Comparative study of line source models for estimating lead levels due to vehicular traffic in Delhi


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ABSTRACT:

Studies concerning the concentration of lead (Pb) in Delhi due to vehicular traffic are being conducted under sponsorship of Ministry of Environment and Forests, Government of India. The comparison of results of two line source models based on Gaussian formulation are made with observed lead values at 13 busy intersections in Delhi.

Results have been obtained based on predicted emission rates of lead from vehicular traffic over next 10 years. Each year the number of vehicles has increased e.g. it has doubled during the last 5 years.

Two types of studies have been made:

i) Hourly lead concentrations due to vehicular traffic in Delhi have been computed using two analytical line source models (IIT and ISCST) are based on the Gaussian plume approach.

ii) Monthly average lead concentrations for the period 1985-2000 have been computed by use of the Climatological Dispersion Model (CDM) and the Industrial Source Complex Long Term (ISCLT) model, both of which are U.S. operational models.
Models results show that three-monthly averaged Pb levels due to an increasing trend in vehicular traffic in Delhi sometimes exceed the US EPA standard (i.e., 1500 ng m\(^{-3}\), Federal Register (US EPA) 1971, 1978). Because, there is no Indian standard for ambient concentration of lead, hence the USEPA standard was used. Accordingly, a strategy needs to be developed for reducing lead emissions from the rapidly increasing vehicular traffic, which is the main source of Pb emissions. Information about vehicular traffic in Delhi over next 10 years indicates that the Government of India needs to introduce appropriate control measures on the emission of lead.

**KEY WORDS:**

Lead pollution, Vehicular traffic, Climatological Dispersion Model, Dispersion parameters, IIT Line Source Model.

**SOFTWARE AVAILABILITY:**

<table>
<thead>
<tr>
<th>Name of the Software</th>
<th>IIT Line Source Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact Address</td>
<td>DR (MRS) PRAMILA GOYAL</td>
</tr>
<tr>
<td></td>
<td>Centre for Atmospheric Sciences</td>
</tr>
<tr>
<td></td>
<td>Indian Institute of Technology</td>
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<td></td>
<td>New Delhi - 110 016, INDIA</td>
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<tr>
<td>Telephone, Fax and E-mail numbers</td>
<td>666979 (Ext. 6054),</td>
</tr>
<tr>
<td></td>
<td>11- 6862037</td>
</tr>
<tr>
<td></td>
<td>tkrishna @ cas.iitd.ernet.in</td>
</tr>
<tr>
<td>Year first available</td>
<td>1993</td>
</tr>
<tr>
<td>Hardware Required</td>
<td>PC/80</td>
</tr>
<tr>
<td>Software required</td>
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</tr>
<tr>
<td>Program Language</td>
<td>Fortran 77</td>
</tr>
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INTRODUCTION

Lead is very old and versatile metal. It is naturally present in the environment. It has been known to man and used in a wide variety of application for thousand of years. Lead is added to gasoline as an antiknock compound. In India, tetra ethyl lead is added to the gasoline. Vehicular emission has been increasing steadily during the past two decades. The increase has been particularly marked in the number of two stroke engine powered scooters, motor cycles and three wheelers.

The use of lead in gasoline has been banned in several countries, including Japan, America and the Russia. The decision of the Ministry of Petroleum and Natural Gas, Government of India to caution oil refineries to reduce the lead content in petrol has come at a crucial time (Ref : International Lead and Zinc study 1990).

* The major source of airborne lead in urban areas is exhaust from gasoline fueled vehicles. Lead is emitted from gasoline fueled vehicles as organic and inorganic compounds. Inorganic lead is emitted with exhaust gases in particulate form. The half life of lead aerosol (inorganic) is about 7-30 days * (Parker Albert, 1978).

Several models have been suggested to predict pollutant concentrations near roadways, which are considered as line sources. A line source model, based on Gaussian formulation has been developed in IIT Delhi, i.e. the IIT Line Source Model, in which improvements have been made in the calculation of source strengths at major intersections in the city by consideration of vehicular speed as well as acceleration / deceleration and idling emissions. The two line source models which have been used for present studies are the IIT Line Source Model and the ISCST Line Source Model. Predictions from these models are compared against observed lead values.

