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DISPERSION PATTERN OF SULFUR DIOXIDE FROM MULTIPLE INDUSTRIAL POINT SOURCES IN THE URBAN COASTAL AREA OF TROPICAL REGION

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ABSTRACT

This study analyze the spatial dispersion pattern of Sulfur dioxide (SO_2) from 192 industrial stacks in Chennai, a coastal city in India, located in the tropical zone. Industrial Sources Complex Short Term Model version 3(ISCST3) was performed for 12 months (June-2011 to July-2012) and 16 wind direction sectors of 22.5º resolution were employed. The spatial dispersion pattern of SO_2 revealed that it varies every month, depends on the prevailing seasonal and meteorological conditions. August and September in the Pre-monsoon season, and November in the monsoon season were the critical periods receiving maximum range of ground-level concentrations of SO_2 (27µg/m^3 to 30µg/m^3) due to steady wind pattern. The unsteadiness prevailing in the wind direction due to transition of monsoon season, during October and February, enhance the dispersion and drastically reduces the ground-level concentration of SO_2 to 17µg/m^3. The results of the study demonstrate that much fluctuations in the wind direction not only prevents over dumping of pollutants in a particular downwind sectors, but also enhance the areas of dispersion and reduces the ambient concentration level of pollutants.

KEYWORDS: Wind Direction Sector, Ground-Level Concentration, Sulphur Dioxide (SO_2)

INTRODUCTION

The United Nations Environment Programme has estimated that globally 1.1 billion people breathe unhealthy air **(UNEP, 2001.** However the fundamental parameters in the movement of contaminants by the atmosphere is the wind, its speed and direction which in turn are interrelated with the vertical and horizontal temperature gradient in the atmosphere **(Harry Wexler, Sc.D).** The heating at the surface of the earth is not uniform, but varies with the latitude because of the variation of the incoming radiation. Over the same latitudinal belt, it varies between land and ocean because the heat capacity of the land is much smaller than that of the ocean (**Sulochana Gadgil et al., 2007).** Seasonal variation is a phenomenon closely associated with the earth's rotation, influencing the concentrations of air pollutants in the ambient air **(Karar et al.,) Krishnamuthi et al.,** and **Wang et al.,** ascertained that the most pronounced annual reversal in atmospheric circulation and precipitation on the Earth is located in the tropical region from 40ºE to 160ºE and from 30ºS to 45ºN. A prediction on unceasing changes in the atmosphere is a challenging task for environmentalists as well as the regulatory authorities in the field air quality management. Usually the air quality management policies include emission inventory, control strategies and air quality monitoring, **(Molina et al, 2004)**. Dispersion modeling is an important tool to simulate the ambient air quality of a region and to predict the ground-level concentrations of pollutants under various atmospheric scenarios **(Amitava Bandyopadhyay et al., 2010). Turner (1964)** presented a working model for the diffusion of gases from multiple sources in an urban area. The Industrial Source Complex Short-Term model, version 3 (ISCST3), a steady state Gaussian Plume Model, is widely used, and USEPA validated model for estimating the ambient concentrations of pollutants from point, area, and line sources **(SCMMUEA).** In India, several studies were carried out in the prediction of downwind ground-level concentrations of pollutants in the past, using Industrial Source Complex Short Term model version-3 (ISCST3). The dispersion pattern and maximum ground-level concentrations of Sulphur dioxide (SO_2) at the downwind locations under various combinations of wind speed classes and atmospheric stability classes were studied in the neighbourhood of thermal power station-II at Neyveli of India **(Palanivelraja et al., 2009).** The downwind ground-level concentration of Sulfur dioxide for an industrial estate in Mauritius of India was predicted using the (ISCST3) Model version 3 by **Aruna D. Mahapatra et al., 2010.** The ambient concentration levels of Sulphur dioxide (SO_2), and Nitrogen dioxide (NO_2) were predicted at Jamshedpur of India for the winter season, using (ISCST3) model version-3, and a good agreement was reported to be exist between the predicted and measured concentrations **(Bhanarkar et al., 2005).**

Chennai is one of the four major metropolitan cities in India strongly influenced by the characteristics of tropical climatic conditions. The most significant phenomenon governing this region is, of course, the monsoon. A Comprehensive Environmental Pollution Index (CEPI) was developed by the Government of India recently, and 88 numbers of industrial clusters were identified as “polluted hotspots’’ and Manali Industrial Cluster of North Chennai is one among them. The objective of the study is to simulate the spatial dispersion pattern of Sulfur dioxide from 192 industrial stacks of North Chennai air basin, to ascertain the factors influencing the dispersion pattern of SO_2 towards 16 wind direction sectors for the period between June-2011 to July-2012. Industrial Source Complex Short-Term version3 (ISCST-3) model is used for the simulation of dispersion pattern of Sulfur dioxide in this study.

MATERIALS AND METHODOLOGY

Description of Study Area

India is situated in the Northern hemisphere and the tropic of cancer divides the country into roughly two equal parts. The study area Chennai is located on the South Eastern Coast of India. The geographical coordinates of the region are 13º10'04"N latitude and 80º15' 43" E longitude. The land surface terrain varies around 6.7 meters from the Mean Sea Level. The city is 25.6 km in length, and extends inland to about 11 Km, and the total area of this metropolitan city is about 174 Sq.Km (**Jayanthi et al., 2006).** Manali Industrial Cluster is located in the northern part of the city, which is the home for a variety of industries including petroleum refinery and allied petrochemical industries. The emissions from petrochemical industries in Manali, thermal power plants at Ennore, and large-scale industrial units in Tiruvottriyur areas, are the sources of causing significant levels of air pollution in North Chennai air basin.

Meteorological and Ambient Air Quality Monitoring

The Tamil Nadu (State) Pollution Control Board is operating three Continuous Ambient Air Quality Monitoring Stations (CAAQMS) in the North Chennai area. One continuous ambient air quality monitoring station is located at Manali, and another one at Kathivakkam, and the third one is at Tiruvottriyur (See Figure 1). The data on concentration levels of Sulphur dioxide observed in the CAAQMS were obtained from the State Pollution Control Board. The meteorological data such as temperature, wind speed and wind direction were obtained from the Indian Meteorological Department for this study.

