East West University

Impact of Particulate Matter Emission from Barapukuria Coal-Fired Thermal Power Plant on Premature Human Mortality

By

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In partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering

Fall, 2014

Department of Electrical and Electronic Engineering

Faculty of Science and Engineering

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Thesis Supervisor	Chairperson
Prof. Dr. Anisul Haque	Dr. Halima Begum

Abstract

This study is carried out to assess the impact of $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant on human health in the adjoining areas. This is the first investigation of its kind. As data for actual concentrations of $PM_{2.5}$ at various locations around Barapukuria are not available, we have adopted the $PM_{2.5}$ emission rate data from coal-fired power plants of India and China for Barapukuria Coal-Fired Thermal Power Plant. Using this adopted emission rate of $PM_{2.5}$, we have calculated the concentrations of $PM_{2.5}$ in the exposed areas using Gaussian Plume Dispersion Equation. As the first attempt of this kind of work, we have estimated annual average concentrations of $PM_{2.5}$ in 11 upazillas along the annual average wind direction (south-east) from Barapukuria. These upazillas fall within 160km from Barapukuria along south-east direction. The calculated results show that around 2.3 million people are exposed to significant concentrations of $PM_{2.5}$. To accommodate the uncertainty of emission rates, we have calculated the impact of $PM_{2.5}$ emission from the power plant for both the best case and the worst case scenarios. We have calculated intake fraction (*iF*) for both the best case and the worst case emission rates, which for both cases is found to be 2.18×10^{-4}. We have also calculated the relative risk (*RR*). The calculated values of *RR* for the best case and the worst case are 1.0226 and 1.0610, respectively. We have theoretically calculated the expected number of premature deaths due to $PM_{2.5}$ exposure. The calculated values for the best case and the worst case scenarios show that on an average 292 to 760 more people will die due to $PM_{2.5}$ exposure every year. This preliminary study done under the mentioned limitations reveals that there is a potential risk of human health hazard due to $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant.

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Authorization

We hereby declare that we are the sole authors of this thesis. We authorize East West University to lend this thesis to other institutions or individuals for the purpose of scholarly research.

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Chapter 1 Introduction

The shortage of electricity is on the rise while the development process of Bangladesh is marching ahead. In order to meet the growing demand of electricity, several electricity generating projects have been undertaken by Bangladesh government. In these electricity generating plants, coal, hydro-power, natural gas, furnace oil, and diesel are being used. Considering the economic condition of the country, Government of Bangladesh has decided to go for the coal-based power plants for future as coal is cheaper than the other fuel options. Though coal is a cheaper option of fuel for thermal power plants, the process of coal-fired electricity generation is hazardous. In this process, the flue gas pollutes the environment and is detrimental to human health. Recently in 2006 the first and the only coal-fired power plant in Bangladesh has been established at Barapukuria in Dinajpur district with a capacity of 250MW. In the mean time the government has approved two more coal-fired power plant projects at Maheshkhali in Cox's Bazar district and Rampal in Bagerhat district. Each of these power plants will produce 1320MW power. So, it is undoubtedly important to assess the impact of coal-fired power plants on both human health and environment with respect to Bangladesh.

1.1 Background

Coal contains mercury, lead, cadmium, arsenic, manganese, beryllium, chromium, and other toxic and carcinogenic substances [1]. Coal crushing, processing, and washing releases tons of particulate matter and chemicals on an annual basis and contaminates water, harming community public health and ecological systems [1]. Coal combustion results in emissions of nitrogen oxide (NOx), sulfur di-oxide (SO_2), volatile organic compound (VOC), ammonia (NH_3), fine particulate matters (PM), such as, PM_{10} and $PM_{2.5}$, and mercury [2]. Emission of these gasses and particles affect human being living near the power plants. Black lung disease, lung cancer, respiratory illness, asthma, bronchitis, shortness of breath, nasal congestion, and pulmonary inflammation can occur due to emission of those flue gases and fine particles.

There are two types of impacts on human health from coal-fired power plants, upstream and downstream impacts [3]. In the downstream process, impacts on human health and environment are caused from two sources [3] – (i) coal combustion waste (CCW) or fly ash and (ii) pollutants emitted from coal combustion. The major air pollutant in fly ash is PM. The other toxic chemicals in fly ash contaminate the soil and the ground water near the power plant producing environmental, agricultural, and human health damages [3]. The major air pollutants emitted from coal combustion are NOx, SO_2, and PM. Among them, SO_2 and PM produce morbidity and mortality problems on human health. However, PM has the most adverse effect on human mortality [3, 4]. In [4], the authors found that PM and SO_2 are associated with all-cause, lung cancer, and cardiopulmonary mortality. In the all-cause mortality rate, the total death rate is counted, where any specific cause for death is not considered. They estimated that 10µg/m^3 elevations in PM is associated with approximately a 4%, 6%, and 8% increased risk of all-cause, cardiopulmonary, and lung cancer mortality, respectively. In the environmental chemical processes, the primary SO_2 and NOx emissions are converted into secondary PM [2] causing increased risk of human morbidity and mortality. Besides, the primary SO_2 and NOx have adverse impact on environment and agriculture [3]. It is important to understand the impact of those pollutants, specially the PM, on human health. The most significant impact of PM is the increased rate of premature mortality.

1.2 Literature Review

Increased premature mortality is the most significant impact on human health, however, no study has yet been conducted to assess this impact due to emission from Barapukuria Coal-Fired Thermal Power Plant.

The impact of pollutant emission from coal-fired power plant on human health is determined in three steps. First, concentrations of the pollutants in the air at various locations are determined. Then, the relationships between pollutant concentration and human health are established. Finally, the effects of pollutant concentrations on human health (concentration response function) are determined.

Analyses of health-related damages of power plant emission for a small number of power plants have generally used complex chemistry-transport models, such as, CALPUFF [5]. CALPUFF is a multi-layer, multi-species non-steady-state puff dispersion model that simulates the effects of time and space varying meteorological conditions on pollutant transport, transformation, and removal. CALPUFF was recommended by the US Environmental Protection Agency (EPA) for simulating long-range transport in the USA, and this has been applied in many previous power plant studies [6, 7, 8]. In general, for a large number of power plants, the Community Multi-scale Air Quality (CMAQ) model [3, 9] is widely considered as the state of the art in process-based air-quality modeling. The CMAQ model has downsides to process the model for isolating the impact of emission from individual sources over a large modeling domain [10].

To overcome the downside of CMAQ model, recently in the USA the Air Pollution Emission Experiments and Policy (APEEP) analysis model [2] is used, which uses a source-receptor (S-R) matrix with county-level sources and receptors that are derived from a Gaussian air-quality model [11, 12]. APEEP model is designed to calculate the marginal damages in the USA related to emissions of SO_2, NOx, $PM_{2.5}$, PM_{10} and NH_3 on a dollar-per-ton basis. This model discusses the damages which include adverse effects on human health, reduced yields of agricultural crops and timber, reductions in visibility, enhanced depreciation of man-made materials, and damages due to lost recreation services. Both CALPUFF and APEEP models use the Gaussian dispersion equation [11, 12] for estimating concentration of pollutants at a given distance from the point source of pollutant emission. These models are not applicable to Bangladesh at the moment as the relevant data are not available.

