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PREDICTION OF $PM_{2.5}$ FROM VEHICULAR POLLUTION BY USING CALINE4 AT HYDERABAD

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ABSTRACT:-
This paper presents a study regarding the vehicular pollution by using CALINE4. All over the world concern is growing over the health effects of emissions from internal combustion engines in the transport fleet. Studies conducted using air pollution exposure information and various health indicators, such as hospital admissions, are invariably showing up real and dramatic effects. It is broadly demonstrated that air pollution in urban areas is mainly due to the intense use of motorized transport for travelling, with particular regard to private cars and heavy goods vehicles. This is a top priority issue for transportation planners and public authorities, given the harmful effects of pollution to human health and the environment

An efficient and effective approach for the prediction of air pollution due to road transport is necessary to improve ambient air quality. Highway dispersion models are widely used for prediction of air quality along road and highway corridors. Various input parameters used by these models for prediction of air quality along the road corridors. In the present study, Prediction of pollutants $PM_{2.5}$ by CALINE4 model was carried out under mixed traffic conditions. The road corridor selected at Sanath nagar, Hyderabad (India) was a stretch which connects National Highway-65 (NH-65) to Fathe Nagar in the city. The selected corridor caters to both inter-city and intra-city traffic and had mixed traffic conditions.

Prediction by CALINE4 model was carried out for 24 hours average input datasets representing different meteorological (wind speed, wind direction, mixing height, stability class), traffic (traffic volume and emission factors) and road characteristic (roadway width) along with terrain (surface roughness) characteristic.

Key words: Air quality, Prediction, Emission factor, Stability class, CALINE4, Receptor, link activity.

INTRODUCTION

There is a rapid growth in motor vehicle activity at a global level and has resulted in serious energy security and climate change implications. The transport sector consumes nearly half of the world's fuel supply. In urban areas in both developing and developed countries, it is predominately mobile or vehicular pollution that use the roadways as there transportation facility that contributes to air pollution. The major sources of pollutants include emissions from the combustion of fossil fuels in motor vehicles and for industrial processes, energy production, domestic cooking and heating, and high dust levels due to local construction, smoking, unpaved roads, sweeping, hotels, restaurants and long-range transport.

Due to all this the quality of air has become very poor that, it has started to affect every individual present. The rapid growth in motor vehicle activity has become a challenge to overcome in urban areas. This has brought a serious range of socio-economic, road safety, environmental, health degradation. The rapid growth in motor vehicles in urban areas is important not only because of their locally harmful air pollution effects, but also because of their regional and global impacts So the paper deals with the harmful effects of air pollution caused by traffic present in the urban areas. In this study, line source dispersion model CALINE4 used to estimate PM_{10}, $PM_{2.5}$ and CO concentrations.

Atmospheric dispersion models are significant to government regulatory agencies assigned with the task of prevention of air pollution and protection and management of ambient air quality. The models are generally used in the design of effective control strategies to reduce emissions of harmful air pollutants and are also employed to establish whether existing or proposed new industrial amenities will meet the Ambient Air Quality Standards (AAQS) in the nation or not. The present study of air pollutants dispersion from a line source deals with the popular accurate, and well updated dispersion model named CALINE4 View version 4.1. For the selected site (SANATH NAGAR, HYDERABAD) CALINE4 dispersion model is apt based on the model requirement conditions. As accuracy, sensitivity, time saving, receptor options, terrain options included in CALINE made it differ from CALINE3 dispersion model. However, the study area was not effecting by chemical actions in atmosphere, visibility constraints and coastal effects which are predominant conditions for use of CALROADS model made the present study to deal with CALINE4 View.

OBJECTIVES

- ✓ To analyze the traffic and meteorological conditions of the study area.
- ✓ To Plot Windrose graph of the study area.
- ✓ To predict the $PM_{2.5}$ by CALINE4 at standard and worst case.
- ✓ To find correlation co-efficient (r^2) between observed and predicted values of $PM_{2.5}$ pollutants by drawing graphs between predicted and observed concentration.
- ✓ To Forecast the traffic growth at the study area i.e. Sanath nagar for the years 2017-2025.
- ✓ To forecast annual average predicted concentration of $PM_{2.5}$.
- ✓ To compare predicted values of $PM_{2.5}$ at selected receptors at Sanath Nagar in Hyderabad with the standards proposed by Central Pollution Control Board (CPCB).

TOOLS

In the present work, CALINE4 series of model tool and GOOGLE EARTH PRO have been used for regulatory purposes. CALINE4 offers several advantages over the other previous models and has been used by many other researchers to predict pollutant concentration of vehicular pollutants along the roads/highways in Indian climatic conditions.CALINE4 (California Line Source Model version 4) is the fourth advanced version of CALINE series models. The dispersion algorithms used in CALINE series model are based on a modified form of a Gaussian point source plume. CALINE4 can be used to predict roadside concentration of carbon monoxide, nitrogen oxides and particulate matters.

Input parameters:

Job Filename: Enter the path and filename where the input data is stored. You may also browse to the file location after clicking the Browse button.

