*Pollution, 2(4): 449-460, Autumn 2016*
DOI: 10.7508/pj.2016.04.007
Print ISSN 2383-451X Online ISSN: 2383-4501
Web Page: https://jpoll.ut.ac.ir, Email: jpoll@ut.ac.ir

# Modeling for vehicular pollution in urban region; A review

**Kumar, A.***

Centre for Environmental Science and Engineering, Indian Institute of Technology, Bombay, Mumbai-400 076, India

Received: 30 Apr. 2016 Accepted: 9 May 2016

**ABSTRACT:** Air pollution is one of the major threats to environment in the present time. Increase in degree of urbanization is a major cause of this air pollution. Due to urbanization, vehicular activities are continuously increasing at a tremendous rate. Mobile or vehicular pollution is predominantly degrading the air quality worldwide. Thus, air quality management is necessary for dealing with this severe problem. The first step to deal with this air pollution problem is to find out the existing concentration of air pollutants in the atmosphere due to vehicular activities. It is not possible to establish ambient air monitoring stations everywhere, especially in developing countries as it is a costly process. Hence, vehicular air quality models are used to predict the concentration of different pollutants in the atmosphere. This review covers the simulation of vehicular emission by different types of models for estimating the pollutant concentration in ambient air from vehicular emissions. The models predict concentrations of pollutants in time and space and relate it to the dependent variables. These can also be used to predict the concentration of pollutants in the future. These models can be useful for imposing regulations by governments and to test techniques for controlling pollutant emissions. This review also discusses where and how the respective models can be used.

**Keywords:** air pollution, air quality dispersion model, vehicular pollution modeling.



## INTRODUCTION

Development in terms of industrialization and vehicular growth causes severe air pollution (Fenger, 2009). With technological advancement humans have progressed and, hence, the number of vehicles is continuously increasing (Sivacoumar and Thanasekaran, 1999). Vehicles cause various pollutants like dust, fumes, gas, mist, odor, smoke or vapor to enter the atmosphere. These contaminants are emitted in a quantity which is sufficient to affect humans, plants or animals adversely (CPCB, 2001). Many studies reported that air pollution is causing a major health impact in urban cities of the world (Brandt et al., 2013; Cassidy et al., 2014; Fridell et al. 2014; Guttikunda and Goel, 2013; Ilyas et al., 2010; Kampa and Castanas, 2008; Kan et al. 2009, 2012; Krewski and Rainham, 2007; Kristiansson et al., 2015; Lai et al., 2012; Maantay, 2007; Mokhtar et al., 2014; Pandey et al., 2005; Patankar and Trivedi, 2011; Rao et al., 2013; Sellier et al., 2014; Spickett et al., 2013; Srivastava and Kumar, 2002; Whitworth et al., 2011). Most of today's cars and trucks use gasoline or other fossil fuels which burn in internal combustion engines. This burning of gasoline or other fossil fuels leads to air pollution as various emissions are released into the atmosphere.

* Corresponding author Email: awkash.narayan@gmail.com, Mobile: +7208246617, Fax: +22-2576-4650

The primary source of vehicular pollution is the pollutants that are directly released from the tailpipes of cars and trucks into the atmosphere.

Air Pollution Control Office of the U.S. EPA started many programs to lead the traffic pollution issues after 1960 (Fensterstock et al., 1971). In order to make assessments related to the extent and type of the pollutants, modeling is required. Air quality modeling tool assesses the present and future air quality and source contribution (Banerjee et al., 2011; Coelho et al., 2014; Gulia et al., 2015; Jiang et al., 2013; Jiménez-guerrero et al., 2007; Jin and Demerjian, 1993; Kesarkar et al., 2007; Ma et al., 2013; Marquez and Smith, 1999; Martins, 2012; Ozkurt et al., 2013; Ritter et al., 2013; Syrakov et al., 2015; Zhang et al., 2014). Vehicular pollution modeling in any region is the air pollution estimation that is caused by the vehicular activity. For the purpose of predicting concentration of pollutants near roads or highways, various models have been suggested. These air quality models can be used for predicting concentration of pollutants in ambient air due to point sources like stacks, area sources like multiple fuel gas stacks or line sources like roadways (Thaker and Gokhale, 2015). For modeling vehicular pollutants in which pollutants are emitted continuously by vehicles, line source models are used (Singh and Gokhale, 2015). Other sources like area and/or point sources are also taken into consideration for urban environment. However, to find out the contaminant concentration due to existing or proposed highways/ roads, the highway dispersion models are used. These can find out the impact up to very large distances. Distance may be from ten meters to hundreds of meters. For air quality prediction analysis in the region of highways and roadways, the effect of vehicles on ambient air quality is considered to be of prime importance. These highway dispersion models are mostly based on Gaussian dispersion equation (Briggs et al., 2000; Barratt, 2000). Vehicular pollution model requires two kinds of input such as emission and meteorology, to provide concentration plots for pollutants.

Several studies were conducted to understand the vehicular emission under realistic driving conditions and other purposes where other sources were minimized (Alves et al., 2014; Brzezinski and Newell, 2000). Global emission projection was carried out for dust emission from exhaust of on-road vehicles under many programs such as four commonly-used global fuel use scenarios from 2010 to 2050 and improvements on regional air quality (Yan et al., 2014; Coelho et al., 2014). In India, emission inventary is prepared using a number of vehicles and emission factors developed by the Automotive Research Association of India (ARAI, 2007). Source apportionment and health impact assessment have also been carried out for vehicular emission using monitoring data (Cheng et al., 2013; Guttikunda and Goel, 2013; Fan et al., 2012).

