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PREDICTING AIR POLLUTANTS DISPERSION FROM RAMPAL COAL BASED THERMAL POWER PLANT IN BANGLADESH

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January, 2018

DEDICATED
TO
MY BELOVED PARENTS
AND
ELDER BROTHER

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First of all, I would like to thank and praise almighty "GOD" the most beneficent and merciful, for all his love and blessings conferred upon mankind. I want to express my sincere gratitude to my beloved parents who brought me to this earth and helped me in every step of my life.

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ABSTRACT

The present study was conducted with the objective to assess the cumulative impacts due to air emissions form a coal based thermal power station is going to situated in the Southern part of Bangladesh. The Gaussian model adopted was to carry out dispersion of gaseous air pollutants emission viz. SO_2 and NO_x for all four seasons (winter, summer, monsoon and post monsoon) to understand the extent of air pollution around the site due to the stack emissions from the plant. Detailed study was conducted including the dispersion modelling of stack emissions for all four seasons using site-specific meteorological data. This study found seven Union such as Gaurambha, Hurka, Rajnagar, Bajua, Banishanta, Laudubi and Kailasganj of Rampal and Dacope Upazila under Khulna District was highly vulnerable by the high level of ground concentration of SO_2 and NO_x that exceed the ambient air quality standard in Bangladesh. The total 96,790 population, 8,327.09 ha water body, 13,219 ha crop land and 2,273.88 ha homestead forest are affected through the emission of SO_2 and NO_x which may create problem to human health, flora and fauna growth and breeding.

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List of Acronyms

PSMP = Power System Master Plan

UNESCO = Educational, Scientific and Cultural Organization

BIFPC = Bangladesh India Friendship Power Company

EPA = Environmental Protection Agency

SPM = Suspended particulates

DOE = Department of Environment

BPDB = Bangladesh Power Development Board

NTPC = National Thermal Power Corporation

CEGIS = Center for Environmental and Geographic Information Services

EIA = Environmental impact assessment

List of Units

gm^{-3} = Gram per meter cubic

gs^{-1} = Gram per second

ms^{-1} = Meter per second

m = Meter

μ = Micro

kg = Kilogram

MW = Megagram

Nm^3/hr = Normal Meter Cubed per Hour

μgm^{-3} = Micro-gram per meter cubic

km = Kilometer

CHAPTER 1

1 Introduction

1.1 Background and Justification of the Study

Socio-economic development of a country depends on sustainable power supply. The Government Bangladesh has given top priority to the development of power sector considering its importance in overall development of the country. For this, the government has set the goal of providing electricity to all citizens by 2020. At present about 53% of the total population of Bangladesh has access to electricity and per capita Electricity generation is only 272 KWh but reliable and quality supply of power is still a faraway (CEGIS 2013). To meet public demand of electricity, the Government of Bangladesh has formulated a Power System Master Plan (PSMP). Power System Master Plan recommends diversification of fuel used for electricity generation because present primary energy i.e. natural gas supply will decrease after 2017 and opt coal as a prime energy for electricity generation (PSMP 2010). The Master plan targets that about 50% of power generation would be coal based including domestic and imported by the year 2030. Coal plants are one of the top sources of carbon dioxide (CO_2) emissions and the primary cause of global warming (Mazumdar et al. 2016). Burning coal is also a leading cause of smog, acid rain, and toxic air pollution. Some emissions can be significantly reduced with readily available pollution controls. Government of Bangladesh establish for a 1320 megawatt coal-fired power station at Rampal Upazila of Bagerhat District in Khulna (SAHR, 2015). This work is proposed as a joint partnership between India's state-owned National Thermal Power Corporation and Bangladesh Power Development Board. The joint venture company is known as Bangladesh India Friendship Power Company (BIFPC) (SAHR 2015).The proposed project, on an area of over 1834 acres of land, is situated 14 kilometers north from the edge of the world's largest mangrove forest 'Sundarbans' which is a UNESCO world heritage site (TIB 2015).

Coal mining industry and coal-based thermal power plant have brought some environmental and socio-economic challenges to the adjacent areas such as soil, water and air pollution, subsidence of agricultural land and livelihood insecurity of inhabitants (Hossain et al. 2015). The water runoff from coal washeries carries pollution loads of heavy metals that contaminate ground water, rivers, and lakes thus affecting aquatic flora and fauna (Finkelman 2007). Fly-ash residue and pollutants contaminate soil and are especially harmful to agricultural activities. Most importantly for human health, combustion of coal releases emissions of sulfur dioxide

(SO_2), nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs), and various trace metals like mercury, into the air through stacks that can disperse this pollution over large areas.

Pollutant Concentration can be measured two level that are ground level pollutant concentration and plume centerline concentration by using Gaussian Model. Most of the study can be done by Gaussian Model. In the recent day, concentration can be measured by using environment software. All of the software use Gaussian Model for estimation pollutant concentration. This study was estimated ground level pollutant concentration and dispersion over the adjacent area of Rampal Power Plant by using Gaussian model equation.

1.2 Objectives of the Study

- Identification of maximum Ground Level Concentrations (GLCs) due to emissions in and around the plant premises using Gaussian dispersion model.
- Identification of possible impact zone from Ground Level Concentrations (GLCs) to the adjacent area.

CHAPTER 2

2 Literature Review

2.1 Gaussian Model

It is possible to solve a single equation for plume rise to estimate the effective height of the plume from a single source. Then by use of a dispersion equation, an estimate of the concentration from this source can he made for a single receptor. The primary inputs to a dispersion model, consists of emission information, meteorological data, and receptor information. For regulatory approved models such as ISC (EPA 1987) the required emission information consists of the coordinates for the location of the source, the physical stack height, the inside stack top diameter, the stack exit velocity, and the stack temperature. The meteorological parameters that are required hourly for input to this model are Pasquill stability class, wind direction, wind speed, temperature and mixing height. These inputs are entries to the dispersion model, which is a mathematical simulation of the chemistry and physics of the atmosphere. The outputs from the model are primarily hourly concentrations at each receptor (Turner 1994).

In order to maintain air quality at reasonable levels many nations have air quality standards that are allowed by regulation to be exceeded only rarely. It is necessary to obtain permit for construction of a new facility in most countries. Part of the permit application is to show that the new facility as completed and operating will not violate the air quality standards for each regulated pollutant. The application of Gaussian dispersion model requires knowledge of emission release rate, atmospheric turbulence, wind speed, dispersion coefficient, effective mixing height, etc. The model assumes an ideal steady state of constant meteorological condition, idealized plume geometry and uniform terrain (U.S. EPA 2004).

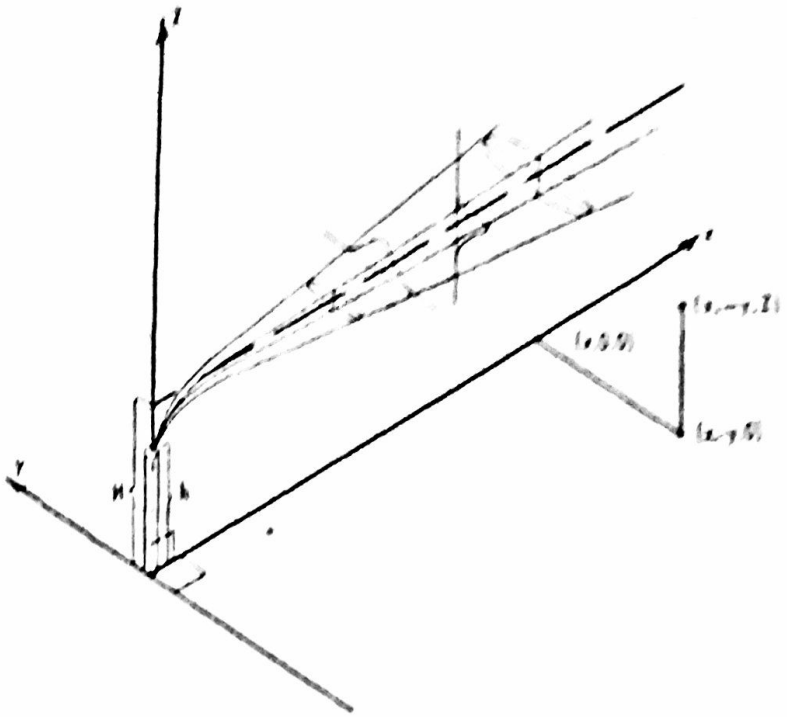

Figure 2.1 Coordinate system showing Gaussian distributions in the horizontal and vertical

Gaussian equation for calculating concentration are given bellow (Turner 1994).

$$\chi(x,y,z;H) = \frac{Q}{2\pi u\sigma_y\sigma_z}\exp\left[\frac{-y^2}{2(\sigma_y)^2}\right]\left\{\exp\left[\frac{-(H-z)^2}{2(\sigma_z)^2}\right]+\exp\left[\frac{-(H+z)^2}{2(\sigma_z)^2}\right]\right\}$$

Where, χ = Air pollutant concentration in mass per volume (gm^{-3}).

Q = Pollutant emission rate in mass per time (gs^{-1}).

u = Wind speed at the point of release (ms^{-1}).

σ_y = The standard deviation of the concentration distribution in the crosswind direction (m), at the downwind distance x.

σ_z = The standard deviation of the concentration distribution in the vertical direction (m), at the downwind distance x.

π = The mathematical constant pi equal to 3.1416...

H = The effective height of the centerline of the pollutant plump (m).

2.2 Air Pollutants

The gaseous constituents of ambient air (Troposphere) are nitrogen (78%), Oxygen (21%), water vapor (H_20), trace quantities of substances such as carbon dioxide ($C0_2$), methane (CH_4), hydrogen (H_2), argon (Ar) and helium (He). In most cases these traces are linked to the human activities or interventions on the planet (Me Cormac. 1971, Rahman 2005). In general the presence of trace components varies significantly depending on the extent of human activities. The presence of one or more of these components in sufficient quantities in the atmosphere for a certain time may be injurious to public health as well as physical and natural environment. The substances that are not normally considered pollutants until its presence and concentration contribute to development of a deleterious effect on the social and physical environment (Corbitt 1990, Rahman 2005). Pollutants emit to the atmosphere from one location may sometimes travel to other parts of the planet causing a global problem.

2.3 Classifications of Air Pollutants

2.3.1 Classification Based on Origin

The air pollutants may be classified in two general categories on the basis of their origin

1. Primary pollutants, and
2. Secondary pollutants

I. **Primary pollutants:** Primary pollutants emit, into atmosphere, directly from natural or man-made sources. Examples of primary pollutants are: sulfur-containing compounds (SO_2, H_2S), nitrogen containing compounds (NO, HCL), radioactive compounds, particulate matters (Seinfeld 1975, Rahman 2005).

II. **Secondary Pollutants:** Secondary pollutants are those formed in the atmosphere by chemical interactions between primary pollutants and normal atmospheric constituents. Several types of reactions in atmosphere may take place: (1) Thermal reactions (gas-phase), (2) Photochemical reactions (gas-phase), and (3) Thermal reactions in small liquid drops (liquid-phase) (Seinfeld 1975, Rahman 2005).

