

Air Quality Assessment along the Highway Due To Vehicular Emissions and Validation of Air Quality Monitored Data with the CALINE4 Model

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ABSTRACT: Rapid urbanization has led to increase in the vehicular emissions into the atmosphere and deteriorating the ambient air quality. This paper focuses on the effects of industrial as well as vehicular emissions along the highway passing through the industrial area of Mysore city, India. Results of windrose plots indicate that, wind directions gradually changed from North-East to South-West from December, 2014 to July, 2015. During winter, wind predominantly blows towards the residential layouts in the outskirts of Mysuru City, however, during pre-monsoon and monsoon period wind blows away from the residential layout. During the study period results of ambient air quality monitored data for SO₂, NO_x and PM_{2.5} were found to be well below the NAAQ Standards. PM₁₀ concentration was exceeding the NAAQ Standards at Location 2 during winter and pre-monsoon seasons found to be 140 µg/m³ and 165 µg/m³, respectively. During pre-monsoon, winter and monsoon period the vehicular traffic count along the highway found to be 26,526, 24,491 and 24,441, respectively. CALINE4 Model, marginally over-predicts the PM₁₀ concentrations with the monitored data and under-predicts the NO_x concentration. Sensitivity analysis of the CALINE4 Model showed, when wind velocity is less than 2 m/sec PM₁₀ concentration was found to be 169 µg/m³ which is greater than the NAAQ Standards.

KEYWORDS: Ambient air quality, Vehicular emissions, CALINE4

I. INTRODUCTION

Increase in technological, industrial and agricultural advancement, coupled with increases in population growth, has triggered the deterioration of environmental quality globally. Urbanization leads to more traffic on roads, growing energy consumption, waste production, and lack of strict implementation of environmental regulations are increasing the discharge of pollutants into air, water, and soil. Utilization of fossil fuels in motor vehicles in turn leads to emissions of Solid Particulate Matters (SPM), Oxides of Sulphur (SO_x), Oxides of Nitrogen (NO_x), Hydrocarbons (HC), etc, which are being the major source of ambient air pollution. Infact, particulate matter and CO₂ emissions are primary contributor to global warming. Heavy-duty vehicles are the main source of NO_x emissions, which contribute to NO₂ concentrations. Diesel cars are now the second-largest source of NO_x and particulate matter emissions. Particulates contains some trace elements such as As, Cd, Co, Cr, Ni, Pb and Se which are carcinogenic to human or animal even in trace amounts. Even though technological upgradation and scientific knowledge has reduced the gaseous pollutant level however, increase in number of vehicles causes more emission of pollutants in turn changes in composition ratio of the pollutants especially the particulate matter. Controlling vehicle traffic can have an immediate impact on improving the air quality even among the most polluted urban centers. With the advances in engine and vehicle technology, technologies such as air injection, exhaust gas recirculation and catalytic converter to detoxify the exhaust are an essential part of emissions control. Emission test results from individual vehicles are in many cases

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compiled to evaluate the emissions performance of various classes of vehicles. **Raslan Alenezi et al. (2012)** have conducted continues ambient air quality monitoring for Non-methane Hydrocarbons, CH₄, CO, CO₂, SO₂, NO₂ and PM₁₀ over a period of one year at Al Jahar, Kuwait. The effects of seasonal variations in pollutant concentration levels were analyzed. Results of ambient air quality analysis showed higher concentrations during winter, this may be due to poor dispersion and shallow inversion layer except for CO₂, O₃ and PM₁₀. **Jie Lin et al. (2006)** have proposed a cell-based time-dependent approach to capture road traffic and roadside pollution modeling. The results have comparable peak CO estimates from field monitored data when compared with CALINE4 estimates and showed clear impact on roadside pollutant concentrations due to traffic heterogeneity. **Rajni Dhyani et al. (2014)** have carried out environmental impact assessment for a highway corridor in Delhi city, India and used CALINE 4 model for the prediction of CO concentration. The results predicted by the model are found to be in line with the monitored data. **Baijayanta et al. (2008)** have studied the automobile pollution using modified CALINE 4 model with correction factor by considering CO as a principle pollutant at Kolkata, India. They proposed to construct a flyover which later shown the decrease in CO concentration. From the above it is observed that, globally most of the major towns/cities are experiencing the air pollution issues due to heavy vehicular emissions. Hence, in the present study an attempt has been made to monitor the ambient air quality status along the highway passing through the industrial area of Mysuru city and also to validate the ambient air quality monitored data with the CALINE4, an air quality dispersion model.

