International Journal of Civil Engineering and Technology (IJCIET)
Volume 6, Issue 10, Oct 2015, pp. 191-200, Article ID: IJCIET_06_10_017
Available online at
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=6&IType=10
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

APPLICATION OF CALINE 4 MODEL TO PREDICT $PM_{2.5}$ CONCENTRATION AT CENTRAL SILK BOARD TRAFFIC INTERSECTION OF BANGALORE CITY

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ABSTRACT

Rapid growth of the vehicular population has resulted in the deterioration of environmental quality and human health in metropolitan cities. Concentrations of air pollutants at major traffic intersections are exceeding the National Ambient Air Quality Standards (NAAQS) in Bangalore. The people are exposed to higher pollution levels and facing severe respiratory diseases. Hence, an attempt was made using CALINE 4 model to estimate particulate matter ($PM_{2.5}$) concentrations at traffic intersection namely, Central Silk Board, Bangalore. Traffic analysis was conducted between 6:00AM to 10:00PM. Peak flows of traffic were recorded between 8.00AM to 12.00 Noon and 4.00PM to 8.00PM. Estimated PM2.5 concentrations using CALINE 4 was ranged from 121.3µg/m^3 to 403.7µg/m^3. Maximum concentrations were observed on Monday's and Friday's. The estimated concentrations of $PM_{2.5}$ were compared with measured concentrations of KSPCB, Bangalore. Based on the comparative test (t-test) results 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 is a useful tool to predict the pollutant concentrations at traffic intersections.

Key words: CALINE 4, Particulate Matter, Vehicular Population, Performance Evaluation.

Cite this Article: Dr. B. Santhaveerana Goud, Sachinkumar Savadatti and Prathibha D. Application of Caline 4 Model To Predict Pm2.5 Concentration At Central Silk Board Traffic Intersection of Bangalore City. *International Journal of Civil Engineering and Technology*, **6**(10), 2015, pp. 191-200.
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=6&IType=10

1. INTRODUCTION

The growth rate of vehicles is the backbone of economic development. This resulted in more and more vehicles being added to the roadways creates traffic congestion, decrease in speed of the vehicles, more fuel consumption leading to high level pollution concentrations near traffic intersections and link roads (Nagendra. S.M.S et al., 2004). The pollutants of concern 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. (N. C. Gupta., 2011). A variety of air pollution models are available for predicting the pollutant concentrations. 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 near road vehicle emissions. (Anjaneyulu M.V.L.R., 2008) In the present study, Gaussian model, CALINE 4 was used to predict $PM_{2.5}$ concentrations near traffic intersection (i.e., Central Silk Board) of Bangalore.

2. LITERATURE REVIEW

The unexpected increase in number of industries and population 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 good 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 ($PM_{2.5}$) has serious impact on climate change, and variety of chemical processes in the atmosphere (Kumar et al., 2010). The health effects of particulate matter have been studied extensively and a strong correlation between human mortality and particulate matter concentration has been found (Dockery et al., 1993). Berico et al., (1997) showed that particulate matter less than 10μm in size (PM_{10}) have significant association with decline in lung function, respiratory and cardiovascular disease death and $PM_{2.5}$ was highly correlated with deaths from cardiopulmonary disease and lung cancer. Bown, (1994) claimed that 10,000 people per annum are dying prematurely because of $PM_{2.5}$ emissions, mainly from car exhausts. Linares and Diaz (2010) reported a link between a 10μg/m^3 increase in $PM_{2.5}$ concentration and up to 3.3% rise in cardio-respiratory-cause admissions among elderly people.

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 model is a 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. 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.

3. 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, traffic intersection namely, Central Silk Board is considered to examine the ambient air quality. The Central Silk Board station is located at 12˚ 55’ 01” N latitude and 77˚ 37’ 19” E longitude as shown in Figure 1. Shops and IT companies are primarily located in zone of influence for this study area. High volume of heavy duty vehicles plying mainly on Hosur road and Ring road have direct affect on air quality.