- **Job Title:** Optional provides a space for the user to enter a brief job description, up to 40 characters in length.
- **Pollutants:** Select one pollutant type to model – Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), or Particulates (PM).
- **Molecular Weight:** Displays the molecular weight input to the model based on the chosen pollutant ("n/a" for Particulates).
- **Settling Velocity:** The rate at which a particle falls with respect to its immediate surroundings. This parameter is an optional parameter for Particulates only ("n/a" for Carbon Monoxide and Nitrogen Dioxide). Only a value greater than or equal to zero can be used in the model.
- **Deposition Velocity:** The rate at which a pollutant can be adsorbed or assimilated by a surface. This parameter may be specified for all pollutants but it is optional and only a value greater than or equal to zero can be used in the model.
- **Aerodynamic Roughness Coefficient:** Also known as the Davenport-Wieringa roughness-length. These choices determine the amount of local air turbulence that affects plume spreading. CL4 offers the three choices for aerodynamic roughness coefficient.

  (I)Rural; Roughness Coefficient = 10cm (II) **Suburban:** Roughness Coefficient = 100 cm (III) **Central Business District:** Roughness Coefficient = 400 cm

Run Type

Different choices are associated with different hourly average wind angle (Wind angle is the angle between the roadway link and the wind direction) and averaging times (for CO concentrations only). CALINE4 calculates the angles based on data in the Link Geometry and Run Conditions tabs

- **Standard** – Calculates 1-hr average CO, NO_2, or PM concentrations at the receptors. The user must input a wind direction on the Run Conditions tab.
- **Worst-Case**– Calculates 1-hr average CO, NO_2 or PM concentrations at the receptors. The model selects wind angles that produce the highest concentrations at each of the receptors. This is the most appropriate choice for most users
- **Multi-Run** – Calculates 8-hr average CO concentrations at the receptors. The user must input wind angles for each hour.
- **Multi-Run/Worst-Case Hybrid** – Calculates 8-hr average CO concentrations at the receptors. The model selects wind angles that produce the highest CO concentrations at each of the receptors.

STUDY METHODOLOGY:

CALINE 4 model is a fourth-generation line source air quality dispersion model that is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion in the proximity of roadways. The model employs source strength, meteorology, and site geometry and site characteristics as input parameters and predicts pollutant concentrations for receptors located within 500 meters either side of the roadways. The CALINE 4 model allows roadways to be broken into multiple links that can vary in traffic volume, emission rates, height, and width. The Components and Instruments used in this study are shown in the Table 1

SI No.	Task	Data Required	Instrument/Method/ Model
1	Plotting Wind Rose	Wind speed. Wind Direction & Rainfall intensity	USEPA WRplot
2	Site selection for Traffic count	Based on local factors & significance of traffic volume	Manual counting
3	Road geometry	Length, Direction, Longitudinal elevation	Manual (Chaining, compass & leveling)
4	Topo-map of study area	Block elevation	Extracted from standard Topo-map.
5	Prediction of vehicular emission dispersion	Meteorological data & surface data, traffic count & emission factors.	CALINE 4

Table 1shows the components and instruments used in the study

Figure 2 shows the sampling location at the study area. The monitoring station is located at Sanath Nagar, which is one of the busiest roads in Hyderabad city. The city lies at 17.366° N latitude and 78.476° E longitude, rises to an average height of 536 m above the sea level. Geographically the city is located in the northern part of Deccan plateau, in Southern India on the banks of Musi River. Occupying 650 square kilometers (250 sq. mi) along the banks of the Musi River, it has a population of about 6.7 million and a metropolitan population of about 7.75 million, making it the fourth most populated and sixth most populated urban agglomeration in India. It was done by standard methods as prescribed by Indian regulatory authority. In order to estimate the performances CALINE 4 used to predict air pollutants. In the present study Sanath Nagar, in Hyderabad city, was considered to examine the ambient air quality.