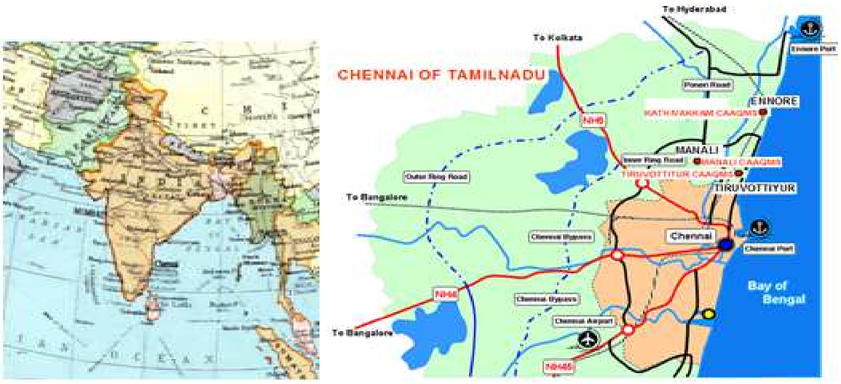

Figure 1: Description of the Study-Area

Emission Inventory

The list of industries located in the study area was obtained from the State Pollution Control Board. The total number of industries identified within the study area were 277. Out of the 277 industries, only 37 large scale industries are letting emissions into the atmosphere, either through their process stacks or through their non-process sources such as DG Sets, boilers, etc. In the remaining 240 industries, 4 are large-scale proposed industries and the other 236 industries are small-scale industries, and they do not have any emission sources causing air pollution. The details such as stack height, stack diameter, volume of flow, exit gas velocity, and stack-gas temperatures were documented after carrying out detailed emission inventory. It was ascertained that the stack height is varying from 10.0 m to 275.0 m, and the total discharge of SO_2 emissions is in the order of 364.56 g/sec. A comprehensive survey was conducted for the collection of data relating to the geographical location of each stack (Latitude& Longitude) using GPS.

Dispersion Modeling

The ISC Short Term model uses a steady-state Gaussian plume equation to model the dispersion of air pollutant emissions from point sources, such as stacks and isolated vents **(USEPA., 1995).** The model was originally developed by the U.S. Environmental Protection Agency during 1970s for using both industry and regulatory-agencies to predict ground-level pollutant concentrations in various downwind receptor points. It may be applied in urban or rural environment with a moderately complex terrain. It works with non-reactive pollutants, including particulate matter, but may include a first order decay **(Ramakrishna et al., 2005).** ISC3 operates in both long-term and short-term modes, and the ISCST3 model is a popular model among the air pollution dispersion models in the UNAMAP series, and it has unique features such as the capability to handle Polar or Cartesian co-ordinates, to simulate point, area, and volume sources, to consider wet and dry deposition phenomena, make terrain adjustments, and building downwash consideration, etc. The model is capable of predicting results within 25km radius from the point source (SCMMUEA). The accuracy of predicted concentration depends on detailed and accurate emission inventory, and accurate measurement of meteorological parameters in that area **(Scupholome et al., 1977).** The large-scale industries situated within the study area are the continuous processing plants, and the stack emission discharges are being emitted during all the hours of the day. Hence, the Industrial Source Complex Short-Term version3 (ISCST-3) is used to predict the monthly spatial distribution of SO_2 from the industrial point sources of North Chennai Air Basin is relevant for this study. The Gaussian plume equation for an elevated continuous point source from an origin at source applicable to homogeneous turbulent flow of air is given by,

$$C(x,y,z,H) = \frac{QKVD}{2\pi\sigma_x\sigma_y u}.\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

Where C is pollution concentration (µg/m^3), Q is emission rate from the point sources (g/sec), z is receptor height above ground level (m), x and y are downwind and lateral distances respectively, from the pollution sources to the receptor point (m), u is mean horizontal wind speed (m/s), H is effetive stack hight (m). σ_y, σ_x are standard deviations of horizondal(lateral) and vertical dispersion co-efficients respectively (m), K is a scaling co-efficient to convert calculated concentration to the desired units, V is vertical distribution of Gaussian plume and D is decay term accounting for pollutant-removal by physical and chemical processes. The mean wind velocity profile throughout the entire depth of the Planetary Boundary Layer (PBL) is represented by power law, and the wind speed at the stack height is one of the basic criteria for ascertaining the dispersion of pollutants in the Gaussian plume model. Dispersion models recommended for regulatory applications employ algorithms of wind speed by power law

$$u_z = u_a\left(\frac{z}{z_a}\right)^p$$

The level of stability are classified into six wind-speed classes, based on five surface wind speed classes, three types of day time insolation and two types of night time cloudiness, and modifying the Pasquill turbulence types according to the meteorological situations prevailing in the Study Area. The vertical momentum and thermal buoyancy are the factors contributing to the vertical displacement of the plume initially. The plume rise estimation was done by many researchers. The formula derived by **Briggs (1971, 1972)** gives the best result, in view of ground realities, and hence the same formula is used for estimating the plume rise in this Study. The source input files, and meteorological input files for ISCST3 model were generated from the detailed emission inventory and meteorological data's as per the methods of procedures prescribed by the USEPA-manual.

RESULTS AND DISCUSSIONS

The ISCST3 model was performed successfully for 12 months (July 2011 to June-2012) to predict the ground-level concentrations of SO_2, emission from the 192 industrial stacks situated within the study area. Isopleths were developed for all the months using surfer software. Evaluation of performance of the model was ascertained, based on the outcome of the model results, by comparing the predicted concentrations with the observed concentrations of SO_2.