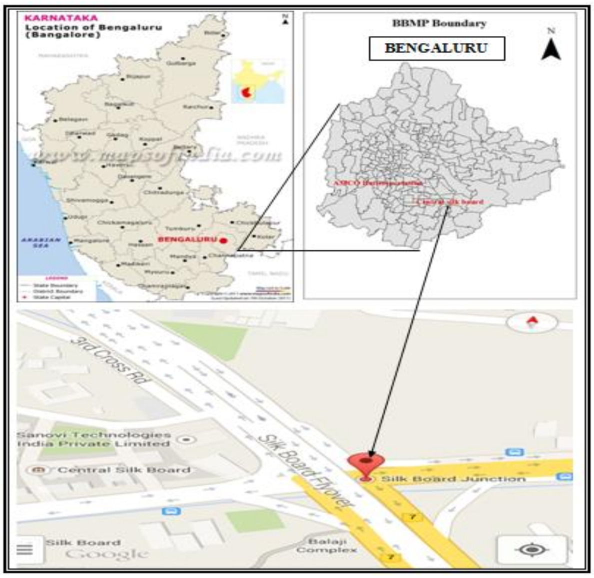


Figure 1 Location of Central Silk Board in Bangalore

4. METHODOLOGY

In the present study, Central Silk Board was considered to examine the ambient air quality. This area is regarded as one of the heavy traffic intersection in Bangalore city and has direct effect on ambient air quality. The traffic volume and peak flow of traffic was estimated using C.C TV camera footage of Central Silk Board junction and Sarjapura check post junction. Sarjapura check post junction was considered to obtain traffic volume on Silk Board flyover. 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 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 Central Silk Board and the exact distance of KSPCB monitoring instrument (High volume sampler) placed at Central Silk Board from roadway was measured. Emission factors prescribed by Automotive Research Association of India (ARAI) for different categories of vehicles (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

The CALINE 4 model was run with the given 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.) to predict the $PM_{2.5}$ concentrations.

The 8 hourly average concentration data of $PM_{2.5}$ was collected from the KSPCB's Ambient Air Monitoring Stations (AAQMS) at Central Silk Board for different days. The predicted results of the model were compared with measured KSPCB concentrations and statistical analysis was carried out. A comparative test was also applied to check the consistency of the observed data with the predicted concentrations by using the t-test. 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). These statistical analyses were performed for the model using predicted concentrations and $PM_{2.5}$ concentrations measured by KSPCB.

5. RESULTS AND DISCUSSION

5.1. Traffic flow at the study area

The morning peak flow of traffic in the region 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 IT sectors are located in and around Central Silk Board area so this may be reason for peak flow during those hours. The estimated average traffic flow at Central Silk Board and Central Silk Board flyover for 16 hours (6.00AM to 10.00PM) ranges between 63,950 to 74,514 and 49,338 to 54,543 respectively.

5.2. Composition of traffic flow

Traffic composition was dominated by two wheelers at 42-43%, followed by cars with 39-40% and auto-rickshaws comprising 8-9%, followed by LCV comprising 5-6% and followed by bus/truck with 4% of the total traffic at Central Silk Board intersection (Figure 2). During survey it was observed that 41% were two wheelers, 38-40% were cars, 7-8% were Light Commercial Vehicles, 7-8% were auto-rickshaws and bus/truck were found to be 5% of the total fleet on Central Silk Board Flyover (Figure 3).

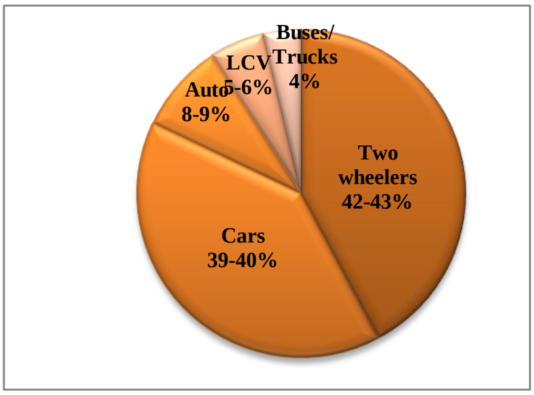


Figure 2 The average 8 hourly composition of traffic at Central Silk Board

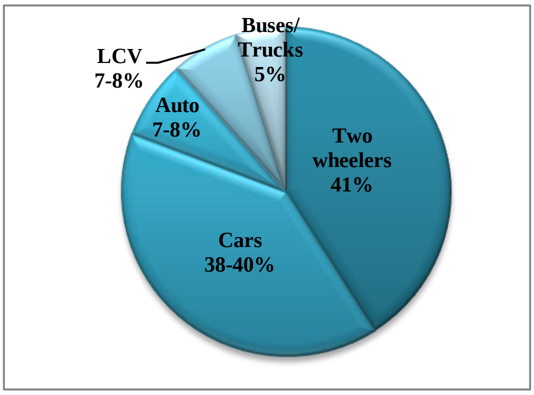


Figure 3 The average 8 hourly composition of traffic at Central Silk Board Flyover

5.3. Road geometry data

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 Central Silk Board was measured and is tabulated below in Table 2.

