IMPACT OF COAL FIRED POWER PLANT EMISSIONS ON AMBIENT AIR QUALITY USING A DIFFUSION MODEL

by

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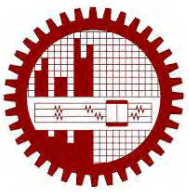

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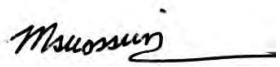
Declaration

It is hereby declared that the studies embodied in this thesis are the results of experiments carried out by the author under the supervision of Dr. Muhammad Ashraf Ali, Professor, Department of Civil Engineering, BUET except where specified by reference to other works. Neither the thesis nor any part of it has been submitted elsewhere for any other purposes.



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Dedicated to

My Family

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ABSTRACT

Bangladesh government plans to supply uninterrupted electricity to all citizens within 2021 by materializing the Vision-2021. As natural gas reserve is predicted to be exhausted within a decade, strategy has been taken to shift the primary energy focus from gas to coal. A number of coal fired power plant projects have been launched, most of which are located in the Southern region of the country. Payra, in Patuakhali district, is set to be a new energy hub of the country with projects such as Payra Power Plant Phase-I and II in the construction stage, and three other power plants proposed by Rural Power Company Ltd, Ashuganj Power Station Company Ltd, Sena Kalyan Sangstha in the preparation stage. Coal based thermal power plants are cited to be one of the major sources of pollution affecting human health and the environment. It is therefore important to assess the impact of emission of the coal fired power plants in Payra region on ambient air quality.

This study involves estimations of emissions of SO_2, NOx, $PM_{2.5}$, PM_{10} and CO from the Payra power plants and evaluation of air quality impacts associated with the operation of the coal fired power plants under three scenarios: (a) Scenarios I: Operation of Payra Phase I power plant; (b) Scenario II: Operation of Payra Phase I and Phase II power plants: (c) Scenario III: Operation of all 5 power plants. A dispersion model, AERMOD, has been used to investigate the pollutant dispersion and ground-level concentration at receptor grids over a 30 km x 30 km model domain for a one-year period. This study simulates the dispersion behavior of SO_2, NOx, $PM_{2.5}$, PM_{10}, and CO for 1 hour, 24 hour and annual averaging periods in close proximity of the power plants.

Compliance evaluation of peak concentrations of the primary pollutants (resulting only from power plant emissions) with Air Quality Standards of Bangladesh and WHO reveals that standards are mostly satisfied only if high efficiency emission control technologies are incorporated in the project. Assessment of seasonal and diurnal variation of pollutants shows that change in pollutant behavior is largely dictated by meteorological parameters (e.g. wind speed, solar radiation and mixing height); over a particular day, peak concentration of pollutants is typically reached in the morning to noon. Sensitivity analysis of predicted pollutant concentrations to chimney height reveals that provision of 165 m height is sufficient to comply with standards and guidelines of most of the pollutants without considering background concentration. Efficiency level of emission control technologies strongly influence ground level concentrations; efficiency drop of Electrostatic Precipitator from 90% to 50% leads to violation of ambient particulate matter standards. Assessment of the coal quality reveals that ash content has moderate impact on ambient particulate concentration, whereas high sulfur content of coal can result in exceedance of the air quality standards of SO_2. Hence, stringent emission control measures should be ensured to curb pollutant emission from power plants as well as other air pollution sources in the vicinity (e.g. brick kilns, motor vehicles, etc.).

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Chapter 1
INTRODUCTION

1.1 Background

Bangladesh has been experiencing significantly high demand of electric energy in recent time. Bangladesh's total installed electricity generation capacity was 16,525 MW as of 13th September 2018 (Bangladesh Power Development Board, 2018). Bangladesh will need an estimated 34,000 MW of power by 2030 to sustain its economic growth of over 7 percent. In Bangladesh, as per the generation capacity by fuel type, 62.47% of power producing plants are gas based, 21.35% are Heavy Fuel Oil (HFO) based, 8.08% are High speed diesel fuel based, 2.0% Hydro based, 1.74% are coal based (Bangladesh Power Development Board, 2016). However, considering the looming gas crisis, the Government has taken a number of strategies including shifting the primary energy focus from gas to coal, importing liquefied natural gas (LNG), and expanding use of renewable resources, including solar and wind.

The high energy demand and availability of coal has led it to be the key energy source in the coming years. Dozens of coal-run electricity-generating plants are in the pipeline in Bangladesh, including the Payra 2 x 1320 MW Thermal Power Plant in Patuakhali district, Matarbari 1200 MW Power Plant in Cox's Bazar district, Dighipara 1000 MW Ultra Super Critical Thermal Power Plant Project, and the Rampal Thermal Power Plant in the Sundarbans. Most of these projects are located in the Southern region of the country, considered as one of the emerging electricity demanding areas of the country in the near future. Among the proposed coal based power plants, the first phase of Payra Thermal Power Plant (1320 MW) is expected to begin generation by 2019, followed by its second phase by 2021. Besides, a number of other coal-based power plants proposed by Rural Power Company Ltd (RPCL), Ashuganj Power Station Company Ltd (APSCL) and Sena Kalyan Sangstha (SKS) will be constructed in the Patuakhali area, close to the Payra Power Hub.

Although, the presence of carbon, hydrogen and sulfur in coal facilitates the energy generation in coal combustion, some pollutants including CO_2, SOx, NOx, particulate matter (PM) and heavy metals are accumulated in air and water which may lead to environmental and health impacts (Munawer, 2017). The World Health Organization (WHO) considers clean air to be a basic requirement of human health and well-being. It recognizes ambient air pollution as a major environmental health problem affecting everyone in developed and developing countries. In 2017, air pollution ranked as the 3rd leading risk factor for mortality in Bangladesh

accounting for almost 14% (123,000) deaths per year (Health Effects Institute, 2019). The Bangladesh country environmental analysis undertaken jointly by the World Bank and Government of Bangladesh (World Bank, 2018), estimated that economic cost associated with environmental degradation is about 3.4% of its 2015 GDP, which is almost equivalent to almost 6.5 billion dollars. Hence, it is pivotal to investigate emission of air pollutants and their contribution to ambient air quality from power plant as well as the impact on human health and environment.

The outdoor air quality pattern can be indexed and predicted using air quality monitoring and air dispersion modeling. The air quality monitoring stations in Bangladesh consists of eleven (11) Continuous Air Monitoring Stations (CAMS) in Dhaka, Narayangonj, Gazipur, Chittagong, Khulna, Rajshahi, Barisal and Sylhet (CASE, 2015), installed by Department of Environment (DoE) of Bangladesh Government, which record the concentrations of PM_{10}, $PM_{2.5}$, CO, SO_2, NO_X and O_3. Various air quality models such as ATMoS, CALPUFF, ISCST3, AERMOD etc. are commonly used to simulate the spatial and temporal dispersion of pollutants. These dispersion model simulations help to investigate the deterioration of ambient air quality owing to emissions from major sources.

Numerous studies have assessed the pollutant transportation, dispersion and health effects from thermal power plants emissions. Lee and Keener (2008) conducted correlation analysis of mercury emissions from two coal fired power plant with meteorological parameters using ISCST3 and determined wet mercury deposition is dependent on precipitation near source, whereas dry deposition depends on a range of other meteorological factors. Khamsimak et al. (2012) developed a regression model to approximate the CALPUFF predicted concentrations and to determine the impacts of sulfur dioxide emission from Mae Moh power plant on ambient concentrations considering the seasonal variation. Mokhtar et al. (2014) studied ambient air quality around Kapar Power Plant in Malaysia and predicted the ground level concentration of pollutants SO_2, Hg, As and Cr to assess the carcinogenic and non-carcinogenic health risks using AERMOD. Dai et al. (2019) investigated the emission of nitrogen oxides, sulfur dioxide and particulate matter from coal power plants in Anhui to assess the impact of control measures on the atmospheric emissions based upon continuous emission monitoring systems (CEMS). To date, such studies related to modeling power plant emissions in Bangladesh has not been published. Limited studies have been conducted on air dispersion modeling in Bangladesh, among them most of the studies were focused on the air pollution from brick kiln and motor vehicles in Dhaka city (Guttikunda, 2009; Rahman, 2010; Azkar et al., 2012).

This dissertation aims to investigate the dispersion of emissions from the five proposed coal fired power plants of Payra Power Hub and determine its effect on the ambient air quality in the surrounding areas. The study uses a dispersion model, AERMOD, to investigate the dispersion of pollutants released from the power plants. The outcome of this study will be crucial in assessment of possible health and environmental effects due to cumulative emission of the five power plants in the Patuakhali area.

1.2 Objectives of the Research Work

The primary objective of this research is to assess the effect of the coal fired power plants in Patuakhali on ambient air quality and recommend options for air quality management in the project area. The specific objectives include:

- Estimation of major pollutant (SO_2, NO_2, $PM_{2.5}$, PM_{10}, CO) emission from the proposed Payra power plants, and prediction of ground level concentration (including seasonal and diurnal variation) of pollutants due to operation of the power plants using an advanced air quality model (AERMOD).
- Evaluation of the compliance of air quality with regulatory requirements/standards.
- Assessment of impact of stack height on ground level pollutant concentration.
- Assessment of the effect of coal quality and control technologies on emission and ambient air quality.

1.3 Scope of the Research Work

This research work has been conducted to evaluate the air quality associated with the operation of coal fired power plants in Payra area under diverse control situations such as varied height of stack, probable coal categories, and efficiency levels of control technologies. Lakes Environmental's AERMOD ViewTM has been used in this study, which incorporates AERMET and AERMAP preprocessors. Meteorological data were purchased from Lakes Environmental in MM5 version. Local terrain data were downloaded from Shuttle Radar Topography Mission in 90 m resolution. This study reports the concentrations of SO_2, NOx, $PM_{2.5}$, PM_{10}, and CO for 1 hour, 24 hour and annual averaging period in close proximity of the power plants.

This study considers three scenarios: (a) 1320 MW Payra Phase I Thermal Power Plant; (b) 1320 MW Payra Phase I and II Thermal Power Plant; and (c) Cumulative scenario (coal fired

power plants proposed by RPCL, APSCL and SKS, to be constructed in the Patuakhali area, along with Payra Phase I and II Thermal Power Plant). Modeling was done over a one-year period (2017) to assess the effects of seasonal meteorological variability. Predicted ambient concentrations were compared with the Air Quality Standards of Bangladesh and WHO Guideline to estimate the conformity of pollutants to the concentration limits. An analysis of pollutant behavior for cumulative emission from all power plants to be installed in the area, together with baseline air quality condition of the area has also been made.

1.4 Organization of the Thesis

The thesis is presented in five chapters where the salient aspects of the entire research have been covered in detail.

Chapter 1 presents the background study and the objectives of this research, along with the scope of this research.

Chapter 2 reviews the basic information on air pollution, its sources and impacts. An overview of the air pollution status and air quality standards in Bangladesh have been presented. A detailed description of the present power generation situation of the country along with the associated hazardous pollutant emissions and relevant emission control techniques have been presented in this chapter. This Chapter further summarizes the various air quality models used for modeling dispersion of air pollutants.

Chapter 3 describes the methodologies adopted in the present study. This Chapter provides a detailed description of the meteorological parameters and measured baseline ambient air quality in the Payra Power Hub area. The procedure followed to model the dispersion of pollutants emitted from the power plants using AERMOD View 9.6.0 has been described in this chapter. It also highlights all pollutants and scenarios considered for model simulation in this study.

Chapter 4 presents the spatial and temporal distributions of the pollutants for three different scenarios. It also includes an elaborate evaluation of seasonal and diurnal variation of pollutant concentrations, and their relationship with various meteorological parameters. The effects of important parameters such as chimney height, coal quality, and emission reduction technology on peak pollutant concentrations have been illustrated in this chapter. This Chapter concludes with assessment of cumulative impact of pollution from all proposed power plants in the study area.

The major conclusions from the present study have been summarized in Chapter 5. This chapter also presents the recommendations for future studies.

Chapter 2
LITERATURE REVIEW

2.1 General

Deterioration of air quality due to coal fired power stations is a global concern. With Payra set to be the next major power hub of the country, statistics on emission of criteria pollutants have become essential for the formulation and implementation of energy saving and emission reduction policies. Brief descriptions on previous research conducted on areas that are relevant to assessment of air quality deterioration in the vicinity of proposed power plants in Payra are presented in this chapter. Furthermore, this chapter characterizes various air pollutants associated with coal based power plant emissions and outlines several national and international air quality standards to regulate their emissions. The chapter also summarizes some relevant concept such as emission control technologies and air quality models along with the necessary input parameters.

2.2 Air Pollution and its Consequences

In order to model the air quality in the vicinity of proposed power plants in Payra, the information on air pollution and impact of the air pollutants are elemental necessities. The subsequent article discusses the air pollution concept and its impact.

2.2.1 Air pollution

Air pollution is the introduction into the atmosphere of chemicals, particulates, or biological materials that cause discomfort, disease, or death to humans, damage other living organisms such as food crops, or damage the natural environment or built environment. The World Health Organization defines air pollution as 'the disequilibrium of air caused due to the introduction of foreign elements to humans' natural and manmade sources to the air so that it becomes injurious to biological communities'. It has also been defined as the contamination of air by discharge of harmful substances, which can cause health problems including burning eyes and nose, itchy irritated throat and breathing problems (USEPA 1994). It can also be defined as the presence in the outdoor or indoor atmosphere of one or more gaseous or particulate contaminants in quantities, characteristics and of duration such as to be injurious to human,

plant or animal life or to property, or which unreasonably interferes with the comfortable enjoyment of life and property (Odigure, 1998)

Pollution of the environment is one of the most concerning ecological crises the world is subjected today. The environment (air, land or soil and water) was in the past pure, virgin, undistributed, uncontaminated and basically most hospitable for living organisms but the situation is just the reverse today. Today, the environment has become foul, contaminated, undesirable and therefore, harmful for the health of living organisms, including man.

2.2.2 Sources of air pollution

Air pollution can result from both human and natural actions. Natural events that pollute the air include forest fires, volcanic eruptions, wind erosion, pollen dispersal, evaporation of organic compounds and natural radioactivity. Pollution from natural occurrences are not very often. However, human activities that result in air pollution include:

a) **Emissions from industries and manufacturing activities**: Waste incinerators, manufacturing industries and power plants emit high levels of carbon monoxide, organic compounds, and chemicals into the air. Also, petroleum refineries also release huge amount of hydrocarbons into the air.
b) **Burning Fossil Fuels**: After the industrial age, transportation has become a key part of our lives. Cars and heavy duty trucks, trains, shipping vessels and airplanes all burn lots of fossil fuels to work. Emissions from automobile engines contain both primary and secondary pollutants. This is a major cause of pollution, and is very difficult to manage. This is because humans rely heavily on vehicles and engines for transporting people, good and services.
c) **Household and Farming Chemicals**: Crop dusting, fumigating homes, household cleaning products or painting supplies, over the counter insect/pest killers, fertilizer dust emit harmful chemicals into the air and cause pollution.
d) **Mining Operations:** Operations, like mining and truck traffic, are some of the top causes of air pollution. These activities release carbon monoxide, sulfur dioxide and nitrous oxide into the air, all of which contribute to development of smog and various health problems. Apart from these emissions, gold mines also release mercury particulates to the atmosphere. In excess amounts, mercury inhalation can lead to sensation disturbances, muscle weakness, respiratory problems, certain cancers, even death.

e) **Radioactive Fallout:** Radioactive sources yield high amounts of energy, as well as harmful quantities of sulfur dioxide and several heavy metals into the air. In highly-industrialized cities, air pollution from radioactive fallout have been proven to create numerous environmental concerns, such as defoliation, deformation and undergrowth damage in trees, to name a few.

f) **Chemical Pesticides:** Pesticides are very helpful for farmers as they keep vermin, bacteria, and fungi that destroy their crops at bay. However, use of pesticides, especially those made from chemicals, also wreaks air pollution. Air pollution caused by pesticides can be fatal for animal, birds, even marine life, especially if the emissions already infiltrate their food sources.

g) **Fertilizer Dust:** Fertilizers are useful for farmers as they accelerate the growth of crops and plants. Nonetheless, the accumulation of fertilizer dust (even those made from organic ingredients) can give way to the production of ammonia and nitrogen oxide, both of which contribute to global warming and harmful acid rain. Such pollution also yields methane, a greenhouse gas. With the presence of high amounts of methane in the atmosphere, the heat that should have been radiated back to the atmosphere are bounced back to earth, keeping the earth insulated.

2.2.3 Classification of air pollutants

A substance in the air that can be adverse to humans and the environment if present in certain concentration is known as an air pollutant. Pollutants can be in the form of solid particles, liquid droplets, or gases. In addition, they may be natural or man-made. Air pollutants can be categorized by various means:

On the basis of source of origin

- **Natural air pollutants:** Natural air pollutants are emitted from natural sources such as volcanic activity, dust, sea-salt, forest fires, lightening, soil outgassing etc.
- **Anthropogenic air pollutants:** These pollutants include the emissions from stationary point sources (e.g. emission from industries), mobile sources (e.g. vehicular emission, marine vessels, airplanes etc.), waste disposal landfills, controlled burning etc.

On the basis of formation of pollutants

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.

- **Primary air pollutants:** Those pollutants which are emitted directly from any emission source in the atmosphere are termed as primary air pollutants, e.g. sulphur dioxide (SO_2), carbon monoxide (CO), lead (Pb), ammonia (NH_3) etc.
- **Secondary air pollutants:** Secondary pollutants are formed by the reactions between primary air pollutants and normal atmospheric constituents. In some of the cases, these pollutants are formed by utilizing the solar energy, e.g. ozone, peroxyacetylnitrate (PAN), smog etc.

On the basis of chemical composition

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

- **Organic air pollutants:** Examples are hydrocarbons, aldehydes, ketones, amines, and alcohols etc.
- **Inorganic air pollutants:** Examples are carbon compounds (CO and carbonates), nitrogen compounds (NO_X and NH_3), sulphur compounds (H_2S, SO_2, SO_3, H_2SO_4), halogen compounds (HF, HCl etc.), flyash, silica etc.

On the basis of 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:

- **Gaseous air pollutants:** Pollutants which are in the form of gas are termed as gaseous air pollutants, e.g. SO_2, NOx, O_3, CO etc.
- **Particulate air pollutants:** Particulate air pollutants or particulate matter (PM) can be defined as the microscopic solid or liquid matter suspended in the earth's atmosphere.

There are various subtypes of particulate matter:

a) **Total suspended particulate matter (TSPM):** The concentration of particulate matter which is obtained when a high volume bulk sampling is done on a filter substrate. It includes particles of all sizes.
b) **PM_{10}:** These are the particles less than 10 μm in diameter
c) **$PM_{2.5}$:** These are the particles less than 2.5 μm in diameter
d) **$PM_{1.0}$:** These are the particles less than 1 μm in diameter

Particles which lie between 10μm to 2.5μm are termed as 'coarse particles' whereas particles with diameter less than 2.5μm are called as 'fine particles'. Fine particles also include ultra-fine particles of size less than 0.1 μm (PM0.1).

According to the types of releases

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

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

2.2.4 Effect of air pollution

a) **Health effects:** People exposed to high enough levels of certain air pollutants may experience: irritation of the eyes, nose, throat, wheezing, coughing, chest tightness, and breathing difficulties, worsening of existing lung and heart problems, such as asthma, increased risk of heart attack. Dust has been documented through the years as one of the biggest occupational killers (Petavratzi et al., 2005) and a wide range of occupational diseases may develop in mine workers depending on the properties of the inhaled dust In addition, long-term exposure to air pollution can cause cancer and damage to the immune, neurological, reproductive, and respiratory systems. In extreme cases, it can even cause death.

b) **Environmental effects:** Air pollution can cause a variety of environmental effects: acid rain is precipitation containing harmful amounts of nitric and sulfuric acids. These acids are formed primarily by nitrogen oxides and sulfur oxides released into the atmosphere when fossil fuels are burned. These acids fall to the Earth either as wet precipitation (rain, snow, or fog) or dry precipitation (gas and particulates). In the environment, acid rain damages trees and causes soils and water bodies to acidify, making the water unsuitable for some fish and other wildlife. It also speeds the decay of buildings, statues, and sculptures that are part of our national heritage.

   Eutrophication is a condition in a water body where high concentrations of nutrients (such as nitrogen) stimulate blooms of algae, which in turn can cause death of fish and loss of plant and animal diversity. Air emissions of nitrogen oxides from power plants, cars, trucks, and other sources contribute to the amount of nitrogen entering aquatic ecosystems. Haze is caused when sunlight encounters tiny pollution particles in the air. Haze obscures the

clarity, color, texture, and form of what we see. Some haze-causing pollutants (mostly fine particles) are directly emitted to the atmosphere by sources such as power plants, industrial facilities, trucks and automobiles, and construction activities.

c) **Effects on wildlife:** Toxic pollutants in the air, or deposited on soils or surface waters, can impact wildlife in a number of ways. Like humans, animals can experience health problems if they are exposed to sufficient concentrations of air toxics over time. Studies show that air toxics are contributing to birth defects, reproductive failure, and disease in animals. Persistent toxic air pollutants (those that break down slowly in the environment) are of particular concern in aquatic ecosystems. These pollutants accumulate in sediments and may biomagnify in tissues of animals at the top of the food chain to concentrations many times higher than in the water or air.

d) **Ozone depletion:** At ground level, ozone is a pollutant that can harm human health, in the stratosphere, however, ozone forms a layer that protects life on earth from the sun's harmful ultraviolet (UV) rays. But this "good" ozone is gradually being destroyed by man-made chemicals referred to as ozone-depleting substances, including chlorofluorocarbons, hydro-chlorofluorocarbons, and halogens. These substances were formerly used and sometimes still are used in coolants, foaming agents, fire extinguishers, solvents, pesticides, and aerosol propellants. Thinning of the protective ozone layer can cause increased amounts of UV radiation to reach the Earth, which can lead to more cases of skin cancer, cataracts, and impaired immune systems.

e) **Crop and forest damage:** Ground-level ozone can lead to reductions in agricultural crop and commercial forest yields, reduced growth and survivability of tree seedlings, and increased plant susceptibility to disease, pests and other environmental stresses (such as harsh weather). Crop and forest damage can also result from acid rain and from increased UV radiation caused by ozone depletion. UV can damage sensitive crops, such as soybeans, and reduce crop yields.

f) **Global climate change:** The Earth's atmosphere contains a delicate balance of naturally occurring gases that trap some of the sun's heat near the Earth's surface. This "greenhouse effect" keeps the Earth's temperature stable. Unfortunately, evidence is mounting that humans have disturbed this natural balance by producing large amounts of some of these greenhouse gases, including carbon dioxide and methane. As a result, the Earth's atmosphere appears to be trapping more of the sun's heat, causing the Earth's average

temperature to rise - a phenomenon known as global warming. Many scientists believe that global warming.

2.3 Air pollution status in Bangladesh

Air pollution is a pressing issue in our country as Bangladesh ranks 179th (out of 180 countries) at the Environmental Performance Index for Air Quality in 2018 (Wendling et al., 2018). Air pollution of Bangladesh for outdoor and indoor is caused due to increasing population, associated motorization, industrial emissions, and use of biomass fuels during cooking with poor ventilation. Industries are mainly concentrated in major urban metropolitan areas such as Dhaka, Rajshahi, the seaport cities such as Chittagong and Khulna, the inland port city Narayanganj, and other divisional towns. Apart from unplanned industrial development in these areas, the severity of the pollution is increased mainly due to exhausts from two-stroke engine and diesel-run vehicles. In the rural areas of Bangladesh, the danger of outdoor air pollution has not yet turned into a point of concern. This is due to less motorized vehicles and industries in rural areas (Drew et al., 2001). Agro based industries like sugar, pulp, paper, tanneries and value added industries like textile, garments, pharmaceutics, oil refineries, and fertilizer and chemical industries are also contributing for air pollution. Other than industrial emissions there are many brick-making kilns which on being operated seasonally, mainly in dry season all over Bangladesh. Brickfields in Bangladesh expel over 9.8 million tons of greenhouse gases into the air annually due to a combination of old technology, weak environmental legislation and enforcement and lack of corporate responsibility. Almost all of these kilns use coal and wood as their prime sources of energy, resulting in the emission of particulate matter, oxides of sulfur, and volatile organic compounds. Rana et al. (2016) studied the trends of atmospheric particulate matter in Dhaka, Narayanganj and Gazipur; the observations revealed that the pollution levels followed the same pattern from November 2012 to March 2015 (Figure 2.1).

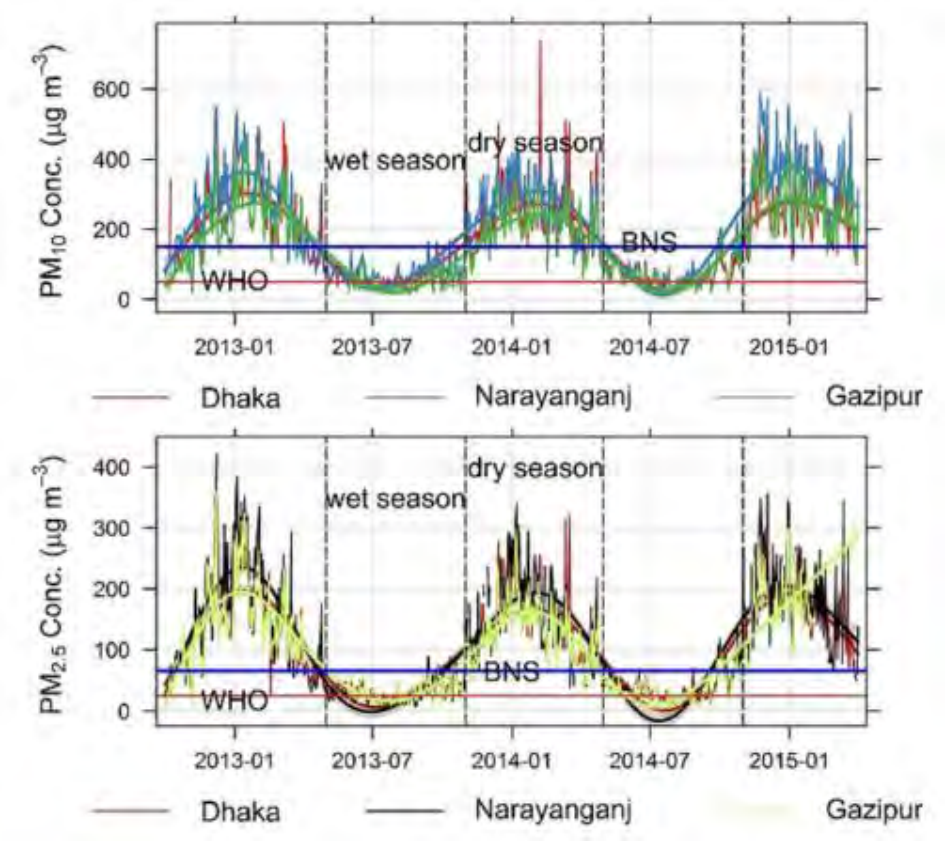


Figure 2.1: Time series plots of daily PM_{10} and $PM_{2.5}$ concentrations captured at Dhaka, Narayanganj and Gazipur (Rana et al., 2016)

Studies in published literature indicate that increased mortality from CVD and respiratory diseases in Bangladesh are likely resulting from the high air pollution exposures (Massey et al., 2013). Outdoor air pollution ranked third among the all risk factors of mortality in Bangladesh, high blood pressure ranked first, and smoking ranked second (Institute for Health Metrics and Evaluation, 2018). According to a global state of air report, the number of annual deaths attributed to the exposure to $PM_{2.5}$ was 122,400 in Bangladesh in 2015 (Health Effects Institute, 2017). In the last two decades, the mortality attributed to air pollution has been estimated to increase by 52% in Bangladesh (Figure 2.2). One recent study reported that the total number of premature death attributed to PM2.5 exposure was 9051 (95% CI: 4596–12,025), including 4435 (95% CI: 1721–5304) for ischemic heart disease (IHD), 2669 (95% CI: 1850–4135) for stroke, 1246 (95% CI: 684–1689) for chronic obstructive pulmonary disease (COPD), 500 (95% CI:204–649) for lung cancer (LC), and 201 (95% CI: 137–248) for acute lower respiratory infection (ALRI) in Dhaka in 2016 (Maji et al., 2018). The estimated total 9051 premature deaths was 6.62% of the total reported deaths in Dhaka in 2016. The

increase in mortality resulting from the increase in exposure, population growth, limited access to proper diagnosis, and limited subsequent treatment.

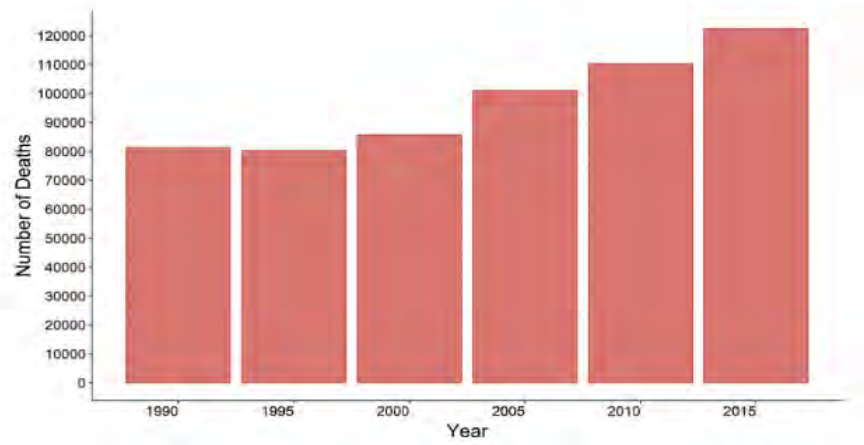


Figure 2.2: Number of deaths attributable to $PM_{2.5}$ exposure in Bangladesh. (Health Effects Institute, 2017)

Ambient air quality standards were first introduced in Bangladesh in 1997 under the Environmental Conservation Rules (ECR), 1997. In different times air pollution issues have been considered, and often guided by the multinational agencies like the World Bank (WB), Asian Development Bank (ADB), United Nations Environment Programme (UNEP), have taken measures or have made plans to reduce and control air pollution. The Department of Environment (DoE), the Government Agency entrusted with safeguarding the environment in Bangladesh, sought proposals to develop an 'Air Pollution Reduction Policy for Bangladesh' under the framework of the Malé Declaration on Control and Prevention of Air Pollution (DoE, 2012).

2.4 Air Quality Standard and Air Quality Index in Bangladesh

Air quality standards provide maximum limits on the amount of a specific pollutant in the air for precise averaging periods. These ambient standards primarily aim at human health protection and have been estimated to permit a margin for citizens susceptible to risk. These guidelines and standards are critical to efficient air quality administration, and they provide the link between the emissions source and the receptor that is provided in the downstream location. These values specify harmless daily exposure quantities for the greater part of the population, all over an individual's life period. 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. 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: Air Quality Standards ([a]S.R.O. No: 220-Law, DoE, 2005; [b]WHO, 2005; and [c]USEPA, 2005)

Pollutant	Averaging Period	Bangladesh Standard	WHO Guideline Values	US EPA Standards
		µg/m^3	µg/m^3	µg/m^3
SO_2	Annual	80	-	78
	24-hr	365	20	365
Pb	Annual	0.5	0.5	-
NOx	Annual	100	40	100
	1-hr	-	200	-
SPM	8-hr	200	-	-
$PM_{2.5}$	Annual	15	10	15
	24-hr	65	25	35
PM_{10}	Annual	50	20	-
	24-hr	150	50	150
O3	8-hr	157	100	157
	1-hr	235	-	235
CO	8-hr	10,000	10,000	10,000
	1-hr	40,000	30,000	40,000

The AQI is a tool for reporting daily air quality of any city or country. It provides information about how clean or polluted the air is, and what associated health effects might be a concern for public. The AQI focuses on health effects that one might experience within a few hours or days after breathing polluted air. The AQI value is a yardstick (Table 2.2) that runs from 0 to 300.The higher the AQI value, the greater the level of air pollution and the greater the health concern. For example, an AQI of 50 represents good air quality with little potential to affect public health, while an AQI value of 300 represents hazardous air quality.

An AQI value of 100 generally corresponds to the national air quality standard for the pollutant, which is the level that set by the mandated Environment Protection Agency (e.g., for Bangladesh Department of Environment) to protect public health. AQI values below 100 are generally thought of as satisfactory. When AQI values are above 100, air quality is considered to be unhealthy-at first for certain sensitive groups of people, then for everyone as AQI values get higher. The main purpose of air quality index are Daily release of air quality conditions to the public, Convey the health implications of air quality, Protect public interest and take actions to reduce emissions and Forecast air pollution level.

In Bangladesh, the AQI is based on 5 criteria pollutants; Particulate Matter (PM_{10} and $PM_{2.5}$), NO_2, CO, SO_2 and Ozone (O_3). The Department of Environment (DoE) has also set national ambient air quality standards for these pollutants. These standards aim to protect against adverse human health impacts. The AQI standard for Bangladesh is given as under.

Table 2.2: Approved Air Quality Index (AQI) for Bangladesh (CASE, 2015)

Air quality index (AQI) Range	Category	Colour	Cautionary Statement
0-50	Good	Green	little potential to affect public health
51-100	Moderate	Yellow Green	Unusually sensitive individuals
101-150	Caution	Yellow	Identifiable groups at risk – different groups for different pollutants
151-200	Unhealthy	Orange	General public at risk; sensitive groups at greater risk
201-300	Very Unhealthy	Red	General public at greater risk; sensitive groups at greatest risk

2.5 Power sector in Bangladesh

Incessant supply of power and energy is the prerequisite for the progress of an economy. The importance of energy is even more supplementary in the context of Bangladesh, an emerging economy that has been experiencing rapid economic growth but also has been experiencing prolonged period of energy crisis. Electricity is the main form of energy that is tapped on both private and commercial scales in Bangladesh. However, the country is still at a very low level of electrification. To meet the increasing demand for Power, the government of Bangladesh has undertaken massive steps towards increasing the power supply in the short span of time by encouraging private sector power production as well as import of power from

native countries. The government of Bangladesh has set a target to bring the whole country under electricity coverage by 2021.

At present, power generation in Bangladesh is mostly dependent on natural gas, around 60 % of electricity is being produced from our gas reserve (Khatun, 2013) and this percentage of electricity generation uses 37% of total gas consumption (Islam, 2011), while demand for gas consumption is increasing by about 8% per year (Khatun, 2013). However, our net remaining recoverable reserve of gas was 1.64 TCF at the end of 2018 and would be available up to 2020 at the present consumption rate (Khatun, 2013). Hence, the government is now looking for big power plants to be run on alternative energy sources such as coal, liquefied natural gas (LNG), wind, solar energy etc. in the near future. The predicted transition of sources of electricity generation in Bangladesh from 2016 to 2021 has been shown in Figure 2.3.

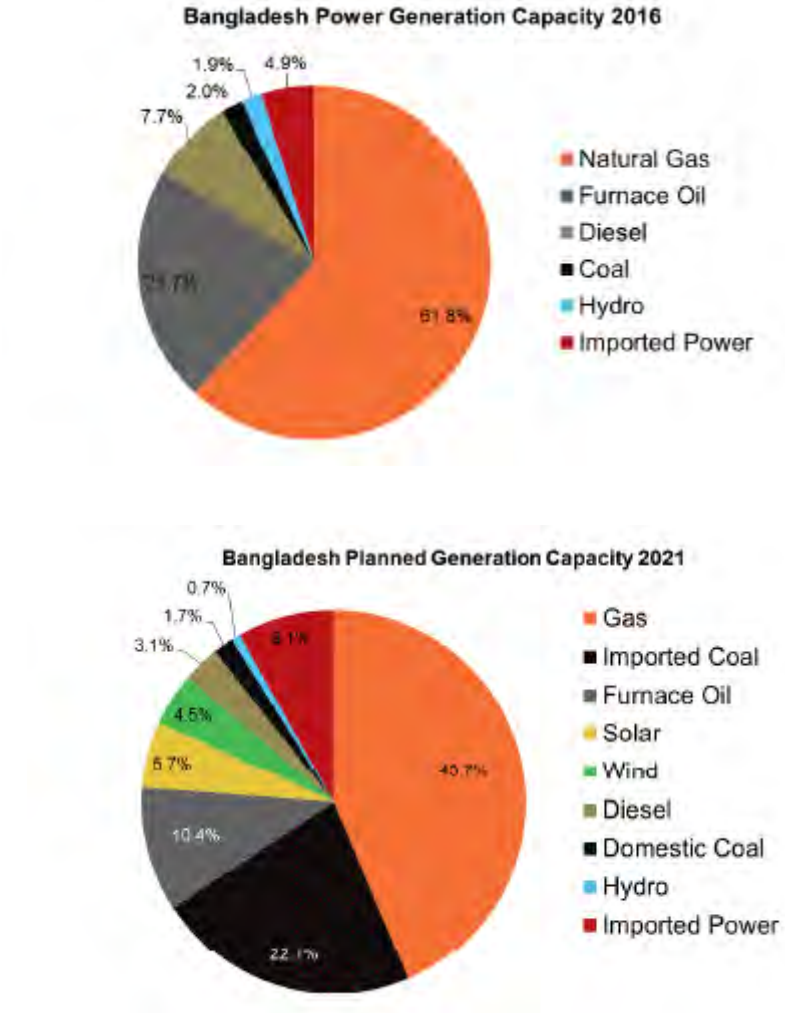


Figure 2.3: Transition of source of electricity generation (Buckley et al., 2016)

Import of LNG by 2018 and implementation of LNG based power project may mitigate the ongoing crisis and can be an alternative low cost fuel for producing electricity. The government have taken initiatives to supply 1000 MMCFD of Regasified LNG into the Gas Grid using 2 Floating Storage and Regasification Units (FSRU), off the coast of Maheshkhali.