Keeping in view the main objective of the investigation, on the basis of projections of vehicular traffic in Delhi over the few years (Table 1), a long term study of Pb concentration on a yearly basis has been made. The CDM and the ISCLT Line Source models have been used to make three monthly simulations of Pb concentrations. Three months, i.e., December, January and February in each year from 1984-85 to 1999-2000 have been chosen as the representative period. It is assumed that these three months have the maximum concentration over the year. Observations of monthly concentrations of Pb are believed to be not available anywhere in the literature as well as from the local monitoring groups.

MODELS CHARACTERISTICS

In the present work four models namely IIT Line Source (IITLS) model, Industrial Source Complex Short Term

Table 1: Lead emission rates in gs⁻¹.

<table>
<thead>
<tr>
<th>Year</th>
<th>Emission rate (gs⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985-86</td>
<td>9.80</td>
</tr>
<tr>
<td>1986-87</td>
<td>11.57</td>
</tr>
<tr>
<td>1987-88</td>
<td>15.10</td>
</tr>
<tr>
<td>1988-89</td>
<td>18.68</td>
</tr>
<tr>
<td>1989-90</td>
<td>32.80</td>
</tr>
<tr>
<td>1990-91</td>
<td>49.00</td>
</tr>
<tr>
<td>1991-92</td>
<td>52.20</td>
</tr>
<tr>
<td>1992-93</td>
<td>54.40</td>
</tr>
<tr>
<td>1993-94</td>
<td>27.40</td>
</tr>
<tr>
<td>1994-95</td>
<td>29.60</td>
</tr>
<tr>
<td>2000-</td>
<td>39.70</td>
</tr>
</tbody>
</table>

(Source: Central Pollution Control Board, New Delhi)
(ISCST) and Industrial Source Complex Long Term (ISCLT) line source models and Climatological Dispersion Model (CDM) have been used for short term and long term Pb concentration over Delhi. The description of models are as follow:

IIT Line Source (IITLS) Model

The concentration due to line source along the x-axis at ground level (Wark and Warner, 1985) is given by the expression

\[ c(x,0,0) = \frac{2q}{(2\pi)^{1/2}a_y \sin \phi} \times \exp \left[ -\frac{1}{2} \left( \frac{H}{\sigma_v} \right)^2 \right] \times \int_{p_1}^{p_2} \frac{1}{(2\pi)^{3/2}} \exp \left( -\frac{P^2}{2} \right) dp \]  

Where 
\[ q = \text{source strength (gm}^{-1}s^{-1}) \]
\[ u = \text{mean wind speed (ms}^{-1}) \]
\[ \phi = \text{angle between line source and the wind direction, } \sin \phi \text{ term is omitted when } \phi < 45^\circ \]
\[ p_1 = \frac{y_1}{\sigma_y} \]
\[ p_2 = \frac{y_2}{\sigma_y} \]
\[ y_1 \& y_2 = \text{edges of the roads,} \]
\[ \sigma_y = \text{Horizontal Dispersion parameter (m)} \]
\[ \sigma_z = \text{Vertical Dispersion parameter (m)} \]
\[ h = \text{source height (m)} \]

The dispersion parameters \( \sigma_y \) and \( \sigma_z \) have been obtained for pasquill classification of stability classes using Brigg's (1973) formula for urban areas. The integral in Eq. (1) has been integrated numerically between the limits \( p_1 \) and \( p_2 \). The source height has been taken as 0.2m same as the height of tail pipe of the vehicles. It is important to note that the source strength is a key parameter of the model. Its method of estimating source strength is specific to this model, which is described below in detail.

**SOURCE INVENTORY:**

Accurate air quality modelling requires an elaborate source emission inventory. Gasoline fueled vehicles, such as cars / taxis and two / three wheelers, are the major sources of airborne lead in urban India. The most crucial parameter of the model is source strength, which can be estimated in the following ways:

i) Direct experimental measurements of exhaust emission from a typical sample of vehicles and interpolation to the number of vehicles crossing the city. Lead emission estimates for Delhi in 1991 were compiled by the Central Pollution Control Board, Delhi. The figure obtained was 53.2 tonnes/year. (CPCB's report, 1991)

ii) By combination of daily fuel consumption with the weight of Pb emitted per gm of fuel consumed. In Delhi, lead content per liter of petrol is 0.18g, as reported by Oil Coordination Committee, Ministry of Petroleum and Natural Gas, Government of India (1983).

iii) From total vehicular population and average distance travelled per vehicle and from total motor fuel consumption per day and average distance of travel per liter of fuel. These values produced an emission rate \( q \) (gs\(^{-1}\) m\(^{-1}\)) as follows.