Though no formal study has yet been made to determine the impact of emission from Barapukuria Coal-Fired Thermal Power Plant, several similar studies have been conducted in neighboring countries like China [6, 7, 8, 13] and India [14, 15, 16]. In [6], a case study was made to calculate the intake fraction (*iF*) of power plant emissions in China using CALPUFF model. The *iF* estimates the amount of a pollutant inhaled by the exposed population per unit of primary pollutant emitted from a pollution source. They found that the *iF* of primary PM is roughly on the order of 10^{-5}, the *iF* of SO_2, sulfate and nitrate are on the order of 10^{-6}. In [7], to find out the population exposure to pollutants in China, the *iF* is estimated. This study considered emission of PM and SO_2 from 25 coal-fired power plants in China. To model the concentration increase due to emissions from the selected power plants, they also used the CALPUFF model. They found that the primary PMs have the highest average *iF*. They also found that near-source population is more affected by PM_{10} and population at medium to long distance is more affected by $PM_{2.5}$ and secondary particles. Their findings show that a significant portion of *iF* occurs beyond 500km of the source, which indicates the importance of using long-range dispersion model. In [8], the impact of emissions from power plants in China on ambient concentrations and population exposure is estimated in terms of *iF* using CALPUFF model and the *iF* is translated into human health risks. In [13], SO_2, NOx, and PM emissions from 24 generating sets from 15 coal-fired power plants in China have been measured. In [14], impact of PM in Delhi, India is studied to determine the impact on mortality change. For this purpose, they estimated the ambient PM concentrations using AERMOD (version 07026) model for the year 2004. The AERMOD model is developed by the U.S Environmental Protection Agency for estimating pollutant concentration from point, line and area sources. In [15], impact of PM, SO_2, and NOx from 63 coal-fired power plants in India is studied to determine the impact on human health. They estimated health damages by combining data on power plant emissions with reduced-form *iF* models. They used concentration-response functions for PM from [4] to estimate premature cardiopulmonary deaths associated with air emissions for persons 30 and older. Their results suggest that 75 percent of premature deaths are associated with PM that results from SO_2 emissions. In [16], the impact of emission from coal-fired power plants in India is studied for the year 2010 to 2011. They estimated that 111 plants with an installed capacity of 121GW generated 580 kilo tons of $PM_{2.5}$, 2100 kilo tons of SO_2, 2000 kilo tons of NOx, 1100 kilo tons of CO, 100 kilo tons of VOC, and 665 million tons of CO_2. These emissions resulted in an estimated 80,000 to 115,000 premature deaths and 20.0 million asthma cases from exposure to $PM_{2.5}$ pollution. A study has been done in the North America in [17], where the characteristics of the power plants in the North America and their emissions are reported.

1.3 Objective

The objective of this study is to estimate the impact of $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant on premature mortality in the adjoining upazillas in the direction of annual average wind flow.

For estimating the impact of $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant on premature mortality, concentration of $PM_{2.5}$ emission from the plant is necessary. However, the data received from the Barapukuria Coal-Fired Thermal Power Plant authority is not relevant to this study. For this reason, we will estimate such data from the emission data of coal-fired power plants in India and China available in the literature. It is assumed that the average emission data in these two countries are similar to ours. Next we will calculate the incremental $PM_{2.5}$ concentration in the exposed upazillas using Gaussian Plume Dispersion model. Using the data of emission, incremental concentration, breathing rate, and population size of each upazilla, we will calculate the *iF*. Next, we will determine the *RR*. Finally, from this *RR* data, the premature mortality rate for the exposed upazillas will be estimated.

1.4 Layout of the Thesis Report

The rest of the thesis report is organized as follows. In Chapter 2, we have discussed in general the impact of coal-fired power plant on human health. We have discussed the model used for calculating concentrations of pollutants at a given location in Chapter 3. We have also introduced the model for determining the health impacts of pollutants in this chapter. In Chapter 4, we have presented the calculated results and have presented our discussions. Finally, we have concluded our findings in Chapter 5 and have highlighted on the possible future works. Additional information needed during the calculations are given in Appendices A and B. Bibliographic references used in this report are then listed.

Chapter 2 Effect of Coal-Fired Electricity Generation on Human Health

2.1 Coal in Electricity Generation

The share of global coal-fired electricity generation is shown in Table 2.1 [3]. From the table it is found that 48.5% of total electricity in the world is generated from coal-fired power plants. As the major share of the electricity generation is from coal, study of its impact on human health is very important for taking remedial actions to reduce the harmful impacts.

Table 2.1 Share of global electricity generation by energy source [3].

Energy Source	% of Generation
Coal	48.5
Petroleum, Natural Gas, and other Gases	22.8
Nuclear	19.6
Hydroelectric	6.0
Other Renewable	3.0

Besides primary PM emission, other primary pollutant emissions from coal-fired power plants are converted into secondary PM in environmental chemical transformations [2]. The primary VOC emission is converted into secondary organic aerosols which is secondary PM. The primary VOC is also converted into tropospheric ozone (O_3). The primary NOx emission is converted into nitrates which are PM. The primary NOx is also converted into O_3. The primary NH_3 is converted into ammonium (NH_4) which is PM. The primary SO_2 emission is converted into sulfates which are PM. It is found that primary emissions other than PM are converted into secondary PM making the total PM a major concern of hazard on human health.

2.2 Effect of Pollutants on Human Health

The pollutants emitted from coal-fired power plants are dispersed in the air at the adjoining areas causing ambient concentrations of these pollutants to increase above the human tolerable limits. In the inhalation process, people intake these pollutants with air. The pollutants then penetrate into the lung wall and are mixed into the blood flow causing various pathogenic effects on human health. The effects of PM on human health include morbidity issues like restricted activity day, chronic bronchitis, cough in children, and cough in asthmatics; and mortality issues like all-cause, lung cancer, and cardiopulmonary mortality. The SO_2 causes reduction of life expectancy. The O_3 causes restricted activity day and asthma attack. It is found that the PM has the most adverse impact on human health. For this reason, in this present study we concentrate only on impact of PM on human health, especially to determine the impact of $PM_{2.5}$ on premature mortality.

2.3 Typical Emission Rates and Human Tolerable Concentration of PM

In this study we will determine the impact of $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant on human health, especially on premature mortality rate. For this reason, we need real emission data from the power plant. We have contacted Barapukuria Coal-Fired Thermal Power Plant authority for supplying emission data from that plant. The power plant authority supplied some data as shown in Table 2.2, but these data are not directly relevant to our study.

Table 2.2 Data supplied by Barapukuria Coal-Fired Thermal Power Plant Authority.

Capacity	2x125MW
Power Generation (upto May-2014)	Unit-1: 42724MWh
	Unit-2: 48967MWh
Calorific Value of Coal used	6100Kcal/Kg (Barapukuria Coal Mine Coal)
Coal Consumption Rate	420kg/MWh
Thermal Efficiency of the Plant	36%
CO_2	No record
NOx*, µg/m³	35.74
SOx*, µg/m³	135
Mercury (Hg)	No record
Lead (Pb)	No record
SPM* (*suspended particulate matter*), µg/m³	480
Stack Height	95m

*Measurements of NOx, SOx and SPM concentrations are done at the stack.

We have collected typical PM emission rate data from selected coal-fired power plants in India [15] and China [13] from literature. Data for PM emission rate from a number of Indian coal-fired power plants in g/MWh are collected from [15] (details are given in Table A.1) and its equivalent emission rate for 250MW capacity is calculated in g/sec. The statistical summary of the equivalent data is given in Table 2.3. Similarly, data for PM emission from a number of Chinese coal-fired power plants are collected from [13] (details are given in Table A.2) and equivalent emission rate for 250MW capacity is calculated. Statistical summary of the equivalent data is also shown in Table 2.3**.**

Table 2.3 Equivalent PM Emission rate of Barapukuria coal-fired thermal power plant calculated from Indian [15] and Chinese [13] data.

Data Source Country	Number of Observations	Equivalent PM emission rate for Barapukuria coal-fired thermal power plant (g/sec)	
		25^{th} percentile	75^{th} percentile
India	63	7.083	14.444
China	25	2.172	10.112
Average	88	4.628	12.278

The PM emission rates (g/sec) in Table 2.3 are at the stack. The concentration (μg/m^3) of PM at a given distance from the stack is computed from the PM emission rate. The World Health Organization (WHO) standard for human tolerable limit of total PM concentration [18] is given in Table 2.4.