Furnace Oil, HFO and Diesel based plants are the best available alternatives for producing electricity. However, Oil based power plants are highly expensive compared to Gas based plants. So, Oil based plants are only short term solution to mitigate the supply shortage of power within the shortest period of time.

Coal is next available alternative. It can be a near term option and can be indigenous or imported. However, Coal based power projects are highly debated as they might be harmful for environment. The government is encouraging coal based projects for mitigating looming electricity shortage and to reduce dependency on gas based expensive fuel oil based plants. Infact, the Bangladesh government has a multitude of thermal project proposals and non-binding MoUs with a myriad of international and domestic counterparties to treble Bangladesh's total installed power generation capacity by 2030 (Buckley et al., 2016). Nuclear power is the safe technology; no pollution; expected to be future Base Load option (power stations which can economically generate the electrical power needed to satisfy this minimum demand).

The generation of power from the conventional systems will be decreasing in near future because the reservoir of fossil fuel is decreasing day by day. To cope with the high demand with increasing population over the world is heading towards the renewable energy sources. Bangladesh itself has different sources of renewable energy such as solar energy, wind energy, biogas, hydro-electric resources and tidal energy. So huge amount energy can be produced from these resources that will help to reserve the fossil fuel, non-renewable energy for the future and our country will be self-dependent for long time.

2.6 Emission of Air Pollutants from Coal-fired Power Plants

Coal-fired power plants are set to be the future of power generation in Bangladesh, hence, emission from this source has become a major concern. Various studies across the globe have shown that emissions from coal-fired power stations can be harmful to the environment and human health (Cagney, 2016; Adappa et al, 2017; Sanchez and Luan, 2018; Kravchenko and Lyerly, 2018). The most important primary emissions associated with coal-fired power stations

which are known for their adverse environmental and/or human health impacts include PM, SO_2, NOx, mercury (Hg) and GHG (Shahzad and Yousaf, 2017; Zhao et al., 2008). Ozone (O_3) is an important secondary pollutant that forms photo-chemically in a reaction with NOx (a primary coal-fired power station emission) (Curtis et al., 2006; Gaffney and Marley, 2009).

2.6.1 Particulate Matter

Particulate matter emissions from coal-fired power stations can either be a primary pollutant in the form of fly-ash emissions directly to the atmosphere or a secondary pollutant when emitted SO_2 and NO_x gases oxidize to form sulphate (SO_4) and nitrate (NO_3), respectively (Levy et al., 2003; Gaffney and Marley, 2009). The primary PM particles that are able to escape PM abatement technology generally have sizes in the order of 0.8 to 2 micron (μm) whereas secondary PM is generally smaller with sizes <1 μm (Linak et al., 2000; Gaffney and Marley, 2009). This size range is effective in scattering solar radiation and is therefore able to impact both visibility and climate (Gaffney and Marley, 2009).

Fly ash is known to contain various potentially toxic trace materials such as heavy metals and radionuclides. The transition metals are of particular concern due to indications of cardiopulmonary damage associated with the inhalation of these constituents (Gaffney and Marley, 2009). Secondary PM from coal-fired power stations is the main constituents responsible for the formation of acid rain. Acid rain changes the acidity of inland water bodies and speeds up the deterioration of construction materials (Gaffney and Marley, 2009). Recent studies reveal that long term exposure to much lower concentrations of combustion-related PM is an important environmental risk factor for cardiopulmonary and lung cancer mortality (Pope et al., 2002). Fine PM emissions have further also been correlated with respiratory and cardiovascular diseases in humans (Sarnat et al., 2008).

2.6.2 Sulfur Dioxide

Sulphur in coal is formed as a result of impurities within the coal itself: mostly from pyrite (FeS_2) (Tzimas et al, 2007). The concentration of sulphur in coal is mainly controlled by the coal age and the location of the coal resource. When coal is burned, about 95 % of sulphur is released as sulphur dioxide (SO_2) (Franco and Diaz, 2009). Significant associations have been found between ambient SO_2 concentrations and hospitalizations for asthma or other respiratory illnesses, particularly for children and the elderly. For susceptible individuals, the inhalation of

SO_2 can cause inflammation of airways, bronchitis, and decreases lung function. Epidemiological studies in European cities have found that long-term exposure to low concentrations of SO_2 are linked to increased risk of developing lung and heart conditions (USEPA[a], 2008).

2.6.3 Nitrogen Oxide

Nitric oxide (NO) and Nitrogen dioxide (NO2) are of primary concern in atmospheric pollution. These two are collectively termed as NOx. Sources of NOx can be divided in different categories. Among them two basic sources of NOx involve combustion of fossil fuel (Seinfeld, 1985):

i. Thermal NOx: Created when N and O in the combustion air are heated to high temperature (>1000 K) to oxidize N.

ii. Fuel NOx: 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 NOx is usually the dominant source.

Almost all NOx 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 can aggravate asthmatic conditions in children and exposure to NO_2 can also increase susceptibility to viral and bacterial infections. In high concentrations it can cause airway inflammation whereas in low concentrations, NO_2 cause decreased lung function in asthmatics (USEPA[b], 2008).

2.6.4 Carbon Monoxide

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

2.6.5 Ozone

O_3 is indirect pollutant from coal-fired power stations which forms when NOx emitted by power stations react with hydrocarbons and carbon monoxide (CO) through a series of photochemical reactions. Exposure to elevated levels of ozone causes acute respiratory symptoms and may cause asthma attacks (Health and Environment Alliance, 2012). As ozone can be transported long distances by wind, it is now recognized as the most important rural air pollutant (Ashmore, 2005; Mauzerall et al., 2005). Ozone also affects sensitive vegetation and ecosystems, including forests, parks, wildlife refuges and wilderness areas. O_3 is also a GHG and therefore contributes to global climate change (Ashmore, 2005).

2.6.6 Mercury

Mercury is a toxic emission from coal-fired power stations and can be released by coal-fired power stations in one of three forms, namely vapor phase elemental mercury, vapor phase oxidized mercury, or adsorbed onto particulate surfaces (Gaffney and Marley, 2009). Mercury is widespread in different ecological zones such as the atmosphere, soil and water. In aquatic systems there is evidence of mercury accumulation with higher concentrations detected in carnivorous fish. The main human exposure pathway to mercury is through fish consumption and inhalation (Zhang and Wong, 2007).

2.7 Emission Control Technologies for Coal-fired Power Plants

Emissions control at coal-fired power stations can take place either before, during or after the combustion of coal takes place. Sulphur and ash can be removed from coal before it is burned whereas the formation of, for instance, NOx emissions can be minimised during the combustion process by modifying furnace processes. Finally, pollutants can be removed from the flue gas stream after combustion but prior to escaping to the atmosphere (Franco and Diaz, 2009).

2.7.1 Pre-combustion cleaning

Pre-combustion cleaning (also called beneficiation) is used to decrease the mineral and ash content in the coal. It can either take the form of physical or biological cleaning. For both processes coal must firstly be crushed and ground into small particles. Physical cleaning separates unwanted matter from coal by relying on differences in physical characteristics such as density, for example. Physical cleaning can therefore only remove matter that is physically

different from the coal. Approximately 30-50% of pyritic sulfur and 60% of ash-forming minerals can be removed by this method. Physical cleaning, however, cannot remove organic sulfur or nitrogen (Cholakov and Shopov, 2001). Biological cleaning is a process whereby suitable bacteria remove impurities from a coal-water slurry. This method is able to remove around 90% of total sulfur (both pyritic and organic) and 99% of ash from the coal; however, this process is still under development and still needs to be tested at commercial scale (Chiang and Cobb, 2000; Cholakov and Shopov, 2001).

2.7.2 PM Control

Primary PM emissions originating from coal-fired power stations are either controlled by means of Electrostatic Precipitators (ESP) or Fabric Filter Plants (FFP) after combustion took place. An ESP works by imparting a charge to particles in the flue gas stream. The particles are then attracted to an oppositely charged collection surface in the form of a plate or tube and removed from this surface to a hopper by means of vibrating or rapping. The effectiveness of an ESP depends on both the electrical resistivity of the particles in the flue gas and on the size distribution of the particles. Flue gas conditioning (by means of injecting Sulphur Trioxide (SO_3)) can be done in order to decrease the resistivity of ash resulting from the combustion of low sulphur coal (Trivedi and Phadke, 2008). ESPs are more effective at removing larger particles (they capture around 99% of total PM) than they are in removing particles that are 2.5 μm or smaller ($PM_{2.5}$) (they are only able to capture 80% to 95% of these particles) (Staudt, 2011).

A FFP removes PM by means of trapping particles in the flue gas before they exit the stack. FFPs are made of woven or felted filter material in the shape of a cylindrical bag or a flat, supported envelope. Included in the FFP system are dust collection hoppers and a cleaning mechanism for periodic removal of the collected particles (Staudt, 2011).

2.7.3 NOx Control

NOx emissions can either be controlled by means of combustion or post-combustion methods. Combustion controls work by minimizing the formation of NOx within the furnace and are usually lower in both capital and operational cost than post-combustion controls. Combustion controls reside within the furnace itself and include such methods as low NOx burners (LNB),

over-fire air (OFA), and separated over-fire air (SOFA) (Staudt, 2011; Moretti and Jones, 2012).

When NOx emissions have to be reduced to a level lower than what is achieved with combustion controls alone, post-combustion controls may be necessary to achieve even lower emissions of NOx. Combustion and post-combustion NOx controls can be (and often are) used in combination. Post-combustion NOx controls include Selective Catalytic Reduction (SCR) (with removal efficiencies of 90% or greater), Selective Non-Catalytic Reduction (SNCR) (with a removal efficiency in the range of 25-30%) and hybrid SCR/SCNR systems (with removal efficiencies greater than SNCR systems are able to achieve). These systems work by means of using ammonia or urea as a reagent that reacts with NOx either on the surface of a catalyst (SCR), in the absence of such a catalyst (SCNR), or a combination of these (SCR/SCNR Hybrid) (Staudt, 2011; Moretti and Jones, 2012).

2.7.4 SO_2 Control

At present, post-combustion SO_2 control is done by means of either wet or dry Flue Gas Desulfurization Plants (FGD). Wet FGD systems are capable of high rates of SO_2 removal. Modern wet systems are capable of SO_2 removal in excess of 90%. In a wet FGD, a lime or limestone slurry reacts with SO_2 in the flue gas stream within a large absorber vessel. Wet FGD systems are both capital and water intensive (Srivastava, 2000; Staudt, 2011).A dry FGD works by means of injecting hydrated lime and water (either separately or combined as a slurry) into a large vessel to react with the SO_2 in the flue gas. The term “dry” refers to the fact that, although water is utilized, the amount of water added is only just enough to maintain the gas above the dew-point temperature. Modern dry FGD systems are able to capture SO_2 at rates of 90% or more (Srivastava, 2000; Staudt, 2011).

2.7.5 Mercury Control

Mercury (Hg) contents in coal vary greatly with coal type and even within coal types. When mercury is released during combustion it becomes entrained in the flue gas stream in one of three forms, namely particle-bound Hg, gaseous elemental Hg, and gaseous ionic Hg. Particle-bound Hg is the species that can be captured the easiest in existing emission control devices, such as FFPs or ESPs as a co-benefit. Ionic Hg is extremely water soluble and is therefore relatively easily captured in a wet FGD. Ionic Hg can also be adsorbed onto fly ash or other

material, and may thereby become particle-bound Hg that is captured by an ESP or FFP. Elemental Hg is less water soluble and less prone to adsorption and therefore the hardest form of Hg to capture. It will remain in the vapor phase where it is not typically captured by control devices unless first converted to another form more readily captured. Activated carbon or halogens can be injected into the gas stream in order to aid the conversion (Staudt, 2011; Moretti and Jones, 2012).

2.7.6 CO_2 control

CO_2 emissions from coal-fired power stations can be controlled by two possible approaches. The first is to reduce the CO_2 emissions per energy unit generated by increasing the thermal efficiency of the power station. The second is through the capture and sequestration of carbon (Marion et al., 2003).

Carbon capture can be done either before, during or after combustion of coal takes place (Kanniche et al., 2009). Pre-combustion capture of CO_2 works by means of capturing CO_2 in a synthesis gas after the conversion of CO to CO_2 takes place. During the combustion process CO_2 can be captured when coal is combusted with near pure oxygen and recycled flue gas or CO2 or water/steam to produce a flue gas consisting essentially of CO_2 and water (Kanniche et al., 2009; Sood and Vyas, 2017). There are several possible methods for removing CO_2 from the flue gas stream after combustion has taken place. These include absorption by amines, different adsorption techniques and the use of membranes, etc. These CO_2 capture methods have significant energy requirements and may reduce a power plant's relative efficiency and net power output by approximately 40%. Approximately 85% to 95% of CO_2 in the gas stream can be removed in this way (Marion et al., 2003).

2.8 Air Dispersion Models

Air quality modeling is an extremely complex phenomenon involving a myriad of factors, including emission of pollutants, atmospheric reactions, and meteorological conditions. The dispersion models employs mathematical and numerical techniques to simulate the physical and chemical processes of air pollutants in the atmosphere. 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. The fundamental aim of the dispersion models is to accurately estimate the

pollutant concentration downwind of any source based on inputs of wide range of meteorological conditions and source information like emission rates and stack height (Yu et al. 2009). There is a range of air dispersion models that have been used in different jurisdictions around the world to treat a wide array of modeling circumstances. They have been developed to assess various source types including point, area, and volume, various terrain (i.e., simple or complex), various locales such as urban, rural, various emission rates include plume, puff and various meteorological conditions. Air dispersion models have many features that cause them to be used in different investigations of air quality. They have the ability to elucidate the interactions of emission sources and the geophysical and meteorological conditions. Moreover, using the dispersion models, it is possible to: determine whether a permissible facility is obeying with state or federal necessities, evaluating where the best location site for an air monitor that reads actual data, etc., and finally, to estimate the possible environmental and health effects due to releases from industrial or trade locations.

2.8.1 Need for air quality modeling

The atmospheric dispersion modeling can be useful in planning and designing urban setup, locating air quality monitoring stations, identifying maximum concentration occurring points. They play vital role in estimating future impact of the proposed expansion of any industrial activity or new industry**.** 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

Modeling of pollutant dispersion is employed for the following two main reasons:

- Modeling can estimate pollutant concentration values at almost all locations wherever air monitoring network is not possible,
- Models can also predict the impact of original sources prior to construction of the facility in addition to how novel pollution control and mitigation devices will influence the generation of the pollutant.

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

2.8.2 Factors effecting dispersion of pollutants in atmosphere

Dispersion, i.e. the transport of pollutants from their source, consist of diffusion and advection processes. It determines whether a pollutant will accumulate or dilute in the atmosphere. Dispersion is influenced by several aspects including weather conditions and local topography (altitude, rivers and streams, etc.). Wind velocity and direction, atmospheric stability and location topography affect plume interaction in complex terrain and cause changes in the transport and dispersion of air pollutants. Drilling, loading and crushing of the ore at both primary and fine crushing plants generate dust which ends up being emitted in the atmosphere. Another possibility of generating dust at the processing plant is wind erosion from coarse and fine ore stockpiles especially during windy conditions. Wind erosion of tailings generates a high quantity of dust at mine. The magnitude of the problem becomes larger during windy conditions

Pollutant dispersion modeling helps as an extensive aid for visualizing the results of these complex interactions and assessing the quantity of ground-level pollution at different distances from origin. Dispersion causes convenient pollutant reduction near the source and harmful pollutant increases at the receptors.

Pollution dispersion in the air is affected by many factors:

- Dispersion from Emission Sources (stationary point, area, or mobile sources such as cars).
- Height of the pollutant emission sources
- Local topographical features Meteorological conditions

- Air Temperature Lapse Rates Atmospheric Boundary layer /Mixing Height Wind speed & direction
- Atmospheric air Inversions
- Humidity & Temperature
- Dispersion Coefficients
- Atmospheric stability

2.8.3 Classification of dispersion models

Air quality models can be classified by mathematical formulation or by objective. One formulation can meet more than one objective, just as one objective can be addressed with more than one formulation. This section discusses mathematical formulations and modeling objectives.

Mathematical Formulations

Each mathematical formulation has inherent assumptions, advantages, limitations, and requirements for its implementation. This section presents information to help you select the formulation most appropriate to the requirements of your modeling study.

i) Empirical or Statistical

An empirical model is an application of mathematics to a series of related data values for the purpose of establishing a relationship among dependent and independent variables. Various types of relationships (e.g., linear, exponential, logarithmic) can be tested to fit the data set. Statistics are applied to determine the values of parameters required for the specific formulation, as well as to estimate how well the resulting equation fits the data (i.e., goodness-of-fit). Also, empirical models are based on mathematics instead of physical science. That is, the relationships developed within the data set may not have connections to principles of physics, chemistry, biology, or other physical sciences. These types of models, therefore, cannot be used to draw conclusions of how processes work in the underlying physical system.

ii) Gaussian

Gaussian models may be expanded in several ways. The surface of the Earth can be a perfect reflector such that any mass from the plume that touches the surface is reflected back up into the plume. Similarly, an elevated inversion layer in the atmosphere can be a perfect reflector.

Some models allow a low level inversion layer below the release height of the pollutant to be a perfect reflector, trapping the plume above the ground. When the low level inversion layer breaks down after sunrise, then the plume is allowed to mix down to ground level in a process known as fumigation.

Also, Gaussian models are not limited to the plume paradigm. Some models have the source emit a series of puffs. Each puff has Gaussian characteristics as it disperses and travels downwind, but now all puffs are forced to travel in the same direction. This allows the model to use varying wind speed and direction within a Gaussian construct.

Steady-state Gaussian plume models should not be applied at distances greater than can be accommodated by the steady state assumptions inherent in such models. This limitation is generally considered to be 50 km. Long-range transport models should be used beyond this distance if a refined model is needed.

iii) Lagrangian

Lagrangian models do not utilize the steady-state assumption. Instead, they are built on probability distributions for wind speed and direction. Therefore, they can support constant, time-varying, and intermittent emission sources. Lagrangian models require more computational resources (i.e., computer memory, CPU speed, and disk storage) than Gaussian models.

Two paradigms of Lagrangian models are particle and puff. In a particle model each particle is separately emitted from the emission source and separately moved throughout the modeling domain based on the probability of wind speed and direction. Each emitted particle may represent the same amount of mass when it is emitted, so more particles are emitted for higher emission rates and fewer particles for smaller emission rates. Deposition can be accommodated by changing the mass represented by a specific particle.

In a puff model each puff is emitted from the source with an initial length, width, and height and containing a specified number of particles, each of which represents the same amount of mass when it is emitted. The particles within the puff are separately moved based on the probability of wind speed and direction, but retain their identity within the same puff. Therefore, the puff changes shape as it moves throughout the modeling domain. A puff may be split into multiple puffs due to impaction with terrain features or buildings. Puffs that occupy the same space may be joined into one puff. Deposition can be accommodated by removing particles from puffs that impact the ground.

iv) Eulerian

Eulerian models are typically used for urban-to-global scale air quality modeling studies and employ five-dimensional data sets. The modeling domain is divided into three-dimensional grid cells, each of which is homogeneous (e.g., a well-mixed reactor). Pollutants are advected between grid cells in the x- and y- directions (horizontal) and the z-direction (vertical), which are the first three dimensions. The fourth dimension is time and the fifth dimension is chemical species.

All relevant chemical species are included in the model in the form of a chemical mechanism. Therefore, Eulerian models are well-suited for full atmospheric chemistry. Some species are handled explicitly in the chemical mechanism, but most species are simulated using species unique to the chemical mechanism.

Eulerian models also require a vast amount of data, which spawns the need for numerous related models and pre- and postprocessors. Eulerian models are, however, customarily used to investigate air quality issues related to tropospheric ozone, $PM_{2.5}$ formation, secondary organic aerosols, and visibility.

Objectives of Models

Many models have been built to meet specific modeling objectives. Therefore, it is important to select a model that meets the requirements of a specific air quality modeling study. This section discusses the types of models that are used most frequently. Examples of models that meet each of these objectives are also presented.

i) Screening

A screening model needs to quickly and easily estimate maximum downwind concentrations from an emissions source of nonreactive pollutants. The model must require less data than a more refined model. The results must be conservative; that is, the model must estimate higher concentrations than those estimated by a more refined model. Therefore, a screening model is typically a steady-state Gaussian plume model.

A screening model should be executed using a source's design capacity (i.e., 100% load), a higher load if the source may be able to operate at greater than design capacity, 75% load, and 50% load, and a range of operating conditions. The goal is to determine a set of conditions that cause the highest downwind concentration.

Examples of screening models are:

- SCREEN3 – This model is available from the USEPA
- AERSCREEN – new screening model under development. When promulgated this model will be available from the USEPA

ii) Local Scale Modeling

Local scale modeling is usually performed for new or expanding industrial sources, large industrial facilities, large construction projects, and major road construction projects. This type of modeling is more refined than screening models.

Local scale models are customarily built using Gaussian principles. Supported types of sources include elevated point (e.g., stack, flare), area, volume, and line. If the model does not directly support a line source, it is simulated as a series of adjacent area sources (e.g., road). These models typically include effects of buildings close to sources on elevated plumes (i.e., building downwash). When modeling the effects of a building on concentration, determine the projected length, width, and height of the building for each wind direction. Either the user's guide or the technical reference manual for the model should provide details on these calculations for the specific model.

Local scale models should also calculate effective plume height, which changes during the simulation based on the difference between ambient temperature and the exit temperature from the stack. The temperature difference causes buoyant plume rise. Exit velocity causes plume rise due to momentum or stack tip downwash due to low exit velocity in high wind conditions.

Examples of industrial source/facility models are:

- AERMOD – This is the most preferred Gaussian model of present time.
- Industrial Source Complex (ISC) – This model changed from a preferred model to an alternative model when AERMOD was promulgated.
- AUSPLUME – This model from the Environmental Protection Authority of Victoria in Australia is derived from the original ISC model (1979). This model supports stack, area, and volume sources in flat terrain with simple winds (i.e., one wind direction in the entire modeling domain each hour).
- AUSPUFF – This non-steady-state Gaussian puff model is by Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO). AUSPUFF uses a three-dimensional meteorology data set.

- Atmospheric Dispersion Modelling System (ADMS 4) – This model from Cambridge Environmental Research Consultants (CERC) supports point, area, volume, line, and jet sources.
- AirWare – This is a large modeling system from Environmental Software and Services of Austria

iii) Source-Apportionment

The purpose of a source-apportionment model is to estimate the relative impact of specific types of sources at a designated location (i.e., a receptor). Also known as receptor models, chemical and physical characteristics of gases and particles that are measured at the source and receptor are used both to identify the presence of and to quantify source contributions to receptor concentrations. Because this type of model is typically based on linear algebra principles, this is a good example of a statistical model.

The primary assumption of source-apportionment models is that each type of source is associated with a unique combination of pollutants that are measured in the ambient air. This unique combination forms a fingerprint for that source type. Examples include gasoline evaporation, diesel truck exhaust, tanker engine exhaust, and painting.

A variety of source-apportionment models are available with differing data requirements, some of which include:

- Chemical Mass Balance model (CMB)
- Unmix
- Positive Matrix Factorization (PMF)

iv) Long-range Transport

Long-range transport models are used when receptors are over 50 km from the source or when the plume of a large facility travels through mountains and valleys. Gaussian-type models are not appropriate for these conditions. Lagrangian or Eulerian models may be suitable for these distances.

Examples of long-range transport models are:

- CALPUFF
- Lagrangian Atmospheric Dispersion Model (LADM)

2.8.4 Model Selection

The study area meteorological factor analysis showed less calm conditions and the terrain is not very complex. So it was proposed to use the particle and grid based models. Of these entire models reviewed AERMOD (American Meteorological Society/Environmental Protection Agency Regulatory Model) seems to be promising. AERMOD is a new generation air modelling system used to support regulatory and nonregulatory modelling requirements worldwide. Hence a comprehensive review of the model was carried out in addition to considering other models.

By using AERMOD or any other advanced models users/industries will be in a position to view, analyze, predict the current impacts and future impacts of the releases from one's facility and effectively devise control technologies and revise repeatedly based on the outcome of the atmospheric dispersion modeling results.

Description of AERMOD

AERMOD is the recommended dispersion model from the USEPA, representing the current state-of-science in regulatory modeling. It is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts. It assumes the concentration distribution to be Gaussian in both the vertical and horizontal. In the convective boundary layer (CBL), the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian Probability Density Function (PDF). The model tracks the dispersion of a pollutant emitted from a source as it travels through space over a defined receptor grid.

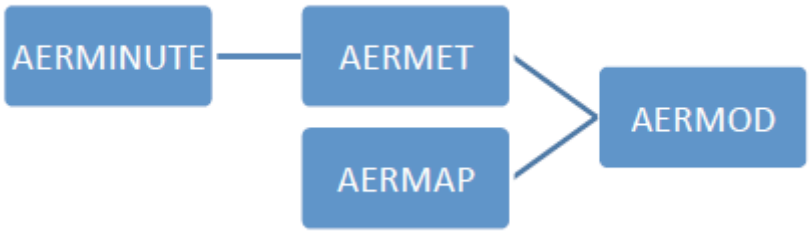


Figure 2.4: AERMOD model framework with preprocessors

The required inputs for AERMOD are: wind speed and direction, temperature profiles, mixing depth, turbulence parameters, plume characteristics, and degree of urbanization. Before these

data are used in AERMOD, meteorological processors are used to format the data. Figure 2.4 depicts AERMOD and the two minimum preprocessors, AERMET and AERMAP, along with an optional preprocessor, AERMINUTE.

AERMET uses meteorological data and surface characteristics to calculate boundary layer parameters and creates two output files: a surface data file and a profile data file. Surface characteristics in the form of albedo, surface roughness and Bowen ratio, plus standard meteorological observations (wind speed, wind direction, temperature, and cloud cover), are input to AERMET. AERMET then calculates the PBL parameters: friction velocity (u*), Monin-Obukhov length (L), convective velocity scale (w*), temperature scale (θ*), mixing height (z_i), and surface heat flux (H). These parameters are then passed to the INTERFACE (which is within AERMOD) where similarity expressions (in conjunction with measurements) are used to calculate vertical profiles of wind speed (u), lateral and vertical turbulent fluctuations (σ_v, σ_w), potential temperature gradient ($d\theta/dz$), and potential temperature (θ).

AERMINUTE, the wind preprocessor is needed for wind speeds that are considered "calm", <1 m/s. Calms are assigned a value of 0 and AERMOD cannot simulate dispersion under missing wind conditions. AERMINUTE processes 1-minute wind data to generate hourly average winds for input to AERMET.

The AERMOD terrain pre-processor AERMAP uses gridded terrain data to calculate a representative terrain-influence height (h_c), also referred to as the terrain height scale. The terrain height scale h_c, which is uniquely defined for each receptor location, is used to calculate the dividing streamline height. The gridded data needed by AERMAP is selected from AERMET and creates a file suitable for use within an AERMOD control file.

Input Data Requirement of AERMOD

AERMOD simulates necessary atmospheric processes and presents the refined pollutant concentration estimates over the modeling domain. As pollutants enter the atmosphere, they undergo various physical and chemical changes prior to reaching a receptor, sometimes resulting with serious effects to people's health and to the environment. So modeling and predicting pollution intensity becomes necessary. For this purpose the required data are as follows:

i) Source data

Location of the power plant, type of source (point, area or line source) emission rates of respective power plants, exit gas velocities etc. constitute the source data. The information on the boiler stack consists of the stack details like height, diameter, exit temperature, flue gas flow rate, plume rise and elevation etc. Information on the sources that considerably result in pollutant concentration at chosen monitoring station is necessary to run the models.

ii) Terrain Data

Terrain and land-use land cover data are necessary for AERMET in order to generate the wind profile fields and additional meteorological factors like:

- Albedo
- Bowen ratio
- Terrain elevations
- Land use categories
- Vegetation leaf area index
- Surface roughness length
- Soil heat flux parameter

These required data were derived from terrain and land use data and processed into individual gridded fields within the modeling domain. Terrain altitudes can hugely affect the pollutant dispersion and deposition and consequently the estimates of potential risk to human health and the environment.

iii) Receptor data

AERMOD computes the concentrations of substances based on user-specified spatial points, commonly referred to as receptors. Receptor selection is critical to capturing the maximum point of impact and proper placement of receptors can be achieved through several approaches.

AERMOD support a variety of receptor types that allow for considerable user control over calculating pollutant concentrations. The major receptor types and grid systems are described in the following sub-sections.

Cartesian Receptor Grids: Cartesian receptor grids are receptor networks that are defined by an origin with receptor points evenly (uniform) or unevenly (non-uniform) spaced receptor points in x and y directions. Figure 2.5 illustrates a sample uniform Cartesian receptor grid.

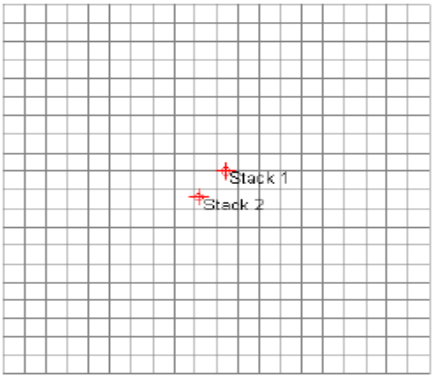


Figure 2.5: Cartesian grid

Polar Receptor Grids: Polar receptor grids are receptor networks that are characterized by an origin with receptor points defined by the intersection of concentric rings, which have defined distances in meters from the origin, with direction radials that are separated by a specified degree spacing. Figure 2.6 illustrates a sample uniform polar receptor grid.

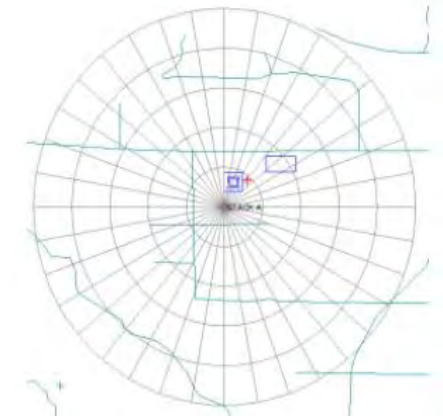


Figure 2.6: Polar grid

Polar grids are a reasonable choice for facilities with only one source or one dominant source. However, for facilities with a number of significant emissions sources, receptor spacing can become too coarse when using polar grids.

Multi-Tier Grids: Each receptor point requires computational time. Consequently, it is not optimal to specify a dense network of receptors over a large modelling area; the computational time would negatively impact productivity and available time for proper analysis of results. An approach that combines aspects of coarse grids and refined grids in one modelling run is the multi-tier grid. Figure 2.7 provides an example of a multi-tier grid.

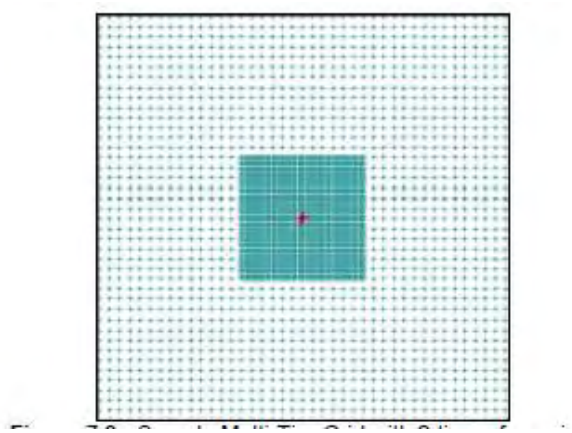


Figure 2.7: Multi-tier grid with two tier spacing

Fenceline Receptors: Receptors must be placed along the plant boundary to demonstrate compliance at the nearest reportable geographical locations to the sources. A receptor network based on the shape of the property boundary that has receptors parallel to the boundaries is often a good choice for receptor geometry. The receptor spacing can then progress from fine to coarse spacing as distance increases from the facility, similar to the multi-tier grid.

Discrete & Sensitive Receptors: Receptor grids do not always cover precise locations that may be of interest in modelling projects. Specific locations of concern can be modelled by placing single receptors, or additional refined receptor grids, at desired locations. This enables the modeler to achieve data on specific points for which accurate data is especially critical. In particular, for elevated receptors the maximum concentrations can be larger than found at ground level. Common locations of sensitive receptors can include, among others, the following: Apartments, Residential zones, Schools, Apartment buildings, Day care centers, Air intakes on nearby buildings, Hospitals, Parks etc.

iv) Meteorological Data

Downwind air pollution concentrations are a function of the meteorological and synoptic measurable parameters. The pollutants transport occurs along the direction of wind known as downwind direction. The pollutants concentration in ambient air is governed by the wind speed, wind direction, relative humidity, temperature etc.

Ambient temperature profile: For the air quality assessments, the maximum and minimum ambient temperatures pertaining to the site account for the variations in possible plume rise. The vertical distribution of temperature in the atmosphere changes with season, location's latitude and longitude, from day to night as well.

Relative humidity: Humidity measurements at the Earth's surface play vital role in meteorological analysis, due to their significance as it represents the changes in state of water in the atmosphere. Relative humidity (RH) is the fraction in per cent of the pragmatic vapour pressure to the saturation vapour pressure with respect to water at the identical temperature and pressure. Evidently, relative humidity is a fraction of tangible amount of water vapour in the atmosphere compared to the maximum water vapour, the atmosphere could hold at that same temperature. RH is inversely proportional to the ambient temperature and is higher at higher surfaces and is lower at ground. RH is maximum at sunrise (minimum temperature) and minimum during late afternoon (Maximum temperature).

Atmospheric stability and Wind characteristics (Wind speed and direction): For dispersion modeling purposes, these levels of atmospheric stability are classified into six classes based on six surface wind speed categories, three daytime insolation types and two night time cloudiness forms (Table 2.3).

Atmospheric Stability serves as measure to analyze the atmosphere's propensity to support or put off vertical motion. The relationships between the ambient lapse rate (ALR) and the dry adiabatic lapse rate (DALR) vitally institute the air stability and the speed with which pollutants can disperse. These stability classes are known as Pasquill-Gifford stability classes (Pasquill, 1961; Gifford, 1961), or categories: very unstable–A; unstable–B; slightly unstable–C; neutral–D; slightly stable–E; stable–F and very stable conditions–G.

Table 2.3: Pasquill-Gifford Stability Categories

Wind Speed (m/s)	Solar Insolation			Night Time	
	Strong	Moderate	slight	Thin overcast or >1/2 low clouds	<3/8 cloudiness
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-4	B	B-C	C	D	E
4-6	C	C-D	D	D	D
>6	C	D	D	D	D

Atmospheric stability is determined by wind and heating effects. In Gaussian models, plume transport/dispersion away from the centerline is characterized by plume dispersion coefficients, σ_y (horizontal) and σ_z (vertical). A, B, and C represent the unstable conditions during daytime hours; stability D denotes the overcast days or nights with neutral conditions, similarly, stabilities E and F suggest nighttime, stable conditions, with class 'A' being the nearly unstable

or mainly turbulent class, and class 'F' the most stable or least turbulent classes (Pasquill, 1961). In general, stability classes F and G are combined into one class, F (Table 2.3).

Wind speed: Wind is the significant meteorological feature in the transport and dispersion of air pollutants, as they move predominantly downwind. Any change in direction of wind over the plume depth (wind shear) will result in a notable lateral dispersion which can contribute to a noteworthy additional effect on the horizontal expanse of the plume. Wind speed records are represented as a wind rose, a graphical depiction of wind speeds and the direction from which the wind blows. Wind roses have 16 spokes representing the directions from which winds blow for the given duration of period. The colors reveal the various categories of wind speeds. The dotted circles convey information concerning the wind speed frequency occurrence and direction classes.

Plume dispersion coefficients (σ_y and σ_z): Dispersion coefficients explain the rate of dispersion of pollutants in the plume in the horizontal and vertical directions (pollutant plume width and height). Horizontal dispersion, also referred to as transport, relating to wind speed and direction and it depends on location, elevation above ground, and to some extent on time of day. Degree of the horizontal dispersion on a given day depends greatly on the synoptic (regional) scale air flow and raises as atmospheric conditions turn into less stable (set out from F to A). Transport of elevated sources is rapid in the nighttime, whereas for low level sources transport is faster during the daytime. As a result the horizontal dispersion of elevated sources exceeds the dispersion from low level sources.

Mixing height: Generally, the meteorological conditions that influence the dispersion prevail in the Planetary Boundary Layer (PBL or Mixing height), approximately at the lower 1000m of the atmosphere. The mixing height (MH) is depth of the boundary layer, which decides the volume available for the dispersion of pollutants and is necessary input data for estimating and forecasting the air quality. The most common methods for determining the mixing height are employment of remote sounding systems, radio-soundings and Parametrization methods. Monin–Obukhov length (L) describes the effects of buoyancy on turbulent flows in the environment, mainly in the lower tenth of the atmospheric boundary layer.

The mixing height is calculated based on the following criteria:

a) During the day, when the Monin–Obukhov Length is negative, it is approximated as the larger of the convective or the mechanical mixing heights.

b) During the night, when the Monin–Obukhov Length is positive, it is equivalent to the mechanical mixing height.

Cloud cover: Cloud cover is the part of the sky obscured by clouds**,** as it is seen from a particular position. Okta is the unit of the cloud cover measurement. Sky cover circumstances are estimated in terms of how many eighths of the sky is covered with clouds, ranging from 0 Oktas (complete clear sky) through to 8 Oktas (completely cloudy). Information of cloud cover levels is used to present estimates of the solar insolation at a specific location

Solar insolation and other data: Depending upon on the equation of the sun's position in the sky throughout the year, the greatest amount of solar insolation on a particular surface at a particular tilt angle can be calculated as a function of latitude and Julian day of the year using surface energy balance method. Radiative Fluxes (Shortwave Radiation, Long wave Radiation) and Turbulent Fluxes (Latent heat flux (e.g. evaporation) Sensible heat flux (heating surface)) are used in approximating solar insolation and satellite data is widely used. Determination of solar radiation and cloud cover is the common practice from satellite images.