## AIR QUALITY MODELS

Pollutants transport and dispersion in the atmosphere are described mathematically by models. Models are used to relate the causes and effects of pollutant levels found in different areas at different locations referred to as receptors. The number of monitors that one could afford to set up is far less than the number of receptors in a model. Therefore, models are a cheap way to analyze the concentration of pollutants over a wide spatial area. These models take into account the factors such as meteorology, topography, and emissions from nearby sources.

Vehicular pollution model is a combination of mathematical equations based on physical principles. These estimate pollutant concentration for different types of emissions and meteorological conditions in space and time. Vehicular models are called line source models. These models are very much effective for finding the concentration of pollutants at various locations and helpful for the estimation of the concentration of pollutants in the future. The available data, geography of the particular area and types of the pollution in the area play an important role in application of these models. These models are also used for the setting of emission standards, emission control techniques and strategies, and rational traffic management. Above all, these help in providing a cleaner environment to the living organisms.

**Air quality models can be developed for various purposes like:**

I. Determination of air quality
II. Framing of laws and fixing of emission standards
III. Land use and urban planning
IV. Optimization of control techniques and programs
V. Selection of sampling sites
VI. Planning for control of air pollution episodes

**Steps Followed for Air Quality Modeling**

I. Objectives
II. Identification of process/parameters
III. Model structure development and solution
IV. Calibration, verification and validation
V. Application of model

## VEHICULAR EMISSION DISPERSION MODEL

Vehicular dispersion model consists of many types which are based on box model or Gaussian Plume model. The discussions of the models are given below.

### Stanford research institute (SRI) model

This model was given by Johnson at Stanford Research Institute (Johnson, et al., 1971). It is known as SRI model. When the wind is parallel to the road, it adverts the pollutants down the road. When it crosses the road at an edge, a vortex or helical stream is produced within the road with speeds lower within the road and moderately higher downwind. As a result there are lower pollutant levels on the windward model. It represents the mechanical air movement brought on by traffic and work under calm conditions.

The concentration of leeward side ($C_L$) of the street is given by the equation:

$$C_L = K \frac{Q}{\left(u_r + 0.5\right)\left(\left[x^2 + z^2\right]^{\frac{1}{2}} + 2\right)} \qquad (1)$$

The concentration of windward side ($C_W$) is given by the equation.

$$C_W = K \frac{Q}{w\left(u_r + 0.5\right)}$$

when the wind is such that neither leeward nor a windward case is appropriate, an intermediate concentration ($C_I$) is found by taking the average of the results of the above equations:

$$C_I = \frac{C_L + C_W}{2}$$

Here, $u_r$ is the wind speed at rooftop, K is the diffusivity constant depending on the stability class, w is width of the traffic lane, x and z are the coordinates along wind and vertical respectively.

### Simple infinite line source

The general standard expression of plume model for ground level source

$$C\left(x, y, z\right) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left[\frac{-y^2}{2{\sigma_y}^2}\right] \exp\left[\frac{-z^2}{2{\sigma_z}^2}\right] \qquad (2)$$

The concentration of pollutants due to line source can be found out by integrating the above equation along y direction from $-\infty$ to $+\infty$. Assuming the line source is infinitely long and wind is perpendicular to roadway and the pollutants are transported along x-direction and dispersed in the z-direction, the model is as follows (Hanna et al., 1982):

$$C = \sqrt{\frac{2}{\pi}}\left(\frac{Q}{u\sigma_z}\right)\exp\left[\frac{-z^2}{2\sigma_z}\right]$$

**Finite line source model**

This model was presented by Casandy (1972) to overcome the problems by infinite line source model from Gaussian plume for point sources. This model is not applicable for calm conditions and appropriate just when the wind is perpendicular to the roadway.

$$C = \frac{Q}{\sqrt{2\pi}\sigma_z u}\left(\operatorname{erf}\left[\frac{L/2 - Y}{\sigma_y\sqrt{2}}\right] + \operatorname{erf}\left[\frac{L/2 + Y}{\sigma_y\sqrt{2}}\right]\right) \quad (3)$$

where,

C = concentration in g/m $^3$

Q = Line source strength in g/m/sec

L = length of the upwind segment in m

Y = perpendicular distance along the line source in m

u = average speed of wind in x-direction in m/sec.

**General finite line source model (GFLSM)**

The General Finite Line Source Model considers co-ordinate transformation (Luhar and Patil, 1989). It assumes that there are two co-ordinate systems, one is wind co-ordinate system and the other is line source co-ordinate system. Co-ordinate system of wind is presented by $x_1$, $y_1$, $z_1$ and co-ordinate system of line source is represented by x, y, z.

- **Development of GFLSM**

The essential way to deal with this model is the co-ordinates change among the wind co-ordinate ($x_1$, $y_1$, $z_1$) and the line source coordinate (x, y, z). Consider the lengths of the street way as L and making an angle of $\theta$ with the wind vector. The point of center of the line source is taken as origin for the two directions which have the common z-axis. The line source is along the y-axis and the wind vector is along the direction of $x_1$. In the co-ordinate of line source, every one of the parameters namely x, y, z and L are known by the street receptor geometry.

