Abstract

The increase in the number of motorcyles in Indian cities is due to several factors such as traffic, low cost, mobility, few parking lots and the low efficiency of public transportation, becoming an important factor in air quality deterioration. In this context, vehicle emissions monitoring is essential to understand the contribution to air pollution as a whole. The development of models for air pollution assessment has been identified as an important area for future research. Air pollution due to massive use of motor vehicles in urban areas of India is one of the most seriours and the fastest growing problem to solve. These motor vehicles emit significant quantities of CO2, CO, hydrocarbons, oxides of nitrogen, SPM and other toxic substances in the atmosphere which adversely affect the environmental and the health. The objective of this study is to understand the chemistry of air pollution with its precise estimation through modeling. The behavior and relation between emission and depositions of pollutants can explain with the help of air quality models. Modeling is a set of different scientific methods that are helpful to analyse the nature and behavior of pollutants in the atmosphere. On the basis of source of pollutant air quality models are classified as point, area or line source models. Various Gaussian based line source models are commonly used in India to assess the impact of vehicular pollution along the roads or highways. The CO pollutant concentration values were compared with the National Ambient Air Quality Standards (NAAQS), and the CO values were predicted by using CALINE4 model. The possible association between CO pollutant concentration and traffic parameters like traffic flow, type of vehicle, and Roadway width was also evaluated.

Keywords: Atmosphere, Modeling, Motorcycle, Air Pollution, Air Quality Models, Pollutants, CALINE 4model

I. INTRODUCTION

Concern with the environment is becoming a common issue in the society. The improvement of the air quality, mainly in large urban centres, is essential to the public health. However, anthropogenic activities, mainly for transport in large cities, combined with unfavorable weather conditions have contributed to an increase of pollutants in the atmosphere. Global problems, such as the greenhouse effect, caused mainly by the release of undesirable compounds generated by human activity, justify the worldwide concern about this issue. Thus, the scientific community increasingly craves new technologies to understand and improve the composition of the atmosphere. Many of these technologies seek to control and monitor air quality. Products of internal combustion engine vehicles can be considered one of the most polluting activities mainly due to the large number of vehicles in cities. The low quality and quantity of public transportation is one of several reasons for vehicular pollution. Ozone formation from motorcycle emissions, the trajectory model OZIPR (Ozone Isopleths Package for Research) coupled with the chemical model SAPRC (State-wide Air Pollution Research Centre) was used. Both are public domain, have wide acceptance in academia and international agencies and are relatively simple to work with. Moreover, its chemical mechanism is extremely detailed for photochemical reactions in the troposphere. The trajectory model OZIPR5 was developed by the United States Environmental Protection Agency (US EPA) as a support for the scenario forecasting of urban air pollution episodes.

The problem of air pollution because of continuous development and the increase of population in the urban areas have become so remarkable that there is urgency for timely information about changes in the pollution level. The transport and diffusion of pollutants in the atmosphere depend on the nature as well as meteorological and emission conditions of pollutants. Respiratory difficulties, heart disease, loss of agricultural products and damage to aquatic and terrestrial ecosystems are main adverse effects of air pollution. Photochemical reactions taking place within the atmosphere are responsible for emission of many pollutants.
pollutants that cause serious health hazards to human. Main traffic related pollutants like CO reduces oxygen carrying capacity of blood, benzene pollutants cause cancer and SO₂ and particulates can cause respiratory diseases (UNEP, 2009). Air quality dispersion models act as a valuable tool to predict the quality of air against the National Ambient Air Quality Standards and are useful in the air pollution management. Modeling of air pollution is based on various models like Gaussian modes, box models, narrow plume models and complex computational fluid dynamic models. Gaussian models are based on a set of empirical equations that is mainly applied to coal burning electricity producing plants and to exhaust from automobiles in the cities.

Some common types of models are

- Dispersion models: which use equations to represent the path that pollutants travel in the air in order to calculate the downwind air concentrations
- Receptor models: which use properties of air pollutants to identify and quantify the sources of air pollutants,
- Meteorological models: which use equations that represent the behavior of the atmosphere in order to predict the meteorological conditions at specific area.
- Physical models: small, used in wind tunnels to simulate actual conditions and
- Statistical models: where statistics are used to relate emissions and the resulting concentrations.