II. METHODOLOGY

Mysore district is one of the tourist destination, in Karnataka, India, which is a fastest growing metropolitan city with a total vehicle population around 6.5 lakh and the growth of vehicles is approximately 4 % annually. Major industrial areas are located in north-western part of Mysore, within a radius of 7 km from the city centre and the industrial area is well connected by State highway and broad ring roads. In the present study, ambient air quality monitored locations along the highway passing through the industrial area of Mysore City is shown in Figure 1. The field study include: selection of monitoring stations, road geometry, road type and mixing zone width which were collected by direct field observation.

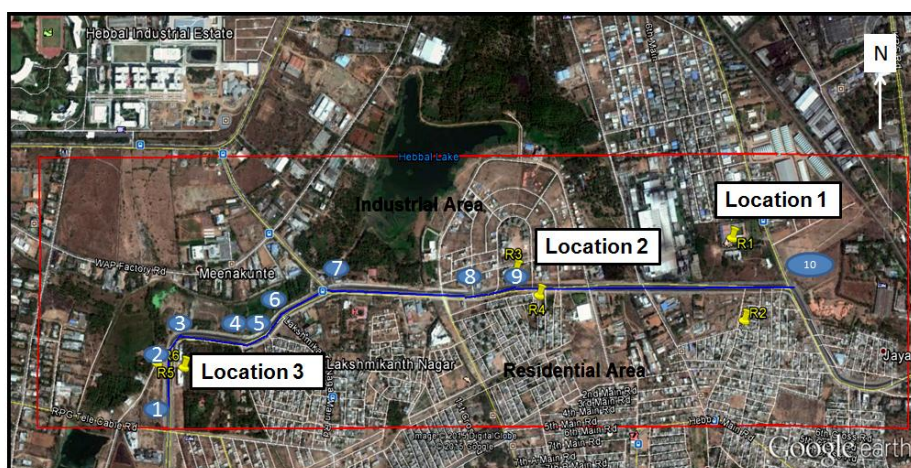


Fig 1 Selected stretch of highway along with monitoring Locations

Vehicular traffic studies

The vehicular emissions are one of the major sources of air pollution in the study area. Unlike industrial emissions, vehicular pollutants are released at ground level and hence their impacts on the recipient population are likely to be significant. Data of vehicular traffic count has been conducted using the CCTV camera fixed on a commercial building on the highway. The compact disc of the CCTV camera recordings in mp4 format were collected and noted down the traffic volume of different categories of vehicles and used in the estimation of Vehicular Emission Inventory.

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Meteorological data

Various atmospheric factors influence the dispersion of air pollutants includes: wind velocity and its direction, temperature, mean mixing depth, atmospheric pressure, rainfall, heating effects and nature of terrain. These data have been collected from Indian Meteorological Department, Naganahalli, Mysore district, India and hourly data was collected from the website www.wunderground.com and used in the present study. The wind data have been used to plot windrose diagrams which represents the magnitude and directions of wind prevailing in the study area.

III. AIR QUALITY MODELING USING CALINE 4

Air pollution models are numerical tools used to describe the casual relationship between emissions, meteorology, atmospheric concentration, deposition and other factors. Air pollutant dispersion models play an important role due to their capability to assess the relative importance of the relevant processes. There are large number of models like ISCST3, General Finite Line Source Model, Delhi Finite Line Source Model, AERMOD, MOBILE, CALINE 3 and CALINE 4 models are available for the estimation of pollutants present at a certain site depending upon the available parameters and weather conditions. CALINE4 model is a fourth-generation line source air quality dispersion model developed by the California Department of Transportation (Caltrans) USA, which offers several advantages over the other previous models such as: General Finite Line Source Model, Delhi Finite Line Source Model, ISCST 3 and CALINE 3 and have been used by many researchers to predict the ambient air quality pollutant concentrations due to vehicular emissions along the roads/ highways under Indian climatic conditions. In the present study, CALINE4 has been use to predict the pollutant concentration..

