Ambient Air Quality Monitoring and Prediction of NO_2 Concentration using CALINE4 Model at Institutional and Commercial Area of Mysuru City, India

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Abstract— Unprecedented growth of traffic volume has resulted in accelerated process of ambient air quality deterioration along major roadways. This paper is focused on determination of ambient air quality near a major traffic intersection and to determine the pollutant dispersion along major roadways of institutional and commercial study areas using CALINE4 Gaussian based dispersion model. Maximum traffic density was noticed near to the commercial area and peak traffic hours were noticed from 10:00 am to 11:00 am and during afternoon 04:00 pm to 05:00 pm. The NO_2 and SO_2 concentrations were found to be more in the commercial area than the institutional area. NO_2 concentrations were more during winter season (14-23 µg/m^3) than summer season (8-18 µg/m^3). Statistical analysis revealed that, CALINE4 model prediction was poor in correlation with observed NO_2 concentrations. However, based on statistical analysis model prediction was better during winter season than summer season. CALINE4 model showed a poor applicability for prediction of pollutants with less concentration.
Key words: Ambient Air Quality; CALINE4; NO2; SO2; Vehicular Count

I. INTRODUCTION

Mysore city is experiencing rapid expansion of transportation sector. A sharply declining air quality is anticipated in the near future. Heavy traffic volumes, higher emission factors and rapid growth of the transportation sector are the known factors attributed to the deteriorating air quality. Mysore city had about 4, 02,170 two wheelers, 11,615 three wheelers, 53,768 light motor vehicles and 10,336 heavy trucks in the year 2014 (Regional Transport Office, Mysore, Karnataka, India). With such a dramatically increasing rate of vehicles each year, the quality of air becomes questionable. Few studies have been previously conducted to monitor and assess the ambient air quality in Mysore city. The present study is conducted to determine the ambient air quality and its deterioration due to vehicular contribution. The study is aimed at monitoring the ambient air quality along roadways of two specified regions, i.e., institutional and commercial areas of the city. CALINE4 is a line source dispersion model, developed by California Department of Transportation, based on Gaussian plume dispersion concept [1]. Konar and Chakrabarty (2012) conducted studies on the applicability of CALINE4 model for determination of concentration of oxides of Nitrogen along the belt of educational institutions in Kolkata [2]. Prusty (2012) conducted a study on surveillance and indexing of ambient air quality around mining clusters in Western Kachchh Region, Gujarat and concluded major sources of atmospheric emissions were due to opencast mining, land clearing, removal of overburden, vehicular movement, excavation, and loading and unloading of ore materials [3]. Hence, in the present study, applicability and validity of CALINE4 Gaussian dispersion model in Mysore city has been studied.

II. STUDY AREA

To examine the influence of vehicular emissions on ambient air quality, air sampling studies were conducted locations near to a busy roadway such as, Hunsur road. The first zone of study is a region of densely occupied institutional area with array of different educational organizations having regular coverage with buildings, open spaces roughly equal to building heights and scattered vegetation cover. The three receptor locations chosen for air quality analysis were, Regional Institute of Education entrance gate (R1), Sri Jayachamarajendra college of Engineering entrance gate (R2) and JSS polytechnic for women entrance gate (R3), which were equally spaced at an approximate distance of 500 m. The institutional study area has been shown in Figure 1. The second zone of study is a region of scarcely populated commercial area with multitude of passenger car showrooms, restaurants, petrol pump, nurseries and recreational lounges. The area of interest was found to have regular coverage with buildings, irregular forests with scattered clearings or open spaces. The three receptor location chosen for air quality analysis were, Renault (R4), Honnasiri Nissan (R5) and TVS Nandi (R6). The three receptor locations were spaced at distances less than 200 m each. This condition has been adopted with the intention of not violating the link spacing not more than 500 m as specified in the CALINE4 model [1]. The commercial study area has been shown in Figure 2.