Evaluation of Model Performance

The measure of agreement developed by Willmott is more appropriate for the investigation of model validation, where the observed and model-predicted values need to be compared **(Lei Ji et al., 2006).** In this study, the model performance was evaluated by comparing the predicted concentrations of SO_2 in the model, with the observed (measured) concentrations in the 3 Continuous Ambient Air Quality Monitoring Stations located at Manali, Kathivakkam, and Tiruvottriyur within the Study Area, by considering the seasonal wind patterns. **Aruna D.Mahapatra et al.,** evaluated the ISCST3 model for the prediction of ground-level concentration of Sulphur dioxide (SO_2) in Mauritius. The statistical parameters namely the coefficient of correlation (r^2), index agreement (d) as recommended by Willmott were used for the evaluation in the present study. The coefficient of correlation (r) represents the level of relation**(Rao et al.,1985).** The Index agreement provides the degree to which the model predictions are error-free **(Banerjee et al., 2011).** Figure 2 shows scatter-plots for the observed (measured) SO_2 concentrations in the Continuous Ambient Air Quality Monitoring Stations (CAAQMS), and the predicted SO_2 concentrations in the downwind receptor locations in the ISCST3 model.

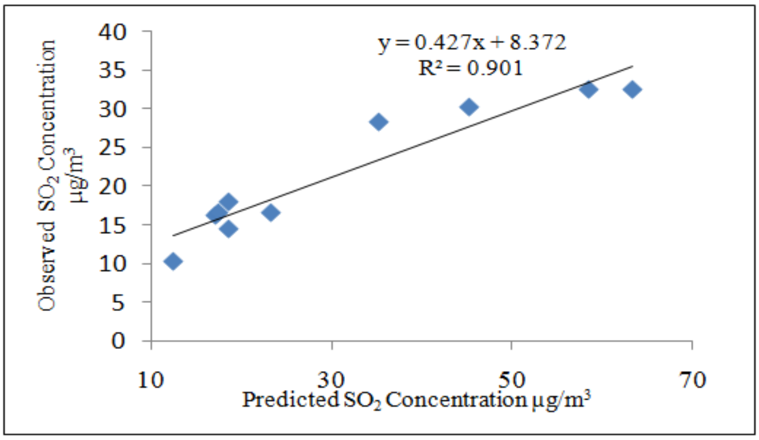

Figure 2: Correlation between Predicted and Observed Concentration of SO2

Perusal of the Figure 2 reveals that the predicted and observed (measured) concentrations of SO_2 show a similar trend and the 'r^2' value is 0.90. The model with r^2 value above 0.75 as excellent (**Woodfield et al., 2003).** The index agreement (d) is expressed as

$$\mathbf{d = 1 -} \frac{\sum_{i=1}^{n}(Pi - Oi)^2}{\sum_{i=1}^{n}(|Pi - \bar{O}| + |Oi - \bar{O}|)^2}$$

The index agreement derived in this study was 0.77. The index agreement (d) value for a model represents 0 for no agreement and 1 for perfect agreement. The results of the statistical analysis of this study implies that the model performed well.

Temperature

The close proximity to the Bay of Bengal and the thermal equator makes the climate and weather in Chennai area as relatively consistent with less variation in the seasonal temperatures. The temperature is ranged between 21.5◦C and 33.1◦C during monsoon season. The variation of temperature during Post-monsoon is between 21.2ºC and 33.6ºC. During Summer, the temperature ranges from 27.6◦C-38.6◦C. The trend of temperature variation during Pre-Monsoon period is from 23.1◦C–35.5◦C. The monthly maximum and minimum temperature recorded from July-2011 to June 2012 are depicted graphically in Figure 3.

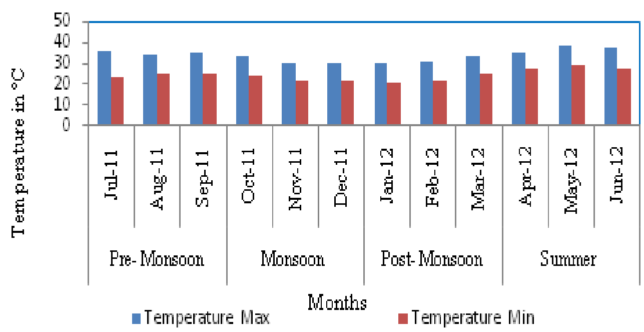

Figure 3: Temperature Variation Recorded from July-2011 to June 2012

Seasonal Wind Pattern

The monsoons are weather phenomena closely associated with the earth's rotation effects on general circulation of the troposphere and Inter-Tropical Convergence Zone (ITCZ) oscillations **(Mbane Biouele César et al.,2014).** Wind regime in the tropics is significantly different from those at mid latitude areas because of the greater incoming solar radiation, vertical mixing of momentum, insignificant Coriolis force in the tropics. The Bay of Bengal and Arabian Sea are the two important basins of the North Indian Ocean which exhibit seasonal circulation in Indian sub continent forced by the southwest and the northeast monsoons (**A. D. Rao, et al., 2012).** The two predominant monsoons occurring in the topical Indian Ocean are northeast monsoon, and southwest monsoon. **(Chithra Shaji et al., 2003).** The wind during southwest monsoon blowing from the Indian Ocean and Arabian Sea towards the Indian landmass from the southwest direction. The wind during Northeast monsoon blowing from Bay of Bengal towards the Indian land mass from the Northeast direction. The monthly average wind speed observed for the period in between July-2011 to June-2012 is depicted graphically in Figure 4.

