ES2201: Introduction to Environmental Science

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Term Paper

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Application of Gaussian Plume Model on 1000MW NTPC power plant to see its contribution to local air pollution in the city of Champa, Chhattisgarh

Quantitative estimation of emission pm-2.5 particulate matter from Atal Bihari Vajpayee Thermal Power Statio n(Marwa Power Plant), Janjgir-Champa C.G and qualitative estimation of other possible sources of pm-2.5 air pollutant.

Abstract

The sates Chhattisgrah has many thermal based power plants and thus are main contributor of air pollutants. This paper aims to analyze the environmental impact of the Atal Bihari Vajpayee Thermal Power Station CG on the ambient air quality. Pollution modelling helps to predict pollutant concentration and identify source, with the help of Gaussian Plume Model we calculate the concentration of the major air pollutants namely SPM (Suspended Particulate Matter) from the data available. By estimating the concentrations, it shall be examined whether these concentrations comply with the standards or not and does it impose any hazard on the two neighbouring schools and colony.

1.Introduction

Air pollution has been one of the biggest concerns we have in our daily lives as it has serious health hazards on humans. As urbanization is increasing day by day, India is witnessing tremendous growth in demand for energy and raw materials for construction and higher consumption of fuels. Our country is a developing nation and has increasing demands but on the other hand, it often tends to neglect the environmental and health concerns arising out of development activities.

We usually notice lots of industries and manufacturing units and power plants surrounding the periphery of a city also there are often many residential areas that emerge as these industries boost economic growth by providing jobs to labor. So it results in settlements of humans around it and they are highly prone to live around

hazardous emissions like SO_2, Oxides of nitrogen, Carbon monoxide, Sulphur, and PM2.5 particulate matter coming out from industries like Cement factories, Thermal power plants, steel plants, mining sites and lot more.
Exposure to PM2.5 is proven to cause tons of respiratory problems, itching of eyes, and indirect effects on lungs and heart. Also, emissions from the automobile and paint industry can have PM2.5 carrying lead metal which can affect brain development in children.

Hence, it is important to study the dynamics of local air pollutant emission from the different sources in order to predict its effect on human lives, make regulatory measures to reduce the number of emissions, and plan locations for upcoming industries and human settlements.

My aim for this term paper is to look at one of the sources (conventional thermal power plant) of PM2.5 emission which is situated nearby to my home at about 8km radial distance and look at its emissions, model it with a mathematical framework, and see how much it contributes to the air quality index of the city. Secondly, I will try to investigate the other sources of PM2.5 emissions around my city.

2 Methods

In this study, air dispersion modeling is carried out using a basic Gaussian plume model (GPM).

2.1 The site

The site chosen is a Marwa Thermal Power Plant (established by NTPC) also known as Atal Bihari Vajpayee Thermal Power Station located at the bank of Hasdeo river in the Janjgir-Champa district of Chhattisgarh. It has a capacity of 1000MW by two units of each 500MW.

