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Sensitivity study of Gaussian dispersion models

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Over the last three decades, strict environmental regulations and the availability of personal computers have fueled an immense use of mathematical models to predict the dispersion of air pollution plumes. This paper discusses how the propagation of seemingly small errors in the Gaussian model parameters can cause very large variations in the model's predictions.

Keywords: Gaussian Plume Model, Over prediction ratio, Sensitivity study

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Introduction

Air dispersion modeling has been evolving since the 1930s. The present practice for ambient air quality predictions is through application of Gaussian Plume Model (GPM) and its available variations. The application of GPM requires knowledge of emission release rate, atmospheric turbulence, wind speed, dispersion coefficient, effective stack height, mixing height etc. The values of these parameters are often adopted from other countries without understanding their applicability in Indian context. It has also been observed that various forms of GPM are used without providing any reasonable justification in doing so.

Study Area

The Neyveli Lignite Corporation, a public-sector enterprise established in 1956, is situated at Neyveli in Tamil Nadu. An epitome of Indo-Soviet collaboration, Neyveli thermal power station-I (TPS-I) was commissioned with one unit of 50MW in May 1962. Presently, this power station has 6 units of 50 MW each and 3 units of 100 MW each. Thermal power station-II (TPS-II) has been a major source of power to all southern states of India. The 1470 MW capacity power station consists of 7 units of 210 MW each (Table 1).

Sensitivity Study

The Gaussian models assume an ideal steady state of constant meteorological conditions over long distances, idealized plume geometry, uniform flat terrain, complete conservation of mass, and exact Gaussian distribution. Such ideal conditions rarely occur. A sensitivity study was performed by assuming reasonable degrees of error in some of the key variables used in the Gaussian models and determining the proposed end-result of those errors on the calculated, ground-level pollutant concentrations. Several comparative models (Table 2; Figs 1&2) were defined as follows:

i) Base Model A

In the base model A, Gaussian plume equation was used to predict ground level pollutant concentration. The concentration (*C*) of the gas at *X, Y, Z* from a continuous source with an effective stack height given by GPM is,

$$C\,(x,y,z) = \frac{Q}{2\prod \sigma y \sigma z \bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{Z-he}{\sigma z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{Z+he}{\sigma z}\right)^2\right]\right\}$$

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Table 1 — Details of stacks in TPS-I and TPS-II

Details of stacks	TPS-I			TPS-II	
	Stacks 1, 2	Stack 3	Stack 4	Stacks 1, 2, 3	Stacks 4-7
Power production, MW	3×50×2 No.	2×50×1 No.	4×50×1 No.	1×210×3 No.	1×210×4 No.
Number of stacks	2	1	1	3	4
Height of stacks, m	60 each	60	120	170 each	220 each
Stack Diameter at exit, m	5.10 each	5.10	5.10	4.85 each	5.47 each
Exit gas temperature, ºC	158	158	158	150	150
Velocity of flow, m/s	20.2	13.5	27.2	15.33	12.06

Table 2 — Calculated ground-level concentrations ((μg/m^2)) at downwind distances ranging from 1-10 km (using power law exponent p=1/7)

Receptor downwind distance, m	A Base Model	B Adjusted Model -1	C Adjusted Model -2	D Adjusted Model 2 plus wind shift	Over Prediction ratio A/D
1000	1.65	5.14	0.018	0.004	412
2000	26.82	35.46	4.29	2.77	9.6
3000	43.67	47.59	14.32	11.46	3.75
4000	51.66	52.16	22.76	19.94	2.59
5000	55.47	53.52	28.41	26.05	2.12
6000	56.87	53.14	32.19	30.23	1.88
7000	56.82	51.81	34.84	33.2	1.71
8000	55.91	50.02	36.79	35.38	1.58
9000	54.42	48.03	38.23	37.04	1.46
10000	52.87	45.49	39.27	38.3	1.38