2.3.2 Classification Based on Physical State

Air pollutants may also be classified in two general categories on the basis of their physical states as follows:

1. Gaseous pollutants, and
2. Particulate pollutants.

I. **Gaseous pollutants:** The gaseous pollutants are in the form of gases such as sulfur dioxide, nitrogen oxides, ozone and carbon monoxide. Vapor pollutants such as gasoline, alcohols, paint solvents and dry cleaning agents are also considered as gaseous pollutants. Gaseous pollutants are further classified into inorganic and organic (Perry and Green 1984, Rahman 2005).

Inorganic (gaseous) pollutants are (Perry and Green 1984, Rahman 2005)

1. Sulfur gases: sulfur dioxide, sulfur trioxide and hydrogen sulfide
2. Oxides of carbon: carbon monoxide and carbon dioxide
3. Nitrogen gases: nitrous oxide, nitric oxide, nitrogen dioxide and other nitrogen oxides
4. Halogens and halides: hydrogen fluoride, hydrogen chloride, chlorine, fluorine and silicon tetra fluoride
5. Photochemical products: ozone and oxidants
6. Cyanides: hydrogen cyanide
7. Ammonium compounds: ammonia

Organic gaseous pollutants consist of (Perry and Green 1984, Rahman 2005)

1. Hydrocarbons: Paraffin's (methane, ethane and octane), Olefins (ethylene, butadiene and Acetylene) and Aromatics (benzene, toluene and benzpyrene)
2. Aliphatic oxygenated compounds: Aldehydes (formaldehyde), Ketones (acetones), Organic acids, Alcohols, Organic halides (cyanogen chloride and bromobenzyl cyanide), Organic sulfides (dimethyl sulfide) and Organic hydro peroxides (peroxyacyl nitrite or nitrate [PAN]).

II. **Particulate Pollutants:** Pollutants in atmosphere are in the form of liquid or solid pallicles with an effective diameter (under normal conditions) are larger than a molecule (about 0.0002 μ) but smaller than 1000 μ. Particles dispersed in air or in a gaseous medium is collectively called aerosol, such as smoke, fog, haze and dust (Rahman 2005).

2.3.3 Main Sources of Air Pollution

2.3.3.1 Burning of Fossil Fuel

2.3.3.2 Air pollution mainly occurs due to burning of fossil fuels like coal, petroleum etc. and associated black smoke. Over 99% of the brick kilns use fossil fuel but don't comply with the "Brick Kiln Ordinance" and pollute enormous air (Alam 2009).

2.3.3.3 Industrial Discharge

Industries cause air pollution through smoke emission. Agro based industries like sugar, pulp, paper, tanneries and value added industries like textile, garments, pharmaceutics, oil refineries, and fertilizer and chemical industries are the major contributors for air pollution (Alam 2009).

2.3.3.4 Emission from Vehicles

One of the major sources of air pollution in urban areas of Bangladesh is due to the unburned fuel from two stroke engine vehicles. Dhaka has been rated as one of the most polluted cities of the world. Bangladesh Atomic Energy Commission reports that automobiles in Dhaka emit 100 kg lead, 3.5 tons SPM, 1.5 tons SO_2, 14 tons HC and 60 tons CO in every day (Alam 2009). Air pollution is a serious environmental health hazard affecting the populations of Bangladesh. Air pollution of Bangladesh is caused due to increasing population and associated motorization. Indoor air pollution is mainly associated with the use of biomass fuels during cooking with poor ventilation. Industrial emissions and automobiles are the principle sources of outdoor air pollution (Alam 2009).

2.3.4 Air Quality Standards in Bangladesh

Bangladesh government set a rule for air quality monitoring. The national ambient air quality standards (table 2.1) of Bangladesh are given bellow:

Table 2.1 National ambient air quality standards of Bangladesh

Land use Category	8- hour average concentration in μgm^{-3}			
	CO	NO_x	SPM	SO_2
Industrial/ mixed use	5,000	100	500	120
Commercial/ mixed use	5,000	100	400	100
Residential/ rural use	2,000	80	200	80
Sensitive use*	1,000	30	100	30

*Sensitive areas include national monuments, health resorts, hospitals, archeological spots, and educational institutions (Department of Environment 1997).

2.3.5 Air pollution from Power Plant

A large number of epidemiological studies have shown that current day outdoor air pollution is associated with significant adverse effects on public health (Brunekreef and Holgate 2002, Pope and Dockery 2006). Pollutants of health concern at current day concentration levels in

developed countries include particulate matter (PM), nitrogen dioxide (NO_2) and ozone (Brunekreef and Holgate 2002).

Coal-fired power plant has been considered as a very important source of regional air pollution and ecosystem acidification, due to its huge emissions of acidic pollutants (Zhao et al. 2008, Dongmei et al. 2012). For power sector developed fast in the past 20 years in China, SO_2, NO_x and PM emissions of coal-fired power plants increased by 1.5, 1.7 and 1.2 times, respectively. The SO_2 emission of coal fired power sector was estimated to be 11,801 kt in 2010. The NO_x emission would increase from 6965 kt in 2005 to 9680 kt in 2010. The TSP, PM_{10}, and $PM_{2.5}$ emissions would be 2540, 1824 and 1090 kt in 2010 respectively (Dongmei et al. 2012). One of the study estimated that the stack height is 152.44 and 6.1 m diameter with emission rate 407.73 lb h^{-1} respectively for the power plant. The stack heights for the refinery were between 16.79-52.43 and 0.9-3.0 m diameter with emission rate 6.0-25 lb h^{-1} respectively. The stack heights for the carbon black plant were between 45.72-64.92 and 2.1-3.5 m diameter with emission rate 123.44-202.57 lb h^{-1} respectively (Alemayehu & Hackett 2015).

2.3.6 Rampal Power Plant

Rampal Power Plant is located in Rampal Upazila under Bagerhat District which is 14 km North-east from Mongla port and 14 km north-west from the nearest point of Sundarbans. It is 4 km away from the declared Ecological Critical Area of Sundarbans (the Sundarbans within 10 Km radius around its boundary). Aerial distance of surrounding important locations and structures from the proposed project site (center point of the project site) are showed in the table 2.3.

Table 2.2 Distance to important location from Rampal Power Plant

Important Location	Distance in Km
Proposed Khan Jahan Ali Air Port	12.12
Zero point of Khulna City	23.33
Rampal Upazila Head quarter	11
Mongla Port	14.16
Sundarbans Reserve Forest boundary	14
10 Km radius boundary from Sundarbans	4
Akram point of Sundarbans	67
Proposed Deep sea anchorage near Akram point	70
World Heritage site of Sundarbans	69.6
Hiron Point of Sundarbans	97

(Source: CEGIS 2013)

BPDB plans for installation of three coal based mega thermal power stations. One of the proposed power stations is Khulna 1320MW Coal based Power plant. The proposed thermal power plant will be a joint venture of BPDB and NTPC Ltd., India under the name of Bangladesh-India Friendship Power Company.

CHAPTER 3

3 Materials and Methods

3.1 Description of the Study Area

This study was carried out in the Rampal Upazila under Bagerhat district that covers Sapmari Katakhali and Kaigar Daskati Mauza of Rajnagar Union. The Rampal Power Plant is locatedat 22°37'0''N to 22°34'30''N and 89°32'0''E to 89°34'5''E (Figure 3.1) which around 23 km southfrom the Khulna City, 11.5 km Northeast from Rampal Sadar Upazila (CEGIS 2013)

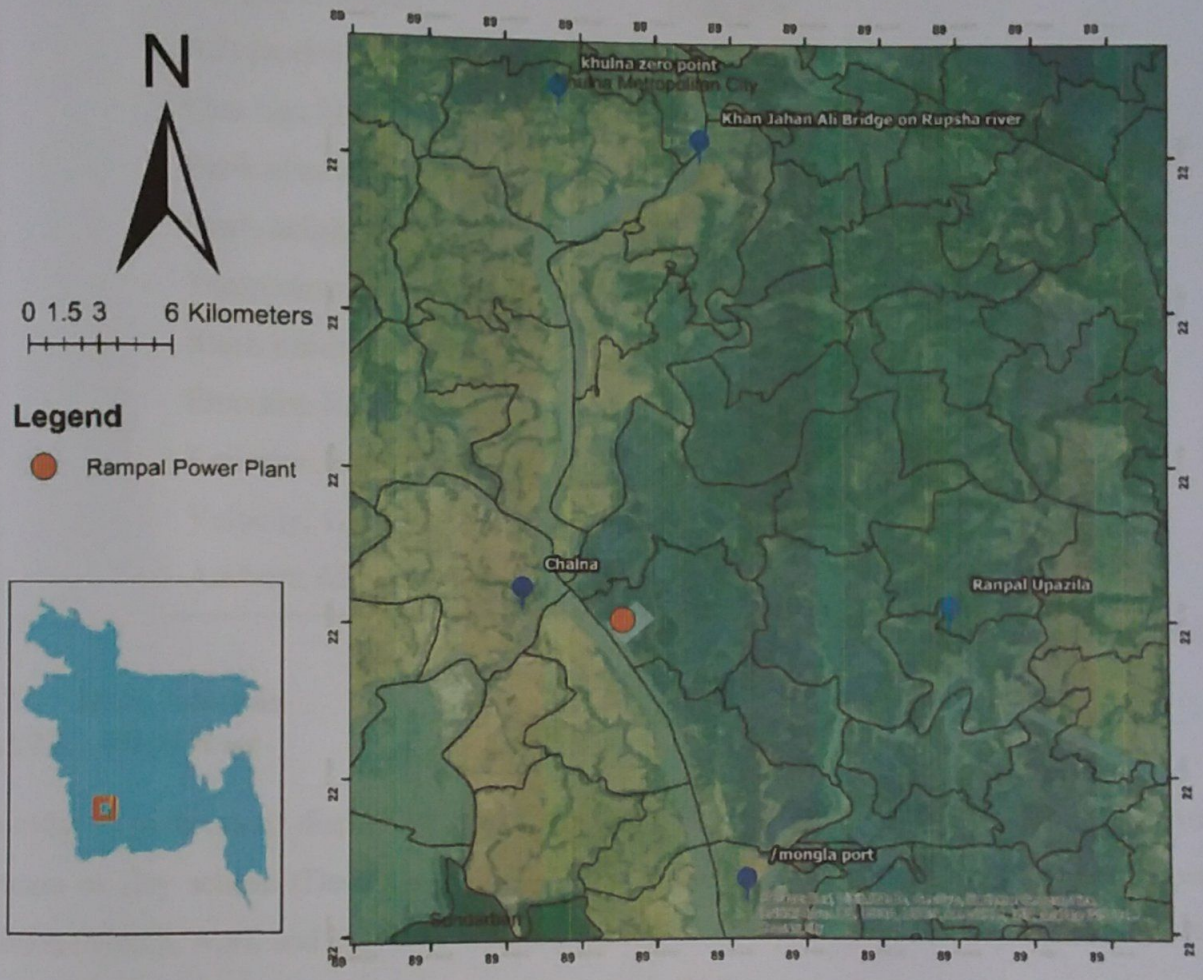

Figure 3.1 Study Location

3.2 Methodology

3.2.1 Data Collection

3.2.1.1 Meteorological Data

All of the meteorological data (Rainfall, Temperature, Humidity and Wind Speed and wind Direction) was collected from EIA report-1 except Wind Speed and wind Direction data was collected from Chowdhury 2017.