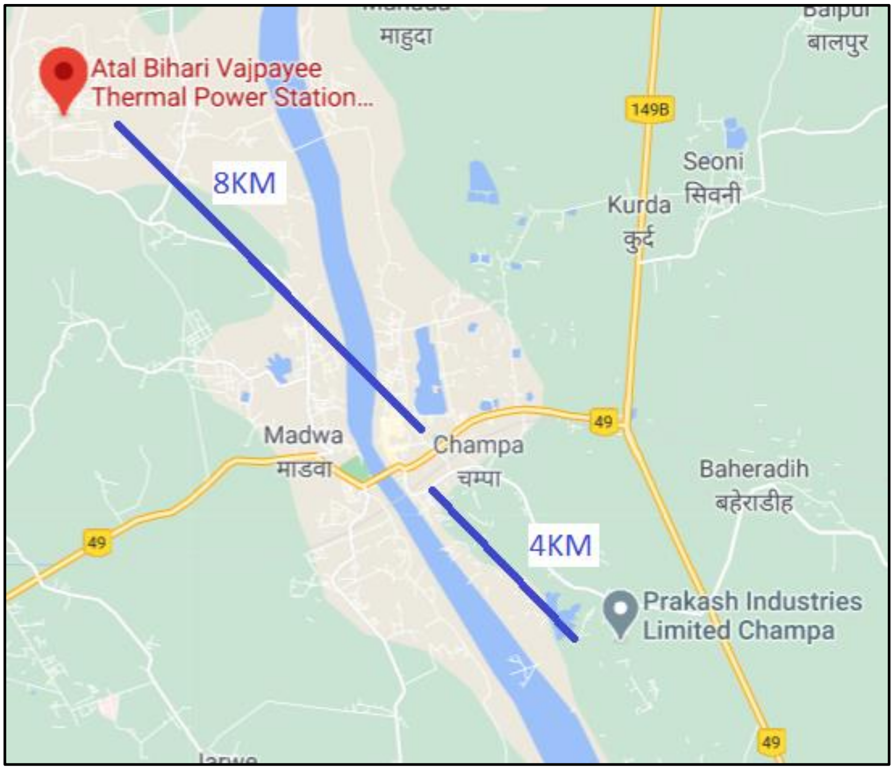

Figure1: The map showing the location of the power plant and the city

Figure 2: Satellite image of the Marwa Power Station

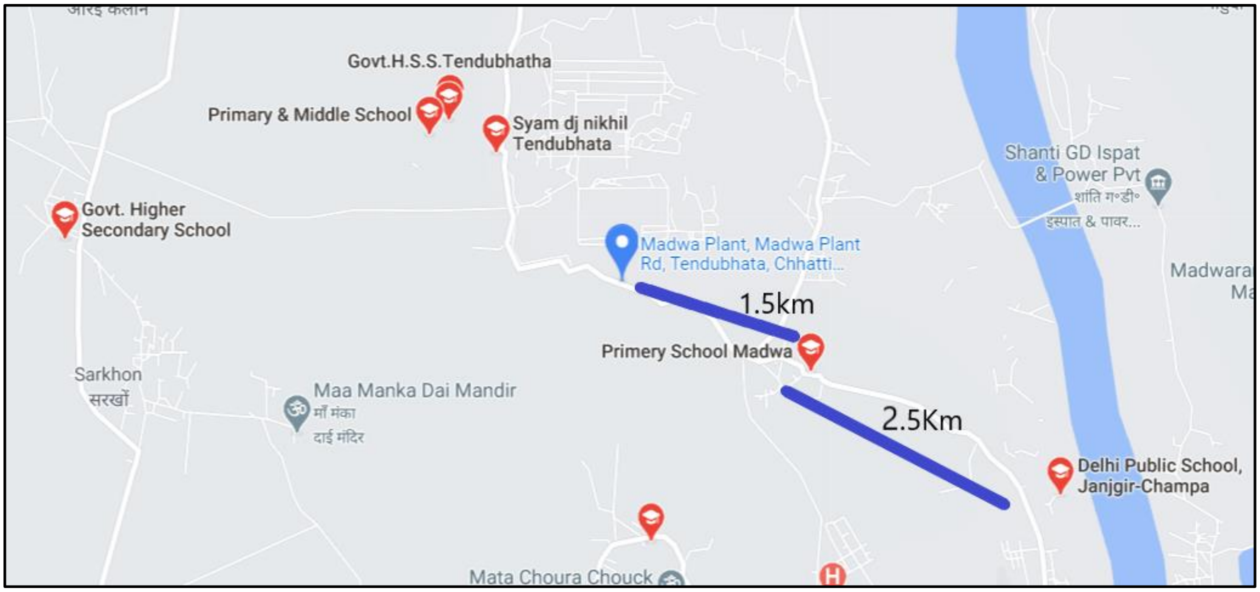

Figure 2: Map showing schools nearby Marwa Thermal Powerplant

It is important to study this particular power station because there are quite a few public and government schools are located within a 5km of radius from the power plant. This can be concerning if the air quality index exceeds the standard permissible concentration of local air pollutants set by the government.

2.2 The Plume model

The non-modified Gaussian plume model will be used for this term paper and the concentration at the ground level will be compared. The Gaussian Plume Model **[1]** equation is as follows-

$$C(x,y) = \frac{Q}{\pi \mu_H \sigma_y \sigma_z} exp(\frac{-H^2}{2{\sigma_z}^2}) exp(\frac{-y^2}{2{\sigma_y}^2})$$

Where,

C(x, y) = ground-level concentration at the point (x,y)
x = downwind distance; y = horizontal distance from the plume centerline
Q = emission or mass flow rate of pollutants; H = effective stack height
uH = horizontal wind speed at elevation H

σy,σz = horizontal and vertical dispersion coefficients respectively.
The Dispersion coefficients can be calculated using the following formulae:

$$\sigma_y = ax^{0.894}$$

$$\sigma_z = cx^d + f$$

where the constants a, c, d, and f are given in the following table for each stability classification
Stability Class

		$x \leq 1$ km			$x \geq 1$ km		
Stability	*a*	*c*	*d*	*f*	*c*	*d*	*f*
A	213	440.8	1.941	9.27	459.7	2.094	−9.6
B	156	106.6	1.149	3.3	108.2	1.098	2.0
C	104	61.0	0.911	0	61.0	0.911	0
D	68	33.2	0.725	−1.7	44.5	0.516	−13.0
E	50.5	22.8	0.678	−1.3	55.4	0.305	−34.0
F	34	14.35	0.740	−0.35	62.6	0.180	−48.6

Wind speed at elevation H can be calculated using the following formula,

$$u_H = u_a \left(\frac{H}{z_a}\right)^p$$

Where, u_a= windspeed at anemometer height, za
p = exponent depending on stability class and location of site or surface roughness

Stability	Description	Rural exponent	Urban exponent
A	Very unstable	0.07	0.15
B	Moderately unstable	0.07	0.15
C	Slightly unstable	0.10	0.20
D	Neutral	0.15	0.30
E	Slightly stable	0.35	0.30
F	Stable	0.55	0.30

