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Research Article

Modelling of Pollutants from a Point Source: A Case study from Coke Industry, Dharwad, India

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Abstract

In the present study, the Gaussian Plume Model (GPM) was applied to predict pollution dispersion due to a point source from a coke Industry from – Dharwad, located in semi arid zone of tropical climate of Karnataka, India. Based on the observed pollutants in different season, metrological data, the model is validated and used to predict the concentration of pollutants for different seasons. Distribution of air pollutants concentration such as Nitrogen Dioxides (NO_2), Sulphur Dioxides (SO_2) and Total Suspended Particulates (TSP) due to a Coke industry is considered. The effect of wind speed and its direction on the pollutant concentration within the affected area is evaluated.

Keywords: *Gaussian Plume Model, Wind rose plots, SPM, SO_2, NO_2*

1. Introduction

Air dispersion modelling is an essential step in the air quality assessment process as it is the only way to evaluate the impact of future changes in air pollutant emission sources. Dispersion modelling is a computer tool that use mathematical equations to simulate how air pollutants disperse in the atmosphere. The model takes emissions from a source, estimates how high into the atmosphere they will go, how widely they will spread and how far they will travel based on hourly meteorological data. The model then outputs the concentrations that will occur at the selected receptors (B. Angelevska). Wind calms and high pressure conditions enhance pollutant accumulation in the atmosphere, leading to deterioration in air quality. High air pollution load in urban cities has been a major contributing factor towards degrading the ambient air quality day by day (I.C.Agrawal *et al,* 2003). In general, the more parameters a model includes, the more accurately the result will represent the real situation. If the parameters necessary for a particular model are unknown, that model should not be used. Even the most sophisticated atmospheric dispersion model cannot predict the precise location, magnitude and timing of ground-level concentrations with 100% accuracy. However, most models used today have affirmed model evaluation process and the modelling results are reasonably accurate, provided when appropriate model and input data are used (Ministry for Environment, New Zealand 2004).

The most common model computing the dispersion of air pollution from a single point source is the Gaussian plume model, which was initially proposed by O.G. Sutton (1932). Although model has its limitations, it is used widely to solve dispersion problems. The process of air pollution modeling includes the four stages (data input, dispersion calculations, deriving concentrations, and analysis) (Visa *et al*, 2007). The accuracy and uncertainty of each stage must be known and evaluated to ensure a reliable assessment of the significance of any potential adverse effects. The Gaussian-plume models are widely used, well understood, easy to apply, and until more recently have received international approval. The Gaussian-plume models play a major role in the regulatory arena. The Gaussian-plume formula is derived assuming the steady-state conditions.

Coke oven industries are considered to be one of the major contributors towards atmospheric pollution in the steel industry (N.K.Ghosh *et al*, 2010). The coal preparation, oven charging, pushing and quenching operations emit a lot of dust, gas, tar, tar fog into atmosphere that are considered to be harmful to the human system. Coke and coke by-products, including coke oven gas, are produced by the pyrolysis (heating in the absence of air) of suitable grades of coal. The coke oven is a major source of fugitive air emissions. For every ton of coke produced, approximately 0.7 to 7.4 kilograms (kg) of PM, 2.9 kg of SOx (ranging from 0.2 to 6.5 kg), 1.4 kg of nitrogen oxides (NOx), 0.1 kg of ammonia, and 3 kg of VOCs (including 2 kg of benzene) may be released into the atmosphere(World bank, 1995).

The study region, Hubli-Dharwad city (Latitude 15^o 27″ N, Longitude 75^o 12″ E) is one of the fast developing industrial hub in Karnataka after Bangalore. More than 1000 allied small and medium industries already established. They are located in Gokul Road & Tarihal

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regions of Hubli and Lakmanahalli and Belur regions of Dharwad. Industrial belt in Hubli-Dharwar covers an area of about 72.78 Sq.kms. There are Machine tools industries, Electrical, Steel furniture's, Ceramic industries, Food products, Rubber and leather industries, Tanning industries, Dairy industries, Coke industries etc. Industrial areas in Dharwad are in close proximity to residential areas therefore, it is important to know the pollutants distribution in this area. There are several factors that affect the distribution of the pollutants from a point source to the nearby area such as stack height, wind direction, and topography. By using Gaussian Plume Dispersion Model, the prediction of the pollutants distribution concentration from a point source can be determined

The objective of the study is to determine the distribution of air pollutants concentration with respect to Total Suspended Particulates (TSP), Nitrogen Dioxides (NO_2), Sulphur Dioxides (SO_2), and Carbon Monoxides (CO), using Gaussian Plume Dispersion Model. The study is useful to predict the future air quality within the affected area. By knowing the air pollutants distribution, this study contributes in planning purposes in locating plants or development of industrial area. By that, proper regulation can be implemented within the area.

