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Modeling of SO_2 Emission from Point Sources in Manali Region of Madras, India

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Abstract: Mathematical models are the best tools available for prediction purpose in the field of air quality management. In the present study a Gaussian Plume Model is developed to determine the concentration of pollutants from point source emissions. The model is applied to the Industrial zone of Manali region, Chennai. Based on the emission inventory, Meteorological parameters, the concentration of SO_2 is determined for three different seasons. Three months of wind speed, wind direction and cloud cover data recorded by India Meteorological Department (IMD) were used for concentration computations. The computed concentrations were compared with the observed concentration in the study area. The statistical evaluation of the model indicates satisfactory performance. Comparison of numerical result with observed data showed a marked seasonal trend along the study period, which is characterized by high levels of SO_2 in winter and decreased progressively through the, monsoon and summer seasons.

Key words: Gaussian plume model, concentration, season

INTRODUCTION

Prediction of likely impact on the air environment due to discharge from point source (s) is a pre requisite for environment impact assessment studies and evaluation of project for granting permission or rejection. Modeling of stack gas dispersion is also essential for selecting the ambient air sampling locations, implementing strategies for air pollution control, stipulating the discharge limits, fixing stack heights and environmental planning of zone/region. Dispersion model types are divided broadly into steady-state Gaussian-plume models and advanced models. Plume models have been in common use for decades, while advanced models are beginning to be used more widely for regulatory applications.

From a practical standpoint, the greatest difference between model types is in the requirements of meteorological information and computer resources. However, some steady-state models are highly sophisticated and not necessarily Gaussian, so the distinction can be blurred. Turner (1964) presented a working model for the diffusion of gases from multiple sources in an urban area.

Rama Krishna *et al.* (2004) and Manju *et al.* (2002) studied the assimilative capacity of industrial zones in Vishakapatinam bowl area and Manali area. Goyal and Sidhartha (2004) studied the seasonal evaluation of SPM from Badarpur thermal station using a Gaussian plume model. Tripathy and Panigrahi (2002) estimated the sulphur dioxide concentration in and around an industrial complex using a Gaussian diffusion model. The effects of change in meteorological parameters on SO_2 concentration was studied (Gupta *et al.*, 2002) by varying the wind speed and stability class using the ISCST-3 model.

Sivacoumar *et al.* (2001) estimated the impact of NO_x emissions resulting from various air pollution sources like industries, vehicles and domestic sources using the Industrial Source Complex short-term model. Marziano *et al.* (1979) studied the SO_2 distribution in Venice by means of an air quality simulation model. Jefrey and Jespen (1977) evaluated the Gaussian plume model at the Dickerson power plant by comparison with measurements of dispersion and ground-level concentration of sulphur dioxide.

In major metropolitan cities of India, air pollution has become a serious problem as a result of industrialization and urbanization (Sivacoumar *et al.*, 2001). Dispersion of pollutants in the atmosphere and their concentrations at different distances from the emission source depend on emission source parameters, meteorological parameters and geographical conditions of the region of interest.

The Gaussian Plume Model (GPM) is widely used and recognized all over the world as a tool for mathematical modeling and impact prediction. The application of GPM requires knowledge of several parameters like wind speed and direction, temperature, humidity, terrain features and atmospheric chemistry. Lack of in depth understanding of these parameters and their application in GPM, without reasonable justification, leads

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to confusion, doubt and often-malicious debate. Users of computerized dispersion, unaware of many assumptions and constraints involved in GPM, most of the times mistakenly believe that the precision achieved with computer simulation equate to accuracy. The propagation of seemingly small errors in GPM parameters can cause large variations in dispersion predictions. The short-term and long-term versions of Industrial Source Complex Models (ISCST3 and ISCLT3) are evaluated for estimating long-term concentrations using sulfur dioxide data from emission inventory of Lucas County (Kumar *et al*., 1999).

