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A modelling assessment of hydrocarbons (HC) and oxides of nitrogen (NO_X) from transport sectors over Delhi

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सार — परिवहन सेक्टर से निकलने वाले हाइड्रोकार्बन्स (एच.सी.) और नाइट्रोजन के आक्साइडों (एन. ओ. एक्स.) की सांद्रता का आकलन करने के लिए दो मॉडलों, आई. आई. टी. लाइन सोर्स मॉडल (आई. आई. टी. एल. एस.) और हाइवे- 2 मॉडल का प्रयोग किया गया है। आई. आई. टी. एल. एस. मॉडल में वाहनों से निकलने वाले हाइड्रोकार्बन और नाइट्रोजन के आक्साइडों के बहिर्वेशन की एक विस्तृत स्रोत तालिका तैयार की गई है। मॉडल की पूर्वानुमानित सांद्रता की तुलना दिल्ली के तीन स्थानों मूलचन्द अस्पताल, आश्रम और मेडिकल से प्राप्त की गई सांद्रता की मात्रा से की गई है। इस मॉडल के कार्य - निष्पादन के मूल्यांकन के लिए मॉडल के परिणामों और प्रेक्षित मानों के सांख्यिकीय त्रुटि विश्लेषण किया गया है। इस अध्ययन से यह पता चला है कि हाइवे-2 मॉडल की तुलना में आई. आई. टी. एल. एस. मॉडल बेहतर कार्य करता है।

ABSTRACT. Two models IIT Line Source Model (IITLS) and HIWAY-2 model have been used to estimate the concentrations of the hydrocarbons (HC) and oxides of nitrogen (NO_X) due to transportation sector. An elaborate source inventory for the extrapolation of the HC and NO_x emissions by vehicular transport has been developed in IITLS model. The model's predicted concentrations have been compared with the observed values at three receptors namely, Mool Chand, Ashram and AIIMS in Delhi. A statistical error analysis of the model's results and observed values has been made for evaluating the model's performance. In the present study, it has been observed that IITLS model performs better than HIWAY-2 model.

Key words — Vehicular pollution, Line source, Model prediction, Source inventory.

1. Introduction

Vehicular population in urban cities of India has increased significantly during the past two decades. The increase has been particularly marked in the number of city diesel buses, two stroke engine powered scooters, motor cycles and three wheelers. The trend in population growth of different types of vehicles in Delhi has been given in Table 1 and also shown in Fig.1. The vehicular population in Delhi has gone up to 10 folds in the last two decades. About 11 lakh vehicles were registered in Delhi up to 1987.

Vehicles contribute various pollutants to the environment. The principal emissions from petrol driven vehicles are carbon monoxide (CO), unburned hydrocarbons (HC), oxides of nitrogen (NO_X) and particulate including lead compound. On the other hand, diesel vehicles contribute largely oxides of nitrogen and particulate (diesel smoke) to the atmosphere. Diesel vehicles also emit carbon monoxide and unburned hydrocarbons but it is relatively low as compared to the emission from petrol driven vehicles.

The urban area of Delhi has a high pollution potential during winter especially during December, January and February. Ground based inversions restrict the mixing height to low levels, resulting in poor dispersal of pollutants from vehicular exhausts. Coupled with the adverse meteorological situation are the relatively high emissions caused by low driving speeds and poor engine maintenance.

Many line source models have been used to estimate pollutant concentration from the transport sectors near roadways. The most widely used USEPA line source models are HIWAY (William 1990), ROADWAY (Robert and Joseph 1987) and CALINE-3 (Caline-3 1973) models. In the present work IIT Line Source model, which has been developed in Indian Institute of Technology (IIT) Delhi, has been used to predict HC and NO_X concentrations over Delhi. The USEPA operational model HIWAY-2 has also been used to predict HC and NO_X concentrations. The comparison to predict HC and NO_X concentrations over Delhi. The USEPA operational model HIWAY-2 has also been used to predict HC and NO_X concentrations. The comparison and evaluation of these two models have been made against the

