A DETAILED STUDY TO ASCERTAIN THE EFFECT OF DIESEL OPERATED TRUCKS, TEMPOS, THREE WHEELERS AND OTHER COMMERCIAL VEHICLES ON THE AMBIENT AIR QUALITY OF DELHI

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PREFACE

Currently in India, air pollution is widespread in urban areas where vehicles are major contributors and in a few other areas with a high concentration of industries and thermal power plants. Vehicular emissions are of particular concern since theses are ground level sources and thus have the maximum impact on the general populations. Also, vehicles contribute significantly to the total air pollution load in many urban areas.

The main source, contributing to the deterioration of air quality in Delhi, is vehicular transport, which is responsible for almost 70% of the total air pollution load in the city. Vehicular pollution in Delhi has increased phenomenally from 2.3 million in 1975 (MOEF, 1997) to 4.2 million in 2004, which has been estimated 7.2 million in 2016 on the basis of transport data obtained from Transport Department, 2004. Vehicular pollution is based on the quality and quantity of the fuel.

To mitigate the pollution generated from transport activity, Delhi government has adopted several measures such as implementation of more stringent emission norms for vehicles, phasing out of the old vehicles from the roads, implementation of metro rail, fuel substituted with CNG, supply of better fuel etc. The impact of few of these measures have been studied as an objective of the present paper, e.g. the changes occurred by application of different fuels on emission norms. The main pollutants of the vehicular traffic are namely carbon-monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM), and hydrocarbons (HCs).

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1 Introduction

Delhi, in terms of pollution, was ranked fourth among the 41 most polluted cities of the world in 90's. The national capital saw an unprecedented growth in population, vehicles and small scale industries, which caused serious ecological unbalance and environmental degradation. The problem got further aggravated by increasing migration from neighboring states. The First Report of the Quality of Urban Air Review Group (QUARG, 1993) concluded that road transport was a major source of urban air pollution and that the proportional contribution to emissions in towns and cities from the transport sector had increased in recent years due to its rapid growth and the decline of other major pollution sources. Both petrol and diesel engine vehicles play their part. In addition to these two fuels, CNG has come up as third fuel in vehicles. The survey conducted by Indraprastha Gas Limited (IGL) shows that the number of private cars running on CNG has increased from 19,351 in July 2005 to 35,229 till July this year. The percentage share of CNG-run vehicles in the total number of private cars in Delhi is increasing. Even though emissions of some pollutants from diesels become relatively more significant as strict emission, controls bite on the petrol driven fleet. Worldwide, diesel fuel consumption accounts for about eight percent of total energy consumption (WRI, 2005).

Sunita Narain, a member of the Environmental Protection Authority said "All CNG gains have been lost by in-action on the part of government and sheer exploitation of air quality by huge registration of private vehicles". Over 1000 vehicles are registered in Delhi everyday and 30% of then ran on diesel, which emit five times more respirable suspended particulate matter (RSPM) and nitrogen oxide (NOx) than those run on petrol. Before 2001, about 500 vehicles used to be registered a day and only 2% were run on diesel (Hindustan Times, New Delhi, November 5, 2007. The study, Assessment of Air Quality after the implementation of CNG, published in the Journal 'Environment Monitoring and assessment' points out that NOx levels have increased by 10 to 20% since the introduction of CNG in 2001. The one reason is significant increase in total number of vehicles, especially diesel vehicles. The city has 50 lakh registered vehicles. The other reason is inefficient use of catalytic converters in CNG vehicles. The study has formed that the level of SPM in air is steadily rising too. The maximum concentration of air pollutants at Bahadur Shah Zafar Marg was noticed during 10 PM to 10 A.M.. The study says blaming the heavy diesel vehicles that pass through Delhi in night (Hindustan Times, New Delhi, June 4, 2007).

Diesel emissions result from the combustion of diesel fuel inside a compression ignition engine. The pollutants of most concern from diesel vehicles are soot particles and NOx. Diesel vehicles produce about 50% of the NOx and particulate matter (PM) contributions to the mobile source inventory (US EPA). Emission from diesel vehicle is also depending on the engine type – two strokes or four-stroke and a combination of these. Diesel consumption in Delhi is estimated as 1,214 thousand tons in 2004-05 (Times of India, Nov 16, 2006). Apart from Delhi's own cars, the satellite townships also add to the number of vehicles playing on Delhi's roads increasing vehicular exhaust and traffic congestion. Buses, trucks and light commercial vehicles are responsible for 55% of NOx and passenger car contribute 35% of the load. About 35% of particulate matter is originating from trucks, buses and light commercial vehicles (LCV). The contribution of 2 stroke 2 and 3 wheelers to PM_{10} is estimated to be 29%.

In India there is a great need to set the quality of diesel fuel as its contribution is the greatest. After the 1988 study initiated by IOC R&D and subsequent activities, considerable changes have been taken place in diesel fuel quality. In Delhi, diesel cars have been increased by 425% over the last decade (1996-2006). The total diesel fuel consumption that was lowered with the ascending of CNG during 2000-04 has begun to increase again. Delhi has phased out 12,000 diesel buses to escape from the lethal affect of toxic diesel particles. But total number of diesel cars in Delhi is equivalent to adding particulate emission from nearly 30,000 diesel buses (CSE Letter to finance Minister, Dec 18, 2006). Society for the Indian Automobiles Manufacturers (SIAM) in Delhi informs that petrol cars have increased at 8.5% annually; diesel cars have maintained a growth rate of 16.6 per annum. Thus growth can be devastating in cities desperate for solutions to smoke, particles and NOx.

To sustain the desired air quality to control the emission value of pollutants from different sources. As indicated above, the diesel fuel among the transport fuels is the major contributions to air pollution. Now it becomes essential to study the effects of diesel operated vehicles especially commercial vehicles to ambient air quality in Delhi.

1.1 Sources and crisis of diesel pollution in Delhi

In recent days, diesel emissions in urban areas are of most concern. Road transport is the dominant freight mode in Delhi, with very little urban freight traveling by rail. Due to high traffic congestion, Delhi's pollution levels increased drastically during the mid-1990s. Infact, 1996 is considered the peak year in terms of air pollution load. The transport, industrial and domestic sectors were the major contributars towards the rising ambient air pollution levels, in addition to the presence of natural dust to meterological conditions.

In addition, significant pollution was also caused by a large number of Diesel Generating Sets, which were installed in various commercial and industrial establishments. A study conducted by the World Bank indicates premature deaths of people in Delhi owing to high levels of air pollution. Delhi has a population of 15.3 million (as sited in Wikepidea) and private diesel vehicles also enhanced. Diesel exhaust that nearby residents could face serious health problems. Hence, it is necessary to determine the effect of the diesel emitting pollutants particularly from commercial transportation and also to be noticed that which type of vehicle is contributing most of the pollutants.

1.2 Meteorological conditions

Besides anthropogenic sources, climate and natural sources too play an important role in the build-up of pollution levels. Delhi has a semi-arid climate, with an extremely hot summer, average rainfall and very cold winters. Mean monthly temperatures range from 14.3º C in January (minimum 3º C) to 34.5º C in June (maximum 47º C) the annual mean temperature is 25.3º C. Dust storms occur frequently during summer months leading to build-up of particulate in the atmosphere. Due to the worst meteorological scenario, the most important season in Delhi is winter, lasting from December to February. This period is dominating by cold, dry air and ground based inversion with low wind conditions ($u \leq 1\ ms^{-1}$), which occur frequently and increase the concentration of pollutants (Anfossi et al. 1990). The pre-monsoon (March, April, May) is governed by high temperature and high winds, while the monsoon (June, July, August, September) is dominated by rains. The post monsoon (October, November) has moderate temperature and wind conditions. The monthly and seasonal variations of concentration and winds have been obtained most of the time from WSW to NNW (Goyal et al., 2002).

2 Objectives of the Study

Air Quality Impact Assessment of diesel operated commercial vehicles namely trucks, tempos, buses, taxis and three wheelers etc. in Delhi.

3. Scope of Study:

i. Preparation of a detailed grided emission inventory of the study area by using secondary data of diesel operated commercial vehicles and roads.
ii. Estimation of emissions of NOx and PM in all grid sources using different methods.
iii. Collection and analysis of daily ambient air quality data of study pollutants at various monitoring sites of Central Pollution Control Board (CPCB).
iv. Collection of surface meteorological data of wind speed, wind direction, cloud cover, mixing height, radiation from India meteorological department (IMD).

v. Concentration contribution of pollutants due to diesel-fuelled commercial vehicles to urban air quality through air quality models in winter months.
vi. Validation of models with observed data of Central Pollution Control Board (CPCB).
vii. Application of models to determine concentration of air pollutants due to diesel operated vehicles, (each type of vehicles separately) to ambient air quality of Delhi.
viii. Discussion of air pollutant levels in the study area by comparing the models values with National Ambient Air Quality Standards (NAAQS) of respective pollutants and their observed values.