A pollution caused by effluents from a single or small group of stacks is a local problem. The combine effect of a large number of stack effluents spread over a large area produces increased concentration of pollutants at a greater distance from the source of emissions. In order to ensure that the industrial activity is not causing any serious environmental degradation the assessment of the impact of emission on the environment both in urban and rural areas, either during daytime or nighttime is imperative (Tripathy and Panigrahi, 2002). Assessment of ambient air quality over Delhi due to SO_2 emissions from domestic, transportation, industrial and large point sources was done by Manju and Dube (2001). Mohan *et al*. (1998) studied in detail the impact assessment and mitigation strategy for air quality change due to a proposed thermal power plant in the Mangrol area of Chittorgarh district of Rajasthan.

In this study major air polluting industries within the study area are identified. The emission inventory consisting of source strength, height of stack, temperature of flue gas, velocity was obtained from Tamil Nadu Pollution Control Board (TNPCB) Manali. The dispersion of pollutants into the atmosphere depends on the initial release, atmospheric conditions and terrain characteristics. The meteorological data consisting of wind speed, direction, atmospheric stability, mixing height were obtained from Indian Meteorological Department, Pune. The data collected are processed and given as input to the model. The evaluation of model performance is a matter of great interest and it becomes particularly important when modeling is applied for a prediction exercise (Sivacoumar and Thanesekaran, 1998). Lars and Christensen (1977) validated a multiple source Gaussian air quality model in the Copenhagen area. A computer program was developed to evaluate the statistical performance of air quality models (Sivacoumar and Thanesekaran, 1998). In this study model performance was evaluated by measuring predicted and observed concentration for three different seasons using statistical technique.

MATERIALS AND METHODS

Backgrond: Chennai is one of the four major metropolitan cities in India. In the past two decades, there has been a significant increase in the industrial development in and around the Chennai metropolitan area. The trend continues with the influx of more and more multinational companies. Simultaneously, the environment problems, often severe, posed by this rapid industrial development are also increasing, affecting the soil, water and quality of air. In Chennai most of the industries are situated in complexes. They are the result of planned governmental zoning as well as being proximity to transportation, labour pools, resources, energy, water etc. There are about six major industrial complexes situated in the Chennai metropolitan area namely Manali, Guindy, Maraimalainagar, Ambattur, Perungudi and Thirumilisai. Of these, major air pollution industries are concentrated in Manali area.

To assess the prevailing air quality in Manali and its surroundings, National Ambient Air Quality Monitoring programme (NAAQM) is conducted by Central pollution Control Board (2000) and its annual/seasonal average concentrations of SO_2 are presented in Environmental Impact Assessment Reports.

Description of study area: The study region, Manali (latitude 13° 10'4'' N, longitude 80° 15'43'' E) is an industrial belt covering an area of about 5×5 km^2 with a flat terrain located close to Chennai metropolis, India (Manju *et al*., 2002). It houses some of the major refineries, petrochemical, fertilizer and chemical industries whose stack emissions contribute significantly to air pollution (Table 1).

The most prominent wind direction pattern was observed as SE-E-SW during summer season followed by SE-E pattern during monsoon and NE-SE during winter season. Moderate to high wind speed was observed during the month of April- May, with prevalence of low to calm wind during the month of December-February. Moderate to heavy rain occurred during the months of October-November. The value of maximum temperature ranges from 33 to 39°C and the value of minimum temperature ranges from 19 to 24°C. In the case of relative humidity, the mean value ranges from 70 to 80%.

Model description: The Gaussian plume model is a straightforward and widely used approach for predicting the ground-level concentrations of emissions from tall stacks (Mohan *et al*., 1998). Goyal and Siddhartha (2004) developed a Gaussian plume Model for seasonal evaluation of SPM in Badarpur thermal power station. An

