Ambient Air Quality Modelling near busy Road Junctions in Coimbatore City using CALINE4 Model

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***Abstract* - In urban air quality, Automobile sources are considered to be threatening issue. Profuse expansion of Coimbatore city has resulted in a drastic increase of air pollution. The main objective of this study is to model the dispersion pattern of vehicular carbon monoxide near busy road junction in Coimbatore city using CALINE4 model. Two consecutive days in every month of 2011 have been chosen to calculate 8-hour average CO concentration at six receptor points. A road network extending from Ukkadam to Lali Road approximately 30 Km in length is considered in this study. The predicted CO concentration at the receptor points are then compared with the observed concentrations of CO. Root mean square error (RMSE) method is used to evaluate the model performance by comparing the predicted and observed CO concentration .**

Key words: Air Quality, CO Concentration, CO Prediction, CALINE4, Modelling

I. INTRODUCTION

Rapid growth of motor vehicles ownership and activities in indian cities are causing serious health, environmental and socio economic impacts(**Badami et al.,2009**). In urban air quality, automobile sources are considered to be threatening issue. The rapidly growing vehicle fleet, distance travelled by each vehicle and change in land use pattern are some of the primary causes of vehicular air pollution and consequently urban air pollution (**Mayer et al.,1999**). The motor vehicle population in India has increased from nearly 0.3 million in 1951 to 115 million in 2009, of which , two wheelers accounted for approximately 70% of the total vehicles(**CPCB**). The pollutants include respirable suspended particulate matter (RSPM) , especially $PM_{2.5}$, Nitrogen dioxide (NO_2), CO and hydrocarbons (HC). Vehicular pollution is the major contributor of urban air pollution in most of the cities of India and estimated to account for approximately 70% CO, 50%HC, 30-40% NO_X, 30% of SPM and 10% of SO_2 of the total pollution load of which two third is contributed by two wheelers alone(**Sharma et al,2005**). The city of coimbatore is no exception. Because of the city is experiencing an exponential industrial and population growth, it has a high potential for vehicular air pollution. Further , the meteorological conditions prevailing in the city are unfavourable for the dispersion of pollutants. The most affected group of people is urban inhabitants especially the people residing in the vicinity of urban roadways as well as pedestrians. The situation further deteriortae at urban roads, where the ventilation is insufficient for dispersion of pollution. Therefore, the prediction of pollutants emitted in the vicinity of urban roadway is of foremost importance in order to improve ways to mitigate vehicular pollution effect.The line source emission modelling is an important tool in control and management of vehicular exhaust emissions in urban environment.

The line sources models are used to simulate the dispersion of vehicular pollutants near roads where vehicles continuously emit pollutants. Various line source dispersion models are used to predict the pollutants concentration along the roads/ highways. However, widely used vehicular pollution model to predict air pollutions concentration along the highway is CALINE4(**Benson et al,1984**) . CALINE4 offers several advantages over other models and has been used in various Indian cities to predict concentration of vehicular pollutants along the roads/ highways(**Jain et al, 2006; Majumdar et al,2009**). In the present study, CALINE4 is used to predict the concentrations near roadways and the model has been tested and validated.

II. METHODOLOGY

A. STUDY AREA

Coimbatore city is a rapidly developing city and it experiences an exponential growth in the vehicular usage and subsequently high fuel consumption. Also the presence of industrial activities on a large scale in and around Coimbatore tends to have a strong impact on the environmental quality of the city. Transportation is the prime source of mobility in urban society. It not only provide a fast, convenient and economical mode or carrier to meet multifarious activities of citizens but vitiates the environment in the process by emanating obnoxious and toxic pollutants in the surrounding atmosphere and there by poses serious health hazards to human and biotic community. It has been found that the vehicular exhaust accounts for the part of the pollution from all sources put together in all major road junctions in Coimbatore city in India.Hence, it was decided to monitor the air quality in some selected locations. In the current study, sampling locations were selected based on the traffic density. The concentrations of CO in the ambient air were estimated .