4 Methodology

The methodology involves following:

i. Detailed source inventory of NOx and PM of commercial diesel vehicles.
ii. Collection of meteorological data including hourly wind speed, wind direction, cloud covers, insolation, temperature and mixing height.
iii. Study of Air Quality models namely IITLS model and Caline-4.
iv. Comparison of models with observed data of CPCB.
v. Spatial and temporal concentration of NOx and PM.
vi. Assessment of effects of commercial diesel vehicles at different places in Delhi.

4.1 Source Inventory

It is usually not practical and economically feasible to monitor continually every emission source and pollutant concentrations in the ambient air. In practice, emission inventories are made using available primary and secondary information about the sources in study area. An emission inventory is a list of the amount of pollutants emitted by all sources within the fixed boundaries of a particular area in a given time period. Emission inventory is a major tool for identifying the sources of pollution and quantitative expression of pollution load in a defined area. The study involves the preparation of detailed emission inventory with estimation of emissions from various categories of vehicles, wherever necessary. Impact of pollution from these sources depends on many factors, viz. vicinity of emission sources, the concentration of pollutants, temporal and spatial variations in emission pattern and receptor types, etc. Extensive survey of primary and secondary data generation in the area of study is a major component in the study.

The transport related data is collected to determine the profile of diesel operated commercial vehicular traffic emissions within the city. The quantity of air pollutants emitted by the different categories of vehicles is directly proportional to the average distance traveled by each type of vehicles, number of vehicles plying on the roads, quantity and type of fuel being used. However, several other factors like geographical locations, unplanned developed business areas, inadequate and poorly maintained roads as well as adopted practices of inspection and maintenance of vehicles, unplanned traffic flow, encroachment of roads, meteorological conditions and non availability of effective emission control technology are also affecting emissions. In order to arrive at the actual vehicular emission scenarios, a vehicle count on major traffic corridors within the city has been made. The vehicles are categorized under various groups' viz. heavy-duty vehicles, light-duty vehicles, passenger cars/taxis, two/three wheelers. Hourly variation in the vehicles count is recorded (manually) during periods of day/night. The traffic volume and its characteristics (including vehicle speed) at the major traffic intersections have been monitored. Emission load is estimated using emission factors for different possible scenarios and the pollutants. The task of estimating emission load is carried out with due consideration to various parameters viz. local distance traveled by each type of vehicles in a day, and deterioration factor etc. The emission inventory is prepared over the map of Delhi.

In the present study, pollutants emitted from commercial diesel vehicles including trucks, tempos, buses, taxis and three wheelers in Delhi are estimated for the year 2006-2007 by base year 1990. The required data for detailed emission inventory has been obtained from different concerned agencies/departments namely Delhi Transport authority, Department of transport Delhi, Government of Delhi:

Government Departments: Transport: General information: Few .pages 1,2 and3 at website http://transport.delhigovt.nic.in /transport/tr0g.htm 3/23/2007.The air pollutants Nitrogen Oxides (NOx) and Particulate Matter (PM) are considered as major pollutants of diesel vehicles. The details of vehicular data obtained from Delhi Transport Authority are as follows.

1) Transport data of vehicles

i) Total diesel operated vehicles

ii) Commercial diesel vehicles

The transport data of diesel vehicles includes the following component of vehicles:

i) All India tourist permit vehicles including Buses and Taxis

ii) Gross Vehicle Weight (GVW) up to 3000 kg (exempted from permit July 2006 clean fuel registered)

iii) Goods Vehicles > 3000 kg GVW (Local permit)

- GVW (3001-7500) LGV (Tempos) 1^{st} July 2006 clean fuel registered
- Goods Vehicle > 3000 kg (national permit)

iv) Goods Vehicles 7501-11999 GVW i.e. MGV (small capacity Trucks)

v) GVW 12,000 onwards i.e. HGV (Trucks)

To make a clear presentation of above component of vehicles, a flow chart is given in Fig. 1.

2) Emission factors of NOx and PM for different types of vehicles for different scenarios from 1995 to 2010 has been obtained from Central Pollution Control Board (CPCB) (Table 1). Annual mileage (km) for different categories of vehicles has been obtained from the report titled as “Transport fuel quality for year 2005” (Table 2(a)).

The Study area of Delhi city (26 km x 24 km) shown in the Fig. 2a and 2b is divided into 156 grids of size 2 km x 2 km. Grid coordinates have been placed at south west corner of each grid. For example Grid No. 1 has the coordinate (1, 1). The major and minor roads with respect to vehicles in each grid have been measured manually with the help of map of Delhi. Emissions of NOx and PM due to diesel operated commercial vehicles have been calculated over the study area using following three different methods.

Method I:

Emission rate of pollutants on a reasonably straight highway from a continuous line source per unit length, i.e. q ($gm^{-1}s^{-1}$) can be determined as the product of the emission factor and traffic density.

$$q_{ij}=TV_{ij}e_i \qquad (1)$$

Where, $TV_{ij}=N_jV_i$

V_i =Speed of i th type vehicle (km h^{-1})

N_j =Number of vehicles traveling per unit length of j type of road (vehicles/ km)

$TVij$ =Traffic density of i th type of vehicle on j type road (vehicle/ h)

q_{ij} =Source emission per unit length (g $m^{-1}s^{-1}$)

e_i =Emission Factor (g km -1vehicle -1) for the pollutant of the vehicular category i

Method II:

Annual emission quantity of any pollutant in a particular year is calculated using the following equations:

$$E(i,y) = \sum(j)\sum(K_y) N(j,K_y).KT(j).DF(i,j,K_y)EF(i,j,K_y).10^{-9} \qquad (2)$$

where

$E(i, y)$ = annual emission of pollutant i in the year y, thousand tones per year

$N(j,K_y)$= number of vehicles of a particular type j and age K_y in the year y.

$KT(j)$ = Kilometers traveled for a type of vehicle j, km/year

$DF(i, j, K_y)$ = *Deterioration factor for component i in the vehicle type j and age K_y in the year y, dimensionless.

$EF(I, j, K_y)$= emission factor for component i in new vehicle type j and age K_y in the year y, gm/km.

i = Pollutant concentration

j = type of vehicle

K_y = age of vehicle in year y.

Deterioration factor* has been taken from the report Transport Fuel Quality for the year 2005, PROBES/78/2000-01(Table 2(b)).

[*Deterioration Factor (Deterioration in emission levels) can be defined as below: When a vehicle is manufactured it needs mass emission standards, but once out on the road the actual emission of the vehicle is expected to deteriorate every year by a certain percent. At present, the percent has been taken as 15% annually for all commercial vehicles for PM. The rate for NOx is based on a Swedish study that has measured deterioration rates after 40,000 km and 80,000 km (Motor Testing Centre, Sweden).]

Method III:

Emission rates of pollutants are estimated by using the emission factors for each vehicle group, length of major and minor traffic roads and volume of different group of vehicles by:.

$$E = \sum_{i=1}^{6} N_i \times L \times e_i \qquad (3)$$

Where,

E = Emission rate (g/s)

i = Index, varies over six categories of vehicles

Ni = Number of vehicle of i th category monitored per hour (vehicle/hour)

L = Road length in each monitored grid (km)

e_i = Emission factor (g/km) for the pollutant of the vehicular category i

Emission of pollutants in each monitored grid over the road length in that particular grid is calculated.

The traffic volume in each grid has been estimated on the basis of the data collected by two different monitoring studies in the year 2004. One study was conducted by Centre for Atmospheric Sciences, IIT Delhi and second was carried out by Transportation Research and Injury Prevention Programme (TRIPP), IIT Delhi. In first study, a detailed monitoring of vehicles for four different groups i.e. 1) cars/taxis and three wheelers, 2) light tonnage vehicles (LTV), 3) Medium tonnage vehicles (MTV) and 4) heavy tonnage vehicles (HTV) have been made nearly at 36 major traffic intersections of Central, South Delhi and National highways connecting the city with neighboring states during day hours i.e. 6 A.M. to 10 PM. These days are chosen randomly nearly 10 in each month.