Table 2 Road geometry monitoring station location of Central Silk Board

Number of Links	**2**		
Link A			
Link height	0.0m		
Road width	22.1m		
Mixing zone width	28.1m		
Link B (Flyover)			
Link height	10m		
Road width	21m		
Mixing zone width	27m		
Monitoring station location (KSPCB)			
Distance from link A	10m		
Distance from link B	75m		
Height above ground level	3m		
Receptor Coordinates			
Receptor	**X**	**Y**	**Z**
	75 m	10 m	3 m

5.4. Predicted and Measured concentrations of $PM_{2.5}$

The predicted 8 hourly concentrations of $PM_{2.5}$ were compared with the measured concentrations for Central Silk Board and the same are tabulated in Table 3 and 4 respectively.

Table 3 Predicted and Measured 8 hourly concentrations (6.00AM to 2.00PM) of $PM_{2.5}$ for the Central Silk Board

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)
09-05-14	Friday	403.7	363
26-05-14	Monday	383.7	288
28-05-14	Wednesday	300.2	269
06-06-14	Friday	361.7	331
12-06-14	Thursday	214.7	157
27-06-14	Friday	249.4	200

Table 4 Predicted and Measured 8 hourly concentrations (2.00PM to10.00PM) of $PM_{2.5}$ for the Central Silk Board

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)
09-05-14	Friday	121.3	165
26-05-14	Monday	318.5	237
28-05-14	Wednesday	230.4	201
06-06-14	Friday	434.9	397
12-06-14	Thursday	258.1	204
27-06-14	Friday	205	136

A comparative test is applied to check the consistency of the measured data with the predicted value by using the t-test for independent samples (T.W. Anderson, 2003). It was found that that there is no significant difference between measured and predicted mean values at 0.05 Level of significance. 't' calculated was less than the critical value. Hence the model can be used to predict pollution levels in areas where there is an absence of a monitoring stations.

5.5. Performance evaluation of model

The U.S. Environmental Protection Agency suggested a few statistical performance measures 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 were 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 which are tabulated in Table 5.

Table 5 Statistical analysis of CALINE 4 model performance for $PM_{2.5}$

Parameter	**Acceptance value**	**Performance of model**	
		CSB	
NMSE	NMSE ≤ 0.5	0.0277	Accepted and Valid
FB	-0.7<FB<0.7	-0.1659	
MG	0.75 <MG<1.25	0.846	
R	Close to 1.0	0.92	

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.

5.6. Vertical distribution of $PM_{2.5}$

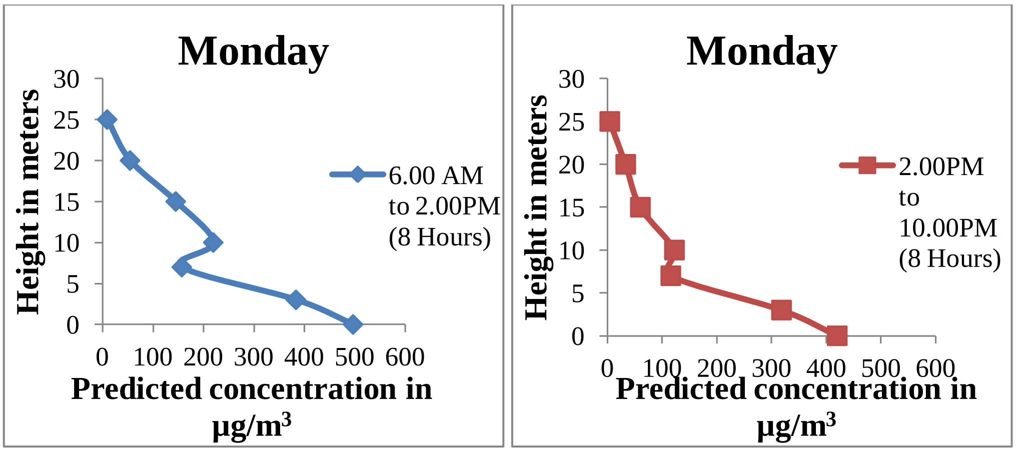
Various studies suggest that total suspended particulate matter, PM_{10} and/or $PM_{2.5}$ show a moderate decrease (<30%) with increasing height or distance from major traffic roads (Rubino et al., 1998). Studies also show upto about five-fold vertical and/or horizontal variations for particulate mass or number concentration (Vankeva et al., 1999).

Variation in concentration of particulate matter with hight was examined using CALINE 4 model for different heights on two different days (Monday and Friday). The concentration of $PM_{2.5}$ decreased gradually as the height increased. The concentrations of $PM_{2.5}$ at various heights are tabulated in Table 6.