It assumes a hypothetical line source along $y_1$ direction such that wind is in perpendicular direction to it. The concentration of pollutants at receptor R caused by this model is given by

$$C' = \frac{Q}{2\sigma'_z\,\sigma'_y\,u_e\sqrt{2\pi}}\left[\exp\left(-\frac{1}{2}\left\{\frac{Z-H}{\sigma'_z}\right\}^2\right) + \exp\left(-\frac{1}{2}\left\{\frac{Z+H}{\sigma'_z}\right\}^2\right)\right] \times \int_{-L/2}^{L/2} \exp\left[-\frac{1}{2}\left(\frac{y'_1 - y_1}{\sigma'_y}\right)\right] dy'_1 \quad (4)$$

where,

Q = source emission rate per unit length

Z = Height of the receptor above the ground

H = Height of the line source

u = Mean ambient wind speed at source height H

$\sigma_z{}'$ = vertical dispersion coefficient and

$\sigma_y{}'$ = horizontal dispersion coefficient and both are functions of distance $x_1$ and stability class. The prime symbol (‘) indicates the parameters in wind coordinate system.

Equation (4) is in first coordinate and parameters which are not in this coordinate are transformed in the function of line source coordinate. The relationship between wind coordinate system and line source coordinate system is given by:

$$x_1 = x\sin\theta - y\cos\theta$$

$$y_1 = x\cos\theta + y\sin\theta$$

Line source is considered to be along the y- axis and

$$dy_1' = \sin\theta dy'$$

Rate of emission per unit length is given by Q in the wind coordinate system. It needs to be converted in the coordinate system of line source where it would become Q/sinθ because of the transformation of the length unit, such that the apparent length of the source Q is multiplied by the factor $1/\sin\theta$ because of the obliquity of the source.

Substituting the value $y_1$', $y_1$, $x_1$, $dy_1$', including the source correction in Equation (4), the following equation is formed:

$$C' = \frac{Q}{2\sigma_z\sigma_y u_e\sqrt{2\pi}}\left[\exp\left(-\frac{1}{2}\left\{\frac{Z-H}{\sigma_z}\right\}^2\right)+\exp\left(-\frac{1}{2}\left\{\frac{Z+H}{\sigma_z}\right\}^2\right)\right]\times \int_{-L/2}^{L/2}\exp\left[-\left(\frac{(y'_1\sin\theta - x\cos\theta - y\sin\theta)^2}{2\sigma_y^2}\right)\right]\sin\theta dy' \tag{5}$$

Here $\sigma_y$ and $\sigma_z$ are the downwind distance functions which are given by $x/\sin\theta$ and stability class. One sided normal cumulative distribution function is obtained from error function properties and definition.

$$\int_{f_1}^{f_2}\exp(-t^2)dt = \frac{\sqrt{\pi}}{2}\left[erf(f_2) - erf(-f_1)\right].$$

Hence Equation (5) becomes:

$$C = \frac{Q}{2\sigma_z\sigma_y u_e\sqrt{2\pi}}\left[\exp\left(-\frac{1}{2}\left\{\frac{Z-H}{\sigma_z}\right\}^2\right)+\exp\left(-\frac{1}{2}\left\{\frac{Z+H}{\sigma_z}\right\}^2\right)\right]\times \left[erf\left(\frac{\sin\theta\left\{L/2 - Y\right\} - x\cos\theta}{\sigma_y\sqrt{2}}\right)\right] + \left[erf\left(\frac{\sin\theta\left\{L/2 + Y\right\} + x\cos\theta}{\sigma_y\sqrt{2}}\right)\right] \tag{6}$$

where,

$u_e$= $u\sin\theta + u_o$

$u_o$= accounts for dispersion which is lateral and concentration divergence when wind speed coming towards zero (calm condition, Luhar and Patil, 1989).

**General motor (GM) model**

GM model was developed by Chock (1978). It is used in line source approach which is finite and one parameter of dispersion is mentioned as a distance function from line source and wind road oriented angle. Importantly, it considers plume rise over the roadways which are in very stable and low wind conditions.

The concentration C at point (x,y) at y = 0 for line source is given by

$$C = \frac{Q}{U_e\sigma_z\sqrt{2\pi}}\left(\exp\left[-\frac{1}{2}\left(\frac{z+h_0}{\sigma_z}\right)^2\right]\exp\left[-\frac{1}{2}\left(\frac{z-h_0}{\sigma_z}\right)^2\right]\right) \tag{7}$$

where,

$h_0$ = height of the plume centre above the ground

The effective wind speed is given by

$U_e$ = $u\sin\theta + u_o$

$u_o$= correction factor for speed of wind due to traffic wake

$U_e$ = effective wind speed in m/sec.

The plume centre height is $h_o = H + h_p$

where H is height of line source and $h_p$ is the plume rise.

**EPA HIWAY model**

In EPA HIWAY Model (Petersen, 1980), a highway is considered in which limited point sources are assumed. The total contribution due to all these points is found out by taking out the integral of the equation of point source by Gaussian for a limited length L and incremental length of dl, as given by:

$$C = \frac{ql}{u}\int fdl \tag{8}$$

If the condition is stable or if the height of mixing is more than or same as 5000 m then

$$f = \frac{1}{2\pi\sigma_y\sigma_z}\exp\left\{-\frac{y^2}{2\sigma_y{}^2}\right\}\left[\exp\left\{-\frac{(z-H)^2}{2\sigma_z{}^2}\right\}+\exp\left\{-\frac{(z+H)^2}{2\sigma_z{}^2}\right\}\right] \tag{9}$$

As the mechanical mixing is significant over the street, some beginning estimations of the vertical scattering and horizontal scattering parameters are assumed by displacement of the point source a virtual separation upwind.