IV. EXPERIMENTAL RESULTS

Meteorological parameters plays a vital role on the dispersion of air pollutants which changes from season to season. The plot of hourly traffic variation along the highway corridor is shown in Figure 2. The peak traffic flow were observed during 10:00-12:00 (morning peak hours) and 17:00-20:00 (evening peak hours). The Heavy duty vehicles were found to be maximum during morning hours, which may be due to supply of raw materials to the industries located on one side of the highway. 3 wheelers were distributed maximum during morning hours. The study involves preparation of detailed emission inventory with estimation of emissions from line source in the study area by using Atomotive Reasearch association of India (ARAI) developed emission factors for vehicular emissions in India.

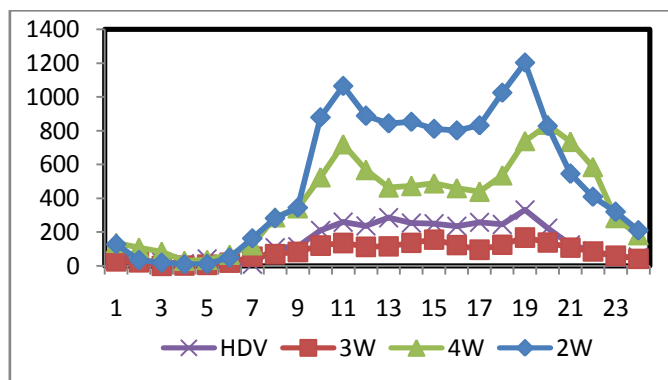


Fig 2 Hourly traffic variation along the study area, Mysore

An emission inventory is a database that lists the sources and the amount of air pollutants discharged into the atmosphere during a given time period. It is useful in determining the significant sources of air pollutants and to establish emission trends over time, target regulatory actions, and estimate air quality through computer dispersion modeling. Emission Inventory depends upon location, elevation, frequency and duration of emission, etc. and it provides the information about the status of air pollution in the urban fringes. In the present study, emission inventory

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has been prepared for CO, NO_x and PM₁₀ based on the emission factors published by ARAI report (2008). The daily and hourly variations in emissions were estimated at each link identified along the study area and Table 1 shows the average daily traffic volume and corresponding emissions in g/mile. From the Table 1 it is observed that, as the traffic volume increases the emission load also increases and load of particulate matter was found to be least when compared with the CO and NO_x load in the study area.

Table 1 Daily Variation				
Link	Traffic Count (Number)	Emission load in g/mile		
		CO	NO_x	PM
1	852	46.605	45.17	5.31
2	852	46.605	45.17	5.31
3	852	46.605	45.17	5.31
4	852	46.605	45.17	5.31
5	786	42.995	41.671	4.898
6	786	42.995	41.671	4.898
7	984	53.826	52.168	5.369
8	993	54.318	52.646	6.189
9	1029	56.287	54.554	6.413
10	1029	56.287	54.554	6.413

Field monitoring

In the present study, SO₂, NO_x, PM₁₀ and PM_{2.5} were monitored over a period of seven months i.e., from December, 2014 to June, 2015 at three monitoring stations which is at an interval of 1 km along the highway passing through the industrial area. The selection of these monitoring stations was based on the nature of terrain as well as the prevailing wind directions. To study the lateral dispersion of vehicular emissions, cross sectional monitoring stations were located on either side of the ring road at an interval of 100 m. The concentrations of SO₂, NO_x, PM₁₀ and PM_{2.5} at Location 1 (near CIPET, Mysore), Location 2 (near V-LEAD, Mysore) and Location 3 (near Sheshadripuram college, Mysore) were plotted for three different seasons such as, winter, pre-monsoon and monsoon seasons shown in Figures 3 (a), (b) and (c). It is observed that, PM₁₀ was exceeded in all the seasons except during monsoon season, other parameters were found to be within the permissible limits of NAAQ Standards at all the monitoring locations. During winter season, the temperature noticed was in the range between 9° C and 22° C, during which due to higher moisture content in the atmosphere higher ground level PM₁₀ concentrations was observed. However, at Location 2 (Samudaya bhavana) and Location 3 (Sheshadripuram College) PM₁₀ concentration was found to be exceeding the permissible limits. Further, all the pollutant concentrations were found to be higher during pre-monsoon which may be due to increase in fleet movement of vehicles during summer holidays. Pollutant concentration recorded in receptors located near CIPET, Mysore (Location 1) and Weigh bridge (Location3) were found to be higher as the wind direction was from South-East and South-West towards the northern part of the study area. During monsoon season all the pollutant concentrations were found to be within the permissible limits of NAAQ Standards at each receptor point which may be due to the precipitation occurred and there by pollutants tends to settle at the ground level.