3.2.1.2 Study Site Data

The study was carried out in the Rampal Power Plant which lies between 22°37'0''N to 22°34'30''N and 89°32'0''E to 89°34'5''E at Bagerhat district in Bangladesh. The basic data (table 3.1) was collected from EIA report-1 for dispersion modeling of pollutant dispersion over the time.

Table 3.1 Proposed project general information

Component	Design condition
Plant type	Supercritical PC
Net power output	1320 MW
Ash production	15%
Flue Gas Flow	4.47×10^6 Nm^3/hr
Particulate matter	100 $\mu g/Nm^3$ from each unit
Stack height	275 m
Temperature of flue gas at stack	125^0 temperature
Stack inside diameter	7.5 m
Emission Rate (SO_2)	819 g/s from each unit
Emission Rate (NO_x)	490 g/s from each unit
Velocity, v_s	25 m/s
Ambient Air Temperature	27^0 C

(Source: CEGIS 2013)

3.2.2 Data Analysis

3.2.2.1 Wind Rose

In order to perform air dispersion modelling, the year was divided in four seasons i.e., winter season or Dry season (December, January and February); Summer season or Pre monsoon season (March, April and May); Monsoon season (June, July, August and September) and Post monsoon (October and November) (Brammer 2002) and make wind rose by using Hydrognomon-4 free software (version: 4.1.0(.26)) which is available at http://hydrognomon.org/.

3.2.2.2 Pasquill Stability Class

Pasquill (I961) was introduced a method of estimating the atmospheric stability, incorporating considerations of both mechanical and buoyant turbulence. The major features of this method are given in table 3.3. The mechanical turbulence is considered by the inclusion of the surface

(approximately 10-meter above ground) wind speed. The positive generation of buoyant turbulence is considered through the insolation (incoming solar radiation). The negative generation of buoyant turbulence is considered through the nighttime cloud cover. The less the cloud cover the greater the amount of heat that escapes from the surface through infrared radiation. High wind speeds or overcast cloudiness will produce neutral conditions, D class stability. Unstable conditions are strongly unstable, A; moderately unstable, B; and slightly unstable, C. Stable conditions are slightly stable, E; and moderately stable, F. The hyphens at low wind speeds at night can be considered strongly stable, and sometimes are referred to as "G".

Table 3.2 Key to pasquill stability categories

Surface wind speed (at 10m) ms^{-1}	Insolation			Night	
	Strong	Moderate	Slight	Thinly overcast or > 4/8 low cloud	< 3/8 cloud
<2	A	A-B	B	--	--
2-3	A-B	B	C	E	F
3-5	B	B-C	D	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

(**Source:** Pasquill 1961, Turner 1994)

This study was used average wind speed at 10 meter above the ground for categorize Pasquill stability class based on four season.

3.2.2.3 Pasquill-Gifford Dispersion Parameters

Pasquill (I961) suggested that to estimate dispersion one should measure the horizontal and vertical fluctuations of the wind. If there are no measurements of wind fluctuations, another method is presented in Pasquill (I961). The horizontal angular spreading of the plume at two distances downwind from the source, for different stabilities, and a graphical presentation of the height of the plume, also at various distances downwind for different stabilities, are given along with equations to determine downwind concentrations. It is stated that the technique is assuming horizontal and vertical concentration distributions that are Gaussian. Gifford (1960) converted the horizontal plume widths to cry and the plume heights to σ_z Note that these are considered to be functions of only downwind distance and Pasquill stability class.

3.2.2.3.1 Pasquill-Gifford horizontal dispersion parameters

$$\sigma_y = 1000 * x * \frac{\tan(T)}{2.15}$$

Where, x is downwind distance in km and T is one-half Pasquill's θ in degrees. T, as a function of x, is determined for each stability from the following:

Table 3.3 Pasquill-Gifford horizontal dispersion parameters

Stability	Equation for T
A	T= 24.167 – 2.5334 * ln(x)
B	T= 18.333 – 1.8096 * ln(x)
C	T= 12.5 – 1.0857 * ln(x)
D	T= 8.3333 – 0.72382 * ln(x)
E	T= 6.25 – 0.54287 * ln(x)
F	T= 4.1667 – 0.36191 * ln(x)

3.2.2.3.2 Pasquill-Gifford vertical dispersion parameters

Pasquill-Gifford vertical dispersion parameters was estimated by the following equation based on categorized Pasquill stability class (Pasquill I961, Turner 1994).

$$\sigma_z = ax^b$$

Where, x was in km

a and b was calculated by following table for estimation of Pasquill-Gifford vertical dispersion parameters (σ_z).

Table 3.4 Pasquill-Gifford vertical dispersion parameters

Stability	Distance(km)	a	b	σ_z at upper boundary
A	>3.11	--	--	5000
	0.5- 3.11	453.85	2.1166	--
	0.4- 0.5	346.75	1.7283	104.7
	0.3- 0.4	258.89	1.4094	71.2
	0.25- 0.3	217.41	1.2644	47.4
	0.2- 0.25	179.52	1.1262	37.7
	0.15- 0.2	170.22	1.0932	29.3

	0.1- 0.15	158.08	1.0542	21.4
	<0.1	122.8	0.9447	14
	>35	--	--	5000
B	0.4- 35	109.30	1.0971	--
	0.2- 0.4	98.483	0.98332	40
	<0.2	90.673	0.93198	20.2
C	All x	61.141	0.91465	--
	>30	44.053	0.51179	--
	10- 30	36.650	0.56589	251.2
D	3- 10	33.504	0.60486	134.9
	1-3	32.093	0.64403	65.1
	0.3- 1	32.093	0.81066	32.1
	<0.3	34.459	0.86974	12.1
	>40	47.618	0.29592	--
	20- 40	35.420	0.37615	141.9
	10- 20	26.970	0.46713	109.3
	4- 10	24.703	0.50527	79.1
E	2- 4	22.534	0.57154	49.8
	1- 2	21.628	0.63077	33.5
	0.3- 1	21.628	0.75660	21.6
	0.1- 0.3	23.331	0.81956	8.7
	<0.1	24.260	0.83660	3.5
	>60	34.219	0.21716	--
	30- 60	27.074	0.27436	83.3
	15- 30	22.651	0.32681	68.8
	7- 15	17.836	0.4150	54.9
	3- 7	16.187	0.4649	40
	2- 3	14.823	0.54503	27
	1- 2	13.953	0.63227	21.6
F	0.7- 1	13.953	0.68465	14
	0.2- 0.7	14.457	0.78407	10.9
	<0.2	15.209	0.81558	4.1

(Source: Turner 1994)

3.2.3 Effective Height of Emission

3.2.3.1 Buoyancy Flux

Most dispersion models calculate both buoyant and momentum rise and then assume that the dominant mechanism is the one producing the higher rise. To calculate buoyant rise, the buoyancy flux must first be calculated using following equation (Briggs 1975, Turner 1994)

$$F = \frac{gvd^2\Delta T}{4T_s}$$

Where, F = buoyancy flux, $m^4 s^{-3}$

g = acceleration of gravity, 9.8 ms^{-2}

v = stack gas exit velocity, ms^{-1}

d = top inside stack diameter, m

ΔT = stack gas temperature minus ambient air temperature, K

T_S = stack gas temperature, K

3.2.3.2 Wind Turbines

Wind turbines are affected by wind gradient. Vertical wind-speed profiles result in different wind speeds at the blades nearest to the ground level compared to those at the top of blade travel, and this in turn affects the turbine operation. The wind gradient can create a large bending moment in the shaft of a two bladed turbine when the blades are vertical. The reduced wind gradient over water means shorter and less expensive wind turbine towers can be used in shallow seas. It would be preferable for wind turbines to be tested in a wind tunnel simulating the wind gradient that they will eventually see, but this is rarely done.

For wind turbine engineering, a polynomial variation in wind speed with height can be defined relative to wind measured at a reference height of 10 meters as (Heier et al. 2005).

$$v_w(h) = v_{10} * \left(\frac{h}{h_{10}}\right)^{\alpha}$$

Where,

$v_w(h)$ = Velocity of the wind (m/s), at height h

V_{10} = Velocity of the wind (ms^{-1}), at height h_{10} = 10 meters

α = Hellmann exponent

The Hellmann exponent depends upon the coastal location and the shape of the terrain on the ground, and the stability of the air. Examples of values of the Hellmann exponent are given in the table below:

Table 3.5 Different Hellmann exponent

location	α
Unstable air above open water surface	0.06
Neutral air above open water surface	0.10
Unstable air above flat open coast	0.11
Neutral air above flat open coast	0.16
Stable air above open water surface	0.27
Unstable air above human inhabited areas	0.27
Neutral air above human inhabited areas	0.34
Stable air above flat open coast	0.40
Stable air above human inhabited areas	0.60

(Source: Kaltschmitt et al. 2007)

3.2.3.3 Final Rise for Unstable-Neutral Conditions

3.2.3.3.1 Unstable-Neutral Buoyant Rise

This study was first consider buoyant rise for unstable and neutral conditions. The plume rise equations that are generally used are largely empirical, having been derived by fitting lines to graphs of plotted data. Therefore there is a different equation used for buoyancy flux less than 55 and another equation for buoyancy flux more than 55. This author speculates that this may be due to the entrainment rates of ambient air being mixed with the plume being somewhat different for different plume sizes.

To calculate the final rise for F less than 55 (Briggs 1971, Turner 1994).

$$\Delta H = 21.425 * F^{\frac{3}{4}} / u_h$$

Where, u_h = the wind speed at stack top.

For F equal to or greater than 55, ΔH was calculated by the following equation (Briggs 1971, Turner 1994).

$$\Delta H = 38.71 * F^{\frac{3}{5}} / u_h$$

Where, u_h = the wind speed at stack top.

3.2.3.3.2 Unstable-Neutral Momentum Rise

The ΔH calculated by the appropriate above equation is then compared with the unstable-neutral momentum rise by the following equation (Briggs 1969, Turner 1994).

$$\Delta H = \frac{3dv}{u_h}$$

The highest of the momentum or buoyant rise is then used. This completes the calculation of final rise for neutral or unstable conditions.

