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Applicability of Caline4 model for Nox in Kolkata Roadway

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Abstract

CALINE4 line source dispersion tool has been applied to model NO_x in the study with the help of CALROADS View software. The model was used with and without canyon options activated near Jadavpur University, Kolkata. It is observed to exhibits better correlation for 'with canyon' option than 'without canyon' against actually measured concentrations of NO_x, which is indeed more realistic to reflect actually prevailing condition, as the study site is situated in a street canyon. A calibration equation is also deduced to calculate the corresponding actual i.e. prevailing concentrations form model predicted values for NO_x. A typical NO_x concentration contour due to traffic is generated around Jadavpur University, Kolkata.

Keywords: CALINE4, Road canyon, NO_x, Emission factor, Concentration contour

Introduction

Automobile sources are threatening issue in urban air quality. The city of Kolkata is no exception. Besides, ill maintained road condition, rampant growth in automobiles and inadequate road network worsen the scenario of this city. Thus, the air quality management in Kolkata demands constant attention. CALINE4 [1] is a widely used line source Gaussian air pollutant dispersion model, developed by California Department of Transportation. The model has been formerly used in Kolkata for modelling dispersion of CO [2,3]. This current study deals with application of this CALINE4 model for vehicular NO_x dispersion. CALROADS View [4], a tool reportedly used in previous literatures [5,6] for CALINE4 dispersion modelling is applied here. A pollutant contour has been generated around the study area with the help of CALROADS View for NO_x in the study.

Materials and Methods

In order to study CALINE4 model of NO_x in Kolkata, a typical city roadway span of Raja Subodh Mullick Road between Jadavpur Police Station to Sulekha is selected (Figure 1). This is one of the major roadways in the city, spanning through a belt of academic institutions, which includes Jadavpur University, Central Glass and Ceramic Research Institute, Indian Association for the Cultivation of Science, Indian Institute of Chemical Biology, Acharya Prafullya Chandra Roy Polytechnic College, KPC Medical College and Jadavpur Vidyapith School.

The major motorised fleet types of this road are taxi\private car, auto, two wheele, public transport (bus) and trucks. The proportion of traffic composition, based on a previously published report by Kolkata Metropolitan Development Authority is prepared and displayed in figure 2 [7]. In the current study both traffic data and NO_x concentration data are collected. Concentration data of NO_x, are taken in different hours of a day starting at 7 am and ending at 21 pm for sampling time of 4 hrs at a stretch at Jadavpur University Gate No.3 on the mentioned roadway (Figure 2), for both, weekdays and weekends (Saturday) from November, 2009 to March, 2010. Table A1 shows the detail sampling schedule of the study. NO_x monitoring was done by Envirotech APM 460BL High Volume Sampler with NO_x sampling attachment, with an instrument height (receptor height) of 1 m above the ground. A simultaneous traffic monitoring is also carried out to count hourly volume of major motorised vehicles i.e. taxi\private car, auto, bus\truck, two wheeler and light goods vehicles. A CALINE4 (CALROADS View) model is validated for predicting NO_x concentration with respect to randomly selected data from the same measured traffic and air pollutant concentrations near Jadavpur University Gate No. 3. The road geometry is approximately described with the help of segmented straight line elements. The CALIN4 model runs with at most 20 numbers of elements, and for activating canyon option the road stretch has to be absolutely rectilinear. Thus the model is run considering 15 segmented links for no canyon case and just a single rectilinear link (fittest one for the given curvilinear road geometry) for canyon option activated case following coordinates are chosen for no canyon case (partially zigzag links in figure 4). Every bracketed number-pare denotes link starting and ending point coordinates respectively.

a) (289.87m, 1372.06m) (313.62m, 1335.65m)

b) (313.62m, 1335.65m) (337.06m, 1275.48m)

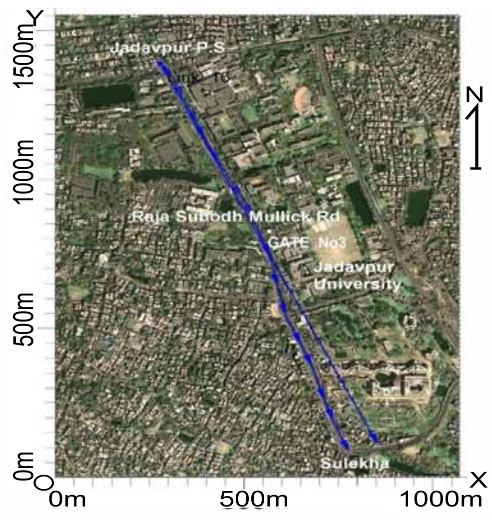

Figure 1: Map of the Study Area with Relevant Details (Google Maps, 2010).