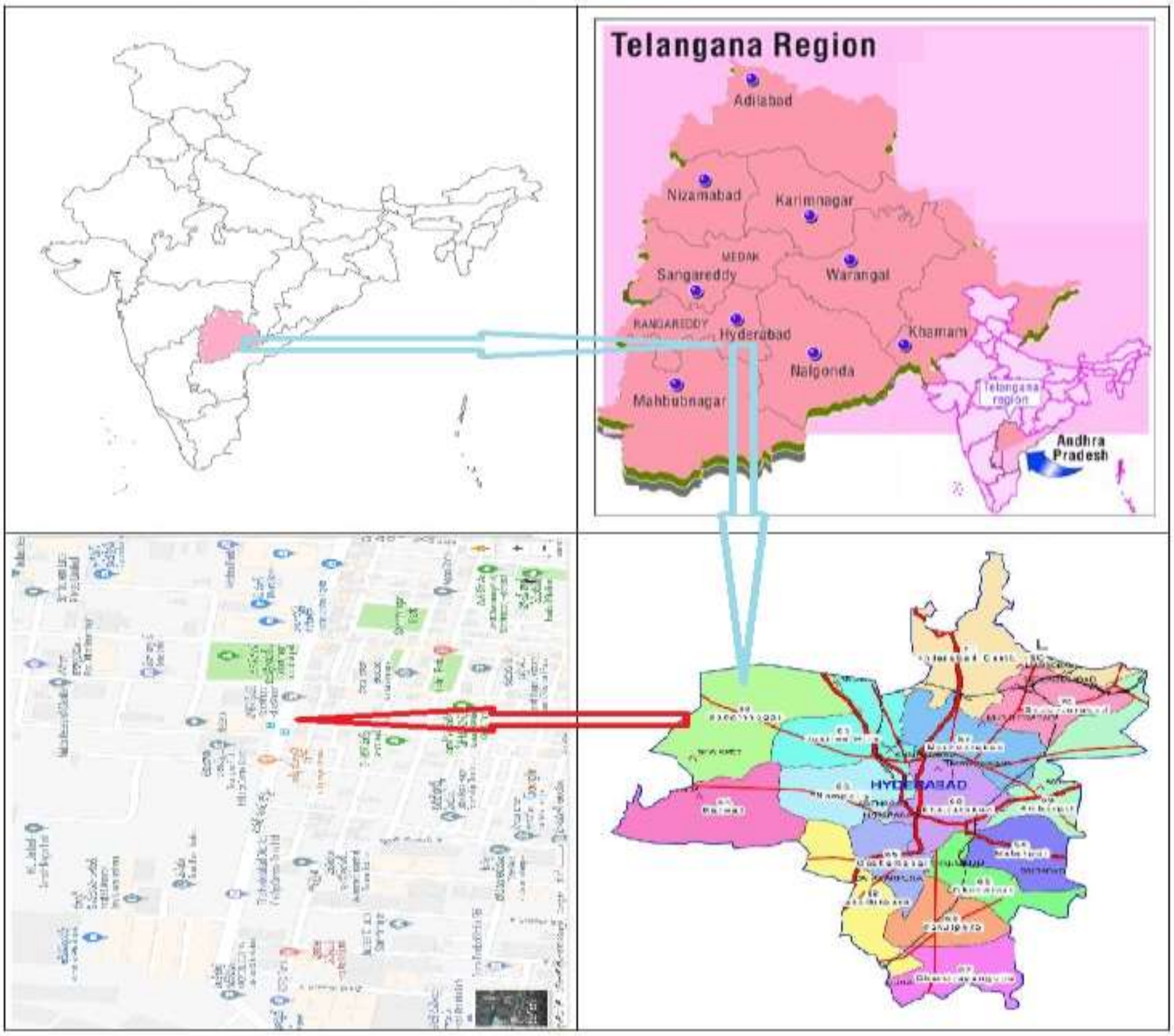

Figure 2 : shows area of the study

DATA COLLECTION:

The source of the data collected for Metrological data from TSPCB, Hyderabad at Sanath Nagar. The dataset included hourly pollutant concentrations ($PM_{2.5}$) and meteorological parameters (wind direction, wind speed, temperature) measurements for the year 2017 at the Sanath Nagar monitoring site, in Hyderabad city.

The traffic data collected at HMDA (Hyderabad Metro Development Authority). The monitoring site is surrounded by a number of primers educational and research institutes. As a result, this region is subjected to intense human activity and vehicular traffic.

SAMPLING DATA

The vehicles plying on these roads were classified into five groups namely, two wheelers, three wheelers, cars, light commercial vehicles (LCV) and heavy duty vehicles (Bus/truck). The weighted emission rate of the local vehicle fleet was calculated in hourly basis. Concentrations of air pollutants on $PM_{2.5}$ at various receptor positions will be predicted by using CALINE4 model.

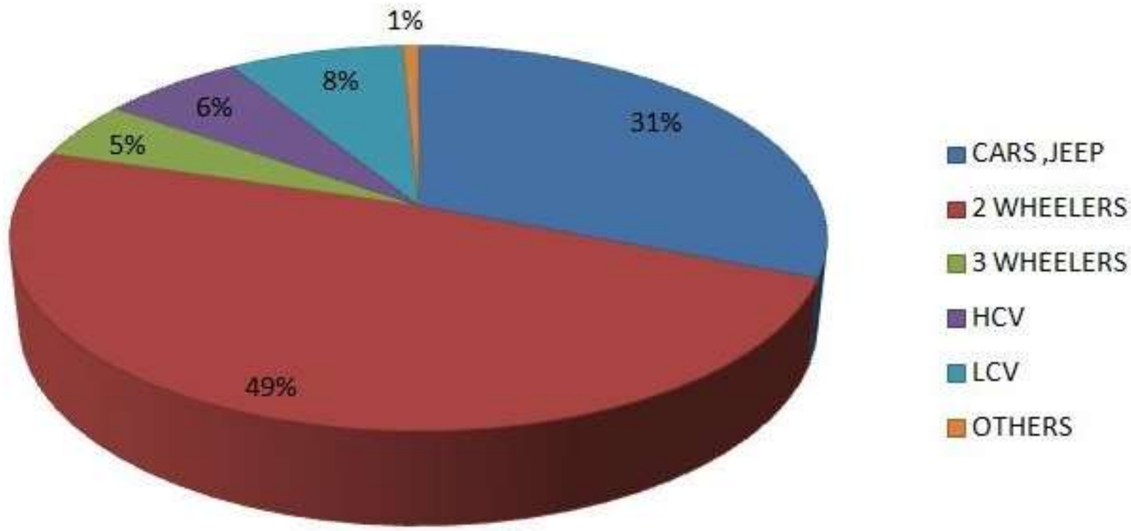

Figure 3: Shows various compositions of vehicles

METROLOGICAL DATA

Metrological data consists of hourly concentrations of pollutants on $PM_{2.5}$, metrological parameters like wind speed wind angles and atmospheric temperature at the study area. The Metrological data was collected from the TSPCB, it is presented for 24 hour data for a week i.e. Sunday to Saturday (**19-02-2017 to 25-02-2017**).