In second study, a detailed vehicular monitoring data by video recording has been obtained from Transportation Research and Injury Prevention Programme (TRIPP), IIT Delhi at five traffic intersections namely Nizamuddin, Punjabi Bagh, ITO, ISBT and Aurbindo Chowk. The above two continuously monitored data were combined to estimate the hourly traffic volume of four groups of vehicles in each of monitored grids. However, the number of vehicles in the non monitored grids, has been obtained through a linear interpolation technique. The hourly traffic pattern of vehicular traffic has been obtained at each grid. For diurnal variations, the traffic volume data of missing hours has also been interpolated using linear interpolation technique. Thus the hourly pattern of different group of vehicles has been obtained all over the 156 grids. For example, the diurnal variation of different category of vehicles at ITO during winter in the year 2004 has been shown in Fig. 3.

Emissions of NOx and PM, from each category of commercial diesel vehicle (tempos, trucks, cars/taxis, buses, tractors etc), in each grid have been estimated separately. Further, the total emission in each grid has been calculated by adding emissions from each type of Vehicle. The distribution of latest year's commercial diesel vehicle in each grid has been updated keeping the same distribution pattern as in 2004 using the following method:

$$V_{i,N} = V_{i,o} \text{ x } (TV_N / TV_o) \qquad (4)$$

Where,

$V_{i,N}$ = Number of vehicles in grid i for the year N

$V_{i,o}$ = Number of vehicles in grid i for the year 2004

TV_N = Total Number of vehicles in the year N

TV_o = Total Number of vehicles in the year 2004.

The data of different types of diesel vehicles at 31.1.2007 as shown in Table 3, is obtained from Department of Delhi. Transport data of different types of vehicles registered in 2006 is procured from the same department as shown in Table 4, and estimated value of criteria air pollutants CO, HC, NOx and PM, shown in Table 5 is obtained from the website of Central Pollution Control Board. Table 5 has been considered for having an idea of emissions of NOx and PM in Delhi due to all vehicles. The Table 3, which gives an idea of diesel vehicles, has been used along with the data of Delhi Transport Authority (Table 6a). The data of Tables 4 and 5 has not been directly used due to inability of giving a separate account of diesel operated vehicles.

Finally, Delhi Transport Authority's detailed data which has been shown in Fig. 1 and Table 6(a) has been used to estimate the NOx and PM due to commercial diesel operated vehicles – Trucks, HTV, MTV, LTV, three wheelers, cars/ taxies and commercial buses as given in Table 6(b).

In this way NOx and PM emissions due to commercial diesel vehicles have been apportioned in all 156 grids spatially as well as temporally. Total estimated values of total diesel NOx and PM from commercial diesel vehicles have been given in Table 6(b).

Hourly meteorological data of December 2006–February 2007 of the following parameters has been procured from Indian meteorological department (IMD)

- Wind speed
- Wind direction

- Cloud covers
- Insolation
- Temperature

Hourly mixing height of the same period has been obtained from National Physical Laboratory (NPL).

Hourly stability has been estimated through Turner's Table (1969) using wind speed, insolation and cloud cover data.

4.2 Air quality models

Air pollution modeling can be viewed as the attempt to predict or simulate, by physical or numerical means the ambient concentration of criteria pollutants found within the atmosphere of a domain. The principal application of air pollution modeling is to investigate air quality scenarios so that the associated environmental impact on a selected area can be predicted and quantified. In many instances, a model can provide an acceptable indication of the distribution of a pollutant much more quickly and cheaply than can a monitoring network. Thus, air quality models are important tools and can play a crucial role as part of the methodology developed to protect air quality.

In the present study, the diesel operated commercial vehicular sources have been treated as line sources, which are the major sources of air pollutants namely, Oxides of Nitrogen (NO_x), and Particulate Matter (PM). The concentration contribution due to each type of vehicle is estimated separately using IIT line source model (IITLSM) and USEPA model namely California line source model, version 4 i.e. Caline-4.

Caline-4 Model:

California line Source Dispersion Model version 4 (Caline-4), is the standard modeling program used by Caltrans to assess carbon monoxide impacts near transportation facilities. It is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over the roadways, predicts air concentrations of carbon monoxide (CO), Nitrogen Dioxide (NO2), and suspended particles near roadways. Options are available for modeling near intersections, parking lots, elevated or depressed freeways, and canyons. It is available at http://www.dot.ca.gov/hq/env/air/calinesw.htm. Details of the model can be seen on the same website.

IIT Line source Model:

The IIT line source model is basically a Gaussian type computer based model, developed to predict concentrations of gaseous pollutants CO, SO_2, NO_2, and Particulates based on various types of roads, speeds of different vehicles and different modes of traffic at intersections. Source inventory of IITLS model has been designed according to traffic data, available in urban cities of India. The model formulation for finite and infinite line sources are developed from Gaussian- plume equation, which are given by:

$$C_p = \frac{Q}{\pi u \sigma_y \sigma_Z} \exp\left[-\frac{(z+h)^2}{{\sigma_z}^2}\right] \exp\left[-\frac{(z-h)^2}{{\sigma_z}^2}\right] \tag{5}$$

where,

Q is the source strength (gs^{-1}),

u is the mean wind speed (ms^{-1}),

y is cross wind distance(m)

z is vertical distance (m)

h is the source height (m),

σ_y ,σ_z is the vertical dispersion parameters (m).

The line source is assumed as a line of infinitesimal point sources. The ground level concentrations of gaseous pollutants can be obtained by integrating Eq. (5) along the length of the line source.

IITLS model uses separate equations for calculating pollutant concentrations under crosswind and parallel wind conditions. In the crosswind case, when wind is normal to the road, the ground level concentration of pollutant is given by

$$C_{Xwind} = \frac{2q}{(2\pi)^{\frac{1}{2}} \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{h^2}{\sigma_z} \right) \right] \qquad (6)$$

C_{xwind} is the ground level concentration of pollutant in crosswind, q is the source strength ($gm^{-1}s^{-1}$).

For parallel wind glc's are determined by

$$C_{\parallel wind} = \sum_{i=1}^{NEL} C_p \qquad (7)$$

where $C_{\parallel wind}$ is the glc's of pollutant when wind is parallel to the road, NEL is the number of elements along the length of roadway.

For other wind angle i.e. $15^0 < \phi < 60^0$, the glc's are determined by weighted average of pure crosswind and parallel wind terms by:

$$C_{obl} = \sin^2 \phi C_{xwind} + \cos^2 \phi C_{\parallel wind} \qquad (8)$$

where C_{obl} is the glc's of pollutant for wind $15^0 < \phi < 60^0$

Input data:

24 hourly emission rates of NOx and PM at 156 grids over an area of (26 km x 24 km) have been estimated by the emission inventory. The meteorological parameters like hourly wind speed, wind direction, insolation and cloud cover have been obtained from Indian Meteorological Department (IMD), Delhi. The hourly mixing height has been collected from National Physical Laboratory (NPL). Hourly stability conditions have been obtained through Turner's Table by using wind speed, insolation and cloud cover data.

5. Results and Discussions

5.1 Source Inventory

In the present section a grided source inventory of commercial diesel vehicles in terms of NOx and PM (Fig. 2(a) and (b)) has been discussed in details. The emissions of NOx and PM from commercial diesel vehicles:- Trucks, Tempos, Buses, Cars/Taxis, three wheelers etc. have been apportioned in every grid according to the monitored data obtained from Delhi Transport Authority.

5.2 Vehicle distribution pattern

The diurnal variation of different types of vehicles namely car/ taxi, LTV, HTV and MTV running on different fuels have been plotted from 6 a.m.. To 11 p.m. in the night (Fig. 3). Two peaks in the figure at 10 a.m. and 5 p.m. are observed, which are matching with the office starting and closing hours. The trend of different vehicles categories is found to be nearly same. As observed, there is a steep rise in the number of vehicles between 9 a.m. to 11a.m., which is the office time in Delhi. This density decreases during 12 noon to 3 p.m., which is probably due to mid day hours in the offices and shops. The second peak of the vehicles is visible between 4 p.m. to 6 p.m. which is quiet obvious as it is the office closing hour. The density of vehicles decreases from 5 p.m. to 11 p.m. The figure reveals that the diurnal variation of LTV is highest (2445) among all the categories. The least vehicular density is that of MTV's, which is nearly 58 at 12 p.m. during night.

5.3 Spatial distribution of NOx emissions

Fig. 4 shows the spatial distribution of emissions of NO_X (tones/day) due to commercial diesel vehicles in the city of Delhi. The figure reveals that there are several pockets where emission of NO_X is found to be highest (0.25 tonnes/day). These places are scattered throughout the study area and majority of them concentrated on the north Delhi (Ashok vihar), Central Delhi (I.T.O., Nizamuddin R.S.) North West Delhi (Janakpuri, Naraina, Azadpur etc.), Shahdara industrial area and Dilshad Garden. It can seen that the emission is high on the border areas also, which justifies to the fact that lots of commercial vehicles move in and out of Delhi increasing the overall emissions.