Table 2.4 WHO standard for human tolerable limit of total PM concentration [18].

PM Category	Human Tolerable Concentration Limit (μg/m^3)
$PM_{2.5}$	10
PM_{10}	20

Chapter 3 Models Used

The focal objective of this study is to estimate the impact of PM emission from Barapukuria Coal-Fired Thermal Power Plant on premature mortality in the adjoining areas. In the absence of measured data, we need to use analytical models. For making the calculations pragmatic we have adopted some assumptions regarding the model. The models used along with the assumptions made are discussed in this chapter.

3.1 Gaussian Plume Dispersion Model

The concentration of a pollutant at a given distance from a point source of emission is classically estimated using Gaussian Plume Dispersion equation [11]. The coordinate system for the Gaussian Plume Dispersion equation is shown in Fig. 3.1. The plume from the point source such as the stack of a coal-fired power plant flows along the direction of the wind flow (x-axis). Besides the flow along the direction of the wind flow, the plume also disperses in both horizontal (y-axis) and vertical (z-axis) directions. The dispersions in horizontal and vertical direction follow Gaussian distributions as shown in Fig. 3.1. The most general form of the Gaussian dispersion equation is

$$\chi(x,y,z,H) = \frac{Q}{2\pi U \sigma_y \sigma_z} \exp\left[-\frac{y^2}{2\sigma_y^2}\right] \left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\} \tag{3.1}$$

where,

χ is the incremental concentration of the pollutant, g/m^3; Q is the pollutant emission rate, g/sec; U is the average wind speed at stack height, m/sec; σ_y, σ_z are the standard deviations of the concentration distributions (diffusion coefficients) in the horizontal (y-axis) and vertical (z-axis) directions respectively, meters; H is the effective stack height, which is the sum of the stack height (h_s) and the plume rise (Δh), that is, $H = h_s + \Delta h$, meters; x is the distance in the direction of wind flow from the stack, meters; y is the horizontal distance from the plume centerline, meters; and z is the vertical distance from ground level, meters.

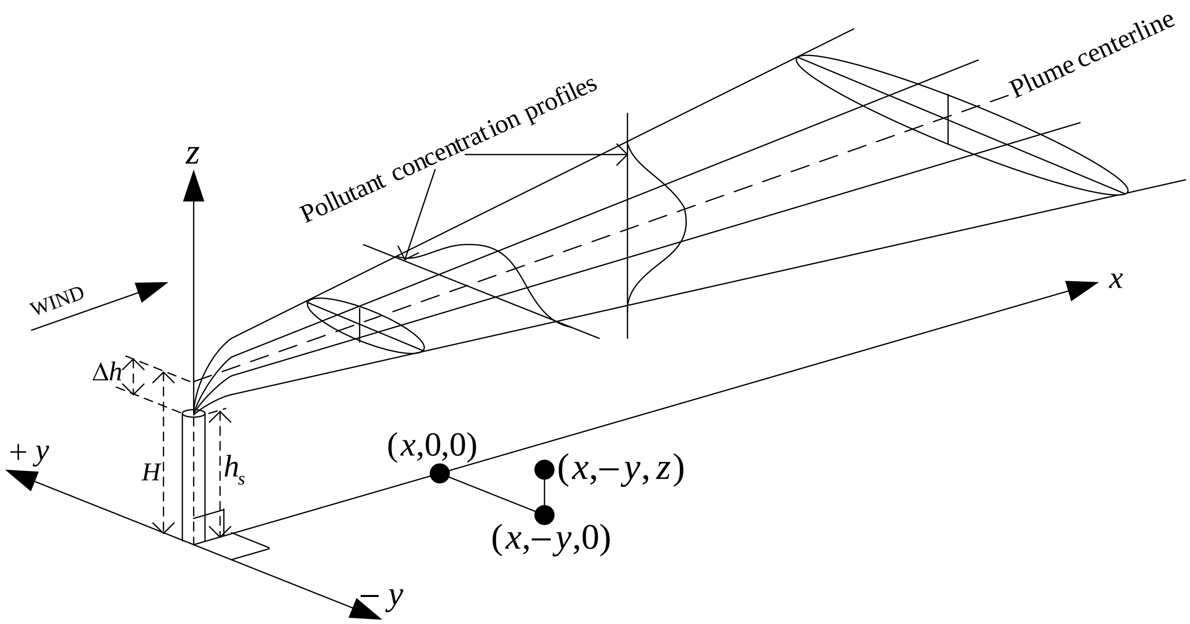

Fig. 3.1 Coordinate system for the Gaussian Plume Dispersion model.

For ground level concentrations at $z = 0$, Eq. (3.1) simplifies to

$$\chi(x, y, 0, H) = \frac{Q}{\pi U \sigma_y \sigma_z} \exp\left[-\frac{y^2}{2\sigma_y^2}\right] \exp\left[-\frac{H^2}{2\sigma_z^2}\right] \tag{3.2}$$

Using the Gaussian Plume Dispersion equation, the ground level incremental concentration χ (in μg/m^3) at the point (x, y) may be written as

$$\chi(x, y, 0, H) = \frac{Q10^6}{\pi U \sigma_y \sigma_z} \exp\left[-{}^{1}\!/_{2}\left(\frac{y^2}{\sigma_y^2}\right)\right] \exp\left[-{}^{1}\!/_{2}\left(\frac{H^2}{\sigma_z^2}\right)\right] \tag{3.3}$$

The Gaussian Plume Dispersion equation of Eq. (3.1) has the following assumptions:

1. The emission rate is constant.
2. Dispersion (diffusion) is negligible in the direction of wind flow (x-axis).
3. Horizontal meteorological conditions are homogeneous over the space being modeled.
    a. An average wind speed is used.
    b. Wind direction is constant.
    c. Temperature is constant.
    d. Atmospheric stability class is constant.
    e. Mixing height is constant.

4. No wind sheer in the horizontal or vertical direction.
5. Plume is infinite with no previous plume history.
6. The pollutants are non-reactive gases or PM that remain suspended in the air following the turbulent movement of the atmosphere.
7. The plume is reflected at the surface with no deposition or reaction with the surface.
8. The dispersion in the horizontal (y-axis) and vertical (z-axis) directions take the Gaussian distribution about the plume centerline.

We will compute PM concentration at ground level (z = 0) using Eq. (3.3). In our calculations, we will use annual average emission rate adopted from data for India and China. We will also use annual average wind direction and speed around Barapukuria, Dinajpur. We will consider neutral atmospheric stability class. The plume rise (Δh) depends on exhaust exit speed, exhaust temperature, exhaust diameter, and wind speed. As these information are not readily available, for making the computations simple, we will assume $\Delta h = 0$, that is, the effective stack height is equal to the physical stack height.

The diffusion coefficients are determined as follows [11]:

$$\sigma_y = cx^d \quad (3.4)$$

$$\sigma_z = ax^b \quad (3.5)$$

where, x is the distance from the stack in the direction of wind flow in meters. The values for a, b, c, and d depend on both distance x and the atmospheric stability class. Details of stability classes and related issues are given in Appendix B. Atmospheric stability classes depend on surface wind speed, daytime insolation, and nighttime cloud cover. We have calculated annual average incremental concentration of $PM_{2.5}$. For this reason, we have not considered seasonal variation of atmospheric conditions and have used atmospheric stability class D representing neutral condition (Table B.1). Neutral stability class represents surface wind speed of 3-5m/s and nighttime cloud cover of greater than 4/8; or surface wind speed greater than or equal to 5m/s, moderate to slight daytime insolation, and any nighttime cloud cover (Table B.2). The values of a, b, c, and d for neutral stability class are shown in Table 3.1 from [11].