Sites were chosen in respect of maximum vehicular usage as the basis. Six sampling stations were selected for monitoring ambient air concentration of CO over Coimbatore city viz.,

- *Site 1:* Ukkadam
- *Site 2:* Railway station
- *Site 3:* Hope college Junction – Peelamedu
- *Site 4:* Gandipuram-Corporation Bus terminal
- *Site 5:* Mettupalayam road bus terminal
- *Site 6:* Lawly road

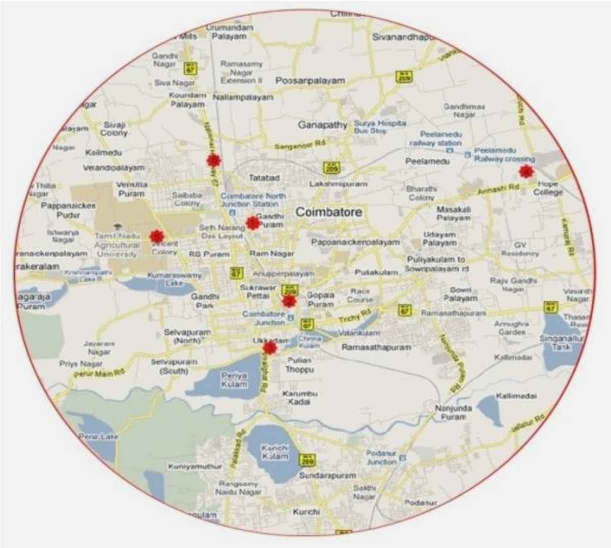

Fig. 1. Location of six sampling stations

B. BRIEF DESCRIPTION OF CALINE-4 MODEL

CALINE-4 is Gaussian based steady state model. This model assume that the dispersion process takes no time to achieve the steady state. The materials and equations presented in this section are based on available model documentation.

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, site geometry and site characteristics as input parameters and predicts pollutant concentrations for receptors located within 150 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, width, etc. CALINE-4 is capable of specifying links at heights above grade (z = 0), links as bridges (allowing air to flow above and below the link) and links as parking lots (which should be defined by the user as having a height of zero). Also, unlike CAL3QHCR, CALINE-4 is capable of analyzing the dispersion of pollutants in wind speeds of less than 1 m/s. The concentration at a point with coordinates (x, y, z) is calculated based on the following equation.

$$C(x,y,z,H)=\frac{Q}{2\pi u\sigma Z\sigma y}$$

$$*\left[exp-\left(\frac{y2}{2\sigma y^2}\right)\right] exp\left[\frac{-(Z-H^2)}{2\sigma z^2}\right]+exp\left[\frac{-(Z+H^2)}{2\sigma z^2}\right]$$

C = Concentration of the pollutant in air [m/L3]
Q = Rate of chemical emission [m/T]
U = Wind speed in X direction. [L/T]
σy = Standard deviation in y direction.[L]
σz = Standard deviation in z direction.[L]
y = Distance along a Horizontal axis perpendicular to the wind. [L]
z = Distance along a vertical axis. [L]
H = effective stack height. [L]

The screening form of the CALINE-4 model calculates the local 8-hour–average contribution of nearby roads to the total concentration. Input requirement for CALINE 4 dispersion model as follows:

- Traffic parameters: Traffic volume (hourly and peak), traffic composition (two wheelers, three wheelers, cars, buses, goods vehicle etc.), type of the fuel used by each category of vehicles, fuel quality, average speed of the vehicles.
- Meteorological parameters: Wind speed, Wind direction, stability class, mixing height
- Emission parameters: Expressed in grams /distance travelled. It is different for different categories of vehicles and is a function of type of the vehicle, fuel used, average speed of the vehicle and engine condition etc
- Road geometry: Road width, median width, length and orientation of the road, number and length of each links
- Type of the terrain: Urban or rural, flat or hilly

C. Traffic Volume

` Selective two days from each month in a year 2011 has chosen to monitor the traffic data of hourly morning peak, afternoon peak and evening peak. Traffic volume comprises of heavy commercial vehicles (Bus/Trucks), light commercial vehicles, car, three wheelers (M3W) and two wheelers (M2W). The number of vehicles had been counted at an hourly basis for all the categories. The continuous traffic counts were performed from 7:00AM to 7:00 PM on hourly basis. The 8 hourly average traffic volumes and its composition with respect to different categories of vehicles have been carried out for the six sampling stations as shown from the Figure.1.

