Dispersion modelling to assess ambient air quality impact due to carbon industry

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***Abstract*—Industrial activities are significant contributors to elevated emission rates of particulate matter, total particulate matter (TPM), and other pollutants. The proximity of numerous industrial plants to densely populated areas can severely impact human health. The ramifications may be exacerbated when these emissions are compounded by pre-existing background concentration levels. This paper addresses the evaluation of TPM pollution attributable to industrial operations near the villages of Patalganga in the Raigad district. An atmospheric dispersion model, AERMOD version 8.8.9, was employed for this analysis. An inventory of emission sources was meticulously compiled for the carbon manufacturing sector. Villages within a 5 km radius were designated as primary receptors. Meteorological data spanning one year was processed utilizing the AERMET processor. The model was executed for TPM pollutants under various scenarios. The model outputs were juxtaposed against the National Ambient Air Quality Standards (NAAQS) established in 2009. Model simulations were conducted for annual, seasonal, and daily averaged emission scenarios. All ground-level concentrations (GLCs) at receptor locations (villages) were found to remain below the prescribed norms. Daily averaged model simulations are instrumental in elucidating plume dispersion and conducting a hotspot analysis of stack emissions. Seasonal averaged model outputs were evaluated in relation to sensitive receptors selected in all four cardinal directions of the industry. It was observed from the seasonal model runs that pollutant concentrations at receptors fluctuated in accordance with seasonal variations in meteorological conditions. All GLC values for TPM at key receptor locations were consistently below the NAAQS, 2009 standards. It was concluded that the aforementioned industry operates safely within this region.**

***Index Terms*—Pollutant, Dispersion, Impact, Modelling, TPM, and Air Mode Model.)**

I. INTRODUCTION

Carbon manufacturing plant is situated in the Patalganga industrial region of Raigad district. Carbon stands as the preeminent manufacturer and supplier of high-quality Carbon Black additives on a global scale. The company offers a comprehensive portfolio of products encompassing ASTM grades and specialty blacks, meticulously designed to fulfill the specific requirements of various sectors, including Rubber, Plastics, Coatings, Inks, and other specialized industries worldwide. Its extensive global manufacturing presence, characterized by substantial production capacities and logistical prowess, guarantees the consistent and uninterrupted availability of products of uniform quality for its clientele. Among its customers are renowned brands and enterprises across the Tires, Rubbers, Plastics, Inks, and Paints industries globally.

This document delineates the air dispersion modeling analysis for Total Particulate Matter (TPM) emitted from the Patalganga Carbon Industries Plant, alongside a comparative assessment with the National Ambient Air Quality Standards established in 2009 by the Central Pollution Control Board (CPCB) and the air emission standards mandated by the Maharashtra Pollution Control Board (MPCB) under the consent to operate. The air emission impact analysis was conducted utilizing AERMOD version 8.2 to ascertain whether the plant's air emissions exert a significant adverse effect on the air quality of the adjacent villages, particularly the Tribal Village.

II. MATERIALS AND METHODS

METHODOLOGY: AIR DISPERSION MODELING USING AERMOD

The AERMOD modeling system comprises a principal program (AERMOD) and two preparatory modules (AERMET and AERMAP). The primary function of AERMET is to compute boundary layer parameters essential for AERMOD. Conversely, AERMAP is tasked with determining terrain elevations and receptor grids pertinent to AERMOD. Both AERMET and AERMAP necessitate observational data to effectively characterize the growth and structure of the atmospheric boundary layer. AERMOD employs terrain, boundary layer, and source data to model the transport and dispersion of pollutants, ultimately calculating temporally averaged air pollution concentrations.

Dispersion modeling necessitates three distinct models alongside requisite inputs, delineated as follows:

AERMET: computes boundary layer parameters for integration into AERMOD.

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

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

AERMAP: determines terrain elevations and receptor grids for input into AERMOD.

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

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

AERMOD: calculates temporally averaged air pollution concentrations at receptor locations for comparison against the NAAQS.

Model inputs: source parameters (derived from permit application); boundary layer meteorology (sourced from AERMET); receptor data (obtained from AERMAP).

Figure 01 elucidates the schematic representation of the various processes involved in dispersion modeling.