Table 6 The concentrations of $PM_{2.5}$ in µg/m^3 at various heights

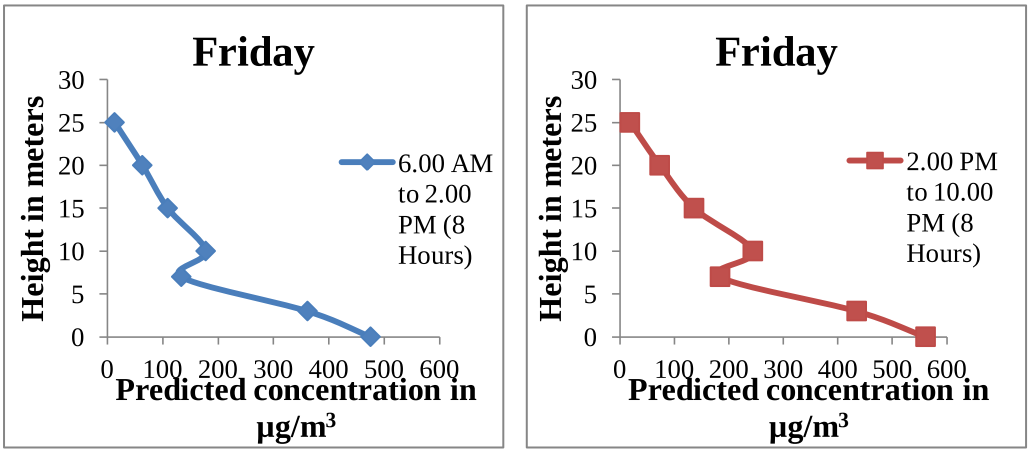
Height (in m)	**Monday**		**Friday**	
	6AM to 2PM	**2PM to 10PM**	**6AM to 2PM**	**2PM to 10PM**
0	496.6	420.4	475.6	561.3
3	383.7	318.5	361.7	434.9
7	157.3	116.2	133.7	184.2
10	219.7	122.8	177.8	244.3
15	145.4	60.6	109.1	136.4
20	54.8	33.8	63.3	73.4
25	9.4	4.7	13.2	17.6

The predicted concentration of Central Silk Board at ground level was ranged between 420.4 to 496.9µg/m^3 and it gradually decreased to 4.7 to 9.4µg/m^3 at 25m height on Monday. Similarly on Friday the predicted concentration ranged between 475.6 to 561.3µg/m^3 and it gradually decreased to 13.2 to 17.6µg/m^3 at 25m height as shown in Figures - 4 and 5 respectively. Due to the presence of flyover at 10m height in Central Silk Board the concentration of $PM_{2.5}$ has slightly increased at 10m for both the days (i.e., Monday and Friday) due the traffic plying on the flyover. Hence, the vehicular emissions on the flyover are also contributing to the $PM_{2.5}$ concentrations. The concentration is gradually decreasing with increasing height above 10m height.



(a) (b)

Figure 4: Variation of $PM_{2.5}$ concentration with respect to various heights at Central Silk Board for Monday during (a) 6.00am to 2.00pm (b) 2.00pm to 10.00pm



(a) (b)

Figure 5: Variation of $PM_{2.5}$ concentration with respect to various heights at Central Silk Board for Friday during (a) 6.00am to 2.00pm (b) 2.00pm to 10.00pm

6. CONCLUSIONS

The present study illustrates an approach for application of CALINE 4 model for predicting $PM_{2.5}$. The concentrations were ranged from 121.3µg/m^3 to 403.7µg/m^3. The maximum concentration was observed on Monday and is due to heavy traffic dominated with two wheelers, cars and bus/trucks. Comparative analysis using t-test indicated that the measured and predicted values are comparable. The values of NMSE, FB, and GMB were well within the prescribed limits, therefore model prediction may be considered as correct and valid. The concentration of $PM_{2.5}$ is inversely proportional to height. The concentrations get diluted and reduced significantly within 25m height.. The concentrations are highly influenced by meteorological parameters viz. wind speed, wind direction mixing height and atmospheric stability. CALINE 4 model can be used to predict the pollutant concentrations at traffic intersections and it also help in providing a database.

7. ACKNOWLEDGEMENTS

I am thankful to **Mr. M. G. Nagendra Kumar**, Assistant Commissioner of Police, Traffic Management Centre, Bangalore and other staff of TMC for providing the C.C TV camera footage of the selected stations. I am also thankful to **Dr. Nagappa**, Scientist, KSPCB, Bangalore, for providing the necessary ambient air quality monitoring data. I am also thankful to **Director,** Meteorological Center, India Meteorological Department, Palace road, Bangalore for providing necessary meteorological data.

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