Modeling of air pollution has been accomplished with the aid of Gaussian Dispersion Plume models that accounted for the temporal and spatial 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 (Nagendra and Khare, 2002 and Venkatraman and Horst, 2005). They are computer-based models that calculate the distribution of the pollutants in the atmosphere from specified emission sources and meteorological scenario. The present research paper, thus, evaluates the application of CALINE 4 in predicting the concentrations of Carbon-monoxide (CO) in the study area. CALINE4, the latest in CALINE series models, is most widely used. Gaussian based vehicular pollution dispersion model to predict air pollutant concentrations along the highway under rural (i.e. Open), semi urban and urban conditions with and without street canyon effects. CALINE series of models have been used extensively all over the world, including India for regulatory purposes. CALINE4 offers several advantages over the other previous models and has been used by many researchers to predict pollutant concentrations of vehicular pollutants along the roads/ highways in Indian climatic conditions. (Nirjar et al., 2002) had used CALINE4 to predict the concentrations of CO along the urban and semi-urban roads in Delhi and the study results showed under prediction and moderate r² correlation values between observed and predicted concentrations. Further, (Gramotnev et al., 2013) used CALINE4 for the analysis aerosols of (fine and ultra-fine particles) generated by vehicles on a busy road and found good agreement between observed and predicted concentrations. (Sharma et al., 2007) used the CALINE4 model in an urban highway corridor in Delhi. The study concluded that model performed satisfactorily in vehicle exhaust contributes in air quality. (Dhyani et al., 2005) evaluated and compared the performance of CALINE4 model for hilly and flat terrain. They observed unsatisfactory performance of the model in hilly regions due to complex topography and micro meteorological conditions which could not be properly simulated in CALINE4. The present paper, briefly discusses parameters influencing the vehicular pollution dispersion beside evaluation of CALINE4 model performance along an urban highway corridor in Delhi as a case study.

Mathematical models can be used to determine the environmental impacts of the existing or developing projects which combine the effects of source strength and meteorology to describe the resulting ambient air concentrations. Air pollution modelling, also known as air pollution dispersion modeling, is the mathematical simulation of how air pollutants disperse in the ambient atmosphere. It is performed with computer programs, called dispersion models, that solves the mathematical equations and algorithms which simulate the pollutant dispersion. The dispersion models are used to estimate or to predict the downwind concentration of air pollutants emitted from emission sources such as industrial plants and vehicular traffic. Such models are important governmental agencies tasked with protecting and managing the ambient air quality. The models also serve to assist in the design of effective control strategies to reduce emissions of harmful air pollutants (Sharma et al., 2005). A dispersion model is a computer simulation that uses mathematical equations to predict air pollution concentrations based on weather, topography, and emissions data. Any model depends on the following inputs.

- Emission parameter: Type of source, emission rate, location, height, temperature etc.
- Topography: Rural or Urban area, terrain elevation, height and width of any obstruction, receptor location (height, distance from source) etc.
- Meteorological Condition: Wind speed and direction, Atmospheric temperature, Atmospheric stability, Cloud cover, solar radiation etc.

Air quality in urban areas is getting deteriorated mainly due to the increased vehicular population in cities. Main traffic related pollutants include: Carbon monoxide (CO), Nitrogen oxides (NOₓ), Sulphur Dioxide (SO₂), hydrocarbons, and particulates. Poorly maintained vehicles given rise to more pollution problems. These pollutants cause both acute and chronic effects on human health. CO reduces oxygen carrying capacity of the blood; benzene pollutants can cause cancer, whereas particulates and SO₂ can cause respiratory diseases like asthma, bronchitis (UNEP, 2009). In urban areas where population and traffic density are relatively high, human exposure to hazardous substances is significant. Due to this concern, the street canyons are considered as hot spots for air pollution problems. Air quality dispersion models serve as a valuable tool for assessing the air quality against the National Ambient Air Quality Standards (NAAQS) and in decision making regarding the air pollution management. A variety of street canyon models are now available, starting from simple empirical models for complex Computational Fluid Dynamic (CFD) models. The pollutant concentration in a street canyon mainly depends upon the traffic characteristics (type and number
of vehicles), canyon geometry, urban background concentration, and meteorological parameters such as wind speed and wind direction (Vardoulakis et al., 2003).