Surface roughness length: In the logarithmic wind profile, the roughness length is defined as the height at which wind speed is zero (*z0*). It presents an estimate of the average roughness elements (Topographic features, buildings or vegetation) of the surface. With vegetated surfaces, as the vegetation itself offers a particular amount of roughness, the logarithmic wind profile reaches zero at a height equal to the displacement height plus the roughness length.

Chapter 3
METHODOLOGY

3.1 Introduction

The overall objective of this research was to assess the effect of the operations of the coal fired power plants in Patuakhali on ambient air quality. The power plants considered in this study included: (a) 1320 MW Payra Phase I Thermal Power Plant; (b) 1320 MW Payra Phase II Thermal Power Plant; and (c) coal fired power plants of RPCL, APSCL and SKS, to be constructed in the Patuakhali area, close to the Payra Power Hub. In this study the AERMOD dispersion model has been used to assess the effects of the proposed coal based power plants of Payra Power Hub on the ambient air quality in the surrounding area under different scenarios.

This Chapter describes the methodology followed in this study. At first, this Chapter describes the location of Payra Power Hub in Patuakhali district and its surrounding areas (Section 3.2). This Chapter then describes the methodology followed to generate pollutant dispersion behavior using the AERMOD View 9.6.0 model in addition to meteorological and terrain data processing with its two preprocessors; AERMET and AERMAP respectively (Section 3.3). It also highlights all the data such as source parameters, pollutant type and averaging time options used as input to the model. The Chapter further discusses the procedure followed to estimate the emission rates of pollutants of concern. Finally this Chapter describes the scenarios for which the model was run in order to assess effect of the operation of the proposed power plants on ambient air quality. This Section also describes the parameters considered for simulation of air quality using AERMOD.

3.2 Description of Study Area

The site of the Payra Power Hub is adjacent to the east bank of Tiakhali River and close to the west bank of Rabnabad Channel at Dhankhali village, Kalapara Upazila, Patuakhali District of Bangladesh. The distance between the Site and Patuakhali is about 39 km, and the distance between the site and Barisal is about 78 km. Figure 3.1 shows the project location in a map of Bangladesh. There is no airport, natural park, wildlife sanctuary and places of historical interest near the site at present. The elevation of the Site is about -1.10 m ~ 6.30 m (PWD).

Currently, no highway is connected to the power plant site now. The site can be accessed from R881 via Kalapara Upazila Township to Londa Kheya Ghat (about 10km in length), and after passing through the embankment, an unpaved road (about 6 km in length) leads to the site. On the west side of the site is the Londa Kheya Ghat Pier, which is a small dock for residents on both banks.

Figure 3.1: Location of the Proposed Power Plant (EQMS, 2018)

The physical setting around the Payra Thermal Power Plant project site is described as follows:

- North – Settlements and canal
- East - Settlement
- South – Rabnabad Channel
- West – Andharmanic and Tiakhali River

Land use in the immediate vicinity of the project area is mainly rural. The google image in Figure 3-2 shows the Power Plant footprint area.

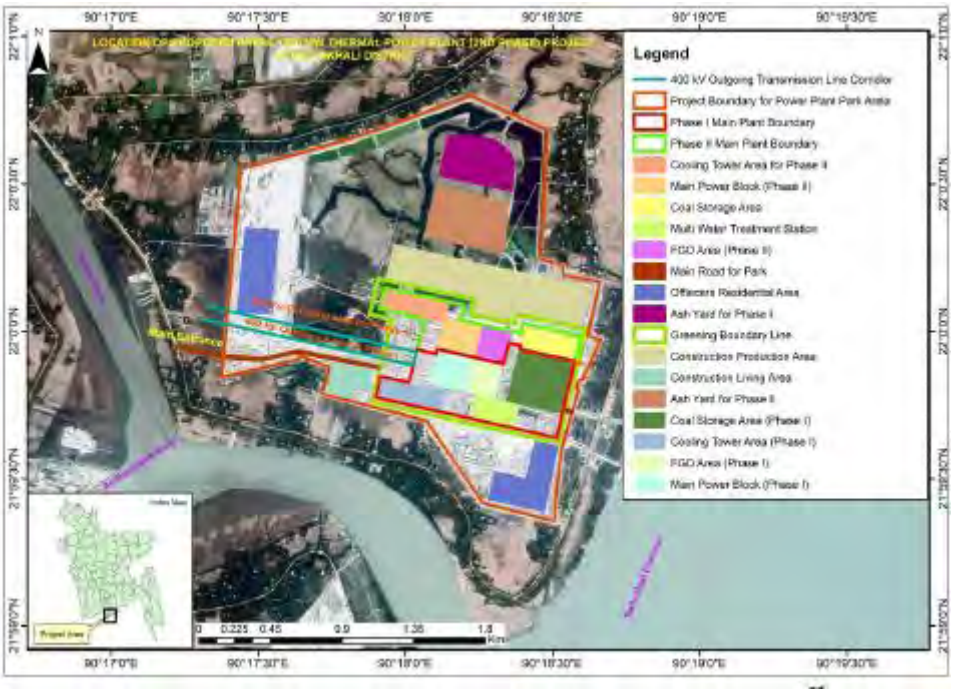


Figure 3.2: Google Image Showing the Payra Thermal Power Plant Footprint Area (EQMS, 2018)

3.2.1 Meteorology

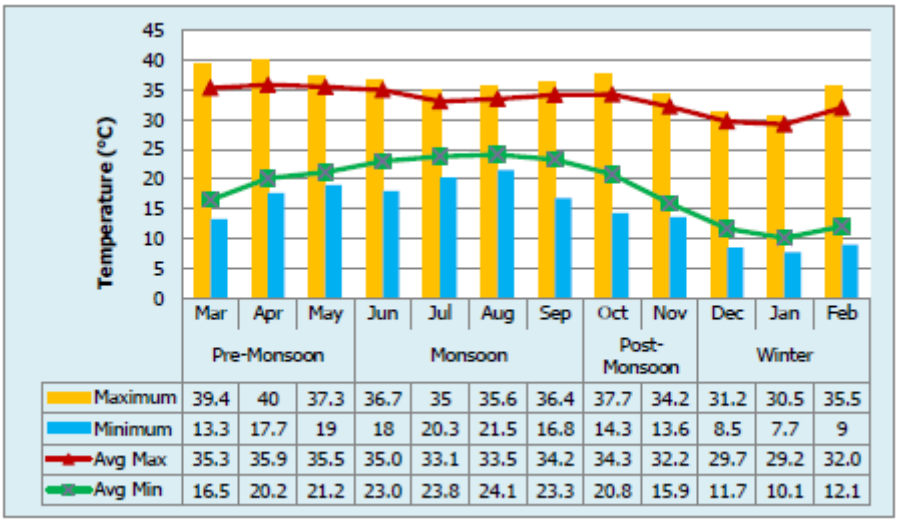
Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures and humidity. There are four distinct seasons in Bangladesh: a short spring from March to May; a cool, rainy monsoon season from June to September; a vibrant, lush green autumn from October to November and a cool, dry winter from December to February. In general, maximum summer temperatures range between 30°C and 40°C. April is the warmest month in most parts of the country. January is the coldest month when the average temperature for most of the country is about 10°C.

The proposed power plant area falls under the tropical climate in the South-eastern climatic zone of Bangladesh. Basically, this region has a distinct monsoonal season which influences all other climatic parameters.

Temperature

The maximum, minimum and average temperatures recorded at the Khepupara weather station are presented below in Figure 3-3. The data analysis of 30 years (1984-2014) shows that monthly maximum temperature varies from 30.5 °C to 40 °C whereas monthly minimum temperature varies from 7.7°C to 21.5°C. The lowest average temperature recorded in the past 30 years was in December 2012 (7.7°C). The highest temperature reached 40°C in April 2014.

Throughout the year the highest temperatures are generally in March through October, and the lowest temperatures are from December to January.



	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
	Pre-Monsoon			Monsoon				Post-Monsoon		Winter		
Maximum	39.4	40	37.3	36.7	35	35.6	36.4	37.7	34.2	31.2	30.5	35.5
Minimum	13.3	17.7	19	18	20.3	21.5	16.8	14.3	13.6	8.5	7.7	9
Avg Max	35.3	35.9	35.5	35.0	33.1	33.5	34.2	34.3	32.2	29.7	29.2	32.0
Avg Min	16.5	20.2	21.2	23.0	23.8	24.1	23.3	20.8	15.9	11.7	10.1	12.1

Figure 3.3: Monthly Maximum, Minimum and Average Temperatures (1984-2014) of Khepupara Weather Station (EQMS, 2018)

Wind Speed and Wind Direction

The study area is prejudiced by the interaction of sea breeze; it has a low topography similar to the sea level. Wind direction and speed exhibit seasonal variation. Winds are generally moderate during non-monsoon season whereas, during the monsoon season, these are moderate to strong. The average wind speed in the study area is 2.72 m/s. Predominant wind speed varies from 1.50-3.50 m/s which is almost 60.1% of the year.

The annual wind rose shows that the predominant wind direction to be SSE to NNW. During pre-monsoon (March-May), the predominant wind direction is north to south, and during monsoon season (June-September) it is SSE to NNW whereas during the post-monsoon (October-November) predominant wind direction is WNW to ESE direction and during the winter season (December-February) it is NNE to SSW.

3.2.2 Baseline Ambient Air Quality

The baseline ambient air quality of the study area was extracted from the EIA report of the Payra Power Plants (EQMS, 2018). Table 3.1 and Figure 3.4 shows the location of the six (6) monitoring stations for two seasons during the monitoring period (January and July 2018). The monitoring parameters included Particulate Matter (PM_{10} and $PM_{2.5}$), Sulfur Dioxide (SO_2), Oxides of Nitrogen (NOx), and Carbon Monoxide (CO). PM_{10} and $PM_{2.5}$, Sulfur Dioxide

(SO_2), Oxides of Nitrogen (NOx) parameters were monitored 24-hourly, whereas CO were monitored for 8 hourly basis during the duration of the study. The results shown in Table 3.2 will be used to determine the cumulative concentration of a certain pollutant at any of these six locations (i.e. by summation of baseline concentration with the predicted concentration from air dispersion modelling).

Table 3.1: Locations of Baseline Ambient Air Quality Monitoring (EQMS, 2018)

Sl.	Sampling Station	Station Code	Geographic Location	Location Setting
1.	Project site (Nishanbari)	AQ1	21°59'36.71"N 90°18'3.29"E	Village and Rural Setting
2.	Londa Kheya Ghat	AQ2	22° 0'40.67"N 90°16'43.35"E	Village and Rural Setting
3.	Dhankhali Union Complex	AQ3	22° 2'17.32"N 90°19'23.42"E	Village and Rural Setting
4.	Tiakhali village	AQ4	21°59'16.74"N 90°16'32.70"E	Village and Rural Setting
5.	Lalua village	AQ5	21°58'26.19"N	Village and Rural
6.	Nishanbari village	AQ6	22° 0'27.59"N 90°18'36.73"E	Village and Rural Setting

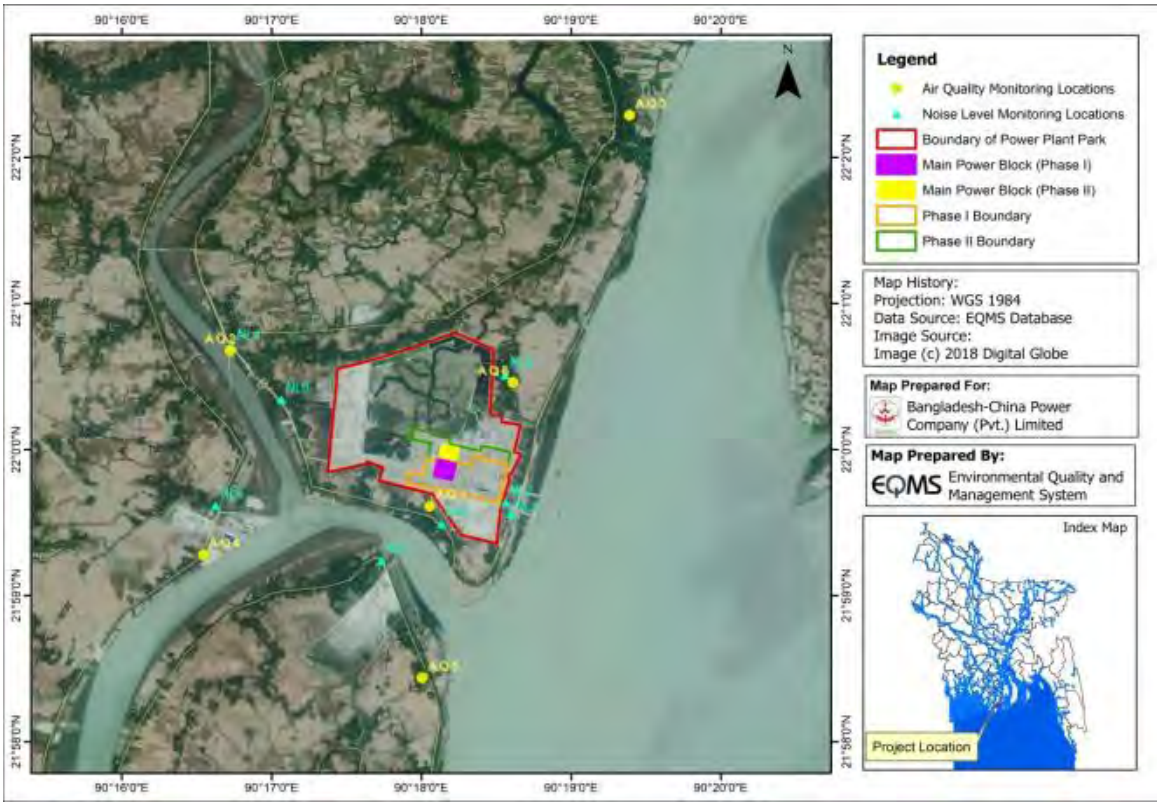


Figure 3.4: Air Quality Monitoring Locations (EQMS, 2018)

Table 3.2: Ambient Air Quality in the Study Area (EQMS, 2018)

SI	Sampling Location	Season	Ambient concentration (µg/m^3)				
			$PM_{2.5}$	PM_{10}	SO_2	NO_X	CO
1.	AQ1	Dry	26.5	62.7	16.8	25.30	1000
		Wet	13.7	59.2	12.1	14.4	750
2.	AQ2	Dry	16.5	81.4	15.2	23.3	1000
		Wet	14.9	57.6	10.1	12.2	750
3.	AQ3	Dry	13.2	66.7	13.8	18.7	750
		Wet	11.8	43.1	8.1	10.5	500
4.	AQ4	Dry	11.6	70.3	14.9	20.2	500
		Wet	10.6	47.2	11.1	14.8	500
5.	AQ5	Dry	12.4	66.9	12.6	18.1	750
		Wet	11.5	44.8	9.4	13.6	500
6.	AQ6	Dry	17.6	54.7	14.5	17.3	500
		Wet	11.8	40.4	10.2	12.8	500
Duration (hours)			24	24	24	24	8
Method of Analysis			Gravimetric method	Gravimetric method	West-Gaeke method	Jacob and Hochheiser method	Digital CO meter

Sampling Date: Dry Period (17-22 January) & Wet Period (19-21 July);
Date of analysis: Dry Period (24 -27 January 2018 & Wet Period (23 – 28 July 2018)

3.3 Air Quality Assessment using AERMOD

In this study AERMOD dispersion model has been used for assessment of the effects of operation of the proposed power plants in Patuakhali on ambient air quality. The basic framework of the model and input data requirements of AERMOD have been presented in Chapter 2. This Section presents the model assumptions, model domain for the present study, and procedure followed for running the model.

3.3.1 Model Assumptions

The main model assumptions considered in this study are as follows:

1) Power plant operation is continuous for twenty-four hours over a 365 day year.
2) Operations are represented at maximum capacity (100% load) in respective power plants.
3) Various control measures are incorporated into the normal day to day operation, which includes low NO_x burner, Electrostatic Precipitator, Flue Gas Desulphurization.
4) Gaussian distribution for pollutant dispersion in both the vertical and horizontal directions.
5) Steady-state condition for each one hour modeling interval; accordingly, for each hour the plume is dispersed in the direction of the given hourly synoptic meteorology in a straight line.
6) Source emission rates are continuous and constant for twenty-four hours and 365 days.
7) All the pollutants liberated into the atmosphere stay in the atmosphere.
8) The boiler stack is modeled as point source.
9) Although AERMOD is capable of estimating building downwash, these effects are assumed to be negligible in current model setup due to absence of tall buildings in the surrounding.

3.3.2 Description of Model Domain

To study the behavior of pollutants released from the power plants, a 30 x 30 km modeling domain (Table 3.3) has been selected, with reference point of the domain positioned at 221997 m Easting, 2436570 m Northing. The reference point was selected such that the emission

sources were located at center of the modeling domain. This domain is in UTM Zone 46Q and encompasses some villages, agricultural, infertile and grazing areas.

Table 3.3: Modeling Domain UTM Coordinates

Model Domain Corners	Lower Left	Upper Left	Lower Right	Upper Right
Easting (m)/ X-Coordinate	207000.65	206990.63	236996.07	236996
Northing (m)/ Y-Coordinate	2421565.38	2451573.45	2421577.65	2451562.83

Figure 3.5 shows a regional view of the modeling area along with terrain elevation contours and topographical view. The land elevation of the study area is in the range 4.0-8.0 m. The distance between the four power plants varied from 2.0 km to 7.5 km.

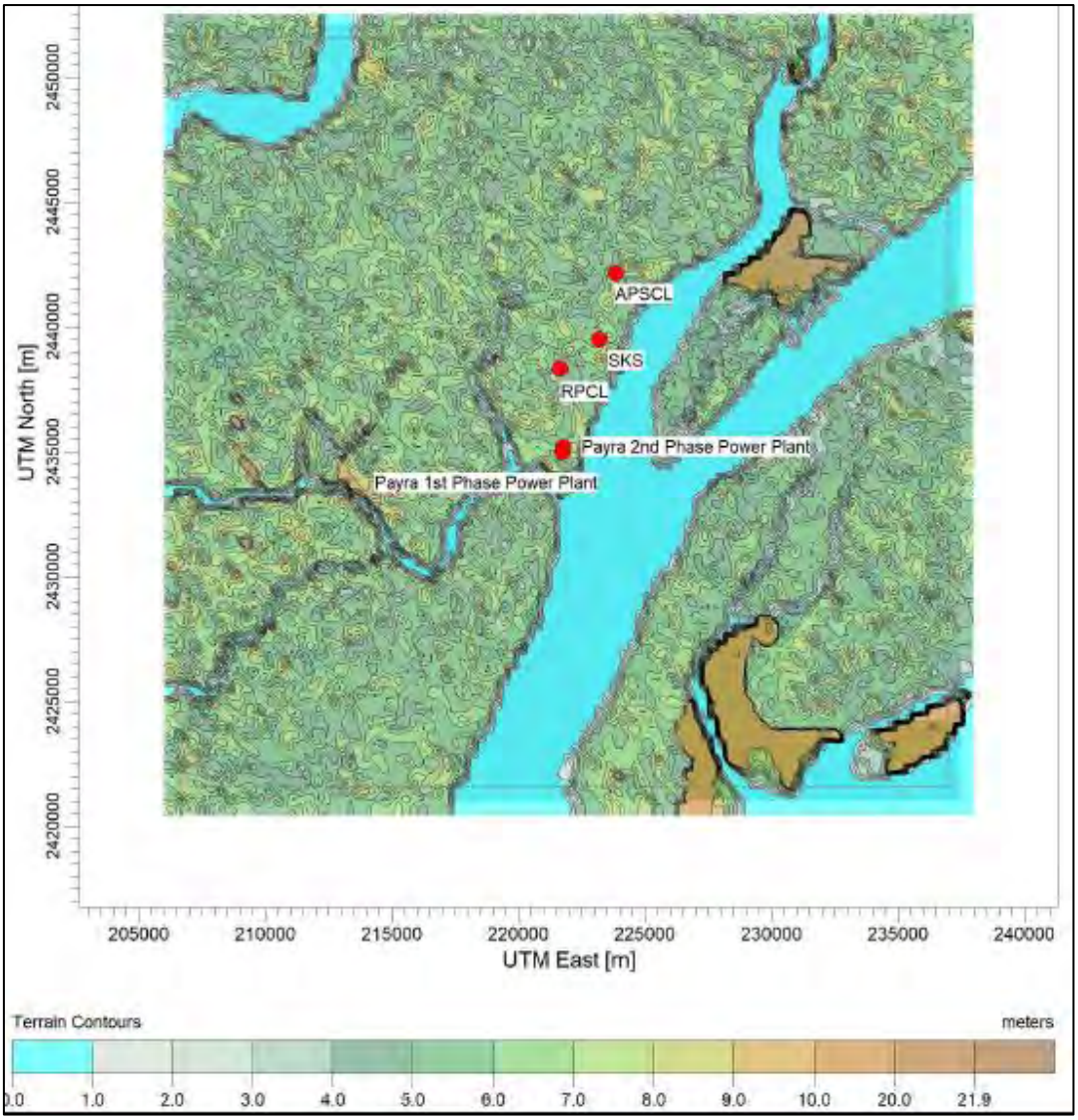


Figure 3.5: Modeling domain with emission sources

3.3.3 Dispersion Modeling with AERMOD View

AERMOD View is the Graphical User Interface (GUI) of AERMOD, built for ease and convenience of the user. It contains three processors namely, AERMAP, AERMET and AERMOD (Figure 3.6). It presumes the pollutant concentration dispersion to be Gaussian in both the horizontal and vertical directions. Also the horizontal distribution in the convective boundary layer (CBL) is assumed to be Gaussian, while vertical distribution is described by bi-Gaussian probability density function of the vertical velocity. Parts of the plume diffusing toward the ground are assumed to be dispersed back away from the ground by turbulent eddies. No variations occur in wind speed or wind direction when transporting from the source to the receptor. AERMOD View assumes that there is no memory of the prior hour's emissions. As

a result, for each hour the plume is dispersed in the direction of the given hourly meteorology in a straight line. It contains a wide array of options for quantifying air quality impacts and modeling of pollution sources.

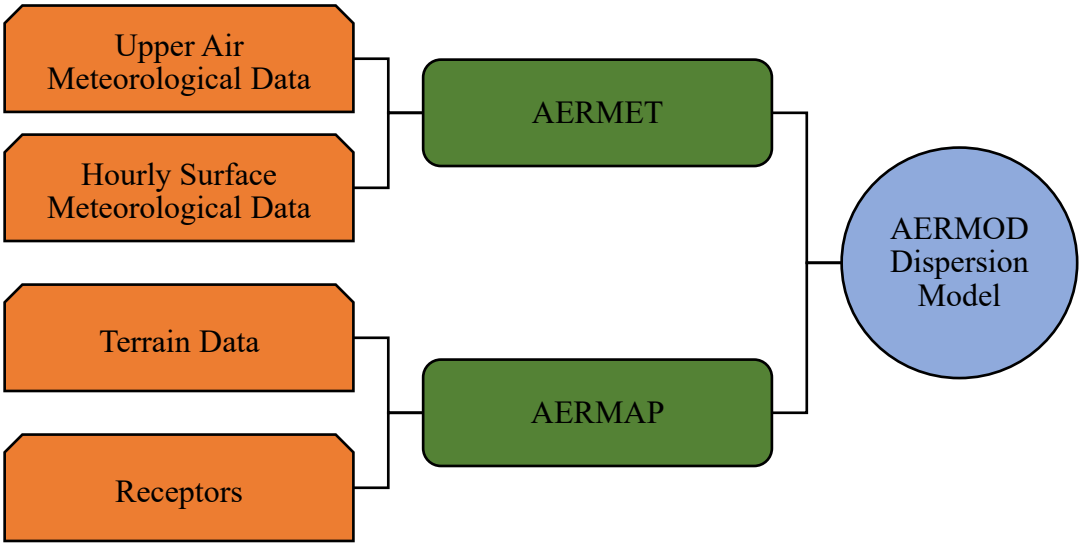


Figure 3.6: Components of AERMOD

3.3.4 AERMAP terrain processing

The terrain elevation data required by AERMAP was obtained from Shuttle Radar Topography Mission (SRTM3), which incorporates the receptor terrain heights and hill height scale. Major terrain heights comprise of all the topography that is by or over a 10% slope from each and every receptor. AERMOD View's software routinely computes the modeling domain depending upon the individual receptor grid being utilized and classifies each 7.5 minute DEM quadrangle that has to be used.

3.3.5 Data processing in AERMET

The input for AERMET is given for representative surface station/onsite meteorological station, in addition to an upper air station. The upper air data set consisted of the following data: Atmospheric pressure in milli bars, wind speed (m/s), height above the ground level (m), wind direction (degrees from the north) and dry bulb temperature (°C). The surface data consisted of single surface hourly data measured at Payra Thermal Power Plant Phase-I. The data included wind speed, wind direction, temperature, humidity, pressure and solar radiation. The meteorological data were processed using the AERMET Pre-Processor in order to get it in

the correct format for model input files. The data flow for AERMET has been presented in Figure 3.7. For this study, one year (2017) meteorological data has been purchased from Lakes Environmental in MM5 version (5th generation Mesoscale Model) which provides two files; Hourly Surface Data File (SAMSON format) and Upper Air Data (TD-6201format).

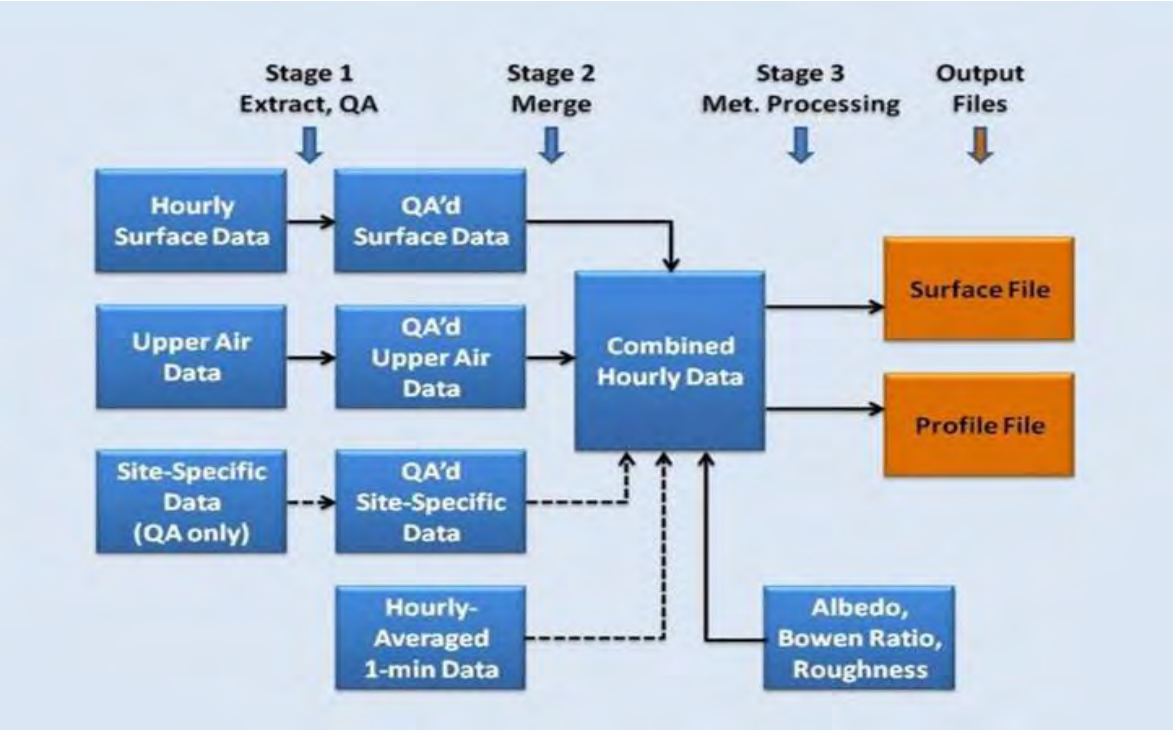


Figure 3.7: AERMET data flow (Li, 2009)

The AERMET generates AERMOD-ready meteorological data files which can be used in modeling analyses. These data were then merged with location specific user-defined values for the Bowen ratio, albedo and surface roughness. These parameters can be varied spatially, over a selection of directional sectors (depending on wind direction) and/or temporally, representing annual, seasonal or even monthly values. AERMET model computes a maximum mixing height, as determined by either convective or mechanical forces in the Convective Boundary Layer. Wind class frequency distribution has been generated in AERMET with the help of WRPLOT View and hourly boundary layer parameters (Figure 3.8). These simulations also estimated primary meteorological parameters and derived meteorological parameters at the site of Payra Power Plant-I.

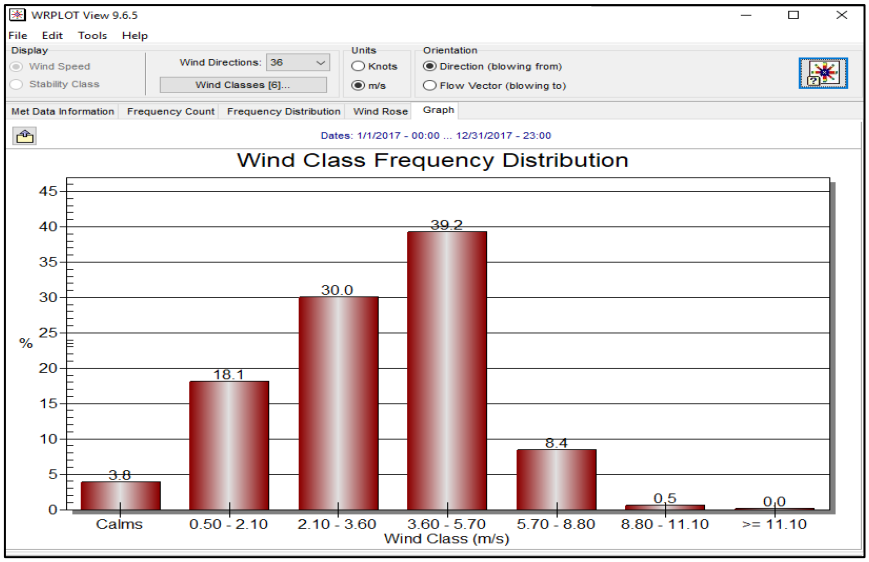


Figure 3.8: Wind Class Frequency Distribution

3.3.6 Running the AERMOD View

First, the Universal Transverse Mercator was selected as project coordinate system. According to the projection system and its corresponding datum, study area lies in WGS-84 corresponding to SRTM3 and the project site comes under the UTM zone 46Q, for the radius of influence of the modeling area selected. Then, the location of the reference point (center of model domain) was selected such that proposed power plants are position at the center of the domain and modeling area dimensions were selected. The entire data of the model domain was then exported to Google earth for obtaining the satellite view of selected area and a base map was generated. Finally, the base map was imported to AERMOD View as the modeling domain. After the simulation run, simulated outputs for all pollutants (hourly, daily, monthly, seasonal and annual) for each scenarios (see Section 3.4) were plotted. AERMOD View modeled pollutant transport and dispersion in the form of temporally averaged air pollution concentrations. The model took care of any missing data related to meteorological conditions in the calm conditions handling routine by putting zero concentration values for that particular hour and averages in short term were computed.

3.3.7 Modeling Procedure

Figure 3.9 shows the data flow and simulation steps in AERMOD. The necessary input data for AERMOD View and the desired output derivatives can be given using the following options.

- Control pathway/options (CO)
- Source pathway/options (SO)
- Receptor pathway/options (RE)
- Terrain Grid Pathway/options (TG)
- Meteorological pathway/options (ME)
- Output pathway/options (OU)

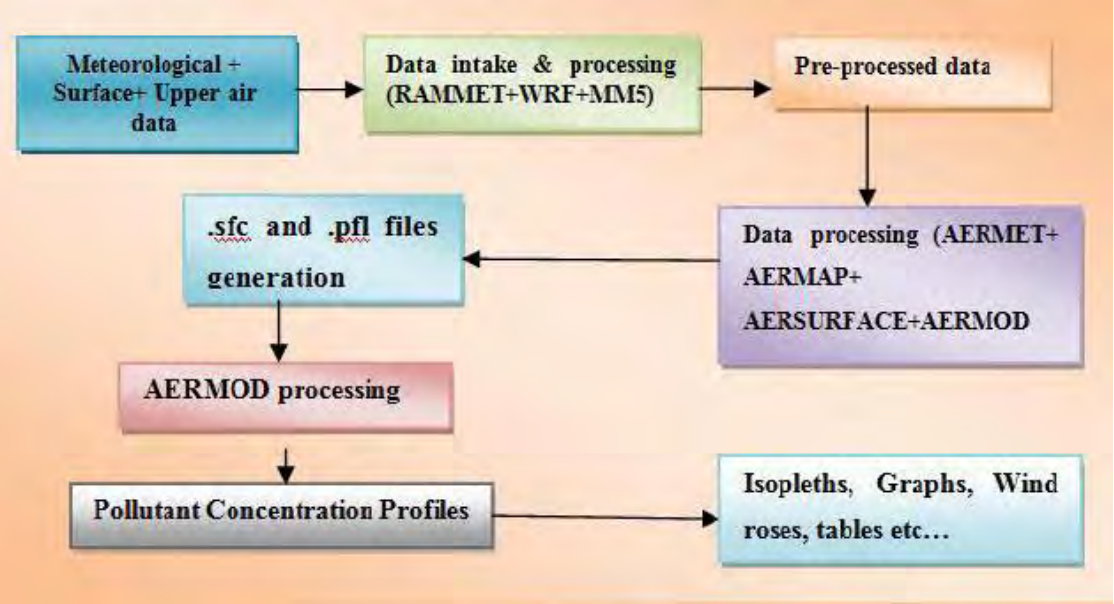


Figure 3.9: AERMOD View data flow (Li, 2009)

The Control pathway explains the modeling set-up and the on the whole control of the modeling run. Source pathway describes the pollutant emission sources location and characteristics. Receptor pathway determines the impact on air quality at particular receptor locations. Meteorology pathway characterizes the atmospheric conditions of the area under modeling, which in turn resolves the dispersion of air pollution and their impacts for the area. Terrain Grid pathway specifies the gridded terrain data and this data is utilized for dry deposition calculations in the terrains of complex or elevated one. The Output pathway gives the kind of output results essential to convene the requirements of air dispersion modeling investigations.

Control Pathway

In control pathway dispersion options (concentration, wet and dry deposition), type of pollutants, pollutant averaging time options, terrain options (elevated, complex- flat and elevated, flat), land use category (urban/ rural) are specified.

The following inputs have been specified for the present study:

- Terrain: Flat
- Pollutants: PM_{10}, $PM_{2.5}$, NOx, SO_2 and CO
- Averaging Periods: 1-hour, 24-hour and annual (depending on the air quality standard of a particular pollutant)
- Dispersion Options: Concentration
- Land Use Category: Rural

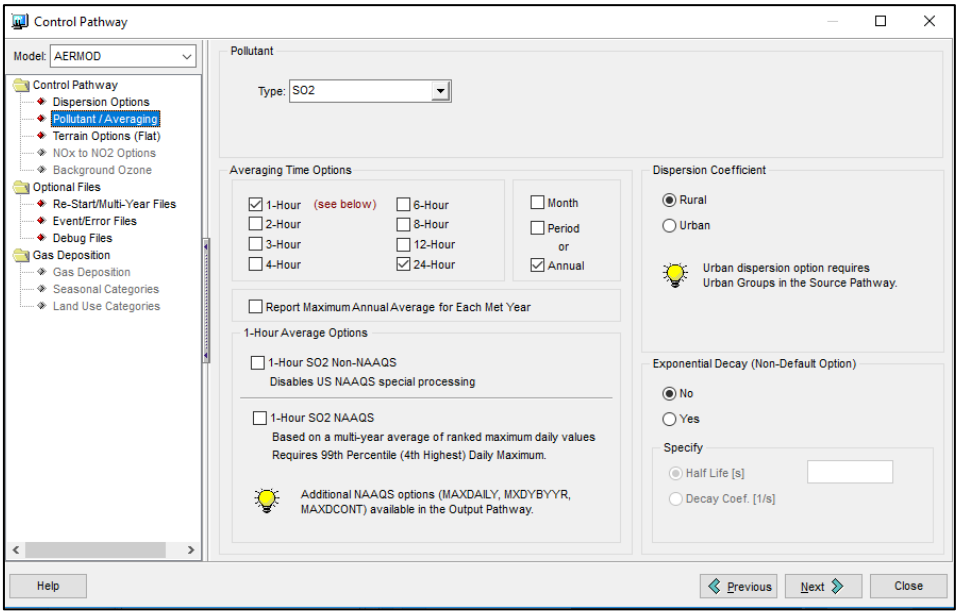


Figure 3.10: Control option specifications used in modeling

Non-default regulatory options for AERMOD View are selected for the model runs (Figure 3.10). The options like the no stack-tip/building down downwash, existing flat terrain effects and calms and missing data handling practices were considered along with the no background concentration.

Source Pathway

Sources of pollutant emissions can be defined here. The model can deal with multiple emission sources (i.e. point, area or/and volume sources). Numerous source groups can be considered in a single run, along with different source contributions come together for each group. Source emission rates are considered as constant during the modeling run time, or varying by hour, day or based on season, annual, or any other required periods.

The study area being located far away from the city, significant urban impacts were nonexistent near Payra power plants. Emission sources and their locations (UTM co-ordinates), emission rate, base elevation, gas exit temperature and velocity, release height, flow rate and stack inside diameter were given as the source pathway input (Table 3.4). The power plant stack locations are presented in Table 3.5.

