Print ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

# A Modelling Approach for Quantification of $SO_2$ Emission from a Typical Coastal Region with Fumigation Effects

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**ABSTRACT**

Atmospheric dispersion simulations were performed using the Gaussian Plume analytical dispersion model (GPM) for quantification of air concentration of gaseous releases from a typical Coastal region having thermal power plants, refineries, chemical industries in a coastal atmospheric environment. A computer program is generated based on the model equations, giving the various atmospheric conditions and stability classifications. The concentration of an air pollutant such as a gaseous release at a given place is a function of a number of variables, including the amount of the pollutant released at the source (the emission rate), the distance of the receptor from the source, and the atmospheric conditions. The most important atmospheric conditions are wind speed, wind direction, and the vertical temperature characteristics of the local atmosphere. In coastal regions, the temperature structure and wind flow are also influenced by the local sea-land breeze circulations and the ensuing coastal fumigation phenomena. The model estimates of air concentrations would also depend on the empirical dispersion relationships. The study area selected is Manali in North Chennai which is a growing industrial and urban area. In the present study the GPM model is adopted to estimate ambient ground level air concentrations of few pollutants $SO_2$ (Sulphur dioxide) from industrial sources in the North Chennai Manali area to understand the local air quality pattern. The GPM equation is modified for coastal fumigation effects to study its impact and to obtain realistic GLC estimates. The simulation results were verified by comparison with available observations. Further, it has been found that the simulated concentrations during sea breeze time are slightly more than those in non-sea breeze time due to fumigation effect. The model slightly overestimated concentrations during the sea breeze time than the observations.

**KEY WORDS**: Air quality monitoring, Atmospheric Dispersion modelling, Model Performance evaluation, Meteorological data, Observed concentration, Predicted concentration.

## 1. INTRODUCTION

**Air and its importance**: A clean environment is the basic need for existence of life. In the advent of industrial and technological revolution, their progress has been accompanied by a growing negative impact on the environment especially air, in terms of pollution. Pollution is not a new phenomenon. The first episode of air pollution probably occurred when early humans, tried to make a fire in a poorly ventilated cave. Reference to polluted air also appears as early as genesis chapter (19:28) in the bible. In the present scenario energy has become the basic necessity of every country. Rapid industrialization in the quest to enhance the quality of life caused immense harm to quality of air. Electric power plants, furnaces give off pollutants as they try to satisfy mankind's need for energy. Pollutants enter the atmospheric air in a number of different ways. For example, wind blows dust into air. Decayed Plants release methane into atmosphere. Automobiles, trucks, buses, airplane's and satellite launching rockets emit pollutants from their engine exhausts.

One method of pollution release that has received more attention than any other pollution is the continuous releases from stationary point sources i.e., stacks. Their function is to release pollutants high enough above the earth's surface so that emitted pollutants can sufficiently disperse in the upper atmosphere before reaching the ground level. The pollutants are transported at a faster rate by the stronger winds in the upper atmosphere. As plume travels, it spreads and disperses.

**Atmospheric Dispersion modelling as a tool to combat pollution:** Dispersion modeling is being used now days as a tool to control pollution from the industrial emissions and thereby reduce the health effects caused by it. It has become an indispensable tool for prediction of air quality. It can be applied to a specific industrial situation and also used in evaluating the ventilation coefficients under the prevailing environmental conditions.

**Need and objectives for the study:** Several dispersion modeling studies have been carried out in India especially Chennai and surrounding industrial zones. Spatial Pollution Rose dispersion pattern of $SO_2$ in the vicinity of Thermal power station at Ennore – Manali area has been reported by Pravin Kumar and Palanivelraja, 2014. They had taken the emissions from Thermal power stations NCTPS, ETPS and used ISCST3 modeling technique in their study. Concentrations of $SO_2$ for the month of February' 2011 were plotted and found to be less than the limit set by CPCB. Gudi Sudhakar (2014), reported about the studies on Atmospheric Pollution over Chennai – A Mega South East Coastal City in India. They evaluated the CPCB air quality monitoring data during 2000 to 2004 and observed the increasing tendency across city. Modeling of $SO_2$ emission from point sources in Manali region of Madras, India is reported by Ganapathy Subramanian, 2006. GPM was developed for point source emissions and seasonal observations were studied. High levels of $SO_2$ in winter and decreasing progressively through monsoon and summer seasons were observed. SPM and $PM_{10}$ impact on the people is an issue to be considered. Manju (2002), reported assimilative capacity in terms of ventilation coefficient and pollutant dispersion studies for the industrial zone of Manali. They have used the emission from the 95 elevated point sources in study area. Vehicular pollution was also added by collecting the details of number of vehicles plying across the study area. Pollutants such as $SO_2$, $NO_x$ and SPM were studied for seasonal fluctuations. ISCST3 model was used for the study. Results shown that, assimilative capacity is highest in summer and least in winter. Coastal fluctuations were observed in their study but not quantified. High pollutant levels were observed in North-east side of Manali and recommended not to install new industries in this area.