III. MATERIALS AND METHODS

A. *Meteorological data collection*

During the ambient air quality monitoring, meteorological parameters were collected during the study period from December 2014 to April 2015. The wind data (wind speed and direction), ambient temperature, atmospheric pressure and precipitation were collected from the webpage of Weather Underground. The wind data were recorded on a daily basis and tabulated in form of month wise data. This data was utilized for the estimation of dispersion of Nitrogen dioxide by using CALINE4 model and also to plot wind rose diagrams. Mixing height values for different meteorological conditions was collected from "Atlas of Hourly Mixing Height and Assimilative Capacity of Atmosphere in India" (IMD Publication on Environmental Meteorology) [4]. The wind rose diagrams are drawn using the WRPLOT view plot developed by Lakes Environment. The required input data such as, year, date, hour, wind speed, wind direction and precipitation are tabulated in the excel spreadsheet. The excel file is imported to the WRPLOT software and converted into document of SAMSON format.

Fig. 1: Google map view of institutional study area including selected highway and Receptor 1, 2 and 3.

Fig. 2: Google map view of commercial study area including selected highway and Receptor 4, 5 and 6.

B. *Air quality monitoring*

The collection of ambient air samples from the specified receptor locations was carried out with the help of high volume air sampler, Envirotech APM 433, which was used for determination of ambient Nitrogen dioxide and Sulphur dioxide concentrations. Modified Jacobs & Hochheiser Method (IS 5182 Part 6 Methods for Measurement of Air Pollution: Oxides of Nitrogen), has been adopted for the determination of concentration of NO_2 and Modified West & Gaeke Method (IS 5182 Part 2 Methods for Measurement of Air Pollution: Sulphur dioxide) has been adopted for determination of SO_2 [5].

C. *Input data for CALINE4 model*

In the present study, CALINE4 model has been used to predict the concentration of Nitrogen dioxide at two different roadway sections, situated in the institutional and commercial areas under different meteorological conditions. Two links were considered on each roadways and link type was selected as At-grade type owing to the surface terrain and road geometry. There were no curvilinear roadways that contributed to disturbance in air flow pattern. The link height was selected as 0 m and the emission factor for the link activity computation was chosen as 2.2 – 3.0 g/mile based on values given by Automotive Research Association of India (ARAI, 2008) [6]. The aerodynamic roughness coefficient was chosen as 100 cm in the institutional area owing to the regular coverage of buildings and scattered vegetation present in the region of study and the mixing zone width was chosen as 14 meters based on the actual field determination. On the other hand, aerodynamic roughness coefficient for the commercial area was chosen as 200 cm owing to the regular coverage of buildings and irregular forests with scattered clearings present in the region of study. The mixing zone width was chosen as 30 meters based on the actual field determination.

IV. RESULTS AND DISCUSSIONS

A. *Micrometeorology*

Meteorological parameters were collected from December, 2014 to April, 2015 considering winter and summer seasons. A maximum temperature of 36°C was observed in the month of April, 2015 (Fig. 3), and a minimum temperature of 15°C was observed during the winter season (February, 2015). The diurnal variation of temperature showed, a minimum temperature during the late night and early morning time, implying a stable atmospheric condition during these period. On the other hand, temperature was increased with the solar radiation during day time. A maximum relative humidity (RH) of > 90% was observed during most of the seasons (Fig. 3) in the morning hours and a minimum RH of 17-30% was observed during day time. The reason for decreased RH during day time may be due to RH and temperature are inversely proportional to each other. Windrose diagrams were plotted for winter and summer seasons (Figs. 4a-b). It was observed that, predominant wind was blowing from East (E) and East-North-East (ENE) direction during the winter season, however, predominant wind was blowing from West-South-West (WSW) during summer season. Average wind speeds were found to be 3-6 m/s and 2-4 m/s during winter and summer seasons, respectively. Wind speeds were found to be more during winter season when compared to summer season.