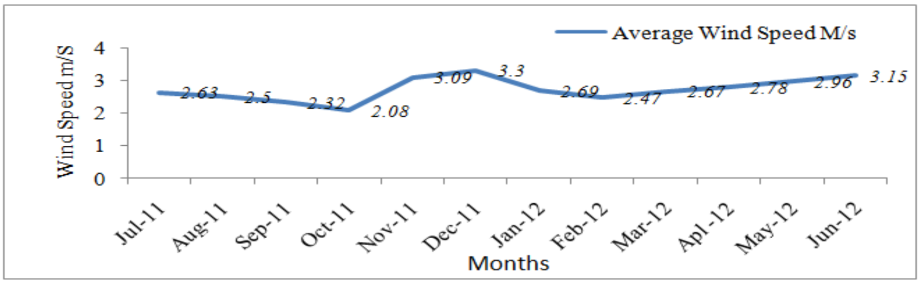

Figure 4: Monthly Average Wind Speed

Month Wise Distribution Pattern of SO_2

July-2011

The monsoonal wind during July is generally blowing from south-west to north-east and the average wind speed observed was 2.63m/s. The percentage frequency distribution of wind direction in the 16 wind direction sectors of 22.5º degree resolution, were 0.4% N, 2.4% NE, 3.5% ENE, 3.7% E, 10.75% ESE, 12.23% SE, 7.1% SSE, 7.5% S, 9.6% SSW, 26.5% SW, 9.6% WSW, 2.6% W, 1.8% WNW,1.2%NW, and 0.25% NNW. The monsoonal wind direction prevailed over a considerable period of 55.8% towards the North Eastern sector. The sea breeze from south eastern sector was 33.78%. The monsoonal wind and the sea breeze blowing from two different sector disperse the SO_2 in two different down wind sector resulting in reduction of ground-level concentrations of SO_2 to 24 µg/m^3. The Isopleths presented in Figure 5 represents the spatial distribution pattern of SO_2 during July-2011 and the corresponding wind rose.

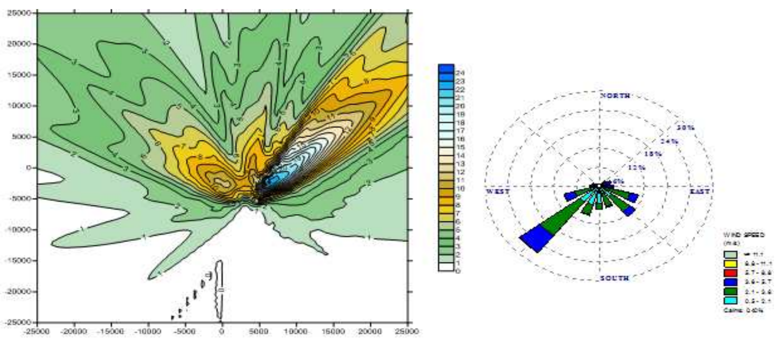

Figure 5: Dispersion Pattern of SO_2 in July-2011 & Wind Rose

August-2011

The average wind speed was 2.5m/s, and the percentage frequency distribution of wind direction in the 16 wind direction sectors were 0.13%NNE, 0.67% NE, 0.53% ENE, 3.09% E, 5.5% ESE, 9.8% SE, 9.6% SSE, 8.3% S, 15.45%SSW, 33.06% SW, 7.93% WSW, 2.68% W, 0.8% WNW, 0.67%NW, and 0.94% NNW. The monsoonal wind direction remains steady over a considerable period of 66.42% towards Northeastern sector and sea breeze towards Northwestern sector was only 19.4%. Though the average wind speed was 2.5m/s, the steady plume towards the Northeastern sector transmitted considerable quantum of SO_2 leads to stagnation, resulting in increase of ground-level concentrations of SO_2 to 30 µg/m^3. **Chaloulakou et al.,** found that the stagnant wind conditions allow air pollutants to accumulate near the earth's surface, resulting in elevated concentrations of air pollutant. The Isopleths presented in Figure 6 represents the spatial distribution pattern of SO_2 during August-2011 and the corresponding wind rose.

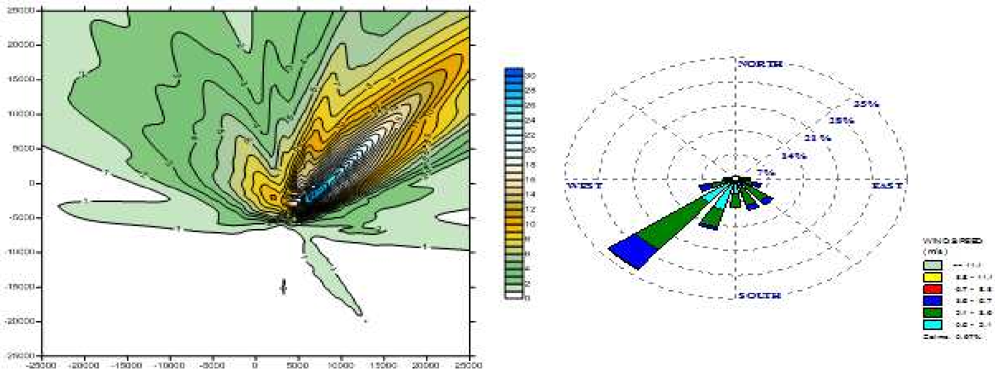

Figure 6: Dispersion Pattern of SO_2 in August-2011& Wind Rose

September-2011

The average wind speed was 2.32m/s and the percentage frequency distribution of wind direction in the 16 wind direction sectors were 0.08%NNE, 1.2% NE, 1.8% ENE, 3.4% E, 9.5% ESE, 13.3% SE, 10.4% SSE, 8.0%S, 15% SSW, 22.22%SW 7.0% WSW, 3.2% W, 1.0% WNW, 0.5%NW, and 0.2% NNW. The monsoonal wind direction remains steady over a period of 55.4% towards Northeastern sector and sea breeze from the south eastern sector was observed only 36.6%. The percentage frequency distribution of wind direction as we found during July-2011 is almost similar to September-2011. The average wind speed during September was 2.32m/s which is low, in comparison with July-2011. Though the percentage frequency distribution of wind direction is almost similar to July, the low wind speed restrict the pollutant dispersion and resulting in elevation of ground-level concentrations of SO_2 to 27 µg/m^3. The Isopleths presented in Figure 7 represents the spatial distribution pattern of SO_2 during September -2011 and the corresponding wind rose.