5.4 Spatial distribution of PM emissions

Fig. 5 shows the distribution of emissions of PM (tones/day) due to commercial diesel vehicles over the study area. The highest PM emission rate in the study area is observed to be 0.049 tonnes/day. The figure shows that the south-west, north Delhi and Shahdara area and the border areas of Delhi are the most affected region in terms of PM emissions from commercial diesel vehicles. It has also been observed that trucks and mini trucks are usually running in these areas.

5.5 Model prediction for NOx and PM

IIT Line source (IITLS) model and Caline-4 model have been used to predict the concentration of NOx and PM due to emissions of commercial diesel vehicles and meteorological data of Dec 2006 to February 2007. The hourly and 24 hourly averaged concentrations of air pollutants have been obtained from both the models. Validation of models with observed data of CPCB of NOx and PM at 6 monitoring stations has been made. However, it is a crude way of validating the model in the sense that there is no monitoring value of NOx and PM due to diesel vehicles is available. However, the comparison gives an idea of performance of both the models for present data in present situation. This reveals that IITLS model performs better than Caline-4 model. It may be due to the development of IITLS model for Indian meteorological conditions. Caline-4 model neglect the winds < $1 ms^{-1}$. Source inventory of caline-4 is also required detailed data of road links and traffic at every grid, which is always not possible. Therefore in the present study all the results of concentration of NOx and PM have been obtained using IITLS Model. This model has already been published in International journal by Goyal et al. (1999).

In the present study, winter months (December, January and February) have been chosen, since winter has worse meteorological scenario. A review of meteorological data of winter months reveals that wind is low i.e. $\leq 1\ ms^{-1}$ (calm) in most of the hour of study months and atmosphere is stable or highly stable. Mixing height data also support the fact by showing the low mixing height.

5.6 Concentration of NOx (µg/m³) over the study area

Fig. 6 shows the isopleths of various concentration of 24-hourly averaged values of NO_X (µg/m^3), obtained from IITLS model due to commercial diesel vehicles during winter months December 2006 - February 2007. Concentrations due to all type of vehicles at each grid of total 156 grids has been listed with appropriate grid numbers and coordinates in Table 7, which ranges from 16.73 to 49.6 µg/m^3. This concentration does not include background concentration. The hot spots due to NOx concentration of commercial diesel vehicles in Delhi has been marked in the same figure. The concentration contribution is maximum at places namely Wazirpur, Azadpur and Sadar Bajar in North Delhi, Dilshad garden NH- 24 and Shahdara in East Delhi, Moti Bagh, NH- 8 in South West Delhi and I.T.O. in central Delhi and Moti Bagh in South Delhi. There are many other places, which have been shown in Table 8. The 24 hourly variation of concentration of NOx at hot spots has been given in Table 8. These places have the concentration between 39 (µg/m^3) to 49 (µg/m^3) which is the highest range of concentration of NOx. Diurnal variation of concentration of NOx at Moti Bagh has been given in Fig. 7, which shows that values of concentration are high in night hours i.e. 11 p.m. to 7 a.m. whereas concentrations of NOx has low values during day hours, which is obvious as most of the commercial vehicles like Trucks, Tempos etc. running on the roads during night hours.

5.7 Concentration of PM over the study area

Models 24-hourly averaged predictions of PM in each grid of study area have been obtained for the same winter period on hourly basis (Fig. 8). The season has, in general, low winds pattern and most of the time stable atmosphere with low mixing heights, which encourages the high concentration of air pollutants. The present study gives an output of grid wise concentration of PM due to all types of commercial diesel vehicles as shown in Table 9, which reflects that 24-hourly averaged concentration of PM in Delhi varies from 3.3 (μg m^{-3}) to 9.7 (μg m^{-3}). It does not include background concentration of PM. Isopleths of various concentration of PM has been drawn to represent the location of hotspots as shown in Fig. 8, which gives a graphical representation of hotspots which are the same as in case of NOx concentrations. The diurnal variation of concentration of PM at hotspots has been given in Table 10.

The graphical presentation of diurnal variation of PM at Moti Bagh has also been shown in Fig. 9, which has the same pattern as of concentration of NOx. High concentrations are observed in night hours and low are in day hours.

5.8 Concentration contribution of different type of vehicles

The concentration contribution made by each type of vehicle individually is as follows:

- Tempos are contributing 58% of the total concentration of NOx and PM as shown in Figs. 10 and 11 respectively.
- Small Trucks (M. T. V.) contribute 3.7% of total concentration of NOx and PM as shown in Figs. 12 and 13 respectively.
- Trucks (H. T. V.) contribute 24.1% of total concentration as Fig. 14 and 15 respectively.
- Tractors, Trailors and others contribute 0.18% of the total as Fig. 16 and 17 respectively.
- Cars/Taxis (L. C. V.) contribute 9.7% of the total as Fig. 18 and 19 respectively.
- Buses contribute 12% of the total as Fig. 20 and 21 respectively.

5.9 Assessment of concentration of NOx and PM

The comparison of model's concentration of NOx and PM with National Ambient Air Quality Standards (NAAQS) (Table 11) and observed values at 7 monitoring stations of CPCB (Table 12, 13 and 14) has been made (Table 15). This Table contains the IITLS models results of 24-hourly averaged concentration of NOx and PM for winter season (December 2006 to February 2007), NAAQS of NOx and PM and 24 hourly averaged values of NOx and PM observed by CPCB at Pitampura, Sirifort, Janakpuri, Nizamuddin, Shahzada Bagh, I.T.O. and Shahdara. It reveals that IITLS model predictions of NOx and PM are below the NAAQS at all the locations. Especially, particulate matter has very low values compared to NOx due to its low emissions . However, the model's NOx values are below the observed values at all the locations. It is noticeable that the model's concentration of NOx are only due to diesel operated vehicles as the observed values are due to all sources, which includes different fueled vehicles, industrial and domestic sources. The above results supports the fact that model's values based on emission of vehicular data of commercial diesel and meteorology of particular place at particular time are always below to the observed values and far below than NAAQS 80 ($\mu g\ m^{-3}$) for residential area. (Pitampura, Sirifort, Janakpuri, Nizamuddin etc.), and industrial area (Shahdara). Overall results lead that model predictions of NOx and PM in Delhi due to diesel operated commercial vehicles are below the NAAQS and observed values, which seems to be correct as predictions are only due to vehicular sources that too only commercial diesel vehicles but the observed concentrations and NAAQS are for mixed sources.

The model values can be compared with NAAQS up to some extent to get an idea that how harmful the concentration of air pollutants, emitted from diesel operated commercial vehicles alone can be in Delhi. Finally it can be concluded that NOx and PM levels in Delhi, emitted from commercial diesel vehicles are well below the standards. At the same time it is worth mentioning that if the number of diesel vehicles will keep on increasing the levels of NOx may exceed the NAAQS. Therefore number of diesel vehicles should be controlled immediately.

6. Conclusions

On the basis of above results and discussion one can conclude that emission inventory of each type of sources is essential for assessing the impact of these sources in Delhi. NOx emissions due to commercial diesel vehicles are substantially high (18.44 tonnes/day) and PM emissions are low as 3.62 tonnes/day but these emissions have the same ratio as the air pollutants due to all fueled vehicles (Table 5).

Air quality models, which are an important tool for impact assessment studies, should be selected appropriately. In the present study, it has been observed that IITLS model is a better choice than USEPA Caline-4 model, since, IITLS model has been developed according to Indian traffic and meteorological conditions.

The model predictions due to each type of commercial diesel vehicle have been made separately. The Tempos contribute maximum amount of concentration of NOx and PM (58%) followed by Trucks (24.1%), Buses (12%), Cars/Taxis (9.7%), Small Trucks (3.7%) and Tractor, Trailor (0.18%). Thus control may require to be made on the new registration of diesel tempos and trucks.

In the present study the winter season has been selected for the assessment due to the worst meteorological scenarios in winter. The similar type of study can be made for the other season also.

Finally, one can say that levels of NOx and PM due to diesel operated commercial vehicles namely Tempos, Trucks, Buses, Cars/Taxis etc. are well within the limits of NAAQS. It is also justifiable that emission of air pollutants may exceed with the increase in the number of vehicles. As the emission of air pollutants are directly proportional to the number of vehicles and the concentration of ambient air pollutants is also directly proportional to the emission of air polluting sources. It is also concluded that a control on emissions of pollutant from vehicular traffic necessitates the control on the new registration of commercial diesel vehicles in Delhi.