Table 3.4: Source Parameters for Air Dispersion Modeling Exercise (EQMS, 2015, 2018)

Stack Parameters	Unit	Payra 1st Phase Power Plant	Payra 2nd Phase Power Plant	NWPGCL, APSCL, SKS
Stack Height	m	275	220	275
Stack Number	No.	1	1	1
Stack Internal Diameter	m	7.2	7	7.2
Stack Exit Temperature	K	398	327	383
Exit Velocity	m/s	25	20.4	22
Gas Exit Flow Rate	m^3/s	1104	784	1104

Table 3.5: Stack Locations of Power Plants

Stack	X Coordinate (m)	Y Coordinate (m)
Stack of Payra 1st Phase Power Plant	221727.00	2434983.00
Stack of Payra 2nd Phase Power Plant	221770.00	2435189.00
Stack of RPCL Phase Power Plant	221639.00	2438328.00
Stack of APSCL Power Plant	223847.00	2442143.00
Stack of SKS Power Plant	223182.00	2439505.00

Receptor Pathway

This pathway is utilized to find out the impact of air quality at definite receptor locations. Multiple receptor networks can be specified in a single run and we could as well combine Cartesian and polar grid receptor networks in the same run. Also, receptor coordinates can be specified by the user in either universal transverse Mercator (UTM) coordinate system or any other user coordinate system.

Typical receptor grid spacing was fixed according to following criteria:

- Medium receptor grid: 500 m spacing up to 10 km from Reference Point,
- Coarse receptor grid: 800 m spacing after 10 km from Reference Point,

This multi-tier grid as shown in Figure 3.11 generated 2605 receptors, which is sufficient to resolve the maximum impacts and any potential significant impact areas. Caution was taken such that coarse grid was placed over the entire chosen modeling field, but with denser grid where higher impacts are expected i.e., within 10 x 10 km area from the modeling grid reference point.

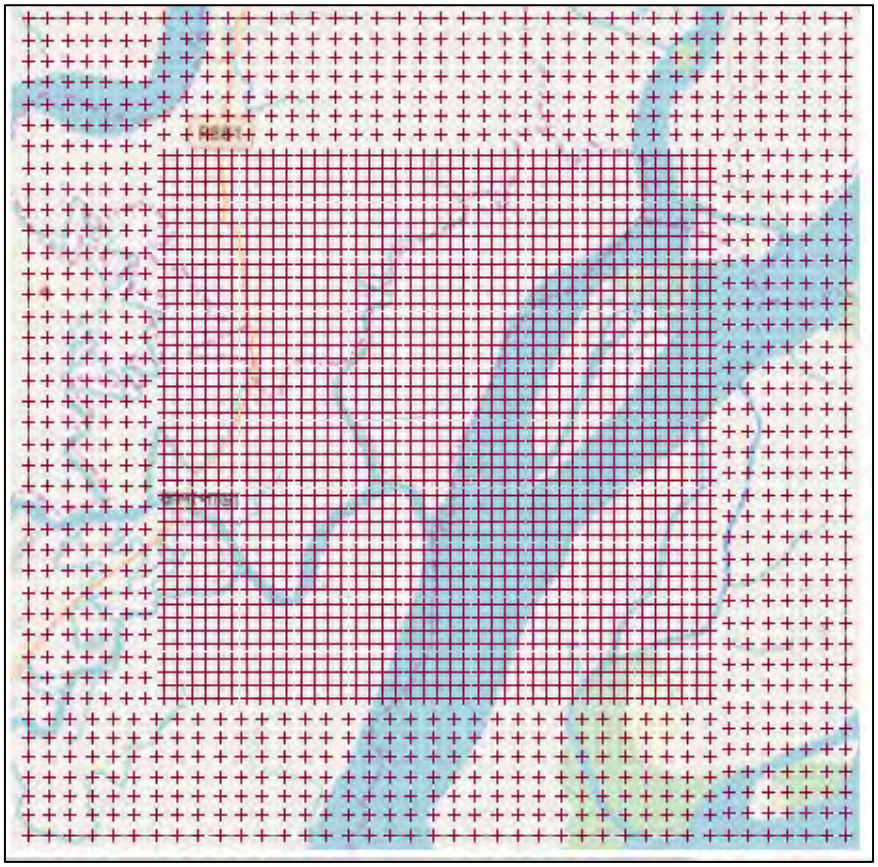


Figure 3.11: Multi-tier grid of modeling domain

In addition to the Cartesian grid receptor, 6 discrete and air sensitive receptors (D1-D6) were selected which correspond to the six baseline ambient air quality sampling sites (Table 3.6 and Figure 3.12). Concentrations of air pollutants were predicted at these receptors too.

Table 3.6: Discrete receptor location and other information

ID	Discrete Receptors	X-Coordinate (m)	Y-Coordinate (m)	Base elevation (m)
D1	Project site (Nishanbari) (AQ1)	221310.70	2434570.00	8.37
D4	Londa Kheya Ghat (AQ2)	219051.80	2436579.30	7.09
D6	Dhankhali Union Complex (AQ3)	223696.80	2439472.10	9.19
D5	Tiakhali village (AQ4)	218700.10	2434002.10	7.38
D3	Lalua village (AQ5)	221185.50	2432402.00	8.25
D2	Nishanbari village (AQ6)	222297.90	2436119.20	8.77

Figure 3.12: Location of Discrete receptors

Elevations of receptors were taken from the Shuttle Radar Topography Mission (SRTM3) with a resolution of 3 arc-second (90 meters) for Bangladesh issued by the USGS, based on the World Geodetic System 1984 (WGS-84). This SRTM3 data was processed with AERMAP in

combination with receptors layout of and emission sources taken for modeling. The terrain elevations of all receptors and sources were run in AERMAP model. AERMAP extracted digital terrain data from USGS website for the particular study area. The processed terrain data was imported and AERMAP was set to run again. After this model run was completed, elevations of the sources and receptors were imported to the model.

Meteorological Pathway

This pathway is intended to utilize for giving input data related to meteorological conditions and additional meteorological parameters, as well as period to be processed from the meteorological file. The parameters given as input to AERMET are: Hour, Day, Month, Year -2017, Local Pressure (mbar), Global Horizontal Radiation flux (Wh/m^2), Wind Direction (deg), Cloud Cover (tenths), Wind Speed (m/s), Relative Humidity (%), Ceiling Height (m), Dry Bulb Temp (°C), Hourly Precipitation (1/100th of an inch) etc.

Surface and raw upper air data for the year 2017 were obtained from the Lakes Environmental databases. AERMET preprocessed these files to produce two files for input into AERMOD. The surface met file (*.SFC) contains observed and calculated surface observations, boundary layer scaling parameters and reference-height winds and temperature. The profile met file (*.PFL) contains one or more levels (profile) of winds, temperature, and the standard deviation of the fluctuating components of the wind. These files are arranged such that every receptor block of data holds all of the observations for a 24 hour period.

Terrain Grid Pathway/options (TG)

In Terrain Grid pathway, we can specify grid data. The terrain elevations of all receptors and sources were run in AERMAP model. AERMOD View simulated the plume dispersed in horizontal direction in stable conditions as well. The predicted results were exported to obtain a natural view of the isopleths. This feature was useful to observe to what degree the pollutants are dispersed around the emission source with satellite imaging. Gridded terrain data is required in computing deposition in flat, elevated or complex topography is processed here.

Output Pathway

The isopleth plots are the plotted contours of constant ground level pollutant concentrations that reflect the pollutant dispersion with respect to distance, time and topography; Figure 3.13 shows the plot for SO_2 24-hr average plume as an example.

Maximum estimated GLC (Ground Level Concentration) for the specified time period, over the whole duration were also obtained from these isopleths. These isopleths imply that, even if a maximum every day concentration is predicted to transpire at distinct receptors, it will only be true for that one day in the total simulation duration. For all the pollutants, isopleth plots were created, entailing only the worst-case scenario (highest predicted GLCs) for all significant averaging periods.

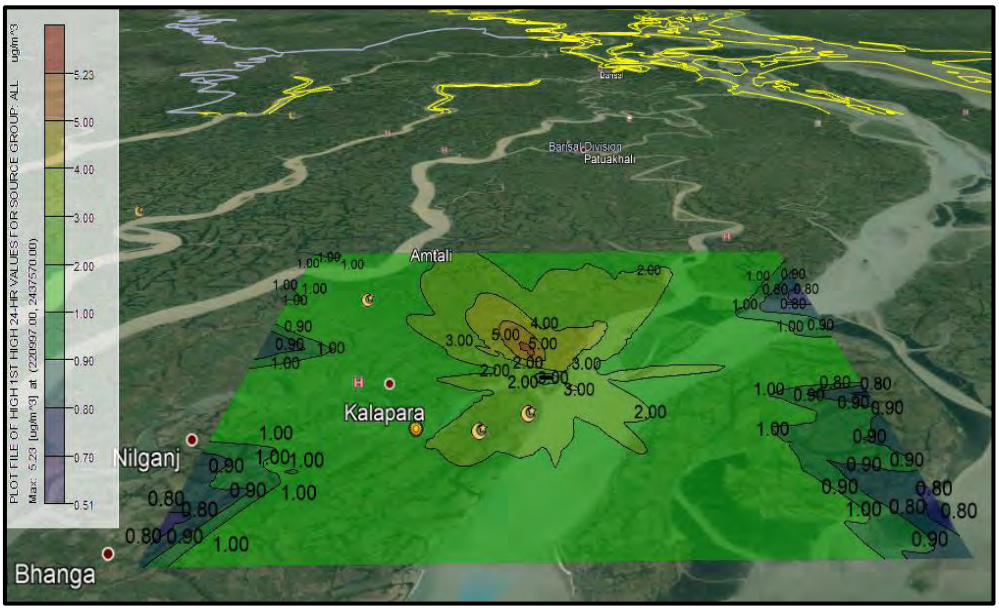


Figure 3.13: A plot showing SO_2 24 hr average plume for the operation of Payra Phase I Power Plant

3.4 Estimation of Emission Rates from the Power Plant

The proposed ultra-supercritical bituminous/ sub bituminous pulverized coal (PC) plants are designed to meet Best Available Control Technology (BACT) emission limits. The primary fuel will be bituminous/sub bituminous coal with a Gross Calorific Value (GCV) of 4700 to 5500 kcal/kg. Even though each power plant has same electricity generation capacity (1320 MW), the coal consumption varies from 4,823,256 Ton/year (Payra Power Plant Phase-II) to 5,546,905 Ton/year (Payra Power Plant Phase-I). Considering the safety of surrounding ecosystem and public health and safety, the specification of the coal has been selected. The specification defined average sulfur content 0.47 %, maximum moisture content 13.57% and gross calorific value as 4700- 5500 Kcal/kg. Specification of the coal considered for the power plants is given in Table 3.7.

Table 3.7: Specification of coal considered for the Payra Power Plants (EQMS, 2018)

Specification	Symbol	Unit	Design Coal (Indo 6)
Calorific Value			
Gross Calorific Value (AD)	GCV	Kcal/kg	5550
Gross Calorific value (AR)	GCV	Kcal/kg	4523
Element Analysis			
Base carbon as received	Car	%	46.59
Base hydrogen as received	Har	%	3.49
Base oxygen as received	Oar	%	14.43
Base nitrogen as received	Nar	%	0.84
Base total sulfur as received	St, ar	%	0.47
Base ash content as received	A, ar	%	4.68
Total moisture as received	M, ar	%	29.50
Total		%	100

There are two general types of emissions from the power plants: particulate matter and hydrocarbons and combustion products such as SO_2, NO_x. An emission inventory has been compiled using the emission estimation equations from the USEPA emission factors from AP-42 manual. These emission rates were subjected to various emission control technologies such as (FGD, ESP, Low NOx burner etc.) which resulted in conservative predictions. In this study, various levels of efficiency of the control technologies were considered in the model simulated, which has been described in Chapter 4. The basic model was run assuming 90%, 99.2% and 45% efficiency of FGD, ESP and Low NOx Burner, respectively. Emission rates were assumed to be constant over each 24 hour period and converted from Ton/day to g/s emission rates for each hourly modeling run.

Estimation of SO_2 Emission Rate

AP-42 Manual of USEPA for 'External Combustion Source' formulates a range of emission factors based on coal firing conditions. The SO_2 emission factor for pulverized coal, dry

bottom, wall-fired, bituminous, Pre-NSPS (New Source Performance Standards) condition, considered in this study, is presented as follows:

Emission factor for SO_2 = 38S (lb/ton)

where, S = Sulfur content in coal expressed as percent weight

The emission factor is then multiplied by ton of coal consumed per day and efficiency of the FGD to estimate the actual emission rate of each plant. As Payra Power Plant Phase I and II considers distinct rate of coal consumption, each plant has specific emission rate. However, as the rate of coal consumption for NWPGCL, APSCL and SKS Power Plants are yet to be decided, these power plants are assumed to have emission rates similar to Payra Power Plant Phase I. Thus,

Emission rate = 38S (lb/ton) * Coal consumption (ton/day) * Efficiency of FGD

Estimation of NO_x Emission Rate

The emission factor for NOx has been calculated considering pulverized coal, dry bottom, wall-fired, bituminous, Pre-NSPS (New Source Performance Standards) with low NOx burner (LNB). LNB can achieve approximately 35 to 55 percent emission reduction from uncontrolled levels (USEPA, 1995). This study considers 45 percent efficiency of LNB while estimating emission rate for all power plants. The emission factor for NOx is as follows:

Emission factor for NOx = 11 (lb/ton)

The emission factor for NOx is thus independent of the characteristic of coal consumed in the power plant. However, estimation of emission rate is similar to SO_2. Thus,

Emission rate = 11 (lb/ton) * Coal consumption (ton/day) * Efficiency of LNB

Estimation of $PM_{2.5}$ and PM_{10} Emission Rate

The US EPA formulates emission factor for $PM_{2.5}$ and PM_{10} for both uncontrolled and controlled condition. The controlled emission rates account for various emission control technologies (e.g. ESP, Scrubber, Baghouse, etc.) incorporated in the power plant and their subsequent efficiency level. As the power plants in Payra proposes installation of ESP the following equations have been used:

Emission factor for $PM_{2.5}$ = 0.024A (lb/ton)

Emission factor for PM_{10}= 0.054A (lb/ton)

where, A = Ash content in coal expressed as percent weight

Thus, the particulate matter emission from power plants is governed by ash content of the coal consumed. Emission rate is expressed as a product of emission factor and coal consumption rate, since efficiency of ESP has already been considered in the emission factor.

Estimation of CO Emission Rate

The rate of CO emissions from combustion sources depends on the fuel oxidation efficiency of the source. By controlling the combustion process carefully, CO emissions can be minimized. For aforementioned coal firing condition, USEPA formulated emission rate for CO is as follows:

Emission factor for CO = 0.5 (lb/ton)

Since no emission control technology has been adopted for curbing CO concentration, the emission rate is a product of emission factor and rate of coal consumed.

3.5 Scenarios and Pollutants Considered

To assess the impact of emissions from power plant on the ambient air quality various scenarios have been simulated considering certain pollutants that has adverse effect on the surrounding environment. The following sections provide a brief description of the scenarios and pollutants considered in this study.

3.5.1 Scenarios Considered

The air quality in the vicinity of the power plants have been predicted using the dispersion model AERMOD under three different scenarios:

i. Only Payra Phase I Plant (1320 MW) in operation. The 1st unit (660 MW) of this power plant is expected to begin operation by December, 2019 and the 2nd unit shall begin power generation by June, 2020.
ii. Payra Phase I and Phase II plants (each 1320 MW) are in operation. The 1st and 2nd unit of this power plant is expected to initiate electricity generation by December, 2021 and June, 2022 respectively.
iii. Payra Phase I, Payra Phase II, and three other coal-based power plants are in operation. It should be noted that implementation of the other coal-based power plants in the Patuakhali area are currently at a preparatory stage.

These three scenarios have been modeled to delineate the trend of deterioration of ambient air quality with time. Moreover, while conducting Environmental Impact Assessment for power plants, concentration of pollutants emitted from the nearby existing power plants is rarely considered. This study, thus, aims to reflect the individual as well as the cumulative impact that multiple power plant emissions impose on the air quality in the surrounding region.

3.5.2 Pollutants Considered

Emissions from the power plant are a serious concern especially for the coal based power plant project. Potential pollutants of concern released from the proposed coal fired power plant are Sulfur Dioxide (SO_2), Nitrogen oxides (NOx), Particulate Matter ($PM_{2.5}$ and PM_{10}) and Carbon Monoxide (CO). The amount of SO_2 released is dependent on the properties of the fuel, the higher the sulfur content of the fuel, higher the amount of SO_2 will be released. High levels of SO_2 can lead to acid rain, which damages crops, forests, and soils, and acidifies lakes and streams. Combustion of coal can also be a significant source of particulate matter. Ash is the main source of particulate maters. Coal-fired power plants also tend to release a significant amount of particulate matter in the form of soot and fly ash. The formation of thermal NOx is dependent on 3 factors during combustion; (i) oxygen concentration, (ii) peak temperature, and (iii) time of exposure at peak temperature. Fuel combustion releases NOx which is composed of NO and NO_2. NO_2 is of particular concern and is considered a criteria pollutant. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO_2 is linked with a number of adverse effects on the respiratory system. The rate of CO emissions from combustion sources depends on the fuel oxidation efficiency of the source. Significant health risks are associated with high levels of ambient NO_2, CO and $PM_{2.5}$ concentrations.

Chapter 4
RESULTS AND DISCUSSIONS

4.1 Introduction

The objective of this research was to assess the effect of the operations of a number of coal fired power plants in Patuakhali on ambient air quality, using AERMOD dispersion model. This Chapter presents the results of the model simulations and discusses the effects of operation of the power plants on ambient air quality under different scenarios (as presented in Chapter 3). . This Chapter first presents the emission rates of different pollutants from the power plants considered in this study. Then the results of the model simulations under different conditions have been presented and discussed. Specifically, this Chapter presents the spatial variation of pollutant concentration of due to operation of the power plants under three scenarios, and also presents an evaluation of compliance with Bangladesh and WHO air quality standards. The seasonal and diurnal variation of pollutants have been illustrated and its correlation to meteorological factors have been presented and discussed. The effect of various parameters such as height of chimney, efficiency of emission control technology, quality of coal on ground level concentration have also been analyzed. Finally, cumulative impact of the operation of the power plants on ambient air quality have been analyzed to assess the extent of impact on the people living in the vicinity of the power plants.

4.2 Emissions Rates from Power Plants

The emission rates of pollutants have been calculated using the emission factors from AP-42 manual for external combustion source formulated by USEPA (Section-3.4). The emission rates are subjected to emission control technologies, characteristics of coal and rate of coal consumed per day, hence each power plant possess distinct pollutant emission rates. However, as NWPGCL, APSCL, SKS power plants are still in preparatory phase information on adopted emission control technologies, coal specification and amount of coal consumed per day is not available yet. Thus, an assumption has been made that these three power plants have emission rates similar to that of Payra Power Plant Phase-I. The calculated emission rates of the pollutants for respective power plants are presented in the Table 4.1.

Table 4.1: Emission rates of criteria pollutants

Pollutants	Payra Power Plant Phase-I (mg/Nm^3)	Payra Power Plant Phase-II (mg/Nm^3)	Power Plants by NWPGCL, APSCL, SKS (mg/Nm^3)	Bangladesh Standard (ECR 1997)
SO_2	129.0	158.0	129.0	200
NO_x	437.0	535.4	437.0	350
PM_{10}	18.3	28.7	18.3	50
$PM_{2.5}$	8.11	12.8	8.1	50
CO	36.1	44.2	36.1	-

Environmental Conservation Rules 1997 specified emission standards for sulfur dioxide, nitrogen oxides (as NO_2) and particulate matter emissions from thermal power plants are 200 mg/Nm^3, 350 mg/Nm^3 and 50 mg/Nm^3 respectively. Even though, sulfur dioxide and particulate matter emissions are in compliance with the standard, nitrogen oxide emissions exceeds the standard notably. Thus, other emission control technologies (e.g. de-nitrification) should be incorporated along with low NOx burner to meet the emission standard.

4.3 Spatial Distribution of Pollutant Concentration

In this study, the dispersion of SO_2, $PM_{2.5}$, PM_{10}, NO_x and CO has been simulated under three prospective scenarios:

(1) Only Payra Phase I Plant (1320 MW) in operation.
(2) Payra Phase I and Phase II plants (each 1320 MW) are in operation.
(3) Payra Phase I, Payra Phase II, and three other coal-based power plants are in operation.

In this study, hourly, daily and annual concentrations were predicted using AERMOD at each of the 2,605 receptors within the model grid assuming that each power plant is operational all year round. In these simulations, it was assumed that the proposed emission control technologies are in full and perfect operating condition; the efficiency level of FGD, ESP and low NOx burner being 90%, 99.2% and 35% respectively. The stack height is assumed to be 275 m for Payra Power Plant Phase-I and the three proposed power plants, whereas, 220 m has been considered for Payra Power Plant Phase-II.

Concentration contours are very important in determining the spatial distribution of pollutants (SO_2, $PM_{2.5}$, PM_{10}, NO_x and CO) over the modeled area. From model predictions, concentration contours were generated, and these contours have been used to determine the spatial and temporal locations for which the Bangladesh Standard and WHO guideline value for any pollutant concentration is approached or exceeded under the different scenarios. The following sections discusses the spatial distribution of pollutants for the different scenarios considered in this study.

4.3.1 Scenario I: Only Payra 1st Phase Power Plant in Operation

Figures 4.1, 4.2, 4.4, and 4.5 show the iso-concentration curves of the pollutants over the grid area, computed over an hour, one day and one year, respectively. The iso-concentration curves have been plotted for an hour, one day and one year to compare among the three future scenarios. These curves were derived from the model computation for each hour. The concentration of a given pollutant was considered at all grid points, while only the highest of the 8,760-hour (1 year) results at each grid point or receptor was used in the plots. Thus, for one-hour average, only a single hour with the highest predicted concentrations at the receptors during the modeled year were used to generate the iso-concentration time curve at each grid point. These concentrations do not represent the concentrations at a specific time; rather represent only the extreme pollution levels at the grid points or receptors during the 1-year study period.

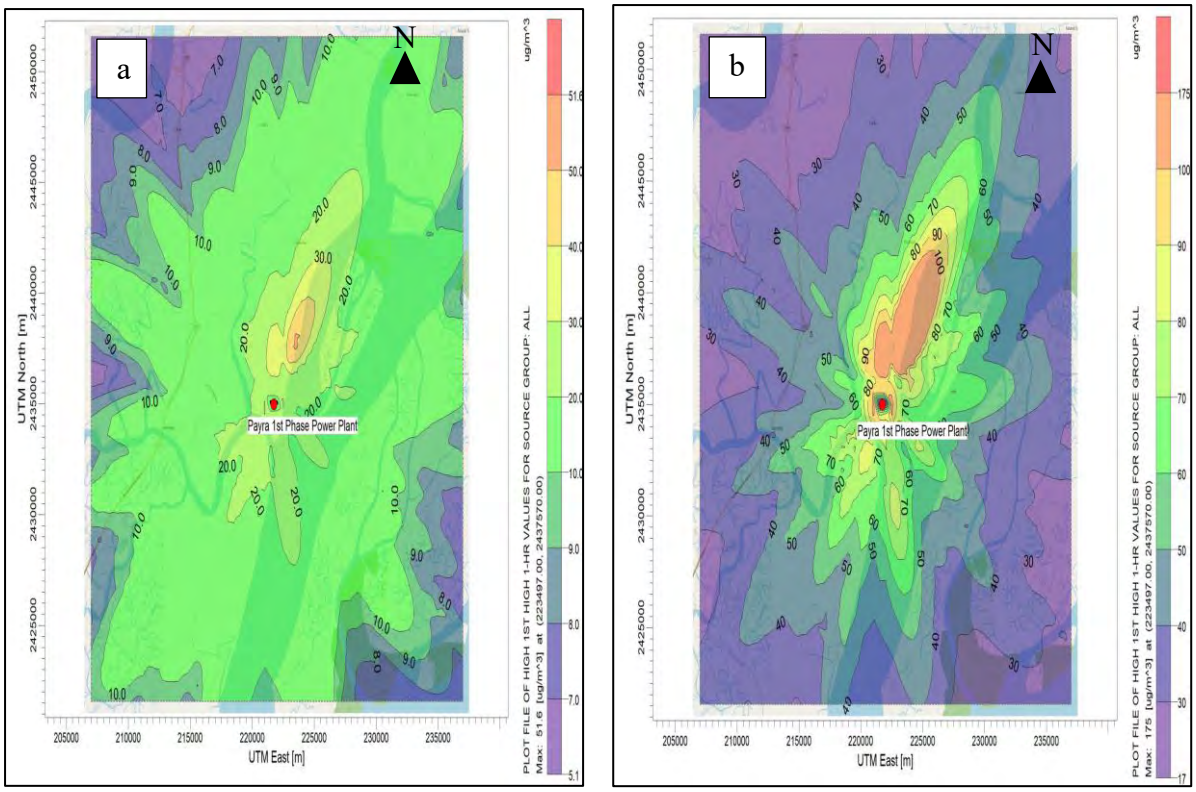


Figure 4.1: Hourly iso-concentration (µg/m^3) curves of (a) SO_2 and (b) NO_x (the red dot identifies the location of the Payra Phase I power plant)

The hourly iso-concentration curves of SO_2, NOx, $PM_{2.5}$, PM_{10} and CO (Figure 4.1 and 4.2) follows the same pattern of pollutant dispersion, and the maximum concentration of each pollutant occurs at the north-eastern direction of the power plant site. For each of these pollutants, the peak concentration is reached on 15th April 2017 at 07:00 p.m. The result is in agreement with the dominant SWS wind in the project area as can be seen from the wind rose diagram of 15th April presented in Figure 4.3. From Figure 4.1 and 4.2, it appears that the ground level concentration of the pollutants is proportional to the respective emission rates; NOx, which has the maximum emission rate, also has the maximum peak concentration and dispersion radius among the pollutants. Peak one-hour concentrations of SO_2, NOx, $PM_{2.5}$, PM_{10} and CO have been found to be 51.6, 175, 3.47, 7.81 and 15.4 µg/m^3 respectively. Among these pollutants, only CO has one-hour standard (40,000 µg/m^3 in Bangladesh air quality standard, 10,000 µg/m^3 in WHO Standard); the predicted peak one-hour concentration of CO (due to operation of the power plant) is much lower than this standard. However, monitored one-hour CO concentration (500-1000 µg/m^3) was found to be significantly higher than the predicted peak concentration.

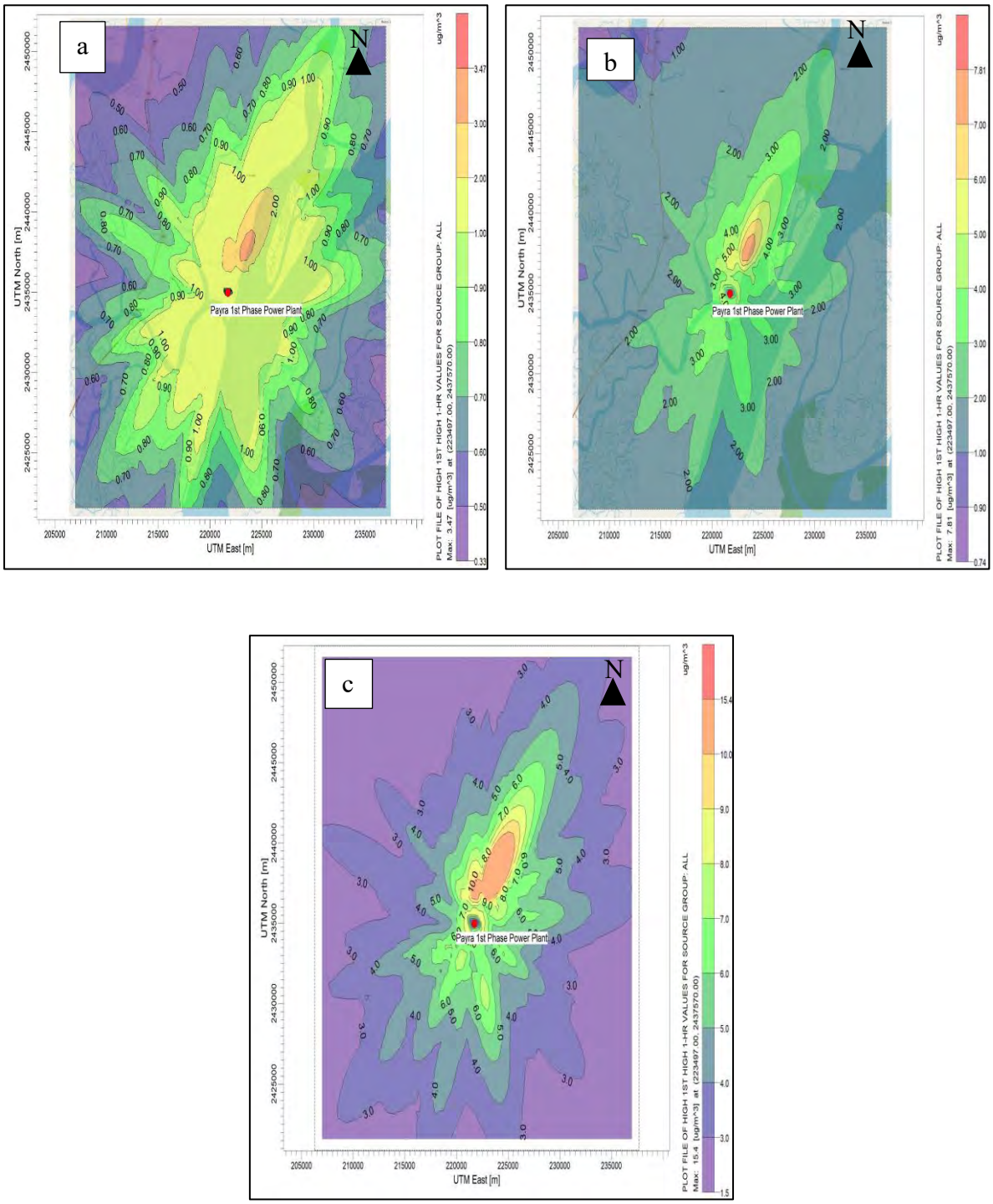


Figure 4.2: Hourly iso-concentration ($\mu g/m^3$) curves of (a) $PM_{2.5}$, (b) PM_{10} and (c) CO (the red dot identifies the location of the Payra Phase I power plant)

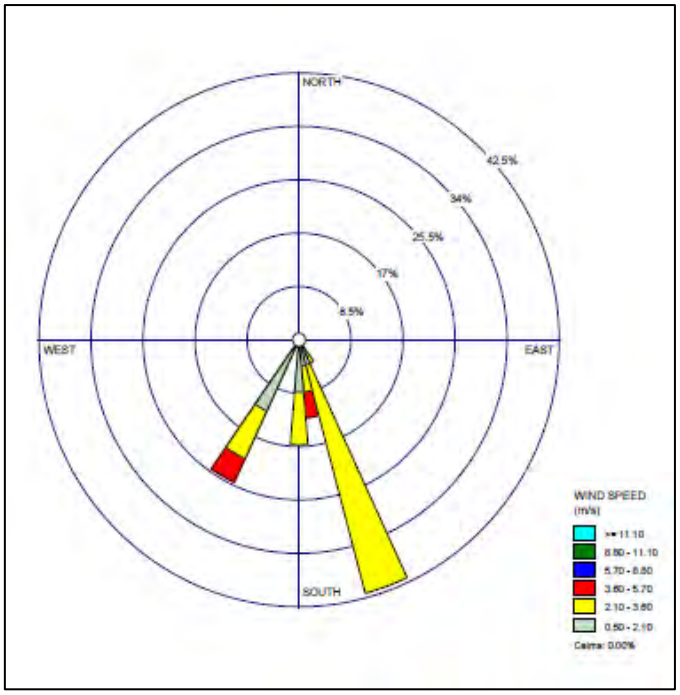


Figure 4.3: Wind rose diagram on 15th April, 2017

The daily iso-concentration curves of pollutants, as shown in Figures 4.4 and 4.5, were derived from the model computation at each grid point followed by a calculation of their average over a day and retaining (for generation of plots) only the highest concentration of the 365-day study period. As expected, the peak concentrations for 24-hour averaging time are lower than the corresponding hourly averages. The peak shifts slightly towards North western direction, which agrees with the wind rose diagram that shows the maximum prevailing wind is in the SSE direction. The peak concentration is predicted about 2.6 km north on an average from the source on 15th April 2017. Of all the pollutants simulated, NO_x and CO tends to have peak concentration spread over a wider zone. Peak 24-hour concentrations of SO_2, NOx, $PM_{2.5}$, PM_{10} and CO have been found to be 5.2 µg/m^3, 17.2 µg/m^3, 0.34 µg/m^3, 0.77 µg/m^3, 1.5 µg/m^3 respectively. The predicted peak concentration of SO_2, $PM_{2.5}$ and PM_{10} for 24 hour average period are well below Bangladesh Standard, and complies with WHO Standard as well. NOx and CO does not have any standard value for 24-hour averaging period. Addition of Payra Power Plant Phase-I in the project area increases the background concentration moderately. However, particulate emission from the power plant has negligible impact in the ambient air quality as compared to the background concentration.

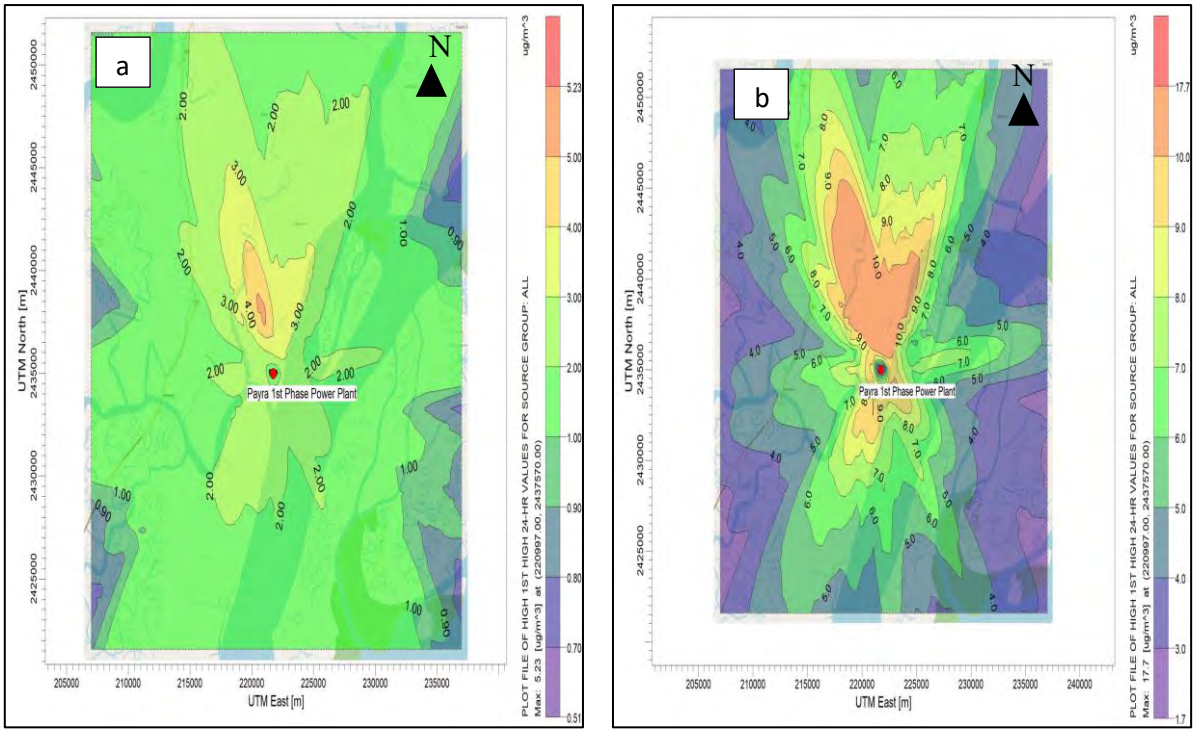


Figure 4.4: Daily iso-concentration ($\mu g/m^3$) curves of (a) SO_2 and (b) NO_x (the red dot identifies the location of the Payra Phase I power plant)

The process used to draw the annual iso-concentration curves was slightly different. In fact, the AERMOD model computes the average of all hourly concentrations modeled over the year, and then connects the points of same concentration. In this case, no maximum value is retained to calculate the annual average at a given point. Figures 4.6 and 4.7 show the annual iso-concentration curves of pollutants and the pollutant concentration is seen to drop vastly compared to the hourly average or daily average concentrations. Among the pollutants, only NO_x has a moderate annual-average concentration, while the annual-average concentrations for the rest of the pollutants are negligible.