Integral is calculated by approximating by the trapezoidal rule and gives:

$$C = \frac{qdl}{u}\left\{\frac{f_1+f_2}{2}+\sum_{i=1}^{n-1} f_i\right\}$$

where $f_i$ is evaluated from equation (9) for $l+dl$.

**California line source model**

Separate equation for the calculation of concentrations of pollutants under crosswind and parallel wind conditions is used by the California model (Miller and Clagget, 1978). Pollutant concentration is calculated by the model in the crosswind case by considering that the dispersion is dependent on the atmospheric stability and turbulent mixing cell is considered above the highway.

- **CALINE 3 Model**

California Line Source Model Version 3 (CALINE-3) is an air quality model for line source. It is a third generation model established by California Department of Transportation (Benson, 1992). It depends on the equation of diffusion by Gaussian and utilizes a mixing zone idea to describe scattering of pollutants over the streets. Each highway links are joined in a progression of components and incremental concentration is calculated. After that this model adds all to get total pollutant concentration on a specific receptor area. The distance of receptor is a perpendicular distance between receptor and the highway centerline. Squares of sides same as that of highway width are taken as the first element formed at the very first point.

With the distance from the receptor, resolution of element becomes less important. In order to permit efficiency in computation the element is made larger. Each component is taken as a "proportionate limited line source" situated normal to the direction of wind cantered in the mid-point of element. A local x, y co-ordinate framework adjusted to the direction of wind and beginning at the component mid-point is characterized for every component. The emission occurring within the element is modeled using the cross finite line source Gaussian equation. The concentration due to source segment of length *dy* is

$$\mathrm{dc} = \frac{\mathrm{qdy}}{2\pi\mathrm{u}\sigma_{\mathrm{y}}\sigma_{\mathrm{z}}}\left[\exp\frac{-\mathrm{y}^2}{2\sigma^2{}_{\mathrm{y}}}\right]\left[\exp\frac{-(\mathrm{z}-\mathrm{H})^2}{2\sigma^2{}_{\mathrm{z}}}+\exp\frac{(\mathrm{z}+\mathrm{H})^2}{2\sigma_{\mathrm{z}}{}^2}\right] \tag{10}$$

where,

$\sigma_y, \sigma_z =$ diffusion coefficient in x and y direction in m.

u = the velocity of wind at effective release height m/sec

q= the line source strength in µg/m/sec

H= the effective height of source in m

dy = the length of source segment in m
dc = the concentration of the source segment dy at receptor (x,y,z) in μg/$m^3$.

In CALINE-3, region directly above the road is treated as a region where the emission is uniform. It defines the zone of mixing as the region above the travelled path including 3 m (approximately two-vehicle width) on either side. The initial horizontal dispersion is accounted by the additional width imparted to the pollutant by the vehicular wake. The model considers pollutants to be inert. So it does not consider the atmospheric reactions of $NO_x$ (Benson, 1979).

**AERMOD**

The AERMOD air dispersion model is USEPAs official "Appendix A" air dispersion model for regulatory use and was developed by the AERMIC (The American Meteorological Society/EPA Regulatory Model Improvement Committee) work group (Cimorelli et al., 2004). It is a steady-state plume model. In the stable boundary layer (SBL), it assumes the concentration distribution to be Gaussian in both the vertical and horizontal. In the convective boundary layer (CBL), the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function (pdf).

AERMOD aims at modeling short-range (up to 50 km) dispersion from a variety of polluting sources (e.g., point, area, and volume sources) using a number of model configurations. These configurations include different sets of urban or rural dispersion coefficients as well as simple and complex topography. The model has the capacity to employ hourly sequential pre-processed meteorological data to estimate concentrations of pollutants at receptor locations at different time scales ranging from 1 h to 12 months. AERMOD is an advanced plume model that incorporates updated treatments of the boundary layer theory, understanding of turbulence and dispersion, and includes handling of terrain interactions.

It has two pre-processors AERMET and AERMAP. AERMET is a meteorological pre-processor that calculates meteorological parameters and passes them to AERMOD. AERMAP is a terrain pre-processor that calculates terrain elevations above mean sea level and passes them to AERMOD. It requires three kinds of input data such as emission (vehicles), geographical and meteorological data (hourly nine meteorological parameters). These hourly meteorological parameters include Wind Speed, Wind Direction, Ceiling Height, Rain Fall, Pressure, Humidity, Global Horizontal Radiation, Cloud Cover and Temperature. AERMOD has been applied in many case studies for vehicular pollution modeling (Kumar et al., 2015; Sonawane et al., 2012).

**Operational street pollution model (OSPM)**

The Operational Street Pollution Model (OSPM) (Aquilina and Micallef, 2003) was developed by the National Environmental Research Institute of Denmark, Department of Atmospheric Environment. It is an air pollution model which is used for foreseeing the scattering pollutants in ambient air in road canyons. This model has been utilized by various countries for more than twenty years for examining level of pollution due to traffic, performing investigations of field campaign estimations, considering effectiveness of contamination reduction techniques, and doing assessments of exposure. As compared to different models OSPM is cutting edge in traffic pollution modeling.

