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Modeling Ambient Carbon Monoxide Pollutant Due to Road Traffic

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***Abstract*—**Rapid urbanization, industrialization and population growth have led to an increase in number of automobiles that cause air pollution. It is estimated that road traffic contributes 60% of air pollution in urban areas. A case by case assessment is required to predict the air quality in urban situations, so as to evolve certain traffic management measures to maintain the air quality levels with in the tolerable limits. Calicut city in the state of Kerala, India has been chosen as the study area. Carbon Monoxide (CO) concentration was monitored at 15 links in Calicut city and air quality performance was evaluated over each link. The CO pollutant concentration values were compared with the National Ambient Air Quality Standards (NAAQS), and the CO values were predicted by using CALINE4 and IITLS and Linear regression models. The study has revealed that linear regression model performs better than the CALINE4 and IITLS models. The possible association between CO pollutant concentration and traffic parameters like traffic flow, type of vehicle, and traffic stream speed was also evaluated.

***Keywords*—**CO pollution, Modelling, Traffic stream parameters.

I. Introduction

ALTHOUGH there has been a phased reduction in the number of vehicles above 15 years of age in India, the significant number of new age automobiles is expected to contribute towards deterioration of ambient air quality. Recent evidence indicates that motorized vehicles are a major source of air pollution in urban areas, [5].While transportation engineers aim at steps to reduce congestion and improve the flow conditions in urban streets; the impact on the environment is neglected and often ignored. With the identification of cities like Calicut as emerging urban centres, it is imperative that studies on ambient air quality are taken up and the effect of traffic parameters analysed for identifying 'Pollution Black spots' and suggesting corrective traffic control measures for the mitigation of the problem.

Exhaustive studies have been conducted on identifying the causes for excessive emissions from automobiles. Air quality standards have been evolved for the different land uses by organisations like Indian Ambient Air Quality Standards Proposed By CPCB (1984), National Ambient Air Quality Standards Proposed By US Environmental Protection Agency (1970) and Air Quality Standards Proposed By WHO (1995).The emission factors have also been evolved by organisations like the Indian Institute of Petroleum (IIP) in 1985 and Automotive Research Association of India (ARAI).

Modelling of air pollution has been accomplished with the aid of Gaussian Dispersion Plume models that accounted for the dispersion characteristics of the pollutants. Vehicular emission is generally considered as a line source in air dispersion models. Line source models are used for assessing the effects of roadway emissions [9]. Many of the air quality models developed by research institutes are based on Gaussian plume diffusion equation to describe temporal and spatial distribution of vehicular exhaust emissions on roadways [6]. Mobile Emission models have been evolved like the Mobile Source Emission Factor Model (MOBILE6) in 1992 by USEPA (United States Environmental Protection Agency), Emission Factor Model (EMFAC) in 2002 by CARB (California Air Resources Board). Some of the dispersion models developed include the California Line Source Dispersion Model - CALINE 4 in 1989, Indian Institute of Technology Line Source Model (IITLS) developed for traffic conditions in Delhi, [2], General Finite Line Source Model developed by Luhar and Patil in 1989 and Delhi Finite Line Source Model in 1996. Time series based zone wise regression models for each type of pollutant was also developed using the pollutant data collected [1]. Traffic simulation and traffic induced air pollution was used to evolve the concentrations of Suspended particulate matter and carbon Monoxide [4]. Integrated land use and Transportation for Environmental Analysis Model was developed using CALINE 4 and spatial data analysis wherein a GIS framework was used in the identification of pollution hot-spots [7].

Micro scale dispersion model have been developed to estimate the concentration of pollutants from motor vehicle exhaust wherein the diffusion parameters of the pollutants and the eddy diffusivity resulting from buildings on either side of the road have been dealt with in detail [8]. Studies on the pollutant concentration in intersections have been taken up wherein intersection variables like traffic pattern, hourly traffic volume, lane width etc were accounted for [10]. Regression models were developed to estimate the concentration of oxides of nitrogen based on the emission factor and the type of test car used with due weightage given to the traffic speed and emission factors [3].