2. Monitoring and Measurement

2.1 Stack sampling

Vayubhodha Stack Sampler is used in the study for stack sampling and the sampling is restricted to primary pollutants i.e. Suspended Particulate Matter, SOx, NOx. Sampling is carried out for different seasons of the Coke Industry. SPM is measured gravimetrically (P.Goyal, 2004). SOx and NOx are analysed as per the standard procedure of CPCB. The eight hourly samples are collected for 24 hours in four different days, in each representative month of the season.

Table 2.1: Details of Stack with the Emissions

Stack No	Stack Height (m)	C/s Area of Stack(m^2)	Flue Gas Velocity(m/s)	Flue Gas Temperature (^oC)
3	34	9.08	11.98	671
4	34	9.08	10.67	623

2.2 Wind rose plots

The most prominent wind direction pattern observed was from south west during summer rainy season Feb to May and June to September respectively followed by south east direction during winter season. Moderate to high wind speed was observed during the month of April-May, and low to calm wind during the months of December-February. Mean maximum Temperature ranges from 36 to 39^{o}C and mean minimum temperature ranges from 12 to 16^{o}C. The relative humidity value ranges from 75 to 80 % in the study area (SPCB, Dharwad).

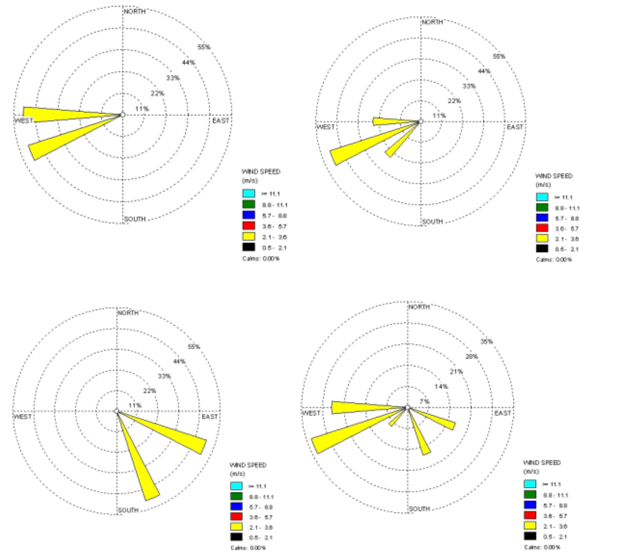


Fig 2.2: 2009 Wind Rose of Rainy, Summer, Winter and Yearly plots.

3. Modelling: Gaussian Plume Model

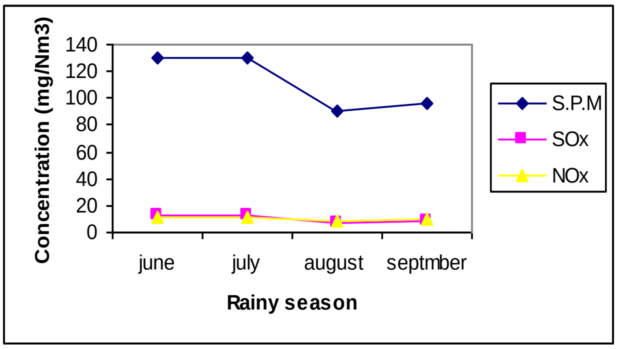
An air dispersion model is a series of mathematical equations that describes the behaviour of gases/particles emitted into the air and used to calculate the concentration of pollutants at various points surrounding an emissions source. For a point source, the user will be asked to provide the following inputs: emission rate (g/s), stack height (m), stack inside diameter (m), stack gas exit velocity (m/s) or flow rate (m^3/s), stack gas temperature (K), ambient temperature (K) (293 K if not known), urban/rural option (U = urban, R = rural), etc. The Gaussian model equations and interactions of the source-related and meteorological factors are described in EPA 1996. The Gaussian plume equation for the concentration C at any point (x, y, z) in the three – dimensional coordinate system of the plume is