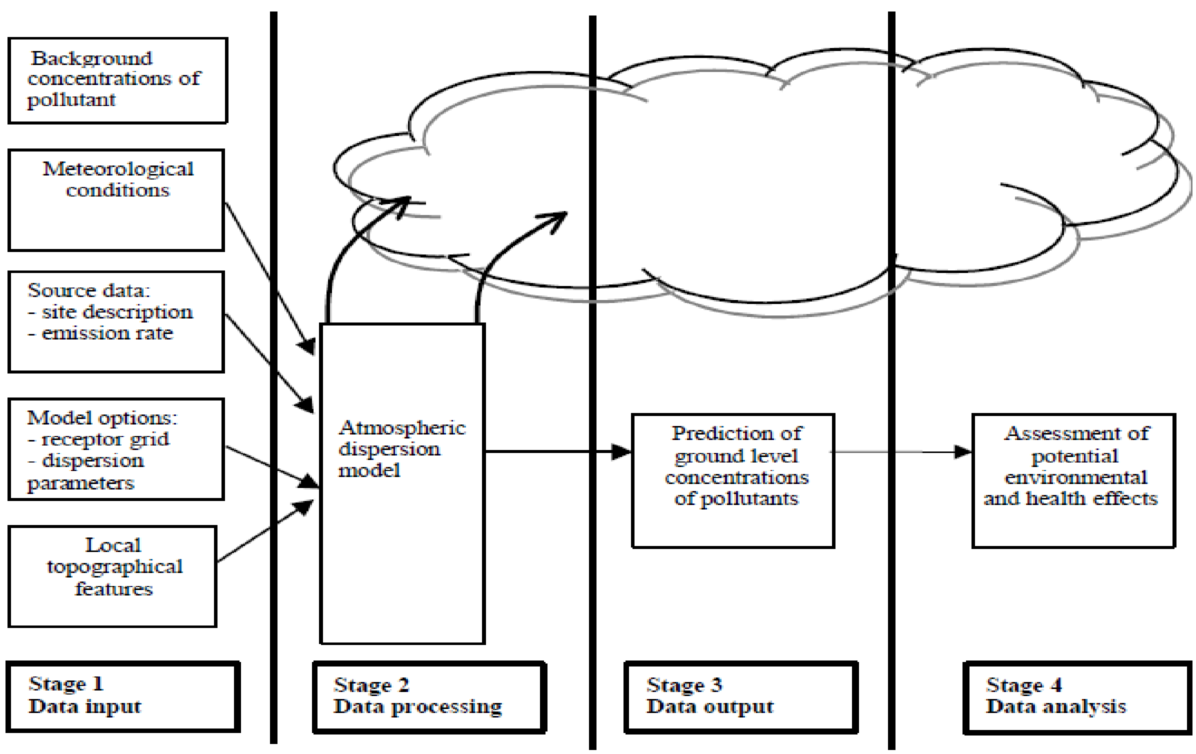

Fig.1 Schematic of various processes involved dispersion modeling.

METEOROLOGICAL DATA FOR AERMOD

AERMET necessitates as input surface characteristics delineated by albedo, surface roughness, and Bowen ratio, in conjunction with standard meteorological observations. Subsequently, planetary boundary layer parameters—including friction velocity, Monin-

Obukhov length, convective velocity scale, temperature scale, mixing height, and surface heat flux—are estimated by AERMET. The fundamental input data for AERMET comprises the following elements:

- Hourly surface data
- Upper air data
- Location of the relevant site, sectors, and surface data.

These components are elucidated below:

Hourly surface data requirements encompass the parameters listed below:

- Cloud cover (tenths)
- Ceiling height (m)
- Dry bulb temperature (°C)
- Global horizontal radiation (Whm^-2d^-1)
- Relative humidity (%)
- Precipitation amount (hundredths of inches)
- Station pressure (mb)
- Wind direction (degrees)
- Wind speed (m/s)

Upper air data

There are two methodologies for estimating upper air data:

1. **Standard AERMET**: This method processes specified upper air data.
2. **Upper air estimator**: This approach estimates upper air data derived from hourly surface data.

Location of the pertinent site, sectors, and surface data: Specific values are assigned for albedo, Bowen ratio, and surface roughness contingent upon land use types. Albedo represents the fraction of sunlight that is reflected back into space without absorption, with values ranging from 0.1 for dense deciduous forests to 0.9 for pristine snow. The Bowen ratio signifies the quantity of moisture available to facilitate turbulent processes; it is defined as the ratio of sensible heat flux to latent heat flux. During daylight hours, the Bowen ratio achieves a relatively stable positive value, fluctuating from 0.1 over aquatic surfaces to 10 over arid deserts at midday. Surface roughness length serves as a measure of the drag exerted by the ground surface on the wind, correlating to the height of obstacles interrupting wind flow. In principle, it denotes the height at which the mean horizontal wind speed approaches zero, with values ranging from less than 0.001 m over tranquil water surfaces to 1 m or more in forested or urban environments.