Now days air pollution problem is not bound to an area and it becomes a global problem (Global warming, ozone depletion etc). It is very difficult to control air pollution on a global scale. To control the air pollution at local or regional scale, air pollution modeling is the most important component in air pollution control policy making. Air pollution modeling required for two major goal 1) increase domain knowledge and 2) Reliable forecasting of pollutant concentration (Karatzas et. al., 2007). Air quality models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on inputs of meteorological data and source information like emission rates and stack height, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and, in some cases, secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere. These models are important to our air quality management system because they are widely used by agencies tasked with controlling air pollution to both identify source contributions to air quality problems and assist in the design of effective strategies to reduce harmful air pollutants. The air quality model is one of the most important components of air quality management. Air quality models are used to predict concentrations of one or more species in space and time. Modeling provides the ability to assess the current and future air quality in order to enable “informed” policy decisions to be made. This will help the regulatory agencies to assess the extent and type of the air pollution control management strategies (Afshar and Delavar, 2007). Air pollution models are routinely used in environmental impact assessments, risk analysis and emergency planning, and source apportionment studies (Macdonald R., 2003). The air quality model also support in the attainment / maintenance of all National Ambient Air Quality Standards (NAAQS).

II. PREVIOUS WORK

The rapid industrialization leading to urbanization, unplanned and excessive exploitation of natural resources has been causing pollution problems in cities and towns of developing countries. Anthropogenic and natural sources of emissions have polluted the air with toxic substances.

Benson (1984) showed that CALINE4 requires hourly traffic flows, meteorological parameters and a composite emission factor which represents the fleet profile of vehicle type, fuel and driving mode. It predicts the hourly concentration of receptors relative to the roadway line source. A composite emission factor of 6.62 g/mile CO was calculated for the vehicle fleet of 71% petrol cars, 21% diesel cars and 8% heavy goods vehicles (HGV). The motorway was modeled as one link, whereas the roundabout was modeled as five links meeting at the centre point of the roundabout.

Benson (1989) CALINE4 model was developed by the California Department of Transportation and the US Federal Highways’ Agency (FHA). It is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over the roadway. CALINE4 is a roadway model designed to calculate a single 1-hour average concentration for a defined single hour meteorological data for local roadways including intersections.

Luhar and Patil (1989) evaluated the GFLSM and CALINE (Benson,1992) for making short-term forecasts of CO and particulate matter concentrations at selected three air quality control regions (AQCR) in Bangalore city to prepare local air quality management strategies. The best model may be further used as warning and decision-making tool during poor meteorological conditions i.e. during air pollution episode conditions.

Luhar et al. (1989 a) stated that models are available for the estimation of pollutants present at a certain site depending upon the available parameters and weather conditions. For their studies CALINE 4 model was chosen, because it often 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 NOx and SPM.

HitoshiKono et al. (1990) developed the regression models to estimate the concentration of oxides of nitrogen based on the emission factor and the type of test car used with due weight age given to the traffic speed and emission factors.

Benson (1991) used the performance evaluation of two Gaussian based line source models, namely CALINE4 and General Finite Line Source Model(Luhar and Patil,1989) to predict the levels of CO emissions at three AQCRRs in Bangalore city, representing busy traffic junction (Amco Batteries-AQCR1), sensitive area (Victoria Hospital-AQCR2), and industrial area (Peenya industrial area-AQCR3) respectively. The traffic flow count has been conducted hourly from morning 8.00a.m to 7.00pm to study the traffic characteristics at the three AQCRs and the peak hour average flow also was measured.

Benson (1992) showed CALINE4, a Gaussian plume-based line source model, is widely used in the prediction of carbon monoxide dispersion for roadways. The NO2 option for CALINE4 is available using its executable from a command line (http://www.dot.ca.gov/hq/env/air/pages/calinesw.htm) CALINE4 considers reactions (R1)—(R3), and the same reaction rate constants are set for both CALINE4 and AERMOD.

Ditty. R (1995) reported the 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.

Loranger et al. (1995) showed that CALINE4 predicted near-road CO concentrations well, but under-predicted manganese (Mn) concentrations.
Broderick et al. (2005) examined CALINE4’s performance of modeling transportation-related CO for a free-flowing motorway and a periodically congested roundabout in Ireland and concluded that CALINE4 functioned well under stable atmospheric conditions but performed poorly under low wind conditions.

III. MATERIALS AND METHODS

A. Site Description Puducherry

Puducherry, a thickly populated, poorly ventilated air basin is being polluted by the ever-expanding transport, construction, and commercial activities. Hence, it is necessary to forecast the impact of pollutants from the various sources located in the Puducherry for the purpose of arriving at a comprehensive air pollution control scenario. Puducherry is a well-known union territory located in the southern region of India on the east coast. It was governed by the French till 1962, when it was ceded to the Indian government. Puducherry has four districts, out of which Mahe is situated on the west coast. The district of Puducherry is the best known tourist spot. There are many tourist attractions in Puducherry and the scenic beauty of the place is equally enchanting. This would necessitate assessing the carrying capacity of the Puducherry air basin in other words, fixing a limitation on the numbers. The population of Puducherry is around a 1.5 lakhs excluding that of tens of existing and upcoming mini satellite townships surrounding.