Emission rate \( q \) is determined from the product of emission rates per vehicle times the number of vehicles per unit length. The latter quantity is found by dividing the rate of vehicle passage through a point by vehicle average speed:

\[
\text{Vehicle per meter} = \frac{\text{Flow(vehicles/hr)}}{\text{Averagespeed(mi/hr)}} \times \frac{1600}{1600} 
\]

Extra lead emissions generated due to acceleration/
deceleration and idling are also taken into account for various vehicle types at busy intersection as follows:

The lead content per liter of petrol was 0.18g. About 70% of the lead supplied to the engine comes out of the tailpipe, while the rest is deposited in the engine combustion chamber and exhaust system (IIP report, 1985).

Therefore, Pb emissions per liter of petrol amount to 0.18g x 0.70 = 0.126g. It is assumed that the cruising speed for two/three wheelers is 35 km hr⁻¹ and

Fig. 1: Gridded Source inventory of Delhi.
they run for an average of 35 km\(^{-1}\) of petrol. So cruising emission (Cs) = 35 \(\mu g \text{s}^{-1} \text{vehicle}^{-1}\).

In case of cars/ taxis, it is assumed that the cruising speed is 40 km hr\(^{-1}\) and that they run at an average of 12 km\(^{-1}\) of petrol. So, Cruising emission (Cs) = 116.66 \(\mu g \text{s}^{-1} \text{vehicle}^{-1}\),
Idling emission = 9 Cs, and emission during acceleration/deceleration = 4 Cs. (Source: User's guide for Intersection Midblock Model (IMM))

A gridded source inventory has been developed over an area of 20 x 24 km\(^2\) in Delhi. This area is divided into 30 grids, with a grid size of 4 x 4 km\(^2\) as shown in Fig. 1. There are 13 major traffic intersection in Delhi at which lead emission was calculated by taking into account emissions due to deceleration, idling and acceleration of MTV (Medium Tonnage Vehicles e.g. car, Taxi) and LTV (Lower tonnage vehicles e.g. motor cycle, scooter, auto-rickshaw). Total lead emission was calculated by addition of the emission at the 13 intersections.

As the total generation of lead in Delhi due to vehicular traffic is known, the generation of lead in the 30 grids due to cruising can be calculated by subtraction of the total lead emitted at the 13 intersections.

The locations of the 13 major intersections are marked in the grid on the map of Delhi (Fig. 1) and emissions are added to the cruising emissions in that grid. Finally the source value of lead in each grid (Fig. 2) considering acceleration/ deceleration, idling and cruising is calculated.

The required meteorological input data of IIT Line Source model includes, Hourly Windspeed, Wind direction, Stability and Mixing Height.

Models characteristics are available in Industrial Line Source model's User's Guide Volume 1 and 2, by Bowers et. al. (1979).

Climatological Dispersion Model (CDM): Model's characteristics is available in User's Guide for CDM by Busse et.al. (1973). ISCST, ISCLT models and CDM are available as part of UNAMAP (Version 6) magnetic tape.

**MODEL EVALUATION**

A number of methods have been proposed to compare air quality models (Kumar et.al, 1991). To determine if one model is significantly better than another, it is necessary to use performance measures. Performance measures estimate the discrepancy between predictions and observations. In this paper, the following 5 statistical performance measures were used to compare the two line source models:

(i) Root Mean Square Error (RMSE)
(ii) Fractional Bias (FB)
(iii) Index of Agreement (IOA)
(iv) Normalized Mean Square Error 1 (NMSE 1)

NMSE_1 = \frac{(C_p - C_o)^2}{C_p \cdot C_o}

The value of NMSE 1 should generally be zero for a perfect model.

(v) Normalized Mean Square Error 2 (NMSE 2)

NMSE_2 = \frac{(C_p - C_o)^2}{C_o^2}

The smaller the value of NMSE 2, the better the performance of the model.

