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Correction Factors of CALINE 4: A Study Of Automobile Pollution in Kolkata

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Abstract

A study of automobile pollution in Kolkata has been made using CALINE 4 model. This model was selected as it offered several advantages over other models. It has been first used as the base model to develop the correction factors for the application of this model for the city of Kolkata, and then the modified model with the correction factors has been validated. Carbon Monoxide was chosen for the model because it is principally emitted from vehicular sources and daily background concentration data of this gas were available for a year for comparative studies. A study of the validation results made near HUDCO crossing shows that CALINE 4 with the correction factors, can be applied reasonably well (mean error 0.37) for the prediction of CO in the city of Kolkata. Using this modified model i.e., CALINE 4 with correction factors, prediction has been made that the construction of a flyover connecting VIP Road to EM Bypass will lead to lessening of CO in the atmosphere.

Key words: Automobile Pollution, Line Source Model, CALINE 4, Carbon Monoxide, Kolkata.

Introduction

According to a report of WHO and UNEP on Global Pollution and Health published in 1996, Kolkata has been placed among the 41 most polluted cities of the world with respect to the level of suspended particulate matter (SPM). Major sources of air pollution in the city are automobile exhausts (50%), industrial emissions (48%) and domestic cooking (2%). It has been estimated that during 2010, contribution from automobile sector to air pollution load would rise to 55% (Gopalakrishnan, 1997). This increase in pollution level is due to a sharp rise in the number of new privately owned as well as public vehicles as also of a large number of highly polluting old vehicles (about 54% of total) plying on the city streets. It is well known that stationary vehicles with running engines and vehicles moving at slow speed release more pollutants than the ones moving at an optimum speed of 60 km/h, and the scenario in the city of Kolkata is that it has inadequate road space (6% of total area against 25-30% expected), high vehicular density, and frequent traffic jams particularly at peak hours, which make the vehicles to move at very low speed (DOE, 2002). Moreover, ongoing activities of several infrastructural modernization projects are likely to further increase negative environmental impacts.

Different studies carried out in Kolkata by different Institutes/Organizations have highlighted the impact of this high air pollution on the health of Kolkata residents, traffic police men and hawkers etc. (Chakraborty, 1998; ROHC, 1999; WBPCB, 2001). It has been thus felt that a properly validated line source model through simulation of the dispersion of vehicular pollutants near the road will play an important role in providing information for better and more efficient air quality management planning.

Selection of the Model and Pollutants

In literature large number of models like HIWAY Model (Zimmerman, 1975,Chock, 1977, Rao, 1980), General Motors Model (Rao, 1980, Sivacoumar, 2001) General Finite Line Source Model (Luhar, 1989), Delhi Finite Line Source Model (Khare, 1999), CALINE 3(Benson, 1979) and CALINE 4 (Benson, 1989) models are available for the estimation of pollutants present at a certain site depending upon the available parameters and weather conditions. For the present studies CALINE 4 model was chosen, because it offered compared to other models, the ability to predict air quality reliably up to 500m from the roadway, and it had special options for modeling air quality near street canyons, intersections and parking facilities. Also, apart from predicting concentrations of Carbon Monoxide (CO), the selected pollutant for the present studies, it could predict the concentrations of NO_2 and SPM. Further, it had certain technical refinements viz. the mixing zone residence time, the initial vertical dispersion parameter, reduced sensitivity to stability class, augmented rate of vertical dispersion to account for the additional thermal turbulence created by more vehicles, and the usage of the directional variability incorporating averaging time and stability class etc, which could better describe the dispersion process near roadways. Lastly, CALINE 4 is user friendly and easy to operate with a WINDOWS based system.

CO was chosen as the pollutant to be predicted because it is considered as a guide to the levels of other vehicular pollutants-gaseous as well as particulate matter, that are small enough to have a long – term suspension in air. CO has several other advantages as a reference material since it is chemically inert in the atmosphere and has a low natural background concentration. Further, it is produced by both petrol and diesel engine vehicles; and more importantly it is possible to measure atmospheric CO concentration continuously and thus it provides data for testing the selected model for short periods when there are considerable fluctuations in traffic flow and meteorological conditions (Khare, 2001).