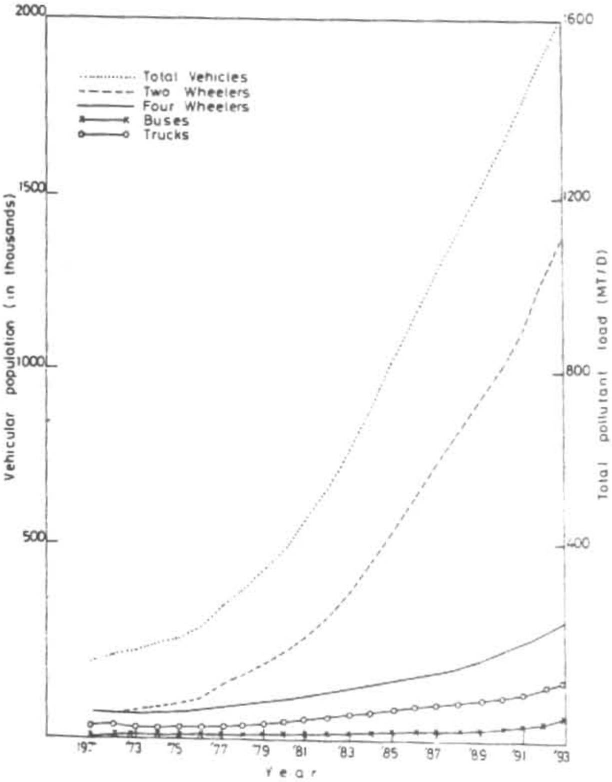

Fig.1. Vehicular population growth in Delhi. (Source: Vehicular Pollution Report of Metropolitan City in Delhi, Central Pollution Control Board, New Delhi)

TABLE 1

Trend in pupulation growth of different types of vehicles in Delhi

Type of Vehicle	Year		
	*1982	**1989	***1992
Two wheelers	386747	1036038	1381582
Three wheelers	21810	55965	69974
Four wheelers (cars) private	128338	306528	468804
Four wheelers (cars) Taxi	6837	9249	11212
Buses	9025	16924	22440
Good vehicles	59827	85696	110465

*Source: Report on vehicular air pollution in Delhi central pollution control Board, Delhi CUPS/10/1982-83.

**Source: Effect of environmental pollution due to road traffic on health of Delhi Traffic policemen - a report by CRRI, New Delhi.

***Source: Central Pollution Control Board, Delhi.

observed values of HC and NOx at different receptor points over Delhi.

The main objective of the present study is to develop a simple operational line source model for predicting ground level concentrations of gaseous pollutants, *e.g.*, HC and NO_x due to vehicular sources in urban areas.

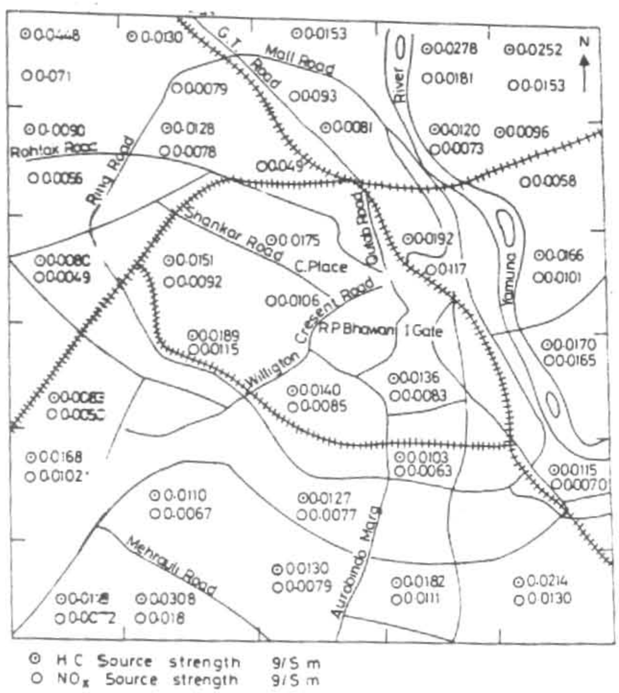

Fig.2. Source strength of HC and NO_x at each grid point

2. Models characteristics

The following two line source models have been used.,

(*i*) IIT Line Source (IITLS) Model

(*ii*) HIWAY-2 Model.

2.1. *IITLS Model*

The ground level concentrations due to line source (Wark and Warner 1981) can be estimated by the formulation as given below:

$$C(X,O,O)=\frac{(2q)}{(2\pi)^{1/2}\sigma_z\, u \sin\phi}\exp\left[-\frac{h^2}{2\sigma_z^2}\right]\int_{p_1}^{p_2}\frac{1}{(2\pi)^{1/2}}\exp(-0.5\,p^2)\,dp \qquad (1)$$

where, q = source strength ($gm^{-1}s^{-1}$); u = wind speed (ms^{-1})

ϕ = road to wind angle; $p_1 = y_1/\sigma_y$; $p_2 = y_2/\sigma_y$; y_1, y_2= edges of the roads; σ_y = horizontal dispersion parameter (m); σ_z = vertical dispersion parameter (m); h = source height (m). The $\sin\phi$ term in Eqn.(1) is omitted when $\phi < 45°$.

