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IASET

MODELING FOR PREDICTION OF SPM, NOX AND SO_2 FROM EMISSIONS OF A CEMENT FACTORY USING AERMOD DISPERSION MODEL

B. TEJASWINI, M. SRIMURALI, & V. SAMPATH KUMAR REDDY

Department of Civil Engineering, Sri Venkateswara University College of Engineering, Tirupathi, India

ABSTRACT

Industrial activities are sources of high emission rates of suspended particulate matter, $SO_{2,}$ NOx, and other pollutants. The existence of many such industrial plants close to a populated area can have a severe effect on human health **(**Alexander Cohan et al (2011)). The effects can be even worse when these emissions are added to existing background concentration levels. This paper deals with the case study for the prediction of the SPM, $NO_{x,}$ and $SO_{2,}$ pollution caused by industrial activities close to the villages of Tadipatri in Anantapur district, Andhra Pradesh state. An atmospheric dispersion model AERMOD 9.1 was used. Meteorological data for one year was processed using AERMET processor (z. mousavi et al (2014)). The model was run for pollutants SPM, $SO_{2,}$ NOx with different scenarios. Model runs were made for yearly, monthly, averaged emission scenarios. The output files for the parameters Suspended particulate matter (SPM), Sulfur dioxide (SO_2), and Nitrogen oxides (NO_x) were evolved for all the months of the study period from January 2014 to December 2014. The isopleths were plotted for the same and these concentration contours are very important in determining the spatial distribution of Suspended particulate matter (SPM), Sulfur dioxide (SO_2), and Nitrogen oxides (NO_x) over the modeled area. For the Ambient Air Quality Monitoring Stations, the predicted concentrations were found to be in good agreement with the measured data. For AERMOD model, values of coefficient of determination R^2 are in the range 0.79 to 0.90. The model outputs were compared with NAAQS, 2009 norms. It may therefore be inferred that AERMOD model gives better results. The results demonstrated that the AERMOD model can be applied to study the dispersion of criteria air pollutant concentrations and that the predictions are of reasonable accuracy and may be used for any other industry in its vicinity up to 50 km Diameter.

KEYWORDS: Pollutant, Dispersion, Impact, Modeling, Isopleths

INTRODUCTION

The cement industry contributes significantly to the imbalances of the environment; in particular air quality. The key environmental emissions are nitrogen oxides (NO_x), sulphur dioxide (SO_2) and grey dust. Industrial plant smokestacks from cement and construction companies are some of the biggest contributors to poor air quality, especially in urban developments. The principal aim in pollution control in the cement industry is to minimize the increase in ambient particulate levels by reducing the mass load emitted from the stacks, from fugitive emissions and from other sources (SandeepZade et al (2015)). The World Health Organization states that 2.4 million people die each year from causes directly attributable to air pollution. Epidemiological studies suggest that more than 500,000 people die each year from cardiopulmonary disease linked to breathing fine particle air pollution (WHO, 2007).

Study Area

Ultra Tech Cement Ltd (UTCL) Andhra Pradesh Cement Works is located at Bhogasamudram, 16 km from Tadipatrimandal in Anantapur district Andhra Pradesh, India. The lattitude 15^0 01' 13'' N and longitude 78^0 01' 54'' E

Cement plant is located at the hill top (351.5 m. MSL) and the packing plant & wagon tippler are located down the hill (266.0 m. MSL). The plant is located at the border line between Kurnool &Anantapur districts, 70 km from Anantapur city. The nearest railway station is "Juturu" between Tadipatri&Gooty on the Guntakal-Chennai line. The grinding unit is located in Arakkonam in the Tamilnadu state. This unit is not producing the clinker and it is taking the clinker from APCW and manufacturing OPC and PPC. Ultra Tech Cement Limited is one of the India's largest cement producers with state-of-the-art dry process plants incorporating pre-calcination technology; advanced instrumentation systems, computerized, process control and online quality control by X-ray ensure consistent production of high quality cement.

UTCL has five integrated cement plants one among is APCW, which has as an installed capacity of 2.3 Million Tonnes per annum, and is situated in Tadipatri, Andhra Pradesh. This plant has one grinding unit installed in Arakkonam, Tamilnadu.

METHODOLOGY

Air Dispersion Modelling Using AERMOD

AERMOD is a steady-state plume model designed for short-range (up to 50 kilometers) dispersion of air pollutant emissions from stationary industrial sources. The AERMOD modeling system consists of one main program (AERMOD) and two pre-processors (AERMET and AERMAP). The major purpose of AERMET is to calculate boundary layer parameters for use by AERMOD. The major purpose of AERMAP is to calculate terrain heights and receptor grids for AERMOD. Both AERMET and AERMAP require observational data to parameterize the growth and structure of the atmospheric boundary layer. AERMOD uses terrain, boundary layer and source data to model pollutant transport and dispersion for calculating temporally averaged air pollution concentrations.

Dispersion Modelling Along With Necessary Model Inputs which are as Follows

AERMET: calculates boundary layer parameters for input to AERMOD

Model inputs: wind speed; wind direction; cloud cover; ambient temperature; morning sounding; albedo; surface roughness; Bowen ratio

Model outputs: wind speed; wind direction; ambient temperature; lateral turbulence; vertical turbulence; sensible heat flux; friction velocity; Monin-Obukhov Length

AERMAP: calculates terrain heights and receptor grids for input to AERMOD

Model inputs: DEM data [x, y, z]; design of receptor grid (pol, cart, disc.)

Model outputs: [x, y, z] and hill height scale for each receptor

AERMOD: calculates temporally-averaged air pollution concentrations at receptor locations for comparison to the NAAQS

Model inputs: source parameters (from permit application); boundary layer meteorology (from AERMET); receptor data (from AERMAP) (Noorpoor et al (2015)).