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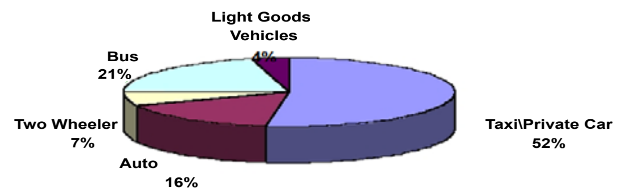

Figure 2: Relative Contribution of Motorised Vehicles in of Raja Subodh Mullick.

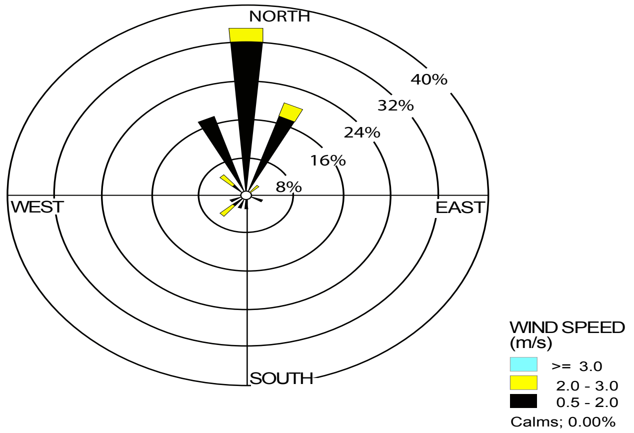

Figure 3: Average Wind Rose Diagram for Sampling Durations.

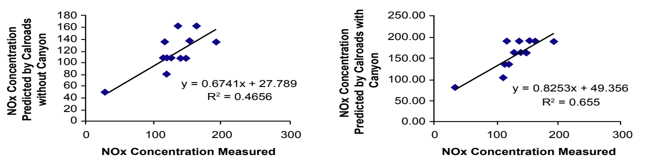

Figure 4: Best Fit Straight Line between Measured NO_x Concentrations and NO_x Concentrations Predicted by CALROADS (a) without Canyon Option (left) (b) with Canyon Option (Right) (All Concentrations in μg/m^3).

c) (337.06m, 1275.48m) (375.00m, 1189.94m)

d) (375.00m, 1189.94m) (392.64m, 1138.47m

e) (392.64m, 1138.47m) (435.89m, 1055.10m)

f) (435.89m, 1055.10m) (491.23m, 941.52m)

g) (491.23m, 941.52m) (521.68m, 876.76m)

h) (521.68m, 876.76m) (567.83m, 742.40m)

i) (567.83m, 742.40m) (587.89m, 643.09m)

j) (587.89m, 643.09m) (609.88m, 542.80m)

k) (609.88m, 542.80m) (650.47m, 447.84m)

l) (650.47m, 447.84m) (679.47m, 374.130m)

m) (679.47m, 374.130m) (712.34m, 260.80m)

n) (712.34m, 260.80m) (735.29m, 191.93m)

o) (735.29m, 191.93m) (777.34m, 88.02m)

Coordinate of single link for canyon option activated case (straight line link in figure 1) is (278.65m, 1386.84m) (854.50m, 110.37m). Left-bottom corner in study area map, the point 'O' (Figure 1) refers to the origin of local coordinate system and unit of axes being metre (m).

The emission characteristics data are collected from The Automotive Research Association of India (ARAI) [8]. The required meteorological data for the study are taken from Jadavpur University Department of Civil Engineering, situated on the study roadway, which uses automated weather monitoring station (Envirotech WM 251 automated weather monitoring station), installed at 16m height. Initially CALINE4 model is validated [3,9-11] using data of traffic count and NO_x measurement of some randomly selected days. This validated model is further used to generate pollutant level contour for NO_x nearby the study area.