In OSPM amount of pollution due to traffic is ascertained utilizing a mix of two models. One is plume model for the contribution which is direct. Second is a box model for portion of pollutants which is re-circulated in the road. The $NO_2$ fixations are computed considering NO-

$NO_2$-$O_3$ science and the time of residence of contaminants on the road. This model is intended to work with the input information and then it gives one-hour averages. OSPM has been applied in many case studies for various purposes such as source contribution and health impact assessment in European cities (Aquilina and Micallef, 2004; Assael et al., 2008; Berkowicz et al., 2006; Berkowicz, 2000; Berkowicz et al., 2008; Hvidberg and Jensen, 2011; Kakosimos et al., 2010; Ketzel et al., 2012; Kukkonen et al., 2001, 2003). The comparison of the above various vehicular pollution models have been presented in Table 1.

**Table 1. Comparison of the vehicular pollution models**

| Model | Advantage | Disadvantage |
|---|---|---|
| SRI | SRI considered that the concentration is inversely proportional to the distance between the receptors and line source for leeward side of road while the method of Johnson et al. (1973) is used to estimate concentration for windward side. | The average values of the downward and windward may give less accurate concentration on both sides of the street for parallel or near-parallel synoptic winds. |
| Simple Infinite Line Source | Wind is perpendicular to roadway and the pollutants are transported along x-direction along the wind. | Line source considered infinite long. |
| Finite Line Source Model | Line source is finitely long. | Model is not applicable for calm conditions. |
| General Finite Line Source Model | This applicable for gaseous pollutants as well as particulate matter with modification. | It is not applicable for street canyon. |
| General Motor Model | Performs well for downwind dispersion of pollutants near the roadway. | Performs worse when the wind angle becomes small relative to the road. |
| EPA HIWAY Model | Model works fairly well under unstable conditions at the pedestrian level downwind from the road. | Performs worse when the number of traffic lanes increases |
| California Line Source Model | It can estimate concentration 500 m from the roadway and special options for modeling air quality near street canyons, intersections and parking facilities provided. | Region considered as a zone of uniform emissions and turbulence. |
| AERMOD | It has introduced planetary boundary layer concept with stable and convective boundary layer concept. | It does not consider building height for recirculation of pollutants. |
| Operational Street Pollution Model | Concentration of exhaust gases is calculated based on plume model for the direct contribution and based on box model for the recirculating part of the pollutants. | Ventilation can be limited by the presence of a downwind building if the building intercepts one of the edges. |



## CONCLUSIONS

A review of various vehicular emission modeling is carried out and compared in this paper. It includes vehicular dispersion models like box model and Gaussian Plume Model. Stanford Research Institute (SRI) model is based on box model while simple infinite line source, finite line source, general finite line source, EPA HIWAY, CALINE and AERMOD are based on Gaussian Plume model. SRI model is used for representing the mechanical air movement brought on by traffic. Simple Infinite Line Source Model considers the Gaussian plume equation and integrates it for infinite length along y-direction. Finite Line Source Model is not applicable for calm condition and is used only when the wind is perpendicular to the roadway. However, there is no such limitation in General Finite Line Source Model as it considers co-ordinate transformation. General Motor model considers plume rise over the roadways under very stable and low wind conditions. EPA Highway model is a highway dispersion model which considers a finite number of point sources on the highway. CALINE 3 is used for finding dispersion of pollutants due to multiple highway links. It considers diffusion by Gaussian and utilizes a mixing zone idea to describe scattering of pollutants over the streets. It can be run for 8 hours period while AERMOD where planetary boundary has been introduced can be run for many years. OSPM is used for predicting the scattering of pollutants in road canyons between the buildings. In OSPM, concentration of exhaust gases is calculated based on plume model for the direct contribution and based on box model for the recirculating part of the pollutants in the street. Nowadays, CALINE3 and AERMOD are preferred for finding dispersion on highways and widely used for air quality management.

Future scope can be extended in several ways. Many of them consider chemical reactions for $NO_x$ but not for other pollutants, so development of the model can be extended to consider more chemical reactions. The particulate matter (PM) emission from tail pipe emission is low while re-suspension of PM is caused by vehicle movement. Generally, re-suspension of particulate matter by vehicles is missed in vehicular pollution modeling. Therefore, a module of emission factor for re-suspension of particulate matter can be developed and incorporated in modeling. Canyon Street has recirculation effect of pollutants from the buildings which is captured by OSPM, but this feature can also be enhanced in other models. Meteorological data needed for air quality modeling can be generated using Weather Research Forecasting or other meteorological model.

## REFERENCES


ARAI (2007). Air quality monitoring project-Indian clean air programme (ICAP). "Emission Factor development for Indian Vehicles", ARAI, Pune, India.

Aquilina, N. and Micallef, A. (2003). Evaluation of the Operational Street Pollution Model Using Data from European Cities. Env. Mont Asses., 95, 75-96.

Assael, M.J.Ã., Delaki, M. & Kakosimos, K.E. (2008). Applying the OSPM model to the calculation of PM 10 concentration levels in the historical centre of the city of Thessaloniki. Atmospheric Environment, 42, 65–77. doi:10.1016/j.atmosenv.2007.09.029.

Alves, C.A., Gomes, J., Nunes, T., Duarte, M., Calvo, A., Custódio, D., Pio, C., Karanasiou, A. and Querol, X. (2014). Size-segregated particulate matter and gaseous emissions from motor vehicles in a road tunnel. Atmos. Res. 153, 134–144. doi:10.1016/j.atmosres.2014.08.002.