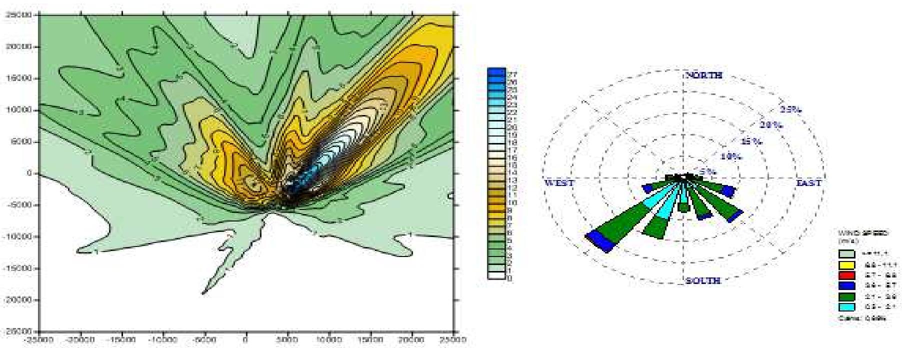

Figure 7: Dispersion Pattern of SO_2 in September -2011 & Wind Rose

October-2011

The average wind speed was 2.08m/s and the percentage frequency distribution of wind direction in the 16 wind direction sectors were 5.91%N, 6.31%NNE, 8.33% NE, 6.8% ENE, 9% E, 7.5% ESE, 3.2% SE, 0.53% SSE, 1.7%S, 1.61%SSW, 12.3%SW 10.2% WSW, 7.79% W, 7.25% WNW, 6.31%NW, and 2.55% NNW. The frequency distribution of wind direction is a peculiar one and it clearly shows the unsteadiness of wind direction because of the transition of monsoon season. The South-westerly wind ends, and North-easterly wind commences generally during October of every year. Even Though average wind speed was 2.08m/s, the transition of monsoon from Southwest to Northeast causing unsteadiness in the wind direction and disperse the pollutants almost in all the direction sector and resulting in drastic reduction of ground-level concentrations of SO_2 to 17 µg/m^3.The Isopleths in Figure 8 represents the spatial distribution pattern of SO_2 during October-2011corresponding wind rose.

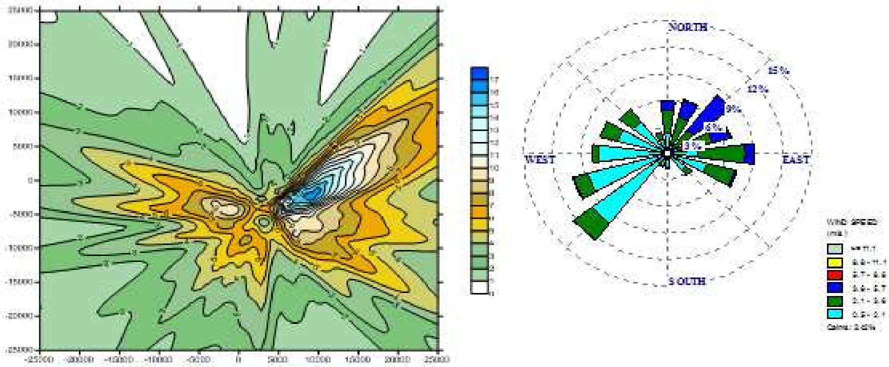

Figure 8: Dispersion Pattern of SO_2 in October-2011 & Wind Rose

November-2011

The temperature was ranged between 24.3 ºC to 30ºC. The average wind speed was 3.09 m/s and the percentage frequency distribution of wind direction in the 16 wind direction sectors were 21.7%N, 27.6%NNE, 13.5% NE, 6.41% ENE, 2.3% E, 0.41% ESE,0.27% SE, 0.13% SSE, 0.13%S, 0.97%SSW, 1.25%SW, 4.58% WSW, 2.91% W,6.2% WNW,7.36%NW, and 6.2% NNW. The monsoonal wind direction remains steady over a considerable period of 71.51% towards Southwestern sector. The sea breeze effect was found to be very low because of low temperature range. The steady Northeasterly wind over a considerable period towards the down wind sector leads to stagnation pollutant and elevate the ground-level concentrations of SO_2 to 28 µg/m^3. The Isopleths in Figure 9 represents the spatial distribution pattern of SO_2 during November-2011 and the corresponding wind rose

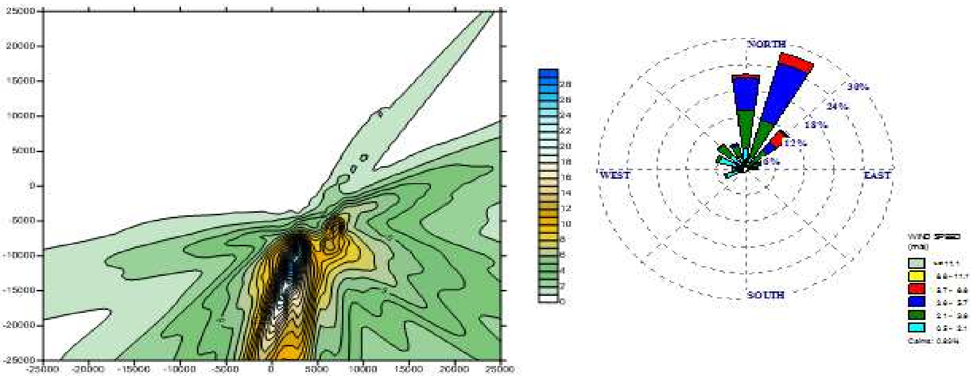

Figure 9: Dispersion pattern of SO_2 in November-2011& Wind Rose.

December-2011

The temperature was ranged between 21.5 ºC to 29.7 ºC. The average wind speed was 3.39m/s and the percentage frequency distribution of wind direction in the 16 wind direction sectors were 23.8%N, 25%NNE,13.44%NE, 2.9% ENE, 2.6% E,2.9% ESE,0.4%SE, 0.4%SSW, 2.28%SW, 4.03% WSW, 3.09% W, 4.8% WNW, 7.3%NW, and 6.1% NNW. The monsoonal wind direction was found predominate (65.14 %) towards southwestern sector. The sea breeze effect was found to be very low because of low temperature range, and 21.29 % of wind towards southeastern sector. Though the monsoonal wind was found predominantly towards South-western sector, the influence due to higher wind speed (3.39 m/s) and the partial distribution of pollutant towards southeastern sector causing in reduction of ground-level concentrations of SO_2 to 23µg/m^3.The Isopleths in Figure 10 represents the spatial distribution pattern of SO_2 during December-2011 and the corresponding wind rose.