B. Description of Sampling Sites

Figure 1 shows the eight sampling sites selected for Ambient Air Quality (AAQ) monitoring in Puducherry. They were Indira Gandhi signal (PDY1), Rajiv Gandhi signal (PDY2), Bus terminus (PDY3), Kanniyakoil(PDY4), Nehru street(PDY5), Tindivanam main road (PDY6), Cuddalore main road(PDY7) and Muruga theatre (PDY8). The selected sites were places of maximum population, heavy traffic, and commercial activities. A continuous sampling has been carried out at all the sites, every month for nine months from 10.00a.m to 06.00 p.m. for 3 days each. The vehicular emissions are one of the major sources of air pollution in the study area. Unlike industrial emissions, vehicular pollutants are released at ground level and hence their impacts on the recipient population are likely to be significant. Figure 1 shows the road network in the study area and form the basis of air quality modeling.

C. Traffic Counting At Different Road Networks

Total eight road link/networks viz., PDY1, PDY 2, PDY 3, PDY 4, PDY 5, PDY 6, PDY 7 and PDY 8 with eight traffic junction points were selected for vehicular pollution source modeling which covers the entire study area. Hourly traffic counting was done for different category of vehicles (2 wheelers, 3 wheelers, Light duty, heavy duty) at different junctions through road networks during 10.00 to 18.00 hours during January 2009 to September 2009. Potential exposure that exceeds the ambient standard may be of greater concern to public health because they increase the total body burden for CO (USEPA 2000). Receptors were located close to the roadway where pollutant concentrations caused by mobile sources are to be measured. Receptors can exist as part of a grid or as discrete receptors. A receptor was located outside the “mixing zone” of a roadway, which is the total width of the travel lanes of a roadway plus 3 meters (10 feet) on either side.
1) Indira Gandhi Signal (PDY1)
This site is one of the busiest urban centres of Puducherry. Large number of vehicles moves on the road. This site has two way traffic system, heavy non-smooth vehicle flow and narrow sharp turn. Percentage traffic shares of two wheelers/three wheelers/light vehicles/heavy vehicles were 59, 10, 20 and 11 respectively. The distribution of automobile vehicles (16395) that were plying during the sampling period at location PDY1 is depicted in a pie chart shown in figure 2.

2) Rajiv Gandhi Signal (PDY2)
This site is one of the busiest urban centres of Puducherry. Large number of vehicles moves on the road. This site has two way traffic system, heavy non-smooth vehicle flow, narrow sharp turn, shopping complex, and parking lots. Percentage traffic shares of two wheelers/three wheelers/light vehicles/heavy vehicles were 67, 11, 15 and 7 respectively. The distribution of automobile vehicles (28751) that were plying during the sampling period at location PDY2 is depicted in a pie chart shown in figure 3.

3) Bus Stand (PDY3)
This site faces large number of bus operations, vehicle queuing, frequent stop-go operation, idling, acceleration, cruising, deceleration, and non-smooth vehicle flow. This site is the junction for vehicles coming into the Pondicherry and going out of the Pondicherry. The monitoring equipment was kept above the hotel (Karthick). This road is busy for almost 24 hours. Percentage traffic shares of two wheelers/three wheelers/light vehicles/heavy vehicles were 0, 0, 0 and 100 respectively. The distribution of automobile vehicles (2252) that were plying during the sampling period at location PDY3 is depicted in a pie chart shown in figure 4.

4) Kanniyakumari (PDY4)
This site has two way traffic system, vehicle queuing, stop-go practice, open-loop signal control, and high vehicle mobility. This road is busy for almost 24 hours. The head of the sampler was faced the road. Percentage traffic shares of two wheelers/three wheelers/light vehicles/heavy vehicles were 61, 12, 16 and 11 respectively. The distribution of automobile vehicles (18162) that were plying during the sampling period at location PDY4 is depicted in a pie chart shown in figure 5.

