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PREDICTING $PM_{2.5}$ CONCENTRATION IN ROADWAY OF BANGALORE CITY USING CALINE 4 MODEL

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ABSTRACT

In metropolitan cities, the extensive growth of the motor vehicles has resulted in the deterioration of environmental quality and human health. In Bangalore, the concentrations of pollutants at major roadways are exceeding the permissible limits. Public are facing severe respiratory diseases and other deadly cardio-vascular diseases. Immediate needs for vehicular air pollution monitoring and control strategies for urban cities are necessary. CALINE 4 model was used to predict and evaluate the particulate matter ($PM_{2.5}$) concentrations at roadway near AMCO Batteries, Bangalore. Traffic study was conducted between 6:00AM to 10:00PM i.e., for 16 hours. The peak flow of traffic was recorded between 8.00AM to 12.00 noon and 4.00PM to 8.00PM. The predicted $PM_{2.5}$ concentrations ranged between 114.2µg/m^3 and 446.6µg/m^3. Higher concentrations were observed on Monday's, Friday's and Saturday's. The predicted concentrations of $PM_{2.5}$ were compared with the measured $PM_{2.5}$ concentrations. Based on the comparative test (t-test) outcome, the performance of CALINE 4 model for prediction of $PM_{2.5}$ concentration is valid and can be accepted. The values of NMSE, FB, and GMB were well within the prescribed limits. Hence, CALINE 4 model can be efficiently used to predict the pollutant concentrations at roadway. Thereby, CALINE 4 model can serve as a database to prevent and reduce the deterioration of environmental quality.

Keywords*: *CALINE 4, Particulate Matter, Prediction, Roadway, Environmental Quality.

I. INTRODUCTION

Metropolitan cities like Mumbai, Delhi, Kolkata, Bangalore etc. have high emissions of air pollutants, which are degrading the ambient air quality day by day. The degradation of air quality is a major environmental problem that affects many urban and the surrounding regions worldwide (Agrawal I.C. et al., 2003).

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The increased growth in number of vehicles has become the main source of air pollution in metropolitan cities of India. The growth rate of vehicles helps in the economic development. As a result, more and more vehicles are added to the roadways creating traffic congestion, decrease in speed of the vehicles, more fuel consumption

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leading to high level pollution concentrations near traffic intersections and link roads (Nagendra. S.M.S et al, 2004).

Some of the major pollutants include Particulate Matter (PM_{10}), Respirable Suspended Particulate Matter (RSPM) especially $PM_{2.5}$, Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), Carbon monoxide (CO) and Hydrocarbons (HC). The most affected group of people is urban inhabitants especially, the population residing in the vicinity of urban roadways as well as pedestrians. The situation further deteriorates at urban streets, where the ventilation is insufficient (Gupta N. C., 2011).

Many models have been developed to predict pollutant concentrations at a receptor and the most commonly used models are the Gaussian models. One such dispersion model developed includes the California Line Source Dispersion Model - CALINE 4. The CALINE 4 model is widely used to predict pollutant concentrations near road due to vehicular emissions (Anjaneyulu M.V.L.R., 2008). In the present study, CALINE 4 Model was used to predict $PM_{2.5}$ concentrations near roadway (i.e., AMCO Batteries) of Bangalore.

II. LITERATURE REVIEW

In recent years Bangalore is facing severe air pollution problems due to vehicular emissions. The rapid growth of population and industries have resulted in increase of motor vehicles and associated air pollution problems. In Bangalore total registered vehicles as on March, 2014 are 34.79 lakh two wheelers, 45.62 lakh light motor vehicles, 1.64 lakh light medium vehicles, 0.95 lakh light goods vehicles, 0.35 lakh buses, 0.87 lakh heavy vehicles, 0.66 lakh taxies and other vehicles accounted for 4.88 lakh giving rise to a grand total of 50.5 lakh vehicles (RTO, Karnataka, 2014).

Particulate matter ($PM_{2.5}$) is one of the main air pollutant demonstrated to have serious impact on climate change and variety of chemical processes in the atmosphere (Kumar et al., 2010). High levels of ambient particulate matter (PM) concentrations are major concerns for health effects and visibility impairment (Chow et al., 2002).

