i16	25.1	15.6	58.6	822.4	813.1	243.9
i17	3.1	1.8	2.0	30.3	1,393.9	418.2
i18	2.3	1.3	7.7	102.8	0.0	0.0
i19	0.3	0.1	5.8	77.0	0.0	0.0
i20	0.3	0.1	3.1	40.5	0.0	0.0
j1	0.0	0.0	0.0	0.0	0.0	0.0
j2	0.2	0.1	0.1	0.4	0.0	0.0
j3	0.3	0.1	0.1	0.8	0.0	0.0
j4	0.3	0.1	0.1	0.8	0.0	0.0
j5	0.3	0.1	4.0	52.8	0.0	0.0
j6	0.3	0.1	9.6	127.7	0.0	0.0
j7	1.6	0.9	11.1	148.7	141.3	42.4
j8	12.3	7.0	17.3	237.2	841.3	252.4
j9	0.3	0.1	0.1	0.8	1,899.2	569.8
j10	0.3	0.1	0.1	0.8	482.7	144.8
j11	0.4	0.2	7.7	102.1	0.0	0.0
j12	8.3	4.8	10.4	144.4	425.9	127.8
j13	13.6	7.9	13.7	191.6	1,087.4	326.2
j14	14.9	8.6	18.3	253.5	440.6	132.2
j15	2.8	1.6	3.2	43.1	25.6	7.7
j16	0.3	0.1	18.4	245.3	425.9	127.8
j17	1.7	0.9	2.4	31.7	0.0	0.0
j18	10.0	5.7	3.6	52.2	0.0	0.0
j19	0.3	0.1	0.1	0.8	0.0	0.0
j20	0.3	0.1	0.1	0.8	0.0	0.0

Appendix C

Grid wise Population

Table C-1: Grid wise Population of DCC area

Grid Id	Total Population	Adult Population
b9	122,838	40,733
b10	347,888	115,360
b11	364,372	120,826
b12	319,019	105,787
b13	22,459	7,447
c9	138,636	45,972
c10	476,893	158,138
c11	499,805	165,735
c12	501,440	166,278
c13	492,047	163,163
d8	30,184	10,009
d9	102,837	34,101
d10	159,211	52,794
d11	304,694	101,037
d12	540,189	179,127
d13	897,248	297,527
d14	207,194	68,706
e7	3,987	1,322
e8	25,370	8,413
e9	35,190	11,669
e10	89,391	29,642
e11	85,593	28,383
e12	465,783	154,454
e13	387,111	128,366
e14	463,999	153,862
f10	49,582	16,441
f11	22,884	7,588
f12	86,425	28,659
f13	105,214	34,889
f14	38,749	12,849
g13	19,375	6,425

Table C-2: Grid wise Population of Greater Dhaka

Grid Id	Total Population	Adult Population	Grid Id	Total Population	Adult Population
a3	18,107	6,004	d8	50,968	16,901
a4	24,143	8,006	d9	117,320	38,903
a5	24,143	8,006	d10	163,670	54,273
a6	24,143	8,006	d11	304,694	101,037
a7	24,143	8,006	d12	540,189	179,127
a8	24,143	8,006	d13	900,570	298,629
a9	24,143	8,006	d14	247,532	82,082
a10	24,143	8,006	d15	45,084	14,950
a11	26,475	8,779	d16	14,237	4,721
a12	38,090	12,631	e7	7,253	2,405
a13	47,457	15,737	e8	60,660	20,115
a14	47,457	15,737	e9	74,863	24,825
a15	30,847	10,229	e10	129,265	42,864
a16	475	158	e11	137,628	45,637
b2	724	240	e12	492,594	163,344
b3	12,072	4,003	e13	426,834	141,538
b4	7,243	2,402	e14	486,002	161,158
b5	7,243	2,402	e15	56,720	18,808
b6	16,900	5,604	e16	35,593	11,803
b7	18,766	6,223	e17	4,746	1,574
b8	33,338	11,055	f7	9,890	3,280
b9	162,213	53,790	f8	32,967	10,932
b10	360,406	119,511	f9	59,547	19,746
b11	360,473	119,533	f10	108,344	35,927
b12	362,504	120,206	f11	103,740	34,400
b13	64,696	21,453	f12	198,951	65,972
b14	47,457	15,737	f13	174,935	58,008
b15	47,457	15,737	f14	97,226	32,240
b16	11,864	3,934	f15	24,329	8,067
c7	16,484	5,466	f16	16,610	5,508
c8	65,276	21,646	g9	5,529	1,833
c9	184,790	61,276	g10	16,586	5,500
c10	488,102	161,855	g11	18,958	6,286
c11	492,377	163,272	g12	31,162	10,333
c12	486,583	161,351	g13	81,022	26,867
c13	661,464	219,341	g14	31,162	10,333
c14	76,663	25,421	h13	6,232	2,067
c15	37,966	12,590	h14	249	83
c16	4,746	1,574			

Appendix D

Monthly Average Particulate Concentration

Table D-1: Monthly average $PM_{2.5}$ concentration in μg/m^3 at different grids due to traffic and brick kiln pollution

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
a1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3
b1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
c1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
d1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
e1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
f1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
g1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
h1	0.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
i1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
j1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
a2	4.5	13.7	3.4	0.0	0.0	0.2	0.0	0.0	0.1	0.1	12.7	0.4
b2	0.3	99.8	167.4	0.0	0.0	0.2	0.0	0.0	0.3	0.2	3.8	0.6
c2	0.4	1.7	1.5	0.7	0.0	0.1	0.0	0.0	0.4	0.3	0.5	12.3
d2	2.9	2.5	4.5	0.1	0.0	0.0	0.0	0.0	0.5	0.4	3.1	0.6
e2	1.9	2.1	5.5	0.2	0.0	0.0	0.0	0.0	0.4	0.3	2.1	4.4
f2	0.4	2.5	1.5	0.3	0.1	0.1	0.0	0.0	0.3	0.2	2.8	0.6
g2	0.3	1.2	1.2	0.2	0.0	0.1	0.0	0.0	0.3	0.2	1.6	1.6
h2	0.3	1.5	1.7	0.2	0.0	0.1	0.0	0.0	0.4	0.3	0.5	0.5
i2	0.3	1.1	1.0	0.2	0.0	0.1	0.0	0.0	0.2	0.2	0.4	0.5
j2	0.2	0.2	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.3	0.5
a3	14.5	21.5	8.4	0.1	0.1	0.3	0.0	0.0	0.2	0.2	20.1	3.9
b3	1.6	162.4	261.4	0.4	0.1	0.3	0.0	0.0	0.6	0.4	22.8	3.3
c3	11.2	25.8	42.8	1.1	0.1	0.2	0.0	0.1	0.8	0.7	15.3	28.0
d3	8.0	7.8	10.5	0.5	0.1	0.1	0.0	0.1	0.9	0.9	15.3	11.3
e3	7.3	4.9	10.8	0.7	0.1	0.1	0.0	0.0	0.5	0.8	6.4	11.9
f3	2.8	4.7	4.3	0.8	0.1	0.2	0.0	0.0	0.3	0.4	8.2	2.1
g3	3.8	1.9	1.6	0.5	0.1	0.2	0.0	0.0	0.3	0.4	3.5	4.8
h3	3.0	2.2	2.5	0.4	0.1	0.2	0.0	0.1	0.6	0.6	3.2	1.9
i3	1.3	1.8	1.7	0.4	0.1	0.2	0.0	0.0	0.3	0.5	1.2	1.1
j3	0.6	0.4	0.5	0.2	0.1	0.2	0.0	0.0	0.1	0.1	0.8	0.8
a4	15.1	15.4	10.7	0.1	0.1	0.3	0.0	0.0	0.2	0.3	8.1	8.4
b4	8.0	48.5	67.0	0.6	0.1	0.4	0.0	0.0	0.4	0.6	31.5	10.8
c4	24.8	23.1	39.4	0.4	0.2	0.2	0.0	0.1	0.9	1.1	25.8	22.5
d4	9.4	12.0	12.4	0.5	0.1	0.2	0.0	0.1	0.6	1.3	25.5	22.6
e4	10.1	7.0	7.7	0.9	0.1	0.2	0.0	0.0	0.3	0.9	14.2	15.6
f4	7.7	5.7	4.6	1.1	0.1	0.2	0.0	0.0	0.2	0.5	10.4	5.4
g4	6.0	2.3	1.7	0.8	0.1	0.3	0.0	0.0	0.3	0.6	5.0	6.8
h4	5.9	2.2	2.2	0.7	0.1	0.2	0.0	0.1	0.6	0.8	5.9	2.8
i4	3.1	1.9	2.2	0.5	0.1	0.3	0.0	0.1	0.3	0.7	3.6	1.6
j4	0.8	0.6	0.7	0.2	0.1	0.4	0.0	0.0	0.1	0.2	1.8	1.2
a5	24.7	202.0	250.8	0.2	0.1	0.3	0.0	0.1	0.8	0.6	55.8	4.6
b5	10.5	371.8	616.4	1.3	0.1	0.4	0.0	0.1	0.5	0.8	30.6	30.2
c5	23.0	14.8	22.0	2.5	0.2	0.2	0.0	0.1	1.0	1.3	13.5	55.5
d5	18.4	13.1	24.2	0.4	0.1	0.2	0.0	0.1	0.6	1.4	26.5	21.7
e5	13.1	10.9	20.3	0.8	0.1	0.2	0.0	0.0	0.4	0.8	26.4	26.8
f5	7.8	11.2	5.4	1.2	0.1	0.3	0.0	0.1	0.6	0.7	21.0	8.4
g5	4.1	5.4	2.9	1.2	0.1	0.3	0.0	0.1	0.6	0.8	7.6	10.4
h5	3.7	3.6	3.7	1.0	0.2	0.3	0.0	0.1	0.9	1.0	6.6	3.9