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Tables:

Table 1: Emission factors for Different categories of Vehicles (gm/km):

Type	Norms	CO	HC	NOx	PM
PCG/MUVG	Pre Euro Norms up to 1995	9.8	1.7	1.8	0.06
	Pre Euro Norms 1996-2000	3.9	0.8	1.1	0.05
	India Stage 2000 norms (Euro-I)	2.4	0.48	0.39	0.04
	Bharat Stage-II (Euro-II)	1.98	0.25	0.2	0.03
	Bharat Stage-III (Euro-III)	1.39	0.15	0.12	0.02
	Bharat Stage-IV (Euro-IV)	1.0	0.126	0.127	0.016
PCD/MUVD	Pre Euro Norms up to 1995	7.3	0.37	2.77	0.84
	Pre Euro Norms 1996-2000	1.2	0.37	0.69	0.42
	India Stage 2000 norms (Euro-I)	1.0	0.25	0.59	0.14
	Bharat Stage-II (Euro-II)	0.9	0.13	0.5	0.07
	Bharat Stage-III (Euro-III)	0.58	0.05	0.45	0.05
	Bharat Stage-IV (Euro-IV)	0.50	0.056	0.5	0.05
LCV	Pre Euro Norms up to 1995	8.7	0.34	3.15	0.8
	Pre Euro Norms 1996-2000	6.9	0.28	2.49	0.5
	India Stage 2000 norms (Euro-I)	5.1	0.14	1.28	0.2
	Bharat Stage-II (Euro-II)	0.72	0.063	0.59	0.07
	Bharat Stage-III (Euro-III)	0.64	0.056	0.50	0.05
	Bharat Stage-IV (Euro-IV)	0.50	0.030	0.025	0.025
Trucks	Pre Euro Norms up to 1995	5.5	1.78	9.5	1.5
	Pre Euro Norms 1996-2000	4.5	1.21	8.4	0.8
	India Stage 2000 norms (Euro-I)	3.6	0.87	6.3	0.28
	Bharat Stage-II (Euro-II)	3.2	0.97	5.5	0.12
	Bharat Stage-III (Euro-III)	2.8	0.77	5	0.10
	Bharat Stage-IV (Euro-IV)	1.4	0.39	2.45	0.06
Bus	Pre Euro Norms up to 1995	5.5	1.78	19	3
	Pre Euro Norms 1996-2000	4.5	1.21	16.8	1.6
	India Stage 2000 norms (Euro-I)	3.6	0.87	12.6	0.56
	Bharat Stage-II (Euro-II)	3.2	0.87	11	0.24
	Bharat Stage-III (Euro-III)	2.8	0.77	10	0.24
	Bharat Stage-IV (Euro-IV)	1.4	0.39	4.9	0.22
2 wheelers 2 stroke	Pre 1995 Norms	6.5	3.9	0.03	0.23
	1996-2000 Norms	4.0	3.3	0.06	0.1
	2001-2005 norms (India Stage 2000)	2.2	2.13	0.06	0.05
	2005-2010 norms (Bharat Stage-II)	1.4	1.32	0.07	0.05
2 wheelers 4 stroke	Pre 1995 Norms	3	0.8	0.31	0.07
	1996-2000 Norms	2.6	0.7	0.3	0.06
	2001-2005 norms (India Stage 2000)	2.2	0.7	0.3	0.05
	2005-2010 norms (Bharat Stage-II)	2.4	0.7	0.3	0.05
3 wheelers 2 stroke	Pre 1995 Norms	14	8.3	0.05	0.35
	1996-2000 Norms	8.6	7.7	0.09	0.15
	2001-2005 norms (India Stage 2000)	4.3	2.05	0.11	0.08
	2005-2010 norms (Bharat Stage-II)	2.45	0.75	0.12	0.08

Source: CPCB

Table 2 (a): Annual mileage (km) for different categories of Vehicles

S. No.	Vehicle type	Annual mileage (km)
1	2 wheelers	10,000
2	3 wheelers	40,000
3	Passenger cars	15,000
4	Taxis	30,000
5	Multi utility vehicles	37,000
6	Light commercial vehicles	40,000
7	Trucks	30,000
8	Buses	60,000

Source: Transport fuel quality for year 2005, CPCB, MoEF

Table 2(b): Deterioration factors for diesel vehicles

Age of vehicles (years)	Passenger Cars			Taxis			Buses			Trucks			MUV+ LCV		
	PM	CO	HC & NOX	PM	CO	HC & NOX	PM	CO	HC & NOX	PM	CO	HC & NOX	PM	CO	HC & NOX
15-20	1.355	1.18	1												
10-15	1.17	1.085	1							1.80	1.475	1	1.275	1.100	1
5-10	1.28	1.14	1	1.263	1.133	1	1.355	1.18	1	1.595	1.33	1	1.255	1.125	1
0-5	1.097	1.05	1	1.187	1.095	1	1.19	1.015	1	1.35	1.17	1	1.19	1.19	1

Source: Transport fuel quality for year 2005, CPCB, MoEF

Table 3: Diesel vehicles (Monthly report of PCC's: Month January, 2007)

BUS		TRUCK		TEMPO		CAR		D/VAN		Others	
TVC	PUCCI	TVC	PUCCI	TVC	PUCCI	TVC	PUCCI	TVC	PUCCI	TVC	PUCCI
733	673	3584	3248	8384	7704	19464	16880	732	672	88	79

Source: Transport Department, Delhi

Table 4: Statistics about number of registered vehicles as on 31.1.2007

S. No.	Category	No. of vehicles
1	Two Wheelers (Pvt.)	3277905
2	Four Wheelers (Pvt.)	1568990
3	Buses (LPV, MPV, HPV)	43447
4	TSR (Auto Rickshaw)	74183
5	Taxis	25223
6	Goods (LGV, MGV, HGV)	135293
7	Others	13670
Total		5138711

Table 5: Estimated vehicular emission load in Delhi

Pollutant	Pollutant load (ton/day)
Carbon Monoxide	421.84
Hydrocarbons	184.37
Nitrogen oxides	110.45
Particulate Matter	12.77
Total Pollution Load	729.43

Table 6(a): Diesel operated vehicles up to 1 May 2007

S. No.	Categories of vehicles	Number of vehicles
1	Diesel vehicles (GVW up to 3000 kg) Cars/Taxis	5432
2	Light passenger buses on diesel	2506
3	Medium passenger buses	0
4	Heavy passenger buses on diesel	1457
5	Light good vehicles (Tempos)	32543
6	Medium good vehicles (Medium Trucks)	2073
7	Heavy good vehicles (Trucks)	13485
8	Tractor + trailor + others	101
	Total	57,597

Source: Delhi Transport Authority

Table 6(b): Estimated emission rates (tonnes/day) of NOx and PM from commercial diesel vehicles up to 1 May 2007

	NOx (tonnes/day)	PM (tonnes/day)
Commercial diesel	18.44	3.62

Source: Data from Delhi Transport Authority

Table 7: 24-hourly averaged concentration of NOx (μg m^{-3}) due to commercial diesel vehicles at 156 grids over study area (26 km x 24 km).

Grid Number	Coordinates		Concentration (μg m^{-3})
	X	Y	
1	1	1	29.012
2	3	1	16.728
3	5	1	18.119
4	7	1	25.968
5	9	1	29.47
6	11	1	20.184
7	13	1	30.643
8	15	1	37.768
9	17	1	23.123
10	19	1	26.915
11	21	1	27.962
12	23	1	25.93
13	25	1	22.799
14	25	3	18.891
15	23	3	20.979
16	21	3	24.117
17	19	3	30.031
18	17	3	28.568
19	15	3	33.182
20	13	3	38.126
21	11	3	27.653
22	9	3	29.932
23	7	3	26.144
24	5	3	17.802
25	3	3	17.517
26	1	3	31.672
27	1	5	28.142
28	3	5	28.541
29	5	5	24.037
30	7	5	33.434
31	9	5	32.274
32	11	5	39.354
33	13	5	40.467
34	15	5	35.555
35	17	5	38.312
36	19	5	34.531
37	21	5	24.986
38	23	5	23.759
39	25	5	18.895
40	25	7	17.494
41	23	7	24.127
42	21	7	24.435
43	19	7	36.281
44	17	7	37.353
45	15	7	41.749
46	13	7	39.066
47	11	7	36.937
48	9	7	42.931
49	7	7	26.74
50	5	7	29.069
51	3	7	31.394
52	1	7	22.295
53	1	9	22.99