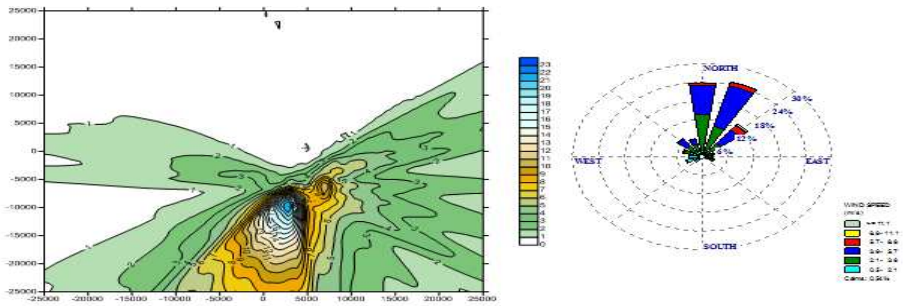

Figure 10: Dispersion Pattern of SO_2 in December-2011 &Wind Rose

January-2012

The temperature was ranged between 21.2 ºC to 29.6 ºC. The average wind speed was 2.69m/s and the percentage frequency distribution of wind direction in the 16 wind direction sectors were 7.4%N, 16.93%NNE, 22.4%NE, 16.4%ENE, 7%E,6.9%ESE,0.53% SE, 0.26% SSE, 0.13%S, 0.134%SSW, 4.6%SW, 5.1% WSW, 5.2% W, 3.22% WNW, 1.47%NW, and 1.61% NNW. The monsoonal wind was found predominant (63.13 %) towards southwestern sector. The southwestern wind towards northeastern sector was 15.16 % and sea breeze towards northwestern sector was 14. 69%. The fluctuations in the wind directions towards the southwestern, northeastern, and north western sectors indicates the beginning of withdrawal of northeast monsoon. Though the monsoonal wind was found predominantly towards South-western sector, the partial distribution of pollutant towards north-eastern, and north-western sectors bring down the ground-level concentrations of SO_2 to 20µg/m^3. The Isopleths in Figure 11 represents the spatial distribution pattern of SO_2 during January-2012 the corresponding wind rose.

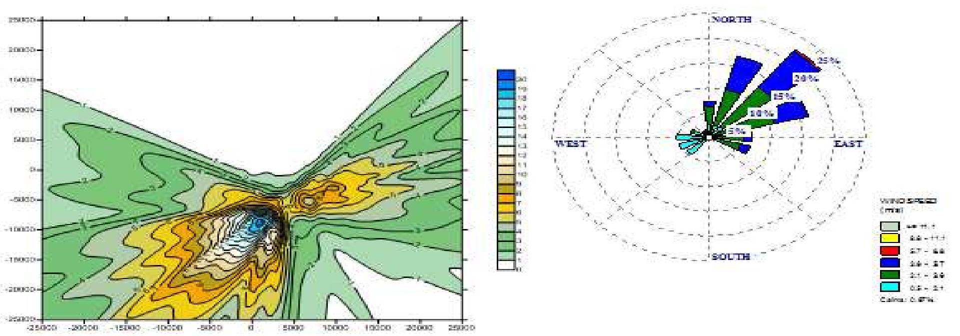

Figure 11: Dispersion Pattern of SO_2 in January-2012 & Wind Rose

February-2012

The temperature was ranged between 21.5 ºC to 30.9 ºC. The average wind speed was 2.47m/s and the percentage frequency distribution of wind direction in the 16 wind direction sectors were 9.22%N,18.15%NNE,17.11%NE,13.4%ENE,7.4%E,5.5%ESE,1.63%SE, 0.29%SSE, 0.15%S,1.48%SSW,5.2%SW, 9.07% WSW, 5.8% W, 2.3% WNW, 1.1%NW, and 1.3% NNW. The monsoonal wind was found predominant (57.88%) towards south-western sector, and 14.83%, 15.75%, 10.5% of wind direction towards Northwest, Southeast and Northeastern sectors respectively. The frequency distribution of wind direction clearly states the unsteadiness of wind direction, because of the transition of monsoon season. The North-easterly wind ends, and South-westerly wind commences at the end of February every year generally. Even though average wind speed was found to be low (2.47 m/s) the transition of monsoon from Northeast to southwest causing unsteadiness in the wind direction and disperse the pollutants almost in all the direction sectors and resulting in drastic reduction of ground-level concentrations of SO_2 to 17 µg/m^3. The Isopleths in Figure 12 represents the spatial distribution pattern of SO_2 during February-2012 and the corresponding wind rose.