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
i5	3.4	3.5	3.8	0.7	0.1	0.2	0.0	0.1	0.6	1.0	5.0	1.7
j5	0.9	1.2	1.2	0.4	0.1	0.4	0.0	0.0	0.2	0.4	3.1	1.4
a6	51.7	214.2	280.8	0.9	0.1	0.5	0.0	0.0	0.5	0.8	79.2	17.7
b6	25.2	439.3	696.2	2.4	0.2	0.5	0.0	0.1	1.0	0.9	104.8	45.3
c6	55.0	101.7	163.1	3.0	0.2	0.4	0.0	0.1	2.0	1.8	75.0	96.4
d6	34.8	30.1	38.4	1.9	0.1	0.2	0.0	0.1	1.5	2.1	59.7	55.3
e6	28.2	19.5	32.3	2.7	0.2	0.2	0.0	0.1	0.8	1.1	33.4	41.6
f6	16.7	14.8	13.0	2.8	0.3	0.3	0.0	0.1	0.5	0.9	34.0	11.5
g6	17.6	7.1	2.9	1.9	0.2	0.4	0.0	0.1	0.3	0.9	13.1	17.7
h6	13.1	3.1	2.5	1.3	0.2	0.4	0.0	0.1	0.4	1.0	12.7	10.3
i6	5.4	3.3	3.3	0.8	0.1	0.3	0.0	0.1	0.6	1.0	4.6	3.5
j6	1.1	2.1	2.0	0.4	0.1	0.2	0.0	0.1	0.3	0.6	3.3	1.8
a7	46.4	78.1	78.9	0.8	0.2	0.4	0.0	0.1	0.9	1.0	45.7	35.6
b7	57.0	75.4	92.7	1.8	0.2	0.5	0.0	0.1	0.7	1.2	109.1	55.2
c7	80.5	54.9	84.2	1.1	0.3	0.6	0.0	0.1	1.9	2.0	93.6	74.6
d7	33.4	41.0	39.6	1.7	0.2	0.5	0.0	0.1	1.4	2.5	88.4	76.8
e7	35.0	25.5	22.0	3.2	0.3	0.4	0.0	0.1	0.7	1.4	53.2	49.3
f7	31.0	16.9	11.0	3.4	0.3	0.5	0.0	0.1	0.5	1.1	32.5	21.7
g7	20.6	7.0	3.7	2.7	0.2	0.4	0.0	0.1	0.4	1.1	21.8	19.7
h7	19.9	4.1	3.1	2.0	0.2	0.4	0.0	0.1	0.4	1.0	19.4	11.1
i7	9.3	4.3	5.2	0.9	0.2	0.4	0.0	0.1	0.7	1.0	12.6	5.2
j7	1.3	8.2	11.5	0.4	0.1	0.2	0.0	0.1	0.4	0.8	5.7	2.2
a8	30.9	110.9	130.4	0.9	0.2	0.2	0.0	0.1	1.4	1.5	31.7	20.0
b8	43.3	38.8	35.6	1.0	0.2	0.3	0.0	0.1	0.9	1.9	45.9	49.6
c8	50.6	48.3	56.1	0.6	0.4	0.5	0.0	0.1	1.7	2.5	28.1	39.4
d8	23.4	33.1	26.6	1.0	0.2	1.0	0.0	0.1	1.7	2.8	44.6	46.8
e8	24.3	24.7	15.4	1.6	0.3	0.7	0.0	0.1	1.2	1.8	48.9	34.9
f8	21.2	17.4	7.4	1.9	0.3	0.6	0.0	0.1	1.0	1.4	27.5	22.1
g8	11.8	15.5	3.9	2.2	0.3	0.4	0.0	0.2	0.7	1.1	23.8	18.0
h8	10.8	6.5	4.5	1.8	0.3	0.4	0.1	0.2	0.8	1.0	19.8	10.1
i8	9.9	15.6	15.8	0.9	0.3	0.4	0.0	0.2	1.0	1.2	18.7	3.6
j8	1.6	37.3	59.3	0.6	0.2	0.2	0.0	0.1	0.8	1.1	9.5	3.0
a9	26.8	100.5	147.7	1.2	0.3	0.3	0.0	0.1	2.0	2.2	33.7	17.2
b9	31.9	85.1	118.3	1.2	0.3	0.3	0.0	0.1	1.5	2.3	40.9	33.7
c9	23.2	37.4	26.7	1.4	0.4	0.4	0.0	0.1	1.8	2.3	28.4	27.8
d9	20.6	31.6	24.5	1.1	0.4	0.5	0.0	0.3	4.1	3.7	27.3	25.6
e9	19.2	20.4	15.4	1.7	0.4	0.4	0.0	0.2	1.6	3.1	26.0	25.3
f9	19.3	13.3	6.2	1.4	0.5	0.5	0.0	0.2	1.2	1.9	24.6	13.8
g9	12.1	17.6	6.0	1.2	0.4	0.4	0.0	0.2	0.9	1.5	21.4	18.4
h9	12.9	12.6	7.8	1.0	0.4	0.5	0.1	0.2	0.5	1.4	15.3	20.7
i9	11.7	40.2	47.8	0.8	0.3	0.4	0.1	0.2	0.4	1.2	20.5	8.3
j9	2.8	79.1	127.6	0.8	0.2	0.3	0.0	0.1	0.2	0.9	15.0	7.1
a10	22.3	40.8	26.4	1.0	0.4	0.3	0.0	0.1	1.9	2.6	37.2	17.0
b10	30.9	120.2	176.4	0.9	0.3	0.3	0.0	0.2	1.9	2.8	43.4	20.1
c10	22.9	31.0	24.5	1.7	0.5	0.5	0.0	0.2	3.0	2.9	36.7	34.4
d10	19.7	29.2	26.9	1.5	0.4	0.5	0.0	0.3	4.2	5.2	37.0	26.0
e10	20.8	18.9	23.2	1.9	0.5	0.5	0.0	0.3	1.9	4.2	24.9	27.1
f10	21.2	11.5	7.0	1.7	0.6	0.4	0.1	0.1	0.9	2.1	23.8	15.9
g10	12.8	12.1	6.8	1.1	0.5	0.4	0.1	0.2	0.7	1.8	19.0	22.7
h10	13.4	14.4	12.5	0.8	0.4	0.5	0.1	0.2	0.5	1.7	15.4	26.6
i10	12.4	33.0	42.7	0.9	0.3	0.6	0.1	0.3	0.4	1.3	15.8	12.7
j10	7.3	28.2	37.3	1.0	0.2	0.3	0.0	0.1	0.3	0.7	21.9	11.9
a11	19.6	26.1	16.2	0.7	0.5	0.2	0.0	0.1	1.7	2.9	14.3	17.4
b11	18.7	30.8	26.1	1.1	0.5	0.3	0.0	0.2	2.6	3.2	26.7	17.3
c11	23.5	30.7	27.9	1.4	0.6	0.3	0.0	0.2	2.7	4.2	32.0	24.2
d11	16.9	36.9	31.9	1.5	0.5	0.4	0.0	0.4	6.2	6.8	34.4	26.6

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
e11	19.8	22.3	25.0	2.2	0.4	0.3	0.0	0.3	3.5	5.5	23.4	20.1
f11	15.9	13.9	10.3	1.9	0.7	0.3	0.1	0.2	1.4	2.5	17.9	15.9
g11	11.9	13.1	8.7	1.2	0.6	0.3	0.1	0.2	1.1	1.9	15.6	18.6
h11	14.5	13.0	9.9	1.0	0.5	0.4	0.1	0.4	1.0	1.8	17.6	15.6
i11	10.5	17.7	14.4	0.9	0.4	0.3	0.1	0.4	0.9	1.4	17.4	8.7
j11	11.0	8.1	7.2	0.7	0.3	0.2	0.1	0.2	0.4	0.8	15.3	12.0
a12	13.6	191.4	291.1	0.8	0.5	0.2	0.0	0.1	1.6	2.8	19.8	12.8
b12	15.8	24.4	24.7	1.9	0.5	0.2	0.0	0.2	3.2	3.8	18.1	38.5
c12	21.9	31.2	34.0	1.5	0.7	0.2	0.0	0.3	4.3	5.4	22.3	15.5
d12	14.7	29.6	33.4	1.9	0.7	0.4	0.0	0.4	5.7	7.8	24.6	28.7
e12	14.7	25.9	26.4	2.0	0.6	0.3	0.0	0.4	4.7	6.8	27.1	16.1
f12	14.6	11.8	10.8	2.1	0.8	0.3	0.1	0.2	1.3	3.1	15.5	17.2
g12	10.2	10.7	11.3	1.4	0.8	0.2	0.1	0.3	1.2	2.4	15.2	15.5
h12	12.3	10.3	8.8	1.3	0.7	0.3	0.1	0.4	0.8	2.2	14.6	11.5
i12	10.9	13.8	13.5	0.9	0.6	0.3	0.1	0.5	0.9	1.8	15.2	7.3
j12	7.3	24.7	35.0	0.6	0.4	0.2	0.1	0.2	0.7	1.2	10.5	8.3
a13	15.5	274.8	418.8	1.4	0.7	0.1	0.0	0.2	2.4	3.0	48.2	12.2
b13	28.5	85.6	125.0	2.3	0.6	0.2	0.0	0.3	4.1	4.5	39.3	54.7
c13	24.3	45.5	45.7	1.8	0.7	0.2	0.0	0.5	7.6	8.3	37.5	33.1
d13	27.0	33.6	43.8	2.9	0.9	0.3	0.0	0.5	7.2	9.6	25.1	35.8
e13	18.2	28.5	28.9	3.1	0.8	0.3	0.1	0.4	4.7	8.0	30.9	18.4
f13	16.9	13.0	10.6	2.5	1.0	0.2	0.1	0.2	1.4	3.8	16.9	20.4
g13	13.4	13.7	9.4	1.6	0.9	0.2	0.1	0.4	1.2	2.9	17.1	16.3
h13	11.7	22.8	20.2	1.4	0.7	0.3	0.1	0.6	0.8	2.6	18.2	14.5
i13	9.9	65.4	95.7	1.0	0.7	0.3	0.1	0.6	1.1	2.1	16.0	8.9
j13	6.5	51.5	77.9	1.1	0.4	0.2	0.1	0.3	1.0	1.5	13.1	12.5
a14	22.0	134.7	188.3	1.6	0.9	0.1	0.0	0.2	2.9	4.1	57.6	25.6
b14	49.3	74.5	109.5	1.8	1.0	0.2	0.0	0.3	3.5	5.3	55.6	49.2
c14	30.2	53.7	54.5	1.7	0.9	0.3	0.0	0.7	10.0	10.7	57.2	50.6
d14	34.1	51.1	56.5	3.6	0.9	0.3	0.0	0.8	11.1	12.5	44.4	42.5
e14	27.1	41.0	41.0	4.5	0.9	0.3	0.1	0.6	8.4	10.5	34.9	28.1
f14	23.6	24.1	17.0	3.8	1.3	0.2	0.1	0.4	2.9	5.7	23.3	30.3
g14	18.8	15.7	9.9	2.4	1.3	0.2	0.1	0.5	1.6	3.7	22.5	25.6
h14	19.7	34.5	33.2	1.5	1.1	0.3	0.2	0.7	1.1	2.9	26.1	19.9
i14	11.8	95.9	144.8	1.3	0.9	0.4	0.2	0.7	1.4	2.7	23.3	12.5
j14	11.5	29.9	41.1	1.5	0.5	0.2	0.1	0.3	1.2	1.9	22.6	21.7
a15	24.1	36.8	33.8	1.3	0.8	0.1	0.0	0.3	2.4	4.9	39.5	30.9
b15	43.5	37.7	44.8	1.3	1.2	0.1	0.0	0.2	2.8	5.9	32.3	35.8
c15	26.6	36.4	33.9	1.4	1.4	0.3	0.0	0.4	5.2	10.8	42.3	43.8
d15	28.3	43.3	40.1	2.2	1.3	0.4	0.0	0.6	8.2	12.9	48.0	37.8
e15	30.8	37.4	34.9	3.2	1.1	0.4	0.1	0.6	7.7	11.2	38.4	28.8
f15	23.3	36.5	29.7	3.3	1.1	0.2	0.2	0.7	6.2	7.9	30.5	33.9
g15	18.9	29.8	24.7	3.1	1.3	0.2	0.2	0.9	5.1	6.3	26.0	31.3
h15	22.8	32.5	28.7	2.6	1.5	0.3	0.2	1.0	4.5	5.6	25.4	18.8
i15	15.7	35.5	37.2	2.3	1.5	0.4	0.2	0.9	2.1	4.6	31.0	15.9
j15	20.6	14.0	18.9	1.4	0.9	0.2	0.1	0.4	1.0	2.3	26.2	21.4
a16	20.7	21.9	17.2	1.2	0.9	0.0	0.0	0.4	2.6	4.6	25.4	20.4
b16	25.9	26.1	21.0	1.4	1.0	0.1	0.0	0.3	2.5	6.5	15.8	22.7
c16	18.7	24.3	17.0	1.4	1.3	0.1	0.0	0.3	3.3	10.1	22.7	25.4
d16	21.8	26.0	17.5	1.4	1.4	0.3	0.0	0.3	4.4	12.0	29.8	29.8
e16	28.7	31.8	31.5	1.5	1.4	0.3	0.1	0.4	6.2	10.1	30.2	22.8
f16	22.2	45.4	41.6	1.8	1.1	0.3	0.1	1.0	11.2	10.2	30.2	26.2
g16	18.4	56.2	49.6	2.9	1.3	0.3	0.2	1.5	10.9	12.8	30.8	26.3
h16	22.9	51.7	43.1	4.3	1.6	0.4	0.3	1.4	6.7	10.4	31.2	20.5
i16	19.6	54.6	70.8	3.1	2.0	0.3	0.3	1.0	3.7	6.5	29.7	20.0
j16	17.6	31.8	44.0	1.8	1.5	0.2	0.2	0.5	1.7	3.3	17.7	20.6