METEOROLOGICAL CONDITIONS AS MODEL INPUTS

AERMET, a pre-processor of AERMOD, was employed to compute the hourly boundary layer parameters, such as Monin-Obukhov length, convective velocity scale, temperature scale, mixing height, and surface heat flux. The parameters (including surface heat flux and Monin-Obukhov length) derived from AERMET are pivotal in the dynamics of the boundary layer, which subsequently affects the dispersion of pollutants.

The aforementioned meteorological data was utilized to execute AERMOD. Both the Climatology Research Group's database and the Eskom database were consulted to acquire surface characteristics, cloud cover, upper air temperature soundings, and near-surface wind speed measurements within the study area. Longitudinal and latitudinal coordinates, as well as the time zone and wind speed thresholds, were incorporated as inputs to AERMET. AERMET generated two files for input into AERMOD, with the surface file encompassing both observed and calculated surface observations.

Elevation data as model input

AERMAP was utilized as a pre-processor to assimilate the elevation data sets,

III. RESULTS AND DISCUSSION

With meteorological data processed through the AERMET processor and providing input for sources and receptors, along with terrain features, the dispersion model was developed utilizing AERMOD version 8.8.9. The model was executed for various pollutants over a comprehensive one-year meteorological dataset, as well as for a one-month winter dataset to evaluate the worst-case scenario. The model was not executed for the monsoon month, due to the substantial rainfall in the study area, which would facilitate a scrubbing action for the pollutants.

The model focused on Total Particulate Matter (TPM). The results, depicted in terms of concentration contours, are presented in this chapter along with their interpretation. The output also encompasses pollutant concentrations at key receptor locations (villages) as well as adjacent areas within a 5 km radius. The receptor concentrations were derived as 24-hour averages (daily) and annual averages, in accordance with the National Ambient Air Quality Standards

(NAAQS) established in 2009. The results were juxtaposed with the NAAQS, 2009, to ascertain any potential violations of norms by the industry.

The model was executed with the TPM pollutant utilizing meteorological data as follows:

- Annual Average - One year of meteorological data
- 24-Hour Average - One year of meteorological data
- 24-Hour Average - One Month of Meteorological Data - January

Key assumptions in the model include:

- The emission rate remains constant
- Dispersion (diffusion) is negligible in the downwind (x) direction
- Horizontal meteorological conditions are homogeneous across the spatial domain being modeled
- For each hour modeled, an average wind speed is employed
- Wind direction is assumed to be constant
- Temperature is held constant
- Atmospheric stability class remains unchanged
- Mixing height is maintained at a constant level
- Pollutants are considered non-reactive gases or aerosols
- The plume is reflected at the surface with no deposition or reaction with the surface
- Dispersion in the crosswind (y) and vertical (z) directions takes the form of Gaussian distributions about the plume centerline.

The final output concentration contours are illustrated in the following figures.

Fig.1 TPM Concentration Contours Annual Average (one year MET data)

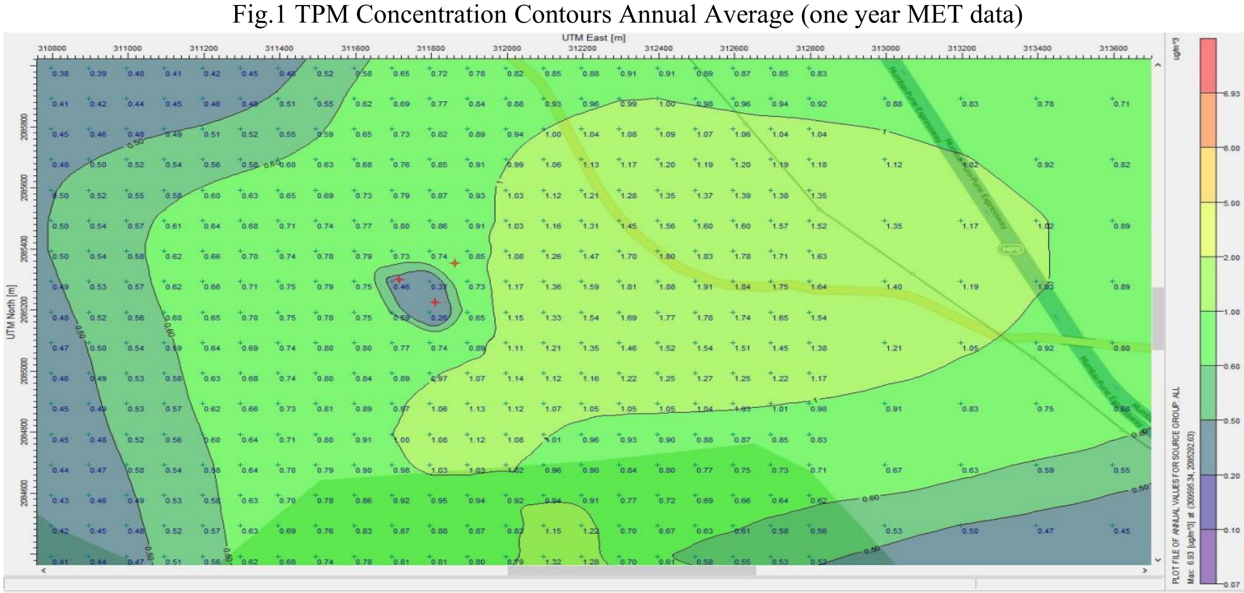

Fig.2 Surface Characteristics TPM Concentration Contours Annual Average (one year MET data)