Result and Discussion

Validation of CALINE4 (CALROADS View) model

CALINE4 (CALROADS View) model is validated against measured NO_x concentrations, which is further applied in predicting of the pollutant. Randomly selected data from the same measured traffic and meteorological data as represented in table A2 and A3 respectively. The values predicted by CALINE4 are compared with the measured values in table A3. The model is run both with and without canyon option activated. The emission factors as collected for the mentioned motorised vehicles from ARAI are shown in table 1.

Composite emission factors i.e. weighted average emission factor considering individual numbers of vehicles of every category are calculated based on traffic volume data as shown in table A1.

As per the methodology followed in previous literatures [12], CALINE4 model is run with the wind speed data at the same height as that of NO_x sampling (1 m above the ground). The wind speed data mentioned are collected from Jadavpur University, Department of Civil Engineering, which is measured by an automated weather monitoring station (Envirotech WM 251 automated weather monitoring station), installed at 16m height. The data is converted to the value at 1 m height by standard equation. It is expected to be reduced in receptor height of 1m as per the given equation [1] [13]:

$$v_h = v \times \left(h/H \right)^p$$

Where, v_h is wind speed at receptor height, i.e. 1m, v is wind speed at height of actual measurement i.e. 16 m, h is height at which wind speed is being calculated (1 m), H is height, at which wind speed is measured (16 m). Values of the exponent (a parametric constant) 'p' depend on stability class. It is observed that wind speed in all cases in 16 m height (Table A3) remains nearly between 2m/s, which are expected to further reduce in 10 m height for any type of stability class.

Thus the wind speed at 10m heigh4t can be taken below 2m/s in all cases. With reference to 'key to stability categories', Turner [14], stability class is then taken to be B throughout the study and hence p value being 0.15 . Or velocity at receptor height is given by: velocity at receptor height (m/s) = 0.66 × velocity measured (m/s) [2].

Relevant parameters e.g., wind velocity at receptor level (1m

	Taxi \ Private Car	Auto	Two Wheeler	Bus\Truck	Light Goods Vehicles
NOx Emission Factor (g/mi/vehicle)	1.05	0.306	0.483	18.096	4.88

Table 1: Emission Factors of Vehicles for NO_x.

height) and composite emission factors to estimate NOx, are presented day wise in table A3. A 16 spoke Wind rose is generated by Lakes Environmental WRPLOT View tool [4], based on the same dataset for study area. Figure 3 shows the wind rose diagram, developed by taking the average wind speed at receptor height and the direction wind blowing from for all sampling durations. This is constructed for the purpose of having a view on the pattern of wind-blow that prevailed on an average throughout the sampling periods.

In order to validate the CALINE4 model for NO_x in study area, measured NO_x concentrations of day 7, 9, 10, 13, 14, 15, 16, 18, 19, 20, 23, 25, 27, 28, 29, 32, 33, 35 are selected. With the help of mentioned meteorological condition and meteorological and emission data in table A3 and traffic volume data in table A2, CALROADS is run without and with canyon option activated. A canyon, 6 m away from either kerbs of the road is considered. Standard background NO_2 and O_3 concentration is taken 2ppb and 10ppb respectively5(Natural Resource Accounting for West Bengal for the Sectors: Air and Water, Govt. of India [15]) and standard values of NO_2 photoly1s6 is rate constant is taken 0.015/s and ratio of NO/NO_2 being 0.32 respectively [16]. Whence, NOx/NO_2 4being 1.32. CALROADS View actually estimates ambient NO2 concentration in ppm [4]. With the help of standard unit conversion equation for ppm to $\mu g/m^3$ and the relationship deduced between NO2 and NO_x ($NO_x/NO_2 = 1.32$), NO_x concentration in $\mu g/m^3$ are calculated for CALROADS View predicted NO_x values. The values are represented in table 2.