Banerjee, T., Barman, S.C. and Srivastava, R.K. (2011). Application of air pollution dispersion modeling for source-contribution assessment and model performance evaluation at integrated industrial estate-Pantnagar. Environmental pollution (Barking, Essex : 1987), 159(4), 865–75. doi:10.1016/j.envpol.2010.12.026.

Barratt, R. (2000). Atmospheric dispersion modeling- An introduction to practical applications, Business and Environment Practitioner Series, Earthscan Publications Limited, London (UK).

Berkowicz, R. (2000). OSPM- a parameterised street pollution model. Environmental monitoring and assessment, 65, 323–331.

Benson, P.E. (1992). A review of the development and application of the CALINE 3 and 4 models. Atmos. Env. 26B (3), 379-390.

Benson, P.E. (1979). CALINE -3: A versatile dispserion model for prediction air pollutant levels near highways and arterial roads. Final Report. FHWA/CA/TL-79/23 California Department of Transportation, Sacramento, CA.

Berkowicz, R., Ketzel, M., Solvang, S., Hvidberg, M. and Raaschou-nielsen, O. (2008). Evaluation and application of OSPM for traffic pollution assessment for a large number of street locations. Environmental Modeling & Software, 23, 296–303. doi:10.1016/j.envsoft.2007.04.007.

Berkowicz, R., Winther, M. and Ketzel, M. (2006). Traffic pollution modeling and emission data.

Environmental Modeling & Software, 21(4), 454–460. doi:10.1016/j.envsoft.2004.06.013.

Brandt, J., Silver, J.D., Christensen, J.H., Andersen, M.S., Bønløkke, J.H., Sigsgaard, T., et al. (2013). Assessment of past, present and future health-cost externalities of air pollution in Europe and the contribution from international ship traffic using the EVA model system. Atmospheric Chemistry and Physics, 13(15), 7747–7764. doi:10.5194/acp-13-7747-2013.

Briggs, D.J., Hough. D., Gulliver, W., Elliott, P., Kingham, S. and Small Bone, K. (2000). A regression-based method for mapping traffic-related air pollution: application and testing in four contrasting urban environments. Sci. of The Tot. Env., 253(1-3), 151-67.

Brzezinski, D.J. and Newell, T.P. (2000). A Revised Model for Estimation of Highway Vehicle Emissions. Air Waste Manag. Assoc. EPA420-S-9, 1–18.

Casandy, G.T. (1972). Crosswind Shear Effect on Atmospheric Diffusion. Atmos. Env., 6, 221-232.

Cassidy, T., Inglis, G., Wiysonge, C. and Matzopoulos, R. (2014). Health & Place A systematic review of the effects of poverty deconcentration and urban upgrading on youth violence. Health & Place, 26, 78–87. doi:10.1016/j.healthplace.2013.12.009.

Cheng, S., Lang, J., Zhou, Y., Han, L., Wang, G. and Chen, D. (2013). A new monitoring-simulation-source apportionment approach for investigating the vehicular emission contribution to the PM2.5 pollution in Beijing, China. Atmos. Environ. 79, 308–316. doi:10.1016/j.atmosenv.2013.06.043.

Chock, D.P. (1978). A line source model for dispersion near Roadways. Atmos. Env., 12, 823–829.

Cimorelli, A.J., Perry, S.G., Venkatram, A., Weil, J.C., Paine, R.J., Wilson, Robert, B., et al. (2004). AERMOD : Description of Model Formulation. EPA-454/R-03-004, USEPA, USA.

Coelho, M.C., Fontes, T., Bandeira, J.M., Pereira, S.R., Tchepel, O., Dias, D., Sá, E., Amorim, J.H. and Borrego, C. (2014). Assessment of potential improvements on regional air quality modeling related with implementation of a detailed methodology for traffic emission estimation. Sci. Total Environ. 470-471, 127–137. doi:10.1016/j.scitotenv.2013.09.042.

CPCB (2001). Vehicular Pollution Control in India, Technical and Non-Technical Measure Policy. Cent. Pollut. Control Board, Minist. Environemntal For. Gov. India.

Fan, X., Lam, K.C. and Yu, Q. (2012). Differential exposure of the urban population to vehicular air pollution in Hong Kong. Science of the Total Environment, 426, 211–219. doi:10.1016/j.scitotenv.2012.03.057.

Fensterstock, J.C., Kurtzweg, J.A. and Ozolins, G. (1971). Reduction of Air Pollution Potential through Environmental Planning, Journal of the Air Pollution Control Association 21(7), 395-399. DOI: 10.1080/00022470.1971.10469547.

Fenger, J. (2009). Air pollution in the last 50 years - From local to global. Atmos. Env., 43(1), 13–22. doi:10.1016/j.atmosenv.2008.09.061.

Fridell, E., Haeger-Eugensson, M., Moldanova, J., Forsberg, B. and Sjöberg, K. (2014). A modeling study of the impact on air quality and health due to the emissions from E85 and petrol fuelled cars in Sweden. Atmospheric Environment, 82, 1–8. doi:10.1016/j.atmosenv.2013.10.002.

Gulia, S., Shiva Nagendra, S.M., Khare, M. and Khanna, I. (2015). Urban air quality management- a review. Atmospheric Pollution Research, 6(2), 286–304. doi:10.5094/APR.2015.033.

Guttikunda, S.K. and Goel, R. (2013). Health impacts of particulate pollution in a megacity-Delhi, India. Environ. Dev. 6, 8–20. doi:10.1016/j.envdev.2012.12.002.