Table 1: Industry wise emission in the study area

Name of Industry	Stack in number	Stack location of (attached to)	SO_2 (mg m^{-3})
Madras fertilizers Ltd	5	Boiler 1	150
		Boiler 2	181
		NPK	BDL
		PRILL tower	0
		Generator	21
SRF limited	3	Cap.pow.plnt 1	64
		Cap.pow.plnt 2	61
		Boiler (IAEC)	51
Kothari Sugar Industries	2	Boiler	95
		Deisel gener.	21
MPL (Plant 1)	2	Boiler	116
		Deisel gener.	32
MPL (Plant 2)	2	Boiler (Nestler)	71
		Deisel gener.	32
CETEX	2	Thermox boiler	24
		Wood fireboiler	21
Balmar Laurie and Co.	2	Thermox boiler	13.2
		Boiler	11
Petrol Araldydes Ltd.	2	Deisel gener.	73.92
		Absorbtion col	BDL
Indian Additives Ltd.	3	Boiler	16
		Hot oil unit	48
		Deisel gener.	42.66
Futura and Co.	3	KT1	26.7
		Boiler (32 tons)	42.66
		Thermoxheater	64
TPL (HCD) plant	3	Cap.pow.plnt 2	32
		Cap.pow.plnt 3	27
		Waste air dechlorination	0
TPL (ECH) plant	3	Proplene fur.	42
		Cap.pow.plant	108
		Boiler	84
TPL (LAB) plant	3	Hot oil packol	95
		combineheater	58
		Thermox boiler	68
		Deisel gener.	
CPCL	11	IFIA	85
		Vacuum col.2	48
		A V V	112
		Vacuum col.	144
		Boiler 4	171
		S R U	101
		Cap.pow.plant	139
		Co-Boiler	96
		Hydro-cracker	75
		Atm.colar(ref3)	43
		S R U (ref 3)	69

BDL-Below Dynamic Level-is assumed to be zero emission

Industrial Source Complex model was used to predict the impacts on air quality due to two-naphtha/natural gas fired combine cycle power plant (Bhanarkar *et al*., 2002). In this study Gaussian dispersion concept has been used for calculation of pollution concentration from a continuous point source at steady state where the concentration distribution perpendicular to the plume axis is assumed to be Gaussian. The basic assumptions and limitations of the Gaussian plume model have been described elsewhere (CPCB, 1998). The Gaussian dispersion model has enjoyed a wide degree of popularity while predicting ground level concentration due to emission releases from stationary point sources mainly due to its simplicity.

Concentration of pollutant at a point (x, y, z) in (μgm m^{-3}) is given by

$$C = \frac{Q}{2\pi U \sigma_y \sigma_z} \exp-\left(y^2/2\sigma_y^2\right) \left[\exp-\left\{(z-H)^2/2\sigma_z^2\right\}+\left\{(z+H)^2/2\sigma_z^2\right\}\right]$$

Where Q is the pollutant release rate (μg s^{-1}), U is the horizontal wind speed at the source level (m s^{-1}), σ_y and σ_z are the vertical and horizontal crosswind dispersion coefficients respectively, which are a function of down wind distance x and atmospheric stability (m), y is the horizontal crosswind distance from plume centerline to the receptor, z is the vertical distance from the plume centerline to the receptor (m), x is the down wind distance from the plume centerline to the receptor (m), H is the effective stack height (m) which is given as $H = h_s + \Delta h$, where Δh = plume rise (m) and h_s = Physical stack height (m). The coordinate system is such that the origin (0, 0, 0) is at the source. X-axis is in the mean downwind direction, y-axis is in the horizontal crosswind direction and z-axis is in the vertical direction. The quantities σ_y and σ_z are the standard deviations of the distribution of concentration at x in the horizontal crosswind and vertical directions respectively. Briggs (1975) plume rise formulae for hot plumes are used for evaluating the pollutant concentrations from elevated point sources.

Briggs (1973) formulas based on downwind distance x and stability's have been used to estimate the dispersion parameters σ_y and σ_z. The basic inputs to the model are shown in Fig. 1. Considering the complexity of the study area and the number of emission sources, it was planned to calculate the pollutant concentration for three different seasons of the year 2000.

Data

Emission inventory data: The detailed emission inventory containing the point source details on number of stack, location of stack, stack diameter, stack height, exit gas velocity, temperature, flow rate are obtained from Tamil Nadu Pollution Control Board, Manali. There are about 14 industries containing a total of 46 stacks.

Monitoring station data: The ambient air quality-monitoring network involves measurement of a number of air pollutants at number of locations in the country so as to meet the objectives of monitoring (CPCB, 2003). The pollutants chosen in the air quality-monitoring programme are the primary pollutants, which are indicators of general pollution profile of the typical urban zones.