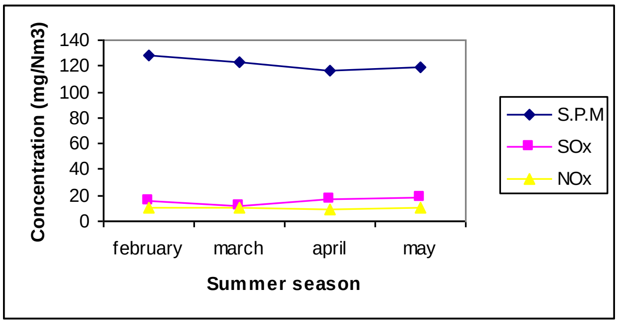
$$C(x,y,z)=\frac{Q}{2\Pi\sigma_y\sigma_z u}\exp\left[\frac{-y^2}{2\sigma_y{}^2}\right]\left\{\exp\left[\frac{-(Z-H)^2}{2\sigma_Z{}^2}\right]+\exp\left[\frac{-(Z+H)^2}{2\sigma_Z{}^2}\right]\right\}$$

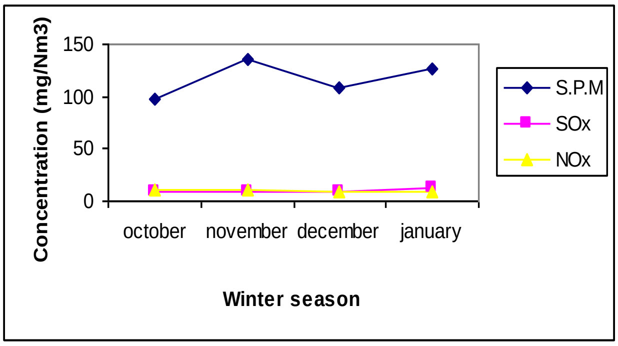
Where, C(*x*, y, z) = centre line concentration of pollutant at any point (x, y, z) in space, μg/m^3, Q = Emission rate of pollutants, μg/s, H = Effective stack height, m, u = Average wind speed at the effective height of the stack, m/s, σ_y = Horizontal dispersion coefficient, m, σ_z = Vertical dispersion coefficient, m

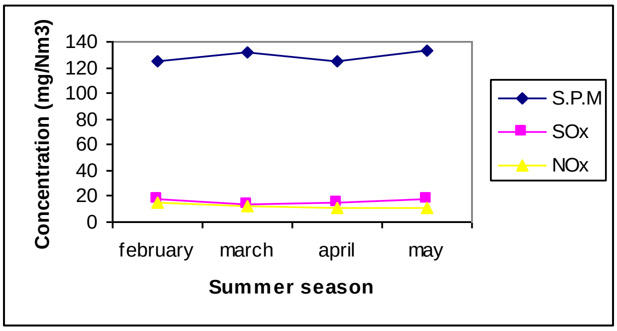
4. Results and Discussion

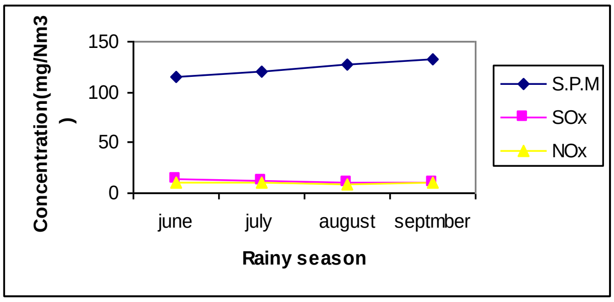
The distribution of Nitrogen dioxides (NOx), Sulphur dioxides (SOx), Total Suspended Particulates (TSP) concentration were sampled and analyzed for different seasons of NRE coke collected from NRE Coke Chimney using Vayubhodha Stack Sampler and the sampling is restricted to primary pollutants i.e. Suspended Particulate Matter, SOx, NOx. Using the Gaussian Model the concentration is estimated and the Variation in concentration with distance from the point source is calculated and presented (Figures 4.2). The Gaussian plots were for different wind speeds from 1 to 10 m/s. The pollutant concentrations were beyond the limits of CPCB upto 2-3 kms from the point source. Hence no more industrial location or the residential sites can come up in that area. The stack results analyzed of NRE coke (Figure 4.1) showed that the suspended particles are in larger concentration compared to the standards of CPCB. The concentration of SOx and NOx were very negligible with respect to the standards of CPCB. The concentration of pollutants were slightly high for summer season compared to rainy and winter seasons because of the effect of the meteorological parameters like wind speed and direction, rainfall and temperature.