3.2.3.4 Final Rise for Stable Conditions

3.2.3.4.1 Stable Buoyant Rise

To calculate the final plume rise for stable conditions, an intermediate variable, the stability parameter, s, must be evaluated by the following equation (Briggs 1971, Turner 1994).

$$s = \frac{g\frac{d\theta}{dz}}{T}$$

Where, g = Acceleration of gravity, (9.8 ms^{-2})

$\frac{d\theta}{dz}$ = Change of potential temperature with height, (Km^{-1})

T = Ambient air temperature, (K)

The change of potential temperature with height is related to the change of temperature with height by the following equation.

$$\frac{d\theta}{dz} = \frac{dT}{dz} + \tau$$

Where, τ is the adiabatic lapse rate and equal to 0.0098 Km^{-1}

$\frac{dT}{dz}$ = 0.005 (Ramaswamy et al. 2006)

Final rise under stable conditions the buoyant rise was determined by the following equation (Briggs 1975, Turner 1994).

$$\Delta H = 2.6\left[\left(\frac{F}{u_h s}\right)\right]^{\frac{1}{3}}$$

The stable buoyancy rise for calm conditions was determined by the following equation (Briggs 1975, Turner 1994).

$$\Delta H = 4F^{\frac{1}{4}} * s^{-\frac{3}{8}}$$

The lower of these two was saved to compare with the stable momentum rise.

3.2.3.4.2 Stable momentum rise

The stable momentum rise was determined by the following equation (Nriggs 1969, Turner 1994).

$$\Delta H = 1.5 * \left[\frac{v^2 * d^2 * T}{4\, T_s\, u_h}\right]^{\frac{1}{3}} * s^{-\frac{1}{6}}$$

The equation for unstable-neutral momentum rise:

$$\Delta H = \frac{3dv}{u_h}$$

Was also evaluated and the lower value from these latter two equations represents the final stable momentum rise.

3.2.4 Concentration

Concentration was estimated for NO_x and SO_x by using Gaussian model equation.

3.2.4.1 Concentration at Ground Level

In order to make concentration estimates for NO_x and SO_x directly beneath the plump centerline ($y = 0$), at ground level ($z = 0$), by the following equation (Turner 1994).

$$\chi(x, 0,0; H) = \frac{Q}{\pi\, u\, \sigma_y\, \sigma_z} * \exp\left[-\frac{H^2}{2\,(\sigma_z)^2}\right]$$

Where, χ = Air pollutant concentration in mass per volume (gm^{-3})

Q = Pollutant emission rate in mass per time (gs^{-1})

u = Wind speed at the point of release, ms^{-1}

σ_y = The standard deviation of the concentration distribution in the crosswind direction (m), at the downwind distance x,

σ_y = The standard deviation of the concentration distribution in the vertical direction (m), at the downwind distance x,

H = The effective height of the centerline of the pollutant plump (m),

3.2.4.2 Identification of possible impact zone

The final output of this study was identification of impact area in the ground level adjacent to the Rampal Power Plant through air pollution by using ArcGIS (version: 10.2.1) software.

CHAPTER 4

4 Results and Discussions

4.1 Results

4.1.1 Pasquill stability categories

In this study, the year was divided in four seasons i.e., winter season or Dry season (December, January and February); Summer season or Pre monsoon season (March, April and May); Monsoon season (June, July, August and September) and Post monsoon (October and November) (Brammer 2002) based on average rainfall in Bangladesh. Pasquill stability can be classified based on average humidity, rainfall, temperature and wind speed and also based on cloud cover and sunlight radiation. In the four season (table 4.1), we found four stability class within two in day (C, B) and another two in night (D, E).

Table 4.1 Identified Pasquill stability Class

Season	Month	Humidity	Rainfall	Temperature	Wind speed	Wind Stability class (Day)	Wind Stability class (Night)
Winter	December, January, February	72.70	14.82	21.31	2.86	C	E
Summer	March, April, May	77.92	96.35	29.07	3.88	B	D
Monsoon	June, July, August, September	87.90	347.26	29.15	3.41	B	E
Post Monsoon	October, November	79.77	111.89	26.49	2.64	B	E

4.1.2 Hellmann Exponent

Among nine Hellmann Exponent, this study conduct only three exponent variation between days to night for estimating wind speed at the stack height of the Power Plant.

Table 4.2 Hellmann Exponent

Wind Stability class (Day)	Wind Stability class (Night)	Hellmann Exponent Day	Hellmann Exponent Night
C	E	0.27	0.6
B	D	0.27	0.34
B	E	0.27	0.6
B	E	0.27	0.6

4.1.3 Wind Rose

The meteorological data were processed in the Hydrognomon software to generate the wind flow patterns for the four seasons, viz. winter, summer, Monsoon and Post-monsoon. The wind roses for Khulna generated using observed data of Meteorological data of Khulna show average wind direction and speed for different period of a year. The yearly average wind rose in winter season (Figure 4.1) shows that wind prevails flowing from north direction (about 60%) and north-west (about 36%) goes to south and south-east direction respectively and maximum wind speed was found 3.6 kmh^{-1}. On the other hand, the yearly average wind rose in summer and monsoon season (Figure 4.2 & 4.3) shows that wind prevails flowing from south direction to north direction about 91% and 92% respectively. Maximum wind speed was found 5.3 kmh^{-1} for summer season and 4.8 kmh^{-1} for monsoon seasons. Diversified condition created in post monsoon season about 30%, 30%, 30% and 10% wind is coming from south, north, north-west and east direction respectively.