Meteorological Data for Aermet

AERMET requires as input;

- Surface characteristics in the form of albedo,
- Surface roughness and
- Bowen ratio plus standard meteorological observations.

Planetary boundary level parameters such as;

- Friction velocity,
- Monin-obukhov length,
- Convective velocity scale,
- Temperature scale,
- Mixing height and
- Surface heat flux are then estimated by AERMET.

AERMET basic input data includes following items:

- Hourly surface data
- Upper air data
- Location of the pertinent site
- Sectors and Surface data.

These are explained below,

Hourly Surface Data Requirements Include Below Listed Parameters

- Cloud covers (tenths)
- Ceiling height (m)
- Dry bulb temperature (OC)
- Global horizontal radiation (whm-2d-1)
- Relative humidity (%)
- Precipitation amount (hundredths of inches).
- Station pressure (mb)
- Wind direction (deg)

- Wind speed (m/s)

Upper Air Data

Estimating upper air data is by upper air estimator.

Upper Air Estimator

Estimates upper air data from hourly surface data Location of the pertinent site, sectors and surface data: There are specific values assigned for albedo, Bowen ratio and surface roughness depending upon the land use types. Albedo is the proportion of sunlight that is reflected back into space without absorption. Albedo values range from 0.1 for thick deciduous forests to 0.9 for fresh snow. Bowen ratio indicates amount of moisture available to drive turbulent processes. It is the ratio of sensible heat flux to latent heat flux. During day time, Bowen ratio attains a fairly constant positive value ranging from 0.1 over water to 10 over desert at mid-day.

Surface roughness length is an indicator of amount of drag the ground surface exerts on the wind. It is related to the height of obstacles to the wind flow and is in principle the height at which the mean horizontal wind speed is zero. Values range from less than 0.001m over calm water surface to 1m or more over a forest or urban area.

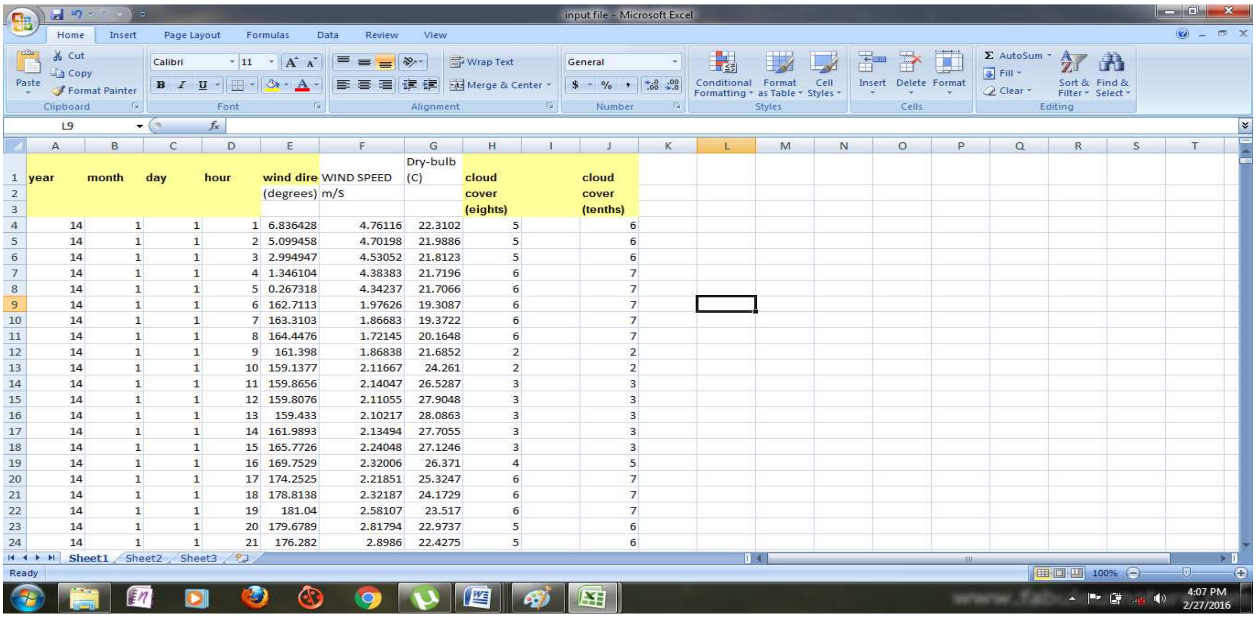
RESULTS AND DISCUSSIONS

The AERMOD model used in this study requires input information on emission sources at the cement industry site-specific meteorological data. The input data that describe both the emission source and meteorology provide a comprehensive set of information which can be used to run the AERMOD model and thus simulate the ground level concentrations of Suspended Particulate Matters (SPM), Sulfur Dioxides (SO_2), and Nitrogen Oxides (NO_x) from stationary sources of a cement industry.

The emission source information that needs to be input into the model is restricted to the physical stack dimensions (height, location, internal diameter) as well as the velocity and temperature of the released gas, and the SPM, SO_2, and NO_x emission rates. In addition the model requires the site-specific meteorological information as input data.The data were collected from India meteorological department and from the website www.metcheck.com/IN/ National solar research satellite data.

It should be noted that the AERMOD model requires meteorological data to be used on an hourly basis format.

Typical meteorological file developed AERMOD format is shown in **figure** 1.