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
a17	17.3	20.1	19.0	1.4	1.0	0.1	0.0	0.4	2.4	3.3	17.8	13.4
b17	18.2	24.2	13.3	1.7	1.3	0.1	0.0	0.4	2.2	4.8	14.2	17.4
c17	16.6	26.2	13.9	1.4	1.3	0.1	0.0	0.4	2.6	7.1	19.2	17.7
d17	23.3	43.6	32.1	1.1	1.0	0.1	0.0	0.4	2.9	7.6	34.5	25.2
e17	27.4	164.3	241.3	1.1	1.3	0.2	0.0	0.4	3.3	7.9	37.7	23.0
f17	19.0	134.1	206.4	1.9	1.8	0.5	0.1	0.5	4.1	10.5	27.6	39.8
g17	21.3	22.7	22.6	2.1	1.5	0.5	0.2	0.6	3.0	13.0	32.9	41.1
h17	28.8	34.9	40.9	1.6	1.2	0.5	0.3	0.8	1.9	9.2	37.8	28.5
i17	19.0	73.3	109.8	1.7	1.0	0.4	0.3	0.9	1.6	5.4	36.0	25.0
j17	16.4	17.9	12.2	1.9	0.8	0.2	0.2	0.7	1.1	3.1	26.5	25.0
a18	18.2	30.2	35.0	1.5	0.6	0.0	0.0	0.3	2.2	3.0	12.9	19.9
b18	20.6	37.9	14.6	2.2	1.0	0.0	0.0	0.4	2.4	3.4	15.7	34.1
c18	19.6	43.0	19.9	1.6	1.1	0.1	0.0	0.4	2.5	4.1	25.0	41.8
d18	45.2	135.4	129.0	1.0	0.8	0.1	0.0	0.4	2.6	4.5	77.3	33.4
e18	36.6	514.4	798.9	1.6	0.8	0.1	0.0	0.4	2.6	6.5	83.8	27.6
f18	28.7	295.6	470.6	4.1	0.8	0.2	0.1	0.4	3.6	9.7	62.4	87.4
g18	43.8	36.8	44.2	2.9	0.6	0.2	0.2	0.5	4.4	10.6	58.7	77.9
h18	39.8	31.4	46.6	1.9	0.6	0.2	0.2	0.5	3.1	7.6	48.3	50.7
i18	25.2	29.6	28.6	2.8	0.6	0.2	0.2	0.7	1.7	5.1	52.6	33.9
j18	23.6	19.6	17.2	2.2	0.6	0.2	0.2	0.9	1.4	3.1	34.9	26.2
a19	31.2	25.7	22.7	1.7	0.4	0.0	0.0	0.2	2.1	2.7	17.5	28.4
b19	26.5	41.8	26.6	2.0	0.6	0.0	0.0	0.3	2.0	3.2	24.9	63.2
c19	23.4	63.6	40.2	1.6	0.6	0.0	0.0	0.2	1.8	2.8	36.6	98.9
d19	59.2	176.2	231.4	1.3	0.6	0.0	0.0	0.2	1.8	2.7	61.9	62.6
e19	55.6	308.3	438.7	3.2	0.6	0.1	0.0	0.2	1.5	3.0	126.9	54.8
f19	81.0	240.5	377.4	3.3	0.7	0.1	0.1	0.3	1.4	3.8	136.4	103.0
g19	73.1	68.1	89.2	2.7	0.6	0.2	0.2	0.4	1.5	4.2	112.6	111.6
h19	48.5	45.0	43.1	3.2	0.6	0.2	0.2	0.4	1.4	4.4	78.2	73.7
i19	39.8	29.5	29.4	4.2	0.5	0.1	0.2	0.5	1.3	4.0	54.8	42.4
j19	33.3	19.0	14.2	3.3	0.4	0.1	0.1	0.5	0.8	3.2	30.8	29.2
a20	39.0	26.1	25.9	1.3	0.3	0.0	0.0	0.1	1.6	2.3	23.0	29.4
b20	36.1	43.6	35.2	1.6	0.4	0.0	0.0	0.1	1.1	2.4	26.0	55.6
c20	24.8	47.6	37.8	1.4	0.5	0.0	0.0	0.1	1.3	2.1	36.5	74.3
d20	43.4	69.8	46.0	1.7	0.4	0.0	0.0	0.1	1.0	2.3	52.0	52.9
e20	73.0	64.9	51.8	2.0	0.3	0.0	0.0	0.1	0.7	2.8	97.9	62.4
f20	89.3	97.8	135.0	1.6	0.4	0.0	0.0	0.2	0.9	3.0	104.3	87.5
g20	64.5	85.3	109.0	1.7	0.4	0.1	0.1	0.3	1.1	3.0	91.9	88.2
h20	41.7	41.2	29.6	2.8	0.5	0.1	0.1	0.3	1.1	2.8	84.3	69.1
i20	43.5	30.5	19.8	3.4	0.5	0.1	0.1	0.3	0.7	2.6	54.8	44.8
j20	28.6	19.8	9.7	3.3	0.4	0.1	0.1	0.3	0.5	2.2	36.6	29.2

Table D-2: Monthly average PM_{10} concentration at different grids due to traffic and brick kiln pollution

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
a1	0.3	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
b1	0.3	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6
c1	0.4	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6
d1	0.4	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6
e1	0.4	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6
f1	0.3	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6
g1	0.3	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6
h1	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6
i1	0.3	0.3	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
j1	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
a2	13.4	42.3	5.0	0.0	0.0	0.2	0.0	0.0	0.1	0.1	22.0	0.7
b2	0.6	302.0	240.2	0.1	0.0	0.2	0.0	0.0	0.3	0.2	9.5	1.5
c2	0.8	2.2	1.9	1.9	0.0	0.1	0.0	0.0	0.4	0.3	0.6	38.1
d2	8.5	4.1	8.6	0.2	0.0	0.0	0.0	0.0	0.6	0.4	8.8	1.3
e2	5.1	3.4	14.4	0.2	0.1	0.0	0.0	0.0	0.4	0.4	5.7	12.8
f2	0.7	5.7	2.8	0.5	0.1	0.1	0.0	0.0	0.3	0.2	6.7	1.1
g2	0.6	1.5	1.5	0.3	0.0	0.1	0.0	0.0	0.3	0.2	2.9	4.4
h2	0.5	2.0	2.3	0.3	0.0	0.1	0.0	0.0	0.4	0.3	0.7	1.0
i2	0.5	1.3	1.3	0.4	0.0	0.1	0.0	0.0	0.2	0.3	0.6	0.9
j2	0.4	0.4	0.4	0.2	0.0	0.1	0.0	0.0	0.0	0.1	0.4	0.8
a3	44.1	66.0	17.4	0.1	0.1	0.3	0.0	0.0	0.2	0.2	34.9	10.7
b3	3.9	484.3	376.8	1.1	0.1	0.3	0.0	0.1	0.7	0.5	50.5	8.6
c3	34.0	72.9	78.6	3.1	0.1	0.2	0.0	0.1	0.8	0.8	26.3	86.0
d3	23.4	17.8	22.8	0.9	0.1	0.2	0.0	0.1	0.9	1.1	40.7	33.5
e3	20.7	10.8	29.3	1.1	0.1	0.1	0.0	0.0	0.5	0.8	17.1	34.6
f3	7.2	12.3	10.7	1.7	0.2	0.2	0.0	0.0	0.3	0.5	18.1	4.4
g3	10.5	3.4	2.4	1.1	0.1	0.2	0.0	0.0	0.4	0.5	6.7	12.9
h3	8.2	3.2	3.4	0.8	0.1	0.2	0.0	0.1	0.6	0.7	7.5	4.6
i3	3.1	2.2	2.3	0.7	0.1	0.2	0.0	0.0	0.3	0.6	1.7	2.0
j3	0.8	0.7	0.8	0.3	0.1	0.2	0.0	0.0	0.1	0.2	1.0	1.3
a4	46.1	46.1	29.9	0.1	0.1	0.3	0.0	0.0	0.2	0.3	17.1	23.7
b4	23.9	133.9	100.1	1.7	0.2	0.4	0.0	0.1	0.4	0.7	63.4	26.4
c4	75.8	63.7	95.3	1.1	0.2	0.2	0.0	0.1	0.9	1.3	45.4	67.4
d4	26.9	31.5	31.4	0.9	0.1	0.2	0.0	0.1	0.6	1.5	62.5	67.3
e4	29.0	18.8	21.0	1.6	0.1	0.2	0.0	0.0	0.3	0.9	33.8	45.3
f4	21.8	15.3	12.1	2.4	0.1	0.2	0.0	0.0	0.3	0.6	20.4	13.8
g4	17.1	4.8	3.2	2.1	0.1	0.3	0.0	0.1	0.3	0.6	11.8	18.0
h4	16.6	3.5	3.3	1.5	0.1	0.3	0.0	0.1	0.6	0.9	14.6	7.0
i4	8.1	2.5	4.1	1.0	0.1	0.3	0.0	0.1	0.3	0.7	7.3	3.2
j4	1.2	1.0	1.1	0.4	0.1	0.4	0.0	0.0	0.1	0.2	3.5	1.9
a5	73.4	613.4	373.0	0.3	0.1	0.3	0.0	0.1	0.8	0.7	106.0	12.1
b5	31.1	1124.0	889.8	3.3	0.1	0.4	0.0	0.1	0.5	1.0	66.6	85.0
c5	69.6	38.7	59.9	7.1	0.2	0.3	0.0	0.1	1.1	1.5	28.7	170.1
d5	54.2	32.2	63.8	0.6	0.2	0.2	0.0	0.1	0.6	1.5	71.1	63.0
e5	37.2	28.4	59.7	1.6	0.1	0.2	0.0	0.0	0.4	0.8	65.0	78.9
f5	21.7	30.0	12.4	3.0	0.1	0.3	0.0	0.1	0.6	0.7	45.1	22.9