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Considering the need to evolve models that could aid in predict the concentrations of pollutants in urban streets, it is imperative that relationships be developed to correlate the vehicle population, traffic parameters and emission factors. In this respect, considering the need to assess the air quality in Calicut city, the following objectives have been identified for the study- i). To conduct air pollution surveys by observing the concentration of carbon Monoxide (CO) at selected links in Calicut city and comparing with the standards proposed by Central Pollution Control Board. Ii). Evaluating the air quality performance at selected links in the Calicut city, (iii) To find the possible relationships between CO pollutant concentration and traffic parameters,(iv) Predicting the air quality levels in the Calicut city by appropriate model and (v) Evaluating the predictive capabilities of the model.

II. Description of the Study Area

Calicut is one of the developing cities in Kerala state of India with a population of 8, 80,168 spread over an area of 2004 sq. km. It is located on the South West Coast of India and situated between North latitudes of $11^{0}\,08^{'}$ and $11^{0}\,50^{'}$ and East longitudes of $75^{0}\,30^{'}$ and $76^{0}\,08^{'}$. The city has registered a phenomenal increase in vehicles in the last decade. This tremendous growth of vehicular traffic coupled with lack of basic road infrastructure for transport and communication has contributed to the deterioration of the city environment. Due to the constraints of budget and time, data collection was limited to fifteen links in Calicut city.

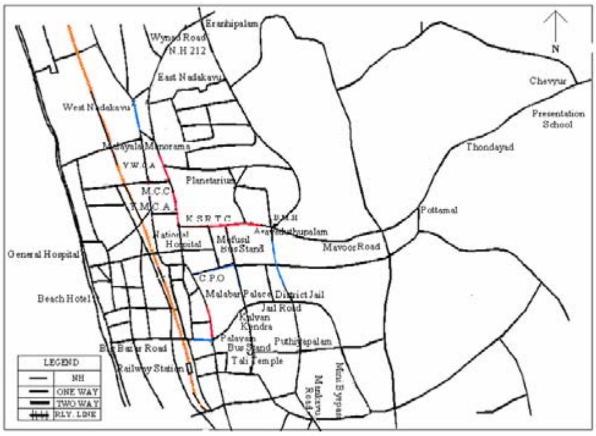

Fig. 1 Map of Calicut City showing the selected links

III. Methodology Adopted

Traffic volume, vehicles' speed, meteorological data, and CO pollutant concentration were collected manually and compiled according to model requirements. To collect the traffic volume on each link manual method was adopted. Classified volume count was taken for each observation period of 15 min in the morning from 8.30 am to 12.30 pm and then from 2.30 pm to 6.00 pm. The link characteristics of the various links such as the length and width of the link, type of operation (one way or two way) were also obtained by manual methods. To find the average speed of each type of vehicle, speed survey was conducted by noting down the registration number of randomly selected vehicles, that does not have the possibility of stopping in the stretch under consideration, at entry and exit of the link.

1996 Indian vehicles CO emission norms established by Automotive Research Association of India (ARAI) were used in this study. Vehicles CO emission for each link taken as weighted average emission was calculated by multiplying the number of vehicles by type with corresponding emission factor and summed up.

TABLE I
CO Emission Factors for Vehicles

Sl. No	Type of Vehicle	CO (grams/km)
1	Four wheeler	23.4
2	Three wheeler	13.2
3	Two wheeler	7.9
4	Truck	3.425
5	Bus	4.38

Anemometer was used to note the wind speed and direction. Digital thermometer was used to record the existing temperature. To monitor the traffic pollutant Carbon Monoxide, a portable multi gas monitor with digital display was used. CO Pollutant was monitored at the edge along the length of the link at five points; near the first junction, after the junction, middle of the road, after middle of the road and near second junction at a height of 1.5m on both sides of the road. Horizontal and vertical dispersion parameters were taken based on the atmospheric stability class B and down wind distance.

IV. Data Analysis and Discussion

The concentration of carbon Monoxide was evaluated using California Line Source Dispersion Model (CALINE4) and Indian Institute of Technology Line Source Model (IITLS). As vehicular emission is generally considered as line source in air dispersion model, CALINE4 and IITLS models were used to predict the traffic based pollutants near roadways. These models require input data of traffic flow, vehicle emission factors, meteorological factors like wind speed, wind direction, temperature, atmospheric stability class and receptor point.