The dispersion parameters, σ_y and σ_z have been calculated for Pasquill's stability classification using Brigg's Nieuwstadt and Van Dop 1984 formulae for urban area. The integral part of Eqn.(1) has been integrated numerically. The pollutants have been emitting from exhaust tail pipe, whose height has been assumed 0.2 m from the ground surface.

2.1.1. *Source inventory*

A grided source inventory has been developed over an area of 24 km × 20 km of Delhi city as shown in Fig.2. The total area has been divided into 30 grids of uniform size 4 km × 4 km. The roads have been classified into three categories, *viz.*, arterial, feeder and residential. The highways and broad roads having 4 to 6 lanes, have been named as arterial roads. (*e.g.*, National highway, Ring road). The roads which are connected to the arterial roads, have been defined as feeder roads. The roads in the residential colonies have been named as the residential roads. The length of each type of road has been measured in each grid.

The vehicles have been categorized into three classes. Light tonnage vehicles (LTV), Medium tonnage vehicles (MTV) and Heavy tonnage vehicles (HTV). Two wheelers and three wheelers have been considered as LTV, cars and other four wheelers have been treated as MTV and buses and trucks have been taken as HTV in the present study.

Let R_a^i , R_f^i , R_r^i be the lengths of the arterial, feeder and residential road types in the ith city grid. Let V_a^i , V_f^i ,V_r^i be the traffic volume on these roads per day. The total vehicle kilometer travel in the ith city grid is given by

$$V_T^i = R_a^i V_a^i + R_f^i V_f^i + R_r^i V_r^i \qquad (2)$$

If the total emission of the pollutant is e_t (g day^{-1}), the pollutant source strength per day in the ith city grid (Singh *et al.*, 1990) is given by

$$E_i = \frac{E_t V_T^i}{\sum_i V^i} \qquad (3)$$

where $\sum_i V^i$ is the total traffic volume over the city

The relative traffic volume of traffic flow per day has been adopted according to (Hemmerle *et al.*, 1976) which agrees well with (Srinivasan *et al.*, 1973) for Indian road types. The amount of a pollutant emitted in each grid square is then distributed throughout the day according to the traffic pattern (Rao 1973). If $e(t)$ is the city wide emission at time t, the city wide pollutant emission for the whole day is given by

$$E_t = \int_{day} e(t) \mathrm{d}t \qquad (4)$$

But $e(t)$ is proportional to traffic volume $V(t)$ at time t. Thus knowing the diurnal traffic pattern, as given by Eq.(4), giving the source strength Q_i in the ith city grid as a function

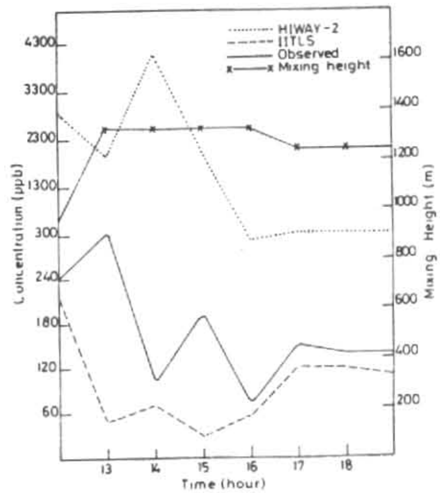

Fig.3. Comparison of IITLS Model and HIWAY-2 Model prediction against the observed values of NO_x and mixing height of Ashram Crossing on 27 August 1992

of time in units of gm^{-2}. This method can be used for any gaseous pollutant.

2.2. *HIWAY-2 Model*

This model is available as part of UNAMAP (version 6). The computer code is available on magnetic tape from computer products, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161.

HIWAY-2 has been used to estimate the concentrations of non-reactive pollutants HC and NO_x from highway traffic. This steady Gaussian model has been applied to determine air pollutant concentrations at down wind receptors. The model is applicable for any wind direction, highway orientation, receptor location. The model was developed for situations when horizontal wind flow dominates. The model cannot consider complex terrain or large obstructions to the flow such as buildings or large trees.