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
g5	10.8	12.0	4.8	2.7	0.1	0.3	0.0	0.1	0.6	0.9	19.2	29.6
h5	9.5	5.3	5.8	2.3	0.2	0.3	0.0	0.2	1.0	1.2	15.7	10.0
i5	8.8	5.2	6.7	1.6	0.1	0.3	0.0	0.1	0.6	1.0	10.3	3.0
j5	1.4	1.8	2.0	0.6	0.1	0.4	0.0	0.0	0.2	0.4	6.2	2.3
a6	157.2	642.6	433.9	1.9	0.2	0.6	0.0	0.0	0.5	0.9	152.3	50.5
b6	75.8	1304.0	1037.2	6.9	0.2	0.5	0.0	0.1	1.1	1.1	222.6	134.5
c6	169.0	297.1	313.8	8.3	0.2	0.4	0.0	0.2	2.1	2.1	149.1	296.9
d6	103.6	75.2	97.7	3.8	0.2	0.2	0.0	0.1	1.5	2.2	157.9	167.6
e6	83.2	49.8	92.4	5.2	0.3	0.2	0.0	0.1	0.9	1.2	84.7	123.1
f6	49.1	40.6	35.2	6.6	0.3	0.3	0.0	0.1	0.5	1.0	73.4	30.6
g6	52.2	18.8	5.7	4.7	0.3	0.4	0.0	0.1	0.3	1.1	31.5	49.3
h6	37.7	6.4	5.0	3.2	0.2	0.4	0.0	0.1	0.4	1.2	33.3	28.3
i6	14.5	6.1	6.1	2.0	0.1	0.3	0.0	0.1	0.6	1.1	8.5	8.1
j6	1.8	3.0	3.0	0.8	0.1	0.2	0.0	0.1	0.3	0.7	5.5	3.0
a7	142.1	220.3	165.2	2.1	0.2	0.4	0.0	0.1	1.0	1.1	98.6	98.1
b7	175.5	190.7	191.5	4.9	0.3	0.5	0.0	0.1	0.8	1.4	213.9	147.0
c7	247.2	152.0	246.9	2.2	0.4	0.6	0.0	0.2	2.0	2.4	187.0	224.4
d7	98.6	111.9	106.0	3.1	0.3	0.5	0.0	0.2	1.4	2.7	209.9	231.1
e7	103.3	69.5	60.7	6.2	0.3	0.4	0.0	0.1	0.7	1.5	123.7	145.8
f7	92.0	45.9	29.8	8.1	0.3	0.5	0.0	0.1	0.5	1.3	69.6	60.8
g7	61.3	16.1	7.9	7.0	0.3	0.4	0.0	0.1	0.4	1.2	55.4	54.6
h7	58.5	9.0	6.5	4.5	0.3	0.4	0.0	0.1	0.5	1.2	49.9	29.8
i7	26.0	8.6	11.2	2.0	0.2	0.4	0.0	0.2	0.7	1.1	28.2	12.7
j7	2.3	20.8	16.6	0.8	0.1	0.2	0.0	0.1	0.4	0.8	11.9	4.1
a8	89.7	323.4	226.6	1.4	0.2	0.2	0.0	0.1	1.5	1.8	71.9	50.1
b8	131.5	103.7	91.3	2.1	0.3	0.3	0.0	0.1	0.9	2.1	86.4	129.0
c8	152.6	132.7	142.1	0.9	0.4	0.6	0.0	0.1	1.9	2.9	58.9	110.9
d8	66.8	75.7	67.2	1.6	0.3	1.0	0.0	0.2	1.8	3.0	102.0	134.5
e8	69.9	56.9	35.4	3.0	0.3	0.7	0.0	0.1	1.3	2.0	107.1	99.6
f8	60.6	43.7	14.9	4.5	0.3	0.6	0.0	0.2	1.1	1.6	55.6	61.6
g8	32.5	38.3	6.7	5.2	0.3	0.4	0.0	0.2	0.7	1.2	60.4	49.8
h8	29.7	14.2	8.6	3.7	0.4	0.4	0.1	0.2	0.8	1.1	48.7	27.0
i8	27.4	40.9	26.5	1.6	0.3	0.4	0.1	0.2	1.1	1.4	37.9	7.5
j8	2.8	106.6	85.5	0.9	0.2	0.2	0.0	0.1	0.8	1.2	21.2	6.4
a9	75.6	289.5	244.4	1.9	0.3	0.3	0.0	0.2	2.1	2.6	72.6	44.6
b9	93.9	242.6	206.4	2.3	0.3	0.3	0.0	0.1	1.6	2.5	92.7	93.6
c9	65.2	95.0	55.0	2.5	0.4	0.5	0.0	0.2	1.9	2.7	61.1	77.8
d9	57.4	54.9	45.3	1.8	0.4	0.5	0.0	0.3	4.3	4.2	50.0	68.7
e9	52.9	35.6	31.6	2.8	0.4	0.5	0.0	0.2	1.7	3.4	55.3	67.5
f9	53.6	30.3	11.1	2.6	0.6	0.5	0.0	0.2	1.2	2.0	51.7	34.4
g9	32.1	43.1	11.1	2.6	0.5	0.5	0.1	0.2	0.9	1.7	45.4	48.5
h9	35.3	33.0	13.9	1.9	0.4	0.5	0.1	0.2	0.5	1.5	32.7	56.9
i9	32.4	119.1	72.3	1.3	0.4	0.4	0.1	0.2	0.4	1.4	36.4	21.0
j9	6.2	235.7	185.4	1.6	0.2	0.3	0.0	0.1	0.2	1.0	29.7	18.4
a10	63.0	101.7	59.4	2.1	0.4	0.4	0.0	0.1	2.0	2.9	73.1	40.9
b10	89.9	341.0	286.4	1.6	0.4	0.3	0.0	0.2	2.0	3.0	94.6	50.0
c10	62.3	71.0	55.1	3.4	0.6	0.5	0.0	0.2	3.1	3.3	74.9	96.8
d10	52.9	56.9	50.6	2.4	0.5	0.6	0.0	0.4	4.3	5.9	71.7	68.9
e10	55.6	32.7	51.2	3.1	0.6	0.5	0.0	0.3	2.0	4.4	54.3	71.6

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
f10	57.8	25.4	14.7	3.0	0.7	0.4	0.1	0.2	1.0	2.2	52.6	38.2
g10	33.7	24.2	15.9	2.2	0.5	0.4	0.1	0.2	0.7	2.0	38.1	60.8
h10	36.3	37.5	24.5	1.5	0.4	0.5	0.1	0.3	0.6	1.9	30.4	74.1
i10	34.4	93.4	68.8	1.5	0.4	0.6	0.1	0.3	0.5	1.4	28.4	32.3
j10	19.8	77.0	60.9	2.0	0.2	0.3	0.0	0.1	0.3	0.7	41.5	31.2
a11	53.3	60.7	40.0	1.3	0.5	0.3	0.0	0.2	1.8	3.2	27.6	39.5
b11	50.4	65.9	55.1	2.1	0.5	0.3	0.0	0.2	2.7	3.5	53.3	37.5
c11	63.4	65.3	67.4	2.1	0.6	0.3	0.0	0.2	2.8	4.7	57.8	63.6
d11	41.8	65.9	54.0	2.4	0.6	0.4	0.0	0.5	6.4	7.5	71.0	69.1
e11	50.0	37.8	46.2	3.3	0.5	0.3	0.0	0.4	3.6	5.8	48.2	48.3
f11	38.9	29.4	21.5	3.3	0.8	0.4	0.1	0.2	1.5	2.7	33.0	35.7
g11	29.7	25.9	19.0	2.3	0.7	0.3	0.1	0.3	1.2	2.1	29.7	46.1
h11	38.1	30.2	20.5	1.7	0.6	0.4	0.1	0.4	1.0	2.0	35.8	40.1
i11	27.5	44.2	28.6	1.4	0.5	0.3	0.1	0.4	0.9	1.5	31.7	19.2
j11	31.1	18.2	19.1	1.0	0.3	0.2	0.1	0.2	0.4	0.8	26.9	29.1
a12	32.3	570.7	432.4	1.2	0.6	0.2	0.0	0.2	1.7	3.0	45.1	26.1
b12	40.5	51.2	45.1	4.3	0.5	0.2	0.0	0.3	3.3	4.2	31.3	99.6
c12	57.0	58.4	72.0	2.2	0.8	0.2	0.0	0.3	4.5	5.9	43.8	34.0
d12	32.7	45.3	62.9	2.6	0.7	0.4	0.0	0.4	5.9	8.6	46.7	71.7
e12	32.1	40.7	41.2	3.2	0.7	0.3	0.0	0.4	4.8	7.2	51.7	33.6
f12	32.0	23.8	20.2	3.3	0.8	0.3	0.1	0.2	1.5	3.3	24.4	36.4
g12	23.1	22.1	26.4	2.9	0.9	0.3	0.1	0.4	1.3	2.6	27.4	35.0
h12	30.6	23.1	18.9	2.2	0.7	0.3	0.1	0.5	0.9	2.4	25.6	26.2
i12	27.4	34.2	25.6	1.3	0.7	0.4	0.1	0.5	1.0	2.0	25.4	15.4
j12	18.7	68.7	56.4	0.8	0.4	0.2	0.1	0.2	0.7	1.2	20.5	19.5
a13	36.9	807.8	611.0	2.8	0.8	0.1	0.0	0.2	2.6	3.3	103.0	25.1
b13	78.3	229.9	214.6	5.7	0.7	0.2	0.0	0.3	4.3	5.0	70.8	155.8
c13	62.8	84.2	82.7	3.2	0.8	0.2	0.0	0.6	7.8	9.0	85.4	86.4
d13	66.4	52.8	85.1	4.1	1.0	0.4	0.0	0.5	7.5	10.6	50.2	87.7
e13	40.7	48.4	50.9	5.2	0.9	0.3	0.1	0.4	4.9	8.4	58.4	37.9
f13	38.5	25.8	19.5	4.4	1.1	0.3	0.1	0.2	1.5	4.1	27.8	43.7
g13	32.0	30.2	20.8	3.5	0.9	0.3	0.1	0.4	1.2	3.1	31.3	35.9
h13	27.4	60.9	34.0	2.7	0.8	0.3	0.2	0.6	0.9	2.9	30.4	33.6
i13	24.0	190.0	142.5	1.6	0.8	0.3	0.2	0.6	1.2	2.3	28.5	20.0
j13	15.9	147.3	115.7	2.0	0.5	0.2	0.1	0.3	1.0	1.6	26.7	32.3
a14	57.4	372.6	281.1	3.5	1.0	0.1	0.0	0.3	3.1	4.4	114.5	54.9
b14	141.0	197.5	223.0	3.9	1.2	0.2	0.0	0.3	3.8	5.9	99.4	135.8
c14	77.4	100.1	100.8	3.1	1.1	0.4	0.0	0.7	10.4	11.9	126.1	139.4
d14	84.4	82.1	94.3	5.4	0.9	0.4	0.0	0.8	11.4	13.8	90.4	107.0
e14	64.1	66.8	65.4	7.3	1.1	0.3	0.1	0.7	8.6	11.2	61.6	62.0
f14	55.8	42.2	27.0	6.7	1.4	0.2	0.1	0.4	3.0	6.1	43.3	69.3
g14	45.8	33.5	20.3	4.4	1.4	0.3	0.1	0.5	1.8	4.0	42.9	61.2
h14	50.6	94.7	56.3	2.7	1.2	0.3	0.2	0.7	1.2	3.2	46.5	48.0
i14	28.5	275.9	215.0	2.3	1.0	0.4	0.2	0.8	1.5	3.0	46.2	29.1
j14	31.2	77.6	70.8	3.0	0.5	0.2	0.1	0.4	1.2	2.1	42.0	59.4
a15	64.2	86.9	61.4	2.3	0.9	0.1	0.0	0.3	2.5	5.4	74.8	65.3
b15	122.0	92.1	114.7	2.2	1.4	0.1	0.0	0.3	3.0	6.5	55.8	86.5
c15	64.6	73.1	74.0	2.3	1.5	0.4	0.0	0.4	5.5	12.0	86.7	113.2
d15	63.9	72.9	66.3	3.5	1.4	0.5	0.0	0.6	8.6	14.2	95.2	94.4