Table 3.1 Values of *a*, *b*, *c*, and *d* used in Eq. (3.4) and (3.5) for atmospheric stability class neutral [11].

Atmospheric Stability Class	$100 < x \leq 500$ meters		$500 < x \leq 5000$ meters		$x > 5000$ meters		$x < 10000$ meters		$x \geq 10000$ meters	
	a	*b*	*a*	*b*	*a*	*b*	*c*	*d*	*c*	*d*
Neutral	.0856	.8650	.2591	.6869	.7368	.5642	.122	.916	.193	.865

3.2 Intake Fraction Approach to Estimate Impact of Pollutants on Human Health

The *iF* [7] is estimated to find out the population exposure to pollutants. The *iF* estimates the amount of a pollutant inhaled by the exposed population per unit of primary pollutant emitted from a pollution source. The *iF* is expressed as follows:

$$iF = \frac{\sum_i P_i \Delta C_i BR}{Q} \tag{3.6}$$

where,

P_i is the population size of the grid cell i. In our case, each exposed upazilla is considered as a grid cell.

ΔC_i is the increase in ambient concentration of the pollutant in grid cell i due to emission from the power plant, g/m^3. In our case, the incremental concentration of the pollutant at the center of the upazilla is considered as the change in ambient concentration of the pollutant.

BR is the population-average breathing rate, whose nominal value is 20m^3/day or 2.315×10^{-4}m^3/sec [15].

In most epidemiological studies of the health effects of air pollution, the relative risk (*RR*) of death or illness associated with a change in pollutant concentration is given by [15, 16]

$$RR = exp(\beta \sum_i P_i \Delta C_i) \tag{3.7}$$

where β is the concentration-response function, which is defined as the change in number of cases per unit change in concentrations per capita.

The number of cases (*E*) of premature mortality is given by [15, 16]

$$E = \big((RR - 1)/RR\big) * BaseCases \tag{3.8}$$

where the *BaseCases* is equal to the product of the population size and the average mortality rate [16].

β is normally estimated from epidemiological study. Since pollutant concentration data is not available for Barapukuria Coal-Fired Thermal Power Plant, we have estimated the value of β from analytical relationships. In [9], it is observed that mortality rate is increased by 1.2% per μg/m^3 increase of annual average $PM_{2.5}$ concentration. From this data, we have *E*/*BaseCases* = 0.012 for $\Delta C = 1$μg/m^3. By rearranging Eq. (3.8) and using the above increase in the mortality rate, we have that

$$\frac{E}{BaseCases} = \left(\frac{RR-1}{RR}\right) = 0.012. \tag{3.9}$$

From Eq. (3.9), we have that *RR*= 1.0121.

For a given ΔC, Eq.(3.7) can be rearranged as

$$RR = exp(\beta \Delta C \textstyle\sum_i P_i). \tag{3.10}$$

From Eq. (3.10), for ΔC = 1μg/m^3 and *RR* = 1.0121, the estimated value of β becomes

$$\beta = \frac{\ln(RR)}{\Delta C \sum_i P_i} = \frac{12.0274 \times 10^{-3}}{\sum_i P_i} \tag{3.11}$$

From total exposed population size of $\sum_i P_i = 2346115$ (determined in Chapter 4, Table 4.1), we find that

$$\beta = 5.1265 \times 10^{-9} \text{m}^3/\mu\text{g}.$$

Chapter 4 Results and Discussions

4.1 Calculation of Concentration of $PM_{2.5}$

We have calculated incremental concentrations of $PM_{2.5}$ in the exposed upazillas or fractions of some upazillas situated on the direction of annual average wind flow from Barapukuria using Eq. (3.3). This equation requires direction (x-axis) and speed (U) of wind flow from the stack. For calculating annual average impact of $PM_{2.5}$ on human health in the exposed areas, we have used annual average wind speed and direction from [19]. The annual average direction of wind flow is south-east from Barapukuria and the average speed is 3.4 to 3.6km/hr. In our calculations, we have used wind speed of U = 3.6km/hr, which is equivalent to U = 1m/sec. From Table 2.2, the stack height is H = 95m. From Table 2.3, the estimated average best case (25th percentile) and worst case (75th percentile) emission rates are Q = 4.628g/sec and Q = 12.278g/sec, respectively. The diffusion coefficients σ_y and σ_z are computed using Eq. (3.4) and Eq. (3.5), respectively. For simplicity of calculating σ_y and σ_z, we have used neutral stability class and the associated values of a, b, c, and d are used from Table 3.1. More details of the stability classes and related issues are given in Appendix B.

The diffusion coefficients σ_y and σ_z depend on the distance from the stack along the x-axis direction. The variations of these two coefficients with the variation of distance x are shown in Fig. 4.1 and Fig. 4.2, respectively. In Eq. (3.3), Q, H, and U are constants. Therefore, the concentration at a given point (x, y) practically depends on only σ_y and σ_z.

The contour plots of the best case and the worst case concentrations along the wind direction (south-east direction from Barapukuria) are shown in Fig. 4.3 and Fig. 4.4, respectively. From the contour plots, it is found that the concentration level is the maximum at 2.1 km distance from the stack along x-axis.

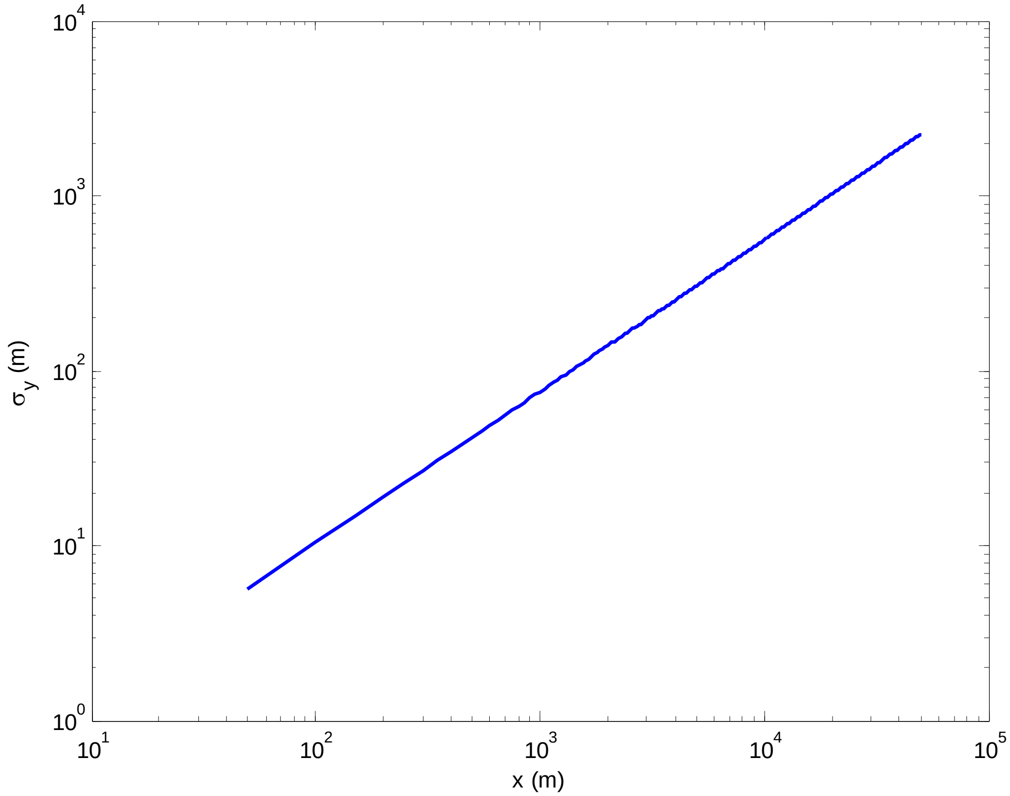

Fig. 4.1 Variation of σ_y as a function of x.