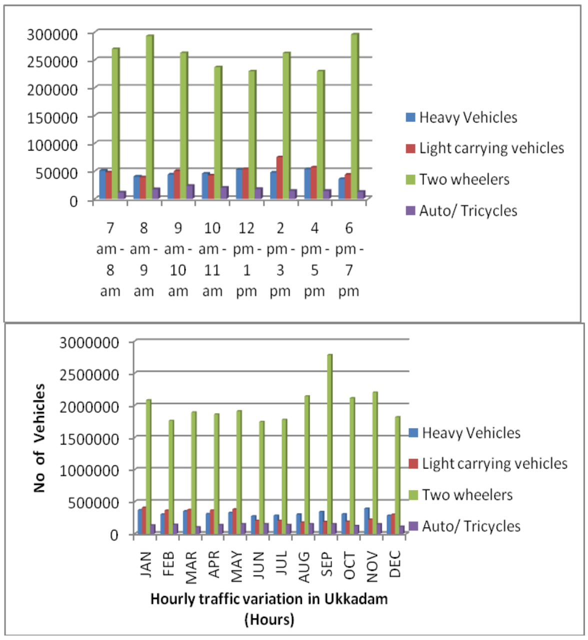

Figure.1.The 8 hourly average traffic volumes and its composition in ukkadam

D. *METEOROLOGICAL DATA*

The meteorolical data such as wind speed, wind direction, temperature and relative humidity has been observed on the corresponding selective days from each month in the year 2011. The hourly mixing height values were obtained from the Indian Meteorological Department (IMD) (**Attri et al,2008**) .

According to **Dhakal et al., (1998)**, the emission factor (gm/km) for heavy 4 wheelers, light 4 wheelers and two wheelers are 12 gm/km, 62 gm/km and 24 gm/km respectively. The weighted average emission rate of the local vehicle fleet is calculated by multiplying the number of vehicular types multiplied by the corresponding emission factor and divided by the total number of vehicles flying on that link. For example, the total number of vehicles on Link A is 2892 out of which 336 are large four wheelers, 948 are light four wheelers and 1608 are two wheelers. Therefore the emission factor (weighted average emission) for Link A is:

Weighted mean of Emission factor in Link A =

$$\frac{12 * 336 + 62 * 948 + 24 * 1608}{336 + 948 + 1608}$$

$$= 35.06 gm/km$$

$$= 56.10 gm/mi$$

E. *ESTIMATION OF CO CONCENTRATION*

CALINE4 is capable of processing a maximum of twenty links and twenty receptor points on each run (**Potoglou et al. 2005**). The road network is divided into five links and six receptor points are created.The road extending from Ukkadam to Lali Road is divided into five different links as shown in the table below:

Table 1 .APPROXIMATE LENGTH OF EACH LINK

LINKS	EXTENSION	APPROXIMATE LENGTH (km)
A	Ukkadam to Railway station	2
B	Railway station to Hopes college	7.1
C	Hopes College to Gandhipuram	7.0
D	Gandhipuram To MTP Road	3.2
E	MTP Road To Lali Road	3.8

In the 'Job Parameters' screen; the run type is chosen as 'multirun' calculate 8-hour average CO concentration at the receptor points. The Aerodynamic Roughness Coefficient is chosen as central business district. The altitude of the study area is set to 460 m above the sea level. In the 'Link Geometry' screen; the link type is set to 'At-Grade' to prevent the plume from mixing below the ground level. In order to enter the 'end point coordinates', it is necessary to define the link geometry in a Cartesian coordinate system which is consistent with the 'Receptor Positions'. However this can be displayed in meters as well which can be used to locate the (x, y) positions of any given point. The consistency in defining the coordinates by using this coordinate system seem to work with CALINE4 model and this is verified by looking at the diagram that displays the link geometry and receptor points in the 'receptor positions' screen. The (x, y) values are noted for all the links (six) and entered in the 'endpoint coordinate'. The Link height is set to 0 as the road network does not contain any major bridges or tunnels. According to **Coe et al. (1998)**, mixing width is the total width of the road network plus 3 meters on either sides of the road. The width of the road network is 28 feet. So, the mixing width for the sampling road is taken as 14 meters. As the road does not contain any major canyons or bluffs, the parameters for canyons and bluffs are not taken into consideration. The 'Link Activity' screen needs traffic volume and auto emission rate observed at each link.

The 'Run Conditions' screen contains all the important meteorological input needed to run CALINE4. The meteorological condition of the selective days from each month of the year 2011 on the study area is used as an input. Some of the parameters are taken from the CALINE4 Manual as recommended for the analysis.