2.2 Meteorological conditions around the site

The meteorological condition i.e average wind velocity, temperature, and cloud cover information have been taken from a weather website (windy.com). Usually, the site and the city have stable weather conditions that mean the average wind speed is very low. The website shows the variation in AQI measurement throughout the day and it was observed that during the evening period starting from 6 pm the PM2.5 concentration increases by two to three-fold by midnight and drops after 3 am.
The stability class is obtained using surface wind speed and other parameters are calculated accordingly

2.3 Data

- Distance of plant from the DPS school 5km
- Distance of plant from the Pimary school 1.5km
- Distance of city center from plant 8km

Specifications of the powerplant -

Number of power generating units	2 (Each of 500MW)
Number of stack	1
Stack height (m)	275
Stack exit diameter (m)	5
Exit velocity of gas (m/s)	22
Emission rate of SPM* (g/s)	176.6
Temperature of gas at stack outlet (°C)	140

Pollution Generated Min -	49 mg/Nm^3
Pollution Generated Max-	36 mg/Nm^3

Results:

We calculated the concentration of the air pollutants from the above data using this Gaussian Plume Model. We considered two stability classes (A and E) corresponding to the surface windspeed and the normal sunny day and a clear sky night respectively. We also considered the urban exponent values while calculating the windspeed at height H = 275 m, considering the location of the site (22.068012, 82.598529). Using GPM, we calculate the ground level concentration from the mass emission rate of the PM2.5 Suspended Particulate Matter.

The stability class will be taken according to different weather parameter which is yet to choose. Also, the main local air pollutant of interest is particulate matter so GPM will be applied to PM2.5 emissions. The concentration obtained will be analyzed and I will try to find out the extent of air pollutant concentration at the city center and the schools which are situated nearby thermal power plant. The obtained concentration will be subtracted from the AQI data and the resultant concentration will be considered as being contributed from other sources nearby.

Location	Distance from plant(km)	Concentration of SPM(µg/m3) in day	Concentration of SPM(µg/m3) in clear night
Delhi Public School	5	1.79	8.43

Primary School	1.5	20.12	0.05
Champa City Center	8	0.68	11.18

Discussion:

We see increase in the concentraion of PM2.5 suspended matter particle during the night with increase in distance from the plant and also the reverse i,e decrease in the concentration of SPM with decrease in the distance of chosen sites from the Thermal Power Plant. This is maybe due to the fact that lower temperature in the night do not let pollutant rise up in the atmosphere and make them remain lower around the ground layer increasing the ground level concentration of suspended particles.

References:

1) Wendell P._ Masters, Gilbert M. - Introduction to environmental engineering and science-Pearson,438–486, (**2014**)

2) B Anggarani1, P Wibowo1, and F Aditama, Air dispersion modeling for emission mitigation of power plant technology,(**2013**)

3) Seema Awasthia, Mukesh Khareb, and Prashant Gargavac, General plume dispersion model (GPDM) for point source emission, (**2006**)

4) Central Pollution Control Board (CPCB),. Annual Report 1993/94, Central Pollution Control Board, Ministry of Environment & Forests, Government of India, New Delhi, 154 pp.(**1995**)

5) Windy.com

Python code for GPM

```
import numpy as np
import sys
from scipy.special import erfcinv as erfcinv
from calc_sigmas import calc_sigmas

def gauss_func(Q,u,dir1,x,y,z,xs,ys,H,Dy,Dz,STABILITY):
  u1=u
  x1=x-xs # shift the coordinates so that stack is centre point
  y1=y-ys

  # components of u in x and y directions
  wx=u1*np.sin((dir1-180.)*np.pi/180.)
  wy=u1*np.cos((dir1-180.)*np.pi/180.)

  # Need angle between point x, y and the wind direction, so use scalar product:
  dot_product=wx*x1+wy*y1
  # product of magnitude of vectors:
  magnitudes=u1*np.sqrt(x1**2.+y1**2.)

  # angle between wind and point (x,y)
  subtended=np.arccos(dot_product/(magnitudes+1e-15))
  # distance to point x,y from stack
  hypotenuse=np.sqrt(x1**2.+y1**2.)

  # distance along the wind direction to perpendilcular line that intesects
  # x,y
  downwind=np.cos(subtended)*hypotenuse

  # Now calculate distance cross wind.
  crosswind=np.sin(subtended)*hypotenuse

  ind=np.where(downwind>0.)
  C=np.zeros((len(x),len(y)))

  # sig_y=sqrt(2.*Dy.*downwind./u1)
  # sig_z=sqrt(2.*Dz.*downwind./u1)
```

```
# calculate sigmas based on stability and distance downwind
(sig_y,sig_z)=calc_sigmas(STABILITY,downwind)

 C[ind]=Q/(2.*np.pi*u1*sig_y[ind]*sig_z[ind]) \
    * np.exp(-crosswind[ind]**2./(2.*sig_y[ind]**2.))  \
    *(np.exp(-(z[ind]-H)**2./(2.*sig_z[ind]**2.)) + \
    np.exp(-(z[ind]+H)**2./(2.*sig_z[ind]**2.)) )
return C
```