Methodology

a) The Model

CALINE 4 is one of a series of line source air quality models developed by the California Department of Transportation. It is based on Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over a roadway to assess impacts of vehicular pollution on air quality near transportation facilities. This model divides individual highway links into a series of elements from which incremental concentrations are computed and then summed up to give total concentration estimate for a particular receptor location.

The receptor distance is measured along a perpendicular from the receptor to the link centerline. The first element $€_0$ is formed as a square with sides equal to the highway width. Its location is determined by the roadway wind angle (PHI). Each element is modeled as an equivalent finite line source (FLS) 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. The emissions occurring within an element are assumed to be released along the FLS representing the element. The emissions are then assumed to disperse in a Gaussian manner downwind from the element. The length and orientation of the FLS are functions of the element size and roadway wind angle.

CALINE 4 has the capability to compute receptor concentrations as a series of incremental contributions from each element of the FLS. The FLS is divided into segments of length equal to σ_y or a fraction thereof. The source strength for each segment is determined by multiplying the Central sub element lineal source strength (QE) by a weighting factor (WT). The weighting factor accounts for the linear decrease of emissions across the peripheral sub elements. The model computes FLS contribution for a maximum of six segments within $\pm 3\sigma_y$ of the receptor. Results beyond this range are insignificant and would only add appreciably to computation time. The total receptor concentration (C) from a particular roadway link is computed as follows:

$$C=\frac{1}{\sqrt{2\pi U}}*\sum_{i=1}^{n}\left\{\frac{1}{SGZi}*\sum_{k=-CNT}^{CNT}\left[\exp\left(\frac{-(Z-H+2*k*L)^2}{2*SGZi^2}\right)+\exp\left(\frac{-(Z+H+2*k*L)^2}{2*SGZi^2}\right)\right]*\sum_{J=1}^{6}\left(WT_J+QE_I+PD_{IJ}\right)\right\}$$

Where, n =Total number of elements; CNT= Number of multiple reflections required for convergence; U= Wind speed; L= Mixing height; SGZ_i = σ_z as f(x) for *i*th element; QE_i = Central sub element lineal source strength for *i*th element and WT_j= Source strength weighting factor for *j*th FLS segment,

$$PD_{ij}=\frac{1}{\sqrt{2\pi}}\int_{\frac{Y_j}{SGY}}^{\frac{Y_{j+1}}{SGY_i}}\exp\left(\frac{-p^2}{2}\right)dp$$