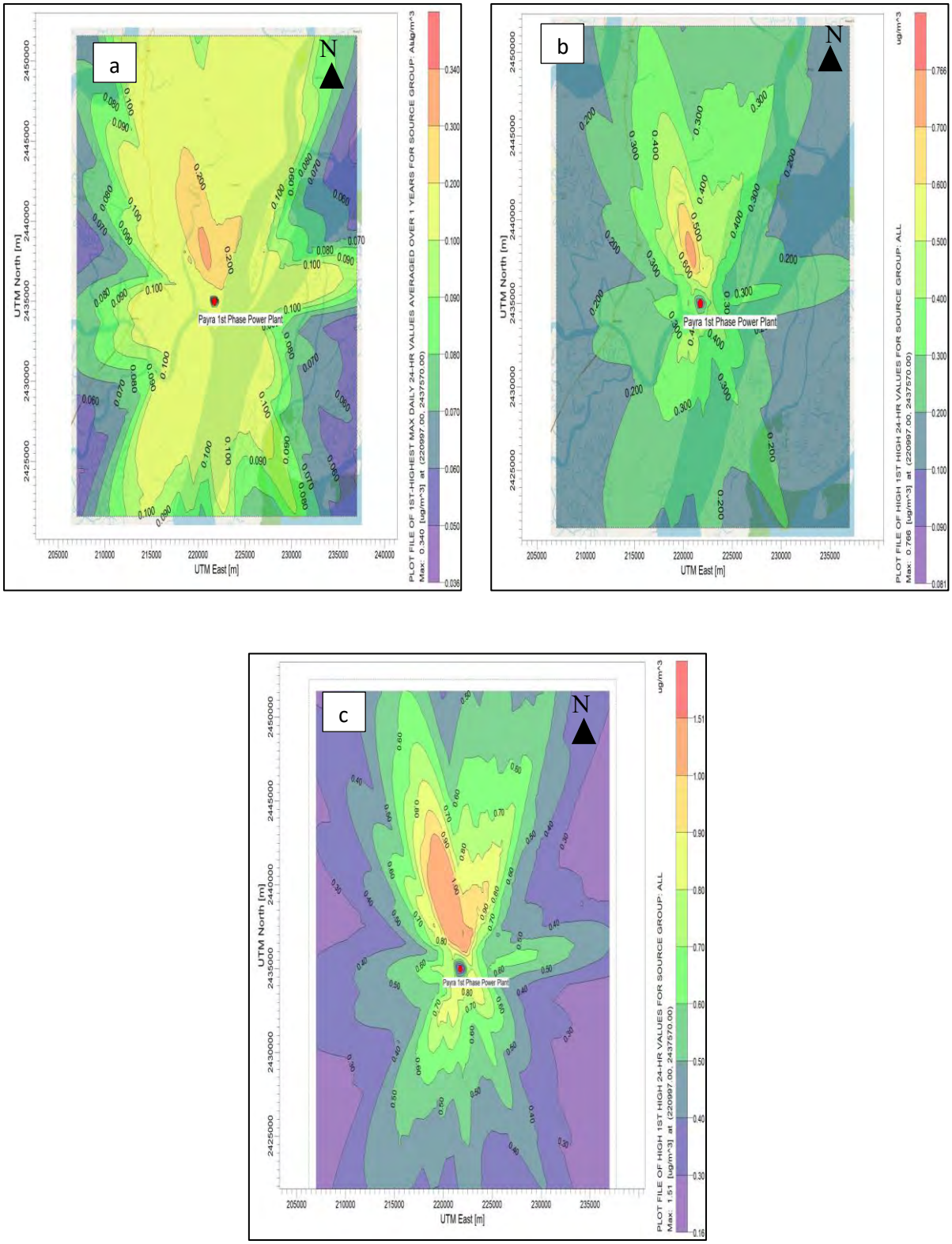


Figure 4.5: Daily iso-concentration (μg/m^3) curves of (a) $PM_{2.5}$, (b) PM_{10} and (c) CO (the red dot identifies the location of the Payra Phase I power plant)

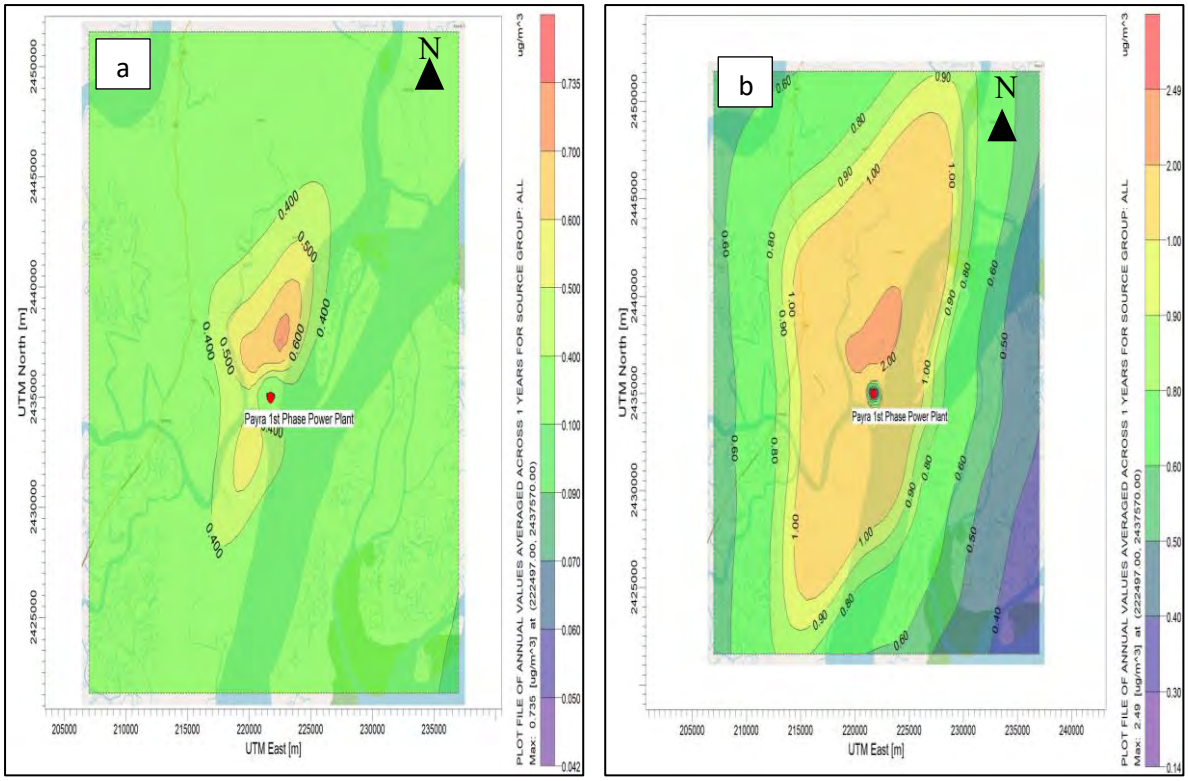


Figure 4.6: Annual iso-concentration (µg/m^3) curves of (a) SO_2 and (b) NO_x (the red dot identifies the location of the Payra Phase I power plant)

4.3.2 Scenario II: Payra 1st and 2nd Phase Power Plants in Operation

For Scenario II, the spatial distribution of pollutants have been found to be similar to those found for Scenario I (described in Section 4.3.1). Like Scenario I, concentration of PM_{10}, $PM_{2.5}$ and CO have been found to be very low over the model grids; while concentrations of SO_2 and NO_x have been found to be relatively high. Therefore, for Scenario II, only spatial distribution (iso-concentrations curves) of SO_2 and NO_x have been discussed elaborately.

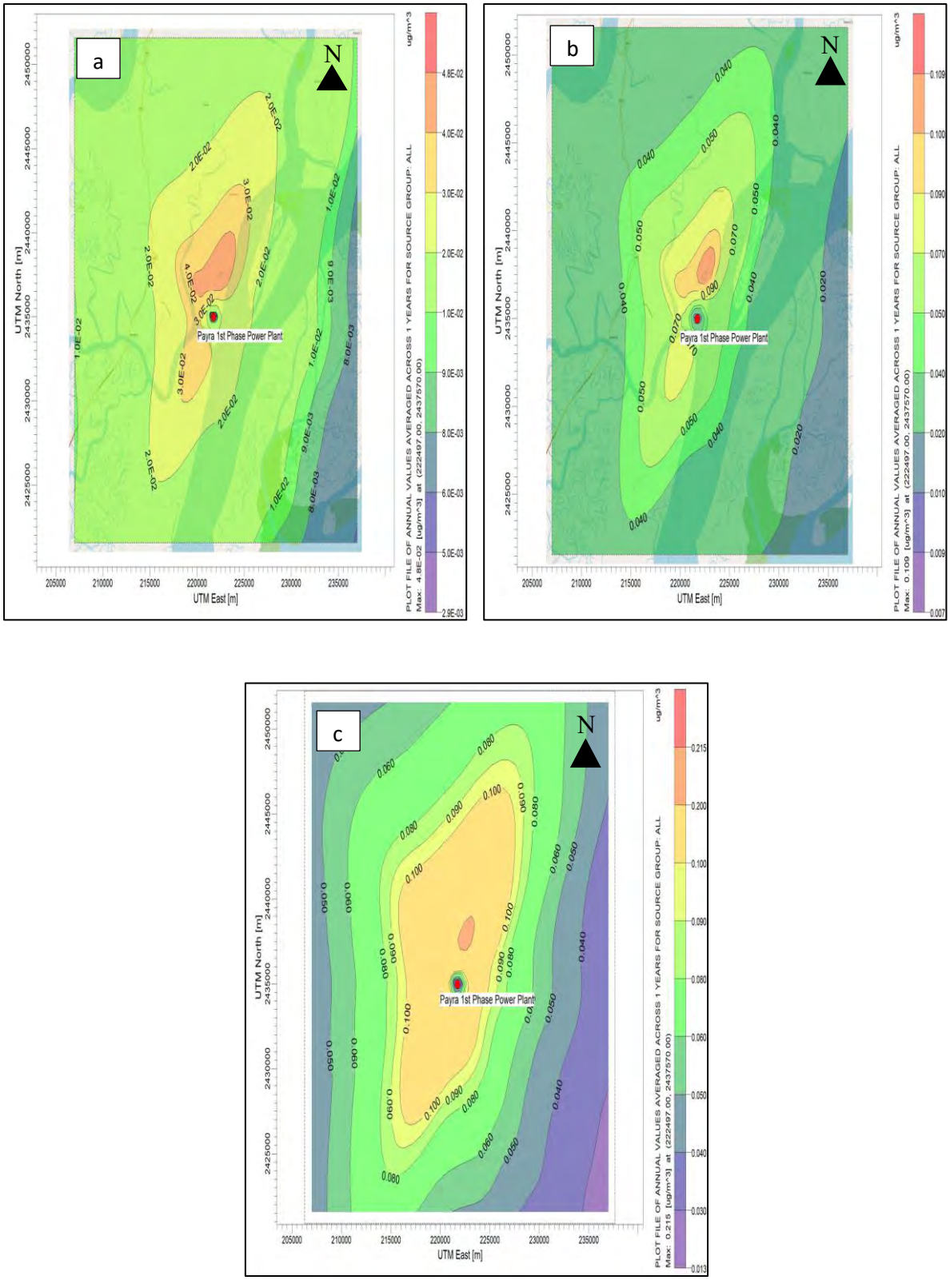


Figure 4.7: Annual iso-concentration (µg/m^3) curves of (a) $PM_{2.5}$, (b) PM_{10} and (c) CO (the red dot identifies the location of the Payra Phase I power plant)

Figure 4.8 (a, b) shows that the peak hourly concentration trend of SO_2 and NOx for Scenario II is similar to that of Scenario I; however, the peak pollutant concentration escalates almost three folds. For example, under Scenario I, peak SO_2 concentration was 51.6 µg/m^3, whereas under Scenario II, the peak reached to be 130.7 µg/m^3. For NOx, the peak concentration under Scenario I was 175 µg/m^3, whereas it reached 444 µg/m^3 under Scenario II. There is a conspicuous increase of the dispersion radius. The peak concentration for both pollutants occur at the same time (15th April) and location. However, the only difference observed in the hourly iso-concentration curves of Scenario I and II is that the peak concentration of NOx covers a small region in the latter (i.e., Scenario II). The predicted peak hourly concentration of SO_2 and NOx are higher than the 24-hr and annual-average standards for these pollutants. However, as discussed below, the 24-hr and annual average peak concentrations of these pollutants are in fact much lower than the corresponding air quality standards.

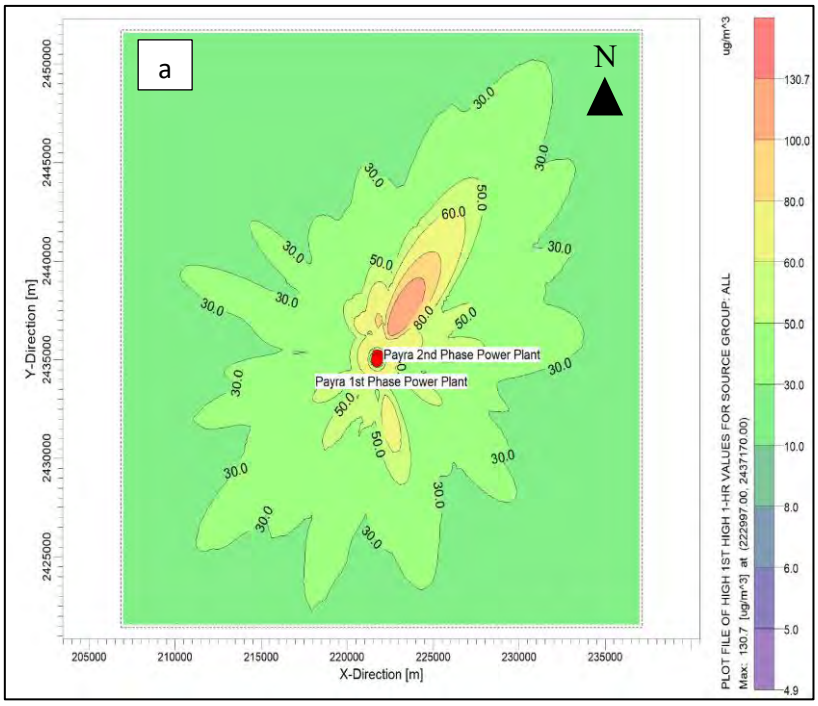


Figure 4.8 (a): Hourly iso-concentration curve of SO_2

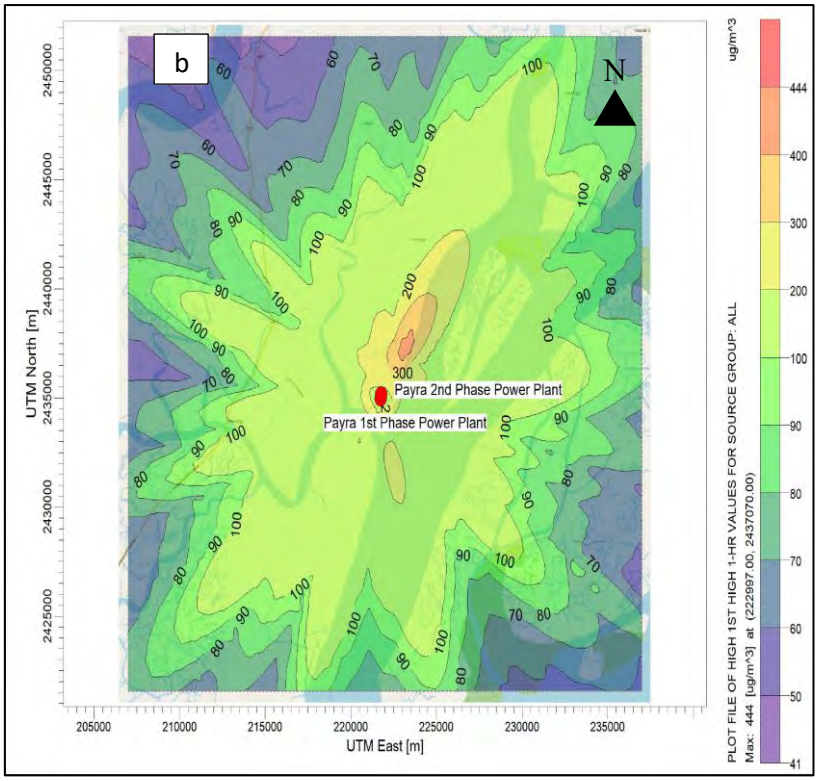


Figure 4.8 (b): Hourly iso-concentration curve of NO_x

Figure 4.9 and Figure 4.10 show the daily and annual-average iso-concentration curves for SO_2 and NO_x, respectively. These figures show that addition of Payra Thermal Power Plant-II significantly increases the pollutant concentration in ambient air. Compared to Scenario-I, the concentration of pollutants in the nearby locations increased more than twice under Scenario II. For example, peak 24 hour average concentrations of SO_2 and NO_x for Scenario-II are 13.7 and 45.8 respectively, whereas, under Scenario-I the maximum concentration reached by these pollutants were 5.2 and 17.7 $\mu g/m^3$ respectively. Predicted peak 24 hour SO_2 concentration satisfies both WHO and Bangladesh Standards. For Scenario-II, the maximum annual concentration attained by SO_2 and NO_x are much less than the corresponding standards. No change in plume direction has been observed for the daily and annual iso-concentration curves.

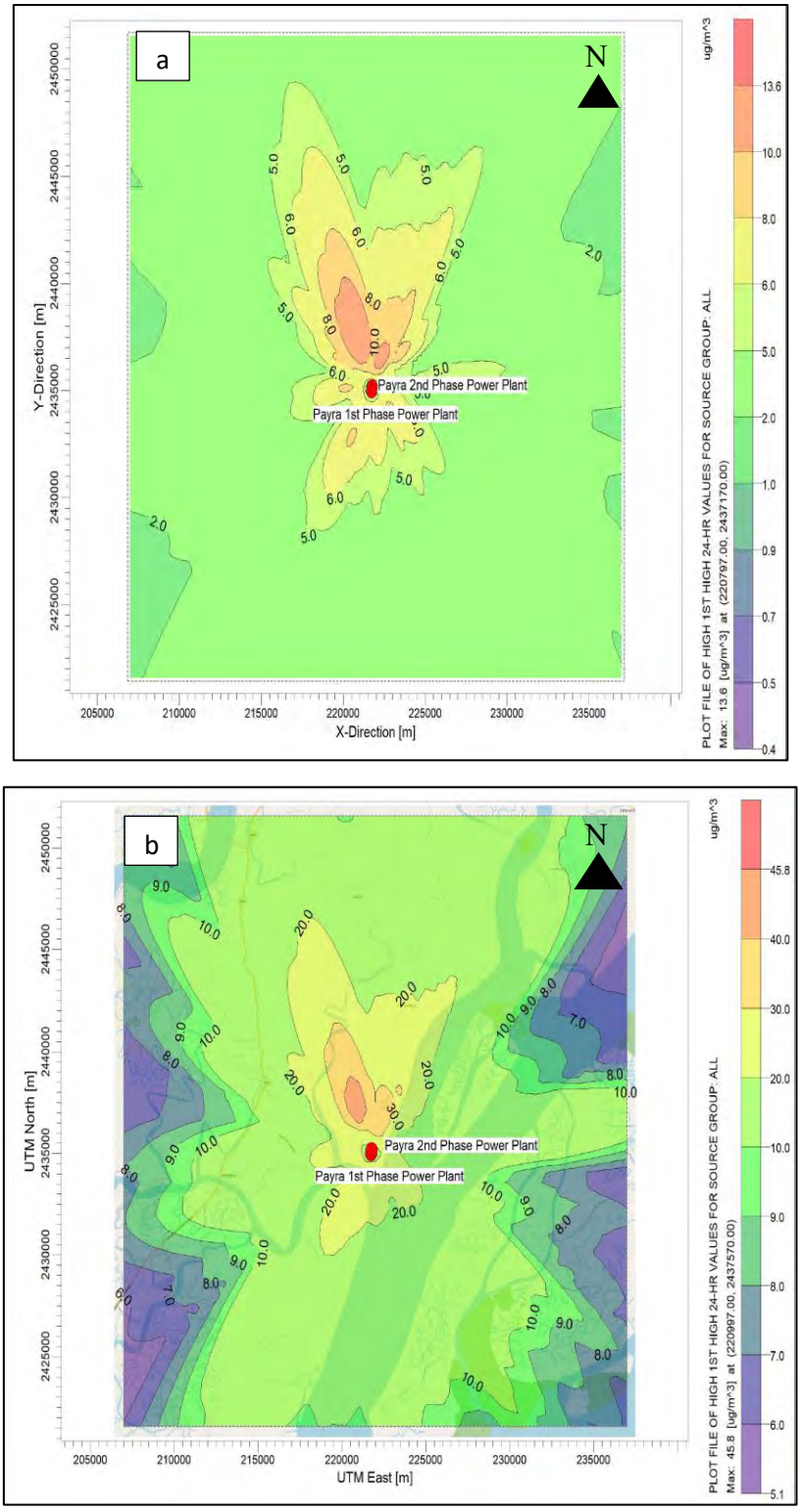


Figure 4.9: Daily iso-concentration curves of (a) SO_2 and (b) NO_x

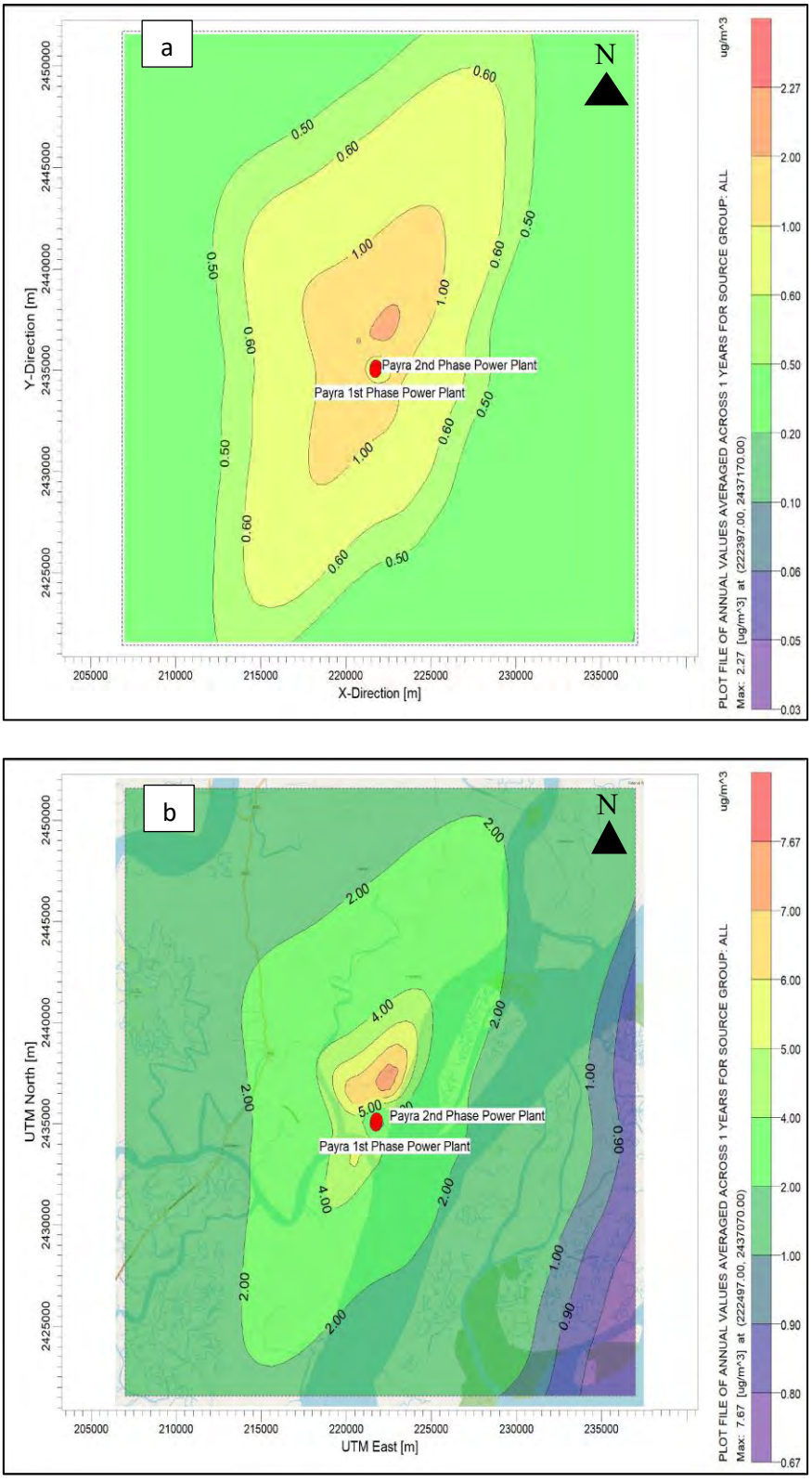


Figure 4.10: Annual iso-concentration curves of (a) SO_2 and (b) NO_x

4.3.3 Scenario III: Five Power Plants in Operation

The third scenario involves simultaneous operation of all five power plants, including Payra Phase I and Phase II. Detail analysis of model predictions under this Scenario revealed that like Scenarios I and II, concentration of PM_{10}, $PM_{2.5}$ and CO are very low (compared to corresponding standards) over the model grids; while concentrations of SO_2 and NO_x have been found to be relatively high. For instance, the peak PM_{10} concentration for 24 hour averaging period is 2.65 $\mu g/m^3$ for Scenario-III, while the WHO and Bangladesh standard for this pollutant is specified as 50 and 150 $\mu g/m^3$ respectively. Thus, detail analysis for these pollutants (PM_{10}, $PM_{2.5}$ and CO) are unnecessary. Hence, this Section primarily focuses on spatial distribution of SO_2 and NOx.

Figure 4.11 (a, b) shows spatial distribution of peak SO_2 and NOx concentrations for Scenario III. It shows that pollutants are dispersed to a wider extent, and the peak concentration moves towards North (225497m E, 2444070m N), near the APSCL Power Plant. The peak concentrations are likely to be associated with wind blowing towards North along a line connecting the five power plants. It clearly suggests that people living in Northern part of the study area are likely to bear consequences of combined emission of the power plants in this Power Hub.

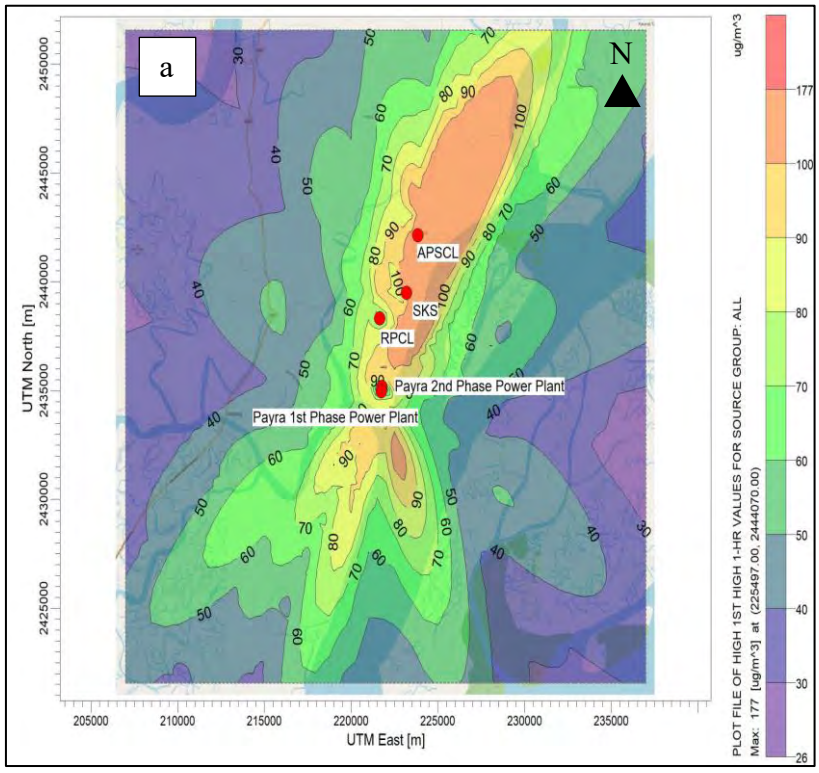


Figure 4.11 (a): Hourly iso-concentration curve of SO_2 (the red dots show locations of the power plants)

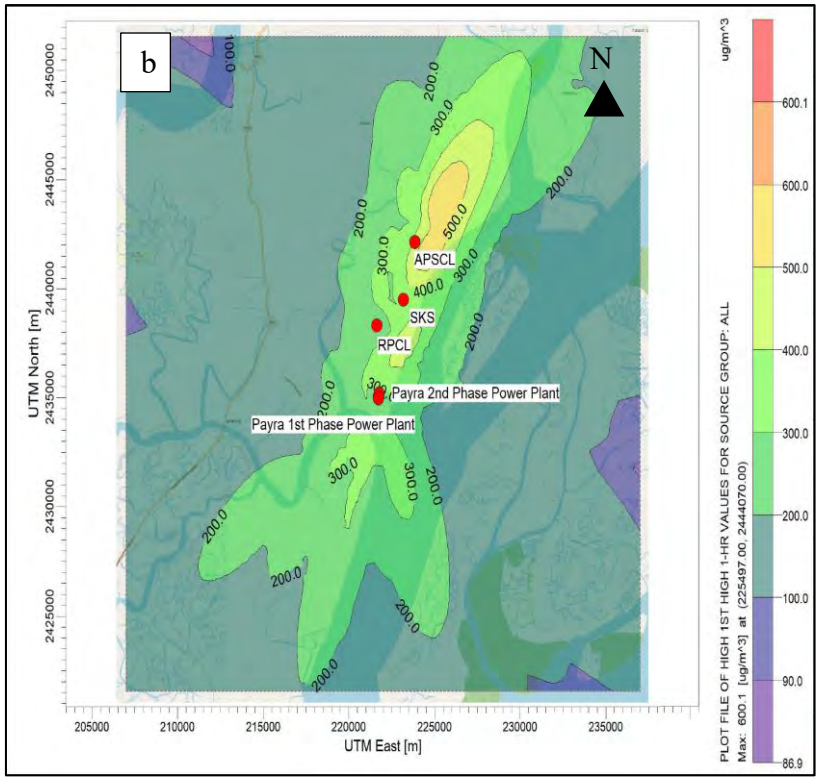


Figure 4.11 (b): Hourly iso-concentration curve of NO_x (the red dots show locations of the power plants)

Figure 4.12 and Figure 4.13 show daily peak and annual-average SO_2 and NOx iso-concentration curves for Scenario III. For Scenario-III, the daily peak concentrations of SO_2 and NOx are about 20% higher than the corresponding values under Scenario-II (SO_2 and NOx peak concentration increases from 13.6 and 45.8 µg/m^3 to 16.2, 54.9 µg/m^3, respectively). However, these predicted daily peak values are much lower than the air quality standards for SO_2 (24-hr) and NOx (annual). The background concentration for SO_2 obtained at the monitoring stations (8.1-16.8 (µg/m^3) is similar to the predicted peak value. However, peak NOx concentration obtained while simulating Scenario-III is much higher than the background condition (10.5-25.3 µg/m^3). The peak concentration moves southward (222497m E, 2436570m N), about 1.5 km from the Payra Power Plants. The major impact of the three additional power plants (RPCL, SKS, and APSCL) lies in amplification of the dispersion radius, as can be seen in Figure 4.12 (a, b) and Figure 4.13 (a, b) which deteriorates overall air quality over a wider area. The maximum concentration of annual iso-concentration curve encompasses all five power plants and is distributed in the center of the modeling domain. However, these yearly-average values are very low, and the predicted yearly average NOx concentrations are much lower than the yearly average standard of NOx.

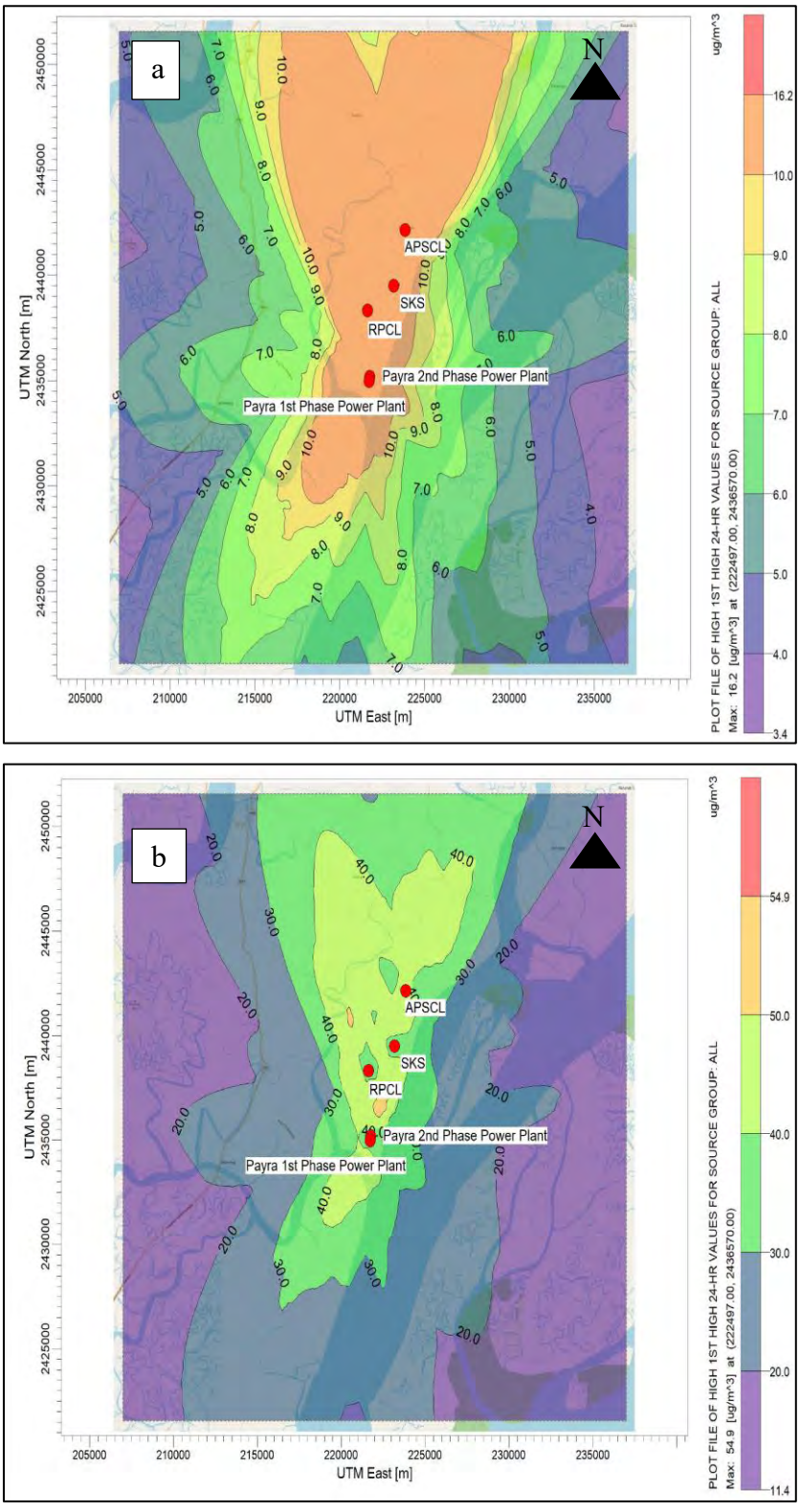


Figure 4.12: Daily iso-concentration curves of (a) SO_2 and (b) NO_x (the red dots show locations of the power plants)

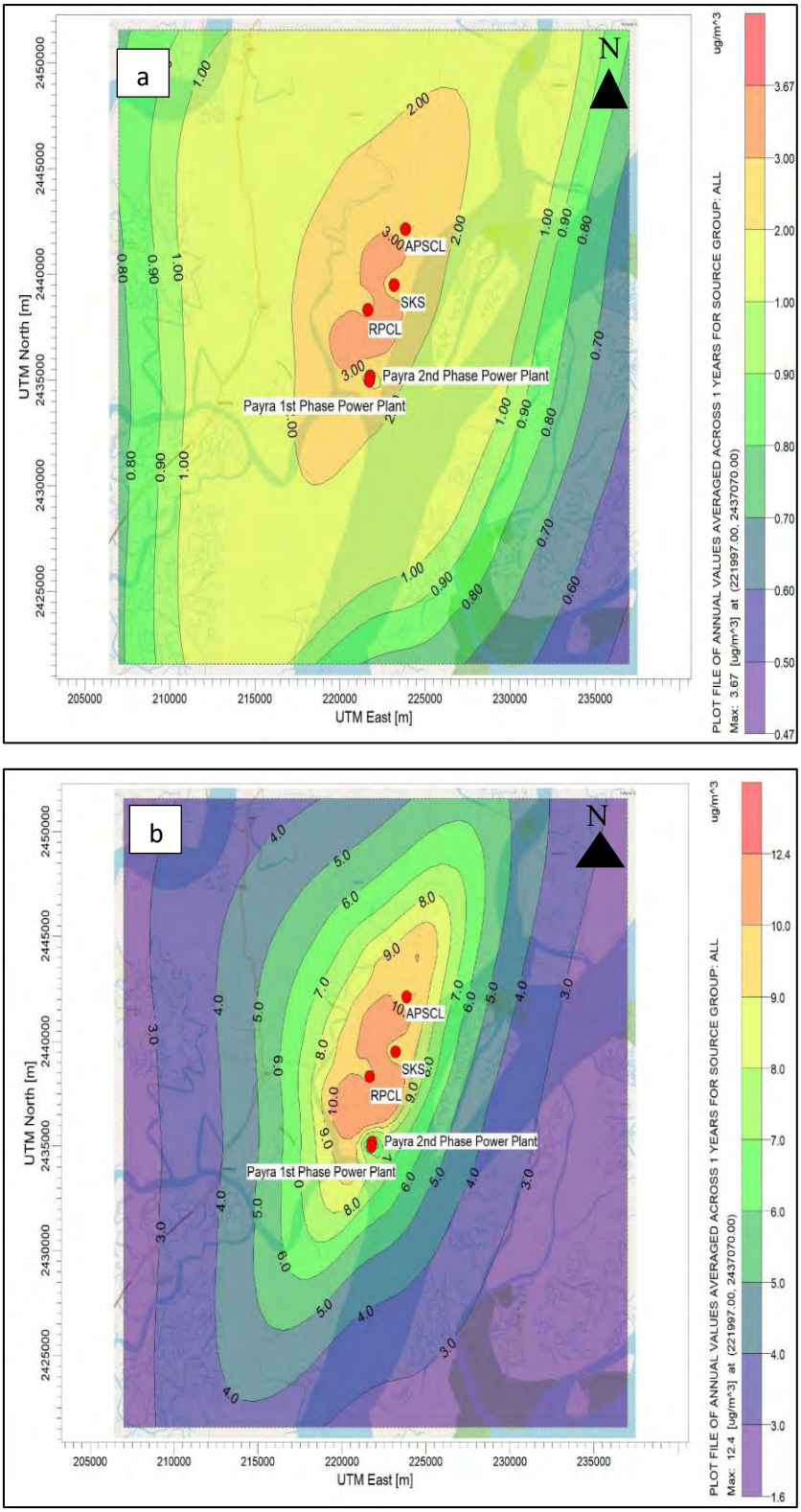


Figure 4.13: Annual iso-concentration curves of (a) SO_2 and (b) NO_x (the red dots show locations of the power plants)

4.4 Evaluation of Power Plant Emissions on Ambient Air Quality

The predicted peak concentrations of pollutants in vicinity of the coal based power plants for the three proposed scenarios were obtained from AERMOD simulations. The reported baseline concentrations of pollutants at six discrete receptors were averaged and considered to represent ambient air quality of the surrounding area. A comparison was then made between cumulative ground level concentration (i.e. summation of peak predicted concentration due to power plant activity and baseline concentration) and the existing WHO and Bangladesh Standards to ensure compliance with the standards. Peak 24 hour and peak annual predicted concentrations of SO_2, $PM_{2.5}$, PM_{10} and NO_x were compared with the corresponding air quality standards; and peak 1 hr and 8 hr CO concentrations for the year 2017 were compared with the respective standards (Table 4.2).