TOTAL EMISSION EVALUATION

The pollutants concentration is proportional of pollutant emission rate from source. In fact, accurate emission inventory leads to accurate prediction pollutant concentration by any air quality model. The emission factor for vehicular pollutants CO, PM_{10} and $PM_{2.5}$ are shown in Table 1.

Table 1- Emission factor for vehicular pollutants CO, PM_{10} and $PM_{2.5}$

Category of Vehicles	**Deterioration factor Emission factor (g/km)**			**Emission factor (g/km)**		
	PM_{10}	**$PM_{2.5}$**	**CO**	**PM_{10}**	**$PM_{2.5}$**	**CO**
Heavy vehicles (Bus, Goods vehicle)	1.35	1.0	1.18	0.56	12.0	3.6
Trucks/Tractors	1.59	1.0	1.33	0.28	6.3	3.6
Light vehicles (cars/taxis, etc)	1.28	1.0	1.14	0.07	0.5	0.9
Three wheeler (Tempo, Auto-Rickshaw)	1.70	1.7	1.70	0.08	0.11	4.3
Two wheeler (Motor cycle, Scooter, moped)	1.30	1.3	1.30	0.05	0.3	2.2

(Source; ARAI –Automotive Research Association of India 2010)

Vehicles mainly emit $PM_{2.5}$ from the exhaust pipe while road abrasion mainly gives rise to larger wear particles ($PM_{2.5}$ to PM_{10}). Particulate matter from road traffic also comes from other sources such as tyre wear, brake-wear and vehicle-induced resuspension of road. There is also a wind induced resuspension of particulate matter. The term resuspension is used both for freshly formed particles from abrasion and older deposited road dust brought into the air.

Well maintained and new engine technology based vehicles causes less pollution as compared to old and poorly maintained vehicles. At night, the traffic flow is very low in cities, during morning and evening; the flow was maximum around 8–10 A.M. and around 5–7 P.M. In addition, heavy vehicles have a long flow maximum between 9 P.M. - 12 P.M.

The emissions are given in g km^{-1} $vehicle^{-1}$ (independent of the vehicle category). When vehicle fleet is maximum at peak hours (5pm-7 pm) fraction of emissions will be higher. The high commercial vehicles emit more PM_{10} per vehicle due to tail pipe emissions or road emissions. The emissions factor for various categorized vehicles for sampling days.

In India, engine technology, fuel type and vintage of vehicle is represented in terms of Emission factor, expressed in terms of gram of pollutant per distance travelled (in km).

The CALINE4 model requires a single value of pollutants emission factor (i.e. weighted emission factor or WEF) representing all types of vehicles.

$$\textbf{Weighted Emission Factor } (WEF) = \frac{[\Sigma\,(j)\;\Sigma\,(ky)\;N\,(j,ky).EF\,(i,j,ky)]}{\text{Total No.of Vehicles}}$$

Where, WEF is in g/km

N (j, ky) is number of vehicles of a particular type j and vintage ky in year y

EF (i,j,ky) is emission factor (g/km) for pollutant i for the vehicle type j and vintage ky in year y.

STANDARD CASE:

In this case, 24 hour average concentration of pollutants CO, PM_{10} and $PM_{2.5}$ and wind directions (0º-360º), wind speed, weighted emission factor g/mile, road geometry are specified in CALINE4 model for the prediction of pollutants ,the predicted and observed valves are represented in table 2.

Table 2- Comparison between Observed and Predicted 24 Hour Average Concentrations of $PM_{2.5}$.

Days	**Predicted $PM_{2.5}$ by CALINE4 (μg/m^3)**	**Observed $PM_{2.5}$ at TSPCB (μg/m^3)**
19-02-2017	78.5	79.5
20-02-2017	71.8	70
21-02-2017	72.2	68.5
22-02-2017	72.9	71.5
23-02-2017	74.2	72.4
24-02-2017	76.2	74
25-02-2017	71.5	69.5

Table 2 shows that the concentrations of predicted on $PM_{2.5}$ from the CALINE4 model and observed concentration is at Receptor R_1 pre identified location i.e. at a distance of 50m from the centre of road where the monitoring station is at TSPCB, Sanath Nagar.