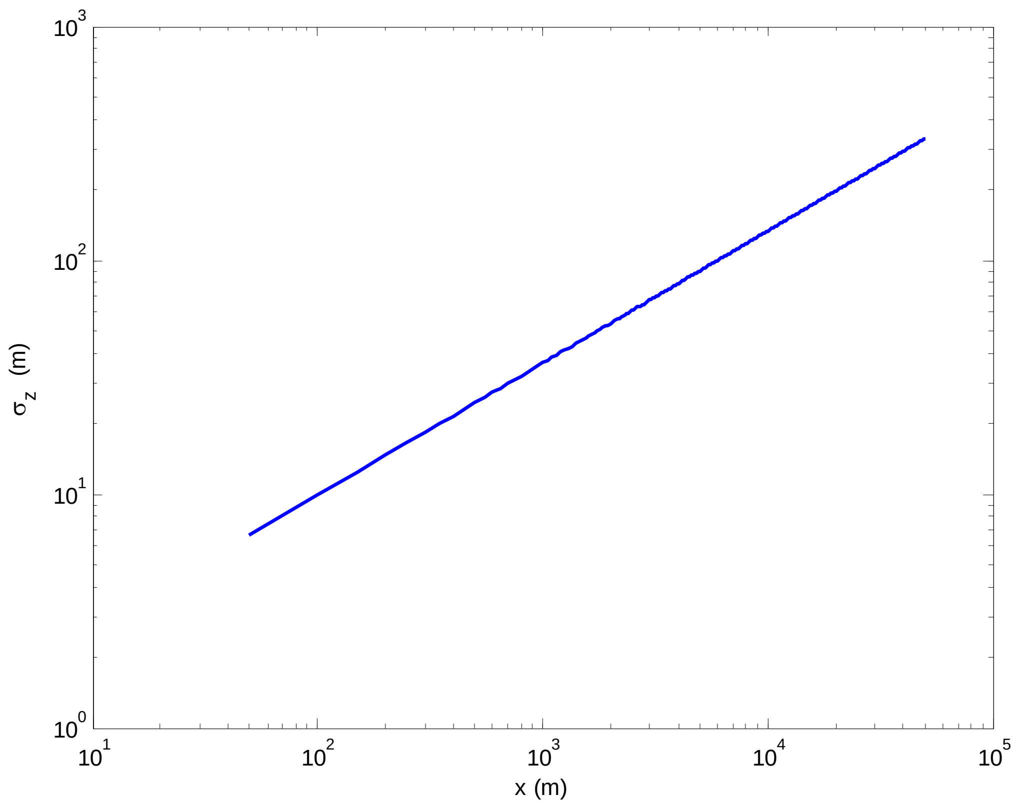

Fig. 4.2 Variation of σ_z as a function of x.

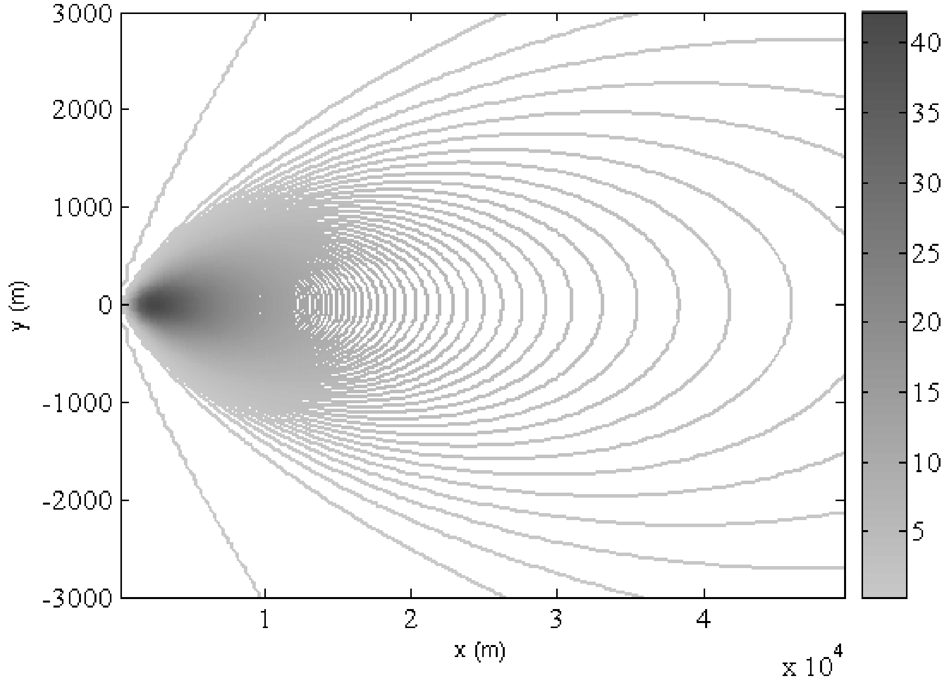

Fig. 4.3 Contour plot of the best case concentrations.

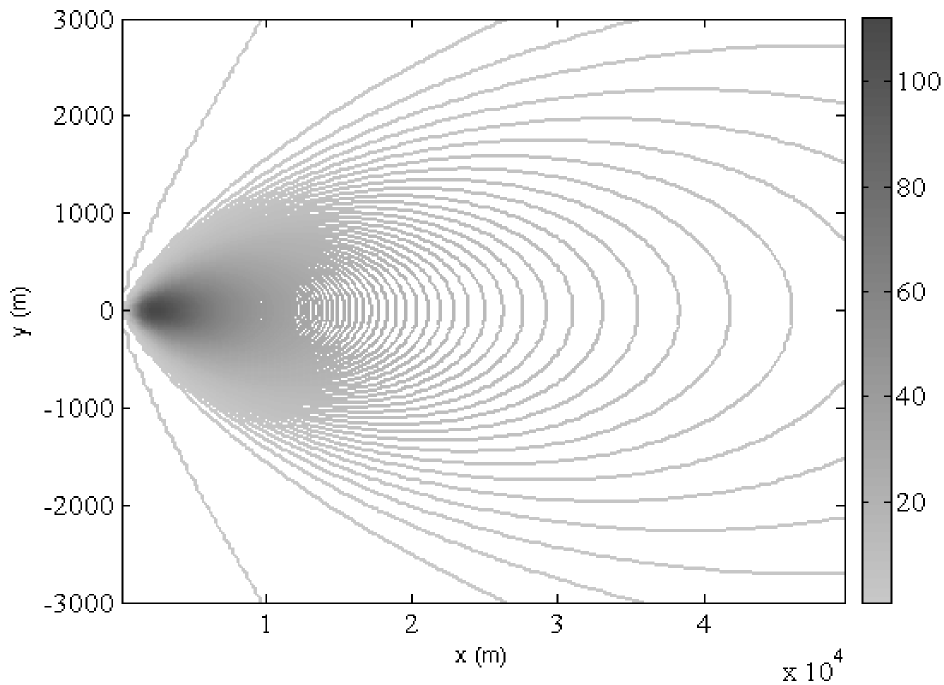

Fig. 4.4 Contour plot of the worst case concentrations.

The variations of the best case and the worst case concentrations with changes in x for different y values are shown in Fig. 4.5 and 4.6, respectively. From these figures it is found that concentration is maximum along the x-axis ($y = 0$) and the concentration decreases sharply with the increase of *y*. It is also found that the peak concentration occurs at different *x* values for different *y* values. If the *y* is smaller, then the peak concentration occurs at smaller *x*. In general, the people along the x-axis near the concentration peaks have more exposure of the pollutant and are in greater threat of hazardous impact of the pollutant.