TABLE 2. CALINE4 METEOROLOGICAL AND RUN CONDITIONS

Parameter	Value	Remarks
Wind speed (m/s)	0.5	Value appropriate for the project location
Wind direction (degrees)	0	Wind blowing from the north (0 = north)
Wind direction Std. Dev. (degrees)	20	
Atmospheric Stability Class (1-7)`	3	The meteorological condition was almost Neutral, so the atmospheric stability is taken as 3
Mixing Height (m)	600	
Ambient Temperature (degrees C)	25	
Ambient Pollutant Concentration (ppm)	1.5	

In the 'Receptor Positions' screen; the (x, y) coordinates of the 6 receptor points are entered. The screenshots of the input together with the CALINE4 output for receptors located in the 0 meters buffer is shown from the Figure-6.

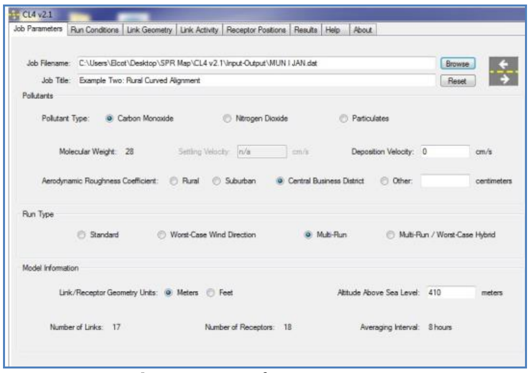

Fig.2.Job Parameter of CALINE4

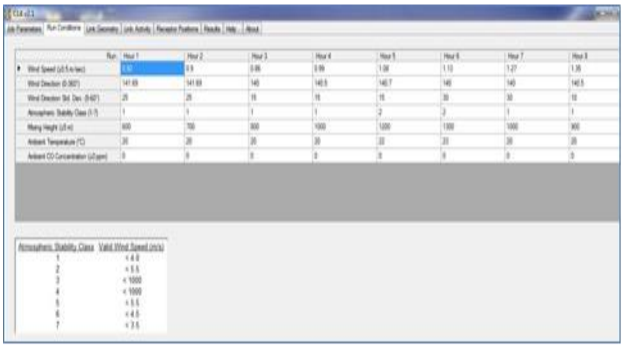

Fig.3.Run Condition of CALINE4

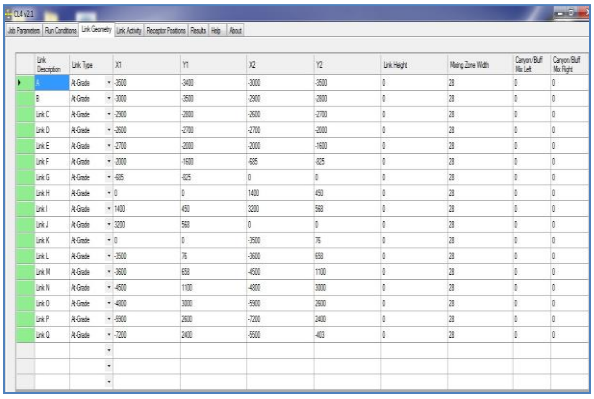

Fig.4.Link Geomentry of CALINE4

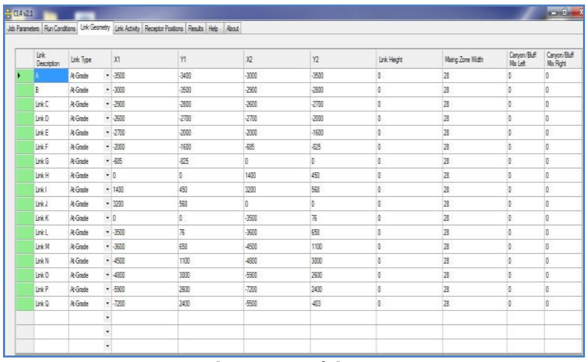

Fig.5.Link Activity of the CALINE4

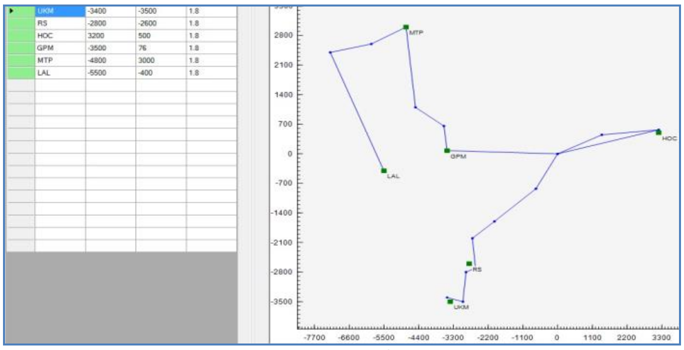

Figure.6.Receptor Positions of the CALINE4

F. RESULTS AND DISCUSSION

CALINE4 model is validated against measured CO concentrations, which is further applied in predicting of the pollutant. Randomly selected data from the same measured traffic and meteorological data as represented in figure 1 and Table-2 respectively. The values predicted by CALINE4 are compared with the measured values. The emission factors as calculated for the mentioned motorised vehicles from Dhakal et al., 1998. Composite emission factors i.e. weighted average