Epidemiological studies have demonstrated a consistent increased risk for cardiovascular functions in relation to both short and long term exposure to the concentrations of ambient particulate matter (Brook R.D. et al., 2004). Small deficits in lung function, higher risk of chronic respiratory disease and increased mortality have also been associated with chronic exposure to respirable particulate air pollution (Pope I.C.A et al., 1995). Exposure to the fine airborne particulate matter is associated with cardiovascular functions and mortality in older and cardiac patients (Riediker M et al., 2004). Bown, (1994) claimed that 10,000 people per annum are dying regularly because of $PM_{2.5}$ emissions, mainly from car exhausts.

The CALINE 4 model is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over the roadway. The CALINE 4 model has better performance than other line source models and is widely used to predict near road vehicle emissions (Benson, 1992). CALINE 4 uses a series of equivalent finite line sources to represent the road segment. The total road networks is divided into finite number of elements, then each element is modeled as an equivalent finite line source positioned normal to the wind direction and centered at the element midpoint. A local X-Y coordinate system aligned with wind direction and originating at the element midpoint is defined for each element (Majumdar et al., 2008). In the present study CALINE 4 model was selected as the base model for Bangalore city to predict $PM_{2.5}$ at traffic intersection and roadway.

III. STUDY AREA

Bangalore city is located between 77°24'E - 77°48'E longitude and 12°46'N - 13°11'N latitude at 920 meters (3020 ft) above Mean Sea Level. In the present study, roadway namely, AMCO Batteries station are considered to examine the ambient air quality.

The AMCO Batteries station is located at 12˚ 57' 08" N latitude and 77˚ 32' 25" E longitude as shown in Fig. 1. Shops and residences are primarily located in zone of influence for this study area. Major sources of air pollutant are vehicular and commercial activities. High volumes of buses and other vehicles plying on Mysore road have serious impact on air quality of this area.

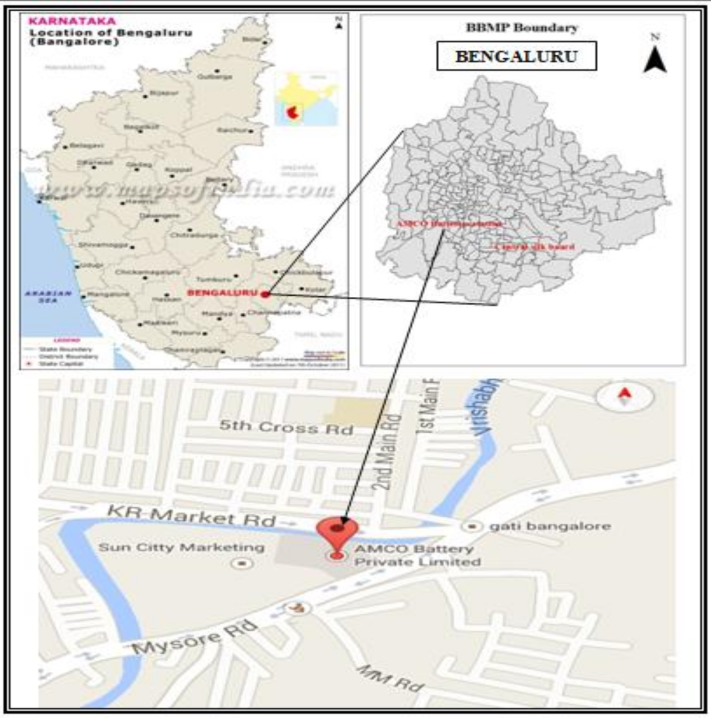

Figure 1: Location of AMCO Batteries in Bangalore

IV. METHODOLOGY

AMCO Batteries station was considered to study the ambient air quality. Since, high volumes of heavy duty vehicles ply mainly on Mysore road the traffic volume is considered to be high at AMCO Batteries station.

A traffic study was conducted between 6:00AM to 10:00PM i.e., 16 hours for different days. The traffic volume and peak flow of traffic at was estimated using C.C TV camera footage of BHEL- KIMCO junction which was collected from Traffic Management Center (TMC), Bangalore. BHEL-KIMCO junction gave the estimate of traffic volume of AMCO Batteries station. The vehicles plying on this road were classified into five groups namely, two wheelers, three wheelers, cars, light commercial vehicles (LCV) and heavy duty vehicles (Bus/truck).

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The hourly meteorological data such as wind speed, wind direction, temperature was obtained from Indian Meteorological Department, Bangalore for the selected days and the same was used as input for the model.

The road geometry data viz. road width, number of links, receptor locations, roadway height (bridge) is required for running the model. The road width at AMCO Batteries station and the exact distance of KSPCB monitoring instrument (High volume sampler) placed at AMCO Batteries station from roadway was measured using measuring tape. Most of the models on vehicular pollution take into consideration the emission factors of the vehicles. In present study, emission factors prescribed by Automotive Research Association of India (ARAI) for different categories of vehicles as indicated in the Table 1 were used as input for the model.