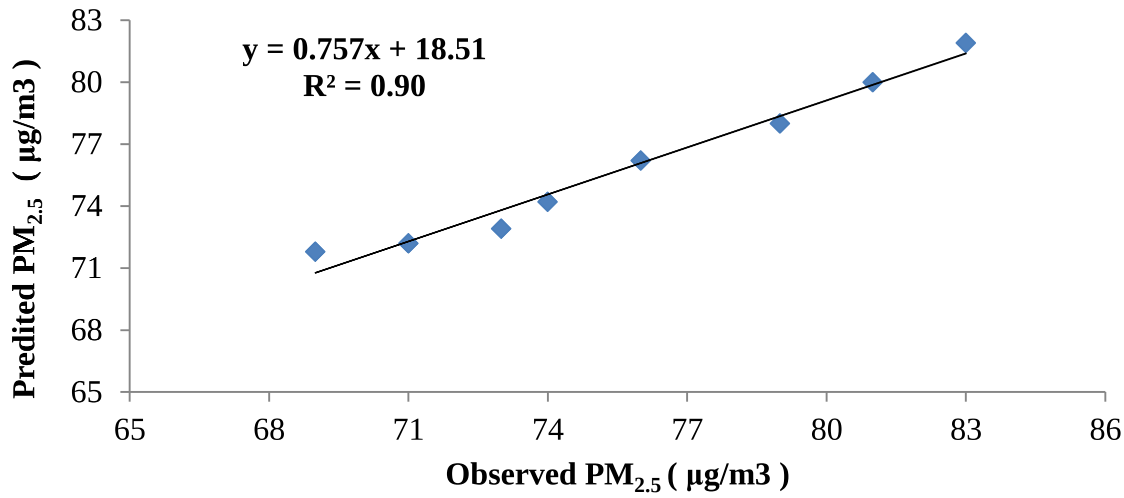

Figure 4 - Correlation value Between Observed and Predicted $PM_{2.5}$ Concentrations

WORST CASE

In this case, the 24 hrs average peak hour concentrations of pollutants are taken but wind direction is set to zero degrees, and same road geometry, mixing zone width, altitude emission factor were considered in the CALINE4 model, the predicted and observed valves are represented in table 3.

Table 3 - Comparison between Predicted and Observed Concentrations of $PM_{2.5}$ At Worst case

Days	**Predicted $PM_{2.5}$ by CALINE4 (µg/m^3)**	**Observed $PM_{2.5}$ at 1TSPCB (µg/m^3)**
19-02-2017	116	109
20-02-2017	120.4	119
21-02-2017	123.2	118
22-02-2017	125.9	111
23-02-2017	131	128
24-02-2017	138	134
25-02-2017	132.6	135

From table 3, it was observed that the concentrations of predicted C0, PM_{10} and $PM_{2.5}$ from the CALINE4 model and observed concentration is at Receptor R_1 pre identified location i.e. at a distance of 50m from the centre of road where the monitoring station is at TSPCB, Sanath Nagar Hyderabad.

While comparing to standard case the predicted concentration of pollutants in worst case have higher concentration due to the consideration of peak hour traffic volume conditions.

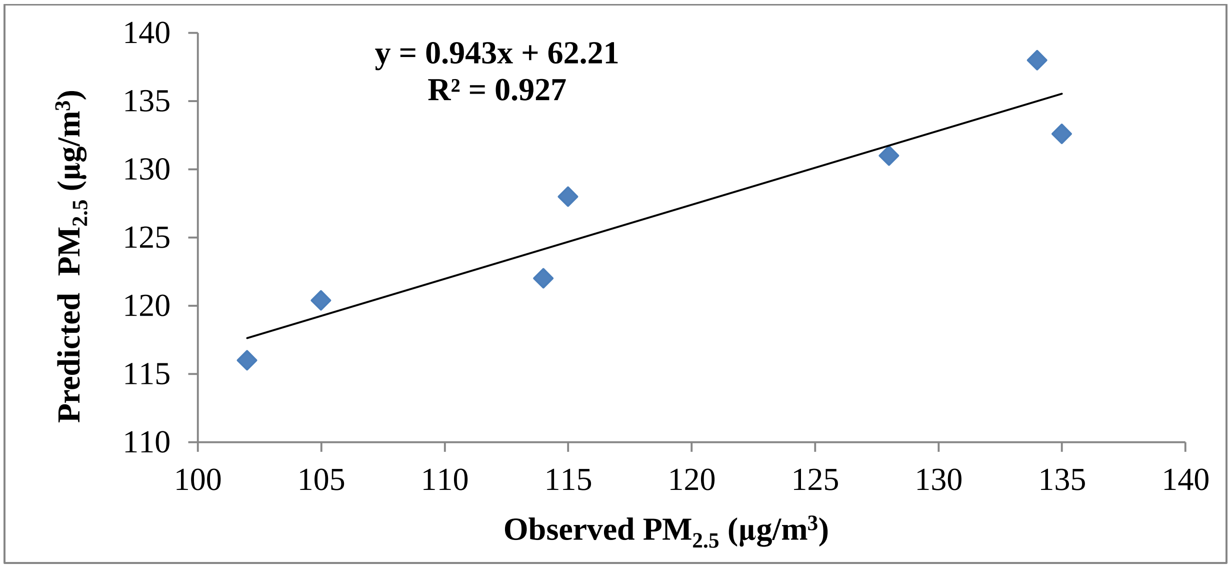

Figure 5 - Correlation value Between Observed and Predicted $PM_{2.5}$ Concentrations.

Table 4- Statistical Evaluation Parameters

Statistical Evaluation Parameters	**Standard Case**	**Worst Case**
	$PM_{2.5}$ ($\mu g/m^3$)	**$PM_{2.5}$ ($\mu g/m^3$)**
Coefficient of Correlation $(R)^2$	0.90	0.927
Fractional Bias (-2 To 2)	0.44	0.48
NMSE ≤ 0.5	0.27	0.31

From table 4, based on statistical analysis values, it was clearly noticed that, CALINE4 model prediction was better for predicting the pollutants CO, PM_{10} and $PM_{2.5.}$ Fractional Bias (FB) values were found to be within standard limit which implies, model was predicting satisfactorily.