The ambient air quality of different pollutant is monitored at several monitoring station in the north chennai region. The monitoring data for SO_2 consists of four hourly average concentrations observed at Manali station. From the observed data 24 h average values are calculated for each day.

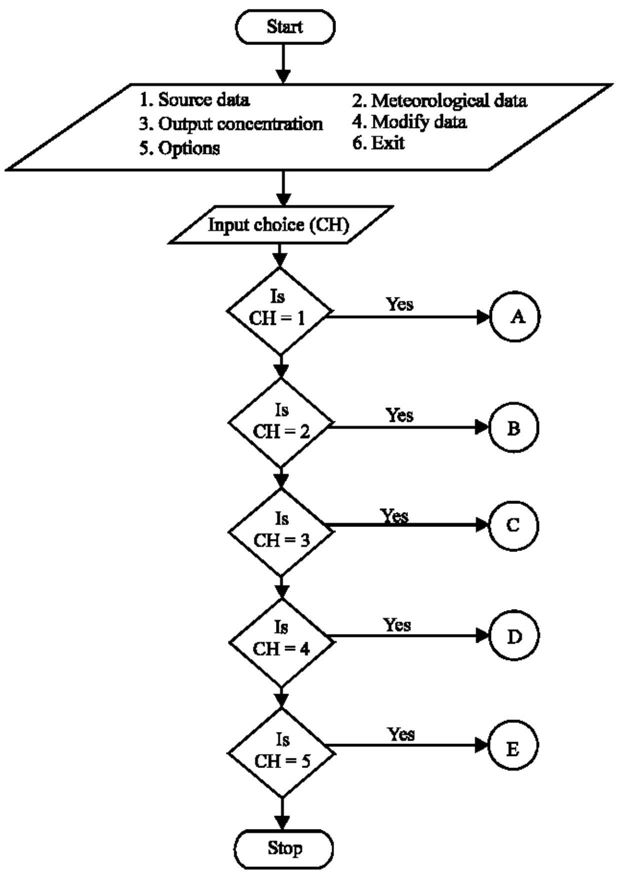

Fig. 1: Model structure

Meteorological data: Meteorological data consisting of wind speed, wind direction, cloud cover, cloud height, surface temperature and mixing heights for the study period were obtained from Indian Meteorological Department (IMD) Chennai and Pune.

The mixing height is defined as the height above the surface through which relatively rigorous vertical mixing occurs. The mixing height is determined using the Holzworth (1967) technique. Lowest value of mixing height has been observed in the winter season and highest mixing height has been observed in monsoon season followed by summer season. Stability classes are predicted using Pasquill Turner (1969) method.

RESULTS AND DISCUSSION

For short-term ground level concentration prediction, Gaussian Plume Model is employed for three different seasons. In the present study, three season's winter, summer and monsoon as represented by February, May and October are considered. Data collection for 46 stacks (emission inventory) and the detailed meteorological data are been used to predict the SO_2 concentration. Further the predicted concentrations are compared with the observed values for nine days in each season for carrying out the statistical analysis (Fig. 2a-c). The statistical parameters correlation coefficient, normalized mean square