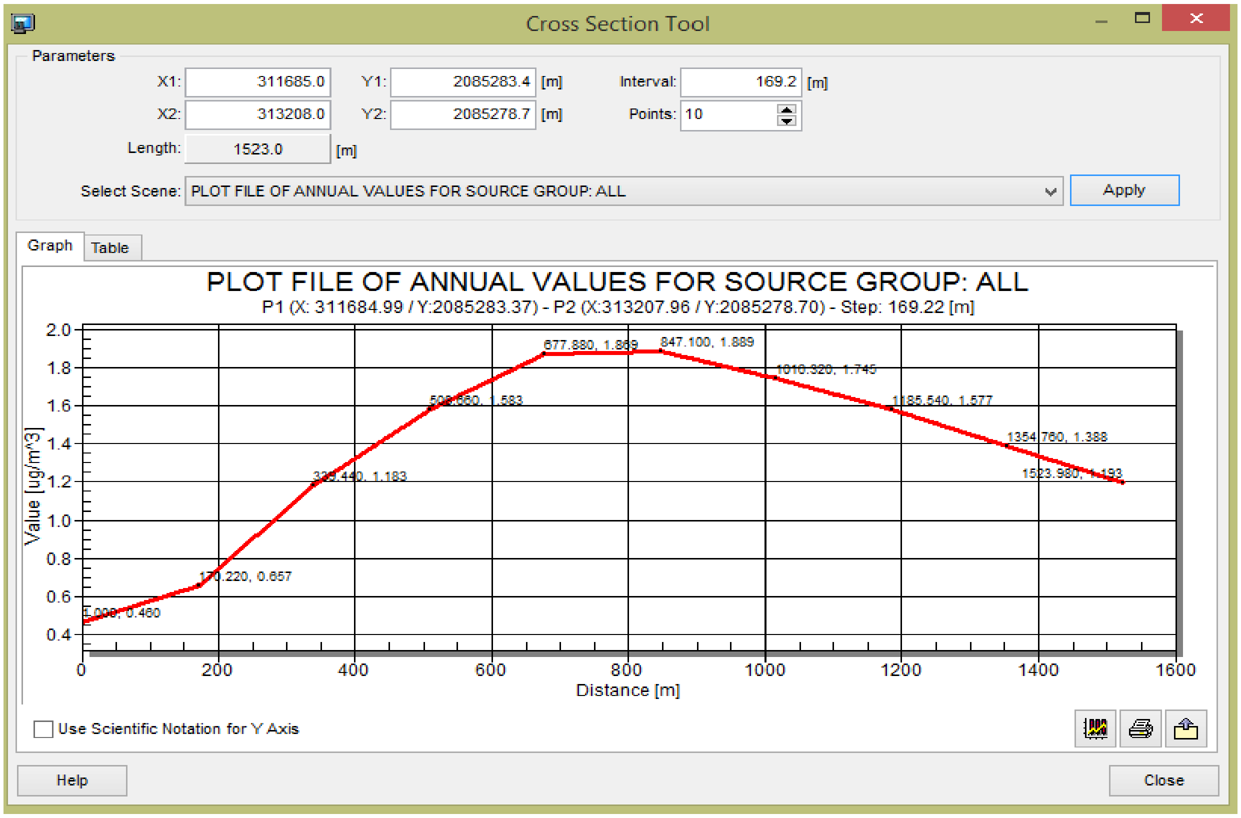

Fig.3 TPM Concentration Annual Average variation over a distance of 1400 m from the sources

Table No. 1 Summary of AERMOD TPM Outputs for Yearly Averaged Model Runs for January 2022

S.N.	Name of the receptor village	Highest GLC-Ground level Concentration in(ug/m3) Annual. Averaged
1	Dandwadi,	2.00
2	Talaveli,	1.00
3	Lohop,	1.00
4	Vadgaon,	0.5
5	Washivali,	0.2
6	Vanivali	0.5
7	Vayal	0.2