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
e15	71.2	61.9	53.2	5.3	1.2	0.4	0.1	0.6	7.9	12.3	62.6	62.1
f15	50.1	61.0	44.3	5.9	1.2	0.2	0.2	0.8	6.5	8.6	54.1	77.2
g15	41.4	48.8	39.7	4.9	1.5	0.2	0.2	1.0	5.3	6.8	49.1	73.4
h15	56.1	65.3	50.7	3.8	1.7	0.3	0.3	1.1	4.7	6.2	46.4	39.4
i15	36.7	81.7	61.6	3.4	1.6	0.5	0.3	0.9	2.3	4.9	58.3	32.7
j15	56.2	34.3	50.2	1.9	1.0	0.3	0.1	0.4	1.0	2.5	45.1	53.4
a16	52.2	49.6	38.8	1.6	0.9	0.1	0.0	0.4	2.8	5.0	52.3	44.1
b16	66.7	59.6	49.4	1.9	1.2	0.1	0.0	0.4	2.6	7.2	28.4	49.1
c16	41.4	45.8	35.8	2.1	1.5	0.2	0.0	0.3	3.5	11.3	38.8	55.0
d16	45.4	44.0	31.2	2.2	1.6	0.3	0.0	0.3	4.8	13.2	55.1	66.2
e16	63.1	62.2	48.1	2.5	1.5	0.4	0.1	0.5	6.6	11.2	49.2	43.9
f16	44.1	76.7	60.4	3.3	1.3	0.4	0.1	1.1	11.7	11.8	50.6	52.5
g16	35.0	79.7	67.0	4.5	1.4	0.4	0.2	1.6	11.3	14.1	52.3	53.4
h16	49.6	97.6	65.3	5.3	1.9	0.5	0.3	1.5	7.0	11.2	50.2	34.8
i16	42.2	138.6	106.2	3.8	2.2	0.4	0.3	1.1	3.9	7.0	47.6	36.3
j16	42.1	83.9	77.1	2.5	1.6	0.2	0.2	0.6	1.8	3.6	29.1	46.3
a17	43.0	44.8	38.1	2.0	1.1	0.1	0.0	0.4	2.6	3.6	38.4	29.5
b17	42.4	52.2	24.6	2.6	1.5	0.1	0.0	0.4	2.4	5.3	27.0	39.0
c17	35.6	52.6	25.1	2.3	1.4	0.1	0.0	0.4	2.8	7.7	27.8	36.2
d17	54.0	107.6	52.4	1.7	1.1	0.1	0.0	0.4	3.2	8.3	60.2	50.5
e17	63.8	476.1	349.6	1.7	1.6	0.2	0.0	0.4	3.7	8.9	71.1	41.9
f17	37.4	378.0	303.6	4.2	2.0	0.6	0.1	0.5	4.5	12.3	48.7	96.6
g17	43.7	42.1	43.7	4.3	1.6	0.7	0.2	0.6	3.2	14.3	56.2	102.2
h17	64.0	84.5	78.1	2.2	1.3	0.5	0.3	0.9	2.1	9.9	63.8	60.5
i17	37.9	203.2	173.5	2.8	1.1	0.4	0.3	1.0	1.7	5.8	66.0	50.9
j17	36.6	39.8	28.2	3.3	1.0	0.3	0.2	0.8	1.2	3.4	46.6	58.0
a18	48.3	71.5	61.4	2.6	0.7	0.1	0.0	0.3	2.3	3.2	27.6	51.4
b18	53.3	81.0	29.8	4.0	1.1	0.1	0.0	0.4	2.6	3.7	28.9	94.6
c18	46.1	101.3	42.4	2.9	1.2	0.1	0.0	0.4	2.8	4.4	39.7	117.2
d18	122.7	396.9	206.6	1.6	0.9	0.1	0.0	0.4	2.8	4.9	137.5	88.2
e18	97.7	1537.2	1159.2	3.7	0.9	0.1	0.0	0.4	2.8	7.5	168.5	69.9
f18	73.9	859.6	706.9	11.1	0.8	0.2	0.1	0.4	4.0	11.1	122.7	256.4
g18	117.9	81.0	105.6	7.0	0.7	0.2	0.2	0.5	4.7	11.6	129.9	224.1
h18	103.3	69.8	118.7	3.3	0.7	0.3	0.2	0.6	3.3	8.3	115.5	135.3
i18	62.9	69.0	75.8	5.7	0.7	0.3	0.2	0.8	1.9	5.5	112.0	81.3
j18	62.5	47.1	43.9	4.4	0.7	0.2	0.2	1.0	1.4	3.4	65.5	63.3
a19	88.6	50.2	51.1	3.1	0.5	0.0	0.0	0.2	2.2	2.9	38.9	78.1
b19	73.4	87.5	66.9	3.4	0.6	0.0	0.0	0.3	2.1	3.4	47.5	185.4
c19	61.9	163.9	95.2	2.7	0.7	0.0	0.0	0.2	2.0	3.1	66.6	295.9
d19	171.9	520.1	382.7	2.3	0.6	0.0	0.0	0.2	2.0	2.9	120.1	181.7
e19	160.6	891.2	672.2	8.2	0.6	0.1	0.0	0.2	1.6	3.3	257.1	149.0
f19	239.6	693.0	654.0	8.6	0.7	0.1	0.1	0.3	1.5	4.2	263.1	298.5
g19	212.8	189.7	218.5	6.3	0.7	0.2	0.2	0.4	1.6	4.7	253.6	331.7
h19	136.4	119.7	115.5	6.2	0.6	0.2	0.2	0.5	1.5	4.9	192.3	213.7
i19	112.0	76.6	82.5	9.0	0.6	0.1	0.2	0.5	1.3	4.4	117.1	114.1
j19	95.1	49.0	38.4	7.8	0.5	0.2	0.1	0.5	0.9	3.5	65.1	75.5
a20	111.7	53.7	60.4	2.8	0.3	0.1	0.0	0.1	1.7	2.6	49.9	81.8
b20	101.9	103.5	93.5	2.7	0.5	0.0	0.0	0.1	1.2	2.6	58.0	157.8
c20	68.2	122.0	103.5	2.0	0.6	0.0	0.0	0.1	1.4	2.2	77.5	215.7

Grid Id	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
d20	125.1	191.7	128.4	2.9	0.4	0.0	0.0	0.1	1.1	2.5	114.0	151.2
e20	218.6	166.7	140.1	3.9	0.4	0.0	0.0	0.1	0.8	3.0	186.1	161.0
f20	270.6	270.0	308.0	3.3	0.4	0.1	0.0	0.2	1.0	3.3	202.7	242.9
g20	190.6	241.2	246.6	3.5	0.4	0.1	0.1	0.3	1.2	3.3	202.9	260.9
h20	119.6	107.5	77.7	5.6	0.5	0.1	0.1	0.3	1.2	3.1	195.8	203.9
i20	126.8	79.5	52.7	7.6	0.5	0.2	0.1	0.4	0.8	2.8	118.6	126.9
j20	82.0	51.7	24.7	7.8	0.4	0.1	0.1	0.4	0.5	2.4	83.1	79.0

Appendix E

Yearly Average $PM_{2.5}$ Concentration

Table E-1: Yearly average $PM_{2.5}$ concentration ($\mu g/m^3$) for different policy options