Hanna, S.R., Briggs, G.A. and Hosker, P.R. (1982). Handbook on Atmospheric Diffusion, Technical information centre USDOE Chapter 9: 59-60.

Hvidberg, M. and Jensen, S.S. (2011). Evaluation of AirGIS : a GIS-based air pollution and human exposure modeling system Matthias Ketzel, Ruwim Berkowicz, Ole Raaschou-Nielsen. International Journal of Environment and Pollution, 47, 226–238.

Ilyas, Z.S., Khattak, A.I., Nasir, S.M., Qurashi, T. and Durrani, R. (2010). Air pollution assessment in urban areas and its impact on human health in the city of Quetta, Pakistan. Clean Techn Environ Policy, 12, 291–299. doi:10.1007/s10098-009-0209-4.

Jiang, P., Chen, Y., Geng, Y., Dong, W., Xue, B., Xu, B. and Li, W. (2013). Analysis of the co-bene fi ts of climate change mitigation and air pollution reduction in China. J. of Cleaner Production, 58, 130–137. doi:10.1016/j.jclepro.2013.07.042.

Jiménez-guerrero, P., Jorba, O., Baldasano, J. M. and Gassó, S. (2007). The use of a modeling system as a tool for air quality management : Annual high-resolution simulations and evaluation. Science of the Total Environment, 390, 323–340. doi:10.1016/j.scitotenv.2007.10.025.

Jin, S. and Demerjian, K. (1993). A Photochemical Box Model for Urban Air Quality Study. Atmospheric Environment, 27B(4), 371–387.

Johnson, W.B., Ludwig, F.L., Dabbrdt, W.F. and Allen, R.J. (1971). Field study for an initial evaluation of an urban diffusion model for carbon monoxide. Comprehensive Report For Coordinating Research Institute and EPA Contract. Stanford Research Institute, Milano park, Calinfornia. CAPA-3-68, 1-69.

Kakosimos, K.E., Hertel, D.O. and B.C.M.K. (2010). Operational Street Pollution Model (OSPM)– a review of performed application and validation studies, and future prospects. Environmental Chemistry, 7, 485–503. doi:10.1071/EN10070.

Kampa, M. and Castanas, E. (2008). Human health effects of air pollution. Environmental Pollution, 151(2), 362–367. doi:10.1016/j.envpol.2007.06.012.

Kan, H., Chen, R. and Tong, S. (2012). Ambient air pollution, climate change, and population health in China. Environment international, 42, 10–9. doi:10.1016/j.envint.2011.03.003.

Kan, H., Huang, W., Chen, B. and Zhao, N. (2009). Impact of outdoor air pollution on cardiovascular health in Mainland China. CVD Prevention and Control, 4(1), 71–78. doi:10.1016/j.cvdpc.2008.08.004.

Kesarkar, A.P., Dalvi, M., Kaginalkar, A. and Ojha, A. (2007). Coupling of the Weather Research and Forecasting Model with AERMOD for pollutant dispersion modeling. A case study for PM10 dispersion over Pune, India. Atmospheric Environment, 41(9), 1976–1988. doi:10.1016/j.atmosenv.2006.10.042.

Ketzel, M., Ss, J., Brandt, J., Ellermann, T., Hr, O., Berkowicz, R. and Hertel, O. (2012). Evaluation of the Street Pollution Model OSPM for Measurements at 12 Streets Stations Using a Newly Developed and Freely Available Evaluation Tool. Civil & Environmental Engineering, S1:004, 1–11. doi:10.4172/2165-784X.S1-004.

Kukkonen, J., Partanen, L., Karppinen, A. and Walden, J. (2003). Evaluation of the OSPM model combined with an urban background model against the data measured in 1997 in Runeberg Street, Helsinki. Atmospheric Environment, 37, 1101–1112. doi:10.1016/S1352-2310(02)00957-3.

Kukkonen, J., Valkonen, E., Walden, J., Koskentalo, T., Aarnio, K., Karppinen, A., et al. (2001). A measurement campaign in a street canyon in Helsinki and comparison of results with predictions of the OSPM model. Atmospheric Environment, 35, 231–243.

Kumar, A., Dikshit, A.K., Fatima, S., Patil, R.S. (2015). Application of WRF model for vehicular pollution modeling using AERMOD. Atmos. and Cli. Sci., 5, 57–62.

Krewski, D. and Rainham, D. (2007). Ambient Air Pollution and Population Health : Overview. Journal of Toxicology and Environmental Health, Part A, 70, 275–283. doi:10.1080/15287390600884859.

Kristiansson, M., Sörman, K., Tekwe, C. and Calderón-garcidueñas, L. (2015). Urban air pollution, poverty, violence and health – Neurological and immunological aspects as mediating factors. Environmental Research, 140, 511–513. doi:10.1016/j.envres.2015.05.013.

Lai, A.C.K., Thatcher, T.L. and Nazaroff, W.W. (2012). Inhalation Transfer Factors for Air Pollution Health Risk Assessment. Journal of the Air & Waste Management Association, 50, 1688–1699. doi:10.1080/10473289.2000.10464196.

Luhar, A.K. and Patil, R.S. (1989). A General Finite Line Source Model For Vehicular Pollution Prediction" Atmos. Env., 23, 555-562.

Maantay, J. (2007). Asthma and air pollution in the Bronx: methodological and data considerations in using GIS for environmental justice and health research. Health & place, 13(1), 32–56. doi:10.1016/j.healthplace.2005.09.009.