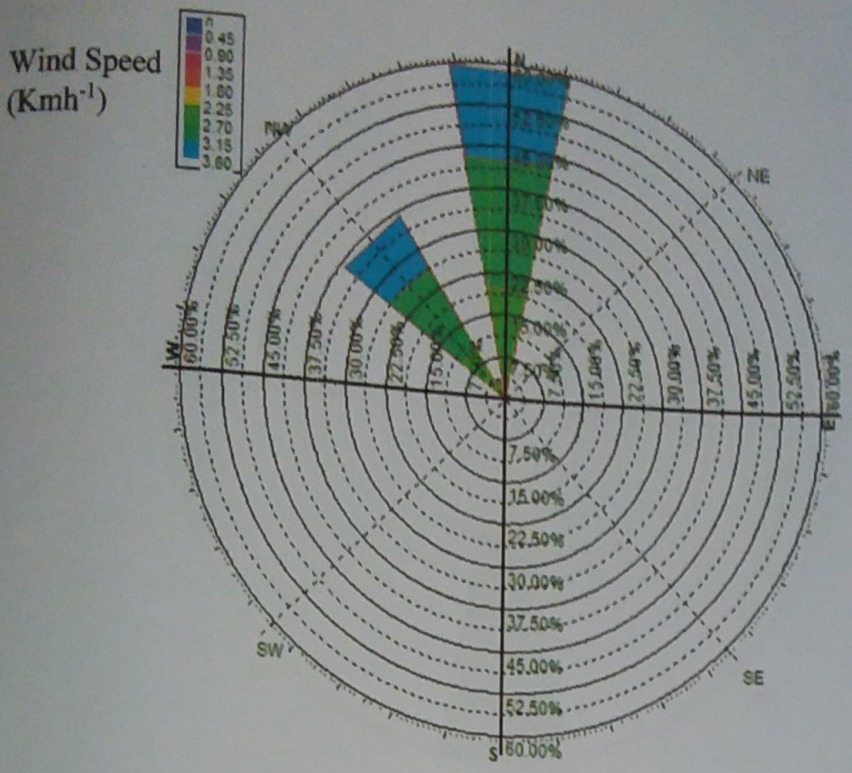

Figure 4.1 Wind rose for Khulna for the period of winter season

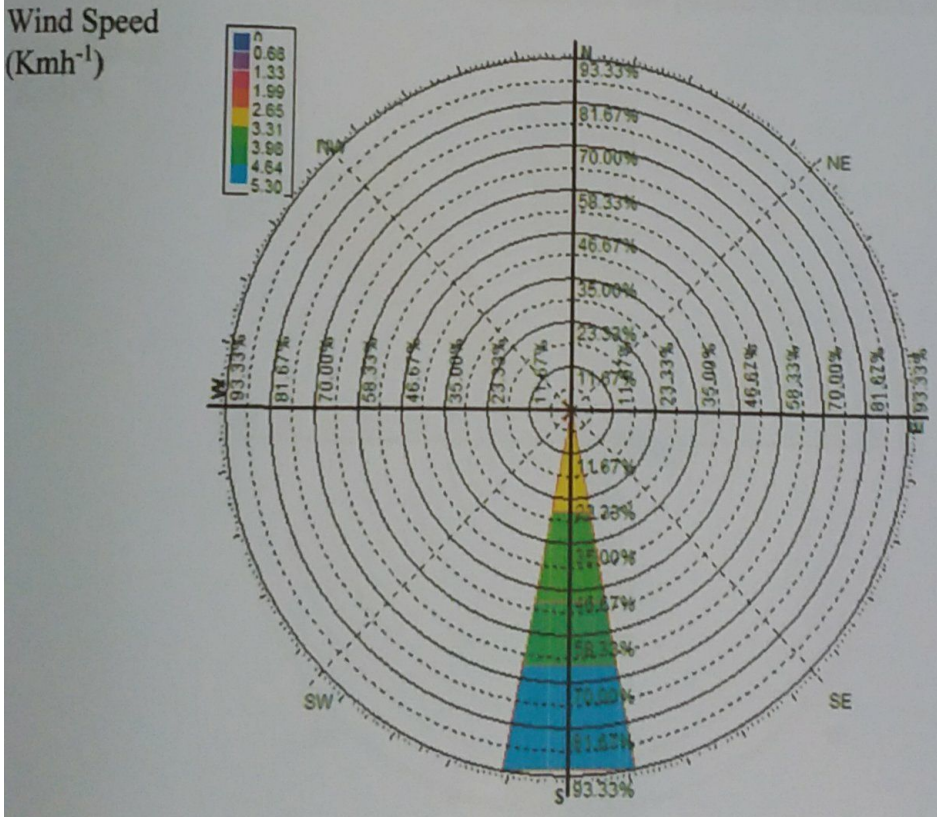

Figure 4.2 Wind rose for Khulna for the period of summer season

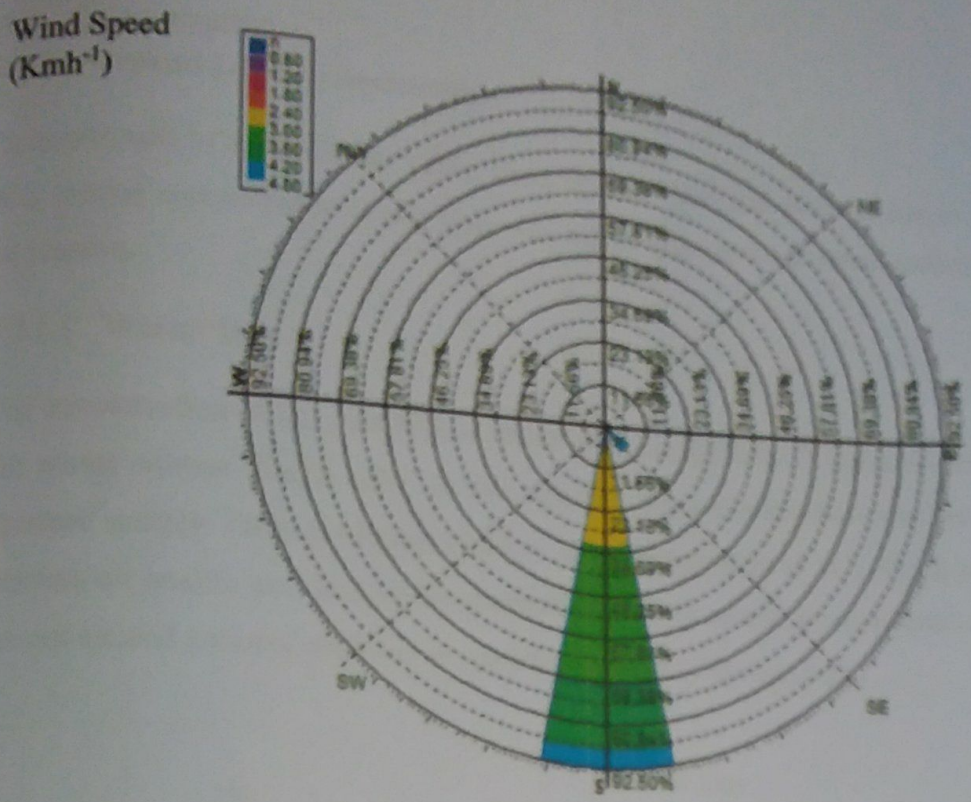

Figure 4.3 Wind rose for Khulna for the period of monsoon season

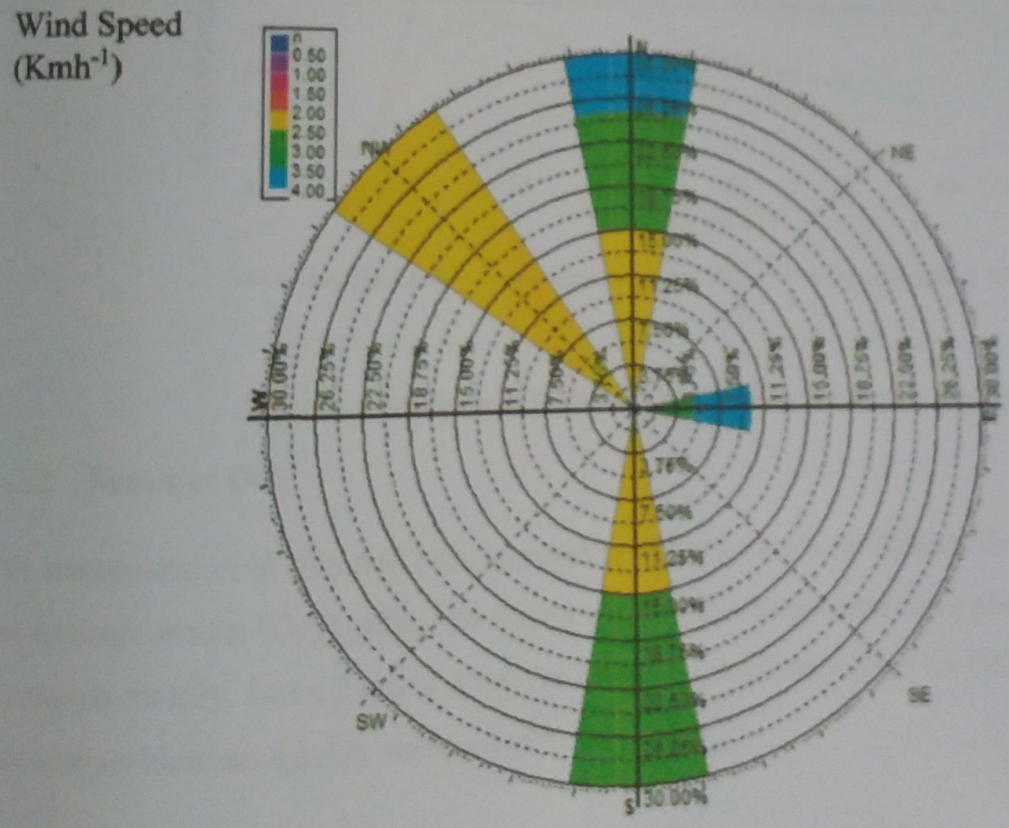

Figure 4.4 Wind rose for Khulna for the period of Post monsoon season

4.2 Concentration

4.2.1 Ground Level Concentration

Concentration of air pollutant varies from time to time and place to place. This study found that, ground concentration in day time was higher than ground concentration in night time for all seasons.

4.2.1.1 Winter Day

The concentration of SO_2 and NO_x increase with the increase of distance from power plant. In the winter season (Day), after certain distance the concentration reaches a peak and then decrease sharply. From 5.4 km to 14.6 km, the concentration of SO_2 which are exceed national ambient air quality standard of Bangladesh but in this season the concentration of NO_x which are not exceed national ambient air quality standard of Bangladesh.

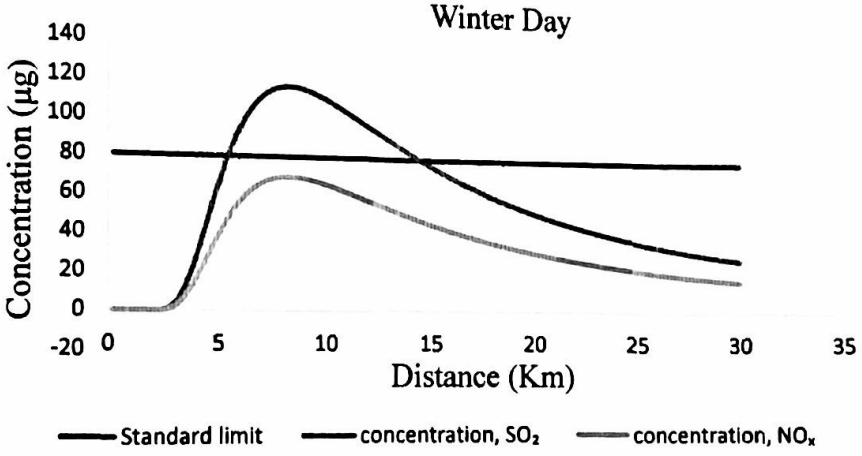

Figure 4.5 SO_2 and NO_x concentration in winter (Day)

4.2.2 Summer Day

The concentration of SO_2 and NO_x increase with the increase of distance from power plant. In the summer season (Day), after few distance the concentration reaches a peak very sharply and decreases sharply. From 2 km to 5 km for SO_2 and 1.4 km to 5.2 km for NO_2 which are exceed national ambient air quality standard of Bangladesh.

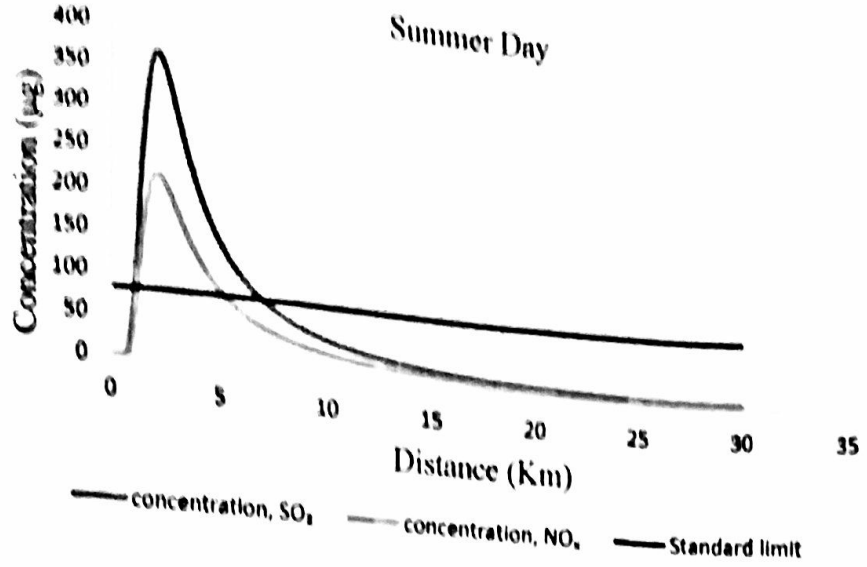

Figure 4.6 SO_2 and NO_x concentration in summer (Day)

4.2.3 Monsoon Day

The ground concentration of SO_2 and NO_x increase with the increase of distance from power plant. In the monsoon season (Day), after certain distance the concentration reaches a peak and then decrease sharply. The concentration of SO_2 is higher than NO_x concentration is greater for SO_2 (1.2 Km to 7 Km) and NO_x (2.4 Km to 4.8) which are exceed the national ambient air quality standards in Bangladesh.

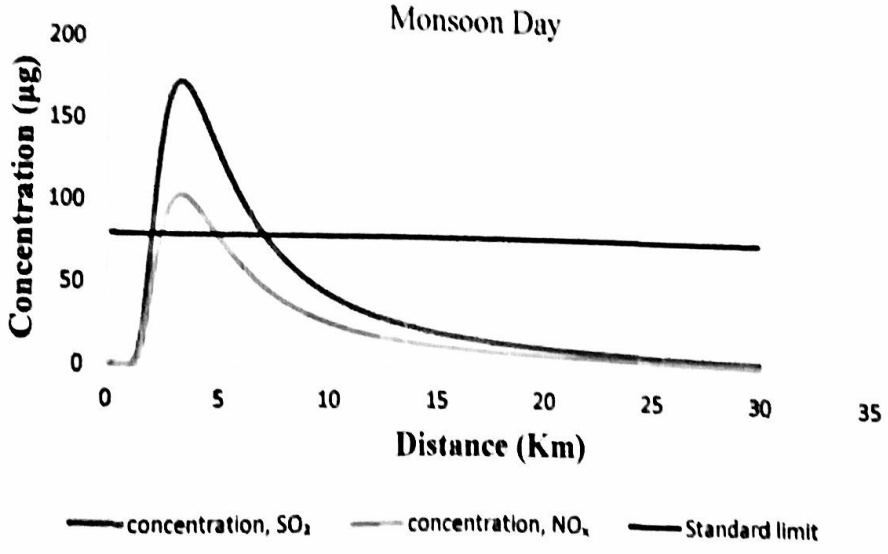

Figure 4.7 SO_2 and NO_x concentration in monsoon (Day)

4.2.4 Post Monsoon Day

The concentration of SO_2 and NO_x approximately zero in the base of the plant. But after a certain distance SO_2 and NO_x concentration is increasing very rapidly and it reaches the peak. In the post monsoon season (Day), the concentration of SO_2 is higher than NO_x, concentration is greater for SO_2 (2.4 Km to 8 Km) and NO_x (2.8 Km to 5.6 Km) which exceed the national ambient air quality standards in Bangladesh.