	A	B	C	D	E	F	G	H	I	J
1	year	month	day	hour	wind dire	WIND SPEED	Dry-bulb (C)	cloud		cloud
2					(degrees)	m/S		cover		cover
3								(eights)		(tenths)
4	14	1	1	1	6.836428	4.76116	22.3102	5		6
5	14	1	1	2	5.099458	4.70198	21.9886	5		6
6	14	1	1	3	2.994947	4.53052	21.8123	5		6
7	14	1	1	4	1.346104	4.38383	21.7196	6		7
8	14	1	1	5	0.267318	4.34237	21.7066	6		7
9	14	1	1	6	162.7113	1.97626	19.3087	6		7
10	14	1	1	7	163.3103	1.86683	19.3722	6		7
11	14	1	1	8	164.4476	1.72145	20.1648	6		7
12	14	1	1	9	161.398	1.86838	21.6852	2		2
13	14	1	1	10	159.1377	2.11667	24.261	2		2
14	14	1	1	11	159.8656	2.14047	26.5287	3		3
15	14	1	1	12	159.8076	2.11055	27.9048	3		3
16	14	1	1	13	159.433	2.10217	28.0863	3		3
17	14	1	1	14	161.9893	2.13494	27.7055	3		3
18	14	1	1	15	165.7726	2.24048	27.1246	3		3
19	14	1	1	16	169.7529	2.32006	26.371	4		5
20	14	1	1	17	174.2525	2.21851	25.3247	6		7
21	14	1	1	18	178.8138	2.32187	24.1729	6		7
22	14	1	1	19	181.04	2.58107	23.517	6		7
23	14	1	1	20	179.6789	2.81794	22.9737	5		6
24	14	1	1	21	176.282	2.8986	22.4275	5		6

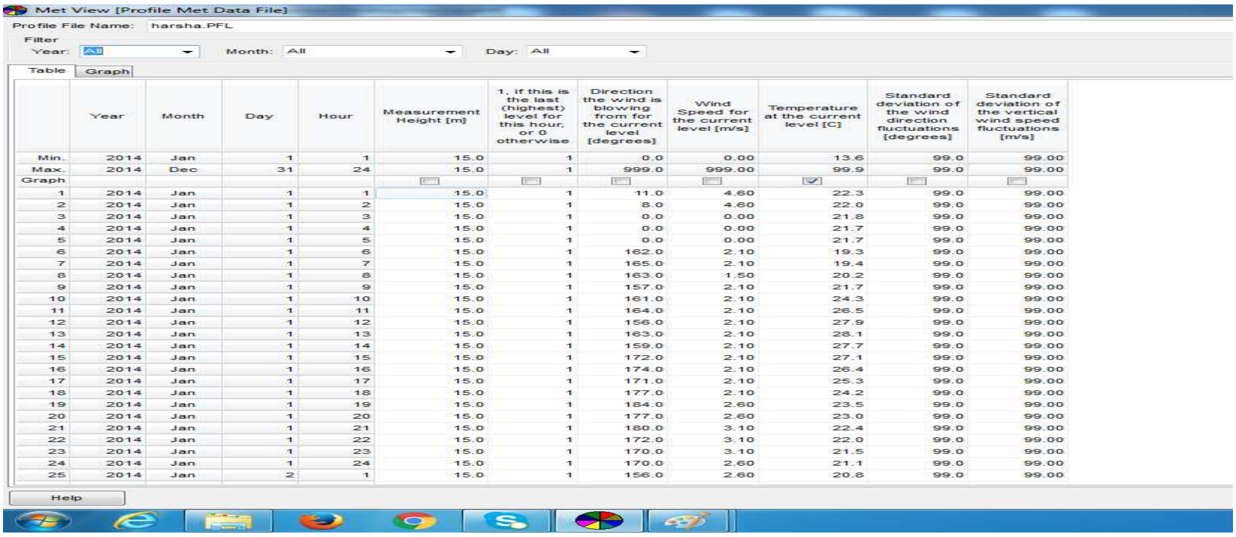
Figure 1: Typical Meteorological Data File Developed AERMOD Format

There are two basic types of inputs that are needed to run the AERMOD model. They are:

- The surface file, and
- The profile file.

The Typical profile file of AERMOD format is shown in figure 2

The Typical surface file of AERMOD format is shown in figure 3



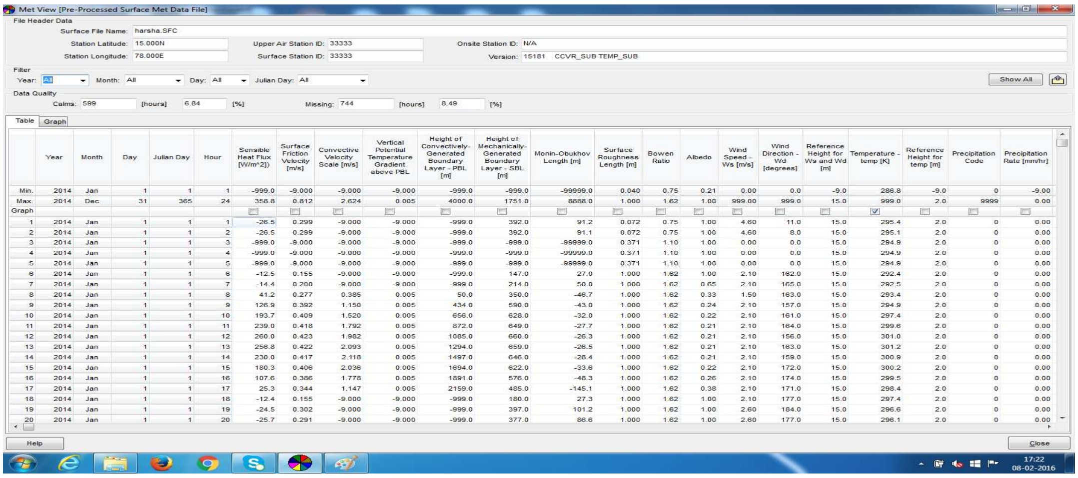
Met View [Profile Met Data File]