emission factor considering individual numbers of vehicles of every category are calculated based on traffic volume data. A 16 spoke Wind rose is generated by Lakes Environmental WRPLOT View tool **(Jain et al., 2006)**, based on the same dataset for study area.

In order to validate the CALINE4 model for CO in study area, measured CO concentrations of days are selected. With the help of mentioned meteorological condition and meteorological and emission data and traffic volume data, CALINE4 is run. The linear regressions between CO concentrations measured and predicted by CALINE4 are plotted and are represented in Figure 7 to 12 . Table-3 lists the performance statistics of the CALINE4 model predictions of CO concentrations on the, six sampling station in Coimbatore. The r^2 value for Ukkadam,Railwaystation,HopesCollege,Gandhipuram,MTP Road and Lawly Road are found to be 0.821,0.985,0.985,0.971 respectively. It indicates that the model perform better at all the above stations. Further the prediction of CO concentration are also closely matching with the observed CO concentration. Figure 7-12 shows observed versus predicted CO concentration for all the six sampling stations.

G. POLLUTANT CONTOUR

Spatial variation of pollutant concentrations or pollutant level contour can be developed if there be multiple numbers of spatial points for prediction of concentration. In order to develop a representative pollutant contour, relevant input values like traffic volumes, meteorological data and emission data are taken. The generated contour map for CO is shown in figure 13.