54	3	9	27.68
55	5	9	35.579
56	7	9	36.757
57	9	9	49.602
58	11	9	46.487
59	13	9	42.242
60	15	9	40.646
61	17	9	36.656
62	19	9	25.659
63	21	9	24.316
64	23	9	34.471
65	25	9	32.021
66	25	11	34.876
67	23	11	37.491
68	21	11	26.505
69	19	11	20.426
70	17	11	37.155
71	15	11	35.2
72	13	11	40.764
73	11	11	47.336
74	9	11	40.944
75	7	11	44.964
76	5	11	45.527
77	3	11	30.41
78	1	11	25.395
79	1	13	29.161
80	3	13	31.848
81	5	13	44.286
82	7	13	28.302
83	9	13	29.082
84	11	13	41.637
85	13	13	40.57
86	15	13	44.662
87	17	13	29.969
88	19	13	24.893
89	21	13	24.381
90	23	13	33.369
91	25	13	27.446
92	25	15	24.044
93	23	15	28.639
94	21	15	33.818
95	19	15	30.737
96	17	15	29.053
97	15	15	41.263
98	13	15	36.344
99	11	15	40.35
100	9	15	25.872
101	7	15	27.201
102	5	15	33.466
103	3	15	29.003
104	1	15	28.691
105	1	17	28.977
106	3	17	29.129
107	5	17	40.985
108	7	17	28.566
109	9	17	34.473
110	11	17	37.957
111	13	17	36.034
112	15	17	42.32

113	17	17	27.832
114	19	17	34.267
115	21	17	29.201
116	23	17	25.478
117	25	17	21.15
118	25	19	28.093
119	23	19	29.864
120	21	19	33.004
121	19	19	38.644
122	17	19	31.412
123	15	19	31.242
124	13	19	35.1
125	11	19	34.942
126	9	19	25.376
127	7	19	31.185
128	5	19	36.903
129	3	19	31.461
130	1	19	31.699
131	1	21	31.473
132	3	21	24.865
133	5	21	30.916
134	7	21	33.569
135	9	21	29.766
136	11	21	31.933
137	13	21	40.358
138	15	21	21.152
139	17	21	24.932
140	19	21	24.682
141	21	21	27.831
142	23	21	34.206
143	25	21	32.546
144	25	23	21.296
145	23	23	23.28
146	21	23	25.539
147	19	23	26.204
148	17	23	27.651
149	15	23	16.075
150	13	23	28.479
151	11	23	30.772
152	9	23	20.183
153	7	23	24.204
154	5	23	29.336
155	3	23	32.942
156	1	23	30.121

Table 8: Hourly Concentration ($\mu g/m^3$) of NOx from Commercial diesel vehicle at various hot spots in Delhi

Receptor Names (coordinate) /hours	Amar Colony	Munirka	Moti Bagh	Sarojini Nagar	India Gate	Cha-nakya Puri	Dhaula Kuan	Cant Area	Nangal Raya	Rashtra-pati Bhawan	I .T. O.	Moti Nagar	Red Fort	Sadar Bajar	Mayur Vihar	Wazir Pur	Shadra
	(15, 7)	(9,7)	(9,9)	(11,9)	(13,9)	(11,11)	(7,11)	(5,11)	(5,13)	(11,13)	(15,15)	(5,17)	(15,17)	(13,21)	(23,11)	(9,21)	(23,21)
1	24.01	20.03	69.19	41.54	30.06	45.19	71.93	76.89	67.59	43.82	40.19	86.96	40.84	46.91	85.11	88.07	80.74
2	64.15	93.13	98.03	60.17	52.16	110.76	109.03	129.5	104.41	58.83	74	90.48	68.54	61.11	31.93	57.45	26.2
3	62.79	106.69	124.47	115.9	96.04	108.4	96.12	94.48	102.07	98.09	68.69	92.09	65.87	66.04	40.45	47.44	23.52
4	82.47	98.16	102.17	97.53	87.79	92.91	83.2	84.63	86.43	82.48	58.09	57.68	59.17	55.5	57.48	41.53	21.99
5	110.84	99.7	106.86	119.26	108.62	107.34	99.59	104.86	93.11	95.07	67.87	58.62	70.67	58.73	76.4	31.61	27.99
6	93.34	88.53	84.36	82.3	83.49	82.52	65.64	76.93	55.63	66.58	78.86	53.88	59.47	49.98	70.47	37.01	21.38
7	112	66.78	80.92	76.8	112.41	74.68	73.85	48.28	51.07	67.1	101.47	53.15	87.9	68.72	92.06	38.75	48.32
8	37.69	29.58	44.09	47.74	43.08	37.44	28.07	28.52	30.73	41.71	38.1	31.87	74.87	42.94	56.78	32.28	28.37
9	30.11	35.79	45.32	45.32	24.71	44.03	37.73	38.88	41.97	39.27	40.38	40.69	43.82	49.04	49.56	23.69	62.42
10	13.94	6.41	26.88	17.58	15.46	18	8.52	12.78	15	13.62	19.34	19.43	13.52	20.24	23.25	25.41	28.44
11	14.54	14.12	13.37	13.52	5.35	13.75	19.83	9.22	10.39	14.78	20.49	15.95	21.06	21.29	16.58	13.9	21.78
12	8.04	2.89	3.93	10.16	13.23	4.74	9.59	11.23	11.42	4.18	11.02	11.03	8.87	14.59	8.07	13.2	13.7
13	23.28	15.3	16.31	10.46	18.33	10.99	11.4	3.17	4.67	18.34	19.13	6.48	22.67	15.82	10.15	15.08	11.48
14	6.87	6.12	7.98	13.17	15.87	12.5	11.13	7.7	10.59	16.29	10.03	12.79	9.12	8.25	6.01	14.02	6.49
15	13.77	23.35	21.92	11.03	12.96	18.05	27.75	21.7	24.6	14	8.37	12.79	7.34	9.99	19.6	11.75	16.71
16	11.41	21.64	18.31	13.6	11.96	9.46	17.6	18.83	18.08	13.77	23.65	18.7	29.57	20.93	21.72	30.73	26.1
17	26.61	63.5	24.2	37.46	17.93	51.75	56.66	65.82	55.25	49.56	28.24	49.78	30.21	33.19	21.29	34.53	13.39
18	39.91	35.79	45.32	45.32	39.66	44.03	37.73	38.88	41.97	39.27	42.36	40.69	45.32	48.8	31.93	23.69	20.09
19	39.91	35.79	45.32	45.32	39.66	44.03	37.73	38.88	41.97	39.27	42.36	40.69	45.32	48.8	31.93	23.69	20.09
20	26.61	23.86	30.21	30.21	26.44	29.36	25.15	25.92	27.98	26.18	28.24	27.12	30.21	32.53	21.29	15.79	13.39
21	39.91	35.79	45.32	45.32	39.66	44.03	37.73	38.88	41.97	39.27	42.36	40.69	45.32	48.8	31.93	23.69	20.09
22	39.91	35.79	45.32	45.32	39.66	44.03	37.73	38.88	41.97	39.27	42.36	40.69	45.32	48.8	31.93	23.69	20.09
23	39.91	35.79	45.32	45.32	39.66	44.03	37.73	38.88	41.97	39.27	42.36	40.69	45.32	48.8	31.93	23.69	20.09
24	39.91	35.79	45.32	45.32	39.66	44.03	37.73	38.88	41.97	39.27	42.36	40.69	45.32	48.8	31.93	23.69	20.09

Table 9: 24-hourly averaged concentration of PM ($\mu g\ m^{-3}$) due to commercial diesel vehicles at 156 grids over study area (26 km x 24 km).