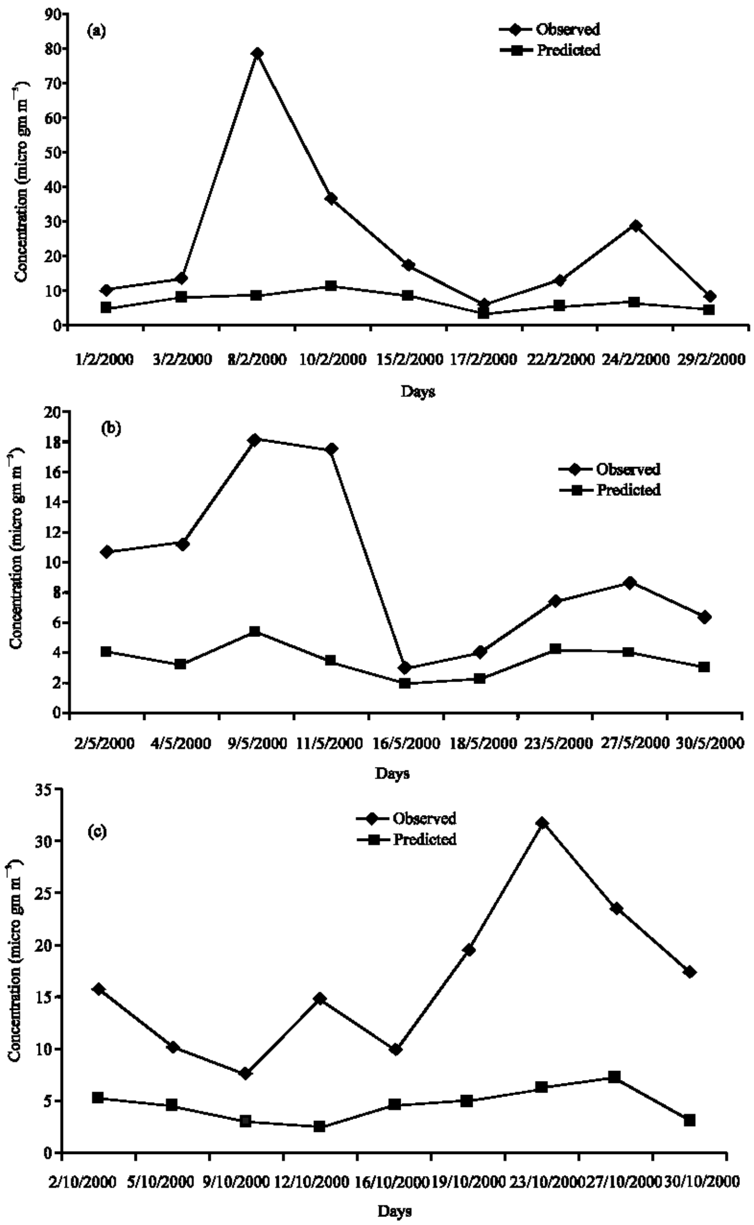

Fig. 2: Predicted and observed concentration during (a) winter (b) summer and (c) monsoon