The source strength is the amount of pollutant emitted into the air per meter per second (g/m/s), and calculated as the sum of emission factor multiplied by number of vehicles for all classes of vehicles. Total line source strength is the amount of pollutant emitted into the air per second (g/s), and calculated as by multiplying the emission source strength with length of the road. Horizontal and vertical dispersion coefficients (σ_y, σ_z respectively) measure spread of the plume. Pasquill & Gifford (1961) atmospheric stability classes are used for calculating the dispersion parameters. Atmospheric stability class B is used in the calculation of dispersion parameters and it is taken based on the wind speed.

$$\sigma_y = a * x^{0.894}$$

$$\sigma_z = c * x^d + f$$

x = down wind distance from source to the receptor (km)
Where constants a, c, d, and f depend on stability class.

A. Development of Possible Relationship between CO Pollutant Concentration and Traffic Parameters

In order to develop certain traffic management measures for reducing pollutant concentration, it is needed to find the variation of pollutant concentration with traffic parameters like type of vehicle traffic, total traffic, and traffic stream speed. Scatter plots were developed to study the relationship between the concentration of carbon Monoxide and the number of four wheelers, three wheelers and two wheelers. The analysis indicated that CO pollutant concentration increased with the increase in number of four wheelers, three wheelers, and two wheelers. But the increase in CO pollutant concentration was more with number of three wheelers than the other type of vehicles.

A study of the variation between Carbon Monoxide pollutant concentration and traffic stream speed indicates that CO pollutant concentration is decreasing with the increasing traffic stream speed; the reason being residence time of the vehicles on the road will be increasing with decreasing speeds of the vehicles. Improper traffic management measures, inadequate road geometrics and poor road conditions have been found to result in interruption to smooth flow of traffic, in the form of stop and go operations.

B. Regression Model for Estimating CO Pollutant Concentration

Linear regression models were developed considering traffic flow, traffic stream speed, petrol and diesel driven vehicles as explanatory variables and observed CO pollutant concentration as dependent variable (y).

The regression model given in Table II is of the form

$$y = a_0 + a_1 x$$

Linear regression models along with R^2 values are given in Table II.

TABLE II
REGRESSION MODELS

Sl. No	Explanatory Variable (x)	Linear regression model	R^2
1	Number of all vehicles	y = 1.4544 + 0.0007x	0.106
2	Number of petrol driven vehicles	y = 1.3651+ 0.0061x	0.125
3	Number of diesel driven vehicles	y = 2.6362 + 0.0011x	0.017
4	Source strength (q)	y = 1.3389 + 0.234x	0.127
5	Source strength/ Stream Speed (q/u)	y = 1.3522 + 1.8915x	0.274

C. Comparison of Performance of CALINE4, IITLS and Linear Regression Models

CALINE4 model values have been found to have a comparatively good agreement with the observed values than IITLS model. In case of IITLS model the CO values were found to be under predicted. Linear Regression model values were found to be close to the observed values. The reason for under prediction and over prediction may be due to high wind speeds and low wind speeds, dispersion parameters and traffic flow.

The validation of the models is done by comparing the RMS Percentage error. RMS Percentage error of CALINE4, IITLS, and Regression models are calculated by taking the observed CO and predicted CO values. Figs. 2, 3 and 4 show the scatter of observed values with estimated values along with RMSE percentage values for the three models. From this analysis it was observed that CALINE4 and regression models are performing well in prediction of CO values than the IITLS model.

High RMS Percentage error shows that variation of certain parameters like wind direction, cloud cover, atmospheric stability, which are assumed to be constant over time and space, have to be considered. The high value of RMS percentage error indicates that the model has to be modified for the atmospheric conditions. For developing dispersion parameters for Indian conditions pollutant concentrations at varying receptor coordinates have to be measured.

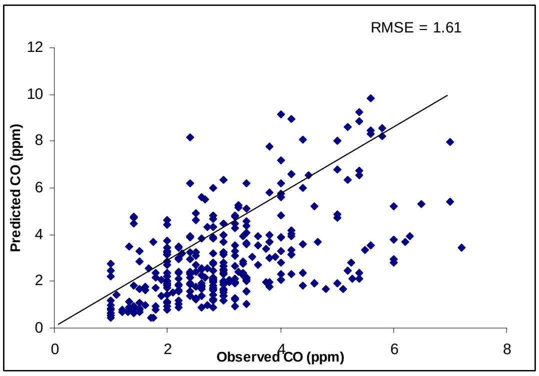

Fig. 2 Observed CO Vs Predicted CO (CALINE4)