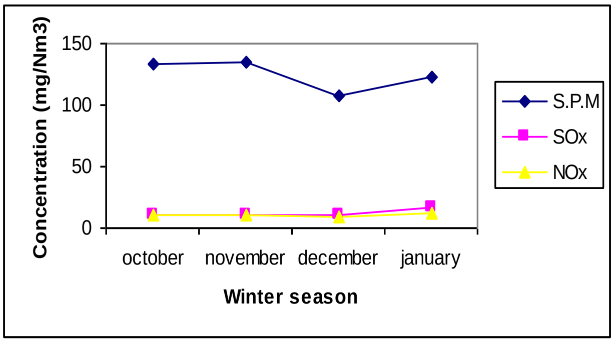
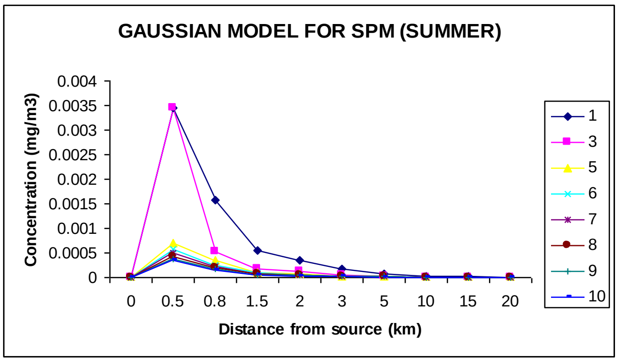
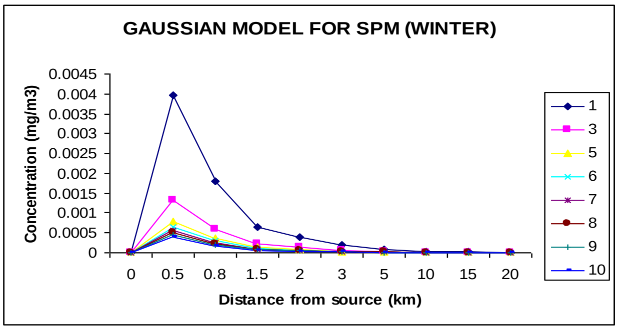
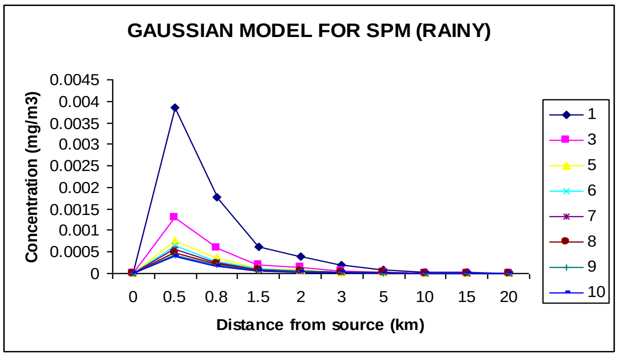
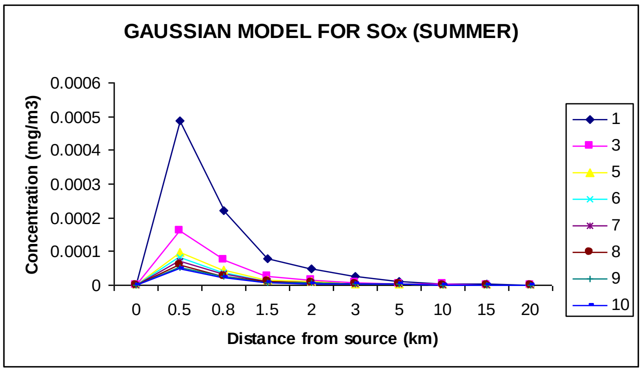


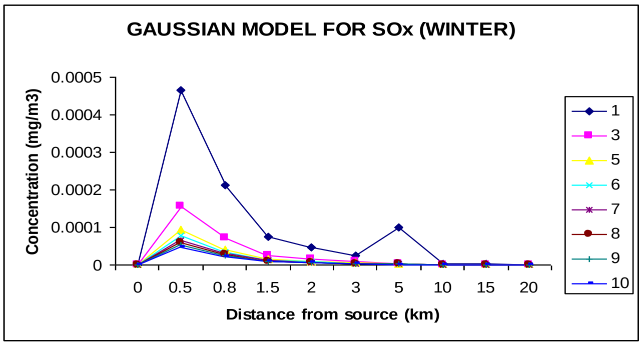
Figure 4.1: Stack analysis of NRE coke for different seasons