Table 1: Emission Factors of Vehicles for $PM_{2.5}$

Vehicles	Two Wheeler	Taxi/ Private Car	Auto	Light Commercial Vehicles	Bus/ Truck
Emission Factor (gram/mile/vehicle)	0.024	0.902	0.19	1.607	3.241

Source: Automotive Research Association of India, 2007

Meteorological condition (i.e., wind speed, wind direction, mixing height, stability class, temperature, background concentrations), emission inventory (i.e., vehicular density and vehicle emission factor) and road geometry (i.e., roadway height, receptor locations and heights, number of links, surface roughness, mixing zone width, etc.) were considered as input data to CALINE-4 Model to predict $PM_{2.5}$ concentrations.

The 8 hourly average concentration data of $PM_{2.5}$ was collected from the KSPCB's Ambient Air Monitoring Stations (AAQMS) at AMCO Batteries for different weekdays and weekends. The predicted results of the model were compared with measured KSPCB concentrations and statistical analysis was carried out to validate the model.

t-test was used to assess the difference between the measured data with the predicted concentrations. Some essential statistical performance measures include the Normalized mean square error (NMSE), the fractional bias (FB), the Geometric Mean Bias (MG) and the correlation coefficient (r) were also used. These statistical analyses were performed for the model using predicted concentrations and $PM_{2.5}$ concentrations measured by KSPCB.

V. RESULTS AND DISCUSSION

Traffic flow at the study area: The morning peak flow of traffic in the regions mostly occurs between 08.00AM-12.00 noon, while the evening peak flows have been found to be scathed between 04.00PM-08.00PM. Many shops and educational institutes are located around AMCO Batteries station and also Mysore road connects Bangalore and Mysore city, hence many KSRTC, private buses and other goods vehicles ply on this road which can be attributed to the peak flow during those hours. The estimated average traffic flow at AMCO Batteries station for 16 hours (6.00AM to 10.00PM) ranges from 71,615 to 81,070 respectively.

Composition of traffic at study area: The total traffic flow at AMCO Batteries station was dominated by two wheelers at 40-43%, followed by cars with 27%, auto-rickshaws comprising 11-12%, LCV comprising 11-12% and bus/truck comprising 8-9% of the total traffic as depicted in Fig. 2.

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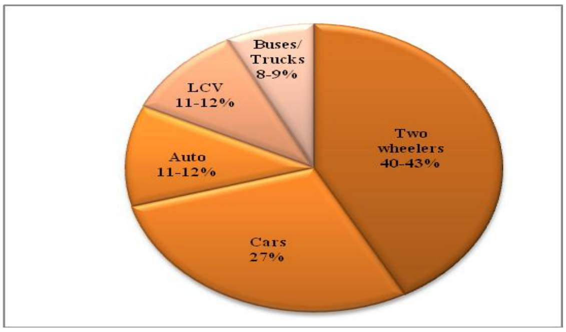

Figure 2: The Average 8 Hourly Composition of Traffic at AMCO Batteries Station

Road geometry data: The CALINE 4 model requires road geometry such as roadway height, receptor locations and heights, number of links, mixing zone width as input. The road geometry data for AMCO Batteries station was measured and the same is tabulated below in Table 2.

Table 2: Road Geometry Data of AMCO Batteries Station

Number of Links	1		
Link A			
Link height	0.0m		
Road width	16m		
Mixing zone width	22m		
Monitoring station location (KSPCB)			
Distance from link A	15m		
Height above ground level	7m		
Receptor Coordinates			
Receptor	**X**	**Y**	**Z**
	0 m	15 m	7 m

Validation of CALINE 4 model: The predicted 8 hourly concentrations of $PM_{2.5}$ were compared with the measured concentrations for AMCO Batteries station and the same is tabulated in Table 3 and Table 4.