Grid Id	Brick and Traffic Emission	Only Traffic Emission	Only Brick Emission	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
a1	0.33	0.11	0.21	0.31	0.28	0.32	0.31	0.3
b1	0.35	0.12	0.23	0.33	0.3	0.34	0.33	0.32
c1	0.36	0.12	0.23	0.34	0.31	0.35	0.34	0.33
d1	0.36	0.12	0.24	0.34	0.31	0.36	0.35	0.33
e1	0.37	0.13	0.24	0.35	0.32	0.36	0.35	0.34
f1	0.37	0.13	0.24	0.35	0.32	0.36	0.35	0.34
g1	0.37	0.13	0.25	0.35	0.32	0.37	0.36	0.34
h1	0.35	0.12	0.23	0.34	0.31	0.35	0.34	0.33
i1	0.33	0.11	0.22	0.32	0.29	0.33	0.32	0.31
j1	0.3	0.11	0.2	0.29	0.26	0.3	0.29	0.28
a2	8.51	0.69	7.83	8.43	6.95	8.47	8.41	8.33
b2	78.31	2.31	76	78.04	63.11	78.16	77.92	77.62
c2	9.22	4	5.22	8.65	8.18	9.04	8.74	8.37
d2	7.33	5.18	2.15	6.68	6.9	7	6.48	5.81
e2	7.35	4.14	3.21	6.75	6.71	7.16	6.85	6.47
f2	4.36	3.05	1.31	3.95	4.1	4.19	3.92	3.57
g2	4.24	3.09	1.15	3.84	4.01	4.05	3.75	3.37
h2	4.49	4.02	0.47	3.97	4.4	4.25	3.88	3.41
i2	3.26	2.74	0.52	2.78	3.15	3.2	3.12	3.02
j2	1.17	0.79	0.38	1.05	1.09	1.14	1.1	1.04
a3	18.03	1.9	16.13	17.79	14.81	17.92	17.75	17.53
b3	134.15	5.3	128.85	133.51	108.38	133.81	133.27	132.6
c3	40.91	8.84	32.07	39.65	34.49	40.49	39.84	39.01
d3	21.39	10.83	10.56	19.99	19.28	20.75	19.73	18.43
e3	17.31	7.94	9.37	16.11	15.44	16.99	16.49	15.85
f3	10	5.24	4.75	9.27	9.04	9.73	9.32	8.79
g3	8.6	5.01	3.6	7.94	7.88	8.32	7.88	7.31
h3	9	6.87	2.13	8.11	8.58	8.61	8	7.22
i3	6.64	5.48	1.15	5.72	6.41	6.5	6.28	6
j3	2.79	2.16	0.63	2.46	2.67	2.72	2.6	2.45
a4	18.54	2.75	15.79	18.18	15.38	18.39	18.16	17.87
b4	57.42	4.86	52.56	56.82	46.91	57.13	56.66	56.06
c4	41.44	10.11	31.33	40.25	35.18	40.75	39.66	38.27
d4	28.41	10.52	17.89	26.87	24.84	27.95	27.21	26.28
e4	20.27	7.29	12.99	19.21	17.67	19.95	19.45	18.81
f4	13.65	5.7	7.96	12.85	12.06	13.39	12.96	12.43
g4	10.77	5.31	5.46	10.05	9.68	10.5	10.08	9.54
h4	11.15	7.26	3.89	10.19	10.37	10.76	10.14	9.36
i4	8.7	6.42	2.28	7.67	8.24	8.51	8.2	7.82
j4	4.02	3.16	0.86	3.53	3.85	3.91	3.74	3.52
a5	152.35	8.03	144.32	151.14	123.48	152.03	151.53	150.89
b5	310.25	7.12	303.13	309.2	249.63	309.96	309.5	308.92
c5	47.34	10.93	36.41	46.13	40.06	46.51	45.22	43.57
d5	34.88	10.54	24.34	33.28	30.01	34.47	33.83	33.01
e5	30.37	7.27	23.1	29.35	25.75	30.02	29.47	28.77
f5	19.83	7.7	12.13	18.84	17.4	19.37	18.66	17.75
g5	16.8	8.52	8.28	15.68	15.14	16.33	15.58	14.63

Grid Id	Brick and Traffic Emission	Only Traffic Emission	Only Brick Emission	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
h5	15.44	10.75	4.7	14.03	14.51	14.84	13.89	12.68
i5	13.36	9.64	3.73	11.89	12.62	12.99	12.4	11.64
j5	6.49	4.91	1.58	5.71	6.17	6.34	6.1	5.79
a6	183.85	6.03	177.82	182.88	148.29	183.59	183.17	182.63
b6	386.78	10.95	375.83	385.17	311.61	386.18	385.24	384.04
c6	146.33	20.48	125.85	142.28	121.16	145.4	143.95	142.1
d6	73.39	21.56	51.83	68.22	63.02	72.74	71.73	70.45
e6	52.28	13.02	39.26	50.05	44.43	51.74	50.89	49.82
f6	32.25	9.14	23.1	30.77	27.63	31.86	31.26	30.49
g6	24.33	7.77	16.56	23.11	21.02	23.97	23.4	22.67
h6	18.93	8.01	10.92	17.79	16.75	18.53	17.89	17.08
i6	14.39	9.26	5.13	13.1	13.37	13.93	13.21	12.29
j6	9.11	6.97	2.14	7.97	8.68	8.9	8.58	8.17
a7	97.92	9.65	88.27	96.43	80.27	97.45	96.71	95.78
b7	133.12	11.6	121.52	131.17	108.81	132.65	131.91	130.98
c7	108.99	20.14	88.86	106.22	91.22	107.7	105.64	103.04
d7	88.76	22.6	66.16	84.72	75.53	87.99	86.78	85.25
e7	61.39	15.29	46.1	58.51	52.17	60.89	60.11	59.13
f7	40.7	10.65	30.05	38.85	34.69	40.26	39.57	38.69
g7	29.49	8.85	20.64	28.02	25.36	29.12	28.54	27.8
h7	23.47	8.41	15.06	22.18	20.46	23.08	22.46	21.67
i7	18.42	9.85	8.57	16.96	16.71	17.94	17.19	16.24
j7	14.67	7.83	6.84	13.39	13.3	14.42	14.04	13.55
a8	111.06	15.93	95.13	108.59	92.03	110.36	109.27	107.88
b8	78.53	14.65	63.88	76.12	65.75	78	77.15	76.08
c8	73.97	19.85	54.12	71.17	63.14	72.76	70.84	68.4
d8	68.81	23.97	44.84	65.04	59.84	67.73	66.02	63.86
e8	54.87	20.54	34.33	51.58	48	53.97	52.55	50.76
f8	39.84	16.74	23.1	37.22	35.22	39.1	37.93	36.44
g8	33.03	13.14	19.89	30.89	29.05	32.5	31.68	30.63
h8	25.29	11.75	13.54	23.56	22.58	24.69	23.76	22.57
i8	27.9	13.33	14.57	25.99	24.99	27.24	26.2	24.89
j8	40.59	11.59	29	38.77	34.79	40.15	39.47	38.61
a9	108.74	20.2	88.54	106.23	91.04	107.33	105.1	102.26
b9	102.7	22.22	80.48	99.19	86.61	101.85	100.5	98.79
c9	60.84	24.51	36.33	57.8	53.57	59.14	56.47	53.09
d9	76.03	44.45	31.58	71.54	69.72	72.09	65.9	58.02
e9	54.83	30.34	24.49	50.19	49.93	53.54	51.51	48.93
f9	40.7	19.97	20.73	37.88	36.55	39.65	38	35.9
g9	37.21	17.64	19.57	34.73	33.3	36.28	34.8	32.93
h9	30.73	13.22	17.51	28.72	27.23	30.16	29.28	28.15
i9	43.29	9.85	33.44	41.79	36.6	42.84	42.14	41.24
j9	72.93	7.52	65.41	71.83	59.85	72.59	72.06	71.39
a10	58.44	20.66	37.78	56.03	50.88	56.89	54.46	51.37
b10	129.52	27.09	102.43	125.9	109.04	127.95	125.48	122.33
c10	70.4	35.89	34.51	66.4	63.5	67.6	63.2	57.61
d10	80.61	51.3	29.31	75.57	74.75	75.96	68.64	59.34
e10	64.92	40.23	24.69	58.87	59.98	63.16	60.39	56.87
f10	43.03	21.84	21.2	40.04	38.79	41.82	39.91	37.48
g10	35.19	17.15	18.04	32.86	31.58	34.2	32.66	30.69
h10	34.9	14.97	19.93	32.78	30.92	34.09	32.8	31.17
i10	43.52	11.64	31.88	41.83	37.15	42.96	42.07	40.93
j10	38.75	7.31	31.44	37.65	32.46	38.43	37.92	37.28

Grid Id	Brick and Traffic Emission	Only Traffic Emission	Only Brick Emission	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
a11	44.14	21.05	23.09	41.88	39.52	42.46	39.81	36.45
b11	59.9	29.99	29.91	56.45	53.92	57.71	54.27	49.9
c11	67.2	39.41	27.79	63.18	61.64	63.98	58.92	52.48
d11	94.01	68.94	25.07	89.66	88.99	86.4	74.43	59.2
e11	75.03	55.42	19.61	70.22	71.11	69.85	61.69	51.32
f11	45.19	29.35	15.84	41.68	42.02	43.19	40.03	36.02
g11	37.29	22.65	14.64	34.53	34.36	35.77	33.38	30.34
h11	36	19.89	16.11	33.59	32.78	34.68	32.61	29.97
i11	34.18	16.14	18.04	32.05	30.58	33.26	31.81	29.97
j11	24.05	9.75	14.3	22.58	21.19	23.64	23.01	22.2
a12	164.47	20.78	143.68	162.52	135.73	162.67	159.85	156.26
b12	67.41	37.72	29.69	64.46	61.47	63.7	57.86	50.44
c12	75.74	53.91	21.84	71.91	71.38	70.31	61.77	50.9
d12	93.14	71.51	21.63	88.86	88.81	85.63	73.82	58.8
e12	85.71	69.85	15.86	80.85	82.53	78.27	66.58	51.7
f12	49.4	36.13	13.27	46.03	46.75	46.26	41.3	35
g12	39.56	26.72	12.84	36.85	36.99	37.41	34.05	29.76
h12	34.08	21.69	12.39	31.69	31.6	32.48	29.96	26.76
i12	32.68	18.75	13.93	30.55	29.89	31.33	29.21	26.51
j12	34.95	13.85	21.1	33.11	30.73	34.2	33.03	31.53
a13	241.33	26.64	214.68	239.33	198.39	238.73	234.64	229.45
b13	130.06	48.53	81.53	126.92	113.75	124.96	116.94	106.74
c13	116.67	86.22	30.44	112.58	110.58	107.29	92.55	73.79
d13	117.84	90.78	27.06	112.8	112.43	108.32	93.36	74.32
e13	94.7	75.68	19.02	89.73	90.89	86.52	73.68	57.34
f13	56.35	40.62	15.73	53.34	53.21	52.35	46.05	38.04
g13	44	29.65	14.34	41.61	41.13	41.22	36.85	31.29
h13	44.27	24.46	19.81	42.12	40.3	42.08	38.64	34.26
i13	72.51	21.61	50.9	70.46	62.33	70.69	67.83	64.18
j13	60.26	17.21	43.05	58.18	51.65	59.19	57.52	55.39
a14	157.71	33.38	124.33	155.36	132.84	154.52	149.51	143.14
b14	126.33	46.74	79.59	123.53	110.41	121.44	113.75	103.97
c14	148.85	108.28	40.57	144.46	140.74	136.82	117.9	93.82
d14	166.81	133.35	33.46	159.84	160.12	153.8	133.36	107.34
e14	137.11	113.12	23.99	129.28	132.31	125.41	107.01	83.59
f14	85.51	64.22	21.29	79.43	81.25	80.35	72.24	61.92
g14	56.3	38.71	17.59	53.3	52.79	52.73	47.12	39.98
h14	60.65	30.24	30.4	58.19	54.57	57.88	53.52	47.98
i14	105.14	27.65	77.49	102.69	89.64	102.73	98.94	94.12
j14	53.34	20.58	32.76	50.96	46.79	51.97	49.82	47.09
a15	84.09	36.92	47.17	81.45	74.65	80.6	75.11	68.13
b15	87.68	45.09	42.59	84.86	79.16	83.13	75.98	66.89
c15	108.26	74.87	33.38	104.61	101.58	99.96	86.94	70.35
d15	142.22	113.08	29.14	136.73	136.39	129.78	110.22	85.33
e15	137.03	114.17	22.86	129.25	132.46	125.49	107.34	84.24
f15	121.5	100.37	21.12	112.02	117.27	113.12	99.96	83.21
g15	99.83	81.8	18.03	91.28	96.22	93.63	83.9	71.51
h15	90.44	68.33	22.12	83.3	86.02	85.2	76.96	66.47
i15	77.6	45.18	32.42	72.28	71.12	74.74	70.26	64.54
j15	46	23.82	22.18	43.38	41.56	44.29	41.6	38.19
a16	60.73	36.61	24.13	57.66	55.91	57.47	52.33	45.8
b16	66.44	44.95	21.49	62.71	62.15	62.29	55.76	47.45
c16	78.64	57.32	21.31	73.9	74.37	73.29	64.9	54.22