	NOx Predicted by CALROADS		
Day	without Canyon Option (µg/m3)	Canyon option (µg/m)	NOx Measured (µg/m3)
7	81.32	108.42	109.63
9	162.64	189.75	161.90
10	162.64	189.75	135.70
13	135.53	189.75	153.43
14	135.53	189.75	116.89
15	135.53	189.75	191.86
16	162.64	189.75	136.37
18	81.32	135.53	118.50
19	108.42	135.53	118.63
20	108.42	162.64	139.32
23	108.42	135.53	115.00
25	108.42	135.53	119.98
27	108.42	135.53	113.12
28	108.42	162.64	126.02
29	108.42	162.64	147.79
32	81.321	135.53	117.56
33	81.32	135.53	119.98
35	54.21	81.32	32.10

Table 2: NO_x Concentration Predicted without and with Canyon Option by CALROADS View along with Measured Values.

Case Type: Canyon Option Activated	**Equation Relating Predicted Value with Measured Value**	y = 0.8253x + 49.356
	Calibration Equation	Actual NOx concentration ($\mu g/m^3$) = 0.7927 (CALROADS Predicted Concentration) + 4.5535
	Pearson's Correlation (r)	0.81
Case Type: Canyon Option Not Activated	**Equation Relating Predicted Value with Measured Value**	y = 0.6741x + 27.789
	Calibration Equation	Actual NOx concentration ($\mu g/m^3$) = 0.6907(CALROADS Predicted Concentration) + 48.31
	Pearson's Correlation (r)	0.68

Table 3: Summery of the CALROADS Model (with and without Canyon Option activated) for NO_x.

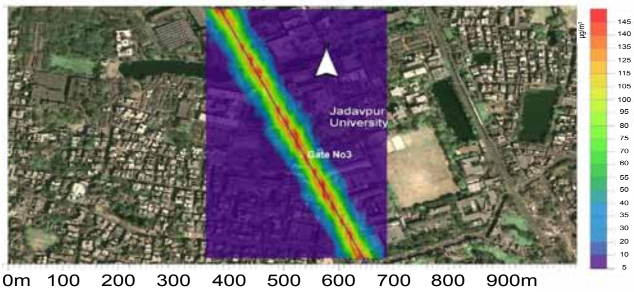

Figure 5: NOx Level Contour around Jadavpur University for 19.01.2010.

The linear regressions between NOx concentrations measured and predicted by CALROADS View, without and with canyon option activated are plotted and are represented in Figure 4a and Figure 4b respectively, which are having R^2 values of 0.4656 and 0.655 respectively and Pearson's Correlation being 0.68 and 0.81.

Selection between with and without canyon cases

Although for NO_x, there are considerable correlations between measured and predicted values, with and without canyon option, but since the study area is situated in Central Business District (CBD) between closely located high buildings and walls situated immediately after the mixing zone, selecting canyon option is realistic choice. Again canyon option has better correlation for NO_x (r values being 0.81 in with canyon case than 0.68 of without canyon case). So with canyon cases is selected for NO_x. The summery of the CALROADS Model run, with and without canyon activated cases for NO_x is presented in table 3.

Pollutant contours for NO_x by CALROADS view

Spatial variation of pollutant concentrations or pollutant level contour can be developed by CALROADS View [4] if there be multiple numbers of spatial points for prediction of concentration. In order to develop a representative pollutant contour for NO_x, 22nd monitoring day (19.01.2010) is randomly picked up. Relevant input values like traffic volumes, meteorological data and emission data are taken as earlier from table A2 and A3 respectively. An array of 441 receptors placed in grid covering 329 m × 575 m area (colourful rectangular area in figure 5), encompassing Jadavpur University compass is selected for contour generation.

The 'with' canyon case is assumed. The generated contour map for NO_x is shown in figure 4. The conto3ur level represented in figure is first transformed by unit conversion factors to convert in µg/m and further modified as per the calibration equations stated in table above. So the contour maps represented in figure 5 is actually calibrated concentration level contours. Concentration values at some typical points are given in Annexure 4.

Conclusion

The study deals with an approach for validation and application CALINE4 model for a Kolkata roadway for NO_x. It has been inferred that CALINE4 model with canyon option activated is more accurate than 'without canyon', as it resembles the real scenario ideally and exhibits better correlation with measured values (r being 0.81, compared to 0.68). In the current study a calibration equation is also derived to get NO_x concentration, comparable to actual level. The study also shows a typical example pollutant contour around the study area, based on spatial data prediction. This approach of modelling thus would be helpful for air quality planning for the city of Kolkata, where spatial distribution of air quality is required to estimate.

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