RESULTS AND DISCUSSION

The IIT and ISCST Line Source Models were used for estimating hourly Pb concentrations for 10 hours at the following 13 intersections for the month of January 1984: Raja Garden, Dhaula Kuan, R.K. Puram Xing, AIIMS, Mool Chand, Ashram, India Gate, Delhi Cantt., Yamuna Bazar, Red fort, Zakira, Motinagar and Azadpur. The averaging period (10 hrs), the month of January and the above receptor points were chosen based on the availability of observed Pb concentrations. It is also assumed that in the hours 8 am to 1 pm and 2 pm to 7 pm, the traffic is maximum. Table 2 shows the comparison of hourly averaged observed and predicted concentrations of lead at these stations for January 1984. Contributions from all the roads at the location of their intersections (receptor sites) were considered. All the thirteen intersections are situated within busy traffic areas with a constant flow of traffic throughout the day.

The overall correlation between observed and predicted Pb concentration is encouraging. It is worth noting that Pb concentrations obtained from IIT Line
Table 2: Comparison of 10 hourly averaged lead concentration of IIT and ISCST Line Source models for the month of January 1984.

<table>
<thead>
<tr>
<th>Intersection</th>
<th>IIT Prediction (ngm(^3))</th>
<th>ISCST prediction (ngm(^3))</th>
<th>Observed values (ngm(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raja Garden</td>
<td>472.6</td>
<td>310.0</td>
<td>385.0</td>
</tr>
<tr>
<td>Dhaula Kuan</td>
<td>698.7</td>
<td>450.0</td>
<td>559.0</td>
</tr>
<tr>
<td>R.K. Puram Xing</td>
<td>498.2</td>
<td>220.0</td>
<td>395.0</td>
</tr>
<tr>
<td>AIIMS</td>
<td>585.0</td>
<td>310.0</td>
<td>450.0</td>
</tr>
<tr>
<td>Mool Chand</td>
<td>1982.2</td>
<td>1100.0</td>
<td>1802.0</td>
</tr>
<tr>
<td>Ashram</td>
<td>505.5</td>
<td>288.0</td>
<td>395.0</td>
</tr>
<tr>
<td>India Gate</td>
<td>693.8</td>
<td>380.0</td>
<td>514.0</td>
</tr>
<tr>
<td>Delhi Cantt.</td>
<td>656.7</td>
<td>410.0</td>
<td>571.0</td>
</tr>
<tr>
<td>Yamuna Bazar</td>
<td>514.8</td>
<td>205.0</td>
<td>390.0</td>
</tr>
<tr>
<td>Red fort</td>
<td>951.4</td>
<td>410.0</td>
<td>670.0</td>
</tr>
<tr>
<td>Zakira</td>
<td>634.9</td>
<td>205.0</td>
<td>481.0</td>
</tr>
<tr>
<td>Motinagar</td>
<td>765.8</td>
<td>310.0</td>
<td>563.0</td>
</tr>
<tr>
<td>Azad pur</td>
<td>844.2</td>
<td>280.0</td>
<td>603.0</td>
</tr>
</tbody>
</table>

Source Model are overpredicted as compared to observed concentrations. This is possibly due to a lack of sufficient information regarding the idling and acceleration/deceleration at busy intersections. On the other hand, the ISCST Line Source Model underestimates the observations at all 13 locations. It is important to note that source strength is a key parameter in these calculations. In the ISCST model, source strength is estimated with the assumption of an area rather than a line source. As a result, source strength is diluted, which leads to underprediction. Source inventories are different in the two models. Hourly Pb emission rates have been estimated from annual emission, which is not an accurate way of finding hourly emission rate. Model’s prediction accuracy is lost by these approximations.

From Fig. 3 it can be seen that maximum Pb concentrations occur during the peak traffic hours (10 am to 12 noon and 5 pm to 6 pm). Model results during these periods also show maximum values. The prediction pattern from both the models are also consistent with the diurnal variation of normalized traffic density. Model Pb concentrations in Delhi always range from 350 to 800 ng m\(^3\), whereas Central Pollution Control Board’s (CPCB) observed values lie between 300 and 600 ng m\(^3\). The deviations from observed concentrations are always within acceptable limits quoted by Hanna et al. (1982). Their criterion for assessing model performance is that the natural variability of predicted deviations must be within a factor of 2-3 times the actual values. Although predicted values from both the models are higher than the corresponding observations, they remain within a factor of two.