Grid Number	Coordinates		Concentration ($\mu g\ m^{-3}$)
	X	Y	
1	1	1	5.699
2	3	1	3.286
3	5	1	3.559
4	7	1	5.101
5	9	1	5.789
6	11	1	3.965
7	13	1	6.019
8	15	1	7.419
9	17	1	4.542
10	19	1	5.287
11	21	1	5.493
12	23	1	5.094
13	25	1	4.478
14	25	3	3.711
15	23	3	4.121
16	21	3	4.737
17	19	3	5.899
18	17	3	5.612
19	15	3	6.518
20	13	3	7.489
21	11	3	5.432
22	9	3	5.88
23	7	3	5.136
24	5	3	3.497
25	3	3	3.441
26	1	3	6.222
27	1	5	5.528
28	3	5	5.606
29	5	5	4.722
30	7	5	6.568
31	9	5	6.34
32	11	5	7.731
33	13	5	7.949
34	15	5	6.984
35	17	5	7.526
36	19	5	6.783
37	21	5	4.908
38	23	5	4.667
39	25	5	3.712
40	25	7	3.436
41	23	7	4.739
42	21	7	4.8
43	19	7	7.127
44	17	7	7.338
45	15	7	8.201
46	13	7	7.674
47	11	7	7.256
48	9	7	8.433
49	7	7	5.253
50	5	7	5.71
51	3	7	6.167
52	1	7	4.379
53	1	9	4.516

54	3	9	5.437
55	5	9	6.989
56	7	9	7.22
57	9	9	9.744
58	11	9	9.132
59	13	9	8.298
60	15	9	7.984
61	17	9	7.201
62	19	9	5.04
63	21	9	4.777
64	23	9	6.771
65	25	9	6.29
66	25	11	6.851
67	23	11	7.365
68	21	11	5.207
69	19	11	4.012
70	17	11	7.299
71	15	11	6.915
72	13	11	8.008
73	11	11	9.299
74	9	11	8.043
75	7	11	8.833
76	5	11	8.943
77	3	11	5.974
78	1	11	4.988
79	1	13	5.728
80	3	13	6.256
81	5	13	8.699
82	7	13	5.56
83	9	13	5.713
84	11	13	8.179
85	13	13	7.969
86	15	13	8.773
87	17	13	5.887
88	19	13	4.89
89	21	13	4.789
90	23	13	6.555
91	25	13	5.391
92	25	15	4.723
93	23	15	5.626
94	21	15	6.643
95	19	15	6.038
96	17	15	5.707
97	15	15	8.106
98	13	15	7.139
99	11	15	7.926
100	9	15	4.543
101	7	15	5.343
102	5	15	6.574
103	3	15	5.697
104	1	15	5.636
105	1	17	5.692
106	3	17	5.722
107	5	17	8.051
108	7	17	5.612
109	9	17	6.772
110	11	17	7.456
111	13	17	7.078
112	15	17	8.313

113	17	17	5.467
114	19	17	6.731
115	21	17	5.736
116	23	17	5.005
117	25	17	4.155
118	25	19	5.518
119	23	19	5.866
120	21	19	6.483
121	19	19	7.591
122	17	19	6.17
123	15	19	6.137
124	13	19	6.895
125	11	19	6.864
126	9	19	4.985
127	7	19	6.126
128	5	19	7.249
129	3	19	6.18
130	1	19	6.227
131	1	21	6.182
132	3	21	4.884
133	5	21	6.073
134	7	21	6.594
135	9	21	5.847
136	11	21	6.273
137	13	21	7.928
138	15	21	4.155
139	17	21	4.897
140	19	21	4.848
141	21	21	5.467
142	23	21	6.719
143	25	21	6.393
144	25	23	4.183
145	23	23	4.573
146	21	23	5.017
147	19	23	5.147
148	17	23	5.432
149	15	23	3.158
150	13	23	5.594
151	11	23	6.045
152	9	23	3.965
153	7	23	4.754
154	5	23	5.763
155	3	23	6.471
156	1	23	5.917

Table 10: Hourly Concentration ($\mu g/m^3$) of PM from Commercial diesel vehicle at various hot spots in Delhi

Receptor Names (coordinate) /hours	Amar Colony	Munirka	Moti Bagh	Sarojini Nagar	India Gate	Cha-nakya Puri	Dhaula Kuan	Cant Area	Nangal Raya	Rashtra-pati Bhawan	I .T. O.	Moti Nagar	Red Fort	Sadar Bajar	Mayur Vihar	Wazir Pur	Shadra
1	4.72	3.93	13.59	8.16	5.91	8.88	14.13	15.1	13.28	8.61	7.89	17.08	8.02	9.21	16.72	17.3	13.38
2	12.6	18.29	19.26	11.82	10.25	21.76	21.42	25.44	20.51	11.56	14.54	17.77	13.46	12	6.27	11.28	6.73
3	12.33	20.96	24.45	22.77	18.87	21.29	18.88	18.56	20.05	19.27	13.49	18.09	12.94	12.97	7.95	9.32	8.17
4	16.2	19.28	20.07	19.16	17.25	18.25	16.34	16.62	16.98	16.2	11.41	11.33	11.62	10.9	11.29	8.16	6.99
5	21.77	19.58	20.99	23.43	21.34	21.09	19.56	20.6	18.29	18.67	13.33	11.51	13.88	11.54	15.01	6.21	7.71
6	18.34	17.39	16.57	16.17	16.4	16.21	12.89	15.11	10.93	13.08	15.49	10.58	11.68	9.82	13.84	7.27	8.45
7	22	13.12	15.9	15.09	22.08	14.67	14.51	9.48	10.03	13.18	19.93	10.44	17.27	13.5	18.08	7.61	10.72
8	7.4	5.81	8.66	9.38	8.46	7.35	5.51	5.6	6.04	8.19	7.48	6.26	14.71	8.44	11.15	6.34	10.7
9	5.91	7.03	8.9	8.9	4.85	8.65	7.41	7.64	8.25	7.71	7.93	7.99	8.61	9.63	9.74	4.65	14.41
10	2.74	1.26	5.28	3.45	3.04	3.54	1.67	2.51	2.95	2.67	3.8	3.82	2.66	3.98	4.57	4.99	4.71
11	2.86	2.77	2.63	2.66	1.05	2.7	3.9	1.81	2.04	2.9	4.03	3.13	4.14	4.18	3.26	2.73	4.3
12	1.58	0.57	0.77	2	2.6	0.93	1.88	2.21	2.24	0.82	2.16	2.17	1.74	2.87	1.59	2.59	2.07
13	4.57	3.01	3.2	2.05	3.6	2.16	2.24	0.62	0.92	3.6	3.76	1.27	4.45	3.11	1.99	2.96	2.57
14	1.35	1.2	1.57	2.59	3.12	2.45	2.19	1.51	2.08	3.2	1.97	2.51	1.79	1.62	1.18	2.75	2.92
15	2.71	4.59	4.31	2.17	2.55	3.55	5.45	4.26	4.83	2.75	1.64	2.51	1.44	1.96	3.85	2.31	3.52
16	2.24	4.25	3.6	2.67	2.35	1.86	3.46	3.7	3.55	2.7	4.65	3.67	5.81	4.11	4.27	6.04	4.58
17	5.23	12.47	4.75	7.36	3.52	10.17	11.13	12.93	10.85	9.74	5.55	9.78	5.94	6.52	4.18	6.78	4.49
18	7.84	7.03	8.9	8.9	7.79	8.65	7.41	7.64	8.25	7.71	8.32	7.99	8.9	9.59	6.27	4.65	6.73
19	7.84	7.03	8.9	8.9	7.79	8.65	7.41	7.64	8.25	7.71	8.32	7.99	8.9	9.59	6.27	4.65	6.73
20	5.23	4.69	5.94	5.94	5.19	5.77	4.94	5.09	5.5	5.14	5.55	5.33	5.94	6.39	4.18	3.1	4.49
21	7.84	7.03	8.9	8.9	7.79	8.65	7.41	7.64	8.25	7.71	8.32	7.99	8.9	9.59	6.27	4.65	6.73
22	7.84	7.03	8.9	8.9	7.79	8.65	7.41	7.64	8.25	7.71	8.32	7.99	8.9	9.59	6.27	4.65	6.73
23	7.84	7.03	8.9	8.9	7.79	8.65	7.41	7.64	8.25	7.71	8.32	7.99	8.9	9.59	6.27	4.65	6.73
24	7.84	7.03	8.9	8.9	7.79	8.65	7.41	7.64	8.25	7.71	8.32	7.99	8.9	9.59	6.27	4.65	6.73

Table 11: National Ambient Air Quality Standards

Pollutants	Time-weighted average	Concentration in ambient air			Method of measurement
		Industrial Areas	Residential, Rural & other Areas	Sensitive Areas	
SulphurDioxide (SO_2)	Annual Average*	80 µg/m^3	60 µg/m^3	15 µg/m^3	- Improved West and Geake Method - Ultraviolet Fluorescence
	24 hours**	120 µg/m^3	80 µg/m^3	30 µg/m^3	
Oxides of Nitrogen as (NO_2)	Annual Average*	80 µg/m^3	60 µg/m^3	15 µg/m^3	- Jacob & Hochheiser Modified (Na-Arsenite) Method
	24 hours**	120 µg/m^3	80 µg/m^3	30 µg/m^3	- Gas Phase Chemiluminescence's
Suspended Particulate Matter (SPM)	Annual Average*	360 µg/m^3	140 µg/m^3	70 µg/m^3	- High Volume Sampling, (Average flow rate not less than 1.1 m3/minute).
	24 hours**	500 µg/m^3	200 µg/m^3	100 µg/m^3	
Respirable Particulate Matter (RPM) (size less than 10 microns)	Annual Average*	120 µg/m^3	60 µg/m^3	50 µg/m^3	- Respirable particulate matter sampler
	24 hours**	150 µg/m^3	100 µg/m^3	75 µg/m^3	
Lead (Pb)	Annual Average*	1.0 µg/m^3	0.75 µg/m^3	0.50 µg/m^3	- ASS Method after sampling using EPM 2000 or equivalent Filter paper
	24 hours**	1.5 µg/m^3	1.00 µg/m^3	0.75 µg/m^3	.
Ammonia1	Annual Average*	0.1 mg/ m^3	0.1 mg/ m^3	0.1 mg/m^3	.
	24 hours**	0.4 mg/ m^3	0.4 mg/m^3	0.4 mg/m^3	.
Carbon Monoxide (CO)	8 hours**	5.0 mg/m^3	2.0 mg/m^3	1.0 mg/ m^3	- Non Dispersive Infra Red (NDIR)
	1 hour	10.0 mg/m^3	4.0 mg/m^3	2.0 mg/m^3	Spectroscopy
*	Annual Arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval.				
**	24 hourly/8 hourly values should be met 98% of the time in a year. However, 2% of the time, it may exceed but not on two consecutive days.				