The results presented in this section were derived from the annual average of Total Particulate Matter (TPM). The concentration contours of TPM were generated as output from AERMOD, as illustrated in Figures 1 and 2, where the variation in concentration is depicted in a spectrum of colors. The TPM concentrations at significant receptor villages are detailed in Table 1. Figure No. 2 delineates the TPM concentrations at each receptor point in accordance with the receptor grid. Notably, all Ground Level Concentration (GLC) values within a 5 km radius remain below the National Ambient Air Quality Standards (NAAQS) for ambient air quality. Figure No. 3 exemplifies the application of AERMOD, elucidating the fluctuations in pollutant concentration with increasing distance. This analysis is facilitated through the cross-sectional tool. Figure No. 3 illustrates the alteration in TPM concentration extending up to 1400 meters from the emission sources.

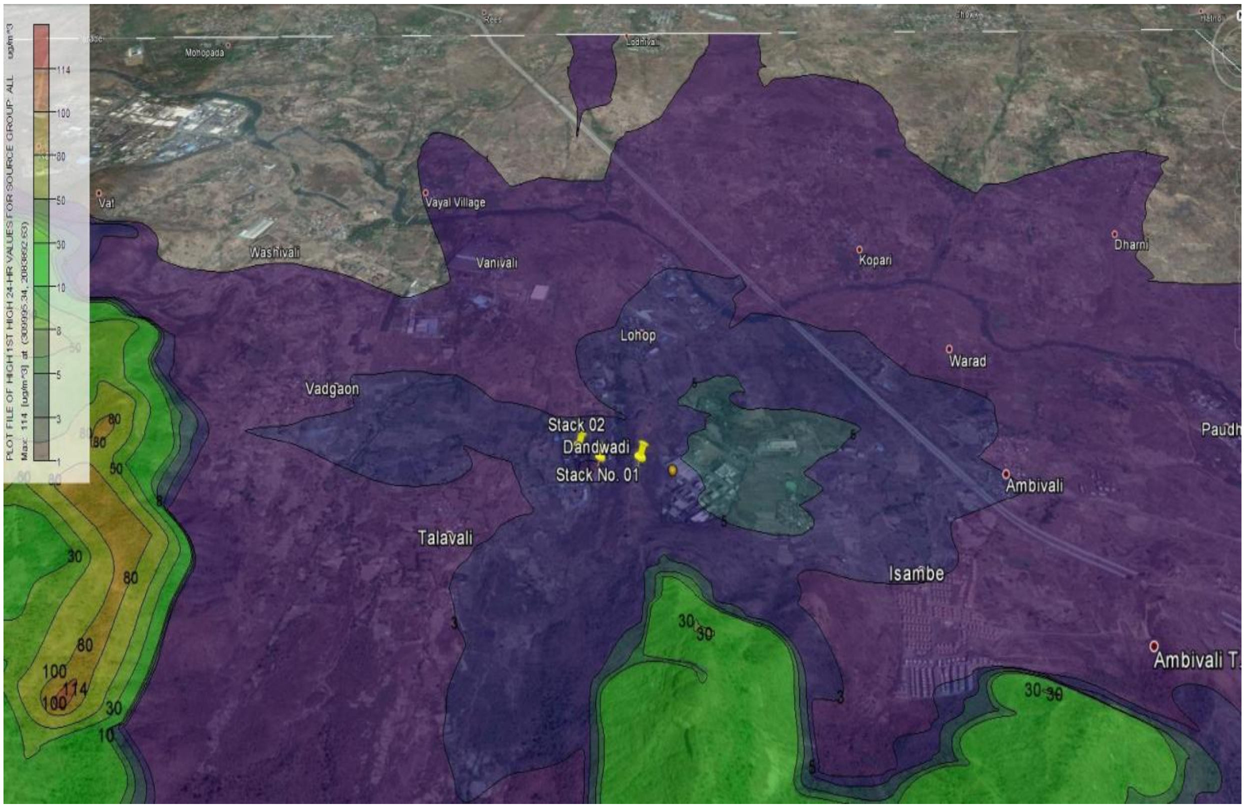

Fig4 TPM Concentration Contours 24 Hr Average (one year MET data)