Grid Id	Brick and Traffic Emission	Only Traffic Emission	Only Brick Emission	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
d16	93.53	73.15	20.37	87.24	89.45	86.7	75.97	62.31
e16	110.56	87.88	22.68	101.39	106.02	102.86	90.75	75.35
f16	148.01	129.77	18.24	125.71	144.36	139.39	125.83	108.58
g16	171.79	155.39	16.39	136.57	168.51	164.62	153.36	139.03
h16	139.22	116.54	22.68	116.15	134.69	133.12	123.53	111.32
i16	112.25	70.8	41.45	101.38	103.96	108.21	101.87	93.8
j16	68.71	41	27.72	62.03	63.17	66.6	63.28	59.06
a17	51.34	32.88	18.46	47.8	47.65	48.72	44.61	39.38
b17	58.41	41.26	17.15	53.55	54.98	55.07	49.83	43.15
c17	69.96	50.61	19.35	64.21	66.09	65.82	59.32	51.04
d17	89.93	58.76	31.17	82.99	83.69	85.26	77.92	68.59
e17	189.08	64.13	124.94	180.64	164.09	184.25	176.66	167.01
f17	183.17	76.22	106.95	172.19	161.78	177.73	169.17	158.29
g17	105.53	82.38	23.15	91.36	100.9	100.72	93.15	83.53
h17	104.82	74.9	29.91	90.95	98.83	100.67	94.15	85.86
i17	120.77	59.87	60.9	109.93	108.59	117.5	112.38	105.85
j17	60.07	41.86	18.22	52.52	56.43	57.92	54.53	50.21
a18	57.21	26.07	31.14	54.23	50.98	55.27	52.22	48.33
b18	64.72	32.94	31.77	60.81	58.36	62.04	57.82	52.47
c18	72.98	38.06	34.91	67.87	65.99	70.15	65.71	60.05
d18	143.45	42.23	101.22	137.73	123.21	140.4	135.59	129.48
e18	449.83	46.79	403.04	443.44	369.22	446.43	441.09	434.3
f18	319.01	59.03	259.98	309.91	267.01	315.07	308.87	300.98
g18	123.22	67.35	55.87	112.15	112.04	119.13	112.73	104.58
h18	104.07	59.31	44.77	93.7	95.12	100.93	96	89.72
i18	84.05	46	38.05	76.04	76.44	81.52	77.54	72.48
j18	60.63	35.37	25.26	54.26	55.58	58.8	55.92	52.26
a19	61.3	24.54	36.76	58.28	53.95	59.56	56.83	53.36
b19	74.51	27.89	46.62	70.94	65.19	72.52	69.37	65.38
c19	88.74	27.76	60.97	85.13	76.54	86.72	83.54	79.5
d19	187.99	31.13	156.86	183.61	156.62	185.82	182.4	178.06
e19	319.1	33.16	285.94	314.38	261.91	316.79	313.17	308.55
f19	290.39	36.65	253.74	285.13	239.65	287.9	283.98	278.99
g19	144.78	39.62	105.16	139.06	123.75	142.09	137.86	132.48
h19	105.06	37.27	67.8	99.37	91.5	102.78	99.18	94.61
i19	78.26	29.89	48.37	73.54	68.59	76.57	73.92	70.54
j19	53.96	23.01	30.95	50.2	47.77	52.67	50.65	48.09
a20	60.81	22.34	38.47	58.18	53.12	59.14	56.51	53.16
b20	71.05	22.75	48.3	67.77	61.39	69.68	67.53	64.79
c20	75.02	21.27	53.74	72.09	64.27	73.58	71.31	68.43
d20	98.81	21.97	76.84	95.8	83.44	97.33	95	92.05
e20	131.43	22.58	108.84	128.28	109.66	129.89	127.47	124.39
f20	161.12	24.65	136.47	157.56	133.82	159.47	156.88	153.59
g20	133.18	26.7	106.49	129.12	111.89	131.43	128.68	125.17
h20	89.53	25.26	64.27	85.54	76.67	87.99	85.58	82.51
i20	68.13	21.09	47.04	64.72	58.72	66.96	65.12	62.78
j20	48.99	17.69	31.3	46.01	42.73	48.02	46.5	44.56

Appendix F

Yearly Average PM_{10} Concentration

Table F-1: Yearly average PM_{10} concentration (μg/m^3) for different policy options

Grid Id	Brick and Traffic Emission	Only Traffic Emission	Only Brick Emission	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
a1	0.51	0.12	0.4	0.5	0.43	0.51	0.5	0.48
b1	0.54	0.12	0.42	0.53	0.46	0.54	0.53	0.52
c1	0.56	0.13	0.43	0.54	0.47	0.55	0.54	0.53
d1	0.57	0.13	0.44	0.55	0.48	0.56	0.55	0.54
e1	0.59	0.13	0.46	0.57	0.5	0.58	0.57	0.56
f1	0.58	0.13	0.45	0.56	0.49	0.57	0.56	0.55
g1	0.59	0.13	0.46	0.57	0.5	0.59	0.58	0.56
h1	0.57	0.13	0.45	0.55	0.48	0.57	0.56	0.54
i1	0.52	0.12	0.4	0.5	0.44	0.51	0.5	0.49
j1	0.46	0.11	0.35	0.44	0.39	0.45	0.45	0.44
a2	19.05	0.79	18.26	18.95	15.4	19.01	18.94	18.86
b2	147.64	2.75	144.89	147.3	118.66	147.48	147.23	146.91
c2	16.95	4.51	12.45	16.3	14.46	16.76	16.45	16.06
d2	11.72	5.74	5.98	10.98	10.52	11.37	10.83	10.13
e2	13.75	4.49	9.26	13.09	11.9	13.55	13.23	12.83
f2	6.7	3.36	3.34	6.24	6.03	6.52	6.23	5.87
g2	5.91	3.45	2.46	5.46	5.42	5.71	5.4	5.01
h2	5.52	4.55	0.97	4.92	5.33	5.28	4.89	4.4
i2	3.91	2.88	1.03	3.41	3.7	3.86	3.77	3.66
j2	1.56	0.86	0.7	1.43	1.42	1.54	1.49	1.43
a3	42.56	2.21	40.35	42.28	34.49	42.45	42.27	42.04
b3	257.86	6.31	251.55	257.07	207.55	257.5	256.94	256.24
c3	83.31	10.02	73.29	81.87	68.65	82.87	82.19	81.32
d3	41.23	12.06	29.17	39.63	35.39	40.55	39.49	38.13
e3	35.04	8.67	26.38	33.73	29.77	34.71	34.18	33.51
f3	18.19	5.84	12.35	17.37	15.72	17.91	17.48	16.92
g3	14.55	5.66	8.89	13.79	12.77	14.25	13.79	13.2
h3	13.46	7.88	5.58	12.41	12.34	13.05	12.41	11.59
i3	8.56	5.89	2.67	7.59	8.03	8.41	8.18	7.89
j3	3.56	2.38	1.18	3.2	3.33	3.49	3.37	3.21
a4	47.83	3.17	44.66	47.41	38.9	47.68	47.44	47.13
b4	119.4	5.71	113.69	118.68	96.66	119.09	118.6	117.98
c4	91.01	11.62	79.39	89.58	75.13	90.28	89.14	87.7
d4	59.54	11.63	47.9	57.83	49.95	59.05	58.28	57.3
e4	42.8	8.12	34.68	41.62	35.87	42.46	41.94	41.26
f4	26.73	6.39	20.34	25.83	22.66	26.45	26.01	25.44
g4	20.54	6.04	14.49	19.71	17.64	20.25	19.81	19.24
h4	18.72	8.39	10.33	17.59	16.65	18.31	17.67	16.85
i4	12.73	7	5.73	11.61	11.59	12.53	12.21	11.8
j4	5.28	3.48	1.8	4.75	4.92	5.17	4.99	4.76
a5	308.44	8.88	299.56	307.09	248.53	308.11	307.58	306.91
b5	601.09	7.9	593.18	599.91	482.45	600.78	600.3	599.68
c5	107.27	12.52	94.75	105.81	88.32	106.41	105.05	103.33
d5	78.13	11.55	66.58	76.37	64.81	77.7	77.02	76.16
e5	71.74	8.14	63.6	70.59	59.02	71.37	70.8	70.06
f5	39.1	8.67	30.43	37.97	33.01	38.62	37.87	36.92
g5	30.81	9.58	21.22	29.52	26.56	30.31	29.53	28.54

Grid Id	Brick and Traffic Emission	Only Traffic Emission	Only Brick Emission	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
h5	23.82	12.23	11.58	22.18	21.5	23.19	22.2	20.93
i5	19.19	10.52	8.67	17.59	17.46	18.8	18.18	17.39
j5	8.65	5.34	3.31	7.81	7.99	8.49	8.24	7.92
a6	386.95	6.77	380.18	385.86	310.91	386.67	386.23	385.67
b6	772.39	12.69	759.69	770.45	620.45	771.76	770.77	769.52
c6	319.83	23.63	296.21	314.96	260.59	318.87	317.35	315.41
d6	164.84	23.42	141.42	159.32	136.55	164.16	163.1	161.75
e6	121.57	14.31	107.27	119.13	100.12	121.01	120.12	119
f6	69.3	10.16	59.13	67.65	57.47	68.89	68.26	67.45
g6	51.76	8.71	43.05	50.4	43.15	51.38	50.79	50.03
h6	37.96	9.1	28.86	36.65	32.19	37.53	36.87	36.02
i6	22.89	10.51	12.38	21.4	20.42	22.41	21.65	20.69
j6	11.77	7.53	4.25	10.56	10.92	11.56	11.22	10.79
a7	236.91	11.08	225.83	235.16	191.74	236.42	235.65	234.67
b7	307.46	13	294.46	305.26	248.57	306.97	306.19	305.21
c7	262.49	23.35	239.13	259.13	214.66	261.13	258.99	256.27
d7	198.81	24.99	173.82	194.32	164.05	198.01	196.74	195.14
e7	137.77	16.78	120.98	134.61	113.57	137.25	136.43	135.39
f7	90.01	11.89	78.12	87.94	74.38	89.54	88.82	87.9
g7	64.49	9.89	54.61	62.86	53.57	64.11	63.5	62.73
h7	49.04	9.52	39.51	47.56	41.13	48.62	47.97	47.15
i7	32.51	11.22	21.29	30.83	28.25	32.01	31.22	30.23
j7	22.21	8.52	13.69	20.83	19.47	21.95	21.55	21.03
a8	238.99	17.79	221.2	236.22	194.75	238.26	237.12	235.67
b8	181.25	16.26	164.99	178.55	148.26	180.69	179.81	178.68
c8	166.07	22.83	143.24	162.75	137.42	164.8	162.8	160.25
d8	140.22	26.73	113.49	135.97	117.52	139.08	137.3	135.04
e8	108.93	22.72	86.21	105.28	91.69	107.99	106.51	104.64
f8	76.53	18.6	57.93	73.6	64.95	75.75	74.53	72.98
g8	65.59	14.5	51.09	63.23	55.37	65.04	64.18	63.08
h8	46.49	13.27	33.22	44.53	39.85	45.87	44.89	43.65
i8	47.76	15.1	32.66	45.57	41.23	47.07	45.99	44.62
j8	69.56	12.85	56.71	67.55	58.22	69.11	68.4	67.49
a9	213.19	23.16	190.03	210.19	175.19	211.71	209.39	206.43
b9	205.57	24.22	181.35	201.73	169.3	204.67	203.26	201.47
c9	117.72	27.73	89.99	114.17	99.72	115.95	113.16	109.61
d9	125.45	49.19	76.25	120.25	110.2	121.34	114.88	106.67
e9	93.64	32.89	60.75	88.61	81.49	92.29	90.16	87.45
f9	72.53	22.17	50.36	69.36	62.46	71.43	69.7	67.5
g9	66.57	19.54	47.03	63.79	57.17	65.59	64.05	62.09
h9	57.12	14.61	42.51	54.9	48.62	56.53	55.6	54.43
i9	81.78	11.03	70.75	80.1	67.63	81.3	80.56	79.62
j9	136.72	8.43	128.29	135.48	111.06	136.37	135.81	135.11
a10	115.91	23.5	92.4	113.03	97.43	114.29	111.75	108.52
b10	247.98	29.97	218.01	243.9	204.38	246.33	243.74	240.45
c10	125.18	40.07	85.11	120.54	108.16	122.25	117.66	111.81
d10	126.55	56.64	69.92	120.73	112.57	121.69	114.06	104.35
e10	105.57	43.04	62.52	99.09	93.06	103.72	100.81	97.1
f10	76.48	24.03	52.44	73.15	65.99	75.2	73.19	70.64
g10	62.29	18.97	43.32	59.67	53.62	61.25	59.63	57.57
h10	66	16.55	49.46	63.64	56.11	65.15	63.8	62.1
i10	82.98	12.82	70.16	81.11	68.95	82.39	81.45	80.27
j10	76.95	8.03	68.92	75.75	63.17	76.61	76.09	75.41