5) Nehru Street (PDY5)
This site possesses one way traffic system, less frequent queuing, less stop-go practice, and commercial bazaar activity. This road is busy for almost 24 hours. The head of the sampler was faced the road. Percentage traffic shares of two wheelers/three wheelers/light vehicles/heavy vehicles were 67, 12, 12 and 9 respectively. The distribution of automobile vehicles (19480) that were plying during the sampling period at location PDY5 is depicted in a pie chart shown in figure 6.

6) Tindivanam High Road (PDY6)
This site has two way traffic signal, heavy traffic flow, non-smooth due to narrowing and abrupt turning of roads. This road is busy for almost 24 hours. The head of the sampler was made to face the road. Percentage traffic shares of two wheelers/three wheelers/light vehicles/heavy vehicles were 68, 11, 11 and 10 respectively. The distribution of automobile vehicles (19355) that were plying during the sampling period at location PDY6 is depicted in a pie chart shown in figure 7.

7) Cuddalore Main Road (PDY7)
This site has two way traffic signal, vehicle queuing, narrow, sharp turn, and heavy traffic flow, non-smooth due to narrowing and abrupt turning of roads. This road is busy for almost 24 hours. The head of the sampler was made to face the road. Percentage traffic shares of two wheelers/three wheelers/light vehicles/heavy vehicles were 62, 12, 14 and 12 respectively. The distribution of automobile vehicles (16452) that were plying during the sampling period at location PDY7 is depicted in a pie chart shown in figure 8. Muruga Theatre Junction (PDY8).
This site has two way traffic signal, vehicle queuing and heavy traffic flow. This road is busy for almost 24 hours. The head of the sampler was made to face the road. Percentage traffic shares of two wheelers/three wheelers/light vehicles/heavy vehicles were 69, 11, 11 and 9 respectively. The distribution of automobile vehicles (19962) that were plying during the sampling period at location PDY8 is depicted in a pie chart shown in figure 9.

D. Model and Pollutant Used
Modeling of air pollution is accomplished with the aid of Gaussian dispersion plume models that accounted for the dispersion characteristics of the pollutants. CALINE 4 model has better performance than other line source models and is widely used to predict near road vehicle emissions (Benson, 1992; Loranger et al., 1995; Nagendra and Khare, 2002). Its purpose is to help planners protect public health from the adverse effects of excessive CO exposure. It embeds the concept of mixing zone and uses modified Gaussian plume distributions (Benson, 1984).

![Fig. 2: Distribution of Automobile Vehicles at PDY1](image1)

![Fig. 3: Distribution of Automobile Vehicles at PDY2](image2)
The ability of the CALINE 4 model is to predict air quality reliably up to 500 m from the roadway and the special options for modeling air quality near street canyons, intersections and parking facilities bestows a great advantage to the model (Majumdar et al., 2010) with respect to given meteorological condition (e.g., wind speed, wind direction, mixing height, stability class, temperature, background concentrations), source strength (e.g., vehicular density and vehicle emission factor) and road-geometry (e.g., roadway height, receptor locations and heights, number of links, surface roughness, mixing zone width, etc.). 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 factors 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. 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). The user defines the proposed roadway geometry, worst-case meteorological parameters, anticipated traffic volumes, and receptor positions. CO has several advantages as a reference for the estimation of traffic-produced pollutants. It is chemically inert in the atmosphere and it has a low natural background concentration, it is produced by both petrol and diesel engine vehicles and more importantly, it is possible to measure atmospheric CO concentrations continuously and, thus, it provides data for testing the model for short periods when there are considerable fluctuations in the traffic flows and meteorological conditions (Khare and Sharma, 2001; Majumdar et al., 2010).

IV. MODELING

A. CALINE4 Model Description

CALINE4 model is the fourth generation simple line source Gaussian plume dispersion model. It predicts the concentrations of carbon monoxide (CO), nitrogen dioxide (NO2) and suspended particulates (PM10/PM2.5) near roadways. It employs a mixing zone concept to characterize pollutant dispersion over the roadway due to vehicles plying on the road corridor. The CALINE4 can predict the pollutant concentrations for receptors located within 150m under given traffic and meteorological conditions.
important input parameters required for CALINE4 model include, classified traffic volume (number of vehicles per hour), meteorological parameters (wind speed, wind direction, ambient temperature, mixing height and stability class), emission parameters (weighted emission factor, WEF), road geometry (road width, median width, road elevation), type of terrain (rural or urban), background concentration of pollutants (ppm or μg/m³) and pre-identified receptor locations along the road corridors. CALINE4 is a dispersion model that predicts carbon monoxide (CO) impacts near roadways. Its main purpose is to help planners to protect public health from the adverse effects of excessive CO exposure. It calculates quantities of pollutants in the air at specified receptors from information on the type and strength of sources of pollutants and information on weather conditions. The CALINE-4 model is a fourth-generation line source air quality model. CALINE4 is the last in a series of line source air quality models developed by the California department of transportation (Caltrans).