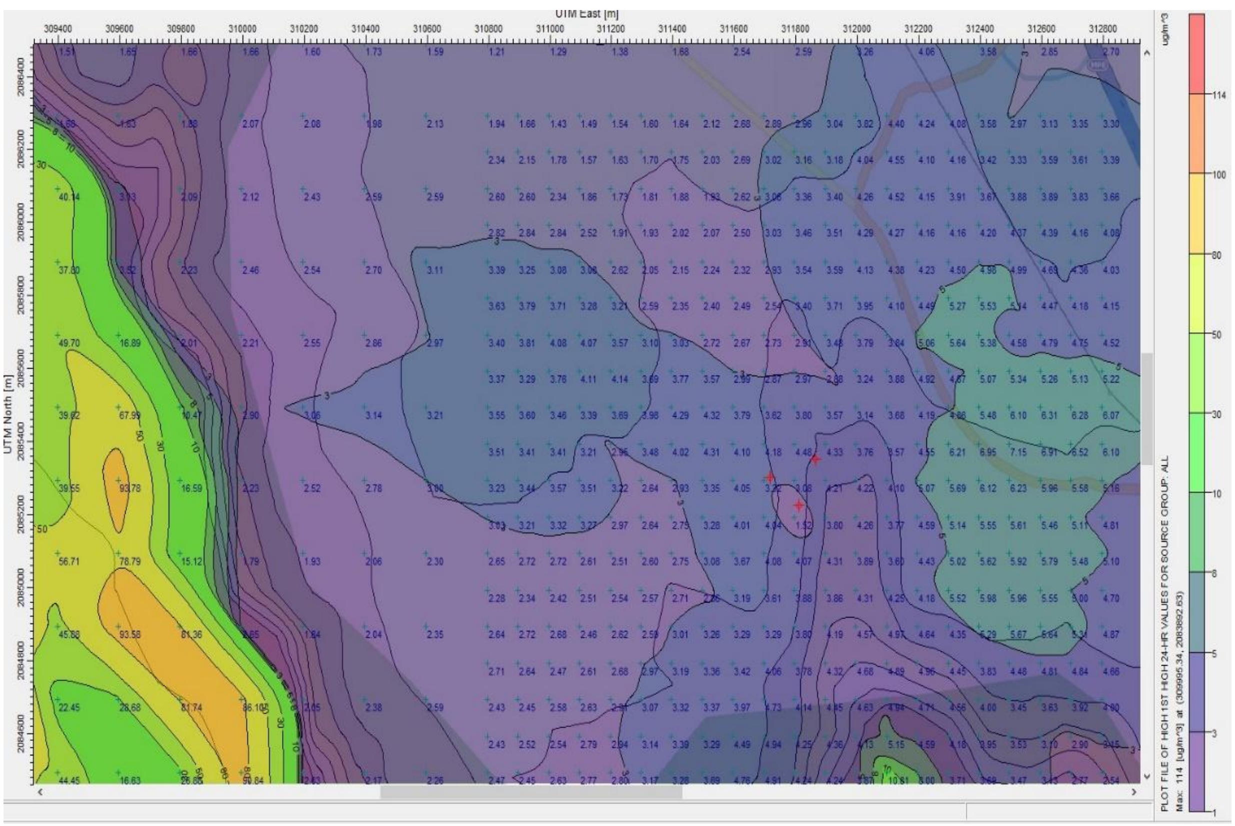

Fig.5 TPM Concentration Contours 24 Hr Average (one year MET data)