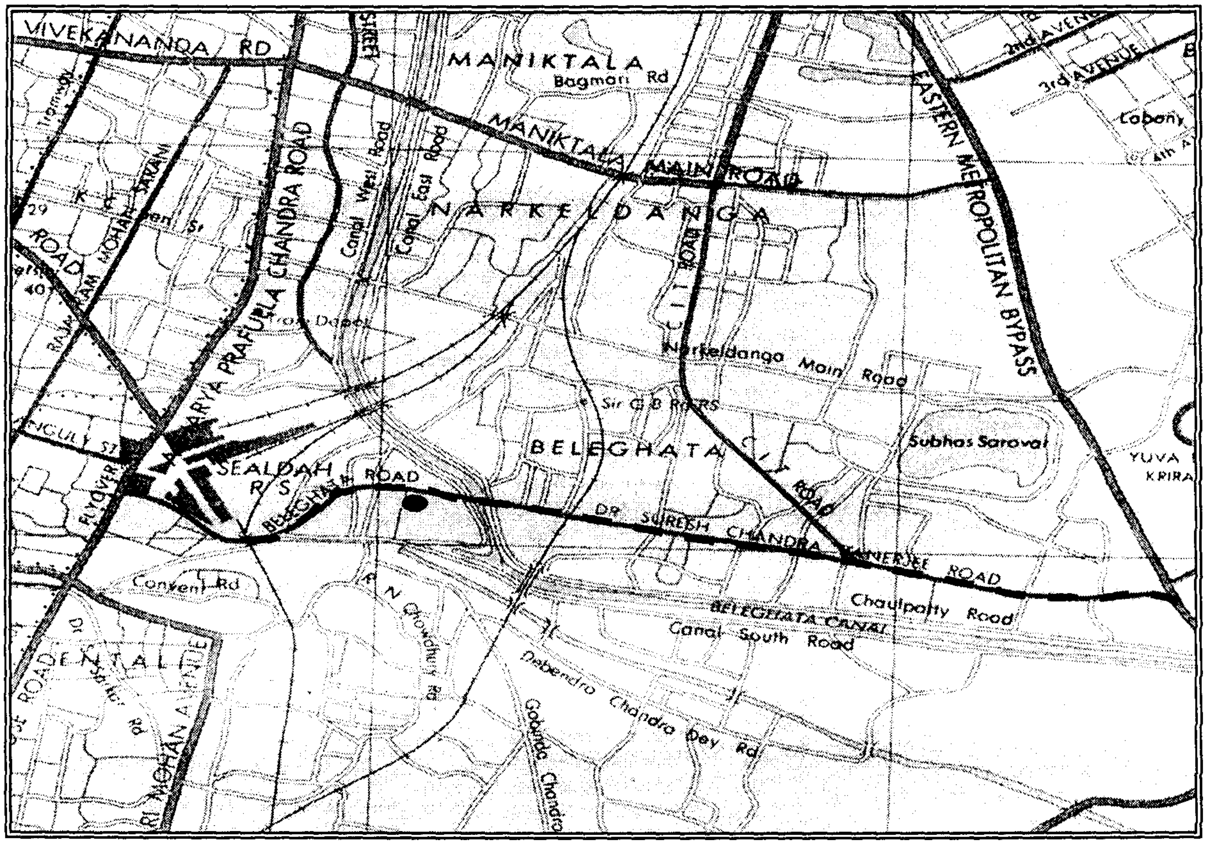
Where, Y_j, Y_{j+1}= Offset distances for *j*th FLS segment and $SGY_i = \sigma_y$ as f(x) for *i*th element.

CALINE 4 treats the region directly over the highway as a zone of uniform emissions and turbulence. This is designated as the mixing zone and is defined as the region over the traveled way (traffic lanes do not include shoulders) plus 3 m on either side. The additional width accounts for the initial horizontal dispersion imparted to pollutants by the vehicle induced turbulence.

Within the mixing zone the mechanical turbulence created by moving vehicles and the thermal turbulence created by hot vehicle exhaust are assumed to be the dominant dispersive mechanisms. Vehicle emissions are released and rapidly dispersed within the trailing wake of each vehicle. Further, initial dispersion occurs through the action of turbulence generated by other passing vehicles. CALINE 4 gives results in parts per million.

b) Input Parameters to the Model

CALINE 4 has been run on two roads in Kolkata, Beleghata Main Road and Taratala Road coupled with Diamond Harbour Road (see Map I) with different link positions (with and without canyon option), receptor positions, wind directions and traffic flows so as to evaluate the performance of the model under different conditions. Comparisons of the predicted results with the measured concentrations have been done considering two winter months (February and December), one summer month (May), and one monsoon month (July).



MAP I: Beleghata Main Road Connected with Dr. Suresh Chandra Banerjee Road (Dotted Line)

The various major input parameters that have been used in CALINE 4 are: link coordinates; receptor co-ordinates; link height; mixing zone width; canyon option; aerodynamic roughness coefficient; wind speed, wind direction, wind direction standard deviation; ambient temperature; atmospheric stability class; mixing height; ambient pollutant concentration; traffic volume and emission factor. All the values were given using the best available information for each site. In cases where pertinent variables were not measured or estimated, conventional default values were used.