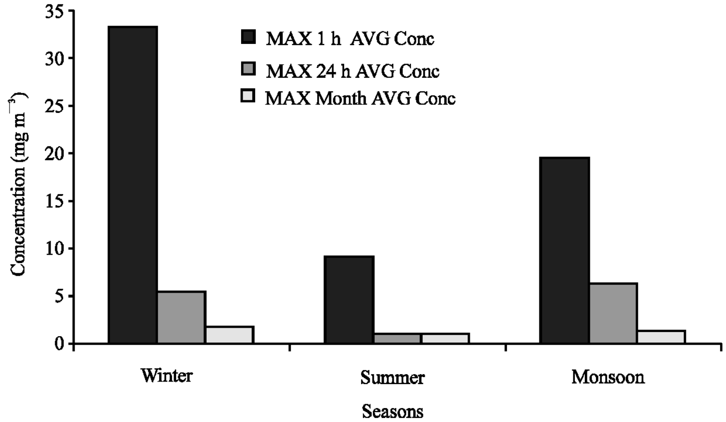

Fig. 3: Predicted concentration of SO_2 during various seasons

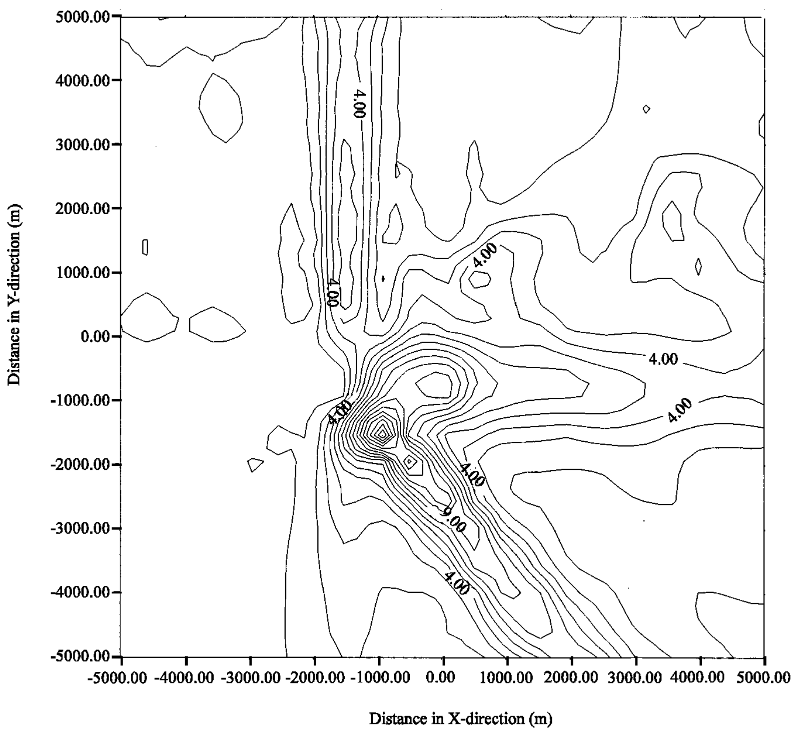

Fig. 4: Isopleths of predicted SO_2 concentration (μg m^{-3}) during winter

Table 2: Performance measures of SO_2 during the three seasons

Seasons	Winter	Summer	Monsoon
COR-COE	0.585975	0.714573	0.646852
NMSE	1.783425	1.115695	1.914805
FB	1.11	0.934	1.13
FS	0.7	1.54	1.0
FA2	0.274	0.363	0.274

error, fractional bias, fractional standard deviation and fraction within a factor of 2 are shown in Table 2.

Three types of model results have been obtained: (i) Maximum hourly average concentration of SO_2, during all seasons (ii) Maximum 24 hourly average concentration of SO_2 during all seasons and (iii) Maximum monthly average concentration of SO_2, during all seasons.

The maximum hourly average concentration, maximum 24 hourly concentration and maximum monthly average concentration of SO_2 shows that the maximum hourly average concentration of SO_2 are higher in winter followed by monsoon and summer, but the average maximum 24 h concentration is minimum in summer and same in winter and monsoon. There is no much variation in the value of average monthly concentration during all the three seasons (Fig. 3).

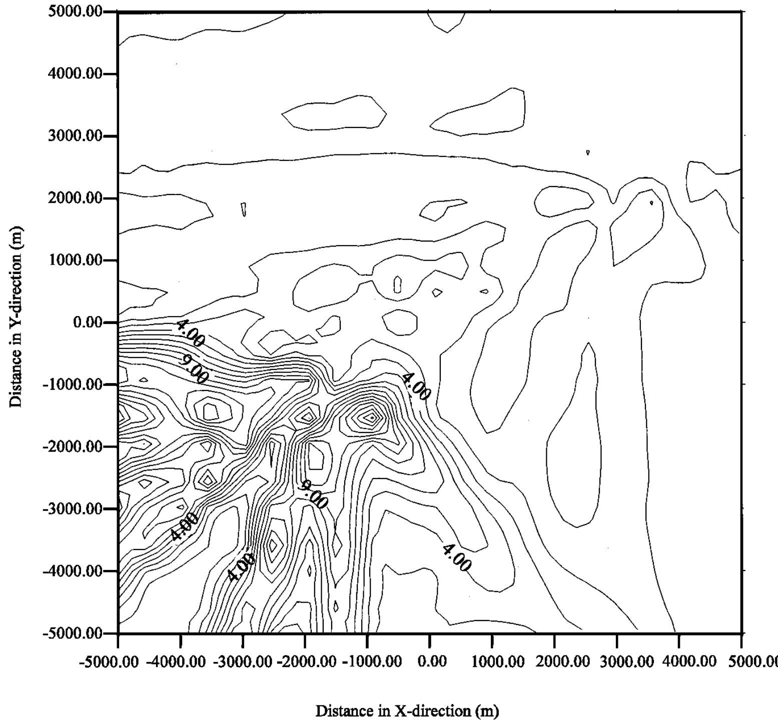

Fig. 5: Isopleths of predicted SO_2 concentration ($\mu g\ m^{-3}$) during summer