B. *Traffic volume studies*

The vehicular emissions or line sources are one of the major sources of air pollution in the study area. Vehicular count of different category of vehicles were conducted manually from 9:00 am to 5:00 pm. It was observed that, vehicular density was maximum at 10:00 am to 11:00 am (morning peak hours) due to presence of school, college and official activities (Fig. 5). The vehicular density was observed from 2500 to 3500 vehicles per hour at institutional area and 3500 to 5000 vehicles per hour at commercial area. Vehicular density was found to be maximum at commercial area due to busy Hunsur Road. A trend of increased traffic volume was also observed during 4:00 pm to 5:00 pm (evening peak hours). Further, traffic volume have been categorized into four major groups i.e., 2 wheelers (2W), 3 wheelers (3W), 4 wheelers (4W) and Heavy duty vehicles (HDV). It was observed that, traffic composition was mainly dominated by 2W in both the locations, varying from 58–65 %, followed by 4W (23–25 %), HDV (9–12 %), and 3W (3–5 %) (Figs. 6a-b). A total of 19,000 2W vehicles were counted during 8 hours of sampling period at commercial area.

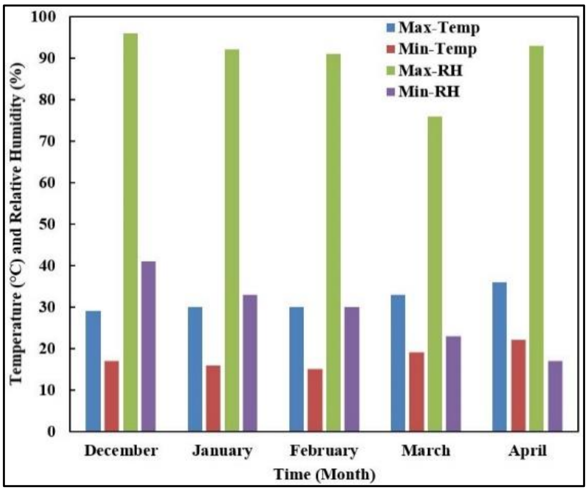
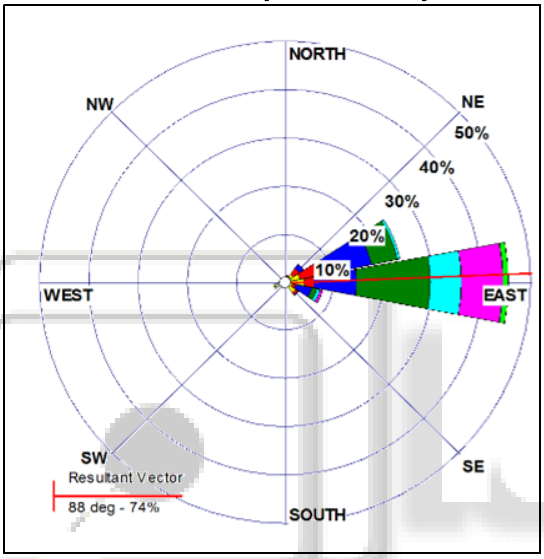
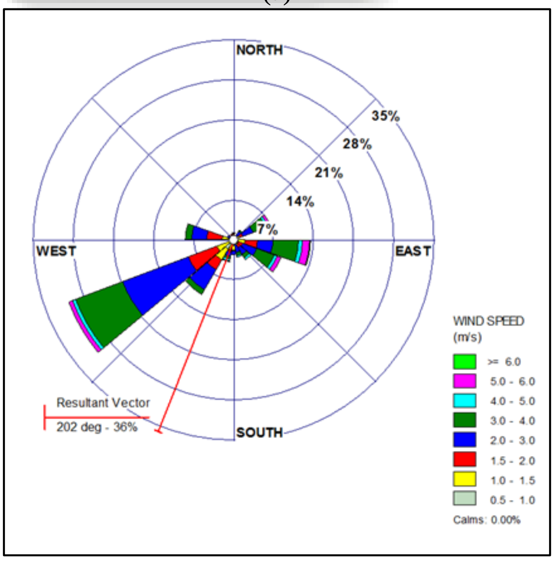


Fig. 3: Variation of maximum and minimum temperature and relative humidity over the study area.



(a)



(b)

Fig. 4: Windrose plot for (a) winter season, (b) summer season over the study area.