Table 4.2 shows that for 24 hour averaging period, cumulative ground level concentration of SO_2 and PM_{10} exceeds WHO standard; however both the pollutants comply with the respective Bangladesh Standards. Although power plant emissions contribute significantly to the elevated SO_2 concentration, the baseline concentration itself exceeds the Standard for the latter. $PM_{2.5}$ marginally satisfies the WHO Standard, whereas, CO concentration is negligible compared to the air quality standards. Annual concentrations of the pollutants are well below the Standard under different scenarios.

Table 4.2: Comparison of Predicted Peak Concentration of Pollutants with Air Quality Standards

Pollutant	Averaging Period	Baseline concentration (BC)	BC + Scenario-I	BC + Scenario-II	BC + Scenario-III	Bangladesh Standard	WHO Guideline Value
SO_2	24 hour	14.6	19.8	28.2	30.8	365	20
($\mu g/m^3$)	Annual	-	0.73	2.3	3.7	80	-
NOx	24 hour	20.5	38.2	66.3	75.4	-	-
($\mu g/m^3$)	Annual	-	2.5	7.7	12.4	100	40
$PM_{2.5}$	24 hour	16.3	16.6	17.3	17.5	65	25
($\mu g/m^3$)	Annual	-	0.05	0.17	0.26	15	10
PM_{10}	24 hour	67.1	67.9	67.9	69.7	150	50
($\mu g/m^3$)	Annual	-	0.11	0.11	0.58	-	20
CO	24 hour	-	15.5	38.1	49.6	40,000	30,000
($\mu g/m^3$)	Annual	750	753.5	758.8	762.8	10,000	10,000

Table 4.2 shows a significant increase in peak concentration of all the pollutants due to the operation of the power plants. The most significant increase in pollutant concentration occurs when Phase II Payra Plant becomes operational (i.e., Scenario II). The rise in the pollutant concentration due to the addition of the Phase II Payra Pant is predicted to be around two-fold, irrespective of the averaging period. The model results suggest that addition of three additional power plants in the region will not have significant additional impact on air quality, as can be seen from Table 4.2. This is because of the significant physical distance of these three plants from the Payra plants (3 to 7 km) and from one another, which disperse the pollutants over a wider region rather than concentrating the peak value. Figure 4.8-4.13 illustrates that the dispersion radius for Scenario-III is almost twice that for Scenario-II.

4.5 Seasonal Variation of Pollutant Concentration

The seasonal variability of pollutant concentration within the model domain was assessed by predicting average and peak 1-hr concentrations of pollutants for the summer (March-June), monsoon (July-October), and winter (November–February) seasons for Scenario I (i.e., only Phase I Payra Port operating), as shown in Table 4.3. The maximum 1 hour concentrations for the pollutants occurred during summer, while lowest 1 hour concentrations were predicted during monsoon. The highest concentration of pollutants in summer is due the effects of meteorological parameters such as wind speed and solar radiation, which also affects mixing heights. During monsoon pollutant concentrations are expected to be low due to scavenging of particulate pollutants from the atmosphere due to rainfall (Stern, 1976) and also due to higher relative humidity, which reduces re-suspension of dust. Thus, changes in seasonal concentration of the pollutants depend on daily climates, which are influenced by seasonal winds and land-sea breeze (Seangkiatiyuth et al., 2011).

Table 4.3: Seasonal concentration of pollutants due to power plant activity only

Season	Peak Concentration-1 hour average, µg/m^3 (Average Concentration)				
	SO_2	NO_x	$PM_{2.5}$	PM_{10}	CO
Winter	30.3 (7.9)	102.8 (26.7)	1.9 (0.50)	4.3 (1.1)	8.9 (2.2)
Summer	51.6 (13.0)	174.9 (44.0)	3.2 (0.82)	7.3 (1.8)	14.5 (3.6)
Monsoon	26.5 (11.2)	89.7 (37.8)	1.7 (0.70)	3.7 (1.6)	7.4 (3.1)

Even though the peak concentrations in summer and in monsoon vary significantly, the mean concentrations have been found to be similar. The display of minimum mean concentration during winter season could be attributed to the fact that tall chimney often release emission at a height above the inversion layer, which disperses upwards (i.e., above the inversion layer). Among the criteria pollutants, NO_x and SO_2 have the highest 1 hour average concentrations, reaching 174.9 µg/m^3 and 51.6 µg/m^3, respectively during summer (15th April, 2017). However, both pollutants have rather low mean concentrations of 44.0 µg/m^3 and 13.0 µg/m^3 in this season. The predicted peak 1-hr SO_2 concentration for the three seasons are shown in Figures 4.14 (a-c).

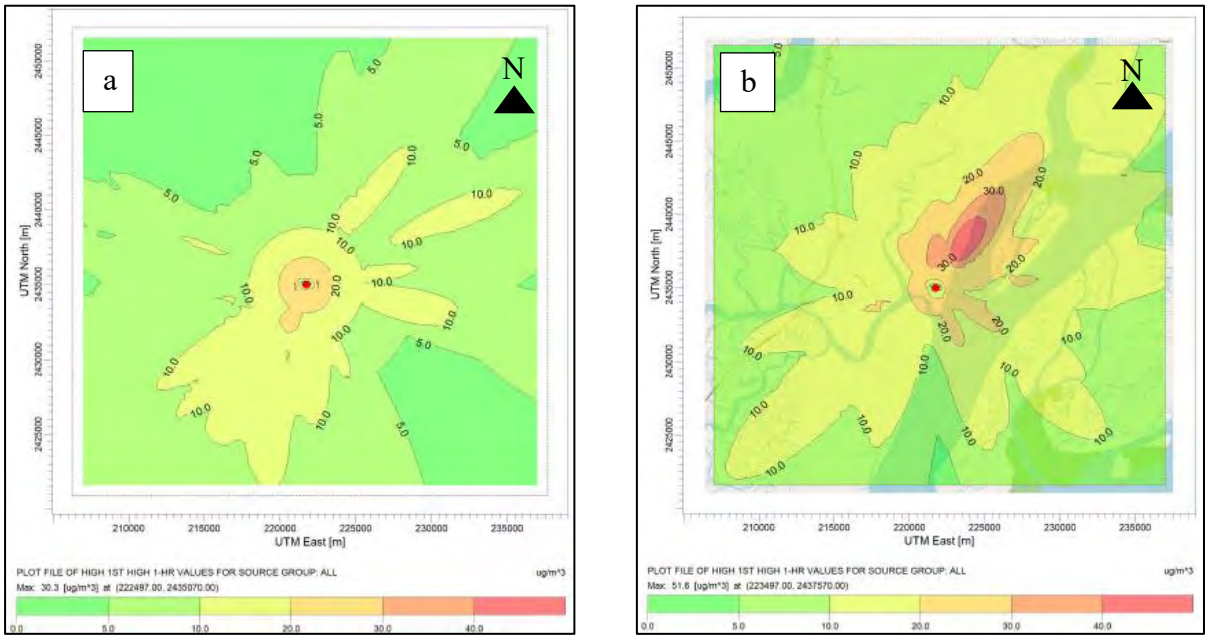


Figure 4.14 (a, b): Distribution pattern of maximum 1-hour average concentration of SO_2 during winter and summer (for Scenario I; the red dot identifies the location of the Payra Phase I power plant)

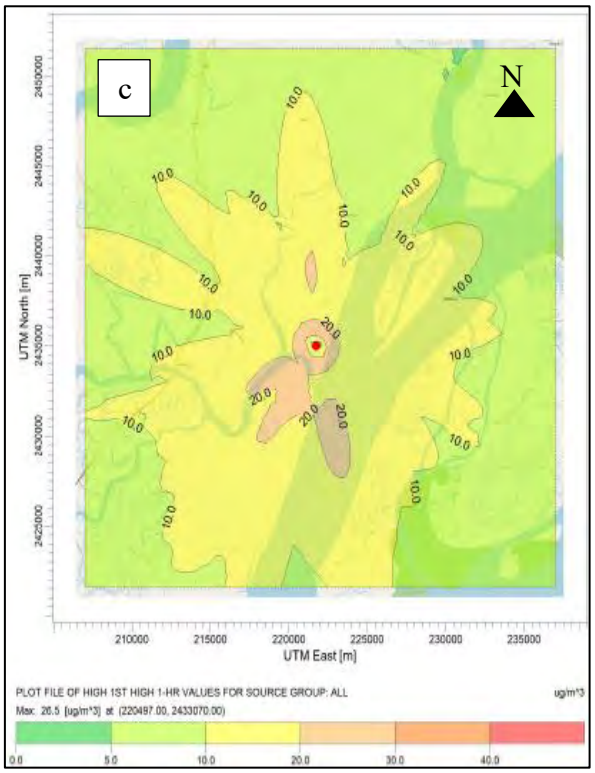


Figure 4.14 (c): Distribution pattern of maximum 1-hour average concentration of SO_2 during monsoon (for Scenario I; the red dot identifies the location of the Payra Phase I power plant)

During winter season, the northeasterly wind carries the pollutants to the SW direction; however, light wind and low humidity being the characteristic of this season, the rate of dispersion of pollutants is relatively low compared to summer and monsoon. Meanwhile, in summer season the country experiences low air pressure which results in strong gusty, hot, dry winds blowing in northward. Hence, the pollutants move linearly with the peak appearing at a distance of 2 km from the source. The heavy precipitation and low solar radiation of monsoon results in a central radial distribution of pollutants. Even though the peak concentration in monsoon is low, the average concentration in monsoon and summer are comparable. The dispersion of the pollutants is consistent with the wind rose diagram of the respective season presented in Figure 4.15.

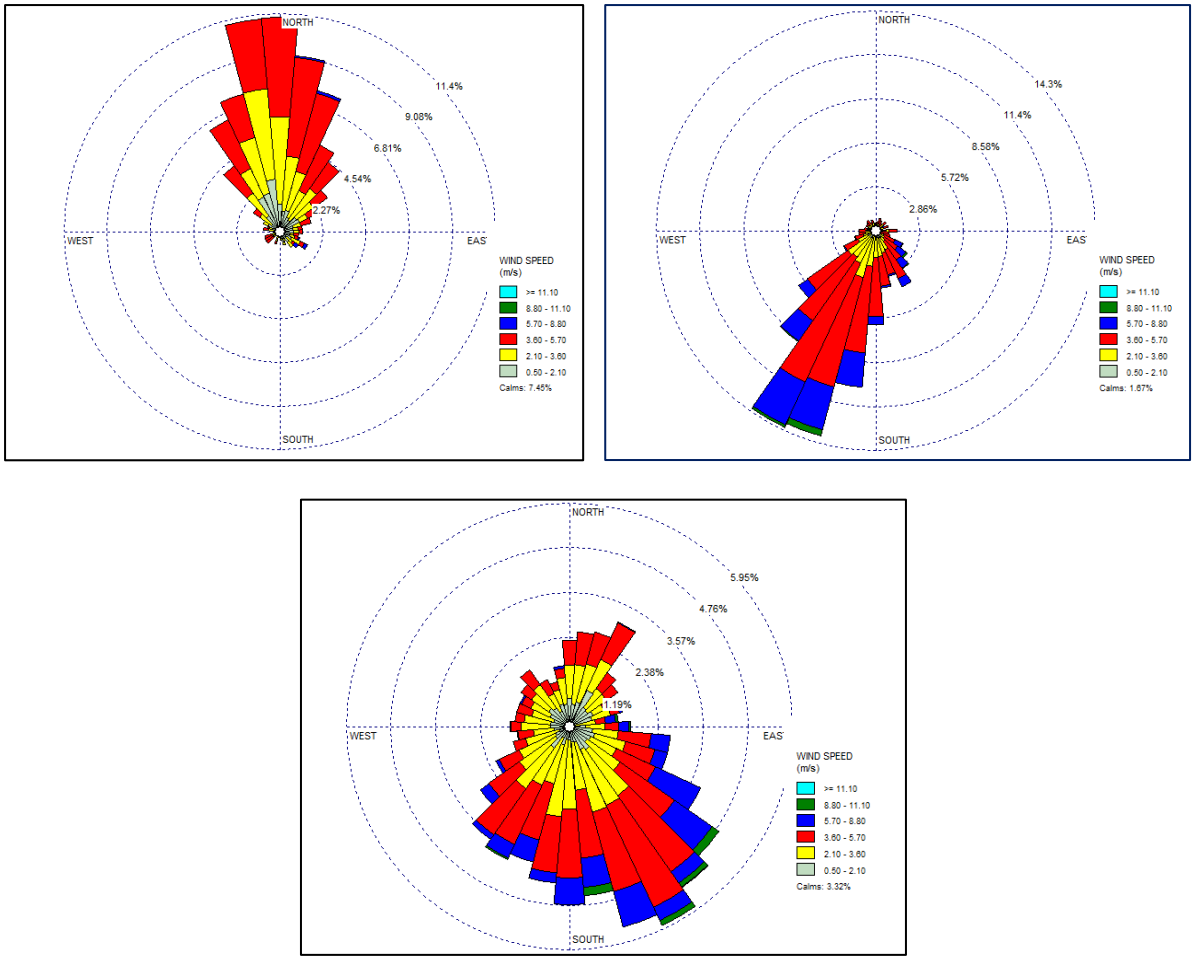


Figure 4.15: Windrose diagram for Payra Power Plant Phase-I during (a) winter, (b) summer and (c) monsoon

It is well documented that the dispersion of pollutants is greatly affected by the local meteorological factors (strength and frequency of wind, the intensity of solar radiations) and land surface features (Lee et al., 2014).

4.6 Diurnal Variation of Pollutant Concentration

The diurnal variation of pollutant concentration were assessed on the dates 15th April, 2017 and on 31st December, 2017 to analyze the pollutant dispersion behavior during summer and winter seasons respectively. This analysis was carried out for Scenario I, and the variations have been studied up to a distance of 5 km from the source. The average hourly concentrations have been shown for each kilometer (from source) over 24 hours. Figure 4.16 (a-e) shows average hourly concentration of pollutants as a function of time of the day ("0" representing mid-night) for different distances (1 km to 5 km) from the source (i.e., power plant).

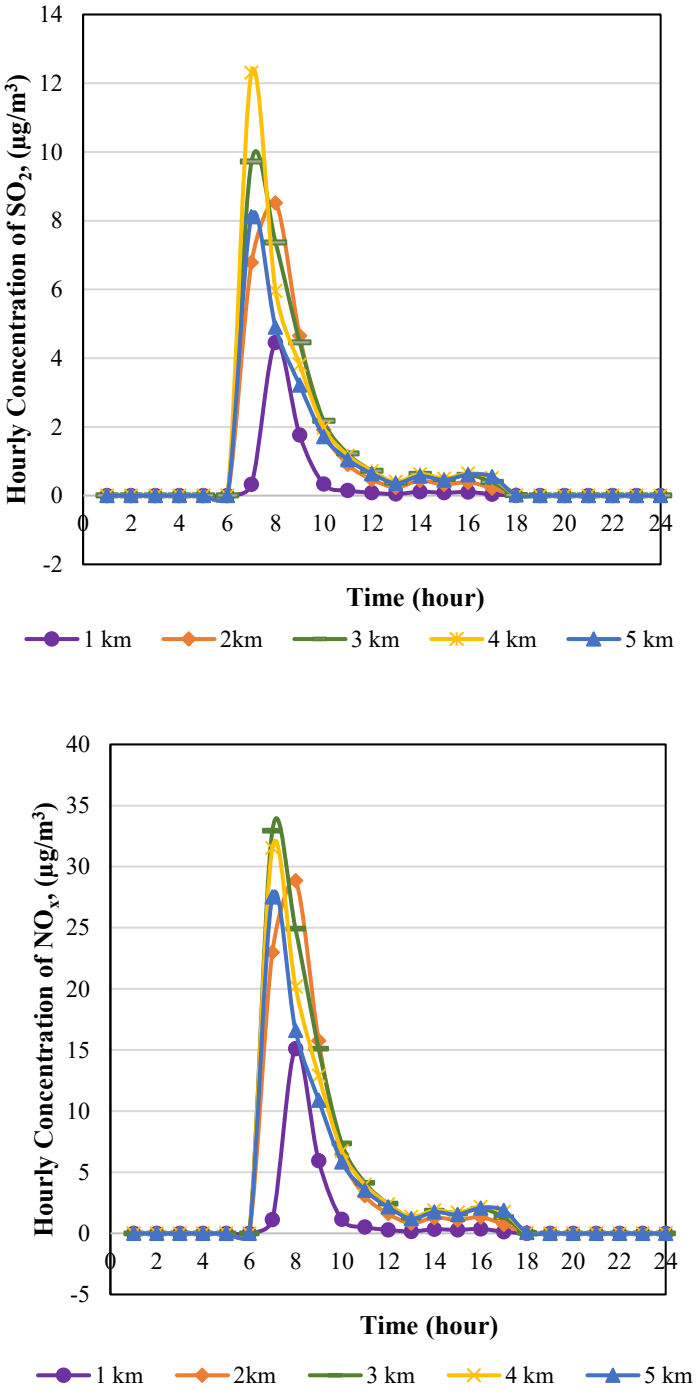
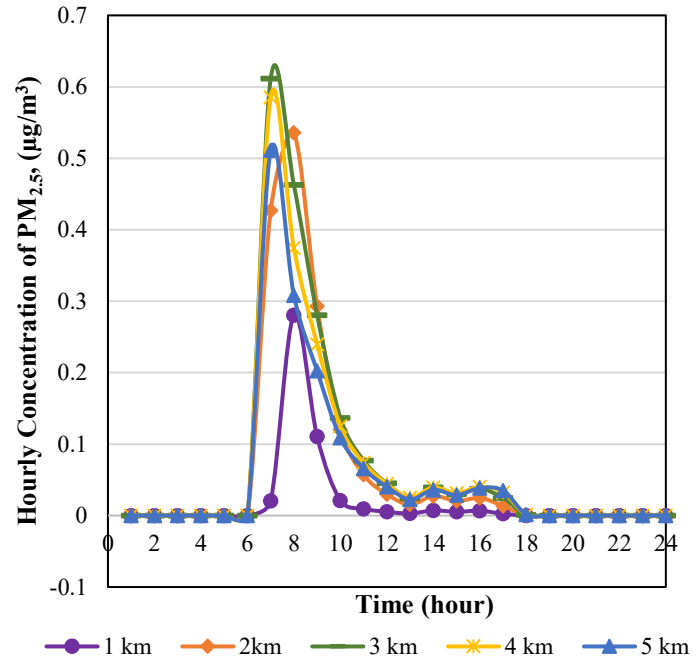


Figure 4.16 (a, b): Concentration of pollutants SO_2 and NOx (due to power plant activity only) as a function of time of the day (on 15 April 2017; "0" representing mid-night) at five different distances (1 to 5 km) from the source



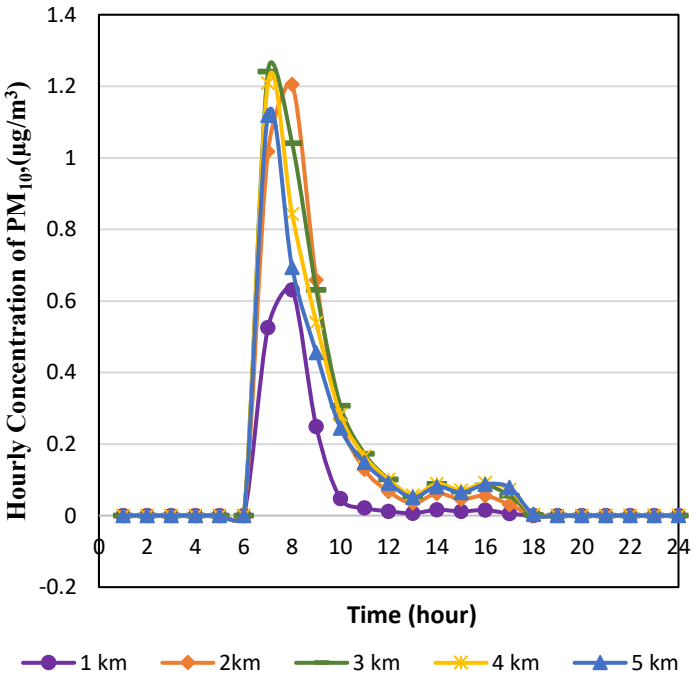


Figure 4.16 (c, d): Concentration of pollutants $PM_{2.5}$ and PM_{10} (due to power plant activity only) as a function of time of the day (on 15 April 2017; "0" representing mid-night) at five different distances (1 to 5 km) from the source

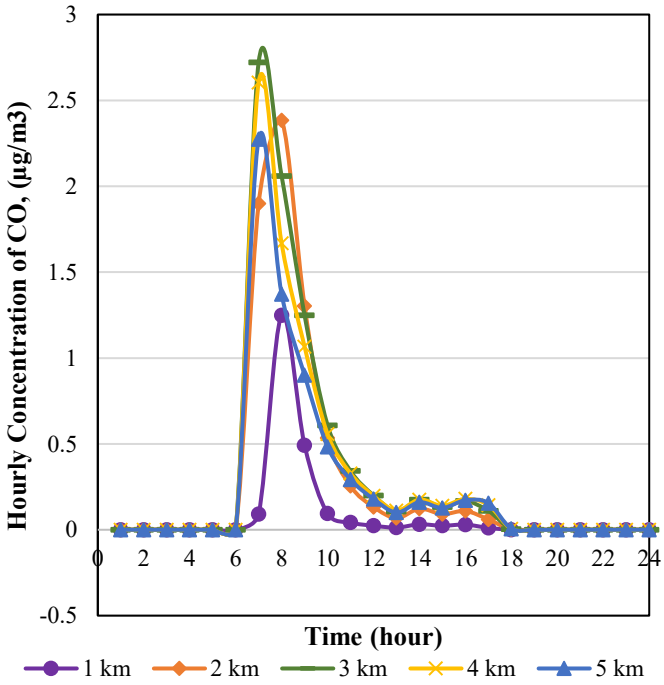


Figure 4.16 (e): Concentration of pollutants CO (due to power plant activity only) as a function of time of the day (on 15 April 2017; "0" representing mid-night) at five different distances (1 to 5 km) from the source

Figure 4.16 clearly shows that at a particular distance (1 km to 5 km) from the source, the concentrations of all five pollutants show a distinctive trend with time. . During the day, just after sun rise concentrations rise sharply and the peak is reached between 7 a.m. to 9 a.m. As the day proceeds, the concentrations witness a drastic decline around 12 noon (reduce up to an order of magnitude); a slight rise in concentration is observed during the afternoon period, which eventually undergoes a soft decay during the night.

Meteorology has great importance in transportation, dispersion and natural cleansing of the air pollutants in the atmosphere (Saini et al., 2017). Mixing height and wind speed are two most important parameters affecting dispersion of pollutants. Efforts were therefore made to assess the effect of mixing height and wind speed on diurnal variation of pollutant concentration. Figure 4.17 shows diurnal variation of mixing height at the location of the power plant on the day of the simulation (i.e., 15th April, 2017). It shows that the mixing height is low up to about 6 a.m. in the morning. The mixing height begins to increase as the day progressed, reaching a peak at about 6 p.m., just before sunset; then the mixing height drops rapidly after sunset. The maximum height was 850 m.

The hourly variation of concentration of pollutants presented in Fig. 4.16 is consistent with the variation of mixing height presented in Fig. 4.17. Figure 4.17 shows that up to about 6:00 a.m., the emissions from the power plant chimney takes place above the mixing height. Therefore, this emission does not contribute to ground level concentration. Thus, up to about 6 a.m., there is virtually no effect of power plant emission on ground level concentration, and ground level concentration is predicted to be near zero. Mixing height increases rapidly right after sunrise at around 6:00 a.m., and from 6:00 a.m. until about 6:30 p.m., the power plant emissions takes place above the mixing height. From about 6:00 am to about 9:00 a.m., the mixing height is relatively low (below 500 m). This low mixing height (together with emission taking place below the mixing height) results in rapid rise in ground level concentration between 6:00 am up to about 9:00 a.m. As discussed below, the lower wind speed during this period also contributes to higher ground level concentration during this time.

As day progresses, the mixing height increases rapidly (up to about 6:30 p.m.), allowing pollutants to disperse quickly with concomitant reduction in ground level concentration. After about 6:30 p.m. mixing height drops suddenly (with commencement of sunset), and drops below the height of the power plant stack/chimney. Therefore, the emissions occurring after 6:30 p.m. does not affect ground level concentration, and ground level concentration become negligible.

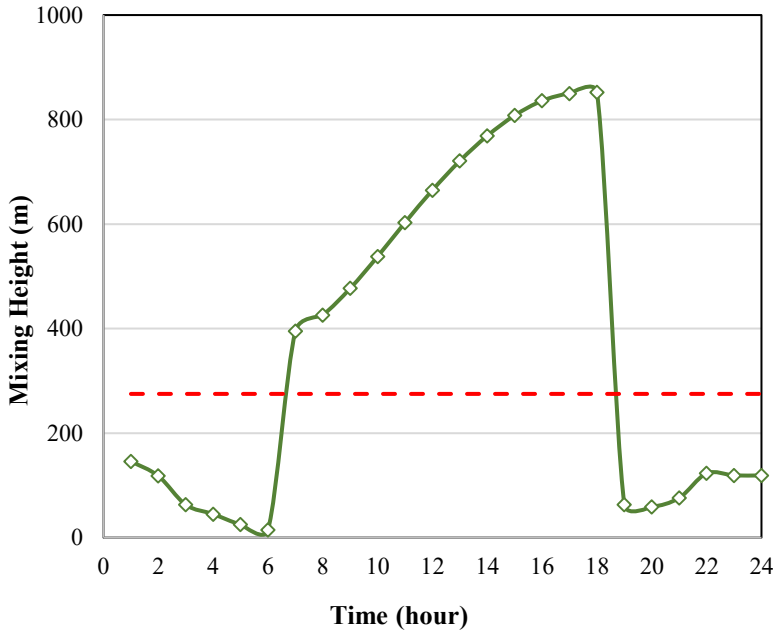


Figure 4.17: Hourly variation of mixing height on 15th April, 2017; the red dotted line represents the height of the stack (chimney) of the power plant

Figure 4.18 shows variation of wind speed over the day on 15 April 2017. This variation is also consistent with the variation of predicted pollutant concentration shown in Fig. 4.16. As discussed above, up to about 6:00 a.m., the emissions from the power plant takes place above the mixing height, and therefore does not impact ground level concentration. Wind speed reaches a minimum value at around 6:00 a.m. After sunrise, from about 6:00 a.m., wind speed begins to increase and reaches the peak value at about 2:00 p.m. From about 6:00 a.m. to about 9:00 a.m., the wind speed is relatively low (from about 0.5 m/sec to about 1.5 m/sec). This low wind speed (together with relatively low mixing height, as discussed above) supports higher ground level concentration (as shown in Fig. 4.16). As the day progresses, the wind speed increases, which contribute to the lowering of pollutant concentration. Pollutant dispersion by higher wind has been reported by Tasic et al. (2013).

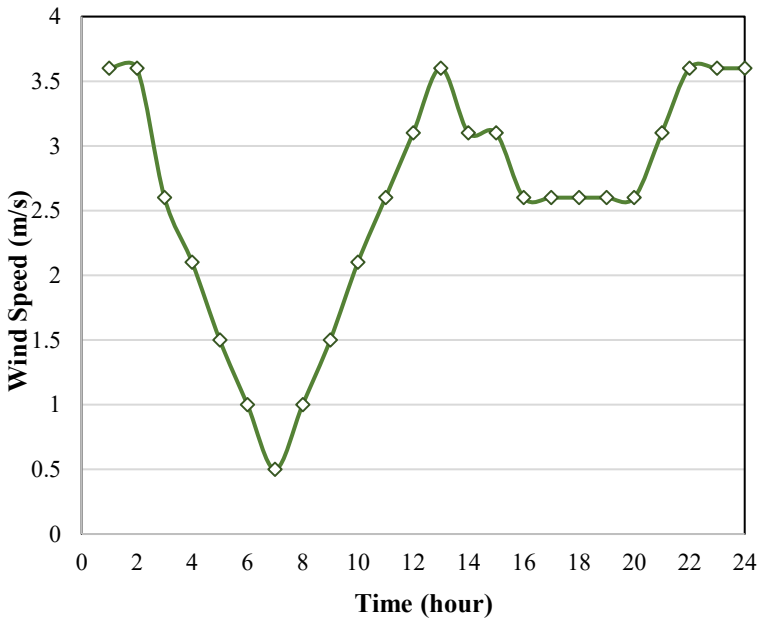


Figure 4.18: Hourly variation of wind speed on 15th April, 2017

To assess diurnal variation of pollution concentration during winter, the daily variation of NOx concentration (Figure 4.19) and meteorological parameters for 31st December, 2017 were studied. Since all the pollutants exhibits similar diurnal variation, data/graph for the rest of the pollutants have not been shown here. From Figure 4.19 it is observed that pollutants begin to accumulate at ground level from 9 a.m. in the morning. The peak is simultaneously attained at around 3 p.m. at different distances from the source. During afternoon period the concentrations decrease steadily and eventually decline sharply after 5 p.m.

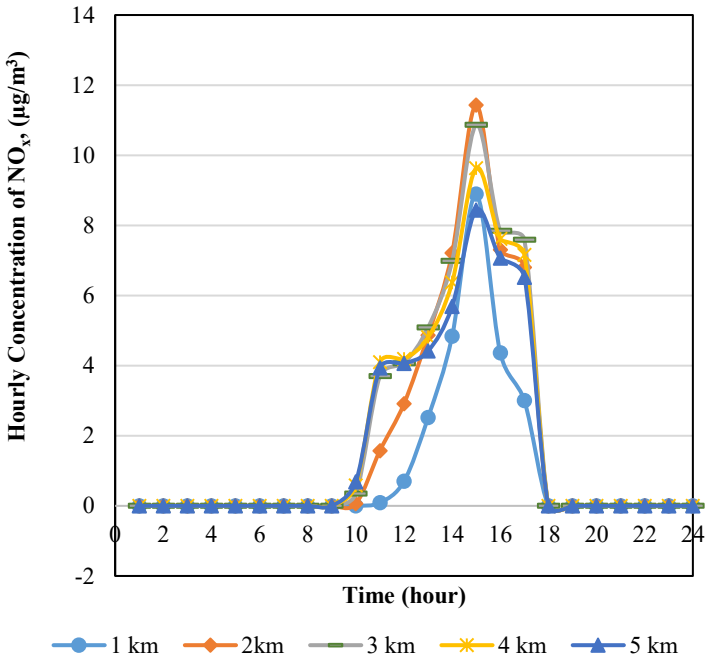


Figure 4.19: Concentration of NOx as a function of time of the day (on 31st December 2017; "0" representing mid-night) at five different distances (1 to 5 km) from the source

Figure 4.20 shows the variation of mixing height over a day (31st December), which reveals that until 8 a.m. in the morning, the mixing height is less than the chimney height. This restricts the ground level concentration of pollutants due to power plant activity to a minimum during that period. After 9 a.m. the mixing height increases sharply and reaches a maximum height of 1,218 m at 5 p.m. However, the mixing height drops drastically after sunset and hence the pollutant concentration becomes negligible evening onwards.

The pollutant behavior can be further explained by the wind speed variation on 31st December. Figure 4.21 shows that high wind speed (up to 5.1 m/s) exists up to 9 a.m. in the morning, which experience a gradual decline afterwards. The appearance of peak NOx concentration at around 3 p.m. is explained by the presence of light wind (1 m/s) along with emission taking place above the mixing height during that period. Furthermore, it is observed that peak NOx concentration during winter (31st December) is lower than that during summer (15th April), due to presence of higher mixing height in winter, which allows greater dispersion of pollutants.

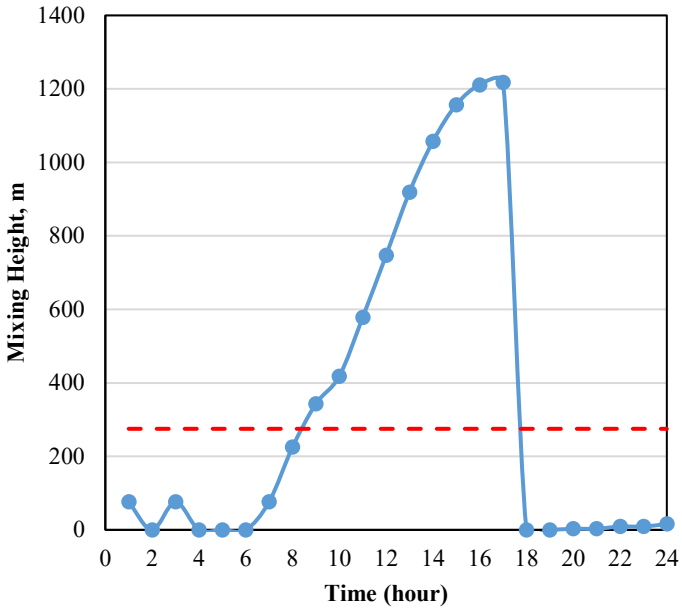


Figure 4.20: Hourly variation of mixing height on 31st December, 2017; the red dotted line represents the height of the stack (chimney) of the power plant

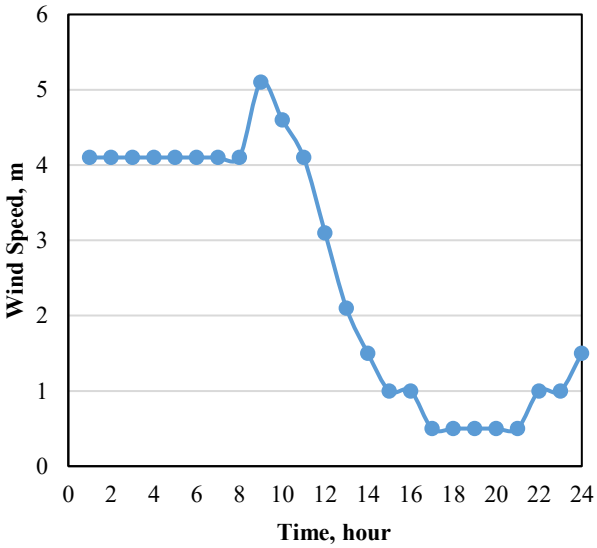


Figure 4.21: Hourly variation of wind speed on 31st December, 2017

Hence, it can be concluded that light wind speeds and limited mixing height confine the pollutants leading to enhanced pollution in the immediate vicinity of the power plant. On the other hand, high wind speed combined with sufficient convective mixing layer allows dispersion and dilution of pollutants preventing their accumulation at ground level.

4.7 Impact of Stack Height on Pollutant Dispersion

Provision of sufficient chimney height is an important criterion for any power plant in order to disperse the air pollutants over a large area. The chimney height of Payra Thermal Power Plant Phase-I has been deduced following Schedule-11 of Environment Conservation Rules (1997): Standards of Gaseous Emissions from Industries or Projects, which states the lowest height of stack for dispersion of sulfuric acid for a coal based power plant generating 500 MW or above should be 275 m. This guideline was originally adopted by Central Pollution Control Board (CPCB), the statutory environmental law implementing national agency of Government of India, for ensuring sufficient inversion layer to prevent buildup of sulfur dioxide. However, incorporation of emission control technologies such as Flue Gas Desulfurization, which provides an efficiency of above 90%, was not taken into account while adopting the guideline. In this study, effect of stack/chimney height on ground level pollutant concentration was assessed using the AERMOD View model. For this purpose, concentration of five criteria pollutants for different averaging periods have been predicted for Scenarios I, II and II, for stack/chimney heights ranging from 50 m to 275 m with increments of 25m.

4.7.1 Variation of Sulfur Dioxide Concentration for Various Chimney Heights

The effect of different chimney height on the peak concentration of sulfur dioxide is illustrated in Figure 4.22 and 4.2, for 24-hr and annual average concentration, respectively. The figures shows that the peak concentration of SO_2 decreases rapidly with increasing chimney height. Figure 4.22 shows that the peak concentration of SO_2 is plummeted by almost 50% for a change in chimney height from 50 m to 125 m, followed by a stable decrease in the pollutant concentration beyond 125 m. Violation of WHO Standard has been observed at 140 m for Scenario-II, and 163 m for Scenario-III, whereas Scenario-I complies with WHO Standard throughout the range of chimney heights studied (Figure 4.15). However, the predicted concentrations are much lower than the Bangladesh standard (24-hr average) of 365 $\mu g/m^3$. It should be noted that the aforementioned simulations have not considered background SO_2 concentrations.