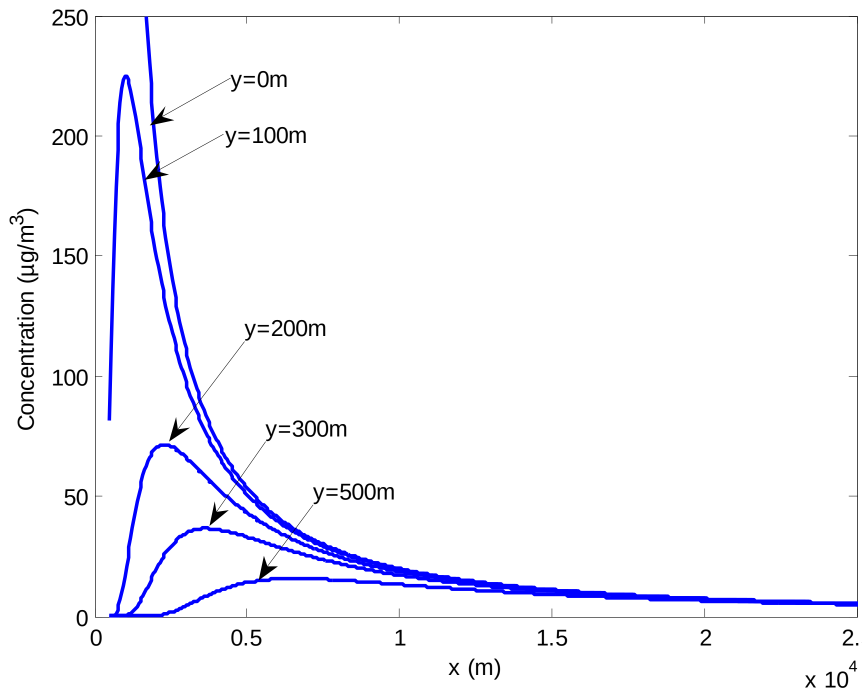

Fig. 4.5 Variation of the best case concentration with the increase of distance *x* for different values of *y*.

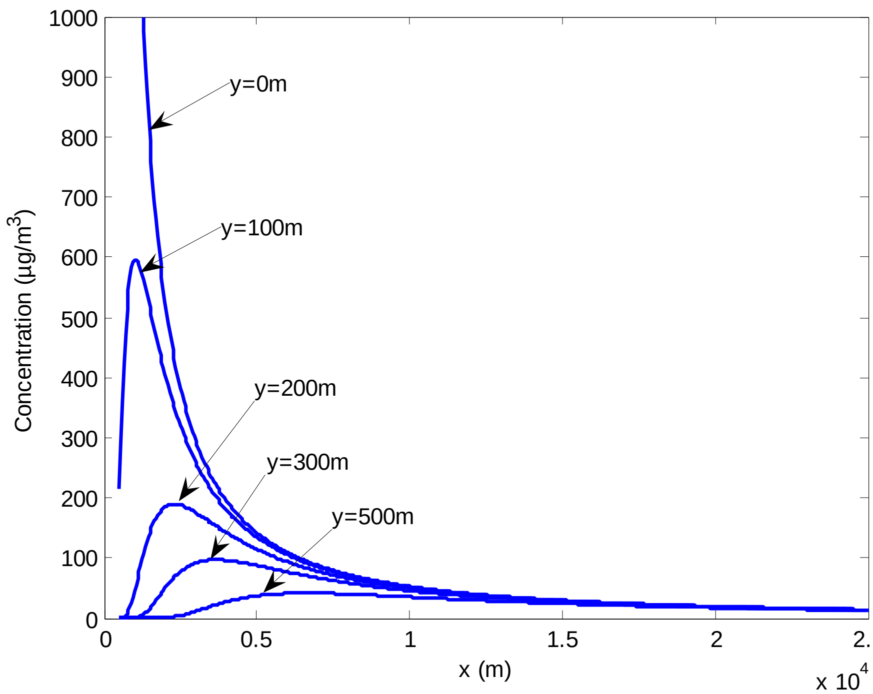

Fig. 4.6 Variation of the worst case concentration with the increase of distance *x* for different values of *y*.

The variations of the best case and the worst case concentrations with the increase of y for different x values are shown in Fig. 4.7 and 4.8, respectively. From these figures it is found that concentration is maximum when $y = 0$ for all values of x and the concentration decreases with the increase of x. Here the concentration decreases more slowly with increasing x. In general, the people along the x-axis ($y = 0$) are in more threats than the people away from the x-axis ($y > 0$).

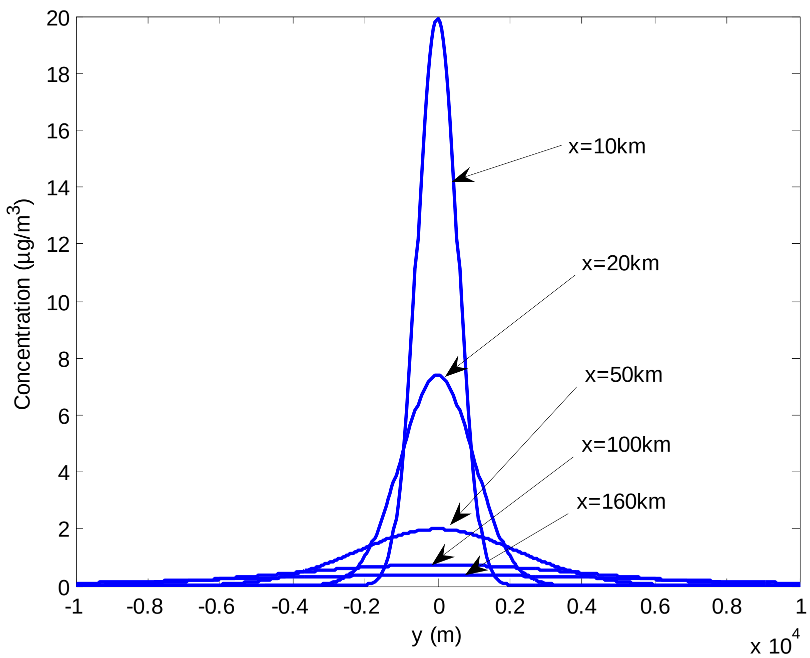

Fig. 4.7 Variation of the best case concentration with the increase of y for different values of x.

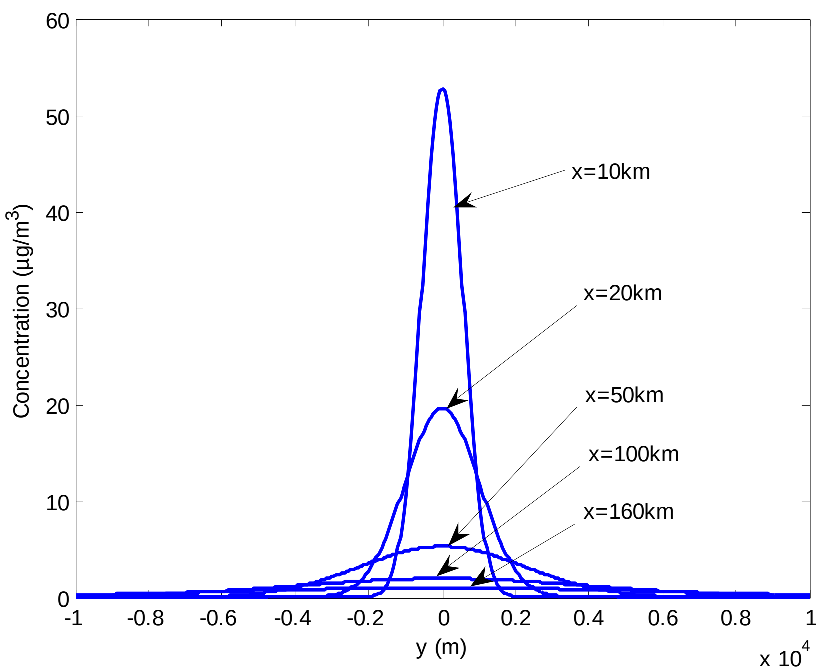

Fig. 4.8 Variation of the worst case concentration with the increase of y for different values of x.