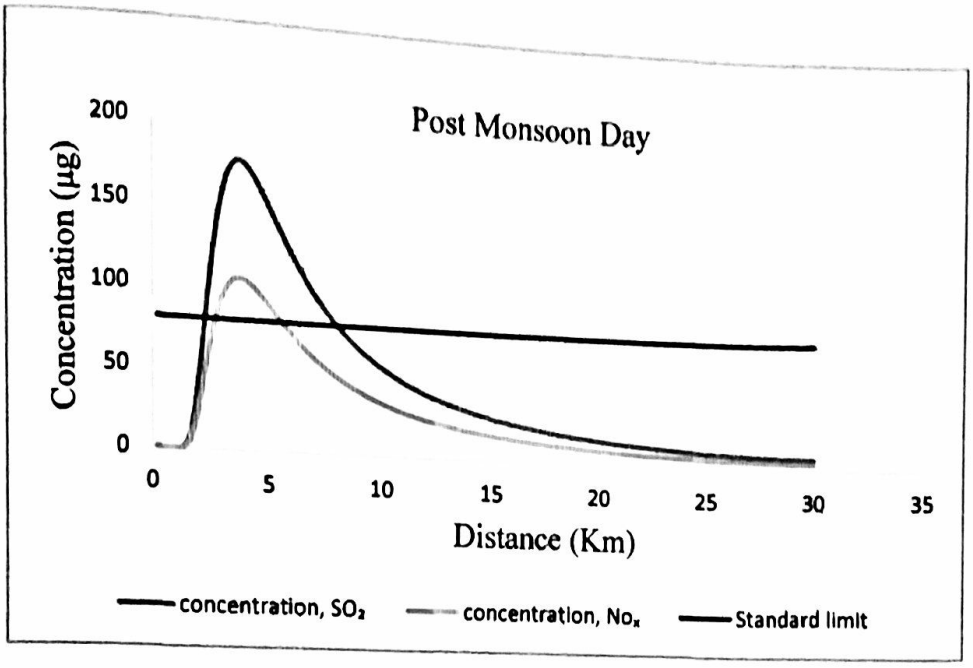

Figure 4.8 SO_2 and NO_x concentration in Post monsoon (Day)

4.2.5 Winter Night

In the winter season (Night), the concentration of SO_2 is higher than NO_x, concentration is greater in 40 Km to 142 Km for SO_2 and NO_x that are not exceed the national ambient air quality standards in Bangladesh. In that time wind is coming from north to south and north-west to south-east. In the winter night time, the concentration of SO_2 and NO_x are very low than national ambient air quality standards in Bangladesh which are not affect the air quality in that area.

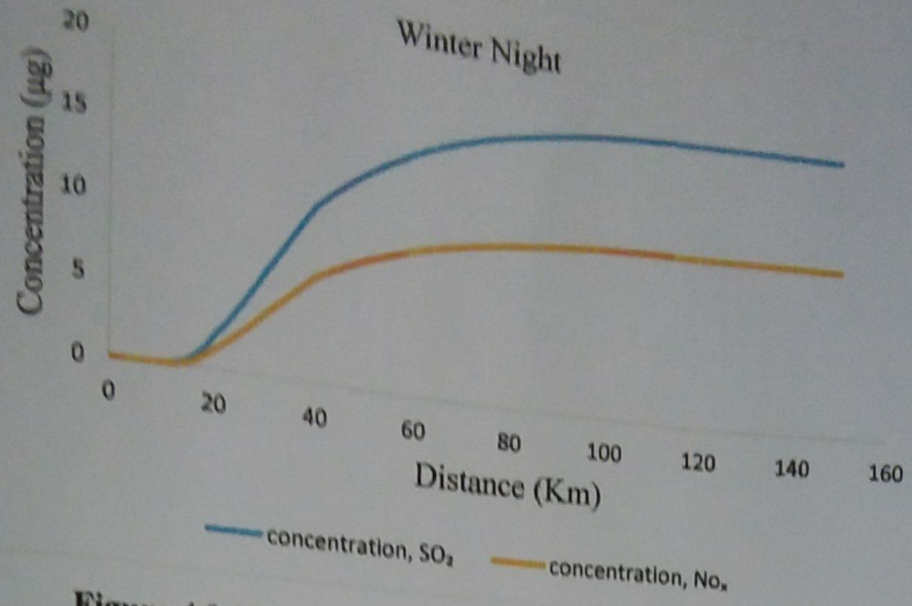

Figure 4.9 SO_2 and NO_x concentration in winter (Night)

4.2.6 Summer Night

In the winter season (Night), the concentration of SO_2 is higher than NO_x, concentration is greater in 20 Km to 100 Km for SO_2 and NO_x which are not exceed the national ambient air quality standards in Bangladesh.

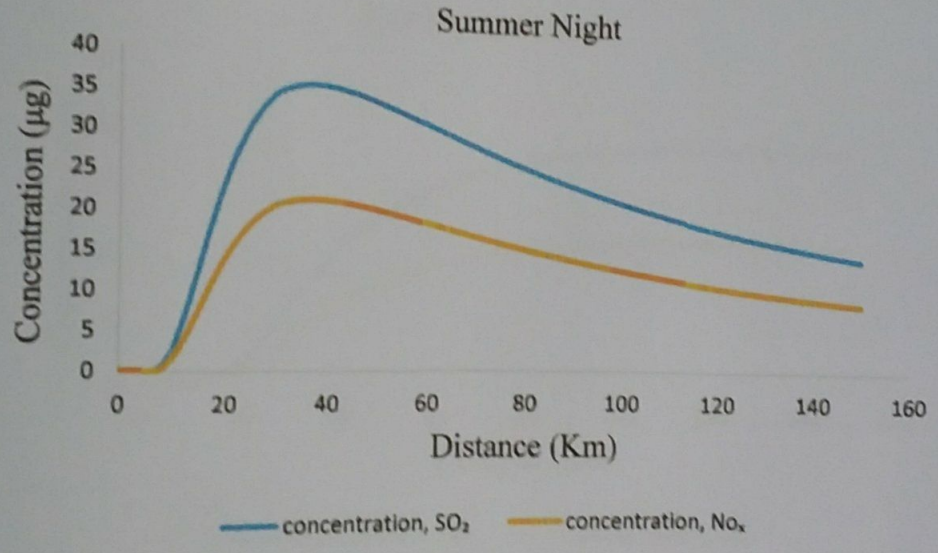

Figure 4.10 SO_2 and NO_x concentration in summer (Night)

4.2.7 Monsoon Night

In the monsoon season (Night), the concentration of SO_2 is higher than NO_x, concentration is greater in 40 Km to 142 Km for SO_2 and NO_x which are not exceed the national ambient air quality standards in Bangladesh.

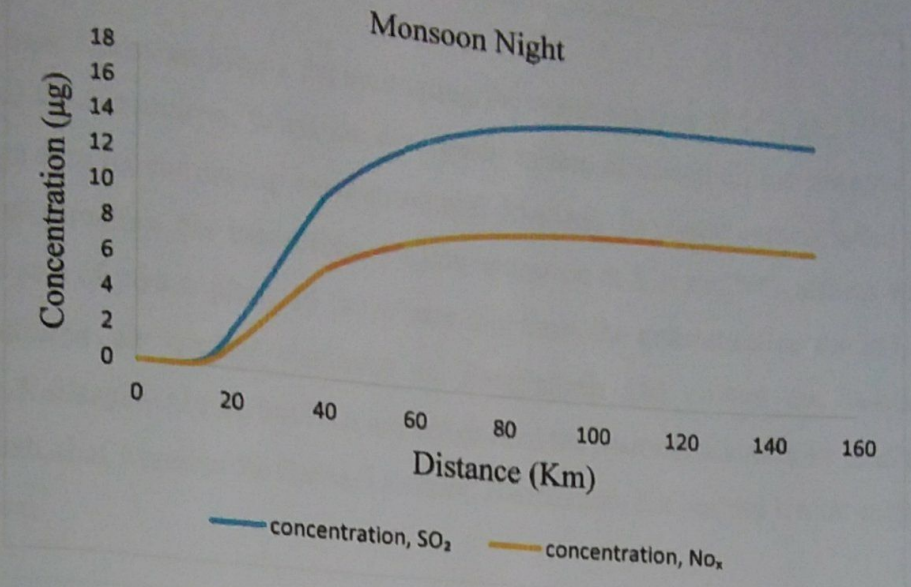

Figure 4.11 SO_2 and NO_x concentration in monsoon (Night)

4.2.8 Post Monsoon Night

In the post monsoon season (Night), the concentration of SO_2 is higher than NO_x, concentration is greater in 47 Km to 142 Km for SO_2 and NO_x which are not exceed the national ambient air quality standards in Bangladesh.

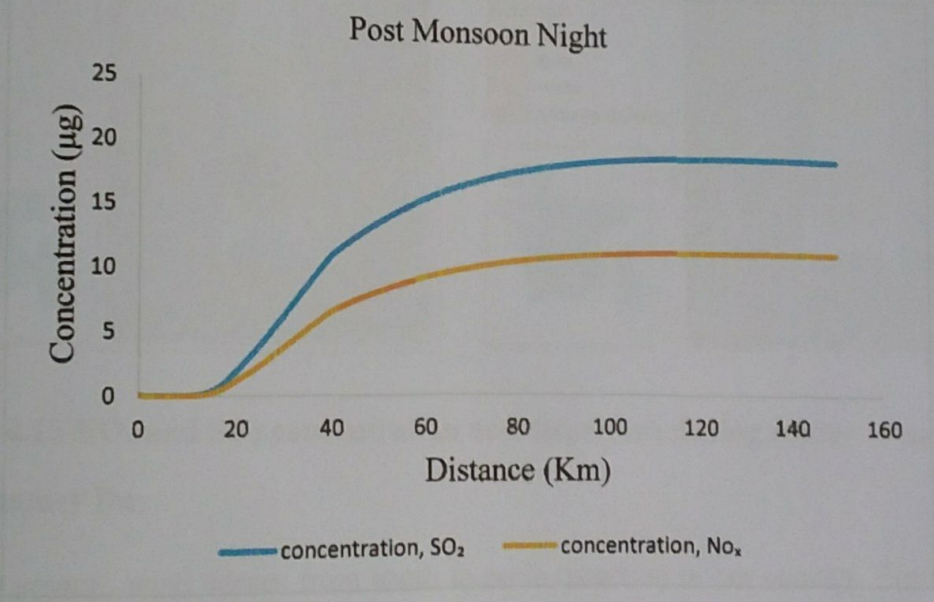

Figure 4.12 SO_2 and NO_x concentration in post monsoon (Night)

4.3 Identification of Possible Impact Zone

In this study found that, only day time ground level concentration is higher than the limit of national ambient air quality standards in Bangladesh. So the Power Plant affects the air quality to the adjacent area in day time.

4.3.1 Winter Day

This study used Gaussian Model for estimating the concentration of SO_2 and NO_x in different distance and wind direction. Wind are not steady in one direction all the seasons. This study used average data for estimating wind speed and direction. In winter season, wind comes from north to south direction. For this reason, the concentration of SO_2 and NO_x affects the air quality of southern part of power plant. In the winter day time, the concentration for SO_2 exceed the national ambient air quality standards in Bangladesh and covers the Bajua, Laudubi, Banishanta, Kailasganj Union but NO_x are not exceed the national ambient air quality standards in Bangladesh, that's means the Bajua, Laudubi, Banishanta, Kailasganj Union suffer from SO_2 concentration.