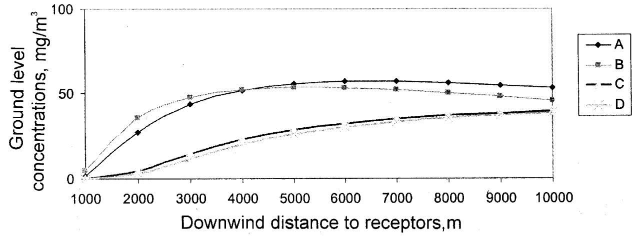

Fig. 1 — Calculated ground-level concentrations (μg/m^2) at downwind distances ranging from 1-10 km (using power law exponent p = 1/7). A, B, C and D are four model types

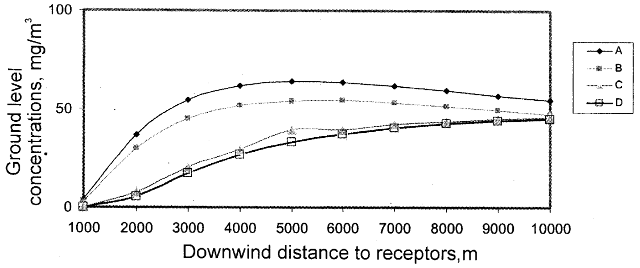

Fig. 2 — Calculated ground-level concentrations (μg/m^2) at downwind distances ranging from 1-10 km (using power law exponent p = 0.1981*).* A, B, C and D are four model types

By setting Z = 0 in above equation for ground level concentration is obtained as follows:

$$C\,(\mathrm{x,y,z}) = \frac{Q}{\prod \sigma y \sigma z \bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{he}{\sigma z}\right)^2\right]$$

where, Q is the pollutant emission rate (μg/sec), C is the pollutant concentration (μg/sec), σy, σz are dispersion coefficients (m), ū is mean wind speed at stack height (m/sec), y, z are distance from the plume axis in the cross wind directions (m), and he is the effective stack height (m).

A number of important parameters required for using the above equation are:

Stability Classification

There are number of stability class definitions, the best known of which is from Pasquill. Six categories (A-F), based on the use of synoptic meteorological data, are distinguished. In this work, Pasquill stability is adopted.

Table 3 — Calculated ground-level concentrations ((µg/m^2)) at downwind distances ranging from 1-10 km (using power law exponent p=0.1981)

Receptor downwind distance, m	A Base Model	B Adjusted Model -1	C Adjusted Model -2	D Adjusted Model 2 Plus Wind shift	Over Prediction ratio A/D
1000	3.97	3.21	0.085	0.024	165
2000	36.81	29.79	7.63	5.31	6.93
3000	54.31	44.7	20.44	17.09	3.17
4000	61.54	51.49	29.6	26.63	2.31
5000	63.73	53.96	39.45	33.01	1.93
6000	63.32	54.21	39.34	37.33	1.69
7000	61.6	52.91	41.98	40.36	1.52
8000	59.28	51.15	43.36	42.49	1.39
9000	56.74	49.12	44.89	43.97	1.29
10000	54.16	47.02	45.53	44.94	1.20

Wind Speed at Stack Height

Wind velocity at the desired level is calculated using the power law expression[1,2] as:

$$\left(\frac{u}{u_1}\right)=\left(\frac{Z}{Z_1}\right)^p$$

where Z_1, is usually taken as the height of measurement, approx 10m, and Z is the height at which a wind speed estimate is desired. The average value of power law exponent p has been determined by many measurements around the world to be about one seventh. This has led to common reference to above equation as 1/7 power law equations[3].