On scrutinizing above studies, there exists a gap between the model prediction and actual observation in the industrial zone area Manali. Most of the above studies have not incorporated studied coastal fumigation effect separately across the Manali which is a coastal area and experiences diurnal sea-land breeze type local scale circulations. When sea breeze makes onset at the coast the general inland boundary layer is altered by the cool and humid onshore winds thus forming an internal boundary layer (IBL) with an unstable atmosphere below and stable atmosphere above the IBL. Also the height of the IBL increases in a parabolic shape across the coast. Pollutants released near the coast are trapped in IBL leading to fumigation or higher concentrations than in inland areas. Incorporation of fumigation effect in a dispersion model may reduce the percentage difference between the model predicted value and actual observation. In the present work the fumigation effect is taken up as a gap area of research and an effort has been made to perform a seasonal variation studies with respect to $SO_2$ at the coastal site. Manali industrial site has been taken as the study area, as it is located at 4.5km distance from the sea and experiences coastal fumigation effect

## 2. MATERIALS AND METHODS

The Gaussian Plume Equation can be used for estimating the concentration of pollutants for various types of releases such as ground, elevated, radioactive emissions, and chemical pollutants considering various correction factors for various processes (Hukkoo, 1988). CPCB 1998 has described the basic assumptions and limitations of the GPM. It is mostly used for predicting ground level concentrations (GLC) due to releases from industrial stacks .i.e. stationary point sources. Concentration of pollutant at a point is given by,

$$C(x,y,z) = ( Q / \{ 2 \pi u \sigma_Y \sigma_Z \} ) \exp (-y^2 / 2 \sigma_Y^2 ) \{ \exp ( -( z-H )^2 / 2 \sigma_x^2 ) + \exp (- ( z+H)^2 / 2 \sigma_z^2)\} \ldots\ldots\ldots (1)$$

Where 'Q' is pollutant release rate (g/sec), 'u' is horizontal speed (m/sec), $\sigma_y$ and $\sigma_z$ are the vertical and horizontal crosswind dispersion coefficients respectively, which are functions of downwind distance (x) and atmospheric stability. 'y' and 'z' are the horizontal crosswind distance from plume centre line to the receptor and vertical distance from the plume centre line to the receptor in meters respectfully. 'H' is the effective stack height given by the formula $H = h_s + \Delta h$, where '$h_s$' is the physical height (m) and '$\Delta h$' is plume rise (m). The source of release is considered as origin (0, 0, 0) in the Cartesian co-ordinate system. From origin x-axis is considered as mean downwind direction, y-axis is in the horizontal crosswind direction and z-axis is in vertical direction. The effective stack height is determined using Briggs plume rise equations, 1975 (alternatively, with modifications incorporated by Brigg in 1984).

**Coastal fumigation correction to std. GPM:** The peculiarities of a coastal site generally depend on two features. One is the land sea breeze system, which dominates the local flows and other, is the significant change and surface roughness felt by the airflow, when air enters land from sea and vice versa. A pictorial view of this system is presented in Fig.1.