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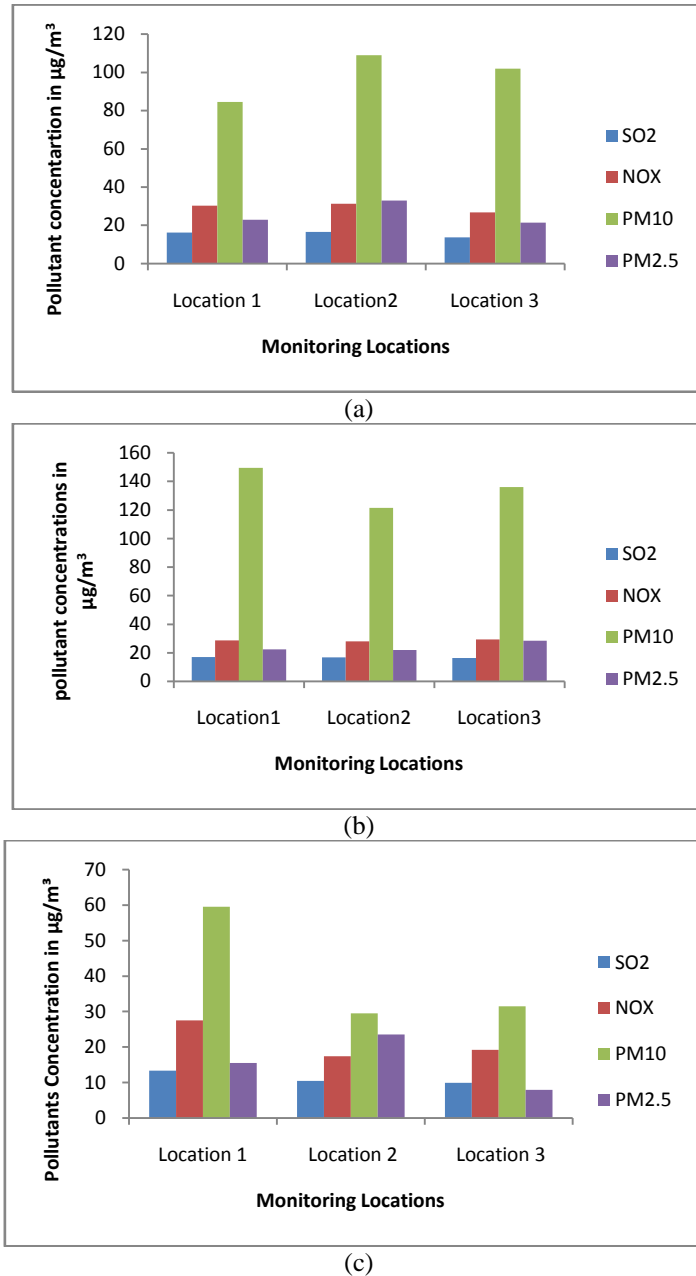


Fig 3 Plots for pollutants concentration at different locations in the study area during (a) winter, (b) pre-monsoon and (c) monsoon season.

Model results

Present study, mainly focused on the applicability of CALINE4 an air dispersion model for seasonal, daily and hourly variations of pollutant concentrations such as, SPM and NO_x. Isoleth plots were developed for the study period i.e., from December, 2014 to July, 2015 for PM₁₀ concentration over the selected stretch of highway from both line source (Vehicular emissions) and point source (Industrial emissions), which shows the influence of the wind direction on the dispersion of pollutants and to which direction the pollutants disperse in different seasons of the study

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period in the study area is as shown in Figure 4 (a), (b) and (c). From Figure 4 (a), it is observed that, pollutant concentration during winter season show higher values, which may due to wind direction that blew towards South-West direction and there by the pollutants from the vehicular and industrial emissions were dispersed towards Location 3 which is being nearer to Sheshadripuram College. During pre- monsoon season, the wind direction was towards Northern part of the study area. Figure 4 (b) shows the dispersion of pollutant concentration from vehicular source towards the industrial sector and higher concentration was found to be near the J.K. Industry, which was due to the point source emission from a rubber tyre industry. During monsoon season, the pollutant concentration was comparatively lower along the identified stretch of highway. Further, it can be observed that, pollutant concentration was mainly due to industrial source and gradually disperse towards Northern part of the study area as the prevailing wind blew from West-South-West direction towards the North-East direction as shown in Figure 4 (c).