Table 3: Predicted and Measured 8 Hourly Concentrations (6.00AM to 2.00PM) of $PM_{2.5}$ for AMCO Batteries Station

Sampling date	Day	Predicted 8-hourly value of $PM_{2.5}$ ($\mu g/m^3$)	Measured 8-hourly value of $PM_{2.5}$ ($\mu g/m^3$)
06-05-14	Tuesday	446.6	322
08-05-14	Thursday	220	191
12-05-14	Monday	213.9	209
16-05-14	Friday	306.3	237
26-05-14	Monday	396.7	326
03-06-14	Tuesday	114.2	155

11-06-14	Wednesday	172.6	219
13-06-14	Friday	284	243
21-06-14	Saturday	211.1	198

Table 4: Predicted and Measured 8 Hourly Concentrations (2.00PM to10.00PM) of $PM_{2.5}$ for AMCO Batteries Station

Sampling date	Day	Predicted 8-hourly value of $PM_{2.5}$ (μg/m^3)	Measured 8-hourly value of $PM_{2.5}$ (μg/m^3)
06-05-14	Tuesday	204.5	176
08-05-14	Thursday	227.1	217
12-05-14	Monday	186.5	185
16-05-14	Friday	232.1	213
26-05-14	Monday	188	110
03-06-14	Tuesday	218.5	167
11-06-14	Wednesday	206.3	203
13-06-14	Friday	212.3	244
21-06-14	Saturday	244.7	219

The T – test established that there is no significance difference between the measured values and the predicted values. Hence, the model can be used to obtain pollution level data.

Performance evaluation of model: Statistical performance measures are suggested by the U.S. Environmental Protection Agency as basis for evaluation of air quality model. These performance measures include the Normalized mean square error (NMSE), the fractional bias (FB), the Geometric Mean Bias (MG) and the correlation coefficient. These statistical errors, namely Normalized mean square error (NMSE), Fractional bias (FB) Geometric Mean Bias (MG) and Correlation coefficient was calculated for the model using predicted and measured $PM_{2.5}$ concentrations.

Therefore the performance of CALINE 4 model for the present study was validated using the statistical parameters results tabulated in Table 5.

Table 5: Statistical Analysis of CALINE 4 Model Performance for $PM_{2.5}$

Parameter	Acceptance value	Performance of model	
		AMCO	
NMSE	NMSE ≤ 0.5	0.0123	**Accepted and Valid**
FB	-0.7<FB<0.7	-0.111	
MG	0.75 <MG<1.25	0.894	
R	Close to 1.0	0.85	

Hence according to results of statistical analysis of CALINE 4 model performance for prediction of $PM_{2.5}$, the values of NMSE, FB, MG and correlation coefficient are well within the prescribed limits and the performance of CALINE 4 model for prediction of $PM_{2.5}$ concentration is accepted and valid.

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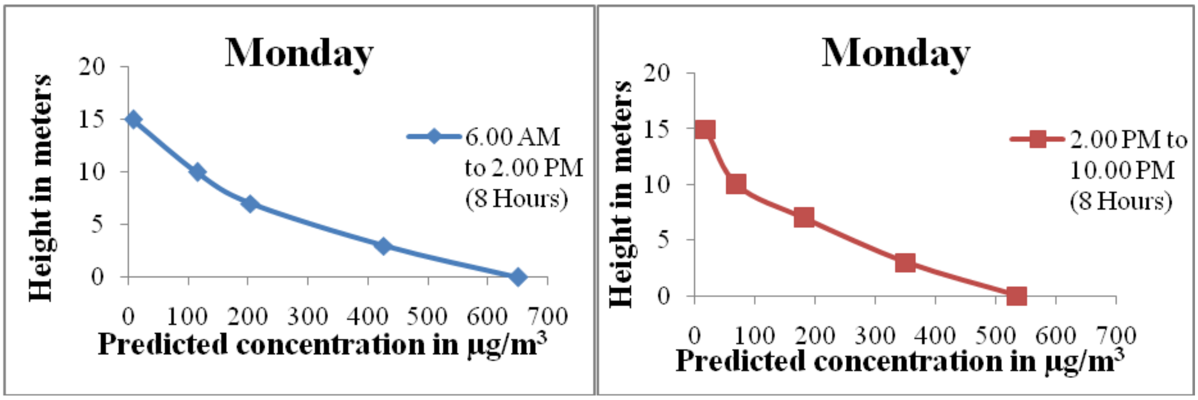
Vertical Distribution of $PM_{2.5}$: It is important to study the changes in the vertical and horizontal concentration of particles in urban cities. The concentration versus height of primary pollutant for the stable and the neutral cases was studied. The concentration of primary pollutants decreases as the height increases for the stable and the neutral cases. The primary pollutant is nearly zero at 25 meters height in the stable case and is nearly zero at 100 meters height in the neutral case. This shows that the neutral case enhances vertical mixing and the stable case suppresses vertical mixing. Therefore the ground level concentration is more concentrated in the stable case and is less concentrated in the neutral case. (Lakshminarayanachari K, 2013)

In the present study, the changes in vertical concentration of particles was examined using CALINE 4 model for different heights i.e., 0m, 3m, 7m, 15m and 20m near the roadway for two different days (Monday and Friday). The concentration of $PM_{2.5}$ decreased gradually as the height increased for AMCO Batteries station. The concentrations of $PM_{2.5}$ at various heights for both the stations are tabulated in Table 6.