Aerodynamic Roughness co-efficient was chosen as 400 cm (Benson, 1989). Link height was chosen as zero and the mixing zone widths for Beleghata Main Road, Taratala Road and D.H. Road were taken as 15m, 26m and 36m respectively. A canyon width of 110m on both sides has been chosen for Beleghata Main Road considering the terrain and receptor distance. However, canyon option was not considered for Taratala Road and D.H Road because of different terrain. Wind parameters have been obtained from the meteorological observations obtained from the Taratala monitoring station of the WBPCB. A standard deviation of 22.5 degrees has been considered. It is seen, on an average, mixing height varies between 200m and 1800m on a 24-hour basis (CPCB, 1984), so an average of 1000m has been considered for this study. For background concentration *bandh* data have been used. Four *bandh* days, in different seasons of the year were chosen and 8hrs background concentration (6am-2pm & 2pm-10pm) of CO for the four *bandh* days at the Victoria Memorial Ambient Air Quality Station of West Bengal Pollution Control Board were considered for obtaining background concentration of CO. Observed CO data was obtained from the ambient air quality monitoring station of WBPCB at the Indian Jute Industries Research Association at Taratala and from PWD building at Sales Tax office in Beleghata. An equivalent emission factor in gm/km for different vehicles have been derived (Table1) on the basis of Indian Emission Factors (CPCB, 2000A) and year wise vehicle population in Kolkata (Bureau, 2002).

Table 1: Equivalent Emission Factors

Private Car	Taxi	Bus	Mini Bus & Midi Bus	Tram	Auto Rickshaws	Heavy Truck	Light Truck	Vans & Others	Motor Cycles & Scooters
1.00	0.72	0.60	0.60	0	1.48	0.60	0.95	0.95	0.51

Results and Discussion

Concentration of Carbon Monoxide has been predicted for the receptor in Beleghata Main Road by invoking both "canyon" option and "without canyon" option. CALINE 4 model has been run in Taratala road and Diamond Harbour road (Taratala area) without invoking the canyon option. Scatter graphs of observed concentration versus predicted concentration have been drawn and the linear fits have been plotted for mixed condition, i.e. considering Beleghata Main Road with the canyon effect and Taratala Area without the canyon effect and non-mixed condition, i.e. considering both Beleghata Main Road and Taratala Area without the canyon effect. The summarized results are given in Table 2.

Table 2: Statistical Analysis with the Slope Equation of the Shifts

Sl. No	Graphs	Correlation Co-efficient	Standard Deviation	Equation
1	Combined shift 1 and shift 2 in Beleghata and Taratala (non-mixed)	0.72797	0.35163	Y=0.94542x+0.46733
2	Only shift 1 considered in Beleghata and Taratala (non-mixed)	0.82653	0.34729	y=1.35016x+0.34033
3	Only shift 2 considered in Beleghata andTaratala (non-mixed)	0.75244	0.33778	y=0.96108x+0.27667
4	Combined shift 1 and shift 2 in Beleghata and Taratala (mixed)	0.71566	0.39782	y=1.02305x+0.38865
5	Only shift 1 considered in Beleghata and Taratala (mixed)	0.80024	0.36999	y=1.30004x+0.28115
6	Only shift 2 considered in Beleghata and Taratala (mixed)	0.64517	0.38449	y=0.78687x+0.311

From Table 2 it is seen that correlation coefficient of shift 1 is better than shift 2. It can be presumed that the unsteady background concentration in shift 2 has played a key role in the resultant pollutant concentration. Thus shift 1 results are better correlated than shift 2. Comparison of the results of the canyon option with the results obtained without the canyon option shows a better performance in case of the latter. This can be attributed to the fact that patterns of one/two-storied buildings at Beleghata Main Road do not qualify as a true canyon.