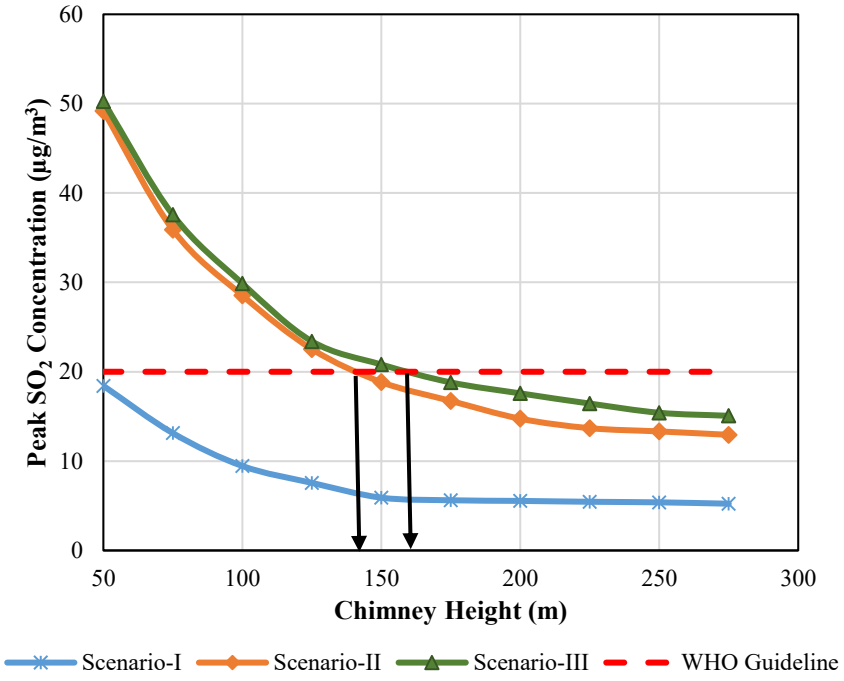


Figure 4.22: Variation of peak SO_2 concentration (24-hour average) with stack height; the red dotted line represents WHO 24-hr air quality standard for SO_2

The chimney height is not a concern while considering annual averaging period as can be seen in Figure 4.23. The maximum annual average concentration of SO_2, predicted due to the power plant emissions is 10.5 µg/m^3 (for Scenario-III), which is significantly lower than the Bangladesh Ambient Air Quality Standards (80 µg/m^3).

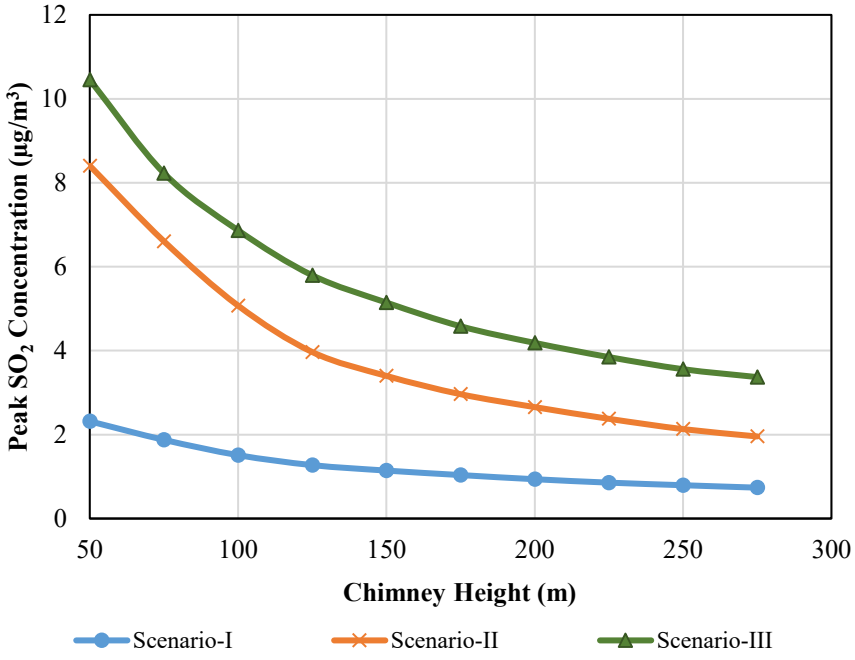


Figure 4.23: Variation of peak SO_2 concentration (Annual average) with stack height

4.7.2 Variation of Nitrogen Oxide Concentration for Various Chimney Heights

Low NOx burner has been incorporated in the proposed power plants as NOx control, which is expected to control the NO_2 emission at the chimney below the emission limit set by Bangladesh (350 mg/Nm^3). Figure 4.24 shows peak NOx concentrations as a function of chimney height for all three Scenarios considered in this study. It shows that the peak NOx concentration for each scenario remained consistently below the ambient air limit of Bangladesh (100 µg/m^3) across the range of chimney heights simulated.

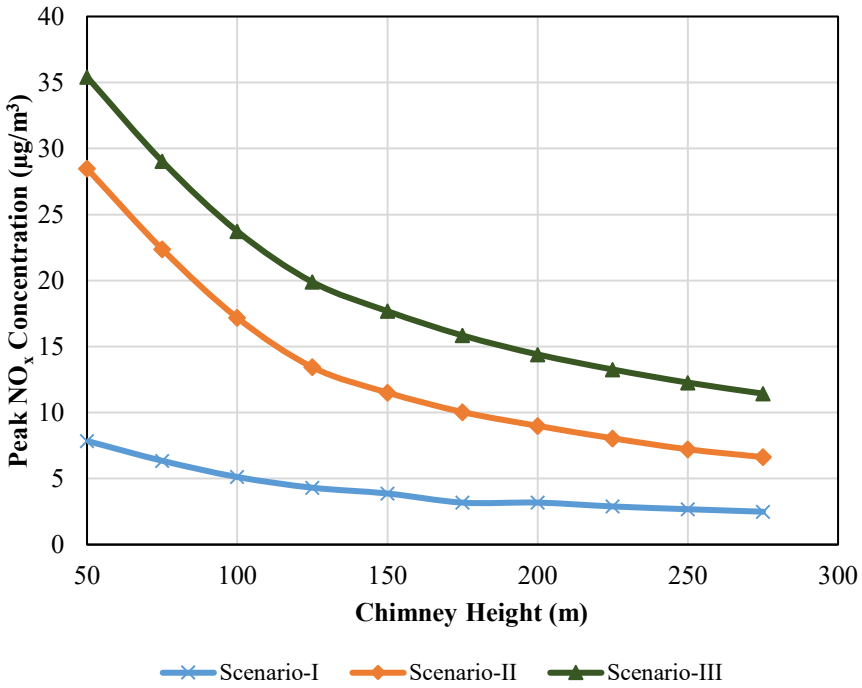


Figure 4.24: Variation of peak NO_x concentration (Annual average) with stack height

Similar to the trend observed for SO_2, NO_x shows almost negligible impact while considering Scenario-I even for chimney height as low as 50 m. However, lower chimney height is a concern as the number of power plant increases. Since the model is developed considering only power plant activities, the concentration of NOx in the atmosphere is likely to escalate when other important NOx sources (motor vehicles) will be taken in to consideration. Based on NOx dispersion, a chimney height of 150 m appears to be sufficient as the rate of change of pollutant concentration becomes stable beyond this height.

4.7.3 Variation of Particulate Matter Concentration for Various Chimney Heights

The plot of particulate matter concentration as a function of chimney height is presented in Figure 4.25 and 4.26. The high efficiency Electrostatic Precipitator (ESP) considered in the design assisted the abatement of particulate matter concentration in the atmosphere. For $PM_{2.5}$, as the chimney height is lowered from 275 m to 50 m, Figure 4.25 reveals that rise in peak concentration for each scenario has been almost three fold. Nevertheless, the maximum concentration (3.8 $\mu g/m^3$) of $PM_{2.5}$, attained for 50 m chimney height in Scenario-III, is still negligible as compared to the WHO guideline value of 25 $\mu g/m^3$.

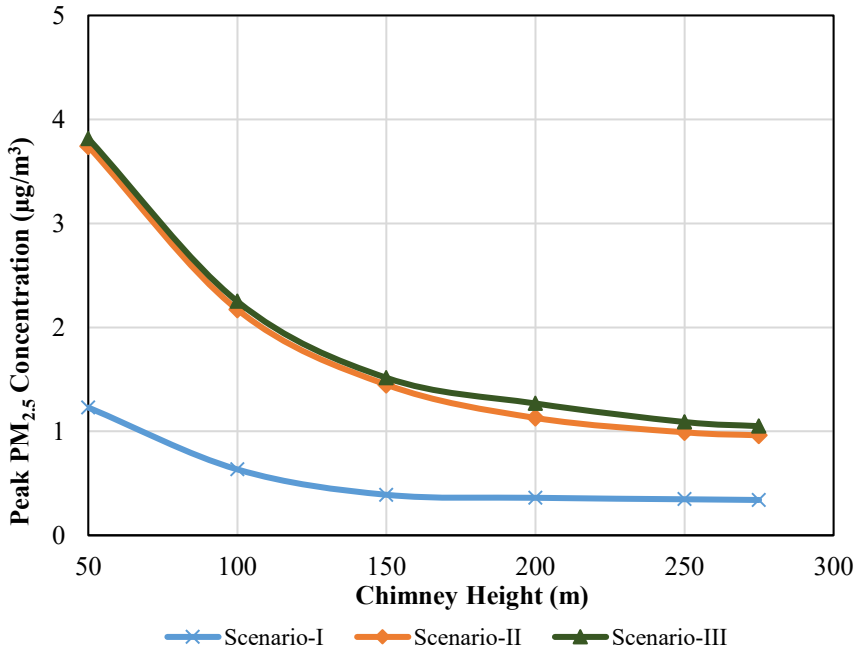


Figure 4.25: Variation of peak $PM_{2.5}$ concentration (24 hour average) with stack height

Variation of peak PM_{10} with respect to chimney height replicates the trend of $PM_{2.5}$. However, the ground level concentrations as received by the receptors have been relatively higher than that of $PM_{2.5}$. Yet, the worst case scenario has produced a PM_{10} level (3.82 $\mu g/m^3$) which is far below the Bangladesh Standard (150 $\mu g/m^3$) and the even more stringent WHO Guideline value (50 $\mu g/m^3$) for 24-hour average.

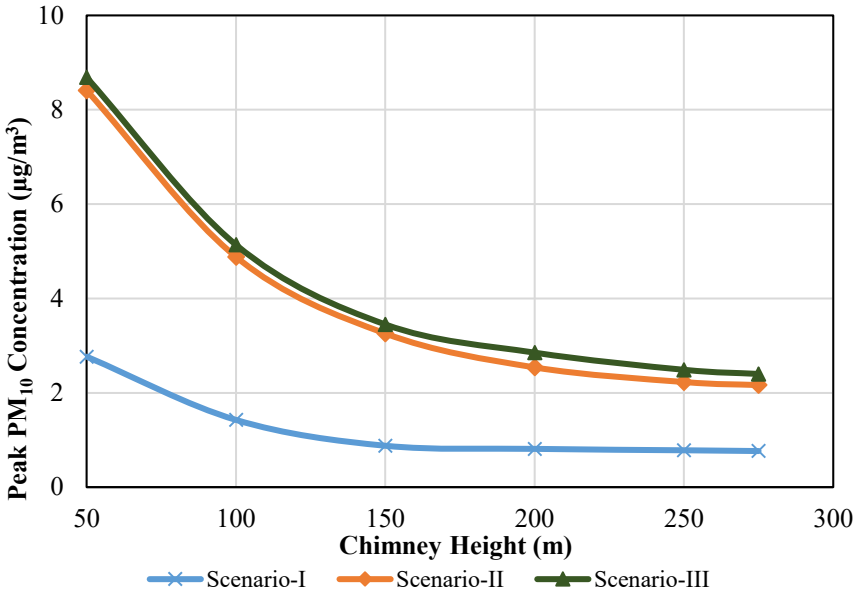


Figure 4.26: Variation of peak PM_{10} concentration (24-hour average) with stack height

4.7.4 Variation of Carbon Monoxide Concentration for Various Chimney Heights

Coal fired power plants usually generate a limited amount of carbon monoxide, commonly produced due to incomplete combustion of fuel. Both, Bangladesh Standard and WHO Guideline have set a maximum concentration limit of 10,000 $\mu g/m^3$ (8 hour average) for CO, which is order to magnitude higher than the values obtained by model simulation, as shown in Figure 4.27. Hence, CO provides no restriction on chimney height under any scenario.

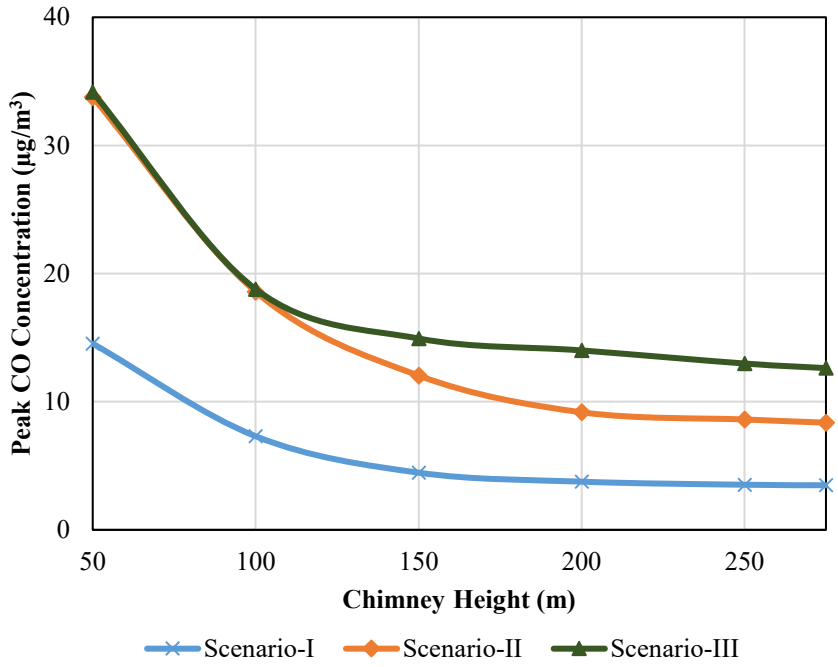


Figure 4.27: Variation of peak CO concentration (24-hour average) with stack height

The analysis of the variation of peak concentration of pollutants as a function of chimney height for the five criteria pollutants reveals that only sulfur dioxide plays a significant role in restricting the chimney height, under the condition when multiple power plants will become operational. As noted earlier, the simulations have excluded the local baseline pollutant concentration. Hence, there is a probability that cumulative impact of power plants on ambient air quality might exceed the WHO Guideline values if lower range of chimney height (50m to 150m) is selected. For pollutants except SO_2, chimney height above 150 m is deemed sufficient to comply with air quality standards. However, peak concentrations of SO_2 suggest higher chimney heights (above 250 m) should be selected to provide allowance for background concentrations. Since, chimney height above 250 m is recommended to meet the emission criteria of SO_2 only, an alternative of using high efficiency FGD (>90%) might be an effective way to reduce the cascading effect on construction cost and time. The health effects of occasional exceedances of SO_2 under lower stack heights should also be carried out to better understand the associated health effects.

4.8 Effect of Efficiency of Emission Control Technologies on Pollutant Concentration

In the quest of being self-sufficient in electricity sector, Bangladesh has shifted to coal and oil fired power plants which result in emissions of sulfur-dioxides (SO_2), nitrogen oxides (NO_X),

particulate matter (PM), metals like mercury (Hg) and other trace metals. A multitude of advanced emissions control technologies are available to address these common targeted pollutants and depending on the type of coal to be burned, different combinations of technologies are needed to meet the regulatory control standards. To ensure compliance with the emissions standards of Bangladesh, particulate matter emission at the Payra Power Plant will be controlled to ≤ 50 mg/Nm^3 by using the high-efficiency Electrostatic Precipitator (ESP). Limestone-Gypsum Wet Flue Gas Desulphurization (FGD) is intended to be adopted to curb SO_2 emissions. To reduce the amount of NOx emission, low NOx burners shall be used in the boilers. Even though these emission control technologies guarantee pollutant abatement at a high rate, however, their efficiency depends on a number of factors such as proper fuel preparation, quantity and quality of fuel, combustion conditions in furnace chamber, design quantity and quality of process water and flue gas at the inlet. This section aims to compare the pollutant behavior at various efficiency levels of the control technologies, as well as, assess the situation in absence (or failure) of these technologies.

4.8.1 Efficiency of Flue Gas Desulphurization Installations

Two basic approaches to reduce sulfur in the fuel are i) fuel blending or fuel switching to a lower sulfur coal, or ii) utilizing a technology to remove the SO_2 from the flue gas (Moretti and Jones, 2012). A variety of SO_2 removal technologies are available which include wet FGD, dry FGD utilizing a spray dryer absorber (SDA), circulating dry scrubber (CDS), and dry sorbent injection (DSI). Wet FGD is the predominate technology used worldwide for the control of SO_2 from utility power plants and has been proposed for Payra Thermal Power Plant Phase I and II. Depending on the pH levels of slurry, slurry recirculation flow rates, fineness of limestone, duration of SO_2 in washer the efficiency of this technology can vary from 50-90% (Neveux et al., 2014 and Romanik, 2016). As per Nihalani et al. (2017), SO_2 removal efficiencies as high as approximately 98% can be achieved using Limestone forced oxidation systems.

A plot of peak SO_2 concentrations as a function of efficiency of FGD has been shown in Figure 4.28. Peak concentrations have been simulated for 90%, 75% and 50% efficiency level of FGD along with no FGD condition for the three proposed Scenarios. In the simulation results presented earlier, the SO_2 concentrations have been simulated assuming an efficiency level of 90% following the EIA report on Payra Thermal Power Plant Phase I and II. At this efficiency

level, the pollutant is seen to comply with WHO ambient air quality limit for each scenario. As the efficiency level drops to 75%, peak concentrations increase almost three folds, and for Scenario-II and III peak SO_2 concentration exceeds the Guideline value. With further 25% decrease in FGD efficiency level, even a single power plant poses threat to the ambient air quality and pollutant concentrations are expected to rise as high as 81.0 µg/m^3 (Scenario-III). It can be concluded from these predictions that just installation of FGD is not sufficient, regular maintenance and careful monitoring of FGD is crucial to comply with ambient air quality limits.

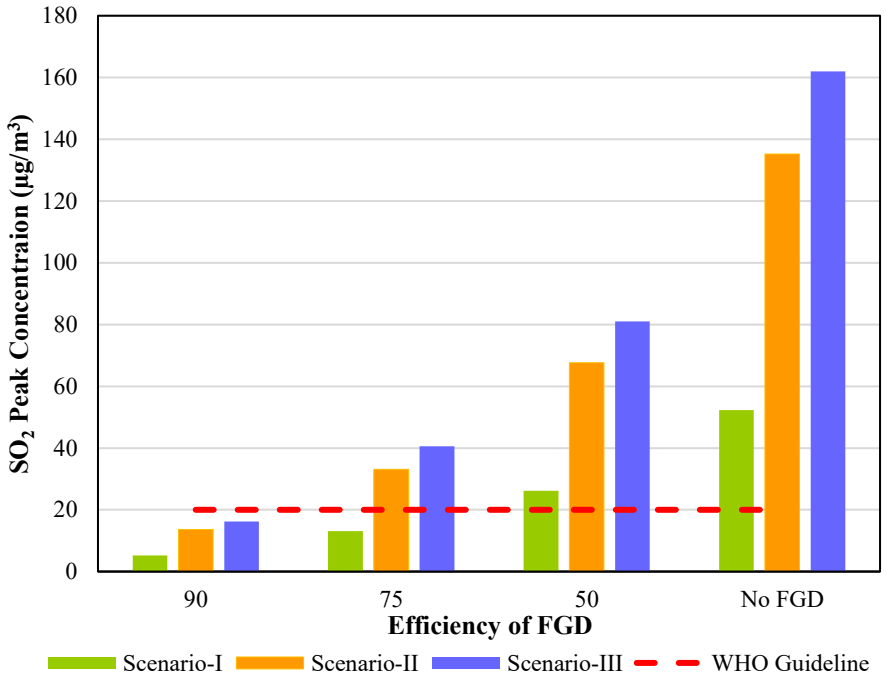


Figure 4.28: Impact of Efficiency of FGD in SO_2 Peak Concentration (24 hour average); the red dotted line represents the WHO 24-hr guideline (20 µg/m^3) value for SO_2

The simulation of scenarios in absence of FGD presents elevated concentrations of SO_2. Even though coal with moderate sulfur content (0.47%) has been used as fuel and sufficiently high chimney height (275 m) has been provided, still the deficiency of FGD has resulted in adverse environmental conditions. Thus the incorporation of and ensuring proper maintenance of FGD is essential for coal fired power plants.

4.8.2 Efficiency of Electrostatic Precipitator

Due to strict regulation and ever increasing air pollution, installing Electrostatic Precipitators (ESP) have become a norm now in power industries. When operating properly, ESPs can achieve overall collection efficiencies of 99.9% of primary particulates (over 99% control of PM_{10} and 95% control of $PM_{2.5}$) (Miller, 2010). However, the efficiency of the ESPs depends on a number of factors such as corona power ratio, resistivity of dust, particle size (Monterosso et al., 2011). ESPs might fail to perform as expected owing to phenomena such as disruptions of the normal corona process, which greatly reduce the ESP's collection efficiency and in server cases the efficiency may fall below 50%.

The impact of various efficiency levels of Electrostatic Precipitator on the peak concentration of PM_{10} and $PM_{2.5}$ are shown in Figure 4.29 (a, b). The efficiency level of ESP has been considered 99.2% following the USEPA AP-42 Emission Factors. At this elevated efficiency both pollutants PM_{10} and $PM_{2.5}$ have negligible concentrations under three Scenarios with the maximum being 2.6 $\mu g/m^3$ and 1.2 $\mu g/m^3$ respectively. Poškas et al. (2014) suggests that the typical collection efficiency of ESP is about 90%. Simulating the PM concentration at this efficiency level satisfies the WHO Guideline value and poses no threat to the ambient air quality. While considering the worst case scenario of 50% efficiency level, Scenario-II and III surpasses the ambient air quality limit substantially and even Scenario-I comes very close to the limit. Thus it can be concluded that regular monitoring of ESP by skilled personnel is essential in keeping the particulate emissions under control.

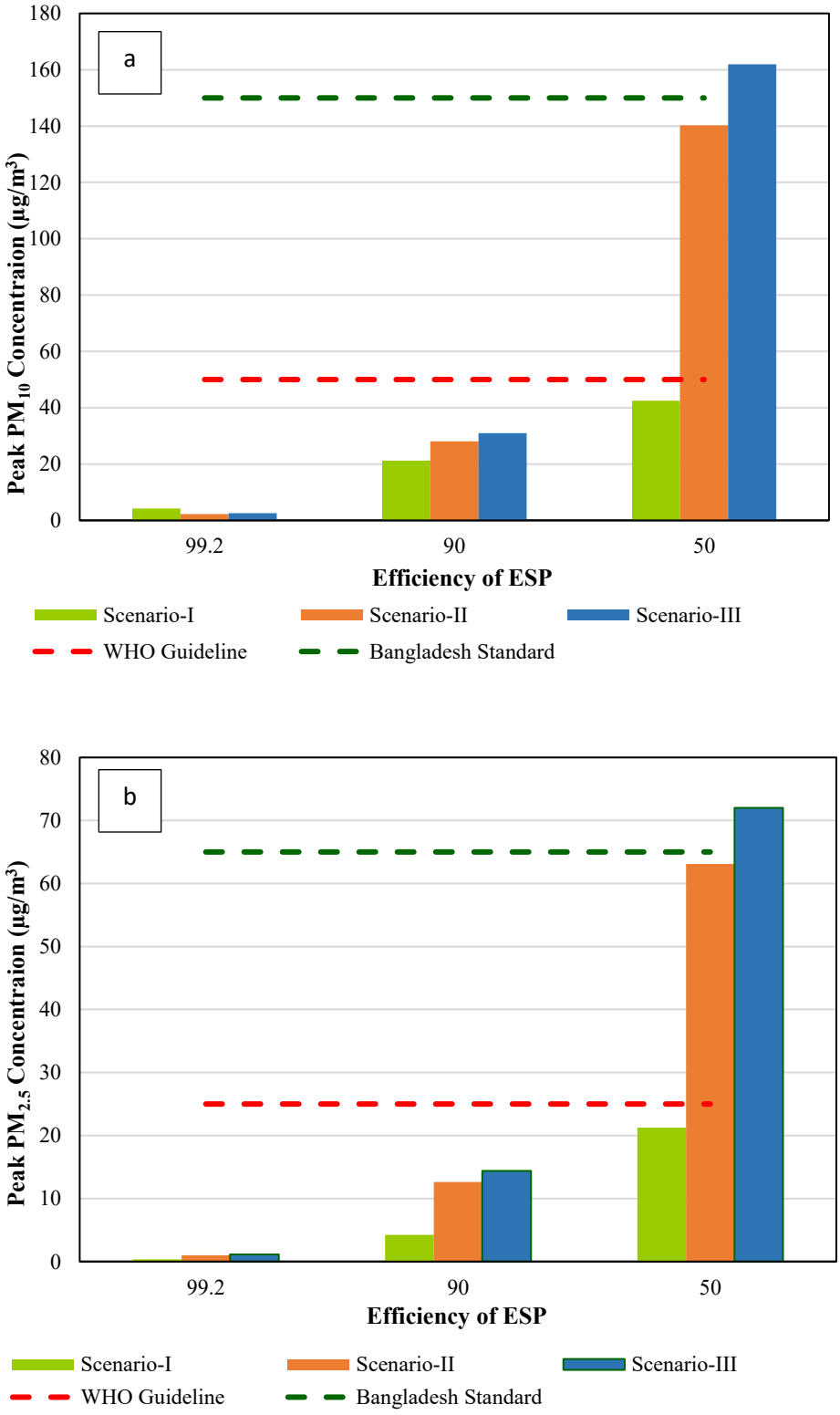


Figure 4.29: Impact of Efficiency of ESP in (a) PM_{10} and (b) $PM_{2.5}$ Peak Concentration (24 hour average); the red dotted line represents the WHO guideline value, while the green dotted line represents the Bangladesh air quality standard.

4.9 Impact of Coal Quality on Pollutant Concentration

Coal determines to a large extent the type and quantity of pollutants emitted from thermal power plants. Sulfur and ash content are important parameters that characterize composition of coal, as it regulates emission of sulfur oxides and particulate matter, respectively. With a single active coal mine located in Dinajpur, Bangladesh is still not self-sufficient in coal production. Hence, coal for operation of power plants will be imported from India, Indonesia and South Africa. Effort was made to assess the impact of coal quality to be used in the proposed power plants on ambient air quality.

4.9.1 Particulate Matter Concentration for Various Ash Content

Coal ash is the residue remaining after the combustion of coal under specified conditions. The ash content of Barapukuria coal mine varies from 5.51-14.23%, the representative value being 12.3% (Bhuiyan et al., 2014). According to the EIA report of Payra Thermal Power Plant, Indonesian coal has been proposed as primary fuel for Payra Thermal Power Plants, which has ash content ranging from 1.40-18.92% (Basel Convention Regional Centre for South East Asia, 2017). However, Indo-6 coal has been used as design coal in pollutant emission estimation, which has an ash content of 6%. Even though Indian coal has a high ash content range of 25-50% (Kumari et al., 2016), every year almost 1 million ton coal is imported from India owing to its low cost. The average ash content of the imported Indian coal is 26% (Bhuiyan et al., 2014). Particulate matter ($PM_{2.5}$ and PM_{10}) response to the ash content of coal to be used in the proposed power plants are shown in Figure 4.30 (a, b).

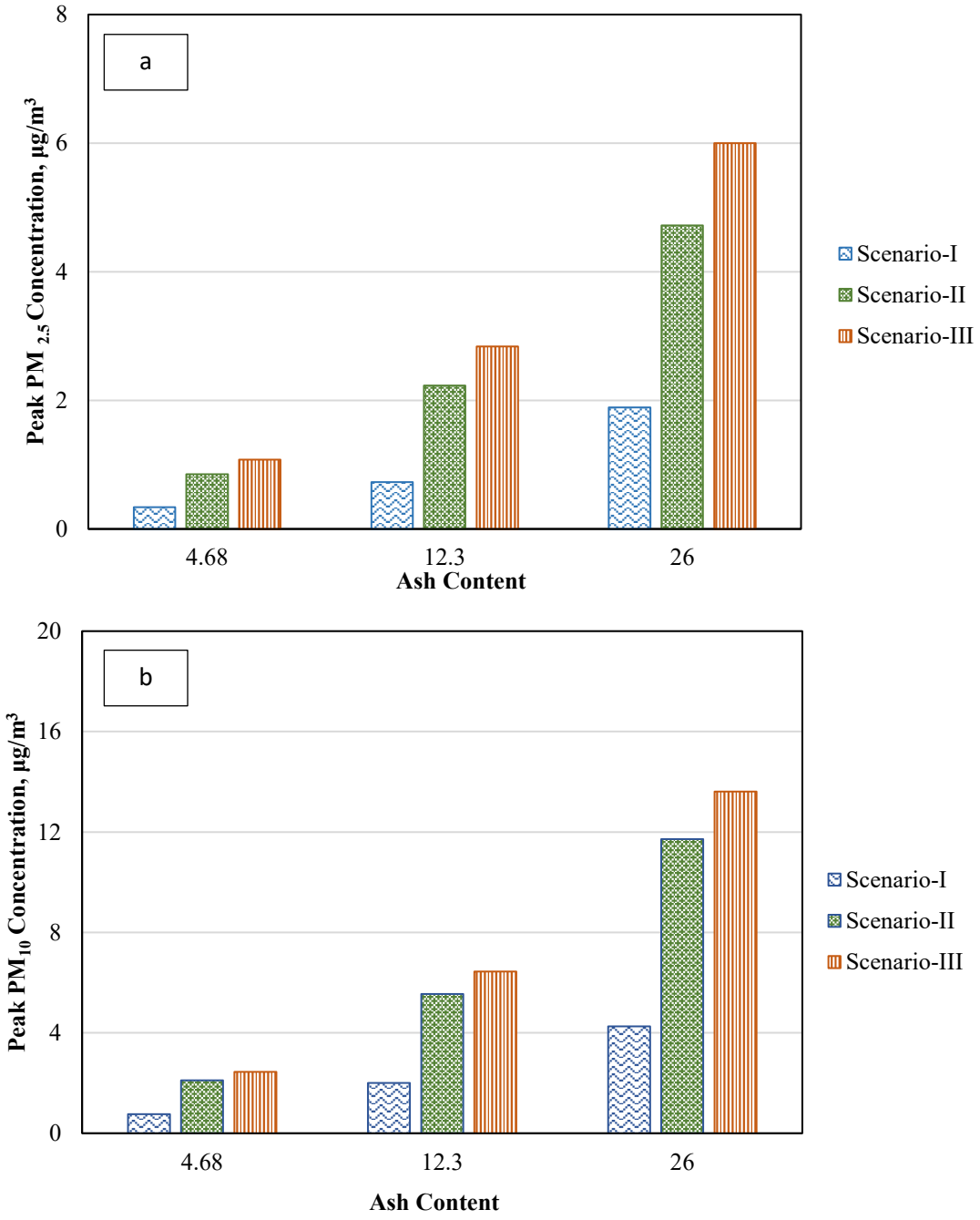


Figure 4.30: Peak 24-hour average concentration of (a) $PM_{2.5}$ and (b) PM_{10} for various ash content

Figure 4.30 shows that ash content of coal has a significant impact on peak PM concentration, and the peak PM concentration corresponding to the higher ash content considered in this analysis could violate the WHO guideline value for PM. Clearly, Indian coal has the highest ash content which yields peak concentration of 6 µg/m^3 and 13.61 µg/m^3 respectively for $PM_{2.5}$ and PM_{10} under worst case scenario. The Barapukuria coal of Bangladesh is a modest option as corresponding ground level concentration is well below the National Ambient Air Quality

limit. However, as the power plants on an average require 13263 ton coal per day, the transportation of this large quantity of coal is a matter of concern as there is no available river route or rail link connecting Barapukuria and Payra. Also, the capacity of Barapukuria coal mine is 3500 ton per day, which is insufficient to run the power plants solely depending on this source. Indonesian coal with low ash content, on the other hand, shows neglible impact on ambient air quality. With Payra Port under construction, shipping tends to become an easier option. Hence, high quality coal can be conveniently imported to meet the emission standards.

4.9.2 Sulfur Dioxide concentration for Various Sulfur Content

Sulfur content is one of the most significant parameters to assess the coal quality. High sulfur content is always undesirable for whatever purpose coal is burnt as the existence of high sulfur degrades the quality of coal and pollutes the environment (Qiu et al., 2011). The local coal has sulfur content in the range 0.59-0.99% (Bhuiyan et al., 2014). Indonesian coal opted for the Payra Thermal Power Plant has 0.47% sulfur content, which makes it preferable to the local coal. However, the Indian coal imported through the border of Tamabil has sulfur content ranging from 1.42-5.3% (Hashan et al., 2016).

Figure 4.31 shows peak 24-hour average concentration of sulfur dioxide for three different sulfur content of coal.

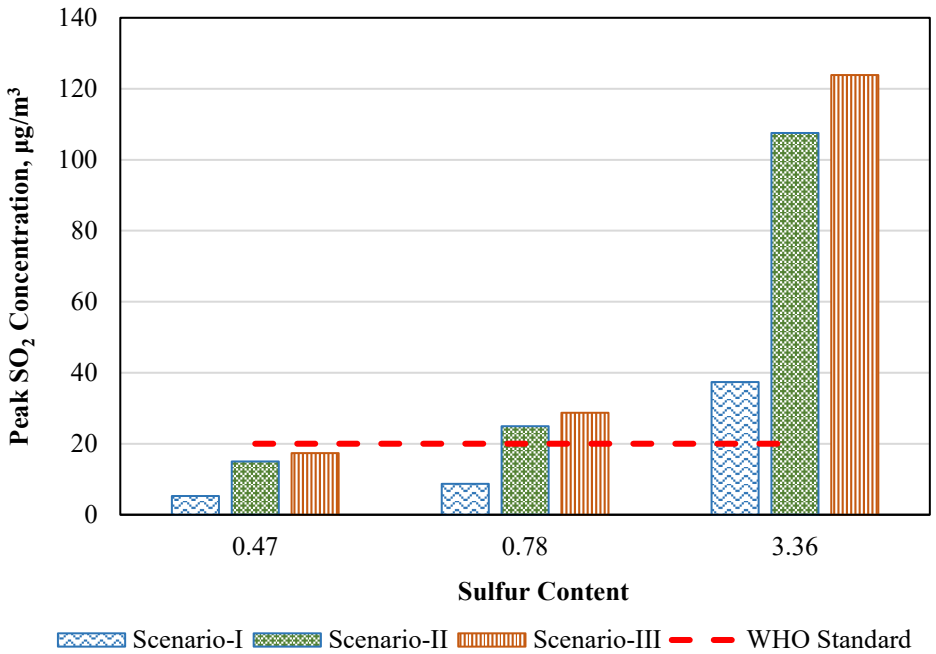


Figure 4.31: Maximum 24-hour average concentration of SO_2 for various sulfur content; the red dotted line represents the WHO guideline value

The peak concentration of sulfur dioxide for the proposed coal (with 0.47% sulfur) is within the Bangladesh Standard (365 $\mu g/m^3$) and WHO Standard (20 $\mu g/m^3$), even though for Scenario-II and III the WHO Standard is marginally satisfied. Considering average sulfur content for the local coal (0.78%) it is observed that only Scenario-I satisfies the WHO Standard, however, for other scenarios the values are well below Bangladesh Standard. On the other hand, use of Indian coal with sulfur content of 3.36% results in peak SO_2 concentration of 123.9 $\mu g/m^3$, exceeding the WHO guideline value (but satisfying the Bangladesh standard of 365 $\mu g/m^3$). Hence, it is imperative to adopt advanced coal cleaning technology such as air spared Hydro-cyclone, Spherical agglomeration etc. besides FGD if Indian coal are used. Additionally, appropriate measures should be taken to use high grade local coal available in our country.

4.10 Contribution of Individual Power Plants to Air Quality

A assessment of incremental concentration due to installation different power plants has been carried out to investigate the contribution of different power plants on the ambient air quality. To establish the baseline condition, available air quality data of the area was collected from the EIA report of the Payra Power Plants. The study area is mainly rural, which has a mix of construction activities, scattered settlements and agriculture areas. Generally, air pollution sources in the Project area consists of road dust, black smoke from diesel engine vehicles, vessels in Rabnabad, Andharmanik River, construction dust, windblown dust from agricultural lands, domestic heating and cooking and brick kilns. The ambient air quality data reported in the EIA report were based on measurement carried out during 24th -27th January, 2018 & 23rd – 28th July, 2018 has been presented as the representative of dry and wet seasons respectively. The data have been presented in Chapter 3 (Table 3.2).

Model simulations were carried out to assess the contribution of individual power plants to the peak ground level concentration of pollutants at the six locations (identified as D1 through D6) where baseline/ background concentration data are available. These receptors are located in human habitat in vicinity of the power plant region. Thus, the cumulative concentration (summation of baseline and modeled concentration) attained at these receptors reveal the susceptibility of surrounding locality to the degree of pollutant exposure. Model simulations were carried out to assess the contribution of: (a) Payra Thermal Power Plant Phase-I, (b) Payra Thermal Power Plant Phase-II, and (c) cumulative emission by RPCL, APSCL and SKS Power Plants.