Profile File Name: harsha.PFL

Filter Year: All Month: All Day: All

	Year	Month	Day	Hour	Measurement Height [m]	1, if this is the last (highest) level for this hour, or 0 otherwise	Direction the wind is blowing from for the current level [degrees]	Wind Speed for the current level [m/s]	Temperature at the current level [C]	Standard deviation of the wind direction fluctuations [degrees]	Standard deviation of the vertical wind speed fluctuations [m/s]
Min.	2014	Jan	1	1	15.0	1	0.0	0.00	13.6	99.0	99.00
Max.	2014	Dec	31	24	15.0	1	999.0	999.00	99.9	99.0	99.00
Graph											
1	2014	Jan	1	1	15.0	1	11.0	4.60	22.3	99.0	99.00
2	2014	Jan	1	2	15.0	1	8.0	4.60	22.0	99.0	99.00
3	2014	Jan	1	3	15.0	1	0.0	0.00	21.8	99.0	99.00
4	2014	Jan	1	4	15.0	1	0.0	0.00	21.7	99.0	99.00
5	2014	Jan	1	5	15.0	1	0.0	0.00	21.7	99.0	99.00
6	2014	Jan	1	6	15.0	1	162.0	2.10	19.3	99.0	99.00
7	2014	Jan	1	7	15.0	1	165.0	2.10	19.4	99.0	99.00
8	2014	Jan	1	8	15.0	1	163.0	1.50	20.2	99.0	99.00
9	2014	Jan	1	9	15.0	1	157.0	2.10	21.7	99.0	99.00
10	2014	Jan	1	10	15.0	1	161.0	2.10	24.3	99.0	99.00
11	2014	Jan	1	11	15.0	1	164.0	2.10	26.5	99.0	99.00
12	2014	Jan	1	12	15.0	1	156.0	2.10	27.9	99.0	99.00
13	2014	Jan	1	13	15.0	1	163.0	2.10	28.1	99.0	99.00
14	2014	Jan	1	14	15.0	1	159.0	2.10	27.7	99.0	99.00
15	2014	Jan	1	15	15.0	1	172.0	2.10	27.1	99.0	99.00
16	2014	Jan	1	16	15.0	1	174.0	2.10	26.4	99.0	99.00
17	2014	Jan	1	17	15.0	1	171.0	2.10	25.3	99.0	99.00
18	2014	Jan	1	18	15.0	1	177.0	2.10	24.2	99.0	99.00
19	2014	Jan	1	19	15.0	1	184.0	2.60	23.5	99.0	99.00
20	2014	Jan	1	20	15.0	1	177.0	2.60	23.0	99.0	99.00
21	2014	Jan	1	21	15.0	1	180.0	3.10	22.4	99.0	99.00
22	2014	Jan	1	22	15.0	1	172.0	3.10	22.0	99.0	99.00
23	2014	Jan	1	23	15.0	1	170.0	3.10	21.5	99.0	99.00
24	2014	Jan	1	24	15.0	1	170.0	2.60	21.1	99.0	99.00
25	2014	Jan	2	1	15.0	1	156.0	2.60	20.8	99.0	99.00

Figure 2: Typical PROFILE File of AERMOD Format



	Year	Month	Day	Julian Day	Hour	Sensible Heat Flux [W/m^2])	Surface Friction Velocity [m/s]	Convective Velocity Scale [m/s]	Vertical Potential Temperature Gradient above PBL	Height of Convectively-Generated Boundary Layer - PBL [m]	Height of Mechanically-Generated Boundary Layer - SBL [m]	Monin-Obukhov Length [m]	Surface Roughness Length [m]	Bowen Ratio	Albedo	Wind Speed - Ws [m/s]	Wind Direction - Wd [degrees]	Reference Height for Ws and Wd [m]	Temperature - temp [K]	Reference Height for temp [m]	Precipitation Code	Precipitation Rate [mm/hr]
Min.	2014	Jan	1	1	1	-999.0	-9.000	-9.000	-9.000	-999.0	-999.0	-99999.0	0.040	0.75	0.21	0.00	0.0	-9.0	286.8	-9.0	0	-9.00
Max.	2014	Dec	31	365	24	358.8	0.812	2.624	0.005	4000.0	1751.0	8888.0	1.000	1.62	1.00	999.00	999.0	15.0	999.0	2.0	9999	0.00
Graph																						
1	2014	Jan	1	1	1	-26.5	0.299	-9.000	-9.000	-999.0	392.0	91.2	0.072	0.75	1.00	4.60	11.0	15.0	295.4	2.0	0	0.00
2	2014	Jan	1	1	2	-26.5	0.299	-9.000	-9.000	-999.0	392.0	91.1	0.072	0.75	1.00	4.60	8.0	15.0	295.1	2.0	0	0.00
3	2014	Jan	1	1	3	-999.0	-9.000	-9.000	-9.000	-999.0	-999.0	-99999.0	0.371	1.10	1.00	0.00	0.0	15.0	294.9	2.0	0	0.00
4	2014	Jan	1	1	4	-999.0	-9.000	-9.000	-9.000	-999.0	-999.0	-99999.0	0.371	1.10	1.00	0.00	0.0	15.0	294.9	2.0	0	0.00
5	2014	Jan	1	1	5	-999.0	-9.000	-9.000	-9.000	-999.0	-999.0	-99999.0	0.371	1.10	1.00	0.00	0.0	15.0	294.9	2.0	0	0.00
6	2014	Jan	1	1	6	-12.5	0.155	-9.000	-9.000	-999.0	147.0	27.0	1.000	1.62	1.00	2.10	162.0	15.0	292.4	2.0	0	0.00
7	2014	Jan	1	1	7	-14.4	0.200	-9.000	-9.000	-999.0	214.0	50.0	1.000	1.62	0.65	2.10	165.0	15.0	292.5	2.0	0	0.00
8	2014	Jan	1	1	8	41.2	0.277	0.385	0.005	50.0	350.0	-46.7	1.000	1.62	0.33	1.50	163.0	15.0	293.4	2.0	0	0.00
9	2014	Jan	1	1	9	126.9	0.392	1.150	0.005	434.0	590.0	-43.0	1.000	1.62	0.24	2.10	157.0	15.0	294.9	2.0	0	0.00
10	2014	Jan	1	1	10	193.7	0.409	1.520	0.005	656.0	628.0	-32.0	1.000	1.62	0.22	2.10	161.0	15.0	297.4	2.0	0	0.00
11	2014	Jan	1	1	11	239.0	0.418	1.792	0.005	872.0	649.0	-27.7	1.000	1.62	0.21	2.10	164.0	15.0	299.6	2.0	0	0.00
12	2014	Jan	1	1	12	260.0	0.423	1.982	0.005	1085.0	660.0	-26.3	1.000	1.62	0.21	2.10	156.0	15.0	301.0	2.0	0	0.00
13	2014	Jan	1	1	13	256.8	0.422	2.093	0.005	1294.0	659.0	-26.5	1.000	1.62	0.21	2.10	163.0	15.0	301.2	2.0	0	0.00
14	2014	Jan	1	1	14	230.0	0.417	2.118	0.005	1497.0	646.0	-28.4	1.000	1.62	0.21	2.10	159.0	15.0	300.9	2.0	0	0.00
15	2014	Jan	1	1	15	180.3	0.406	2.036	0.005	1694.0	622.0	-33.6	1.000	1.62	0.22	2.10	172.0	15.0	300.2	2.0	0	0.00
16	2014	Jan	1	1	16	107.6	0.386	1.778	0.005	1891.0	576.0	-48.3	1.000	1.62	0.26	2.10	174.0	15.0	299.5	2.0	0	0.00
17	2014	Jan	1	1	17	25.3	0.344	1.147	0.005	2159.0	485.0	-145.1	1.000	1.62	0.38	2.10	171.0	15.0	298.4	2.0	0	0.00
18	2014	Jan	1	1	18	-12.4	0.155	-9.000	-9.000	-999.0	180.0	27.3	1.000	1.62	1.00	2.10	177.0	15.0	297.4	2.0	0	0.00
19	2014	Jan	1	1	19	-24.5	0.302	-9.000	-9.000	-999.0	397.0	101.2	1.000	1.62	1.00	2.60	184.0	15.0	296.6	2.0	0	0.00
20	2014	Jan	1	1	20	-25.7	0.291	-9.000	-9.000	-999.0	377.0	86.6	1.000	1.62	1.00	2.60	177.0	15.0	296.1	2.0	0	0.00