B. Input for CALINE – 4

The CALINE-4 highway dispersion model requires the following data as input:
- Traffic parameters: Traffic volume (hourly and peak), traffic composition (two wheelers, three wheelers, cars, buses, goods vehicle etc.), type of the fuel used by each category of vehicles, fuel quality, average speed of the vehicles.
- Meteorological parameters: Wind speed, wind direction, stability class, mixing height.
- Emission parameters: Expressed in grams /distance travelled. It is different for different categories of vehicles and is a function of the type of the vehicle, fuel used, average speed of the vehicle and engine condition.
- Road geometry: Road width, median width, length and orientation of the road, number and length of each links.
- Type of the terrain: Urban or rural, flat or hilly.
- Background concentration of pollutants.

C. Methodology

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. The Classified volume count was taken for each observation period of every one hour from 10.00 am to 06.00 pm. The link characteristics of the various links such as the length and width of the link, type of operation (one way or two ways) were also obtained by manual methods. The CALINE-4 model allows roadways to be broken into multiple links that can vary in traffic volume, emission rates, height and width. The screening form of the CALINE-4 model calculates the local hourly–averaged contribution of nearby roads to the total concentration. CALINE 4 highway dispersion model requires the following data as input:

D. Traffic and Road Geometry Data

Air quality modeling needs a comprehensive set of input information on traffic volume and composition, road geometry and emission factors for different vehicular fleets. Data on traffic composition was collected from all sites of puducherry city. Traffic volume (hourly and peak), traffic composition (two wheelers, three wheelers, cars, buses, goods vehicle), type of the fuel used by each category of vehicles, fuel quality, average speed of the vehicles. L. Veh (Light Vehicle) = Car, Jeep, Taxi, Pajero, Microbus, Ambulance, Pickup, Maxi, Duranta; Bus = All type of buses; Truck = All type of trucks; T. Wheel (Three Wheeler) = Tempo, Baby taxi, Mishuk;

Road geometry includes the road width, median width, length and orientation of the road, number and length of each link. Estimating emission rates of different sources of pollution or emission factor is crucial for developing emission inventories. In India, comprehensive emission factors have not been developed. Two sets of emission factors for vehicles in India have been calculated by Indian Institute of Petroleum (IIP) and the Automotive Research Association of India (ARAI), Pune (Tables 1 & 2).

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>CO (g/km)</th>
<th>NOx (g/km)</th>
<th>SO2 (g/km)</th>
<th>Particulate (g/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-Wheelers</td>
<td>8.30</td>
<td>-</td>
<td>0.013</td>
<td>-</td>
</tr>
<tr>
<td>Cars (Four wheeler)</td>
<td>24.03</td>
<td>1.57</td>
<td>0.053</td>
<td>-</td>
</tr>
<tr>
<td>Three-Wheelers</td>
<td>12.25</td>
<td>-</td>
<td>0.029</td>
<td>-</td>
</tr>
<tr>
<td>Urban Buses</td>
<td>4.381</td>
<td>8.281</td>
<td>1.441</td>
<td>0.275</td>
</tr>
<tr>
<td>Trucks</td>
<td>3.425</td>
<td>6.475</td>
<td>1.127</td>
<td>0.450</td>
</tr>
<tr>
<td>Light Commercial Vehicles</td>
<td>1.30</td>
<td>2.50</td>
<td>0.40</td>
<td>0.100</td>
</tr>
</tbody>
</table>

Emission Factors calculated by the Automotive Research Association of India (ARAI) in 1998

<table>
<thead>
<tr>
<th>Description</th>
<th>Two-Wheelers</th>
<th>Three-Wheelers</th>
<th>Four-Wheelers</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO Average</td>
<td>7.9</td>
<td>13.2</td>
<td>23.4</td>
</tr>
<tr>
<td>Variation</td>
<td>4.9 to 16.8</td>
<td>5.1 to 39.4</td>
<td>14.3 to 36.7</td>
</tr>
<tr>
<td>HC Average</td>
<td>4.5</td>
<td>10.9</td>
<td>4.7</td>
</tr>
<tr>
<td>Variation</td>
<td>3.6 to 5.4</td>
<td>7.7 to 15.1</td>
<td>3.1 to 6.8</td>
</tr>
<tr>
<td>NOx Average</td>
<td>Values insignificant</td>
<td>Values insignificant</td>
<td></td>
</tr>
<tr>
<td>Variation</td>
<td>Values insignificant</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
E. Methodology and Emission Factor