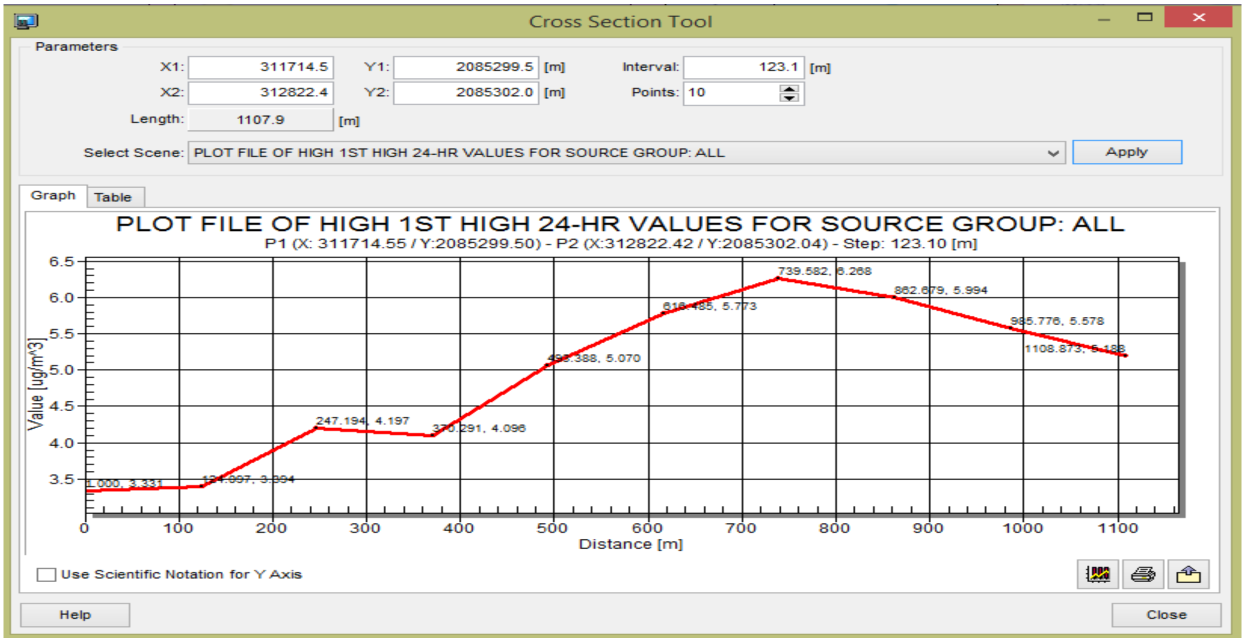

Fig.6 TPM Concentration 24 Hr Average variation over a distance of 1100 m from the sources

Table No.2 Summary of AERMOD TPM Outputs for Daily Averaged (24 Hr) Model Runs for 2022

S.No.	Name of the receptor village	Highest GLC – Ground level concentration in (µg/m3) 24 Hr. Average Daily average
1	Dandwadi,	5.00
2	Talaveli,	3.00
3	Lohop,	3.00
4	Vadgaon,	3.00
5	Washivali,	ND (Not Detected)
6	Vanivali	3.00
7	Vayal	ND (Not Detected)

The results presented in this section were derived from the 24-hour average of Total Particulate Matter (TPM). The concentration contours of TPM are generated as outputs from AERMOD, as depicted in Figures 4 and 5, where concentration variations are illustrated using a spectrum of colors. The TPM concentrations at key receptor villages are detailed in Table 4. The concentrations at each receptor point correspond to the receptor grid delineated in Figure 5.

Notably, all Ground Level Concentration (GLC) values within a 5 km radius are below the National Ambient Air Quality Standards (NAAQS) thresholds. Figure 6 exemplifies the application of AERMOD, facilitating an understanding of how pollutant concentration varies with distance, accomplished through the utilization of the cross-section tool. Figure 6.

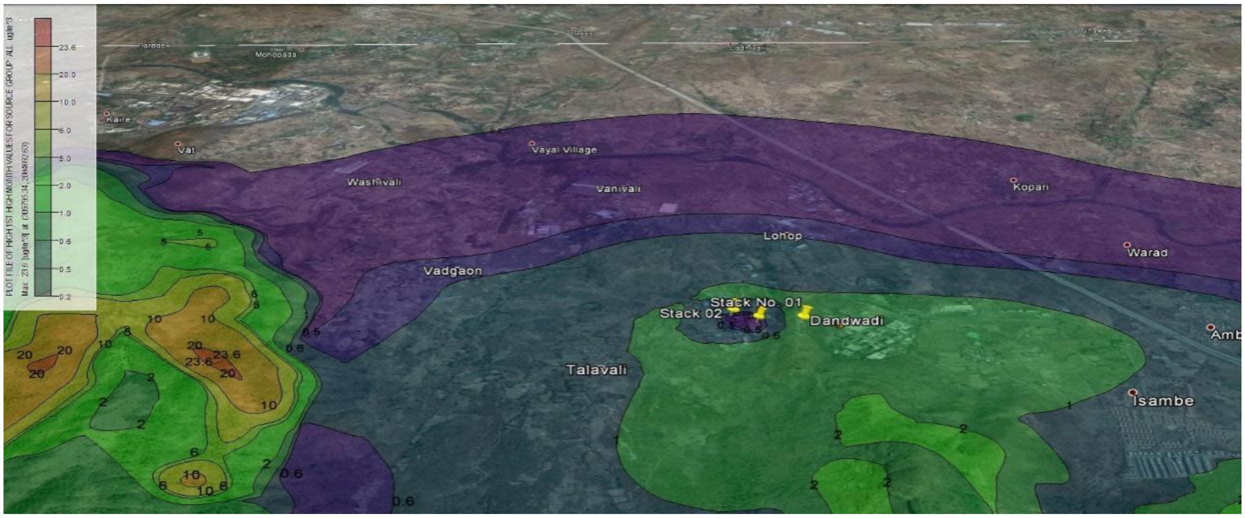

Fig 7. TPM Concentration Contours 24 Hr Average (one winter Month MET data- January)