Table 6: The concentrations of $PM_{2.5}$ at various heights

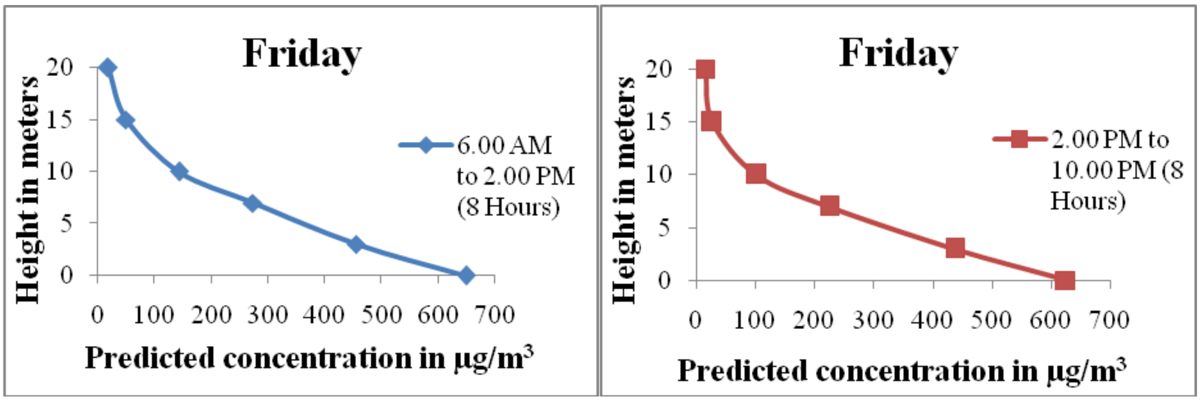
Height (in m)	**Monday** (µg/m³)		**Friday** (µg/m³)	
	6AM to 2PM	2PM to 10PM	6AM to 2PM	2PM to 10PM
0	651.5	536.8	648.7	625.4
3	426.7	351.6	454.9	437.7
7	204.1	183.5	272.7	225.3
10	114.7	70.6	143.2	102.4
15	8.4	18.4	50.3	27.2
20	-	-	18.2	15.4

The predicted concentration of AMCO Batteries station at ground (3m) ranged between 536.8 to 651.5µg/m^3 and it gradually decreased to 8.4 to 18.4µg/m^3 at 15m height (Monday). Similarly on Friday the predicted concentration ranged between 625.4 to 648.7µg/m^3 and it gradually decreased to 15.4 to 18.2µg/m^3 at 20m height as shown in Fig. 3 and Fig. 4.



(a) **(b)**

Figure 3: Variation of $PM_{2.5}$ concentration with respect to various heights at AMCO Batteries station for Monday during (a) 6.00am to 2.00pm (b) 2.00pm to 10.00pm



(a) **(b)**

Figure 4: Variation of $PM_{2.5}$ concentration with respect to various heights at AMCO Batteries station for Friday during (a) 6.00am to 2.00pm (b) 2.00pm to 10.00pm

VI. CONCLUSIONS

This paper illustrates an approach for validation and application of CALINE 4 model for predicting $PM_{2.5}$ concentrations. The model predictions of 8 hourly $PM_{2.5}$ concentrations for the AMCO Batteries ranged from 114.2µg/m^3 to 446.6µg/m^3. Heavy traffic was witnessed on Monday's, Friday's and Saturday's due to large number of bus/trucks, cars and two wheelers playing on Mysore road. The comparative test (t-test) indicated that there is insignificant difference between measured and predicted mean values of model and therefore model prediction is correct and valid. The values of NMSE, FB, and GMB were well within the prescribed limits of U.S. EPA. The concentration of $PM_{2.5}$ decreased gradually as the height increased. The concentrations get diluted and reduced within 25m height during strong winds and it may lift up to 100m during weak winds. From this study it can hence be concluded that CALINE 4 model can be effectively used to predict the pollutant concentrations. A database can be generated using CALINE 4 model to prevent and minimize the deterioration of environmental quality.

VII. ACKNOWLEDGEMENTS

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