We have computed both the best case and the worst case concentrations of $PM_{2.5}$ along the x-axis (y = 0), which is south-east direction from Barapukuria. We have considered a distance of up to 160km along x-axis, which include 13 upazillas or fractions of some upazillas as shown in Table 4.1. The table also shows the distances of the upazillas considered. The exposed population size of each considered upazilla is also shown in Table 4.1. The population statistics is taken from [20]. From the table, it is found that the concentrations in Badarganj and Hakimpur upazillas are insignificant, since they are situated away from the x-axis. These two upazillas are not considered for determining the impact of $PM_{2.5}$ on human health.

Table 4.1 $PM_{2.5}$ concentrations in 13 upazillas along the annual average direction of wind flow from Barapukuria (south-east direction) and the exposed population sizes.

Exposed Upazilla or Part of Upazilla	Approximate Distance from Stack (km)			Exposed Population	$PM_{2.5}$ Concentration ($\mu g/m^3$)	
	Direct	Along x-axis	Along y-axis		Best Case	Worst Case
Fulbari (20%)	7	7	0	35204	22.779	60.432
Birampur (20%)	13	13	0	34161	11.306	29.995
Nawabganj	21	21	0	229337	6.168	16.363
Ghoraghat	42	42	0	117740	2.432	6.451
Gobindaganj	62	62	0	514696	1.419	3.764
Sonatala (20%)	80	80	0	37355	0.994	2.636
Sariakandi (66.7%)	95	95	0	181382	0.781	2.071
Madarganj	105	105	0	263608	0.678	1.799
Sarishabari (66.7%)	138	138	0	217964	0.461	1.223
Madhupur	150	150	0	296729	0.410	1.087
Ghatail (10%)	160	160	0	417939	0.374	0.992
Badarganj	16.66	1.5	16	287746	insignificant	insignificant
Hakimpur	31.68	29	16	92599	insignificant	insignificant

The map of the exposed upazillas is shown in Fig. 4.9. The best case and the worst case concentrations of $PM_{2.5}$ for each exposed upazilla are shown on the map. Direction of wind flow (south-east direction from Barapukuria), which is the x-axis in the computational model, is also shown. If the direction line goes through the middle of an upazilla, then the total population of that upazilla is considered to be exposed under the pollutant. If the direction line goes along a side of an upazilla, then only the exposed portion of that upazilla is considered. For calculating the exposed population size of a fraction of an upazilla, it is assumed that the population of each upazilla is uniformly distributed.

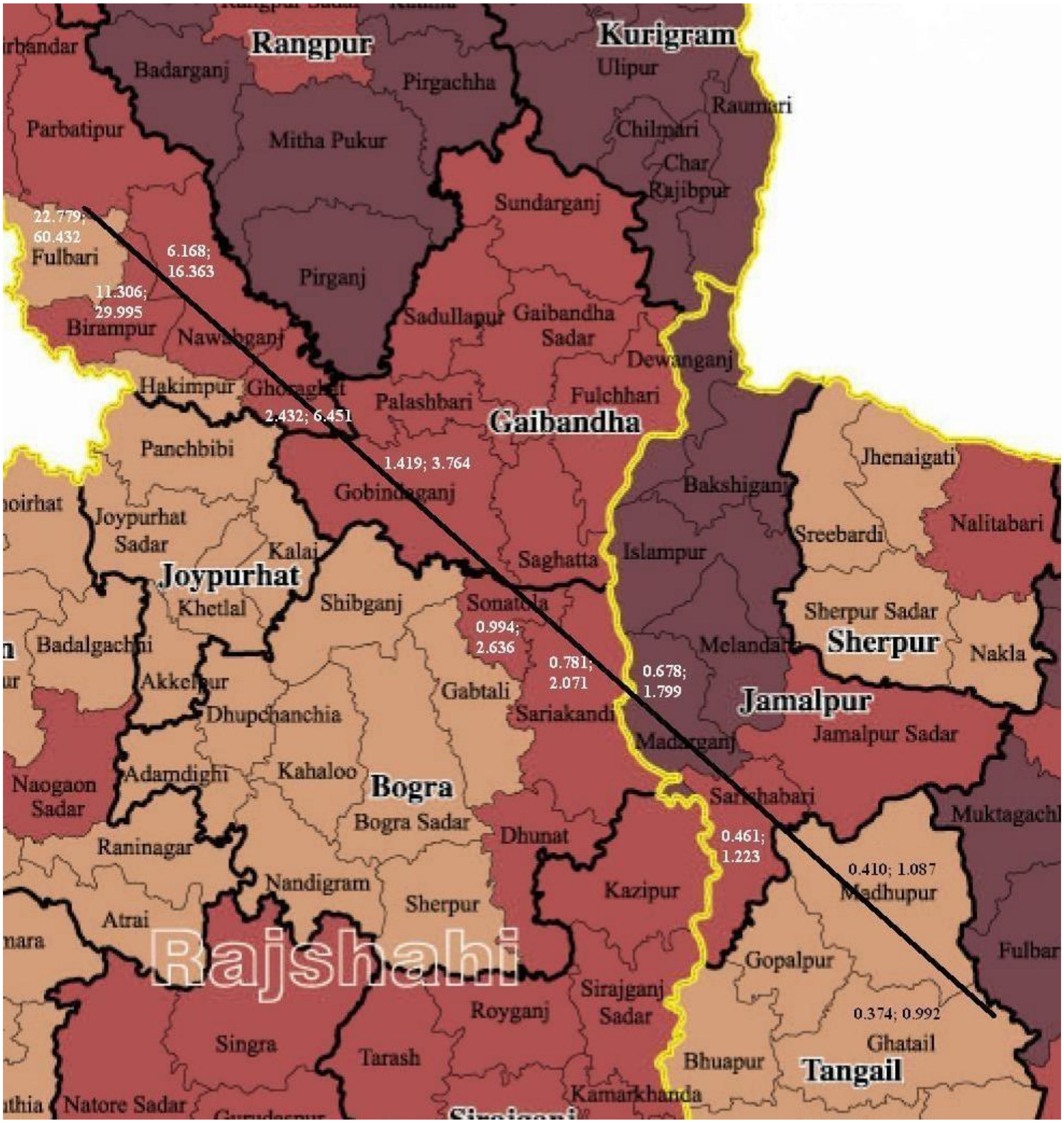

Fig. 4.9 Map of exposed upazillas showing their best case and worst case $PM_{2.5}$ concentrations. The map is taken from [21].

4.2 Calculation of Impact of $PM_{2.5}$ Concentration on Human Health of the Exposed Populations

The *iF* is calculated using Eq. (3.6) and is shown in Table 4.2. The *RR* is calculated using Eq. (3.7) and is shown in Table 4.2. The *E/BaseCases*, which is the increase of rate of mortality, is calculated using Eq. (3.8) and is also shown in Table 4.2. In both the best case and the worst case, 2.18×10^{-4} portion of the total $PM_{2.5}$ emission is inhaled by the exposed population. This inhalation of $PM_{2.5}$ produces the best case and the worst case *RR*s of 1.0226 and 1.0610, respectively. Both the best case and the worst case *RR*s are greater than 1, which implies that the risk of human health damage is significant. In the best case scenario, the expected increase of mortality rate is 2.21%, which implies that at least 2.21% more people will die from the health hazards of $PM_{2.5}$ emission. In the worst case scenario, it is expected that 5.75% more people will die from $PM_{2.5}$ exposure.