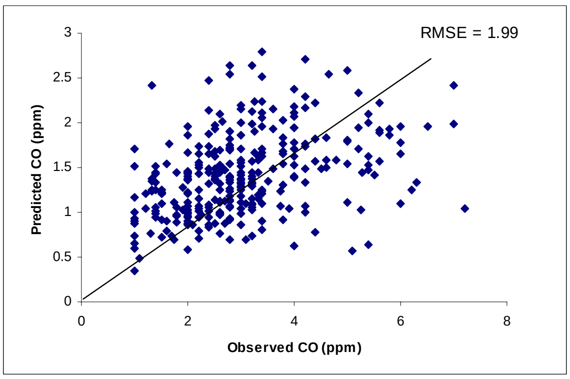

Fig. 3 Observed Vs Predicted CO (IITLS)

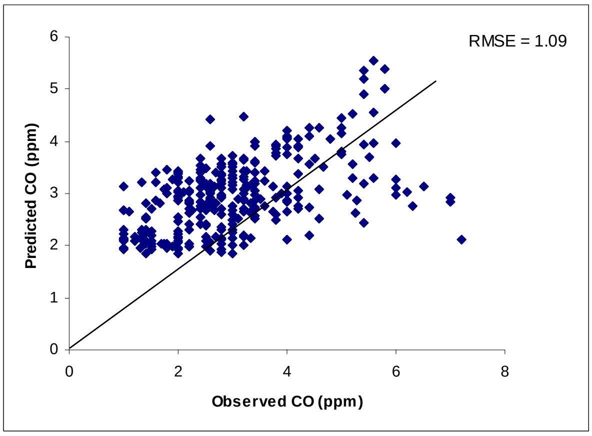

Fig. 4 Observed Vs Predicted CO (Regression model)

D. Air Quality Index

Maximum one hour average CO pollutant concentration value over each link was calculated. Among the 15 links studied, 5.6 ppm is the maximum CO pollutant concentration observed. Air quality indices are used to compare air quality over different links. It is expressed as percentage of the relevant standard of the pollutant. As lower the index better is the air quality. Air quality index for each link is calculated based on the index ambient air quality performance is estimated over each link. Among fifteen links air quality performance is good at 2 links, fair at 6 links, and poor at 7 links.

E. Comparison of Linkwise Ambient Co Pollutant Concentration with NAAQS

Maximum one hour average CO pollutant concentration at each link is compared with the National Ambient Air Quality Standards (NAAQS) proposed by Central Pollution Control Board (CPCPB). Ambient CO pollutant concentration is 4.0 ppm in residential areas. The maximum one hour average CO concentration was calculated over each link, and in seven links CO value was exceeding the NAAQS, and in the remaining eight links CO value was below NAAQS.

V. Conclusion

The following conclusions were derived from the study:

1. CO pollutant concentration is found to increase with the number of four wheeler, three wheeler and two wheeler. But CO concentration is found to increase more with number of three wheelers than other type of vehicles.
2. CO pollutant concentration is increasing with decreasing speeds of the vehicles. The reason is that vehicles will spend more time in traffic stream.
3. A comparatively high value of R^2 was observed between q/u and the CO concentrations indicating that concentration of vehicles on the links is positively correlated to the carbon monoxide concentration.
4. Linear regression model is performing better than the CALINE4 and IITLS models. This indicates that models have to be modified including other variables.
5. Ambient air quality performance is estimated over 15 links. The estimations have revealed that air quality is good at 2 links, fair at 6 links and poor at 7 links.
6. Maximum 1 hour average CO concentration value is calculated over each link. In seven links CO concentration is exceeding NAAQS and remaining links CO is below 4.0 ppm.

The model developed for predicting CO concentration is useful to develop traffic control measures and environmental capacity standards for urban roads.

VI. Scope for Further Work

More detailed surveys have to be conducted taking into consideration the location of intersections and consequent queuing situations that often arise on the road network. Similarly surveys have to be conducted in different seasons and at locations deeper inside, so as to determine the extent of the spread of pollution. Such studies should also be conducted in many other cities in India to develop a proper model for the prediction of ambient air quality. By projecting the traffic parameters and air quality levels for future time period, the model can be used for forecasting.

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