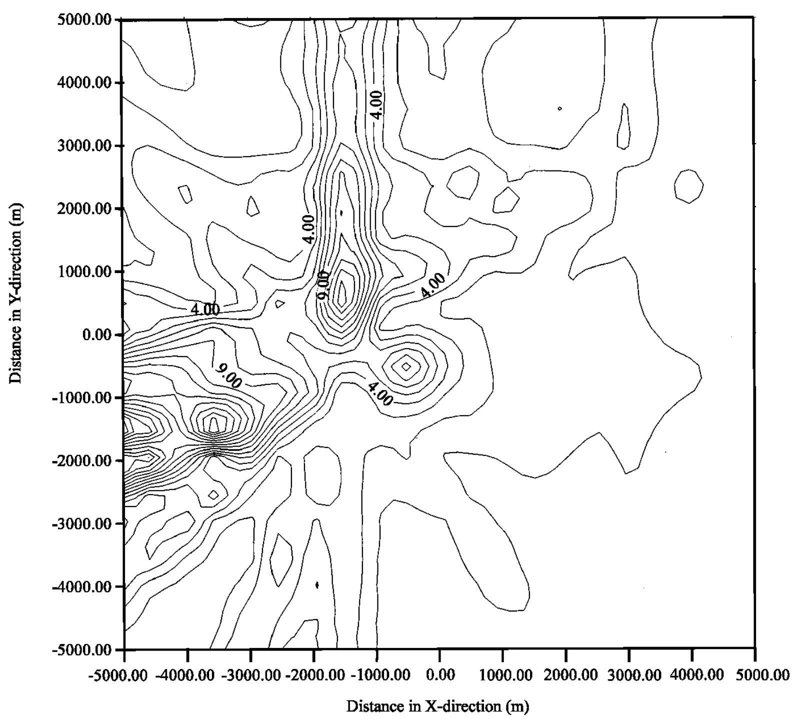

Fig. 6: Isopleths of predicted SO_2 concentration ($\mu g\ m^{-3}$) during monsoon

The predicted and observed concentrations are shown in Fig. 2a-c. It is found from the Fig. 2 (a) that the model prediction of SO_2 during winter was found to vary from minimum 2 μ m^{-3} to maximum of 12 μ m^{-3}. The observed value during the period varied from 10 to 80 μ m^{-3}. Figure 2b shows that during the summer season the predicted value varied between 2 to 6 μ m^{-3} and the observed value varied between 4 to 18 μ m^{-3}. Figure 2c shows that the there was no much variation of predicted SO_2 concentration during monsoon season compared with the observed concentration.

From Table 2, it is clear that the correlation is highly satisfactory for winter. However, for summer and monsoon correlation is poor. In our model we are considering only the emissions due to point sources. The emissions from other sources are not considered in the model, which may be the reason for such deviations. Normalised mean square error is high in monsoon compared to other two seasons. Wash out of pollutants during this period may be the reason for discrepancies. Fractional bias and fractional standard deviation are close to one during all seasons. Besides, 27 to 36% of the values are within a factor of two. Even with a perfect model that predicts the correct ensemble average, there are likely to be deviations from the observed concentrations in individual repetitions of the event, due to variations in the unknown conditions. The statistics of these concentrations residuals are termed inherent uncertainty which is alone may be responsible for a typical range variation in concentrations of as much as $\pm$50% (Hanna, 1982).

Isopleths of 24 hourly average SO_2 concentrations are shown for each season in Fig. 4-6. From the isopleths it is clearly evident that the concentration are more in the downwind direction during winter and more in the up wind direction during summer and monsoon seasons. The wind pattern during the study period is having a significant effect on the pollutant dispersal during the various seasons.

CONCLUSION

The present study focuses on the seasonal evaluation of SO_2 in Manali region using a Gaussian Plume Model. A detailed source inventory (emission) and meteorological inventory were prepared for model analysis. Model performance was carried out by statistical technique shows better performance of the model during winter season. The study shall be useful in estimating the impact of point source emissions from other industrial areas of Chennai.

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