Figure 3: Typical SURFACE File of AERMOD Format

With MET data processed through AERMET processor and providing input for sources and receptors along with terrain features, dispersion model was prepared using AERMOD 9.1. The model was run for pollutants SPM, SO_2, NO_X

- One year met data.
- Monthly

The MODEL was run for SPM, SO_2, NO_X.

The results in terms of concentration contours were represented in this chapter along with its interpretation. Output also includes pollutant concentration at key receptors locations (Villages) as well as nearby locations within a boundary of 15 km.

The model was run for one year met data the receptors concentrations were obtained for 2 hr ,6 hr, 12hr, 24 hr average (daily) , monthly and Annually ,based upon NAAQS, 2009 norms. Results were compared with NAAQS, 2009 to check any violation of norms by the industry.

The Model was run with spm, so_2, no_x pollutants and MET data for one year.

- 2 Hr Average- One year MET data
- 6 Hr Average- One year MET data
- 12 Hr Average- One year MET data
- 24 Hr Average- One year MET data
- Annual Average- One year MET data

Key Assumptions in the Model

- The emission rate is constant.
- Dispersion (diffusion) is negligible in the downwind (x) direction
- Horizontal meteorological conditions are homogenous over the space being modeled.

For Each Hour Modeled

- An average wind speed is used
- Wind direction is constant
- Temperature is constant
- Atmospheric stability class is constant
- Mixing height is constant
- Pollutant are non-reactive gases or aerosols
- The plume is reflected at the surface with no deposition or reaction with the Surface
- The dispersion in the crosswind (y) and vertical (z direction) take form of Gaussian distributions about the plume centerline.

Spatial Distribution of Concentrations of CRITERIA POLLUTANT

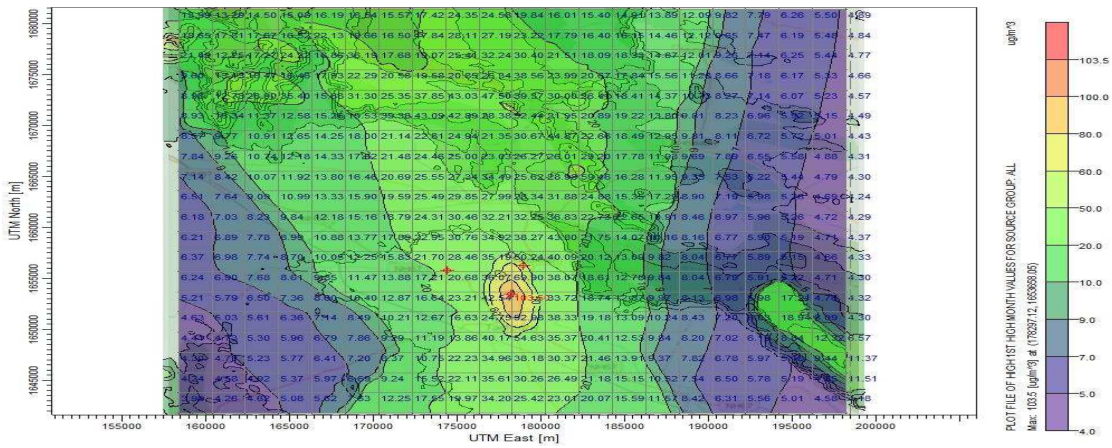


Figure 4: Isopleths of SPM Concentration Contours 24 Hr Average (One Year Met Data)