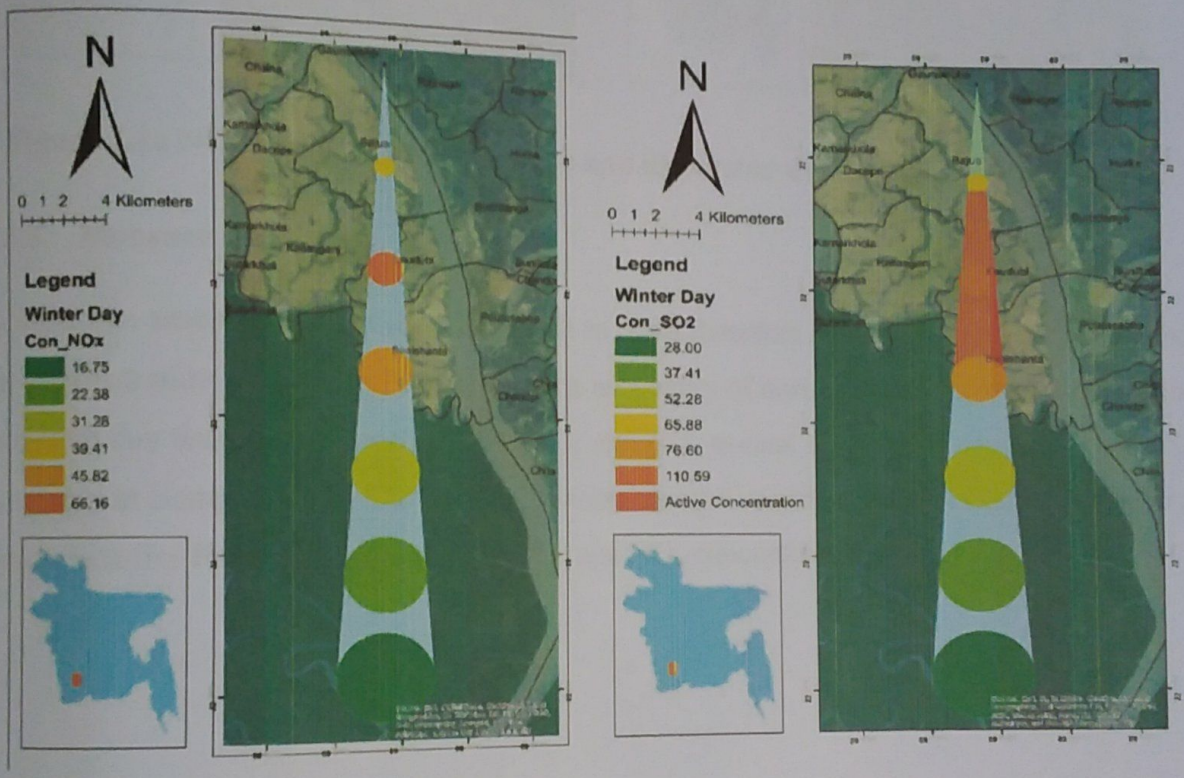

Figure 4.13 NO_x and SO_2 concentration and dispersion during winter season (Day)

4.3.2 Summer Day

In summer season, wind comes from south to north direction in our country. For this reason, the concentration of SO_2 and NO_x affects the air quality of northern part of power plant. In the summer day time, the concentration of SO_2 and NO_x exceed the national ambient air quality standards in Bangladesh of Gaurambha Union area, that's means the Gaurambha Union is highly affected both for SO_2 and NO_x concentration.

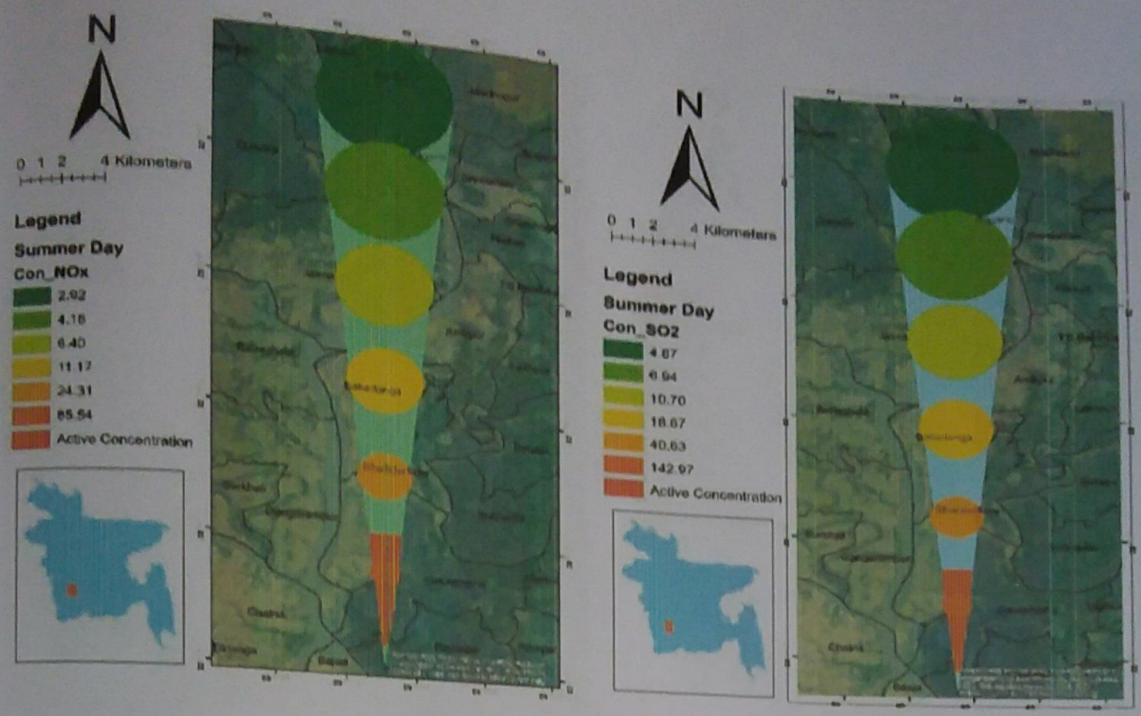

Figure 4.14 NO_x and SO_2 concentration and dispersion during summer season (Day)

4.3.3 Monsoon Day

In monsoon season, wind comes from south to north direction in our country. For this reason, the concentration of SO_2 and NO_x affects the air quality of northern part of power plant. In the monsoon day time, the concentration of SO_2 and NO_x exceed the national ambient air quality standards in Bangladesh for Gaurambha Union at rampal upazila, that's means the Gaurambha Union is suffer from very high level of SO_2 and NO_x concentration.

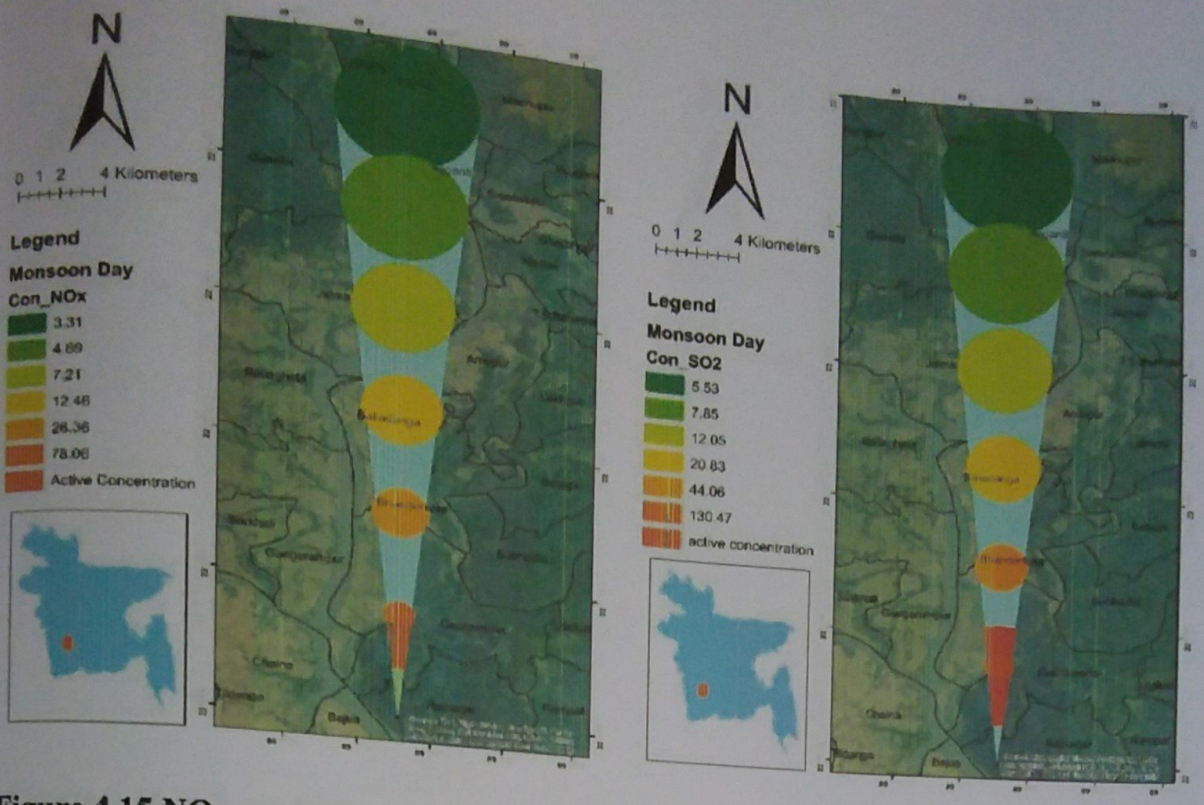

Figure 4.15 NO_x and SO_2 concentration and dispersion during monsoon season (Day)

4.3.4 Post Monsoon Day

In post monsoon day, a diversified condition created for SO_2 and NO_x concentration. In this season, the concentration of NO_x exceed the national ambient air quality standards in Bangladesh for Gaurambha, Bajua and Rajnagar Union at Rampal upazila but the concentration of SO_2 exceed the national ambient air quality standards in Bangladesh at Hurka and Kailasganj union at Rampal upazila.