Grid Id	Brick and Traffic Emission	Only Traffic Emission	Only Brick Emission	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
a11	83.45	23.7	59.75	80.78	71.5	81.68	78.91	75.39
b11	105.9	33.45	72.45	101.92	91.41	103.61	100.02	95.44
c11	112.72	43.21	69.51	108.19	98.82	109.35	104.05	97.3
d11	135.7	74.99	60.71	130.65	123.56	127.76	115.27	99.38
e11	108.13	59.53	48.61	102.84	98.41	102.71	94.18	83.33
f11	70.36	31.99	38.37	66.47	62.68	68.25	64.94	60.72
g11	60.21	24.8	35.41	57.15	53.13	58.61	56.11	52.92
h11	61.98	21.87	40.11	59.28	53.96	60.6	58.43	55.66
i11	61.06	17.68	43.38	58.69	52.39	60.1	58.58	56.66
j11	46.4	10.45	35.94	44.83	39.21	45.98	45.31	44.47
a12	309.14	23.03	286.11	306.89	251.92	307.26	304.3	300.53
b12	112.32	41.89	70.44	108.84	98.24	108.44	102.34	94.58
c12	113.97	58.75	55.22	109.67	102.93	108.29	99.36	87.99
d12	131.59	78.36	53.23	126.61	120.95	123.74	111.39	95.68
e12	112.78	74.79	37.99	107.46	105.18	105	92.77	77.21
f12	70.45	39.26	31.19	66.72	64.21	67.14	61.93	55.31
g12	60.45	29.23	31.22	57.42	54.21	58.2	54.66	50.16
h12	53.57	23.69	29.88	50.91	47.59	51.89	49.25	45.89
i12	52.51	20.65	31.86	50.12	46.14	51.1	48.88	46.06
j12	60.44	15.07	45.37	58.42	51.37	59.66	58.43	56.87
a13	454.47	29.61	424.86	452.13	369.5	451.74	447.46	442.01
b13	233.95	53.31	180.64	230.31	197.82	228.61	220.23	209.56
c13	173.01	94.02	78.99	168.34	157.21	163.21	147.81	128.21
d13	169.87	99.31	70.56	164.07	155.76	159.91	144.26	124.34
e13	128.52	81.12	47.39	123.12	119.04	119.96	106.51	89.4
f13	81.84	44.14	37.7	78.5	74.3	77.63	71.01	62.59
g13	67.45	32.39	35.06	64.77	60.43	64.53	59.94	54.1
h13	71.35	26.67	44.68	68.95	62.42	69.06	65.45	60.86
i13	126.1	23.85	102.24	123.75	105.65	124.19	121.19	117.38
j13	106.3	18.85	87.45	103.99	88.81	105.19	103.44	101.21
a14	298.31	36.65	261.66	295.64	245.98	294.96	289.71	283.02
b14	239.73	51.39	188.33	236.5	202.06	234.6	226.54	216.28
c14	224.7	118.82	105.88	219.49	203.52	212.13	192.36	167.21
d14	232.03	145.67	86.36	224.04	214.76	218.43	197.04	169.83
e14	183.1	122.9	60.2	174.29	171.06	170.85	151.6	127.11
f14	122.64	69.04	53.61	116.12	111.92	117.22	108.69	97.84
g14	86.71	42.23	44.48	83.37	77.82	82.97	77.07	69.58
h14	103.67	33.03	70.63	100.91	89.54	100.76	96.2	90.39
i14	187.52	30.47	157.05	184.72	156.11	184.99	181.03	175.98
j14	96	22.56	73.44	93.36	81.31	94.57	92.32	89.46
a15	154.51	40.35	114.16	151.56	131.67	150.84	145.09	137.77
b15	159.91	49.66	110.25	156.68	137.86	155.13	147.63	138.07
c15	169.38	82.55	86.83	165.1	152.01	160.69	147.04	129.66
d15	197.99	124.14	73.86	191.6	183.22	184.97	164.5	138.45
e15	182.05	125.69	56.37	173.02	170.78	169.96	150.96	126.77
f15	163.83	110.06	53.77	153.15	153.08	155.06	141.26	123.71
g15	135.52	89.25	46.27	126.01	126.26	129.03	118.83	105.85
h15	130.88	74.75	56.12	122.87	119.65	125.39	116.76	105.79
i15	123.46	48.67	74.8	117.71	108.5	120.47	115.76	109.77
j15	82.55	26.01	56.54	79.65	71.24	80.76	77.95	74.37
a16	101.84	40.08	61.76	98.37	89.49	98.42	93.04	86.2
b16	105.54	49.57	55.96	101.26	94.34	101.18	94.33	85.62
c16	115.55	63.58	51.97	110.03	105.16	109.94	101.14	89.93

Grid Id	Brick and Traffic Emission	Only Traffic Emission	Only Brick Emission	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
d16	130.57	81.08	49.48	123.31	120.67	123.4	112.14	97.8
e16	150.85	98.5	52.35	139.92	140.38	142.77	130.08	113.92
f16	193.59	148.9	44.69	166.43	184.65	184.56	170.37	152.32
g16	210.43	170.68	39.75	171.48	202.48	202.93	191.14	176.14
h16	180.97	126.18	54.79	156.16	170.01	174.58	164.54	151.76
i16	165.73	77.2	88.53	153.73	148.03	161.5	154.86	146.4
j16	107.34	44.46	62.88	100.02	94.76	105.13	101.65	97.22
a17	80.81	36.15	44.67	76.76	71.88	78.08	73.78	68.31
b17	87.19	45.58	41.62	81.64	78.87	83.7	78.22	71.25
c17	99.98	56.16	43.81	93.34	91.21	95.64	88.83	80.17
d17	136.03	65.46	70.57	127.95	121.92	131.14	123.45	113.67
e17	321.02	71.6	249.43	311.22	271.14	315.96	308.01	297.89
f17	300.39	86.07	214.32	287.38	257.53	294.69	285.74	274.34
g17	149.53	92.09	57.44	133.19	138.05	144.49	136.57	126.48
h17	155.15	82.87	72.27	139.54	140.69	150.8	143.97	135.28
i17	194.24	65.86	128.38	182.18	168.56	190.82	185.45	178.61
j17	91.42	45.76	45.66	83.08	82.29	89.16	85.61	81.1
a18	98.95	28.49	70.46	95.59	84.85	96.92	93.74	89.69
b18	112.39	36.36	76.03	107.88	97.19	109.6	105.2	99.61
c18	125.16	42.11	83.05	119.32	108.55	122.21	117.57	111.66
d18	272.03	46.65	225.38	265.54	226.95	268.84	263.82	257.44
e18	848.67	52.36	796.31	841.18	689.41	845.12	839.54	832.44
f18	596.64	66.33	530.31	586.01	490.58	592.52	586.04	577.8
g18	222.25	74.98	147.27	209.61	192.8	217.99	211.3	202.77
h18	188.03	65.03	123	176.49	163.43	184.75	179.59	173.02
i18	150	50.53	99.47	141.07	130.11	147.35	143.19	137.9
j18	103.23	39	64.23	96.1	90.38	101.32	98.32	94.5
a19	117.12	26.93	90.19	113.73	99.08	115.31	112.47	108.85
b19	146.9	30.35	116.54	142.92	123.59	144.81	141.54	137.37
c19	187.54	30.63	156.91	183.42	156.16	185.44	182.13	177.91
d19	388.92	34.26	354.66	383.97	317.99	386.66	383.1	378.56
e19	647.14	36.57	610.56	641.8	525.02	644.73	640.95	636.15
f19	602.96	40.57	562.4	596.97	490.48	600.36	596.27	591.07
g19	317.79	43.86	273.93	311.29	263	314.98	310.57	304.96
h19	223.67	40.93	182.73	217.32	187.12	221.28	217.53	212.75
i19	159.03	32.72	126.31	153.78	133.77	157.27	154.5	150.98
j19	106	25.19	80.81	101.84	89.83	104.66	102.56	99.88
a20	121.68	24.52	97.16	118.7	102.25	119.94	117.21	113.73
b20	149.62	24.64	124.98	146.02	124.62	148.19	145.95	143.1
c20	163.48	23.22	140.26	160.23	135.43	161.98	159.63	156.63
d20	231.9	23.97	207.93	228.55	190.31	230.36	227.94	224.87
e20	307.02	24.74	282.28	303.49	250.56	305.42	302.9	299.7
f20	367.15	27.28	339.87	363.08	299.18	365.44	362.74	359.32
g20	296.59	29.36	267.23	292.03	243.14	294.76	291.89	288.24
h20	194.4	27.67	166.74	189.99	161.05	192.8	190.29	187.09
i20	144.72	23.1	121.62	140.93	120.39	143.5	141.58	139.14
j20	101.61	19.56	82.05	98.23	85.2	100.61	99.02	97