It was also observed that, CALINE4 model accuracy was up to two decimal points and not applicable for the pollutant with less concentration. Goud et al. (2015) have reported the performance of CALINE4 model based on NMSE, FB for predicting PM_{10} and $PM_{2.5}$ concentrations were within the permissible limits.

FORECASTING THE TRAFFIC GROWTH

With the recent thrust on improving and developing highways for boosting National Economy, the importance of Traffic Demand Forecasting (TDF) has increased significantly as the forecasted traffic volume contributes substantially in engineering design, economic and financial viabilities of highway improvement projects.

Therefore, estimation of traffic growth rates and its related issues is concerned primarily to improve the rationality of traffic forecast is of prime importance. The traffic growth rate which was developed by NHAI for the three states of Karnataka, Telangana and Andhra Pradesh. The growth rates of various categorized vehicles like car, buses, two wheelers, three wheelers are. as shown in table 5.

Table 5- Traffic Growth

Duration	**(2013-20)**	**(2021-25)**	**(2026-30)**	**(2031-35)**	**2036 and above**
Car	9.60%	10.20%	8.60%	7.20%	5.90%
Buses	5.60%	6.00%	5.10%	4.20%	3.50%
Two Wheelers	9.60%	10.20%	8.60%	7.20%	5.90%
Three Wheelers	7.70%	8.20%	6.90%	5.70%	4.80%
LCV	6.90%	7.30%	6.20%	5.10%	4.30%
2 Axle	4.70%	5.00%	4.20%	3.50%	2.90%
3 Axle	6.30%	6.70%	5.60%	4.70%	3.90%
Multi Axle	8.10%	8.60%	7.20%	6.00%	5.00%
Multi Axle >6	8.10%	8.60%	7.20%	6.00%	5.00%
Mini Bus	5.60%	6.00%	5.10%	4.20%	3.50%

(Source; National Highway Authority of India)

The annual averages of various categorized vehicles are shown in table 1.5. The annual average daily traffic was calculated by using below formulae.

Annual average daily traffic (AADT) = Average Daily Traffic (ADT) × Seasonal factor

Table 6- Annual Average Daily Traffic

MODE	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Car, Jeep, Van	2628	2775	2883	2930	3157	3133	3375	3330	3533
Mini Truck (<3T)	315	336	360	376	400	433	433	468	512
Mini Truck (>3T)	252	270	283	300	325	351	365	385	414
Mini Bus (<3T)	219	231	247	264	277	294	302	318	344
Mini Bus (>3T)	157	166	177	189	198	211	216	228	246
Two Axle (LCV)	1049	1099	1168	1263	1365	1496	1546	1611	1659
Three Axle (HCV)	323	344	372	402	440	474	479	488	503

MAV - Three to Six Axle	104	112	121	133	143	148	152	155	163
Bus	1868	1972	2162	2283	2440	2609	2731	2853	2903
Two wheeler	3627	3883	3775	3952	4130	4274	4357	4431	4535
Three Wheeler & Auto Rickshaw	1689	1819	1874	1930	1968	2008	2068	2107	2238
Tractor	367	379	390	388	405	425	438	459	489
Total vehicles	9670	10370	10746	11539	11762	12691	12835	13435	13995
Average VPH	402	432	447	481	490	528	535	550	566

Seasonal factors of various categorized vehicles are represented in table 1.4.

Table 7- Seasonal Factors of Different Types of Vehicle

SI No	Vehicle Type	Seasonal Factor
1	Car	1.07
2	Light Commercial Vehicles (LCV)	1.10
3	2- Axle vehicles	1.10
4	3- Axle vehicles	1.10
5	Multi Axle Vehicles (MAV)	1.10
6	BUS	1.10

(Source: HMDA)

1. PREDICTION OF $PM_{2.5}$

Considering forecasted traffic growth annual average daily traffic from the year 2017-20 to 2021-25 and evaluating weighted emission factors in g/mile for the corresponding years prediction of air pollutant $PM_{2.5}$ from Receptors (1- 10) are shown in table 8 and also graphical representation of PM_{10} during the period 2017-2020 and 2021-2025 in figure 6 and 7.

Table 8 Comparison of Predicted $PM_{2.5}$ Concentration with NAAQS at Various Receptors

Receptors	$PM_{2.5}$ permissible limit (μg/m³)	Predicted $PM_{2.5}$ (μg/m³)								
		2017	2018	2019	2020	2021	2022	2023	2024	2025
R_1 (50m)	60	71.5	72.1	73.6	74	75.5	76.9	78.8	81.5	82.6
R_2 (100m)	60	71	71.8	72.8	73.3	75	76.5	78.4	81	82
R_3 (150m)	60	70.6	71.2	72.2	73	74.5	76	78	80.6	81.8
R_4 (200m)	60	69.5	70.4	71.8	72.4	74.2	75.6	77.5	80	81.2

R_5 (250m)	60	69.1	70	71	72	73.8	75.2	77	79.4	80.5
R_6(300m)	60	68.4	69.7	70.2	71.6	73	74.8	76.6	79	80
R_7(350m)	60	67.6	69.4	69.6	71	72.6	74	76.1	78.5	79.4
R_8 (400m)	60	67.3	69	69.1	70.5	72	73.4	75.4	78.1	79
R_9 (450m)	60	66.5	68.6	68.8	70	71.5	73	75	77.6	78.6
R_{10} (500m)	60	65.7	67.4	68	69.3	71	72	74	77	78

The dispersion of pollutants occurs in both side of road, the PM_{10} concentration are exceeding the NAAQS standards i.e. 60 µg/m^3. Hence, the Sanath Nagar regions have effects of $PM_{2.5}$ pollutant concentration.