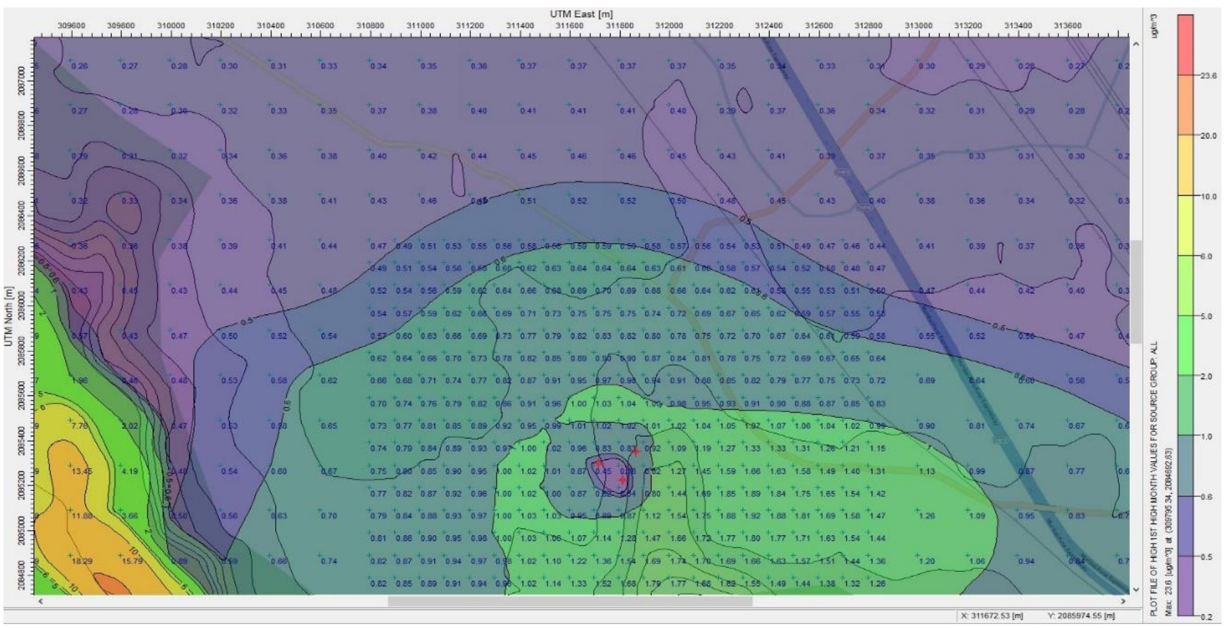

Fig.8 TPM Concentration Contours 24 Hr Average (one winter Month MET data- January

Table No.3 Summary of AERMOD TPM Outputs for Daily Averaged (24 Hr) Model Runs for January 2022

S.N.	Name of the receptor village	HighestGLC-Groundlevel concentration in(ug/m^3) Daily Averaged-24 Hr
1	Dandwadi,	5.00
2	Talaveli,	3.00
3	Lohop,	3.00
4	Vadgaon,	3.00
5	Washivali,	ND
6	Vanivali	ND
7	Vayal	ND

AERMOD was executed utilizing meteorological data from January, with the objective of validating ground-level concentrations (GLCs) during the winter season and assessing the impact of calm wind conditions indicative of stable atmospheric circumstances. The results presented in this section pertain to total particulate matter (TPM) measured as a 24-hour average for the month of January. The concentration contours of TPM were derived from AERMOD outputs, as illustrated in Figures 7 and 8, wherein the variation in concentration is depicted using a spectrum of colors. TPM concentrations at pivotal receptor villages are detailed in Table 3. Notably, all GLC values within a 5 km radius are in compliance with the National Ambient Air Quality Standards (NAAQS) 2009 norms for ambient air quality.

IV. CONCLUSION

Based on the data meticulously collected and analyzed using AERMOD 8.8.9, the following conclusions can be substantiated. A comprehensive literature review revealed that AERMOD 8.8.9 is predominantly employed for dispersion modeling of non-reactive pollutants, such as Total Particulate Matter (TPM), from analogous industrial sources. Meteorological parameters, including wind velocity, precipitation, temperature, solar radiation, and topography, significantly influence the dispersion of these pollutants. Ground Level Concentrations (GLCs) tend to be relatively diminished during the rainy season due to the scrubbing effect of precipitation on pollutant gases. Conversely, GLCs during the winter months are markedly elevated, attributed to stable atmospheric conditions. The geographical terrain plays a pivotal role in the dispersion dynamics of pollutants; in urban settings, the presence of multi-story edifices induces a building downwash effect. The output from the AERMOD 8.8.9 model indicates that pollutant concentrations in ambient air remain within acceptable limits as per the National Ambient Air Quality Standards (NAAQS) 2009 guidelines within a 5 km radius. While certain locations exhibit elevated concentrations of pollutants in ambient air quality, these areas are uninhabited. Consequently, the industry under scrutiny is deemed safe for operation in this region and is well-positioned to pursue the expansion of its manufacturing capabilities.

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