CO emission norms for Indian vehicles established by Indian Institute of Petroleum (IIP) were used in this study. Vehicular 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. The emission factors were further combined to calculate the composite EF to provide inputs to the source strength of the models. The composite EF was calculated for four categories of vehicles using Eq. (1). Table 3 shows the selected emission factor for the vehicular fleet in Chidambaram (in gm/km).

\[
\text{EF}_C = \frac{\sum \text{EF}_i \times \text{V}_i}{\sum \text{V}} \tag{1}
\]

Table 3 – CO Emission Factor for Vehicles

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Type of Vehicle</th>
<th>CO (grams/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Four wheeler</td>
<td>23.4</td>
</tr>
<tr>
<td>2</td>
<td>Three wheeler</td>
<td>13.2</td>
</tr>
<tr>
<td>3</td>
<td>Two wheeler</td>
<td>7.9</td>
</tr>
<tr>
<td>4</td>
<td>Truck</td>
<td>3.425</td>
</tr>
<tr>
<td>5</td>
<td>Bus</td>
<td>4.38</td>
</tr>
</tbody>
</table>

V. RESULTS AND DISCUSSION

A continuous investigation to evaluate the pollutant levels of SPM, SO\textsubscript{2}, NOx and CO in ambient air of Puducherry has been carried out. Eight different select pollution prone locations were intentionally identified and 8 hour sampling on 3 days a month per each location were carried out during January to September 2009. The results of the investigations are on the anticipated lines, making a clear case warranting immediate installation of a “continuous ambient air quality monitoring” process on stream.

A. Suspended Particulate Matter (SPM)

The yearly mean value of suspended particulate matter (SPM) at the eight locations were 325.90 µg/m\textsuperscript{3}, 384.30 µg/m\textsuperscript{3}, 370.30 µg/m\textsuperscript{3}, 333.80 µg/m\textsuperscript{3}, 341.17 µg/m\textsuperscript{3}, 350.88 µg/m\textsuperscript{3}, 361.20 µg/m\textsuperscript{3} and 332.51 µg/m\textsuperscript{3} respectively as shown in figure 10. The highest SPM level at Puducherry was in PDY2, Rajiv Gandhi signal due to the large number of vehicle operations, vehicle queuing, frequent stop-go operation, idling, acceleration, cruising, deceleration, and non-smooth vehicle flow and second highest in bus terminus may be due to the result of increased vehicular traffic, vehicle queuing, frequent stop-go operation, idling, acceleration, cruising, deceleration in the area. Vehicular pollution is due to Increase in population of vehicles, particularly the personalized vehicles. This may be due to emission from vehicles, suspension of traffic dust. The reason for high particulate matter levels may be vehicles, engine, suspension of traffic dust, commercial and domestic use of fuels, etc. The yearly mean value of suspended particulate matter (SPM) was found to be highest at Rajiv Gandhi signal and lowest at Indira Gandhi signal. The level of SPM was observed above the safety limit at all the eight sites in Puducherry.

B. Sulphur dioxide (SO\textsubscript{2})

The yearly mean values of SO\textsubscript{2} at Indira Gandhi Signal, Rajiv Gandhi Signal, Bus Terminus, Kanniyakoil, Nehru street, Tindivanam main road, Cuddalore main road and Muruga theatre were 46.44µg/m\textsuperscript{3}, 52.14µg/m\textsuperscript{3}, 49.32 µg/m\textsuperscript{3}, 44.80 µg/m\textsuperscript{3}, 48.26 µg/m\textsuperscript{3}, 49.56 µg/m\textsuperscript{3}, 45.39 µg/m\textsuperscript{3} and 42.43µg/m\textsuperscript{3} respectively as shown in figure 11. The average level of SO\textsubscript{2} was below the permissible limit (80 µg/m\textsuperscript{3}) as prescribed by NAAQS at all the eight sites. The yearly mean value of SO\textsubscript{2} was found to be maximum in summer season at Rajiv Gandhi signal and minimum at Muruga theatre during July.
C. Oxides of Nitrogen (NO\textsubscript{x})