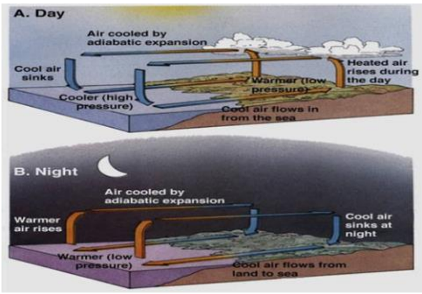


**Figure.1. Land-sea breeze system at coastal site**

The land and sea breeze system is basically a thermal wind system caused by the density gradients due to unequal heating of air above land and water bodies. The sea breeze on the west coast has an onset time around noon and lasts up to late evening. The land breeze has an onset time late at night and last up to early morning. On east coast, the situation is more complex. Since the sea lies to the east and the tendency of the gradient flow is westerly, the thermal wind opposes the gradient flow during the sea breeze regime and sea breeze is felt only if thermal wind is stronger than the gradient wind. As far as short distance dispersion is concerned, this aspect of sea and land breeze does not impose any problem since it is reflected in the wind records. The change of the roughness feature along sea and land surface is more complicated. At the incidence of sea breeze a front (also called the zone of abrupt discontinuity) forms between the onshore wind and the existing boundary layer wind over the land. This discontinuity arises due to differential temperatures, humidity in the air masses from the sea and the land. The wind coming from the sea, as soon as it crosses the shore, develops an internal boundary layer (IBL), the thickness of which depends upon the downwind distance from the shore and the potential temperature difference between the sea and surface. The aerodynamically smooth flow from the sea is slowly converted in to a rough flow due to increased surface roughness. The height of the internal boundary layer (IBL) is given by the relation $H_i = 8.8 (x / u. \Delta\theta)^{0.5}$…. (2)

Where '$\Delta\theta$', is the potential temperature difference between top and bottom of the initial stable layer (at the shore). The IBL is characterized by unstable atmosphere in the region of IBL and a stable atmosphere above the IBL. Pollutants released near the coast can encounter the IBL leading to rapid mixing within the IBL and with restricted vertical mixing across the IBL. This leads to higher concentrations in the IBL layer near the coast otherwise called the fumigation effect. The concentration during fumigation condition can be estimated using the IBL height in the mixing height in GPM equation

$$C(x, y, z) = \{(Q / (2 \pi u \sigma_y H_i)^{0.5}\} \exp(-y^2/ 2 \sigma y^2) \ldots (3)$$

Where, $\sigma_y$ relevant to initial layer should be used.

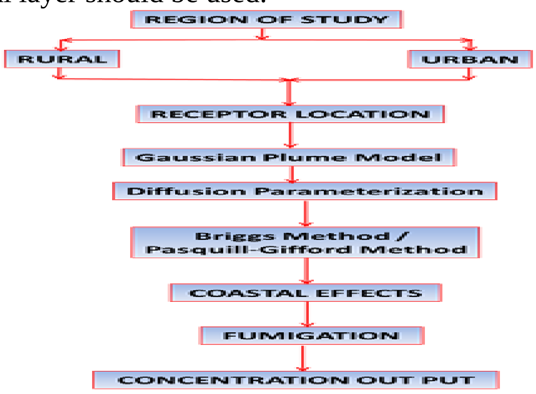


**Figure.2. Methodology followed in Atmospheric dispersion program**

**Data:**

**Emission inventory data**: The emission inventories in the study area (Fig.3) were referred from Manju, 2002 and Ganapathy Subramanian, 2006.


**Figure.3. Pictorial view of the study area**

The latest status was updated from Tamil Nadu Pollution control Board. The thermal power stations located to the North east side of the study area is also taken into the study to reduce the errors in calculated and observed data. A graph was plotted which is presented as Fig.4.

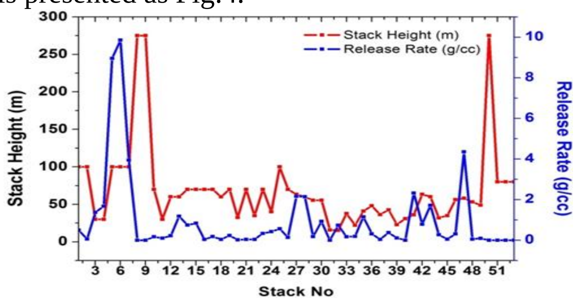


**Figure.4. Graph showing emission details**

**Meteorological data**: Meteorological parameters consisting of air temperature ($^0$C), wind speed (m/sec), wind direction (deg), atmospheric pressure (m bar) and humidity (%) were collected from IMD website. The IBL is estimated from the temperature difference between the land and sea as reported by Srinivas, (2007). Stability classes were calculated by using Pasquill Turner (1969) method.