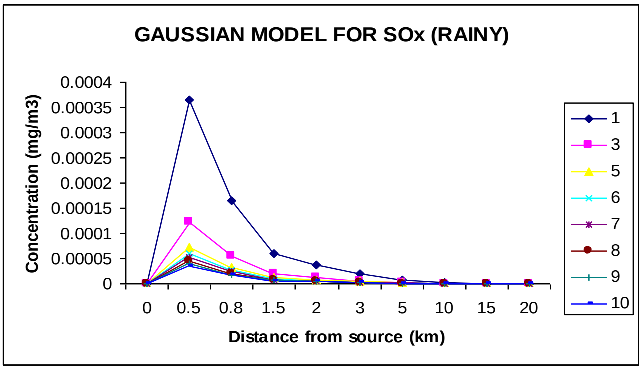


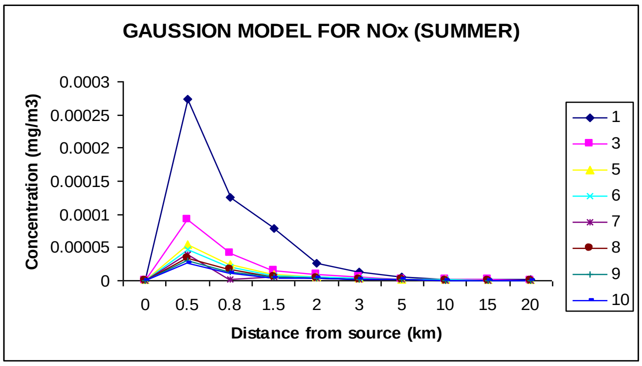


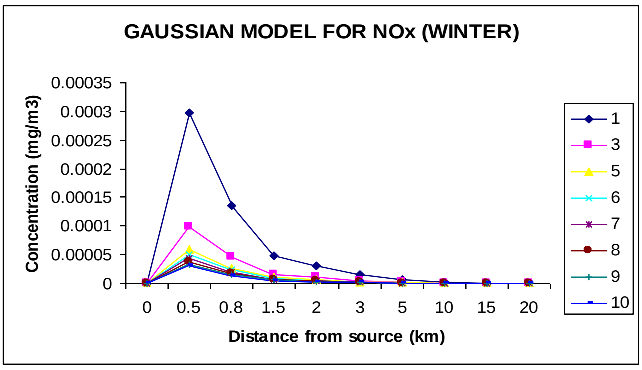












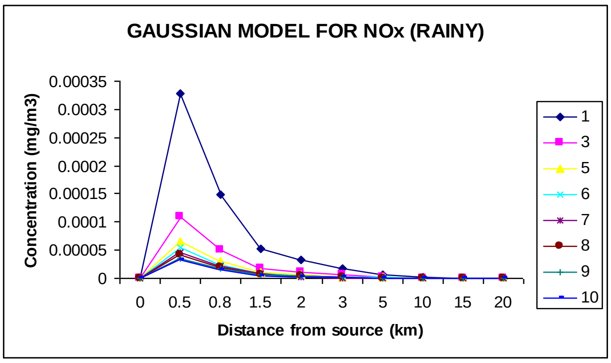


Figure 4.2: Gaussian Model for Different Season and Pollutants

Gaussian model is used to calculate concentration and deposition of plume components using c – program written for Gaussian equation where the profile of air pollutants concentration were plotted. Hence, the most affected area resulting by the plume dispersion can be identified easily. After the modeling process is completed, a process of data validation was done. For this study, data sampling was done at NRE Coke industry, Dharwad. The results from the sampling were transferred to Microsoft Excel and profile of air pollutants concentration were obtained and compared with Gaussian model predicted concentration. The model predicted compares well with the ground observed data hence the model is validated.

Conclusion

Results that are obtained from analysis of the ground based data and concentration pattern derived from Gaussian Dispersion Model have provided important information regarding the distribution of air pollutants. Integration of the dispersion pattern and the meteorological show that region to the North and Eastern part of the Chiminy (NRE Coke Industry) are the polluted regions compared to the others. This situation occurred because of the wind speed and direction in the area, as concentration of pollutants is inversely proportional to the wind velocity. High velocity of wind produced lower pollutants concentration in the atmosphere compared to the low wind velocity. From the air quality profiles that produced by Gaussian Plume Dispersion Model, they show that wind velocity is the most important factor that affect the concentration of the pollutants. It shows that the difference of pollutants concentration between maximum and minimum wind speed are about 76 to 85%. The results presented in this paper are preliminary outcomes of ongoing research. The model will be further developed and assessed with the eventual goal being to develop an Urban Air Quality Decision Support System.

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