The yearly mean value of NO\textsubscript{x} at the eight locations were 114.55 µg/m\textsuperscript{3}, 126.77 µg/m\textsuperscript{3}, 115.43 µg/m\textsuperscript{3}, 104.35 µg/m\textsuperscript{3}, 109.65 µg/m\textsuperscript{3}, 111.84 µg/m\textsuperscript{3}, 100.12 µg/m\textsuperscript{3}, 107.47 µg/m\textsuperscript{3} respectively as shown in figure 12. Yearly mean of NO\textsubscript{x} level exceeds the prescribed NAAQS (80 µg/m\textsuperscript{3}) limit at all the eight sites. The highest oxides of nitrogen level at puducherry were in PDY2, Rajiv Gandhi signal due to the large number of vehicles passed through this signal, queuing, frequent stop-go operation, idling, acceleration, cruising, deceleration, and non-smooth vehicle flow. This road is busy for almost 24 hours. The heavy vehicular traffic is the main attribute at puducherry for the maximum level of oxides of nitrogen. Also, due to high emission from two and three wheelers, poor fuel quality (high sulphur, benzene and olefin), adulteration of fuel, violation of emission norms, lacking in maintenance of vehicle, large number of old vehicles in use (high emitters), erratic traffic behavior leading to congestion (jam) and more emission of gases, older vehicle engine technology, inadequate road space preventing better mobility of traffic, poor maintenance of roads reducing traffic speed, inadequate traffic management and increase in population of vehicles.
D. **Carbon Monoxide (CO)**

The yearly mean value of CO at the eight locations were 2.18 mg/m³, 2.15 mg/m³, 2.16 mg/m³, 2.20 mg/m³, 2.18 mg/m³, 2.18 mg/m³, 2.17 mg/m³, and 1.57 mg/m³ respectively as shown in figure 13. The highest CO level at Puducherry was in PDY4, Kanniyakoil due high emissions of carbon monoxide and hydrocarbons from 2 and 3 wheelers consisting of two stroke engines. Inadequate road and traffic network unable to meet the needs of the increasing population, leading to traffic congestion and traffic jams. Such areas and traffic intersections are regions of high levels of pollution. Carbon monoxide was found to be highest at Kanniyakoil and lowest at Muruga theatre road.

E. **Development of possible relationship between Pollutant Concentration of CO and Traffic Parameters (Puducherry)**

Figure 15 presents a comparison of CO concentration values obtained by Caline4 with those observed during field survey. The simulation was made for the traffic condition prevailing in January 2009 to September 2009 and compared with CO concentration measured at the same period.

The results show that the predicted values are in between the observed highest average and lowest average hourly values. CALINE4 model is in good agreement with the observed values. Observed CO concentrations at the monitoring spot are more or less close to the predicted value. Monthly variation of CO in ppm is shown in 14.

VI. **CONCLUSION**

This paper is devoted to evaluating emission levels of CO due to vehicular exhaust at various traffic junction points in the study area. These data bases were used in the CALINE 4 model (line source) for evaluating its suitability for line source modeling. With respect to one hour modeling of CO for vehicular traffic, CALINE 4 indicates more appropriate. The problem of vehicular pollution mainly arises due to emissions from plying of vehicles at various road networks. As such, it is quite necessary to have regular assessment and prediction of air quality. This will help in providing database to prevent and minimize the deterioration of air quality in the study area. Vehicular pollution dispersion models have been used world over for regulatory purpose. In India various roads and highway project carry out the air dispersion modeling to predict the future air quality and air quality trends to make an effective air quality management plan along the proposed corridor. The present study highlights the application of CALINE4 model for air quality management purpose along the road/ highway corridor(s). The R² value indicated fairly good relationship between observed and predicted value(s). Model performance statistical indicators show that air pollution dispersion
model could be used for predictions the future air quality. As any model’s accuracy depends upon accuracy of various input parameters therefore the air pollution/vehicular pollution dispersion model can become an effective tool for air quality management if the model is provided with accurate input parameters. Thus, the present CO prediction indicates that along an urban highway corridor (without street canyon effect) can be performed satisfactorily using CALINE4 model under Indian meteorological and heterogeneous traffic conditions. Moreover, accurate prediction capabilities and user-friendly nature of CALINE4 model could make it an effective tool for vehicular pollution management in urban road corridors in Indian cities. The CALINE4 dispersion model results show that the predicted values are in between the observed highest average and lowest average hourly values. Predictions through CALINE4 model are in good agreement with the observed values.

REFERENCES


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