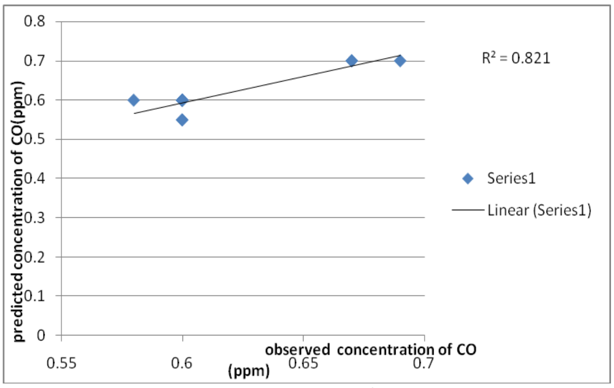

Fig.7.CO concentration of Ukkadam

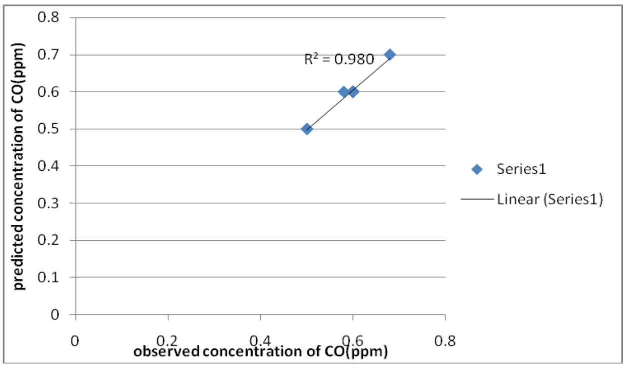

Fig.8. CO concentration of Railway Station

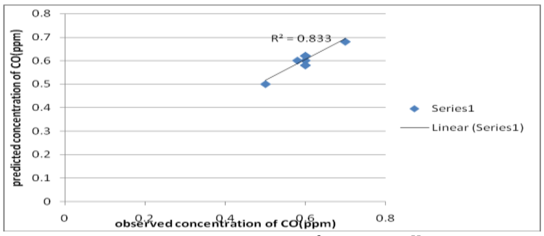

Fig.9. CO concentration of Hopes College

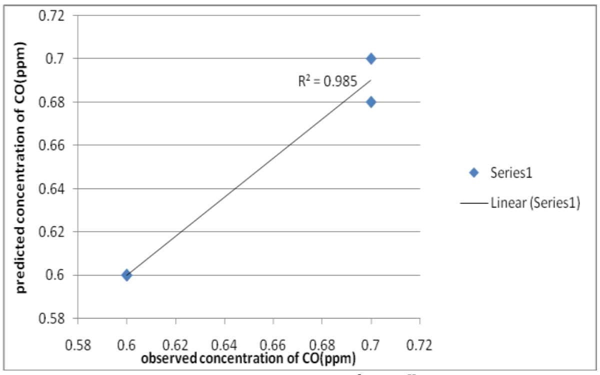

Fig .10. CO concentration of Gandhipuram

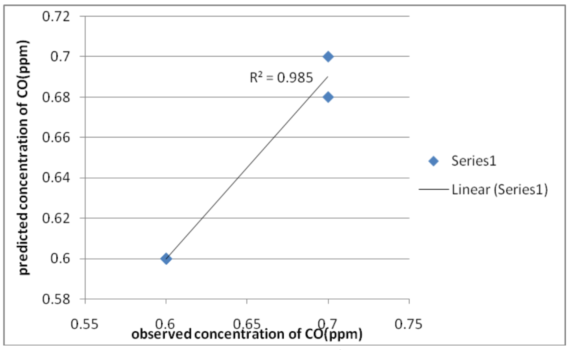

Fig.11.CO concentration of MTP ROAD

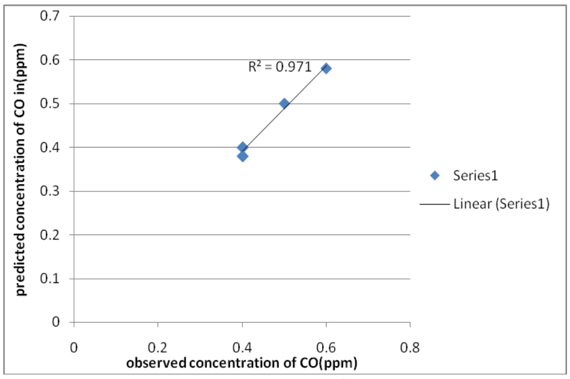

Fig 12. CO concentration of LALI ROAD

TABLE 3.THE PERFORMANCE STATISTICS OF THE CALINE4 MODEL

S. NO	AAQ STATION	R^2
1	Ukkadam	0.82
2	Railway station	0.98
3	Hopes College	0.83
4	Gandhipuram	0.98
5	MTP road	0.99
6	Lali road	0.97

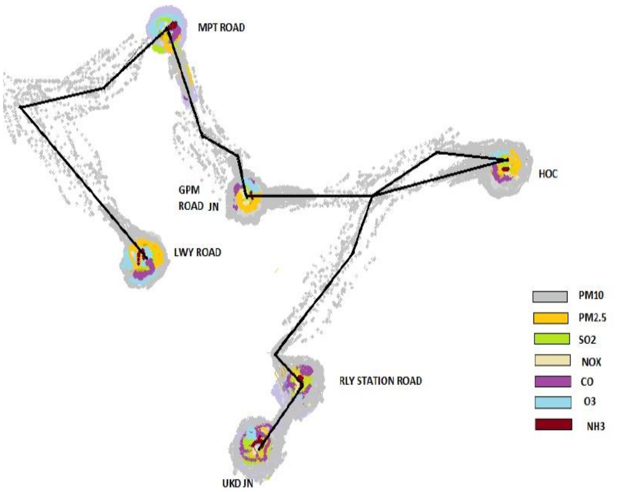

Fig. 13 Pollutant Contour

H. CONCLUSION

The study deals with an approach for validation and application CALINE4 model for a busy road juctions in Coimbatore city for CO. It has been inferred that CALINE4 model prediction is more accurate as it resembles the real scenario ideally and exhibits better correlation with measured values (r^2 being 0.82 to 0.99). The study also shows a typical example pollutant contour around the study area, based on spatial data prediction. This approach of modelling thus would be helpful for air quality planning for the city of Coimbatore where spatial distribution of air quality is required to estimate

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