The source strength q (gm^{-1}s^{-1}) has been calculated by dividing the source strength (gs^{-1}) by the total road length in each grid, as shown in Fig.2. In the present study the highway has been considered as a single lane of width 8m, with a centre strip of 1.5m. The source height and the receptor height are considered near the ground level.

3. Meteorological data

The meteorological data used in both the models (IIT Line source model and HIWAY-2 model) are as follow: Hourly averaged wind speed, wind direction, mixing height and the atmospheric stability of Pasquill's classification.

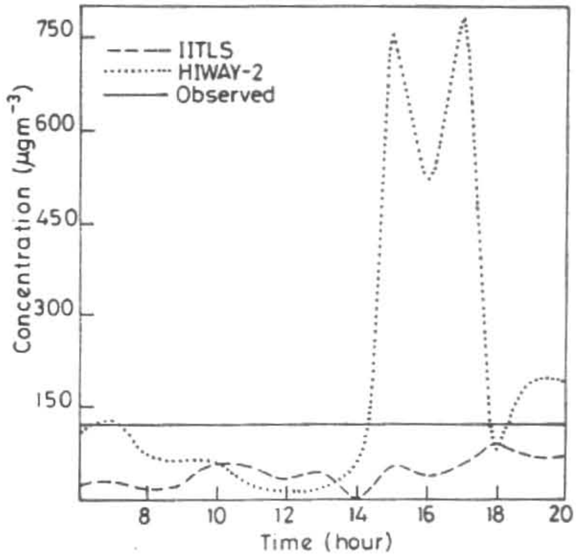

Fig.4. Comparison of IITLS Model and HIWAY-2 Model predictions against the observed values of HC at Mool Chand Hospital

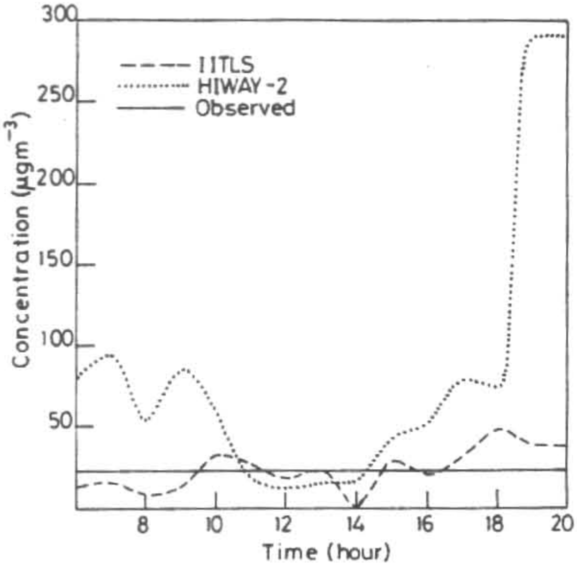

Fig.5. Comparison of IITLS Model and HIWAY-2 Model predictions against the observed values of NO_x at All India Institute of Medical Sciences (AIIMS)

4. Results and discussion

The two line source models IITLS and HIWAY-2 have been used to estimate the hourly concentrations of NO_x and HC at three stations in Delhi. In order to estimate maximum ground level concentrations (glc) of pollutants, this study has been made for typical winter month, *i.e.*, February 1992. Because in winter, meteorological conditions are mostly unfavourable to the dispersion of the pollutants in the atmosphere.

In the present study, the particular stations and particular months have been chosen due to availability of data.

As HIWAY-2 model is specifically designed for highways in United states, it might not be suitable for Indian type of roads. The IITLS model is a simple Gaussian line source model. It is advisable to make a comparative study of the performance of both the models for a Indian highway road. In view of the applicability of HIWAY-2 model, Mathura highway road, linked with highly traffic intersection Ashram, has been chosen for the present study.

Ground level concentrations of NO_x due to both the models with observed values of ambient air quality and mixing height have been represented in Fig.3. This represents that IITLS model values are quite close to the observed values but on little lower side. The ambient air quality has been monitored bearing varying number of anthropogenic sources of pollution, whereas IITLS model predictions are only due to vehicular traffic. This may be the reason of its underprediction compared to observed values.