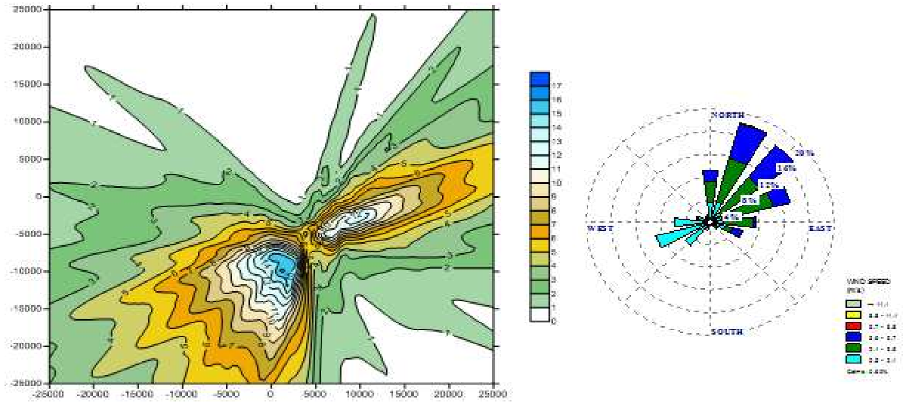

Figure 12: Dispersion Pattern of SO_2 in February- 2012 & Wind Rose

March-2012

The atmospheric temperature starts increasing and it was ranged between 25.1 ºC to 33.6 ºC. The average wind speed was 2.67m/s and the percentage frequency distribution of wind in the 16wind direction sectors were 0.4%N,1.47%NNE,4.9%NE,5.5%ENE,7.9%E,17.74%ESE, 26.9%SE, 7.4%SSE, 7.4%S, 8.1%SSW, 6.1%SW, 2.8%WSW, 1.61%W, 0.94%WNW, and 0.13%NW. After the transition of monsoon from Northeast to Southwest, the wind starts bowing from southwestern direction. The percentage frequency distribution of monsoonal wind direction (Southwesterly wind) was 24.4 % and south easterly wind was 59.94%. The reduction in percentage frequency distribution northeasterly wind to 12. % reflects the ending of northeast monsoon season. The moderate wind speed and the distribution of pollutant towards the northwestern, northeastern, and southwestern sector bring down the ground-level concentrations of SO_2 to 20µg/m^3. Isopleths in Figure 13 represents the spatial distribution pattern of SO_2 during March-2012 and the corresponding wind rose.

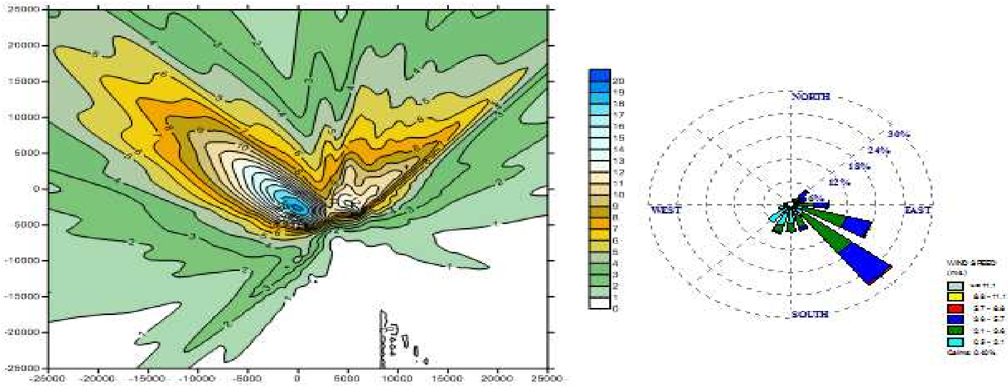

Figure 13: Dispersion Pattern of SO_2 in March-2012 & Wind Rose

April-2012

The atmospheric temperature was ranged between 27.6 ºC to 34.6 ºC. The average wind speed was 2.78m/s and the percentage frequency distribution of wind in the 16 wind direction sectors were 0.41%NNE, 2.6%NE, 3.47%ENE, 5.41%E, 19.16%ESE, 29.86%SE, 13.88%SSE, 7.9%S, 5.97%SSW, 5.55%SW, 2.9%WSW, 0.55%W, 0.97%WNW, 0.69%NW and 0.13% NNW. The percentage frequency distribution of monsoonal wind direction (Southeasterly wind) towards Northeastern sector was 22.32%, and the south easterly wind towards Northwestern sector was 68.76%. The domination of sea breeze is higher than the monsoonal wind in summer because of the uneven heating of land and sea occurs quicker due to higher temperature range. The monsoonal wind direction remains steady over a considerable period of 71.51% towards. The moderate wind speed, and the predominant south easterly and south westerly wind enhance the level of atmospheric turbulence and favouring unstable atmospheric conditions, resulting in reduction of ground-level concentrations of SO_2 in the downwind locations to 23 $\mu g/m^3$. The Isopleths in Figure 14 represents the spatial distribution pattern of SO_2 during April-2012 and the corresponding wind rose.

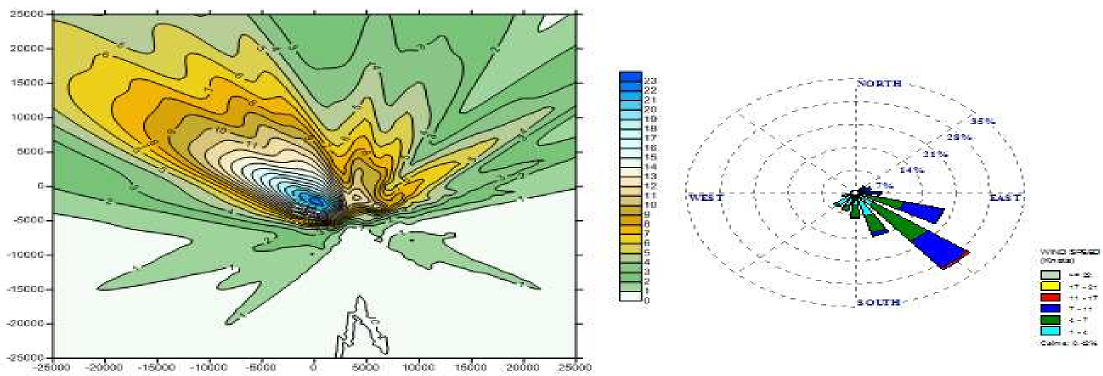

Figure 14: Dispersion Pattern of SO_2 in April-2012 &Wind Rose

May-2012

The atmospheric temperature reaches the maximum in May and it was in the range of 29.4 ºC to 38.6 ºC. The average wind speed was 2.92m/s and the percentage frequency distribution of wind in the 16 wind direction sectors were 0.13%N 0.40%NNE, 0.53%NE, 2.01%ENE, 2.1%E, 5.2%ESE, 28.89%SE, 21.37%SSE, 12.2%S,11.7%SSW,11.4%SW, 2.3%WSW, 0.94%W, 0.4%WNW, and 0.26%NW. The percentage frequency distribution of monsoonal wind direction (Southwesterly wind) was 37.6% and the south easterly wind was 57.56%. The meteorological situation as we found in

May -2012 was almost similar to April-2012, except the increase in the wind speed to 2.92m/s and the increase in percentage frequency distribution of monsoonal wind to 37.6%. This could be the possible explanation for the reduction of SO_2 concentration in the downwind sector to 21µg/m^3. The Isopleths in Figure 15 represents the spatial distribution pattern of SO_2 and the corresponding wind rose.