4.10.1 Contribution of Power Plants to SO_2 Concentration

Sulphur dioxide is a key concern for the coal based power plant projects. The contributions of different power plants to peak 24-hr ground level concentration (GLC) of SO_2 has been shown in Figure 4.32; this figure also shows the background/ baseline concentration of SO_2 in the project area. The Figure illustrates that dry season dominates in terms of maximum pollutant concentration at every receptor. The receptors arranged in incremental distance from the Payra Thermal Power Plant shows a declining trend; the closest receptor D1 located at a distance 0.56 km from the source shows a maximum cumulative concentration of 56.6 µg/m^3, whereas D6 located 4.98 km away exhibits a maximum cumulative concentration of 43.2 µg/m^3.

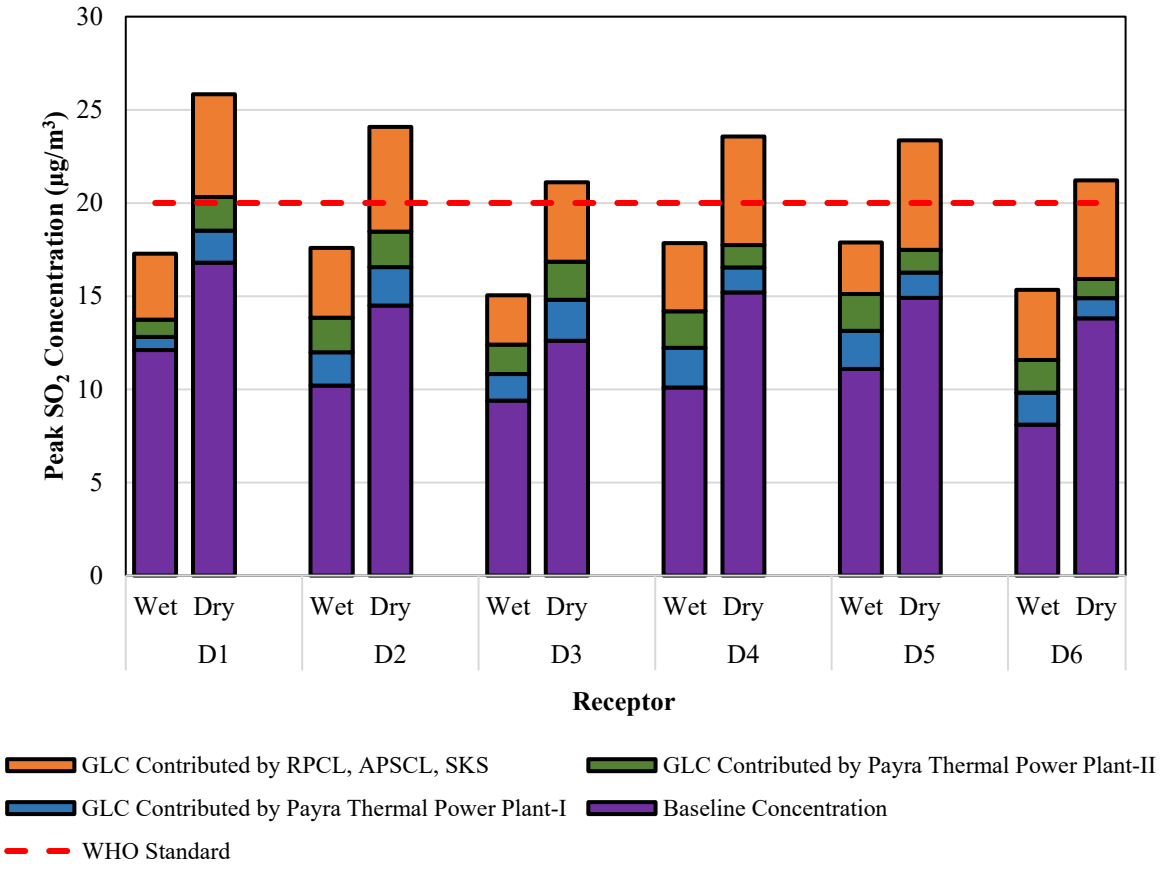


Figure 4.32: Maximum cumulative SO_2 concentration during dry and wet season

The 24-hourly SO_2 concentrations were recorded in the range of 12.6 – 16.8 µg/m^3 during the dry period and 8.1-12.1 µg/m^3 during the wet period. The background concentration of SO_2 (reported in the EIA report) is low at all locations due to their rural setting; the maximum SO_2 concentration is reported at Power Plant site as 16.8 µg/m^3. SO_2 concentrations at all the monitoring locations were well below 365 µg/m^3, which is National Ambient Air Quality

Standard (NAAQS) for SO_2 in Bangladesh, as well as the WHO Standard (20 µg/m^3). The assessment of contribution of the different power plants to cumulative ground level concentrations show that predicted SO_2 concentrations at the six receptors (together with the background concentration) satisfy the stringent WHO standard (20 µg/m^3) even after the installation of Payra Thermal Power Plant I and II. However, as three other proposed power plants (RPCL, APSCL, SKS) comes into operation, the dry season peak SO_2 concentration at each receptor would exceed the WHO Standard; but the concentration values would still be well below the NAAQS in Bangladesh (365 µg/m^3).

Figure 4.33 (a, b) shows that the spatial distribution of SO_2 is similar for Payra Thermal Power Plants Phase- I and II, and exhibits similar concentration levels owing to their proximity and identical emission rates. The maximum concentrations for these two power plants are centrally dispersed in the study area. Even though the combined operation of RPCL, APSCL, SKS, located north of Payra Power Plants, yields peak northward (Figure 4.33(c)), these plants also contribute to the SO_2 concentration at the receptors D1 through D6 (located at center of domain), resulting in higher concentration of SO_2 at these receptors.

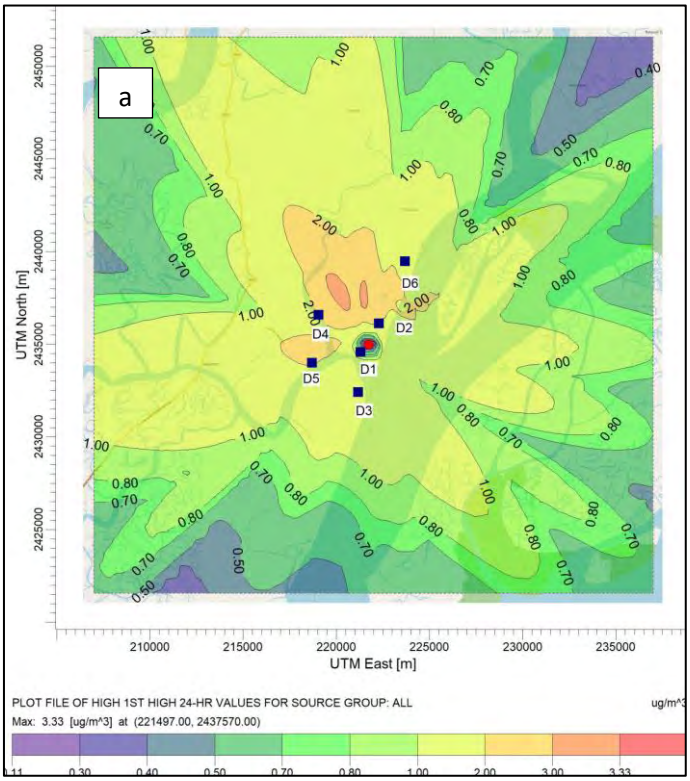


Figure 4.33(a): Spatial distribution of 24-hour average concentration of SO_2 due to emission contribution by Payra Thermal Power Plant-I during June; the red dots represent the location of the power plants, while the blue dots represent the location of air quality monitoring stations

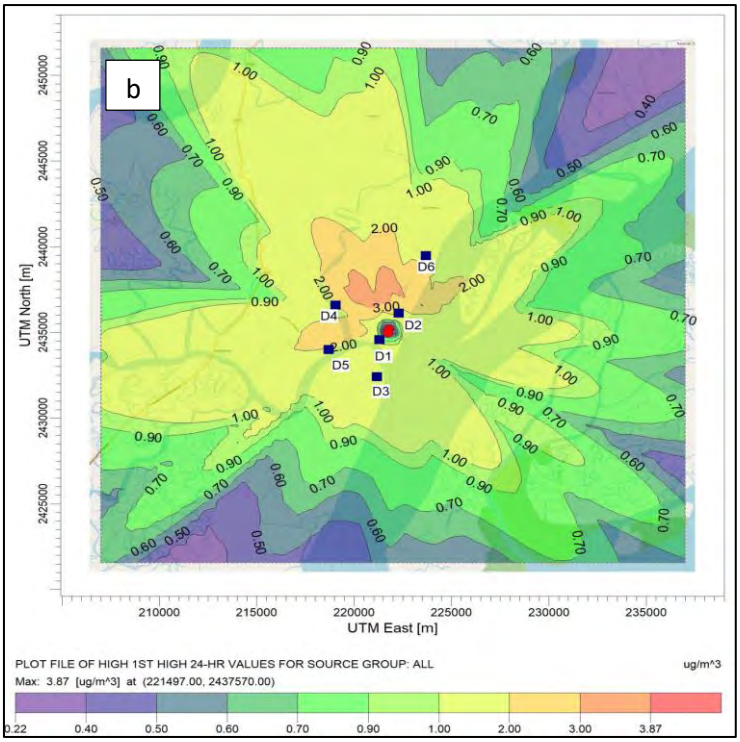


Figure 4.33(b): Spatial distribution of 24-hour average concentration of SO_2 due to emission contribution by Payra thermal Power Plant-II during June; the red dots represent the location of the power plants, while the blue dots represent the location of air quality monitoring stations

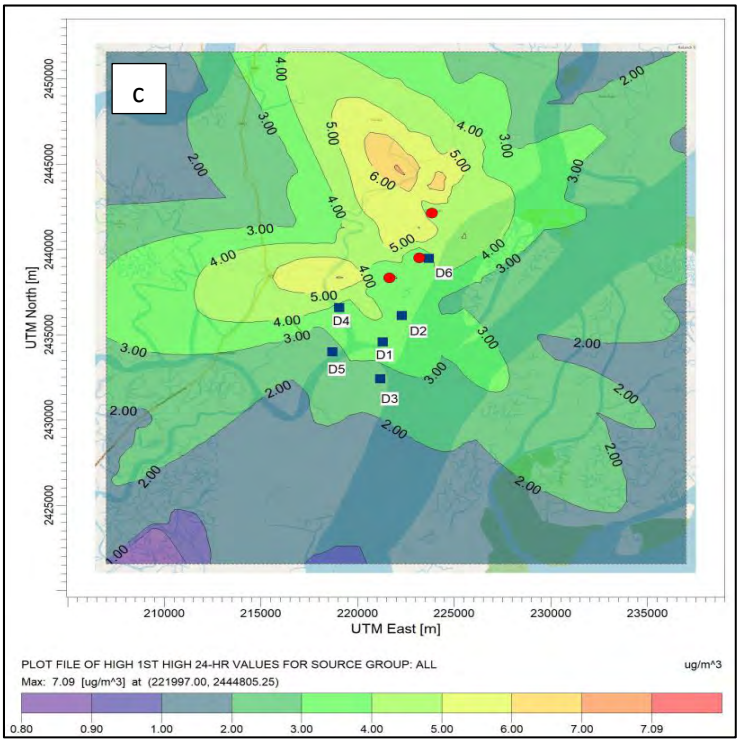


Figure 4.33(c): Spatial distribution of 24-hour average concentration of SO_2 due to emission contribution by RPCL, APSCL, SKS during June; the red dots represent the location of the power plants, while the blue dots represent the location of air quality monitoring stations

4.10.2 Contribution of Power Plants to NOx Concentration

NO_X is the key concern for the coal based power plant projects. The contributions of different power plants to peak 24-hr ground level concentration (GLC) of NO_x has been shown in Figure 4.34; this figure also shows the background/ baseline concentration of NO_x in the project area.

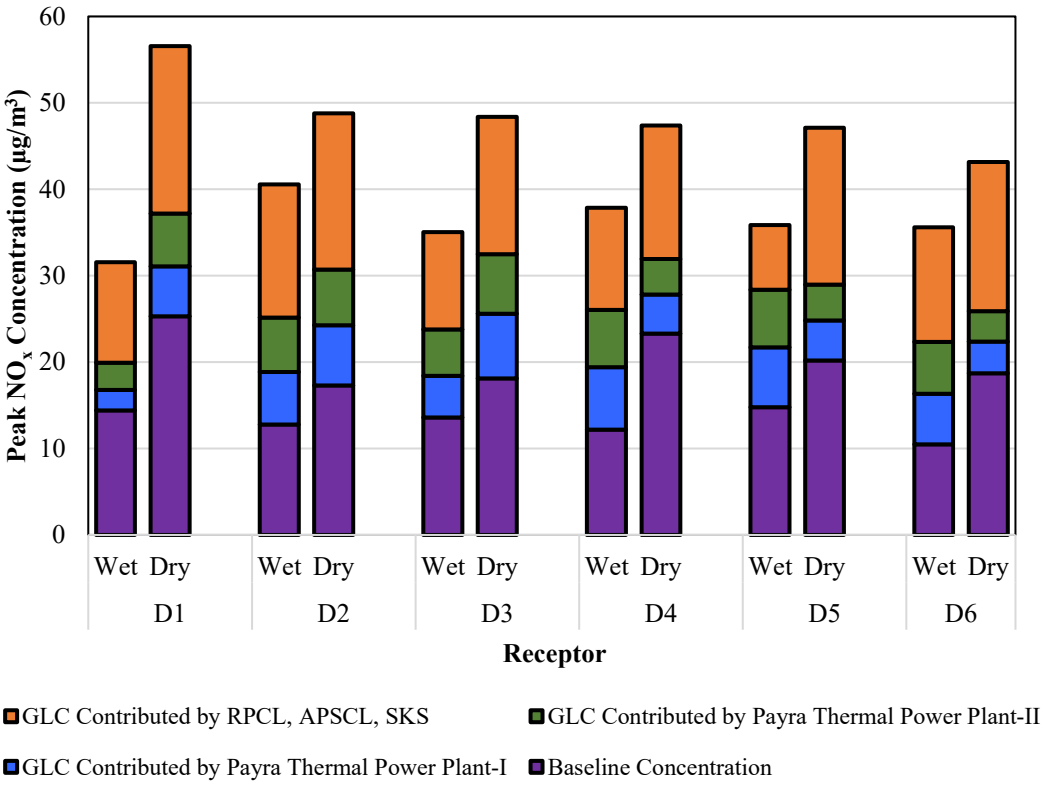


Figure 4.34: Maximum cumulative NO_x concentration during dry and wet season

The 24-hour NOx concentration were recorded (during EIA study) in the range of 17.3 – 25.3 µg/m^3 during the dry period and 10.5 – 14.8 µg/m^3 during the wet period. The highest NOx concentration was recorded at Nishanbari near the project site as 25.3 µg/m^3 due to the construction machinery, and the vehicle running frequently.

The predicted NOx concentrations at the selected receptors (D1 to D6) exhibit significant difference during dry and wet seasons; the highest variation being displayed by receptor D1 with a peak concentration of 31.3 µg/m^3 and 17.2 µg/m^3 during dry and wet seasons, respectively. There are no standard for 24-hour NOx concentration; however, the predicted concentrations are well below the annual average Bangladesh standard for NOx (100 µg/m^3). Among the power plants, the combined contribution (to NOx concentration) of RPCL, APSCL, SKS power plant appear to be most significant at the receptors considered.

4.10.3 Contribution of Power Plants to $PM_{2.5}$

The measured (during EIA study) concentrations of $PM_{2.5}$ and predicted maximum concentration values due to power plant emissions are shown Figure 4.35 (a) and (b), respectively.

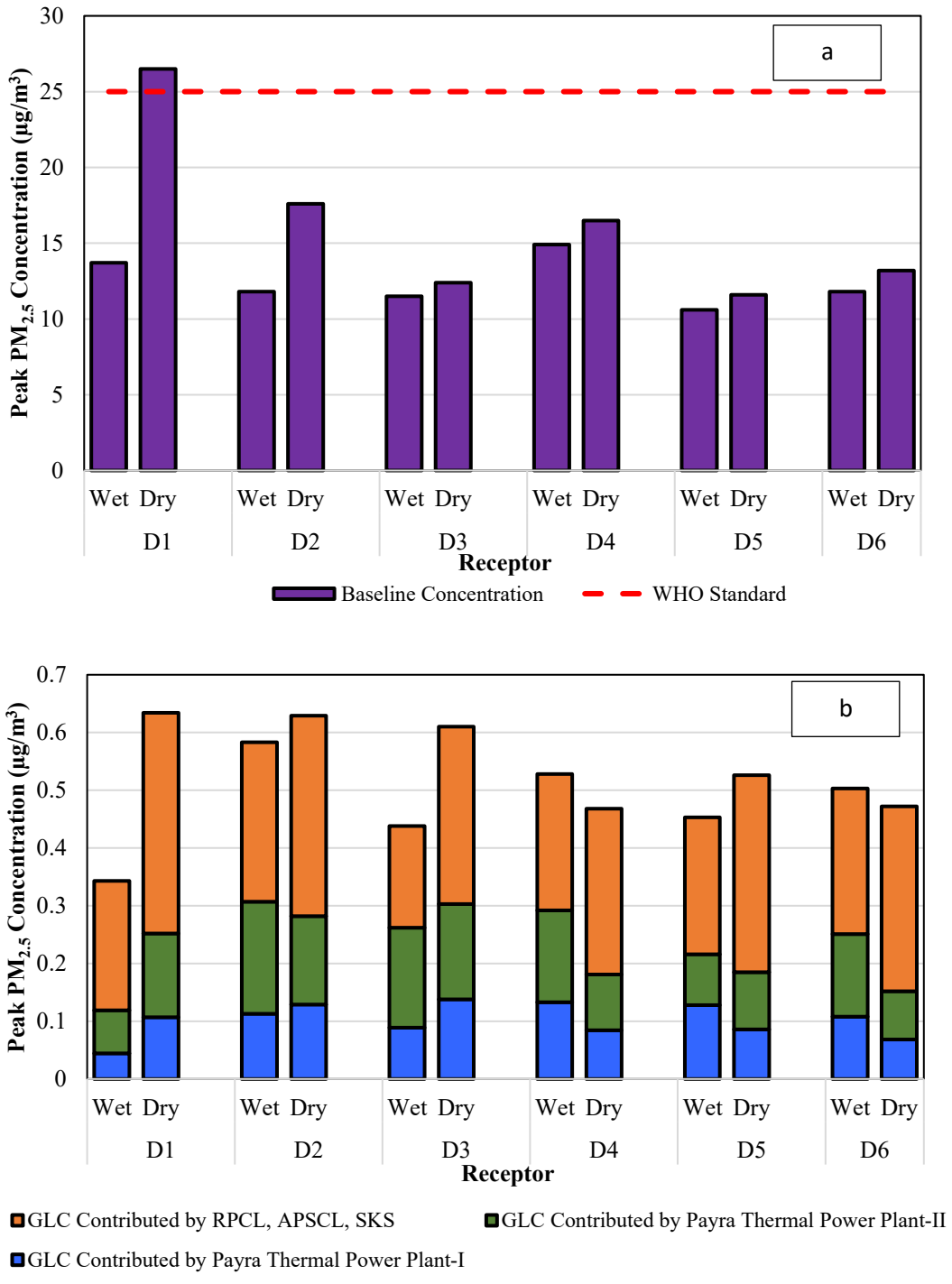


Figure 4.35: Maximum $PM_{2.5}$ concentration for (a) baseline case and (b) project case during dry and wet season

The 24-hour $PM_{2.5}$ concentrations in ambient air of the study area were recorded in the range of 11.6 – 26.5 µg/m^3 during the dry period and 10.6 – 14.9 µg/m^3 during the wet period [Figure 4.35 (a)]. The maximum $PM_{2.5}$ concentration of 26.5 µg/m^3 was reported from Nishanbari village near the project site. All the measured ambient concentrations were within the 24-hourly National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ in Bangladesh, except at receptor D1, which violates WHO Standard (25 µg/m^3) marginally during dry season.

The predicted peak $PM_{2.5}$ 24-hour average concentrations at the receptors (see Fig. 4.35b) are insignificant compared to the maximum baseline concentrations. This is largely attributed to the low emission rate of $PM_{2.5}$ due to the high efficiency of electrostatic precipitator. Among the power plants, the combined contribution (to $PM_{2.5}$ concentration) of RPCL, APSCL, SKS power plant appear to be most significant at the receptors considered.

4.10.4 Contribution of Power Plants to PM_{10}

Similar to $PM_{2.5}$, the baseline measured concentrations and the predicted concentrations (due to power plant emissions) of PM_{10} displays large variations, as shown in Figure 4.36 (a, b); the measured baseline concentrations are much higher than the predicted concentrations).

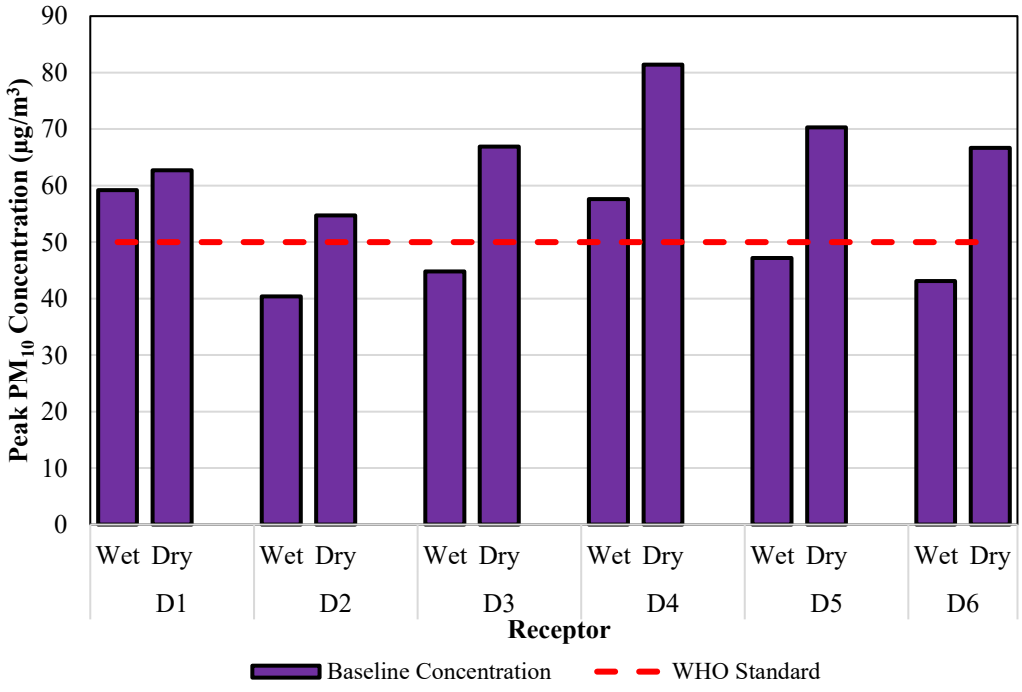


Figure 4.36 (a): Maximum PM_{10} concentration for baseline case during dry and wet season

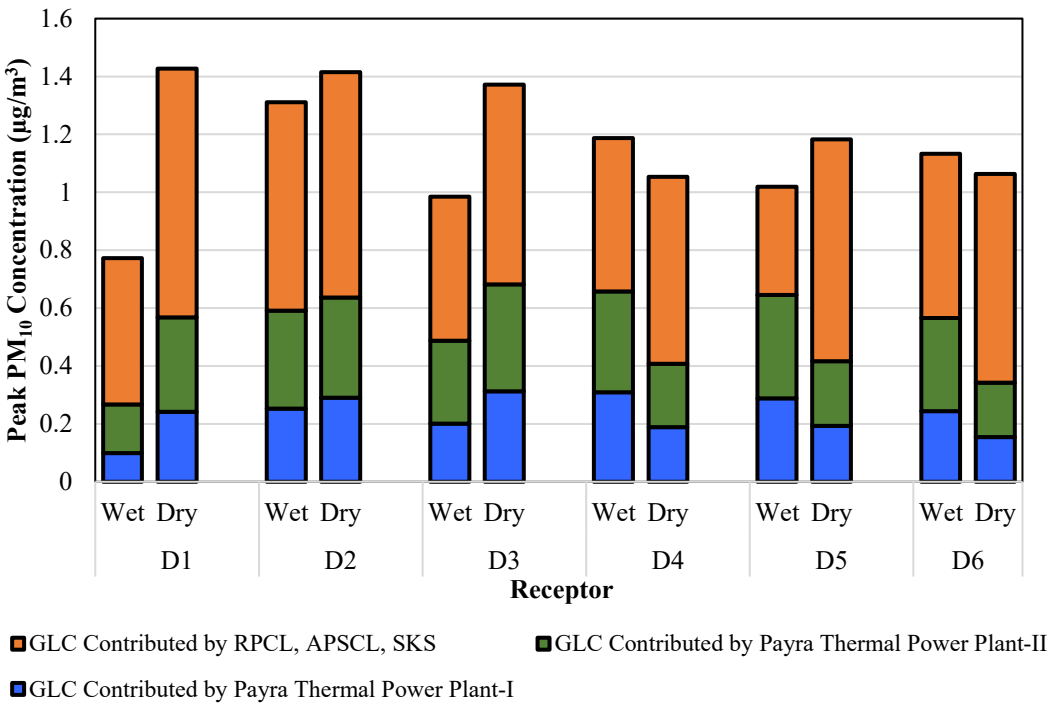


Figure 4.36 (b): Maximum PM_{10} concentration for project case during dry and wet season

The 24-hour PM_{10} concentrations in the ambient air of the study area were recorded in the range of 54.7 – 81.4 µg/m^3 during the dry period and 40.4 – 59.2 µg/m^3 during the wet period. During the monitoring period, the maximum PM_{10} concentrations of 81.4 µg/m^3 was reported for Londa Kheya Ghat. The measured PM_{10} level at all monitoring locations was below the NAAQS in Bangladesh (150 µg/m^3); however, the receptors fail to meet WHO guideline value (50 µg/m^3), particularly during the dry season.

In comparison to the measured concentrations at the monitoring locations, the predicted PM_{10} concentrations due to power plant activity are negligible. Among the power plants, the combined contribution (to $PM_{2.5}$ concentration) of RPCL, APSCL, SKS power plant appear to be most significant at the receptors considered. Thus, it appears that installation of power plants in the study area is not a concern with respect to PM_{10} concentrations. However, this holds true only if the electrostatic precipitator functions at a high efficiency level.

4.10.5 Contribution of Power Plants to CO Concentration

Formation of carbon monoxide is commonly attributed to incomplete combustion of fuel. Emission control technologies have not been adopted for carbon monoxide since the baseline CO concentration as well as the predicted CO concentration due to emission from power plants

are well below NAAQS. The measured concentration values and predicted maximum concentration values due to operation of power plants are shown in in Figure 4.37 (a, b).

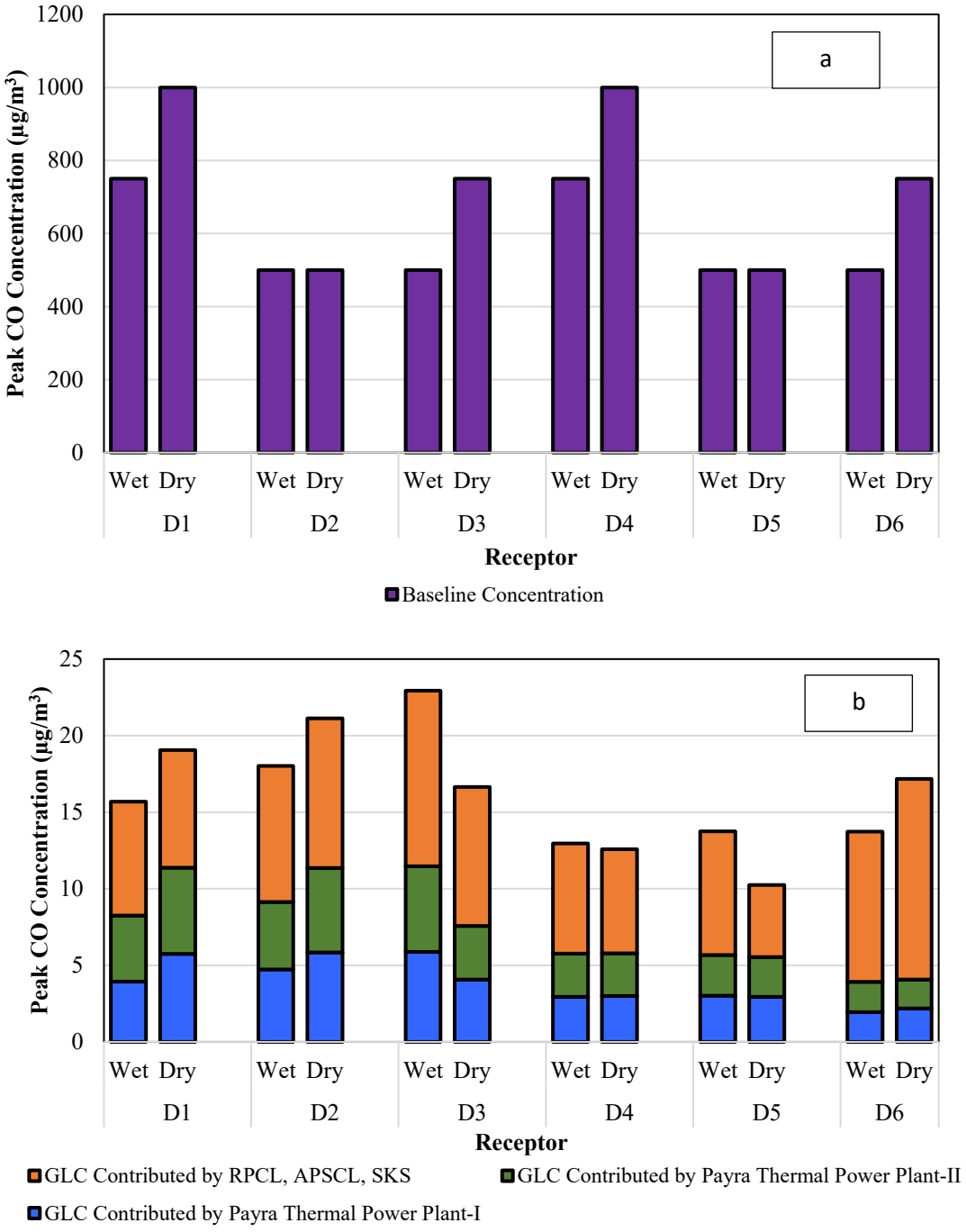


Figure 4.37: Maximum CO concentration for (a) baseline case and (b) project case during dry and wet season

CO concentrations were reported to be low at all the monitoring locations, while comparing with the Bangladesh Standards and WHO Standard (10,000 µg/m^3). The 8-hour CO concentrations in the ambient air of the study area were recorded in the range of 500 – 1000

μg/m^3 during the dry period and 500-750 μg/m^3 during the wet period. The cumulative maximum concentration values of CO due to operation of all power plants ranged from 10.2-21.1 μg/m^3 during dry season and 13.0-22.9 μg/m^3 during wet season.

Chapter 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 General

The main objective of this study was to assess ambient air quality due to operation of the under construction and proposed coal fired power plants in Payra, Patuakhali. The air quality in the vicinity of the power plants have been predicted using the dispersion model AERMOD for a wide range of conditions, including three scenarios: (a) Scenarios I: Operation of Payra Phase I power plant; (b) Scenario II: Operation of Payra Phase I and Phase II power plants: (c) Scenario III: Operation of all 5 power plants. Meteorological data for the year 2017 has been used in all model simulations. The model results have been analyzed to understand the spatial and temporal (diurnal, seasonal) variation of air quality, as well as effects of different operating conditions/ parameters (e.g., coal quality, different levels of efficiency of pollution control technologies) on air quality. The major findings of the current study are described in the Chapter 4. This Chapter summarizes the key findings of the study and presents recommendations for future study.

5.2 Conclusions

The major conclusions from the present study are as follows:

i. Emissions (sulfur dioxide, carbon monoxide and particulate matter) from the five proposed power plants, estimated following the USEPA AP-42 guidelines, are in compliance with the emission standards specified in the Environmental Conservation Rules 1997, provided the high efficiency control technologies considered in the design are fully operational. However, nitrogen oxide from the power plants exceeds the emission standards even though low NOx burner has been incorporated in the plants. Considerations should be given on installation of additional NOx control technologies (e.g. Over Fire Air, Selective Catalytic Reduction) in future.

ii. Predicted peak concentration (hourly average, 24-hr average, and annual average) of pollutants (SO_2, $PM_{2.5}$, PM_{10}, NO_x and CO) over the modeled area (illustrated by iso-concentration contours) increases from Scenario I (only one power plant operating) to Scenario III (all five power plants operation). When added to the relatively high background level, the combined concentrations of SO_2 and PM_{10} (24-hr) exceed the

WHO guideline value. The predicted PM concentrations due to power plant emissions (without considering secondary PM) appears to be negligible.

iii. The distribution of predicted peak concentrations over the model domain for different scenarios follow similar trend, and the highest peak has been recorded for 15th April, 2017 which may vary depending on meteorology for a different time period. Hourly and annual peaks appear in NNE direction, whereas daily peaks are found to occur in NNW direction. These are in agreement with the dominant SSW and SSE winds in the project area during the period of study.

iv. The most significant increase in ambient pollutant concentration occurs when both Phase I and Phase II Payra Plants become operational. The rise in the pollutant concentration due to the addition of the Phase II Payra Plant is predicted to be around two-fold, irrespective of the averaging period. The rise in peak concentration is minimal due to the three additional power plants in the region, possibly because of the significant physical distance of these three plants from the Payra plants (3 to 7 km) and from one another; however, when five power plants are in operation the air quality of the surrounding area is affected significantly.

v. Higher pollutant concentrations have been predicted during summer (March-June), while least concentrations appeared during monsoon (July-October). Central radial distribution of pollutants is observed during winter and monsoon seasons, whereas, strong southern winds linearly carry the pollutants northward during summer. The seasonal variation of pollutant concentration is influenced by a number of factors including wind direction and solar radiation, which in turn determines “mixing height”.

vi. There appears to be significant diurnal variation of pollutant concentration in the vicinity of the power plants. Light winds combined with limited mixing height (with emission taking place below the mixing height) contributes to enhanced pollutant concentration in the vicinity power plant vicinity; however, depending on meteorology, the time of attainment of peak concentration may vary.

vii. Sensitivity analysis of predicted peak pollutant concentration to chimney heights (50 m to 275 m) reveals that any height above 150 m is sufficient to comply with air quality standards for most pollutants (without considering background level). However, when all 5 power plants are operational, a higher stack height (about 165 m) is needed to comply with 24-hr WHO guideline value for SO_2.

viii. Efficiency of emission control technologies (e.g. FGD, ESP) has a strong influence on ground level pollutant concentration. For example, as the FGD efficiency drops from 90% to 75%, peak SO_2 concentration increase by almost three folds. Lower efficiency may lead to violation of standards/ guidelines for some parameters. Thus, ensuring proper operation of the proposed control technologies is indispensable for these power plants.

ix. Ash content of coal does not have a significant impact on predicted particulate concentration; on the other hand, sulfur content of coal has significant impact on ground level SO_2 concentration. . For example, use of Indian coal with sulfur content of 3.36% would result in peak SO_2 concentration of 123.9 $\mu g/m^3$, exceeding the WHO guideline value. Thus, coal with acceptable sulfur content should be used in the power plants.

5.3 Recommendations for Future Study

The utilization of air dispersion models in predicting the potential impact from future emission sources on ambient air quality is still at its preliminary phase in Bangladesh. There is significant opportunities for extensive research and development in this field. The following recommendations are made for future research in this area:

i. Model validation substantiates that a simulation model possesses a satisfactory range of accuracy consistent with the intended application of the model. For this, a comparative analysis should be carried out between the measured values from monitoring sites and model predicted values to generate various parameters such as correlation coefficient, regression coefficient, index of agreement, etc. These parameters determine the degree of accuracy of the models. Since the power plants in Payra are currently not operational, such validation could not be performed. However, as the power plants begin operation, this exercise should be carried out.

ii. This dissertation considers the US EPA AP-42 emission equations for external combustion source to generate the emission rates for various pollutants emitted from the proposed power plants. Nevertheless, plant-specific and parameter-specific (e.g. coal characteristics, process attributes, control equipment aspects) emission rates should be developed in future by comparing the trends of percentage change in annual emission estimates and observed ambient air concentrations of the criteria pollutants.

iii. Due to the increase in coal consumption for power generation, there is a critical need to evaluate the health risks for the population living in the vicinity of a coal-fired power plant in Payra. Health risk assessment shall be conducted for short-term and long-term dispersion of pollutants to investigate population exposure to morbidity and, in some cases, premature mortality.

iv. Classical air pollutants (particulate matter, NOx and SO_2) and greenhouse gases from combustion of fossil fuels impose significant environmental damage costs. Future research activities in quantification of damage cost can facilitate determination of socially optimal level of pollution tax, identification of technologies with lowest social cost, etc. Modification of public policy is illustrated by examples of cost-benefit analysis of estimated damage costs and green accounting.

v. This study considers the emission from proposed power plants only. Emission from other major sources e.g., road traffic and dust, cement factories, brick kiln, etc. should be considered in future modeling studies to assess the cumulative impact of pollutant sources on the ambient air quality.

vi. Focus of this dissertation was coal based power plants only, however, many power plants in Bangladesh use natural gas, LNG and diesel as fuel. Hence, research should be carried out to assess emission from such power plants and their impact on ambient air quality and on health and ecosystem.

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