Dispersion Coefficients and Plume Rise

The Brigg's interpolation formulae are used to find out the dispersion coefficients as suggested in the guidelines published by Central Pollution Control Board. Similarly, Brigg's plume rise equation was used to predict buoyant plume rise as:

$$\Delta h=\left(\frac{2.47Q_h^{1/3}H_S^{2/3}}{\bar{u}}\right)$$

where, Q_h is the stack gas heat flux (kcal/sec), H_s is the stack height (m), and $\bar{U}$ is the wind speed at stack height (m /sec).

ii) Adjusted Model B

The wind velocity is an important parameter in determining the vertical and cross wind Gaussian dispersion of stack gas components from continuous, point-source plumes. The wind velocity used in the Gaussian dispersion equation (GDE) should be the velocity, which prevails throughout the vertical, and crosswind spread of the plume. This creates a dilemma in that: a) Deviation of the generalized GDE assumes a constant wind velocity throughout the plume; and b) Wind velocity is not constant throughout the plume since it typically varies with altitude[4]. Thus as a minimum requirement, wind velocity used in the GDE should be determined at the emission height or so called effective stack height[5]. So, using power law conversion, the wind velocity at effective height was obtained and the same was used in the Gaussian equation for predicting the ground level concentration[6].

iii) Adjusted Model C

Most Gaussian models use modifications of dispersion coefficient derived experimentally by Paquill. These coefficients are derived based on the assumption that the wind speed and atmospheric stability class were known exactly. But in actual case, atmospheric stability class and wind speed are not known exactly at plume height and they are not constant for the entire distance from the source stack to downwind receptor[7]. Hence in this model, the ground level concentration arrived same as in model B except that the plume rise increased (20%) and Pasquill vertical dispersion coefficients decreased (25%).

iv) Adjusted Model D

Deriving the Gaussian dispersion models assume the wind speed and direction are constant from source point to receptors. Such ideal conditions rarely occur (for a wind speed of 2 m/sec and a distance of 10 km, 80 min of constant conditions would be needed). Slight error in the estimation of wind direction can result in tremendous errors of concentration where the problem is to estimate the concentration at specified locations. In this model, the ground level concentrations were calculated same as in model C except that an assumed winds direction shifts 25 degrees.

Results and Discussion

The inputs for the dispersion model consist of emission information, meteorological data and receptor information. 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 hourly concentrations at each receptors applying Microsoft excel. Minor changes in some of the key variables (Table 2) can result in the propagated over-prediction factor (1.38-412). Also, the above steps are performed taking power law exponent p=0.1981 based on 12 years of wind data pertaining to the study area (Table 3). The over-prediction factor of the Base Model A varies from 1 to 165.

It is unrealistic to expect the Gaussian models to predict real-world dispersing plume concentrations consistently by a factor of 2 or 3. It is probably more realistic to expect consistent predictions of real-world dispersing plume concentrations within a factor that may be as high as 10. The model errors, smaller in the far field (>2 km), are due to uncertainty of the atmospheric stability class, wind speed, and they are not constant for the entire distance from the source stack to the down wind receptors.

Conclusions

Gaussian model over prediction ratio arrived in this paper can be improved by observing hourly wind data, which could be used to estimate wind power law coefficients. Similarly, all meteorological parameters are collected only at Central Applied Research and Development (CARD), which is located in the premises of Neyveli township at a down wind distance of 4.5 km and wind direction sectors of southwest with reference to TPS-II. It is suggested to install some more meteorological stations at Neyveli to improve data set, so that both metrological and air pollutants are forecast more accurately.

References

1 Chinnasamy T V & Haridasan T M**,** Wind energy potential at Palkalainagar, *Renew Ener*, **1** (1991) 815-821.

2 EI- Shobokshy M S & EI- Zayat R E, Site assessment and feasibility analysis for small wind energy conversion systems, *Int J Amb Ener*, **12** (1991) 79-94.

3 Peterson E W, On the use of power laws for estimates of wind power potential, *J App Meteorol*, **17** (1978) 390-394.

4 Prakasa Rao G S, Jawal A K & Kumar M S, Effect of urbanization on meteorological parameters, *Mausam,* **55** (2004) 429-440.

5 Bruce Turner D, *Work Book of Atmospheric Dispersion Estimates* (US EPA Publication AP-26) 1970.

6 Justus C G, Hargraves W H R & Ali Y**,** Nationwide assessment of potential output from wind-powered generators, *J Appl Meteol,* **15** (1976) 673-678.

7 Milton R Beychok, Fundamentals of Stack Gas Dispersion (New port Beach, CA 92660) 1995.