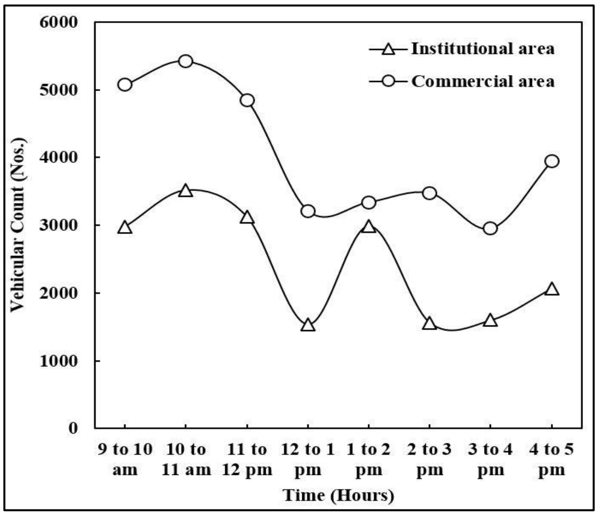
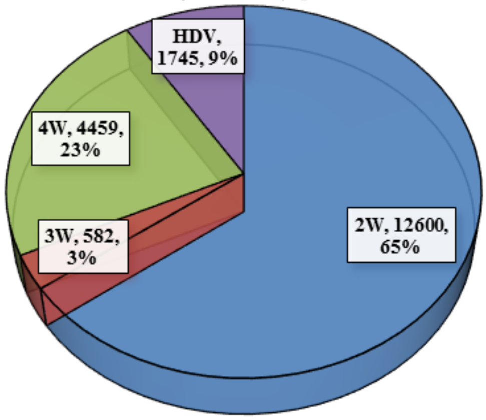
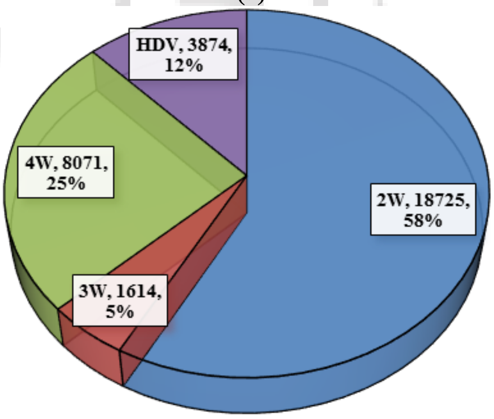


Fig. 5. Traffic variation at institutional and commercial area during the study period.



(a)



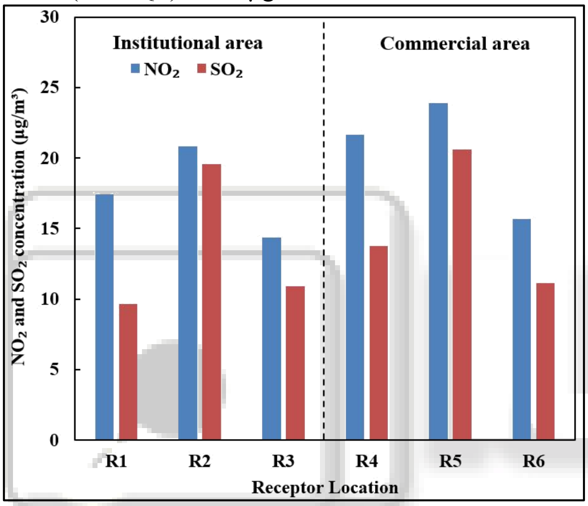
(b)

Fig. 6: Percentage distribution of different category of vehicles at (a) institutional area, (b) commercial area.