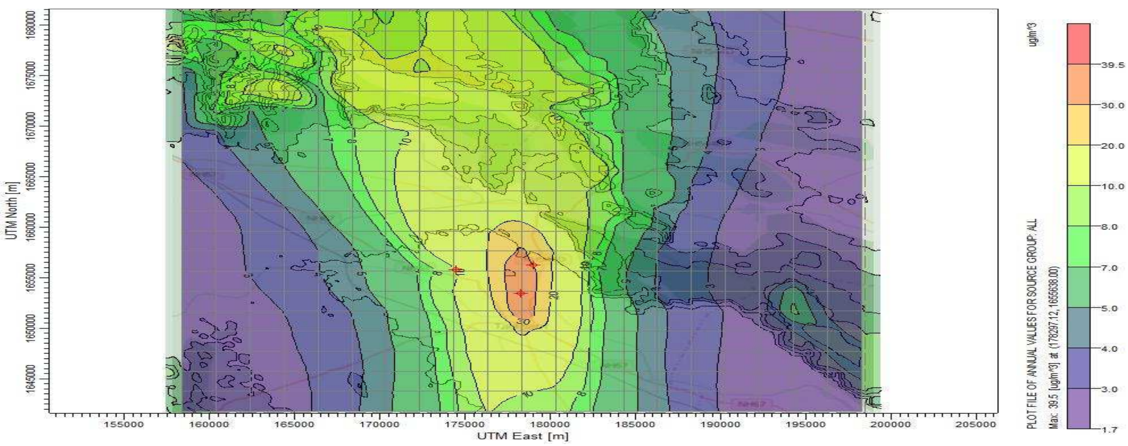


Figure 5: Isopleths of SPM Concentration Contours Annual Average (One Year Met Data)

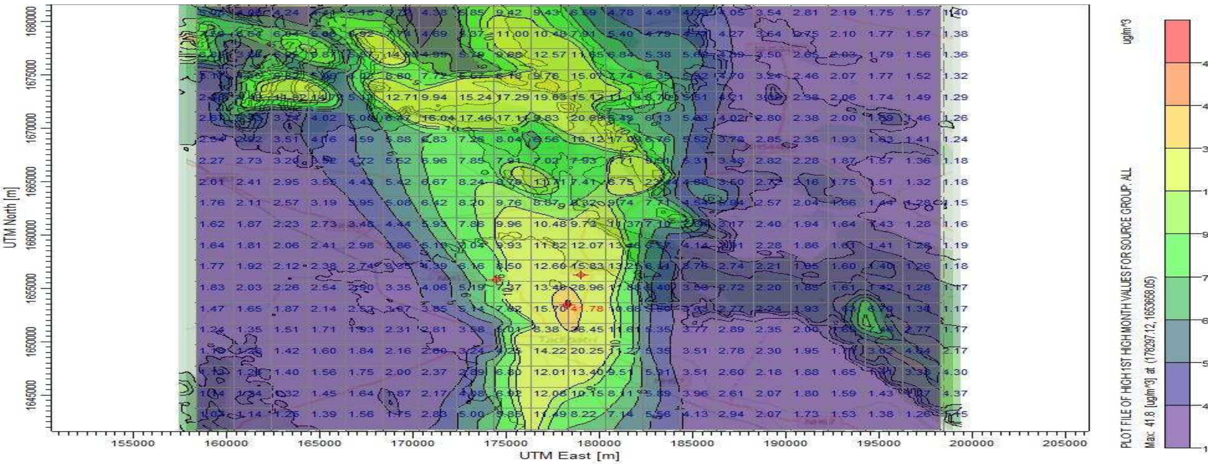


Figure 6: Isopleths of NO_X Concentration Contours 24Hr Average (One Year Met Data)

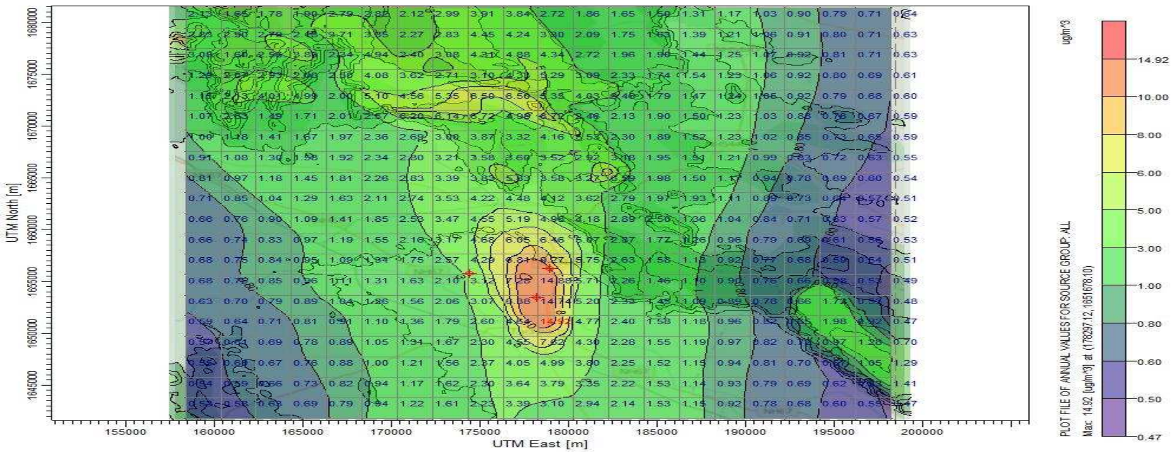


Figure 7: Isopleths of NO_X Concentration Contours Annual Average (One Year Met Data)