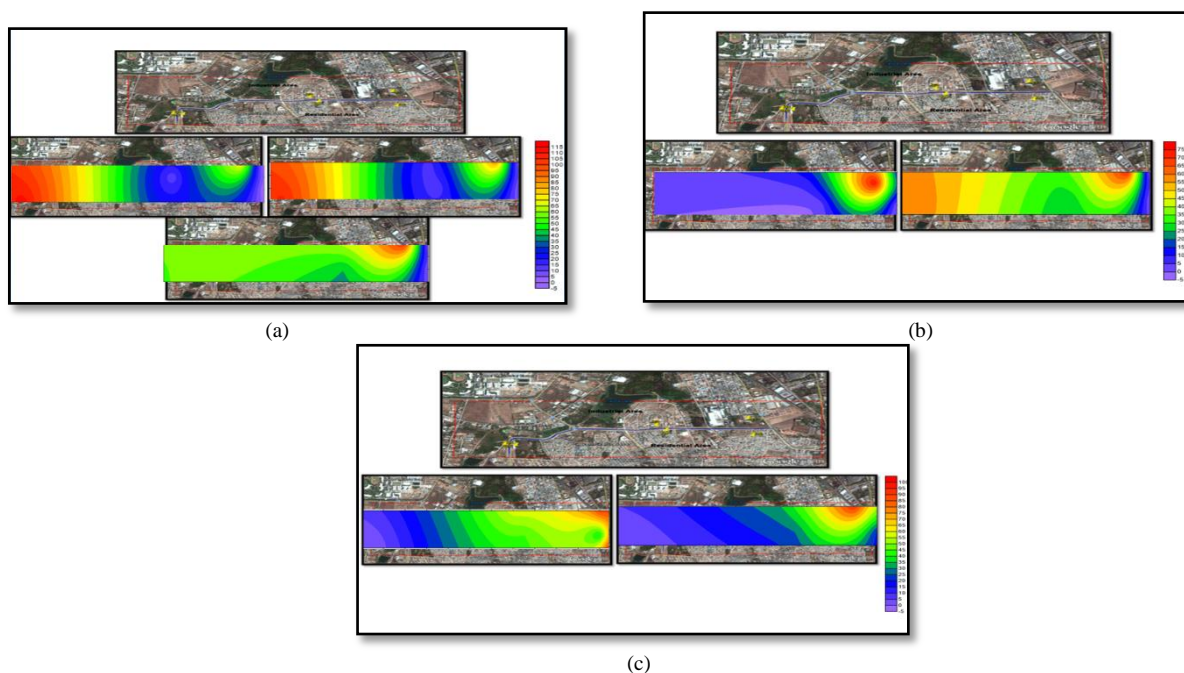


Fig 4 CALINE4 predicted PM10 concentration along with point source PM10 concentration during (a) winter, (b) pre-monsoon and (c) monsoon season.

Predicted results for SPM from the CALINE4 model were marginally over-predicted than the actual results. Whereas for NO_x, the model predicted results were marginally under-predicted when compared with the actual field data. Plot for PM₁₀ and NO_x observed versus predicted concentration has been shown in Figures 5 and 6. It is observed that, predicted concentration from CALINE4 was found to be 151 µg/m³ and the actual field monitored data for the same conditions was found to be 140 µg/m³ which infers that, the model results were satisfactory. The plot for monitored versus predicted concentration of PM₁₀ and NO_x gives the R² values of 0.924 and 0.943, respectively. The equations relating to the predicted with observed values are given in eqns. (1) and (2).

$$y = 0.886 x + 14.34 \quad (1)$$

$$y = 1.133 x - 20.58 \quad (2)$$

From the plot, it is observed that, CALINE4 model slightly over-predicts the PM₁₀ concentration and under-predicts the NO_x concentration when compared with monitored values. The obtained R² value of 0.924 and 0.943 indicated that, the model results are in good agreement with the monitored data.