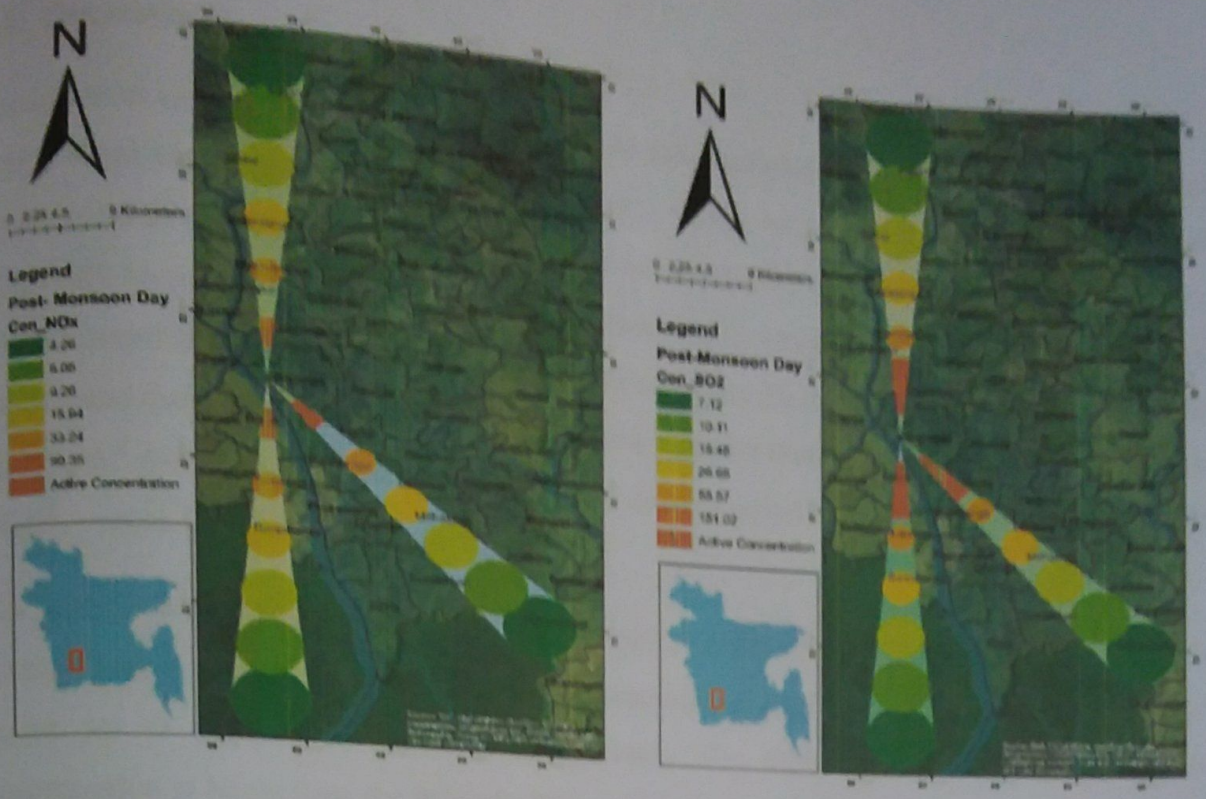

Figure 4.16 NO_x and SO_2 concentration and dispersion during post monsoon season (Day)

4.4 Population and land use impact zone

Table 4.3 Affected Zone Information

Upazila	Union	Population	Water body (ha)	Crop land (ha)	Homestead forest (ha)
RAMPAL	Gaurambha	21,625	2099.31	2308	479.70
	Hurka	7,515	1268.19	1195	176.59
	Rajnagar	13,228	1998.86	2100	350.50
DACOPE	Bajua	15,019	478.64	2250	334.46
	Banishanta	16,124	923.93	2140	307.61
	Laudubi	8,529	57.92	1026	206.90
	Kailasganj	14,750	1500.24	2200	418.12
Total		96,790	8327.09	13219	2273.88

(Source: Ministry of land 2011)

The total 96,790 population, 8,327.09 ha water body, 13,219 ha crop land and 2,273.88 ha homestead forest are affected through the emission of air pollutants particularly SO_2 and NO_x.

4.5 Discussion

Ground level concentration is varies from time to time and place to place and depends on wind speed, wind turbulence, pollutant exit velocity, amount of pollutant wind direction, cloud cover, wind direction and so on. Ground level concentration also varied in diurnal variation. This study found that the Day ground level concentration was much higher than Night ground level concentration range from 363 μgm^{-3}(maximum) to 36 μgm^{-3}(maximum) for SO_2. This study found that highest ground level concentration can be found during summer (Day) season (363 μgm^{-3} for SO_2) and lowest ground level concentration can be found during monsoon (Night) season (9 μgm^{-3} for NO_x).

The highest and lowest ground level concentration at Day time for SO_2 was 363 μgm^{-3} in summer season and lowest ground level concentration at Day time was 116 μgm^{-3} in winter season up to air ambient limit in Bangladesh. The highest and lowest ground level concentration at Night time for SO_2 was 36 μgm^{-3} in summer season and 16 μgm^{-3} in monsoon season respectively. The highest and lowest ground level concentration at Day time for NO_x was 217 μgm^{-3} in summer season and 69 μgm^{-3} in winter season respectively. The highest and lowest ground level concentration at Night time for NO_x was 21 μgm^{-3} in summer season and 9 μgm^{-3} in monsoon season respectively. So the highest ground level concentration was found in summer season both for SO_2 and NO_x. In the summer season, the concentration of SO_2 and NO_x are exit the Department of Environment (DOE 1997) limits.

This study used Gaussian model for distributions in the horizontal and vertical directions of SO_2 and NO_x air pollutants. This study used ArcGIS software for dispersion of air pollutants over the adjacent area from Rampal Thermal Power Plant. From this study found that, two Upazilas or Sub-districts (Table 4.3) are vulnerable by SO_2 and NO_x concentration. Form this two Sub-districts Gaurambha, Hurka, Rajnagar under Rampal Upazila and Bajua, Banishanta, Laudubi and Kailasganj union under Dacope Upazila are highly vulnerable for SO_2 and NO_x ground level concentration. Most of the season the Gaurambha under Rampal Upazila are face high level of concentration both for SO_2 and NO_x from the wind rose and pollutant dispersion.

In winter and post monsoon seasons pollutants goes to southern part from Rampal power plant. Very high level of concentration found nearest upazilla of Sundarbans. Continuous injection of pollutants to the Sundarbans through the Power Plant may affect the air quality of Sundarbans. It may be damage to wildlife, plants and its growth and breeding, moreover it may create hamper the ecosystems of the world largest mangrove forest. NO_2 is a strong oxidizing

agent that reacts in the air to form nitric acid, as well as toxic organic nitrates (Bernard 2001). Flora and fauna community may be affects by the acid rain.

Summer season, monsoon season and post monsoon season wind comes south to north. So air pollutants comes to the adjacent area from the power plant. Highest level of concentration found in summer season both for SO_2 and NO_x. According to Bernard 2001 health effects of exposures to carbon monoxide, sulfur dioxide, and nitrogen dioxide can include reduced work capacity, aggravation of existing cardiovascular diseases, effects on pulmonary function, respiratory illnesses, lung irritation, and alterations in the lung's defense systems. So many people are affected by this type of diseases for the reason of high concentration level of SO_2 and NO_x.

4.5.1 Limitation of the study

This study used average meteorological data for predicting air pollutants dispersion from Rampal Coal Based Thermal Power plant to identify ground level concentration. This study was not included pollution from particulate matter and plume centerline concentration. Further study is needed for improving dispersion model.

CHAPTER 5

5 Conclusion

The preset study estimated predicting ground level concentration from Rampal Coal Based Thermal Power plant in Bangladesh. The amount of SO_2 and NO_x concentration varies from place to place and time to time. The methodology adopted was to carry out air pollutant dispersion modelling of gaseous emissions viz. SO_2 and NO_x for all four seasons (winter, summer, monsoon and post monsoon) to enable the understanding of the extent of air pollution around the site due to the stack emissions from the plant. The analysis of results of dispersion modelling for four seasons revealed that highest ground level concentration found in summer season for both SO_2 and NO_x. About 96,790 people affected by the highest level of air pollutant concentration which may affect the the human health including reduce work capacity, aggravation of existing cardiovascular diseases, effects on pulmonary function, respiratory illnesses, lung irritation, and alterations in the lung's defense systems.

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APPENDICES

Appendix 1: Average meteorological Data

Subject	Dec	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov
Humidity	74.575	72.3065	71.2323	74.9677	78.0935	80.7097	87.7516	89.4516	88.4968	85.8968	82.2194	77.3133
Rainfall	2.5	11.67	30.28	49.39	60.72	178.94	355.11	388.22	309.83	335.89	182	41.78
Temp max	26.6135	25.296	28.7815	32.6465	34.6185	34.4925	32.737	31.752	31.7765	31.904	31.55	29.461
Temp min	15.78	13.887	17.4785	21.895	24.8215	25.9425	26.4815	26.2615	26.3765	25.934	24.4625	20.501
Temperature	21.1968	19.5915	23.13	27.2708	29.72	30.2175	29.6093	29.0068	29.0765	28.919	28.0063	24.981
Wind speed	2.52	3	3.05	3.37	4.33	3.95	3.65	3.36	3.2	3.43	2.8	2.48

(**Source:** CEGIS 2013)

Appendix 2: Wind Speed and Wind Direction

	Jan		Feb		Mar		Apr		May		June		July		Aug		Sep		Oct		Nov		Dec	
Year	Spd	Dic	Spd	Dic	Spd	Dic	Spd	Dic	Spd	Dic	Spd	Dic	Spd	Dic	Spd	Dic	Spd	Dic	Spd	Dic	Spd	Dic	Spd	Dic
2001	3.4	N	2.9	NW	3.8	NW	4.7	S	5.2	S	4.8	S	4	S	3.8	S	3.4	S	3	S	2.6	N	2.3	NW
2003	3.3	NW	3.3	NW	3.4	S	4.9	S	4.8	S	3.4	S	3.3	S	3.3	S	4.1	SE	3.6	E	2.1	NW	2.5	NW
2004	2.9	NW	3	N	4	S	4.6	S	4.1	S	3.9	S	3.6	S	3.5	S	3	S	2.4	S	2.1	NW	2.3	NW
2005	2.8	NW	2.8	NW	3	S	5	S	3.9	S	3.8	S	3.4	S	2.9	S	2.8	S	2.4	S	2.3	N	2.5	N
2006	2.7	N	3.6	N	3.9	S	4.8	S	4.4	S	3.2	S	3	S	3	S	2.6	S	2.7	N	2.5	N	2.4	N
2007	3.1	N	3.3	NW	3.6	S	4.8	S	4	S	4.1	S	3.5	S	3	S	2.6	S	3.4	E	2.2	NW	2.9	N
2008	3.6	N	2.9	NW	3.9	S	5.3	S	3.2	S	2.8	S	3.3	S	4	SE	3.7	S	2.3	NW	2.2	NW	2.4	N
2009	2.8	N	2.7	S	2.8	S	2.9	S	3.2	S	3.5	S	3.3	S	2.7	S	4.3	SE	3	S	2.3	NW	2.4	NNW
2010	2.6	N	2.6	S	2.1	SW	2.8	S	3.7	S	3.9	S	2.9	S	2.9	S	4.4	S	2.8	S	4	N	3.2	N
2011	2.8	N	3.4	S	3.2	S	3.5	S	3	S	3.1	S	3.3	S	2.9	S	3.4	S	2.4	W	2.5	N	2.3	N

(**Source:** Chowdhury 2017)