HIWAY-2 is highly overpredicting comparatively to the observed and IITLS model values. The reason may be due to the use of different dispersion parameters in IITLS and HIWAY-2 model. HIWAY- 2 model has used the Pasquill-Gifford dispersion parameters with a combination of initial dispersion due to vehicular turbulence. On the other hand IITLS has used Brigg's urban formulae with a combination of initial dispersion limited to 0.2 times mixing height. Initial dispersion with an assumption of 0.2 times mixing height are found to be more suitable for small height sources like vehicles. It is noticeable at this juncture that this type of combination of dispersion parameters may be more suitable to our Indian conditions.

The second reason of different behavior of HIWAY-2 and IITLS model may be due to the inclusion of calm winds. HIWAY-2 model has not been capable of handling calm winds (low winds <2.0 ms^{-1}). Whereas, IITLS model is specifically designed for treating calm winds. It has been observed from meteorological data that more than 40% of the time wind in tropical countries like India is found to be less than 1 ms^{-1}. Therefore the inclusion of calms are essential for tropical countries.

A comparative study to know the behaviour of both the models has also been made at two busy intersections, Mool Chand Hospital and All India Institute of Medical Sciences (AIIMS).

The concentrations of NO_x and HC obtained from both the models and observed values at Mool Chand Hospital and AIIMS have been shown in Figs.(4-6). From Figs.(4-6), it has been observed that HIWAY-2 model has been under-

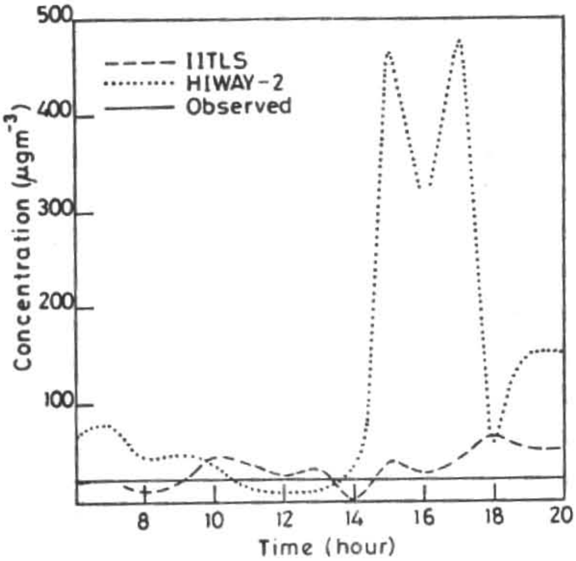

Fig.6. Comparison of IITLS Model and HIWAY-2 Model predictions against the observed values of NO_x at Mool Chand Hospital

predicting from 11 A.M. to 1 P.M. comparatively with IITLS and observed values whereas, it is overpredicting during the of the hours. The IITLS model concentrations have been agreed well with the observed values.

Fig.4 shows the concentrations of IITLS, HIWAY-2 and observed values at one of the busiest traffic intersections at Mool Chand Hospital of Delhi. It has been observed that IITLS model has been underpredicting the HC concentrations compared to the observed values, whereas, HIWAY-2 model does not show the same behaviour. One of the reasons of IITLS model's underprediction may be due to the lack of complete emission data. The hourly emission in each grid has been extrapolated from annual emission over the city. The IITLS has two peak values of ground level concentrations at 10 A.M. and 6 P.M. which are the peak traffic hours. At the same time, it has also been observed that HIWAY-2 model has peak values from 2 P.M. to 6 P.M. which is different from IITLS as well as hourly traffic pattern.

Fig.5 shows the NO_x concentrations obtained from IITLS and HIWAY-2 models and their comparison with the observed values at AIIMS. It is a major traffic intersection of Delhi. The IITLS model concentrations have been found to be close to the observed values throughout the day. At the same time, it has also been observed that the HIWAY-2 model results from 12 P.M. to 2 P.M. have agreed with the observed values. Whereas, in the rest of the hours, it has been overpredicting. The HIWAY-2 model agrees well with observed and IITLS model only in those hours which are minimum traffic hours. Most of the time, the IITLS model values have been found to be a good agreement with the observed values, whereas HIWAY-2 model has not followed the same practice.

TABLE 2

Comparison of errors NMSE and NNR of IITLS and HIWAY-2 models at three receptors

Pollutant	Place	NMSE		NNR	
		IITLS	HIWAY-2	IITLS	HIWAY-2
HC	Mool Chand	0.017	0.029	0.419	0.009
NOx	Mool Chand	0.034	0.750	0.760	4.502
NO_x	AIIMS	0.018	0.362	0.275	10.185.