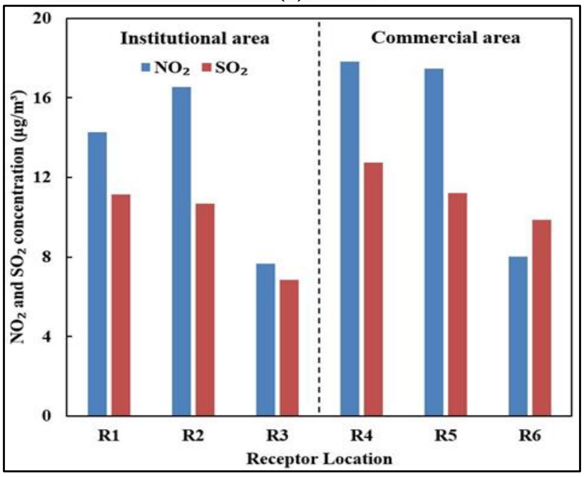
C. Ambient air quality

Ambient air quality was monitored during winter and summer season at Institutional and Commercial area, Mysuru city from December, 2014 to April, 2015. Three receptor locations at institutional area i.e., Regional Institute of Education entrance gate (R1), Sri Jayachamarajendra college of Engineering entrance gate (R2), JSS polytechnic for women entrance gate (R3), and at commercial area i.e., Renault (R4), Honnasiri Nissan (R5), TVS Nandi (R6) were selected. The results of ambient air quality study during winter and summer seasons are presented in Figures 7 (a-b).

It was observed that, NO_2 and SO_2 concentrations were varying from 17-23 μg/m^3 and 10-20 μg/m^3, respectively, during winter season at both the locations (Fig. 7a). However, NO_2 concentration was found to be more at location 2 (R4-R6). This may be due to more number of vehicles, which may contribute NO_2 to the atmosphere. As the number of vehicle increases pollutants such as, CO, NOx and PM_{10} concentration also increases with the vehicular exhaust [7, 8, 9]. Further, pollutant concentrations were found to be less in summer season. NO_2 concentration was varying from 8-18 μg/m^3 over the study area (Fig. 7b). This may be due to unstable atmospheric condition, as temperature was found to be 36°C during summer season. As temperature increases, atmosphere becomes unstable, which implies a better mixing or dilution of the pollutants into the atmosphere. A similar result of maximum pollutant concentration during winter season was observed by Prakash et al., 2015 [10]. However, pollutant concentrations were found to be within the National Ambient Air Quality Standard (NAAQS) of 80 μg/m^3.



(a)



(b)

Fig. 7: Variation of NO_2 and SO_2 concentrations at different receptor points during (a) winter, (b) summer season.

D. CALINE4 Model Prediction

The result of CALINE4 model prediction for NO2 is presented in Table 1. In the present study, commercial area was found to have greater pollutant concentrations owing to the regular coverage of buildings, which led to constricted air flow pattern in the area. Institutional area was found to have lesser pollutant concentration because of low traffic density and lower emission factor. This kind of result may be attributed to the relatively greater number of scatterings, spacing and irregular coverage of buildings. The predicted pollutant concentration showed greater magnitude of concentration in the months of January and February, than in the months of March and April due to stable atmospheric condition and high RH, which were responsible for minimum initial dispersion of pollutants.

Receptor location	CALINE4 predicted NO_2 concentration (μg/m^3)	
	Winter	Summer
Institutional area		
R1	25.73	23.36
R2	28.31	24.08
R3	27.58	22.17
Commercial area		
R4	31.79	26.07
R5	32.58	26.13
R6	26.48	22.35

Table 1: CALINE4 model prediction for NO_2 concentration at institutional and commercial area during winter and summer season

E. Statistical Analysis

Statistical analysis was carried out to evaluate the model performance with monitored pollutant concentration. Statistical analysis such as, Absolute Bias (AB), Fractional Bias (FB), Normal Mean Square Error (NMSE), Root Mean Square Error (RMSE), Index of Agreement (d) and Factor of Two (FAC2) have been considered in the present study. The detail results obtained for statistical analysis is showed in Table 2. Based on statistical analysis values, it was clearly noticed that, CALINE4 model prediction was better during winter season than summer season. Fractional Bias (FB) values were found to be negative, which implies, model was overpredicting the NO_2 concentrations. However, FB and NMSE values during winter and summer seasons were found to be within the limit. Further, Index of Agreement values were found to be less than the standard range. This may be due to the fact that, model input parameters into CALINE4 model was found to be very limited and CALINE4 predicts the NO_2 concentration in ppm which further has to convert into μg/m^3. It was also observed that, CALINE4 model accuracy was upto 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 and MG (Geometrical Mean) for predicting $PM_{2.5}$ concentration, which was well within the permissible limits [11]. Ganguly et al. (2009) have found FB value very close to zero using CALINE4 and GFLSM (General Finite Line Source Model) model, which indicates a very good model predictions [12].