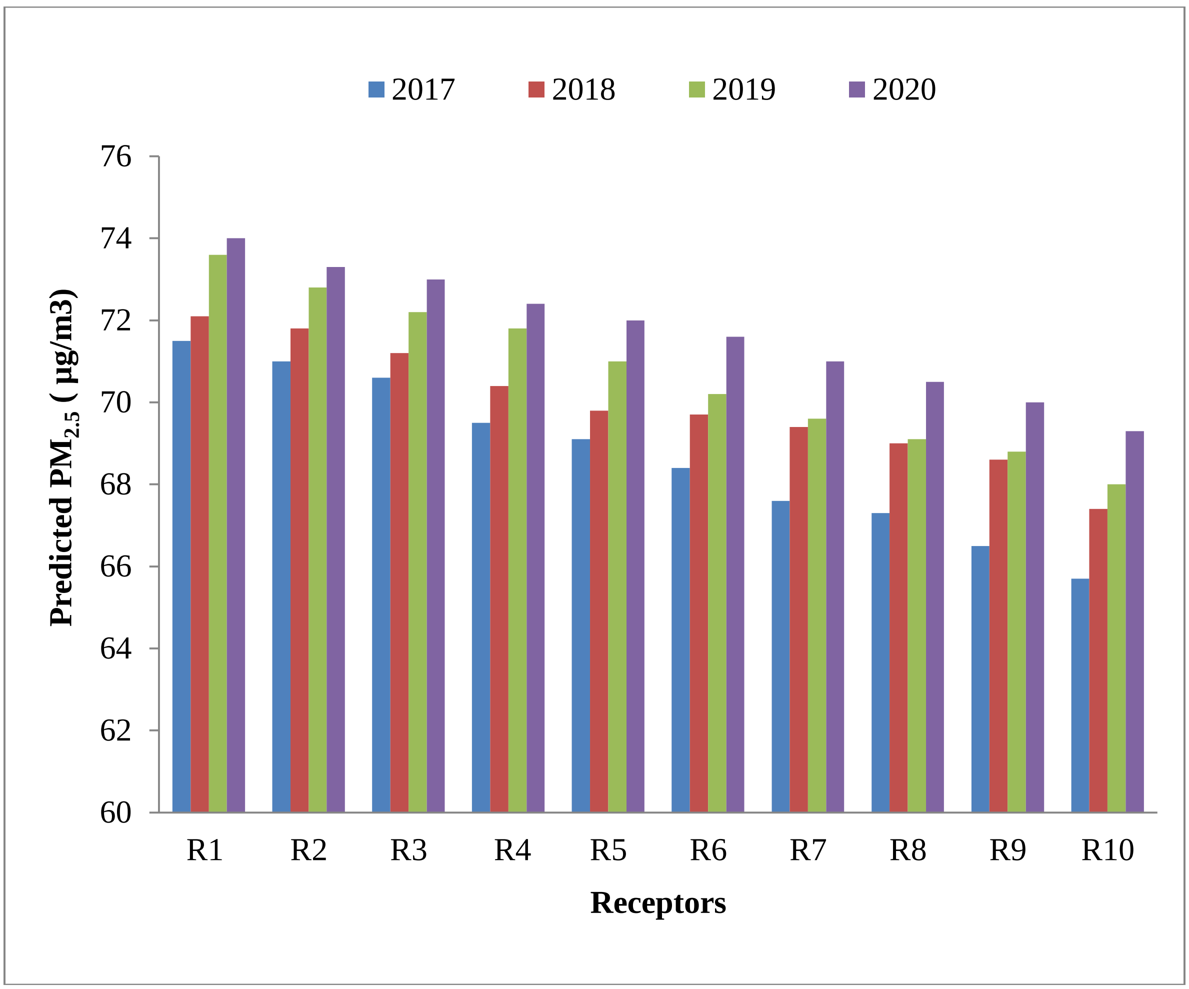

Figure 6 Forecasted Annual Average Predicted Concentration of $PM_{2.5}$ During 2017-2020

From the figure 6, it was observed that the annual average concentration of $PM_{2.5}$ varies from R_1 (71.5 µg/m^3) to R_{10} (65.7 µg/m^3) in the year 2017. The concentration at all receptors increases from the year 2017 to 2020. When the distance of receptors increases from the road, concentration of PM_{10} decreases. The R_1 (50m) grid have high PM_{10} concentration which are having locations of police station, TSPCB building, public apartments and minimum at 500m grid i.e. at receptor R_{10} which are having locations of Balanagar, BK guda and Nature cure hospital