In Fig.6, similar behaviour, as in Fig.5, of IITLS and HIWAY-2 has been observed.

In order to evaluate the performance of both the models, a statistical error analysis has been made. Two types of error Normalized Mean Square Error (NMSE) and Normalized Ratio (NNR) (Poli and Cirrilic 1993), have been estimated for models predicted values and the observed values, which has been given in Table 2.

Table 2 shows the statistical errors *e.g.* NMSE and NNR of IITLS model are small compared to the HIWAY-2 model. The ideal value of NMSE is 0.0. The IITLS model has an NMSE of 0.017 and HIWAY-2 has 0.029 in case of HC concentrations of Mool Chand Hospital respectively. Similarly at AIIMS, in case of NO_x concentrations, IITLS has an NMSE of 0.018 and HIWAY-2 has an NMSE of 0.362 respectively. The errors estimated by the IITLS are close to the ideal value of NMSE. For statistical error NNR, one can see that most of the time, IITLS values are close to ideal values (0.0), whereas, HIWAY-2 has values on the higher side. On the basis of the above discussion, one can conclude that IITLS model behaves better compared to HIWAY-2 model.

5. Conclusions

The IITLS model has been compared with observed values and HIWAY- 2 model, which is an US EPA operational model. It has been observed that the IITLS model has performed better compared to HIWAY-2. The present study indicates that accuracy of model predictions, depends directly on source strength, since the model concentrations are directly proportional to the source strength. Therefore to get a good quality result, it is essential to have accurate source emissions. It has also been concluded that the behaviour of IIT-developed Line Source model is better than US EPA operational HIWAY-2 model. Though both the models are Gaussian models, based on same emission data have different dispersion parameters which in turn leads to the different behaviour of both the models.

Most of the two and three wheelers are powered by the small 2- stroke generating engines and these are high emitters of the unburned HC. About 60-75 % of the total vehicular unburned HC are contributed by two and three wheelers, while the combustion of NO_x are rather low. The fuel burning efficiency of the two and three wheelers are very low and gives rise to HC emissions amount to 20-30% of the fuel supplied to engine. So in order to obtain significant reduction in vehicular pollution in urban areas the following alternatives are required to be developed.

(a) Modification of the conventional design

(b) Use of oxidation type catalytic convertors

(c) Use of small 4-stroke engine instead of 2-stroke engine.

(d) Development of new concept engines employing in-cylinder fuel injection or stratified charging etc.

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References

Caline-3, 1973, "A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets", *Interim Report*, Ref. No. FHWA/CA/TL-79/23, Federal Highway Administration.

Hemmerle, J.R., 1976, "Emission Inventory in Air Pollution", Edited by A.C. Stern, Academic Press, New York.

Nieuwstadt, F.T.M. and Van Dop, H., 1984, "Atmospheric Turbulence and Pollution Modelling", Edited by F.T.M. Nieuwstadt and H. Van Dop, Atmospheric Science Library, D. Reidel Publishing Company, 293p.

Poli, A.A. and Cirrilio, M.C., 1993, "On the use of the Normalized Mean Square Error in Evaluating Dispersion Model Performance", *Atmospheric Environment*, **27A**, 15, 2427-2434.

Rao, M.S.V., 1973, "Traffic and Transport Studies for Connaught Circus at Metropolitan City Centre of Delhi", *J. Ind. Roads Congress*.

Robert, E. E. and Joseph, A.C., 1987, "User's Guide of Roadway - A Numerical Model for Predicting Air Pollutants near Highways", No. E.P.A. 68-02-4106.

Singh, M.P., Goyal, P., Basu, S., Agarwal, P., Nigam, S., Manju Kumari and Panwar, T.S., 1990, "Predicted and Observed Concentrations of SO_2, SPM and NO_x over Delhi", *Atmospheric Environment*, **24A**, 4, 801-810.

Srinivasan, N.S., Sripathi Rao, S.B. and Shaffruddin, S.M., 1973,"Forecasting of Traffic and standardization of Widths of Roads in Industrial Townships", *J. Indian Roads Congress*, **35**, 571p.

Wark, K. and Warner, C., 1981, "Air Pollution: Its Origin and Control", Second Edition, Harper and Row Publishers, New York.

William, B.P., 1990, "User's Guide of HIWAY-2", No.E.P.A. 600/8-80-018.