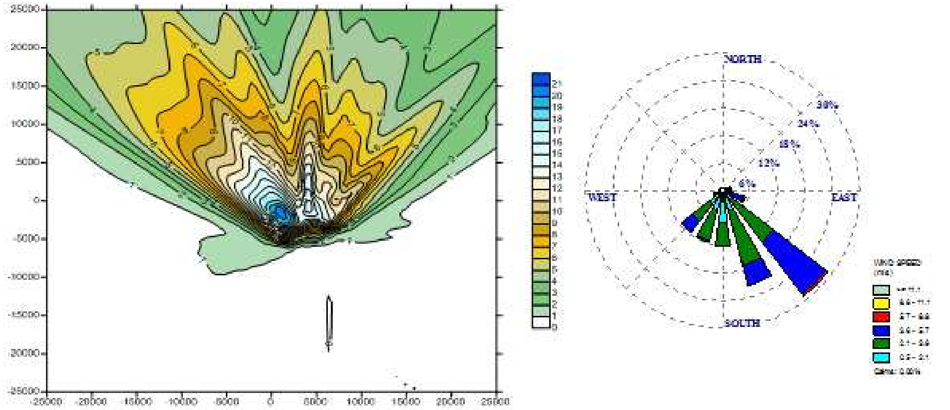

Figure 15: Dispersion Pattern of SO_2 in May-2012 & Wind Rose

June-2012

The atmospheric temperature started decreasing and it was in the range of 27.6 ºC to 37.2 ºC during June-2012. The average wind speed was 3.15 m/s and the percentage frequency distribution of wind in the 16 wind direction sectors were 0.13%N 0.27%NNE, 0.69%NE, 1.94%ENE, 2.91%E, 9.7%ESE, 14.4%SE, 14.02%SSE, 6.1%S, 8.2%SSW, 28.47%SW, 9.44%WSW, 1.52%W, 1.52%WNW, and 0.13%NNW. The percentage frequency distribution of monsoonal wind direction (southwesterly wind) was 52.2% and the southeasterly wind was 41.0%. The occurrence of steady wind pattern over a considerable period towards the northeastern sector denotes the domination of Southwest monsoon season. Though the percentage frequency distribution southerly sea breeze is high, the steady south-westerly wind over a considerable period towards the down wind sector leads to stagnation pollutant and elevate the ground-level concentrations of SO_2 to 22 µg/m^3. The Isopleths in Figure 16 represents the spatial distribution pattern of SO_2 and the corresponding wind rose.

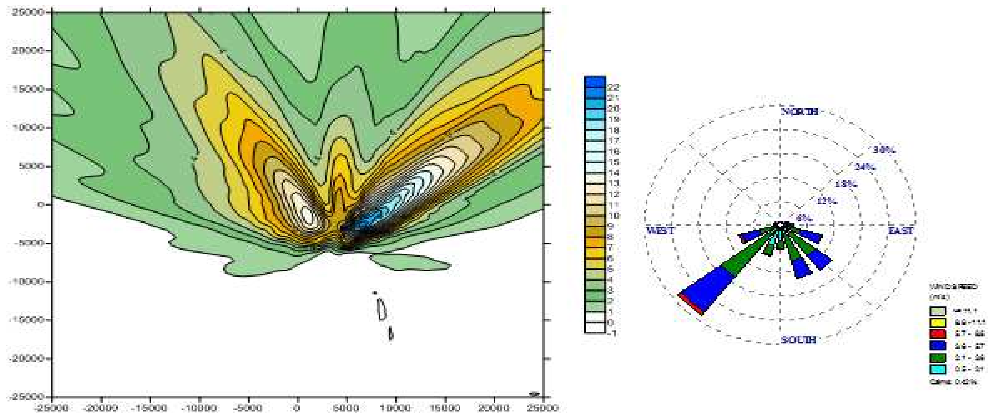

Figure 16: Dispersion Pattern of SO_2 in June 2012 & Wind Rose

CONCLUSIONS

The spatial dispersion pattern of Sulfur Dioxide (SO_2) from multiple industrial point sources in North Chennai was derived using Industrial Sources Complex Short Term (ISCST3) Model for the period between July-2011 to June 2012, and the findings are stated below:

- The ISCST3 model predictions were found to be good. The index agreement of 77% and the coefficient of correlation of 90% were obtained in the statistical evaluation of the model.
- The dispersion patterns of SO2 vary with respect to the prevailing wind speed, wind direction and seasonal change of the month.
- The sea breeze dominates the usual Southwesterly winds during the period between March to July due to higher temperature range and causing frequent fluctuations in the wind direction and makes unstable atmospheric condition resulting in moderate range of SO_2 concentration (20 µg/m^3 to 24 µg/m^3) in the downwind locations.
- The unsteadiness in the wind direction due transition of monsoon season, during the months of October and February, disperse pollutants in almost in all the wind direction, and drastically reduce the ground-level concentration of SO_2 up to 17 µg/m^3.
- This study predicts that August and September in the Pre-monsoon season, and November in the monsoon season were the critical periods receiving maximum ground-level concentrations of SO_2 (27ug/m^3 to 30ug/m^3) due to stagnation of pollutant in the down wind direction because of the study wind pattern.
- It is ascertained from this study that the SO_2 level reduces with respect to the increase in the areas of dispersion, due to much fluctuation in the wind direction.

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