An attempt to validate the results obtained in Table 2 was made for the traffic at HUDCO crossing which is a meeting point for EM Byepass, CIT Road from Kankurgachi, and CIT Road from Ultadanga Bridge. Input values were chosen in the same manner as mentioned above. The crossing was divided into three links- Link 1 starting from beyond Kankurgachi crossing to HUDCO crossing, Link 2 starting from HUDCO crossing to the start of VIP Road, and Link 3 starting from HUDCO crossing to EM Byepass near 1st avenue. The receptor was placed at a height of 4.5m on the rooftop of the North Bengal State Transport Corporation building. CALINE 4 model was run for the above area and the predicted values obtained were converted to modified predicted values based on the equations (non-mixed only) obtained in Table 2. Scatter plot of modified predicted ppm versus observed ppm is shown in Figure 1. Only non-mixed cases were chosen owing to the fact that "without canyon" option had produced better results.

Results for shift 1 and shift 2 combined shows the standard deviation of error (difference of modified predicted and observed values) to be 0.37 and the mean error to be 0.37. The analysis of the above reveals that CALINE 4 with the correction factors can be applied reasonably well for the prediction of CO in the city of Kolkata

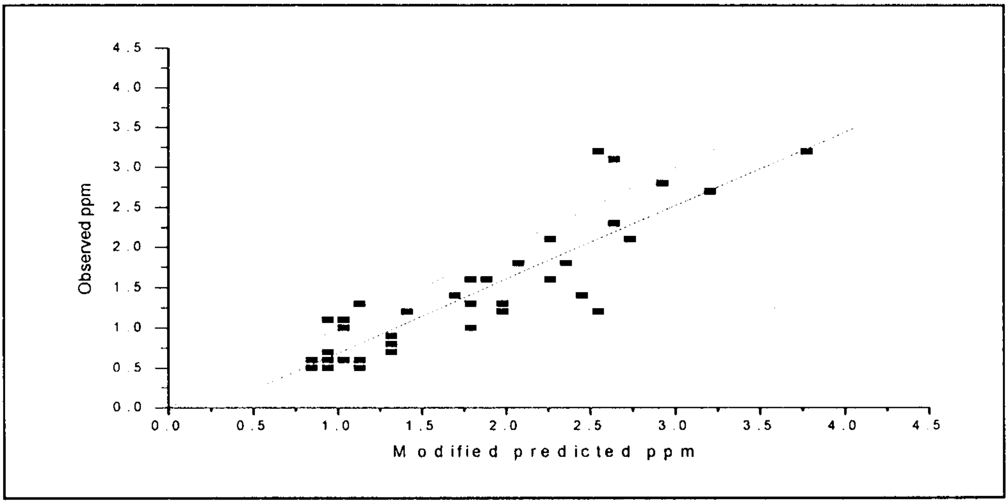
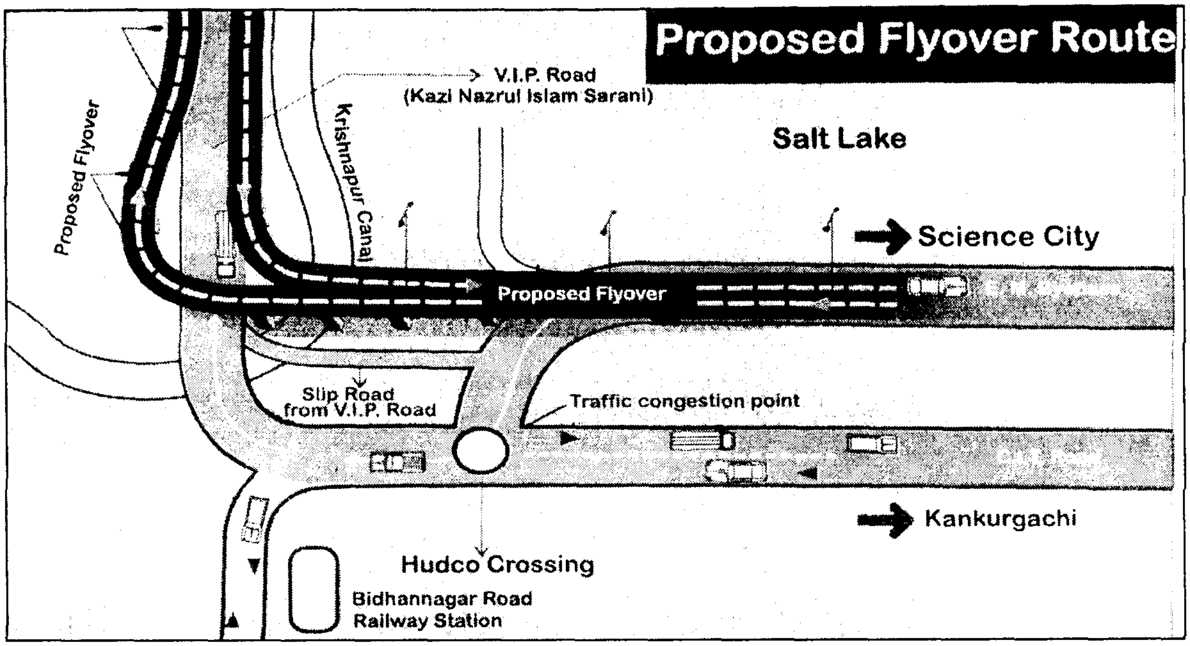