Statistical measures provide the means for comparing model performance. According to the desired
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values of the statistical measures for a good model, the IIT Line Source Model ranks better than the ISCST Line Source for three out of five measures (Table 3).

The CDM and ISCST Line source models have been used to obtain 3-monthly averaged Pb concentrations at Red Fort, a major traffic intersection and model's predicted values have been compared with ambient air quality standards (WHO, 1992). Figure 4 compares yearly Pb concentrations with its yearly emission rates. It can be easily seen that the trend of yearly Pb emission and Pb concentrations are similar. Meteorological data were available only for years 1984-1990, as such data for the years 1991 onwards were not available at the time of these model calculations. The climatological averaged data of last five years (1985-1990) is thus used as input data for the years 1991 onwards.

Figure 4 shows that model results from both the CDM and ISCST Line Source model for 1984 to 1991 never exceed the US EPA standard, but in the year 1992-93, values are exceeding the US EPA standard (1500 ng m⁻³). Again from 1993-94 onwards, model predictions never exceed US EPA standards, since during that period Pb emission has been reduced due to adoption of pollution control measures.

It is worth pointing out at this juncture that the concentrations obtained from the CDM model are grid square averages. In order to take into account the effect of traffic on each road within a 4 km x 4 km grid, source strength is assumed concentrated at the centre of the grids. Depending upon the traffic on each of these roads, a representative average value of the source strength is

| Table 3: Statistical measures of two line source models. |
|-------------|-------------|-------------|
| Measure     | IIT Model   | ISCST Model |
| RMSE        | 1.12        | 1.568       |
| FB          | 0.24        | -0.11       |
| IOA         | 0.0023      | 0.0834      |
| NMSE 1      | 0.061       | 0.33        |
| NMSE 2      | 0.056       | 0.152       |

Fig. 3: Diurnal variation of Pb concentrations from IIT and ISCST Line Source Models and normalized hourly traffic pattern.

Fig. 4: Yearly Pb concentrations from CDM and ISCST models and Pb emission rates.
obtained at each grid. Each square grid has been treated as an area source in CDM. It might be better to use line source, but the area source assumption saves computer time. In Figure 4, a minimum concentration of Pb is shown in the year 1984-85, which is understandable in the case of minimum value of emission rate of Pb. In broad terms, the performance of ISCLT (Line source model) is more or less the same as that of CDM (Fig. 4).

6. CONCLUSIONS

The present study concerning the concentration of lead (Pb) in Delhi due to vehicular traffic, is based on a projection of the requirements of vehicular traffic in Delhi over the next ten years.

It may be mentioned here that in Delhi, major source of lead is the vehicular emission. In out skirts of Delhi, there were some unauthorized lead smelting units but these have been closed. The steady increase of gasoline operated vehicles in Delhi has resulted in increase in gasoline consumption and ambient lead concentration. Hence, new strategies should be undertaken to reduce ambient emissions to a safe and accepted level.

From Fig. 4, It is evident that lead concentration due to vehicular traffic alone may exceed even the US EPA standard i.e. 1500 ng m\(^{-3}\). Lead emitted from the stacks of fossil- fuel burning (Lee, et. al, 1973) power plants will be an additional load in the air environment of Delhi. Hence the burden of lead in the environment of Delhi should be regulated.

Both the Line Source Models and the Climatological Dispersion Model (CDM) are Gaussian plume models. The Line Source Model overpredicts concentration levels in comparison to observed concentrations, possibly due to the lack of sufficient information regarding source emissions. Similarly, CDM uses Pasquill- Gifford (1961) curves for evaluating \(a\) & \(b\) in the dispersion formula \(\sigma_v = ax^b\). Dispersion formulations based on parameters determined from field tracer experiments conducted in mid-latitudes may not be tenable in the tropical atmosphere, where dust tends to interfere with both outgoing and incoming radiation. More data may help to resolve these gestations.

The analysis of the relevant statistical parameters (Table 3) shows that the performance of IIT Line Source Model against observations is better than the ISCST Line Source Model, which is a US operational model.

The main reason for the high lead content in the air is the quality of Indian petrol. The Petroleum and Environment Ministries have proposed to reduce the lead content in petrol from 0.56 to 0.15 grams per liter. This will further reduce the pollution levels in the city.

Acknowledgement:

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