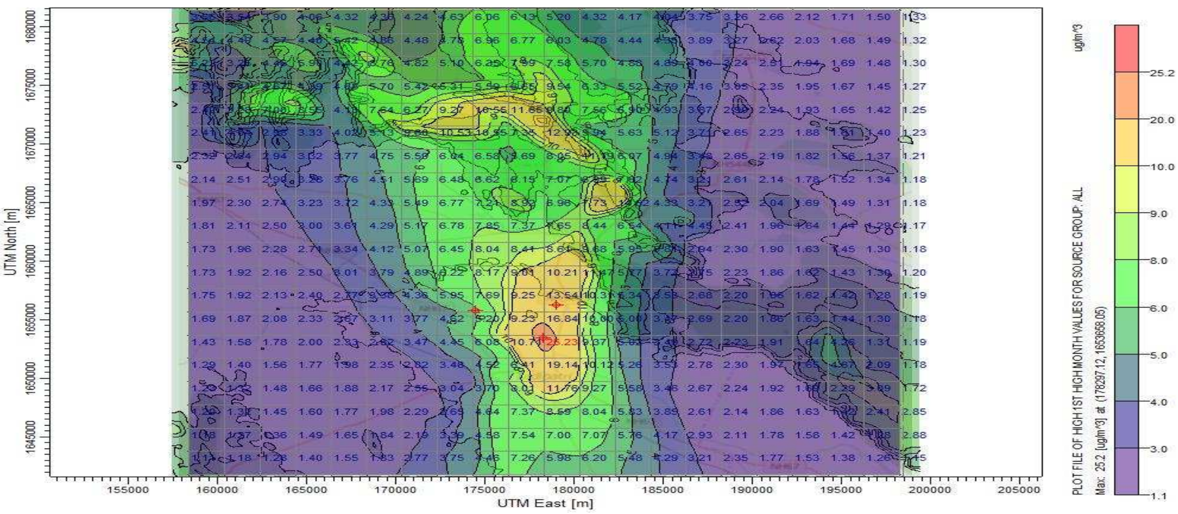


Figure 8: Isopleths of SO_2 Concentration Contours 24 Hr Average (One Year Met Data)

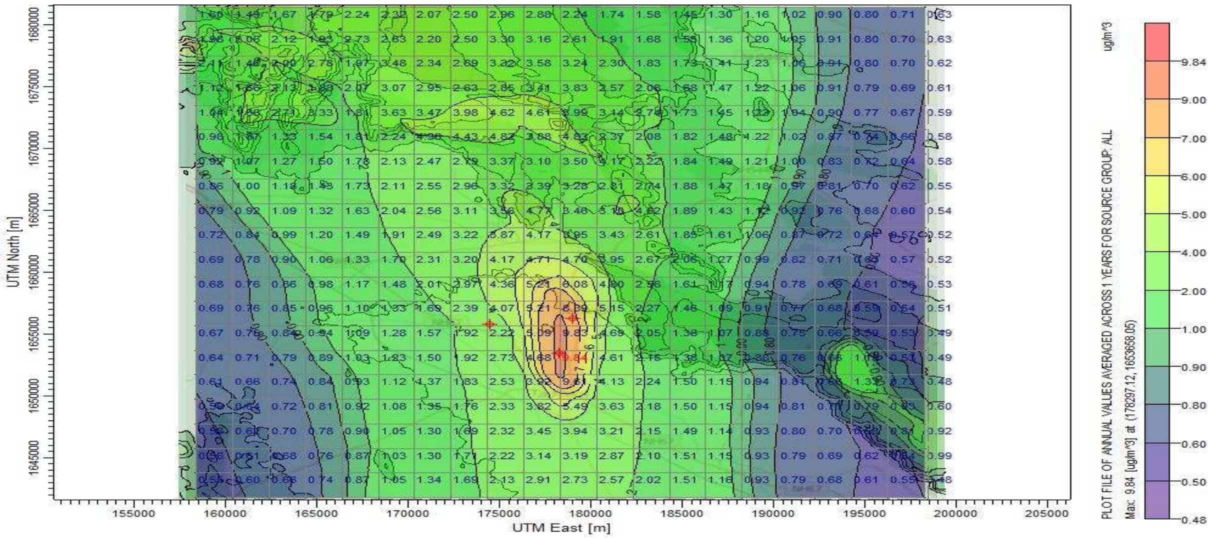


Figure 9: Isopleths of SO_2 Concentration Contours Annual Average (One Year Met Data)