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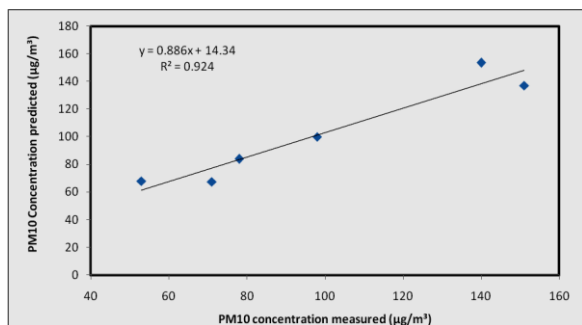


Fig 5 Plot of correlation between predicted and observed values of PM₁₀ concentration

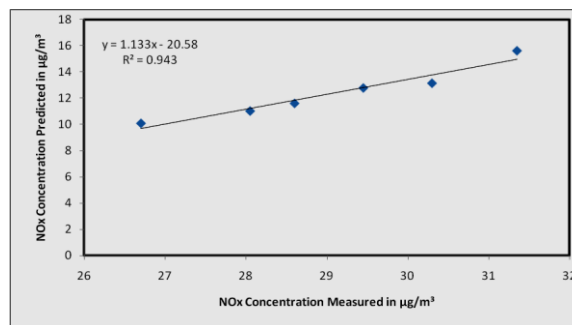


Fig 6 Plot of correlation between predicted and observed values of NO_x concentration

Further, CALINE4 model has been run for three seasons, i.e., winter, pre-monsoon and monsoon season, respectively, at ambient temperatures ranging from 9 °C to 32 °C under different atmospheric stability class from 1 to 7. The monitored wind velocities during the study period was ranging from 1 m/s to 5.28 m/s. From the monitored data, it was observed that, the PM₁₀ concentration when the wind speed was less than 2.5 m/s was found to be exceeding the permissible limits (100 µg/m³) i.e. 141 µg/m³ at Location 2 and pollutant concentration were less (34 µg/m³) when the wind speed was 5.28 m/s during monsoon season at Location 1. From the above discussion, it can be inferred that, the CALINE4 model prediction depends on the meteorological parameters such as: ambient temperature, atmospheric stability class and wind velocity.

V. CONCLUSION

Air quality monitoring was carried out along the selected stretch of Mysore-Bangalore highway at three locations for three different seasons i.e., Winter, Pre-monsoon and Monsoon season. The windrose plots clearly indicates that, the wind direction was gradually changed from North-East to West-South-West direction during the study period (i.e., from December, 2014 to June, 2015). During winter, wind predominantly blew from North-East direction, which indicated that, pollutant dispersion was towards the Mysore city limits (Residential layouts) however, in other two seasons the wind direction was towards Northern direction indicating the pollutants were transporting away from the Residential layout. SO₂, NO_x and PM_{2.5} were observed to be within the permissible limits of NAAQ Standards. PM₁₀ concentration was exceeding the permissible limits of NAAQ Standards (100 µg/m³) at Location 2 during winter as well as pre-monsoon i.e., 140 µg/m³ and 165 µg/m³. This may be due to the nature of terrain (gentle valley condition) and low temperature (11° C). Maximum PM₁₀ concentration was found to be 165 µg/m³ during pre-monsoon at Location 2 (near V-LEAD), which may be due to receptors located near to the roadway as well as due to the peak traffic flow of 26,526 was observed. However, during winter and monsoon season peak traffic flow of 24,491 and 24,441, respectively, was noticed. The isopleth plots were developed using CALINE4 Model showed, the vehicular emissions contribution have significant impact on ambient air quality. Results of CALINE4 Model for PM₁₀ concentration was found to be marginally over-predicted when compared with the monitored data during the study period (i.e., from December, 2015 to July, 2015). NO_x prediction from the CALINE4 Model was found to be under-predicted when compared with the monitored data. This may be due to the presence of atmospheric nitrogen in the ambient air which also contributes to the field monitored NO_x concentration. Sensitivity analysis of the CALINE4 model when wind velocity < 2 m/s showed, the PM10 concentration was found to be 169 µg/m³ which is greater than the NAAQ Standards.

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