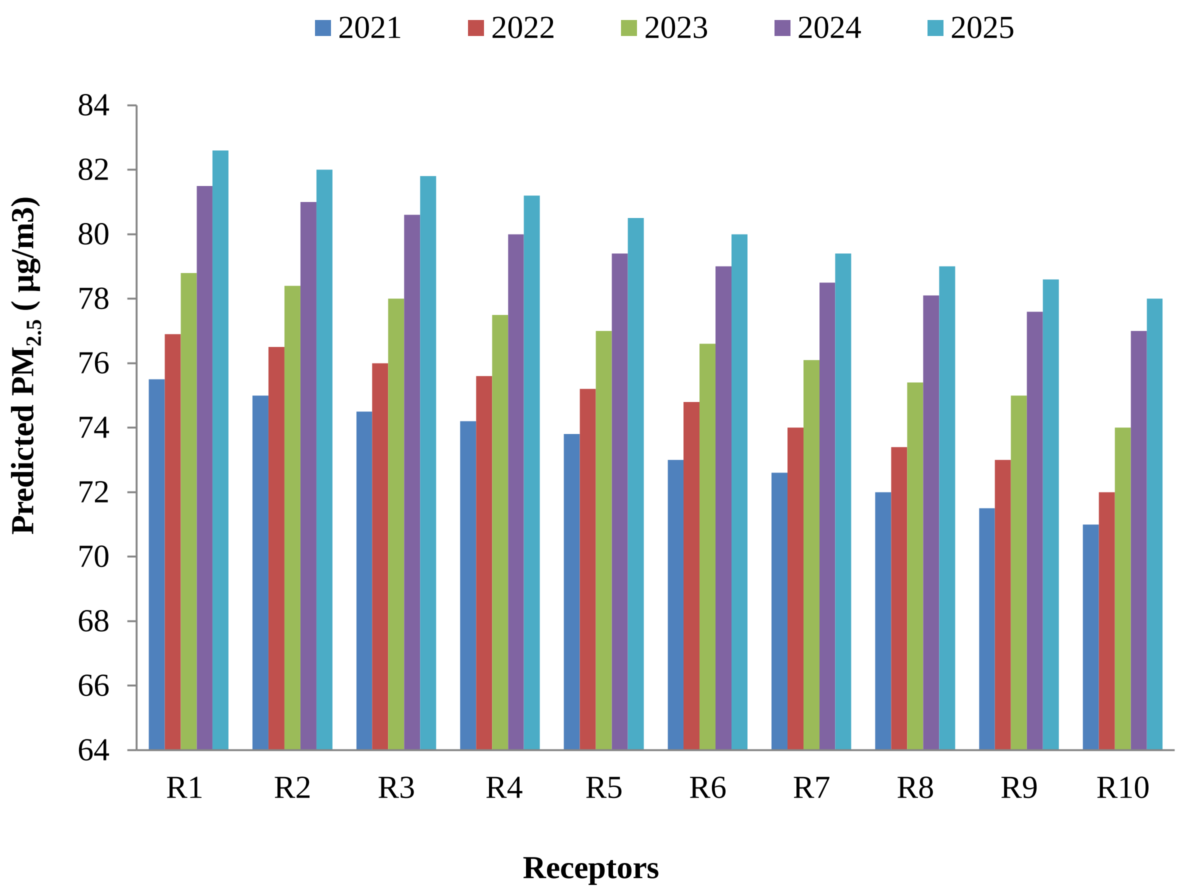

Figure 7 Forecasted Annual Average Predicted Concentration of $PM_{2.5}$ During 2021-2025

From the figure 7, it was observed that the annual average concentration of $PM_{2.5}$ varies from R_1 (75.5 µg/m^3) to R_{10} (71 µg/m^3) in the year 2021. The concentration at all receptors increases from the year 2021 to 2025. When the distance of receptors increases from the road, concentration of PM_{10} decreases. The R_1 (50m) grid have high PM_{10} concentration which are having locations of police station, TSPCB building, public apartments and minimum at 500m grid i.e. at receptor R_{10} which are having locations of Balanagar, BK guda and Nature cure hospital.

PREDICTION_OF_PM2.5_FROM_VEHICULAR_POLLUTION_BY_USING_CALINE4_AT_HYDERABAD-IJTIMESV04I08150809232414

CONCLUSIONS:

The following conclusions were drawn from the study area.

- ✓ The concentration of pollutants $PM_{2.5}$ from vehicular emissions were predicted by using CALINE4 at Standard and Worst case.
- ✓ The concentrations of $PM_{2.5}$ are 0.87 ppm,185 (µg/m^3) and 78.5 (µg/m^3) respectively are maximum at receptor $R_1$50m and minimum concentration of $PM_{2.5}$ 71.5(µg/m^3) at receptor R_{10} 500m in Standard case.
- ✓ The concentrations of $PM_{2.5}$ are 3.3 ppm, 254.7(µg/m3), 138(µg/m^3) respectively are maximum at receptor $R_1$50m and minimum concentration of $PM_{2.5}$ 116(µg/m^3) at receptor R_{10} 500m in Worst case.
- ✓ The traffic growth was observed, the total number of vehicles increased from 9670 in the year 2017 to 13995 in the year 2025.

- ✓ The forecasted annual average predicted concentration of vehicular pollutants were found to be maximum at R_1 50m receptor, minimum at R_{10} 500m receptor.

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