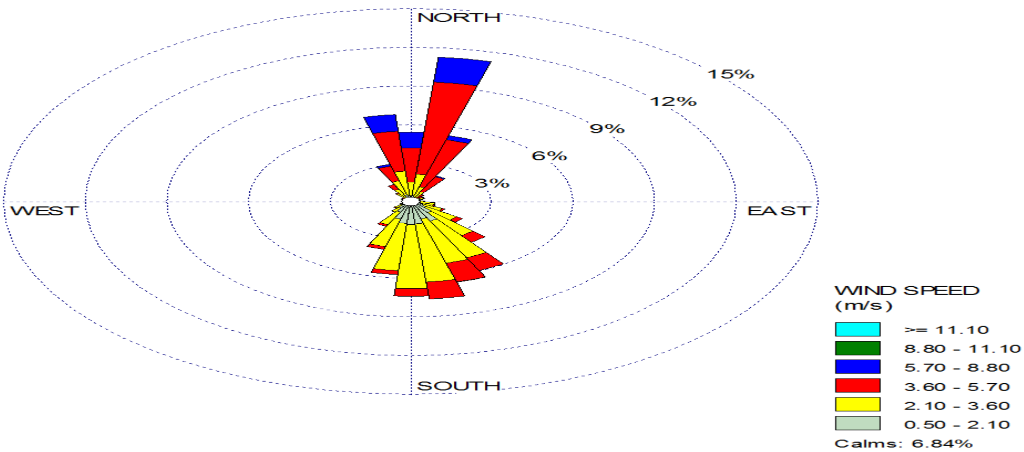


Figure 10: Typical Wind Rose Diagram

Spatial Distribution of Criteria Pollutant as Over GOOGLE MAP of Location

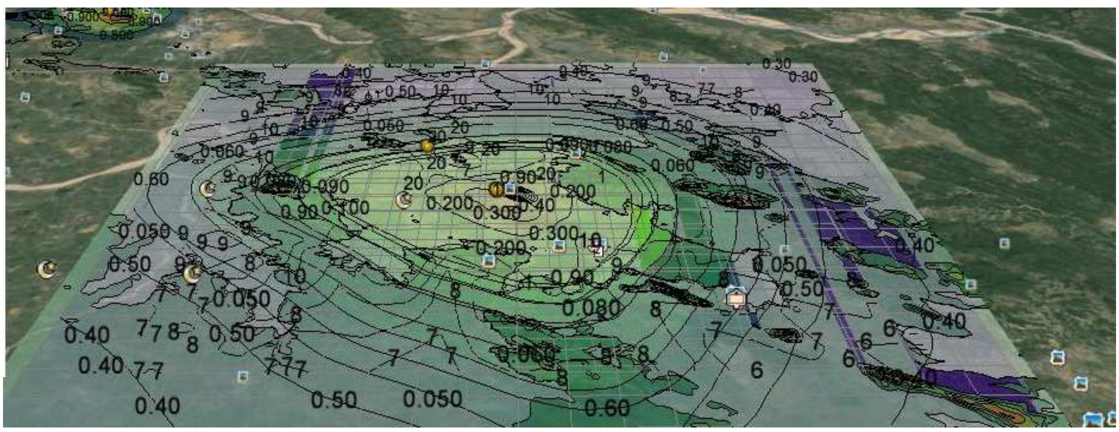


Figure 11: Spatial Distribution of SPM over Study Area

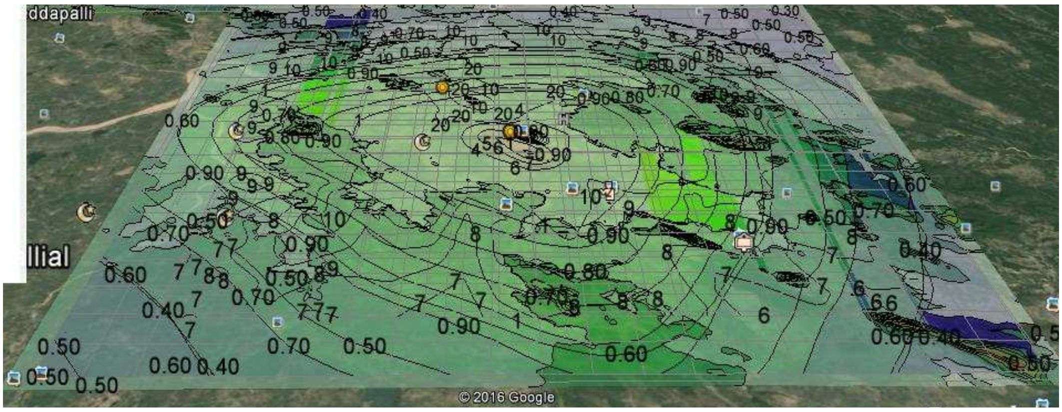


Figure 12: Spatial Distribution of SO_2 over Study Area

Figure 13: Spatial Distribution of NO_X over Study Area

Validation of Aermod

Andhra Pradesh State pollution control board (APPCB) established two ambient air quality monitoring stations around the source point of ultra tech cement industry. The coordinates of the monitoring stations are identified from the grid map. Details of source and monitoring stations in the study area are shown in the following table 1.

Table 1: Details of Source and Monitoring Stations in the Study Area

Source/Monitoring Station	Latitude	Longitude	Coordinates	
			X	Y
AAQMS-1	15.7114	78.4690	178926.58	1662584.17
AAQMS-2	15.7119	78.4642	17894.32	1662553.10

Modeled output values are collected from the output files of the AERMOD model, these values are not included the background concentrations of the site. Predicted (P) values can be calculated by adding the background concentrations to the modeled output concentrations. APPCB provided the measured (M) values from the monitoring stations for the period of January-2014 to December-2014. Validation of modeling is carried out through the predicted and measured concentrations of SPM, SO_2 and NO_X.

Statistical Performance

The coefficient of determination, R2, is calculated using a Pearson correlation coefficient calculator for predicted concentrations from Aermod and measured values from all the Ambient Air Quality Monitoring Stations. For the best curve fit R^2 must be 1. **Table**1 provides a Statistical performance measure of Aermod model.

Table 2: Statistical Performance Measures of AERMOD Model

Parameter	Monitoring Station	R^2	Inference
SPM	AAQMS-1	0.84	Strong positive correlation
	AAQMS-2	0.83	Strong positive correlation
SO_2	AAQMS-1	0.79	Strong positive correlation
	AAQMS-2	0.81	Strong positive correlation
NO_X	AAQMS-1	0.90	Strong positive correlation
	AAQMS-2	0.88	Strong positive correlation

CONCLUSIONS

The replication of pollutant (SPM, SO_2 and NO_X) dispersion from the cement industry was obtained by applying a AERMOD model and the results of predicted values were compared with the measured concentrations at the UTCL site from January 2014 to December 2014 made available by APPCB. For the Ambient Air Quality Monitoring Stations, the predicted concentrations were found to be in good agreement with the measured data. For AERMOD model, values of coefficient of determination R^2 are in the range 0.79 to 0.90. It may therefore be inferred that AERMOD model gives better results. The results demonstrated that theAERMOD model can be applied to study the dispersion of criteria air pollutant concentrations and that the predictions are of reasonable accuracy and may be used for any other industry in its vicinity up to 50 km Diameter.

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