Statistical Analysis	Std. Range	Winter	Summer
Absolute Bias		-9.76	-10.39
Fractional Bias	-0.7 to +0.7	-0.41	-0.55
NMSE	-0.5 to +0.5	0.17	0.33
RMSE		3.98	4.24
Factor of 2	0.5 to 2	0.66	0.57
Index of Agreement	0.4 to 1	0.23	0.17

Table 2: Statistical analysis for observed and model predicted data during winter and summer season

A plot of correlation between predicted values against the monitored NO_2 concentrations have been made and best fit line has been drawn and are shown in Figures 8 (a-b). The best fit straight line between measured and predicted NO_2 concentrations showed a R^2 value of 0.6905 for winter season and 0.8196 during summer season.

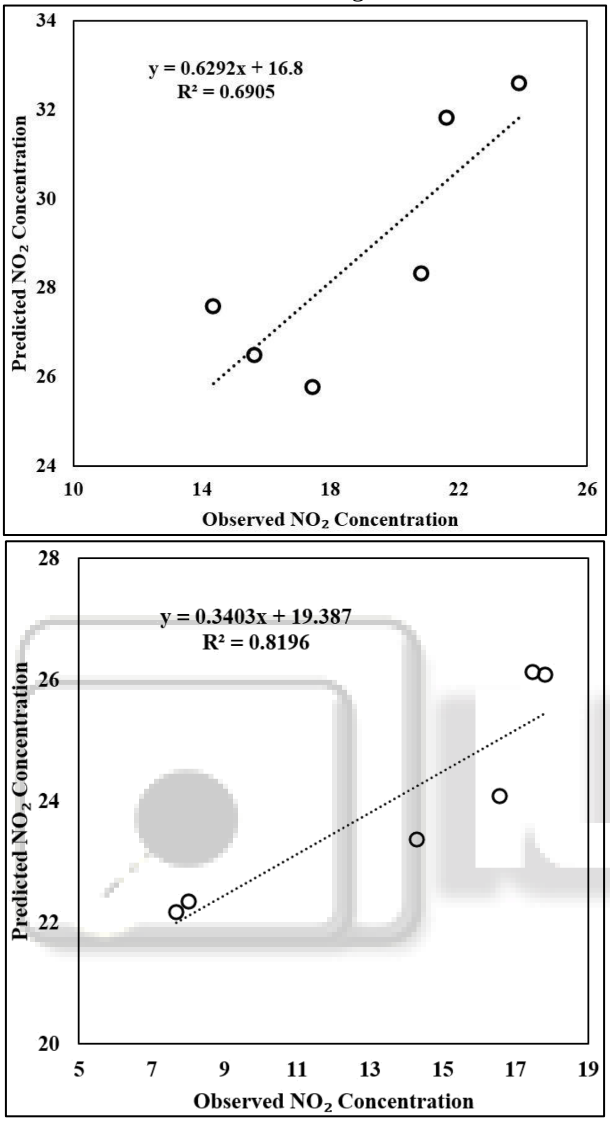


Fig. 8: Best fit straight line between measured NO_2 concentrations and predicted NO_2 concentrations by CALINE4 model (a) winter, (b) summer season.

V. Conclusions

The vehicular emissions are major sources of pollution in the present study area. Predominant wind was blowing from E direction during winter season and WSW direction during summer season. Further, maximum vehicular density was noticed near to the commercial area and a peak traffic hour was identified from 10:00 am to 11:00 am and from 04:00 pm to 05:00 pm. The gaseous pollutant concentrations were found to be more in the commercial area than the institutional area. Higher concentrations of the ambient air pollutants were observed in the months of January and February, when compared to the remaining study period. CALINE4 model prediction was varying from 25-33 $\mu g/m^3$ during winter and 22-26 $\mu g/m^3$ during summer season. Statistical analysis revealed that, CALINE4 model prediction was better during winter season than summer season, and most of the statistical analysis were not within the standard range. Finally, best fit line between measured and predicted NO_2 concentrations showed a R^2 value of 0.6905 during winter season and 0.8196 during summer season.

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