Figure 1: Validation graph of both shift 1 and shift 2 (combined) at Ultadanga (without canyon)

Future Prediction of CO

Kolkata Metropolitan Development Authority (KMDA) will be constructing a 1350 m long flyover (shown in the diagram map 2) linking VIP Road with EM Bypass so as to ease traffic congestion at HUDCO crossing and other nearby crossings (ABP, 2005). CALINE 4 model was run so as to evaluate the impact on the atmosphere due to lessening of traffic flow rate at HUDCO crossing. The results are shown in Table 3 that indicate that there shall be a decrease of 18.4% in CO concentration with commissioning of the flyover.



Map 2: Construction of the proposed flyover by the KMDA linking VIP Road with EM Bypass

Table 3: Percentage Reductions in CO

Month		Observed ppm (Average)	Predicted ppm (Average)	Predicted ppm after flyover construction (average)	Percentage reduction in CO after flyover construction wrt. to predicted value (4)
July	Shift1	0.72	0.9	0.8	11
	Shift2	0.6	1.15	1.11	3.3
Feb	Shift1	2.22	2.4	2.2	8.3
	Shift2	2.66	2.9	2.6	10.5
May	Shift1	1.04	1.2	1.0	16
	Shift2	0.98	1.34	1.09	18.4
Dec	Shift1	1.54	1.9	1.7	10.8
	Shift2	1.28	2.21	2.09	5.1

Concluding Remarks

The non-availability of a proper line source model applicable for Kolkata as opposed to Delhi and Mumbai, which have dedicated line source models, has been a stumbling block here for planners and management experts. The modified CALINE 4 model with suitable correction factors is expected to bridge this gap and should serve as a guide whilst prioritizing the list of air quality management measures to be undertaken. The development and validation exercise described above has shown that CALINE 4 with correction factors can be applied for the prediction of CO in the city of Kolkata.

The application of the modified Caline 4 model has further shown that the construction of the proposed flyover linking VIP Road with EM Bypass will lead to a lessening of CO in the atmosphere, which, in turn, can have a beneficial impact on other environmental polluting parameters.

From the above it can be thus stated that Authorities embarking on development projects should follow up the predictive analysis done with CALINE 4 with a cost benefit analysis, as this would paint a true picture of the effects of the project. However, in order to make it more useful, refinements need to be carried out so as to make it a more complete tool for prediction. Further, preparation of a complete data inventory consisting of traffic flow, meteorology etc. covering the entire city of Kolkata is the urgent need of the hour, as otherwise prediction of pollutants in different parts of the city through the use of this model is difficult.

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