Table 4.2 Impact of $PM_{2.5}$ concentration on human health in the exposed areas.

Intake fraction (*iF*)		Relative risk (*RR*)		Increase of mortality rate (*E/BaseCases*)	
Best Case	Worst Case	Best Case	Worst Case	Best Case	Worst Case
2.18×10^{-4}	2.18×10^{-4}	1.0226	1.0610	2.21%	5.75%

The 2014 estimated annual death rate of Bangladesh is 5.64 deaths per 1000 of population [22]. From Table 4.2, we see that due to $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant, in the best case, mortality rate will increase by 2.21%. Thus, in the best case, E = 292. That means, in the best case, 292 more people will suffer death every year in the exposed area due to $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant. Similarly, in the worst case, E = 760. That means, in the worst case 760 more people will die in the exposed area every year due to $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant. These values are summarized in Table 4.3. These data also imply that in the exposed area the average annual all-cause mortality rate will be increased to a value between 5.765 and 5.964 per 1000 of population.

Table 4.3 Number of premature mortality in a year in the exposed area due to $PM_{2.5}$ exposure emitted from Barapukuria Coal-Fired Thermal Power Plant.

	Number of premature mortality, *E*
Best Case	292
Worst Case	760

Chapter 5 Conclusion and Future Works

5.1 Conclusion

The main objective of this study is to determine the impact of $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant on human health in the adjoining areas. For this purpose, we need actual concentrations of pollutants at various locations from emissions of the power plant. As this data is not available, we have adopted the $PM_{2.5}$ emission rate data from coal-fired power plants of India and China for Barapukuria power plant.

We have calculated the concentration of $PM_{2.5}$ in the exposed areas using Gaussian Plume Dispersion Equation. To estimate an average annual concentration of $PM_{2.5}$, we have used annual average wind speed and direction. As the annual average wind direction is towards south-east from Barapukuria, we have considered only the upazillas along the south-east direction from Barapukuria.

In this study, we have found that the $PM_{2.5}$ concentrations in the regions along the south-east direction from Barapukuria are significant. A total of 23,46,115 persons are exposed to significant concentrations of $PM_{2.5}$. We have estimated that for both the best and the worst cases, $iF = 2.18\times10^{-4}$. We have estimated the risk factor of $PM_{2.5}$ exposure by determining *RR*. The *RR* calculations show that the best case and the worst case values are 1.0226 and 1.0610, respectively. Finally, we have estimated the expected number of premature deaths due to the $PM_{2.5}$ exposure. The calculations reveal that on an average, 292 (best case) to 760 (worst case) more people will die due to this $PM_{2.5}$ exposure every year.

The concentration of $PM_{2.5}$ at a given location from the power plant depends on wind speed and direction as well as atmospheric stability class near the power plant. Therefore, concentration of $PM_{2.5}$ at a given location will vary in different seasons of the year. As detailed data regarding wind speed, direction, and other parameters determining the atmospheric stability classes in different seasons of the year are not available, we have used the annual average wind direction and speed as well as neutral stability class for our calculations. This study is the first one of its kind and the calculations are done under the mentioned limitations to initiate study of assessing human health damage due to $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant. The calculated results are an average indication of human health damage due to $PM_{2.5}$ emission from Barapukuria Coal-Fired Thermal Power Plant. To make the estimates more meaningful, we have calculated both the best case and the worst case additional deaths in a year due to $PM_{2.5}$ exposure in the exposed area. It is expected that the actual number of premature deaths in a year in the exposed area will be within the range between the best case and the worst case values.

5.2 Future Works

The present study has been done using assumed emission rates of $PM_{2.5}$ from Barapukuria Coal-Fired Thermal Power Plant from similar data from India and China. Realistic study has to be made using real measured data. Analytical results will have to be verified from measured data from adjoining areas. Wind speed and direction varies with the seasons of the year. Moreover, the value of the dispersion coefficients depends on the environmental stability classes, which vary with the seasons. So, seasonal study may be done to determine the actual seasonal impact of $PM_{2.5}$ emission. As annual average number of premature death due to $PM_{2.5}$ exposure is significant, economic loss due to these premature deaths are to be estimated in terms of monetary values. In this study, only premature deaths due to $PM_{2.5}$ exposure are considered. $PM_{2.5}$ also causes many other illnesses requiring treatment which refrain the ill people from normal works. Economic impacts of such illnesses have to be studied. Similar study should be made for other pollutants like SO_2 and NOx.

Appendix A $PM_{2.5}$ Emission Rate Data from Coal-Fired Power Plants in India and China

Table A.1 $PM_{2.5}$ emission rate data from coal-fired power plants in India [15].

Pollutant	Number of observations	Mean	Standard Deviation	Percentile				
				5th	25th	Median	75th	95th
$PM_{2.5}$ (g/MWh)	63	227	389	48	102	143	208	496

Table A.2 $PM_{2.5}$ emission rate data from coal-fired power plants in China [13].

No.	kg/h	MW	g/MWh	g/MWh
1	9.2	300	9.667	25th percentile 31.277
2	2.3	155	14.839	
3	25.7	135	19.037	
4	12.6	318	39.62	
5	24.3	600	40.5	
6	19.2	300	64	
7	14.8	220	67.27	
8	22.1	300	73.667	
9	44.8	600	74.667	
10	15.8	210	75.2	
11	10.5	125	84	
12	26.3	300	87.67	
13	33.1	300	110.33	
14	34.3	300	114.33	75th percentile 145.618
15	41.9	350	119.71	
16	15.5	125	124	
17	48.9	300	163	
18	102.7	600	171.167	
19	54.3	300	181	
20	63.8	318	200.63	
21	75.7	330	229.39	
22	143.3	600	238.83	
23	85	300	283.33	
24	180.4	300	601.33	
25	299.9	300	999.67	

Appendix B Data Related with Calculation of Pollutant Concentration Using Gaussian Plume Dispersion Equation

Table B.1 Stability classification scheme [11].

Stability description	Stability Class
Extremely unstable	A
Moderately unstable	B
Slightly unstable	C
Neutral conditions	D
Slightly stable	E
Moderately stable	F

Table B.2 Stability classification [11].

Surface wind speed (m/s)	Daytime insolation			Night time	
	strong	moderate	slight	Thin overcast or >4/8 low cloud cover	<3/8 cloud cover
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Table B.3 Power law exponents and coefficients for σ_z [11].

Atmospheric Stability Class	Downwind Distance, meters $100 < x \leq 500$		Downwind Distance, meters $500 < x \leq 5000$		Downwind Distance, meters $5000 < x$	
	a	*b*	*a*	*b*	*a*	*b*
A=1	0.0383	1.281	0.0002539	2.089	0.0002539	2.089
B=2	0.1393	0.9467	0.04936	1.114	0.04936	1.114
C=3	0.1120	0.9100	0.1014	0.926	0.1154	0.9109
DD=4	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642
DN=5	0.0818	0.8155	0.2527	0.6341	1.297	0.4421
E=6	0.1094	0.7657	0.2452	0.6358	0.9204	0.4805
F=7	0.05645	0.8050	0.1930	0.6072	1.505	0.3662

Table B.4 Power law exponents and coefficients for σ_y [11].

Atmospheric Stability Class	Downwind Distance, meters $x < 10000$		Downwind Distance, meters $x \geq 10000$	
	c	*d*	*c*	*d*
A=1	0.495	0.873	0.606	0.851
B=2	0.310	0.897	0.523	0.840
C=3	0.197	0.908	0.285	0.867
DD=4	0.122	0.916	0.193	0.865
DN=5	0.122	0.916	0.193	0.865
E=6	0.0934	0.912	0.141	0.868
F=7	0.0625	0.911	0.0800	0.884

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