Ma, J., Yi, H., Tang, X., Zhang, Y., Xiang, Y. and Pu, L. (2013). Application of AERMOD on near future air quality simulation under the latest national emission control policy of China: A case study on an industrial city. Journal of Environmental Sciences, 25(8), 1608–1617. doi:10.1016/S1001-0742(12)60245-9.

Marquez, L.O. and Smith, N.C. (1999). A framework for linking urban form and air quality. Environmental Modeling & Software, 14(6), 541–548. doi:10.1016/S1364-8152(99)00018-3.

Martins, H. (2012). Urban compaction or dispersion? An air quality modeling study. Atmospheric Environment, 54, 60–72. doi:10.1016/j.atmosenv.2012.02.075.

Miller, T.L. and Clagget, M. (1978). A Comparison of Three Highway Line Source Dispersion Models. Atmos. Env., 12, 1323-1329.

Mokhtar, M.M., Hassim, M.H. and Taib, R.M. (2014). Health risk assessment of emissions from a coal-fired power plant using AERMOD modeling. Process Safety and Environmental Protection, 92, 476–485.

Ozkurt, N., Sari, D., Akalin, N. and Hilmioglu, B. (2013). Evaluation of the impact of SO2 and NO2 emissions on the ambient air-quality in the ??an-Bayrami?? region of northwest Turkey during

2007-2008. Science of the Total Environment, 456-457(2), 254–266. doi:10.1016/j.scitotenv.2013.03.096.

Pandey, J.S., Kumar, R. and Devotta, S. (2005). Health risks of NO2, SPM and SO2 in Delhi (India). Atmospheric Environment, 39(36), 6868–6874. doi:10.1016/j.atmosenv.2005.08.004.

Patankar, A.M. and Trivedi, P.L. (2011). Monetary burden of health impacts of air pollution in Mumbai, India: implications for public health policy. Public health, 125(3), 157–64. doi:10.1016/j.puhe.2010.11.009.

Petersen, W. (1980). A Highway Air Pollution Model, User's guide for HIWAY2, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-600/8-80-018, 69 p.

Rao, S., Pachauri, S., Dentener, F., Kinney, P., Klimont, Z., Riahi, K. and Schoepp, W. (2013). Better air for better health: Forging synergies in policies for energy access, climate change and air pollution. Global Environmental Change, 23(5), 1122–1130. doi:10.1016/j.gloenvcha.2013.05.003.

Ritter, M., Müller, M.D., Tsai, M.Y. and Parlow, E. (2013). Air pollution modeling over very complex terrain: An evaluation of WRF-Chem over Switzerland for two 1-year periods. Atmospheric Research, 132-133, 209–222. doi:10.1016/j.atmosres.2013.05.021.

Sellier, Y., Galineau, J., Hulin, A., Caini, F., Marquis, N., Navel, V., et al. (2014). Health effects of ambient air pollution: do different methods for estimating exposure lead to different results? Environment international, 66, 165–73. doi:10.1016/j.envint.2014.02.001.

Sivacoumar, R. and Thanasekaran, K. (1999). Line source model for vehicular pollution prediction near roadways and model evaluation through statistical analysis. Environ. Poll., 104, 389–395. doi:10.1016/S0269-7491(98)00190-0.

Sonawane, N.V., Patil, R.S. and Sethi, V. (2012). Health benefit modeling and optimization of vehicular pollution control strategies. Atmos. Environ. 60, 193–201. doi:10.1016/j.atmosenv.2012.06.060.

Spickett, J., Katscherian, D. and Harris, P. (2013). The role of Health Impact Assessment in the setting of air quality standards : An Australian perspective. Environmental Impact Assessment Review, 43, 97–103. doi:10.1016/j.eiar.2013.06.001.

Srivastava, A. and Kumar, R. (2002). Economic valuation of health impacts of air pollution in mumbai. Environmental monitoring and assessment, 75, 135–143.

Singh, N.P. and Gokhale, S. (2015). A method to estimate spatiotemporal air quality in an urban traffic corridor. Sci. of the Tot. Env., 538, 458–467.

Syrakov, D., Prodanova, M., Georgieva, E., Etropolska, I. and Slavov, K. (2015). Simulation of European air quality by WRF–CMAQ models using AQMEII-2 infrastructure. Journal of Computational and Applied Mathematics. doi:10.1016/j.cam.2015.01.032.

Thaker, P. and Gokhale, S. (2015). The impact of traffic- fl ow patterns on air quality in urban street canyons. Environmental Pollution, in press.

Whitworth, K.W., Symanski, E., Lai, D. and Coker, A.L. (2011). Kriged and modeled ambient air levels of benzene in an urban environment : an exposure assessment study. Environmental Health, 10(1), 21. doi:10.1186/1476-069X-10-21.

Yan, F., Winijkul, E., Jung, S., Bond, T.C. and Streets, D.G. (2011). Global emission projections of particulate matter (PM): I. Exhaust emissions from on-road vehicles. Atmos. Environ. 45, 4830–4844. doi:10.1016/j.atmosenv.2011.06.018.

Zhang, H., Chen, G., Hu, J., Chen, S., Wiedinmyer, C., Kleeman, M. and Ying, Q. (2014). Evaluation of a seven-year air quality simulation using the Weather Research and Forecasting (WRF)/ Community Multiscale Air Quality (CMAQ) models in the eastern United States, Science of the Total Environment 474, 275–285.