**Observed (monitoring station) data**: For validating the simulated concentrations ambient air quality observations are collected from CPCB for $SO_2$ at available location in Manali. The data are available at hourly intervals and same is corrected for sampling time correction for $\sigma_y$. The diffusion parameterization .i.e. sigma functions of Pasquill Gifford are essentially for a sampling time of 3 minutes. Empirical correction factor of power law type is applied for obtaining concentration for different sampling times. The meteorological data obtained is having an interval of 1 hour. Hence the following correlation is used for correction. $Б_y (T) = б_{yp} (T/3)^{-\alpha}$……………………..…(4)

Where T is the sampling time (min), $б_{yp}$ is the horizontal dispersion coefficient obtained from Pasquill Gifford curves which are for a sampling time of 3minutes. The following values were used.

$\alpha$ = 0.5 for 15 minutes < T < 60 minutes…………………………………..………………………. (5)

$\alpha$ = 0.4 for 60 minutes < T < 240 minutes………………………………………………………….... (6)

## 3. RESULTS AND DISCUSSIONS

The 24-h average and hourly GLC values are studied pertaining to all three seasons using Briggs Urban diffusion relationships in GPM. Daily average variation of $SO_2$ concentration at Manali receptor is studied assuming the source at CPCL in the study area Manali. An actual radial distance of 4500m where CPCB receptor is located is used for the study. Meteorological observations for 3 days from 1-May-2014 to 3-May-2014 from IMD for summer season, 5-Oct-2014 to 7-Oct-2014 and 2 days .i.e. 20-Jan-2014 to 21-Jan-2014 for winter respectfully. The results of GPM presented in the Fig.5, 6 and 7.

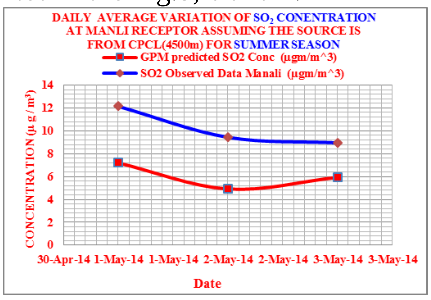


**Figure.5. Daily avg. seasonal variation in summer season**

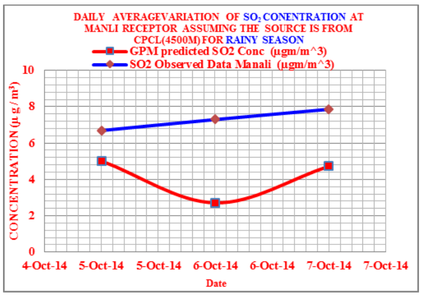


**Figure.6. Daily avg. seasonal variation in rainy season**

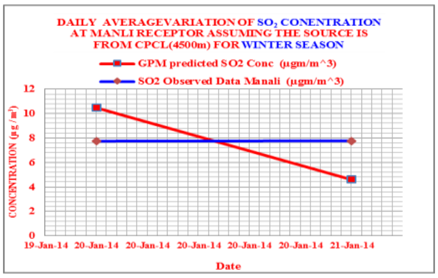


**Figure.7. Daily avg. seasonal variation in winter season**

The results of GPM presented in the Figs.5, 6 and 7, show the same trends as of monitoring data but underestimated the average concentrations by ~4μ g / $m^3$ in summer, ~5μ g / $m^3$ in rainy and ~3μ g / $m^3$ in winter respectfully. The GPM slightly underestimated the GLC which is due to omission of vehicular and other unaccounted sources in the calculation. The under estimation could also be due to not properly picking up the hourly variation in the GLC which is examined below for summer season on 1-5-2014 and presented in Fig.8.

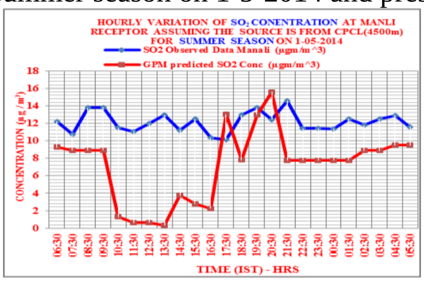


**Figure.8. Seasonal hourly variation in summer season**

The time series of simulated GLC from GPM presented as Fig: 8 shows large diurnal variation in the model values while the observations show lesser variation. The observed concentrations are noted to be high in the morning stable conditions (~12-14 μg/$m^3$) and during unstable daytime hours between 1130 and 1730 IST (~14 μg/$m^3$). The morning concentrations are underestimated by GPM. The GPM without correction factor for fumigation simulated very low concentrations during the daytime too. This was corrected for fumigation effects with respect to summer season and presented as Fig.9.

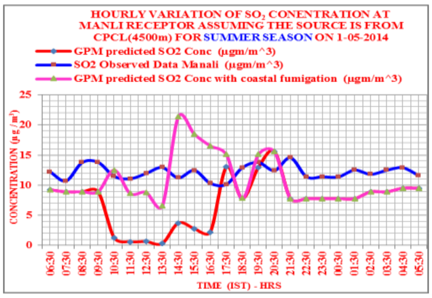


**Figure.9. Seasonal hourly variation in summer season with coastal fumigation effect**

The results presented in Fig.9, showed significant improvement in simulated daytime concentrations due to inclusion of IBL effects for summer season on 1-5-2014. The daytime observed concentrations range as 10-13 µg/m$^3$. The simulated GLCs after incorporation of fumigation effect varied as 8-20 µg/m$^3$ with an average concentration of about 14µg/m$^3$. From the comparison of simulated GLCs from the plot without using the fumigation effect, it can be recognized that the underestimation of daytime concentrations is considerably reduced using fumigation formulations in GPM. However the GLCs show unrealistic peak concentration of about 20µg/m$^3$ during sea breeze time which needs further modifications. This correction was applied for all days under study and the variation in improvement of daily average concentrations for summer season is presented as Fig.10.

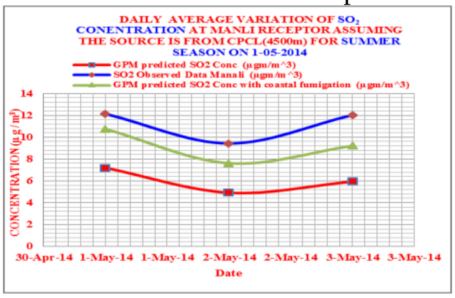


**Figure.10. Seasonal daily average variation in summer season with and without coastal fumigation effect**

Comparison with observations presented in Fig.10 indicate considerable improvement in the 24-h average concentrations in the simulations using the coastal fumigation. Still a variation of 1-1.5 micro g/m$^3$ is observed. This may be due to vehicular pollution of $SO_2$ in the environment that is not considered in the present calculation. The same procedure was used for correcting concentrations with respect to rainy and winter seasons and the results obtained are presented as Fig.11 and Fig.12 respectfully.

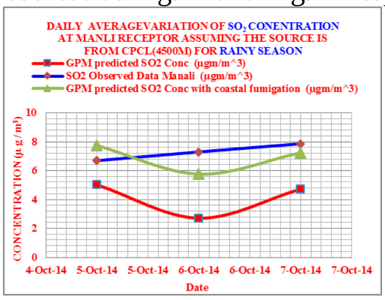


**Figure.11. Seasonal daily average variation in rainy season with and without coastal fumigation effect**

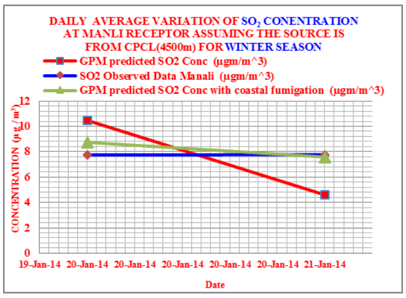


**Figure.12. Seasonal daily average variation in rainy season with and without coastal fumigation effect**

The hourly variations of simulated GLCs are drastically improved by applying the correction for fumigation effect and the underestimation of GLC is reduced to less than 2%. This also improved the 24-hour average concentrations for winter season.

## 4. CONCLUSION

For all the three seasons (summer, monsoon, winter) the actual modeled 24-h average concentrations are found to be lesser than the actual observations. This is because the model underestimated the concentrations during both stable morning conditions and the unstable sea breeze hours. A correction is made for the fumigation effect in GPM and the simulated concentrations with incorporation of fumigation effect are found to better match the observed concentrations (~10-13 µg/m$^3$) during the sea breeze time. This fumigation correction has improved the 24-h average concentrations. The calculations with GPM using diffusion formulae indicated the hourly and 24-h average concentrations of $SO_2$ due to emissions from the major industries in Manali are less than the national ambient air quality standards (24h average $SO_2$ limit for industrial area is 120µg/m$^3$).

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