Table 12: **December – 2006,** Ambient Air Quality data of Delhi (CPCB)

PARAMETERS /LOCATIONS	NO_2 (24 HOURLY AVERAGE) $\mu g/m^3$				SPM (24 HOURLY AVERAGE) $\mu g/m^3$			
	Min	Max	Mean	Percentage Exceedence	Min	Max	Mean	Percentage Exceedence
Pitampura (R)	31	52	39	0	226	552	361	100
Siri Fort (R)	27	51	40	0	298	554	430	100
Janakpuri (R)	51	75	59	0	262	538	427	100
Nizamuddin (R)	31	57	42	0	257	515	378	100
Shahzada Bagh (I)	34	60	47	0	321	525	416	33
Shahdara (I)	49	64	56	0	326	709	461	17
I.T.O.	58	113	85	61	263	836	545	100

Table 13: **January – 2007,** Ambient Air Quality data of Delhi (CPCB)

PARAMETERS /LOCATIONS	NO_2 (24 HOURLY AVERAGE) $\mu g/m^3$				SPM (24 HOURLY AVERAGE) $\mu g/m^3$			
	Min	Max	Mean	Percentage Exceedence	Min	Max	Mean	Percentage Exceedence
Pitampura (R)	25	59	42	0	236	332	276	100
Siri Fort (R)	32	59	45	0	381	496	453	100
Janakpuri (R)	38	60	53	0	396	587	467	100
Nizamuddin (R)	29	76	49	0	261	427	332	100
Shahzada Bagh (I)	29	66	46	0	235	427	318	0
Shahdara (I)	51	63	58	0	427	810	527	33
I.T.O.	61	118	86	71	358	899	578	100

Table 14: **February – 2007,** Ambient Air Quality data of Delhi (CPCB)

PARAMETERS /LOCATIONS	NO_2 (24 HOURLY AVERAGE) $\mu g/m^3$				SPM (24 HOURLY AVERAGE) $\mu g/m^3$			
	Min	Max	Mean	Percentage Exceedence	Min	Max	Mean	Percentage Exceedence
Pitampura (R)	22	31	26	0	119	366	233	60
Siri Fort (R)	31	41	36	0	127	694	351	83
Janakpuri (R)	31	46	39	0	184	858	471	83
Nizamuddin (R)	22	30	25	0	148	313	223	50
Shahzada Bagh (I)	28	35	32	0	118	403	280	0

Shahdara (I)	37	59	51	0	286	629	463	50
I.T.O.	52	102	82	59	198	805	441	96

Table 15: Comparison of model predicted 24 hourly averaged values of NOx and PM with National Ambient Air quality Standards and Observed values at different receptor points

Locations	24 hourly averaged concentration of NOx ($\mu g\ m^{-3}$)			24 hourly averaged concentration of PM ($\mu g\ m^{-3}$)		
	IITLS Model	NAAQS	CPCB Observed Values	IITLS Model	NAAQS	CPCB Observed Values
Pitampura	30.916	80	35.7	6.073	200	290.0
Sirifort	40.467		40.33	7.949		411.3
Janakpuri	29.161		50.33	5.728		455.0
Nizamuddin	36.656		38.67	7.201		311.0
Shahzada Bagh	29.766		41.67	5.847		338.0
I.T.O.	29.053		84.33	5.707		521.3
Shahdara	29.864	120	55.00	5.866	500	338.0

Figures:

Figure 1: Flow chart representing various categories of vehicle as given by Delhi Transport Authority:

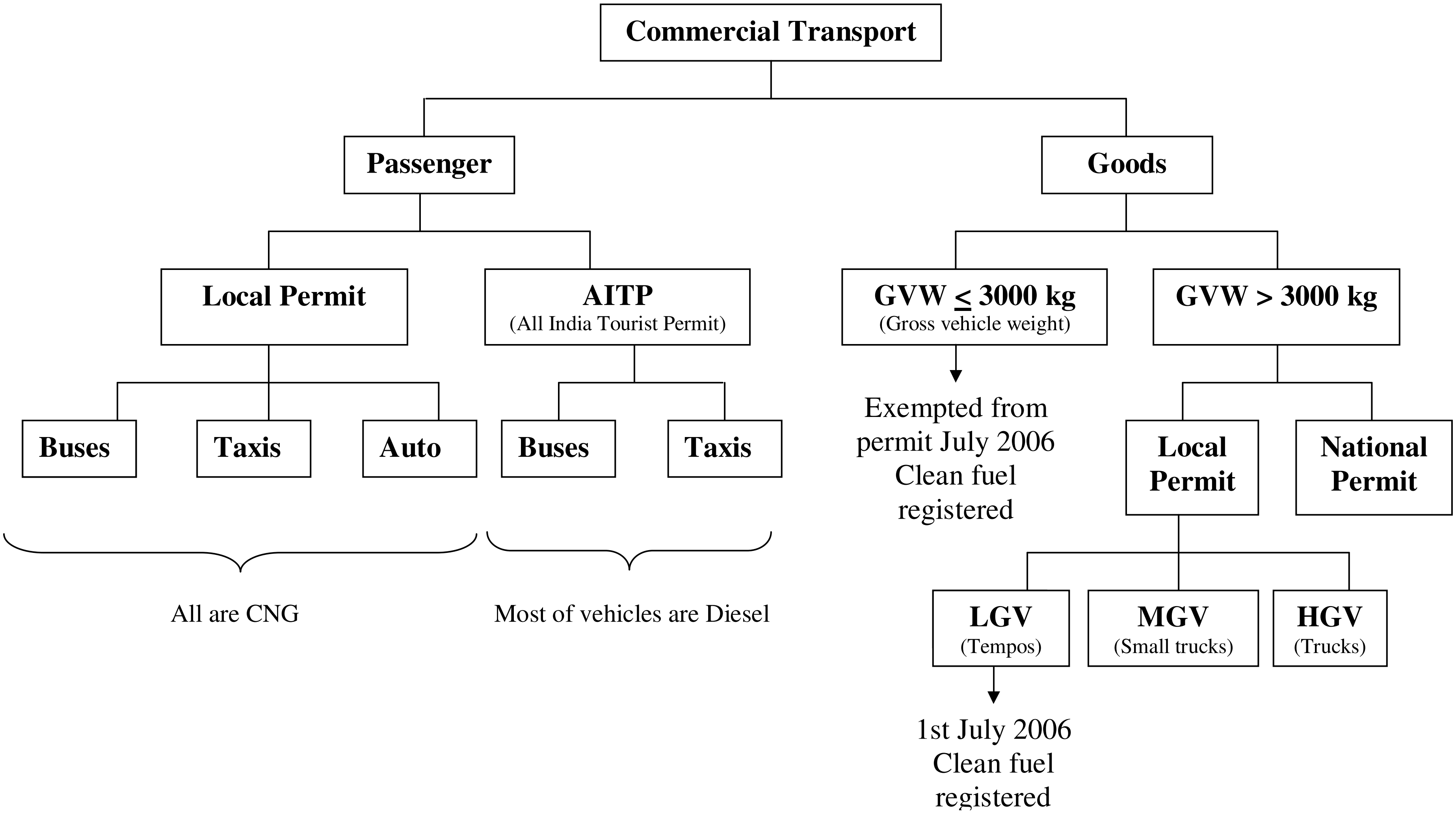

Figure 2a: Study area of Delhi City (26 km x 24 km)

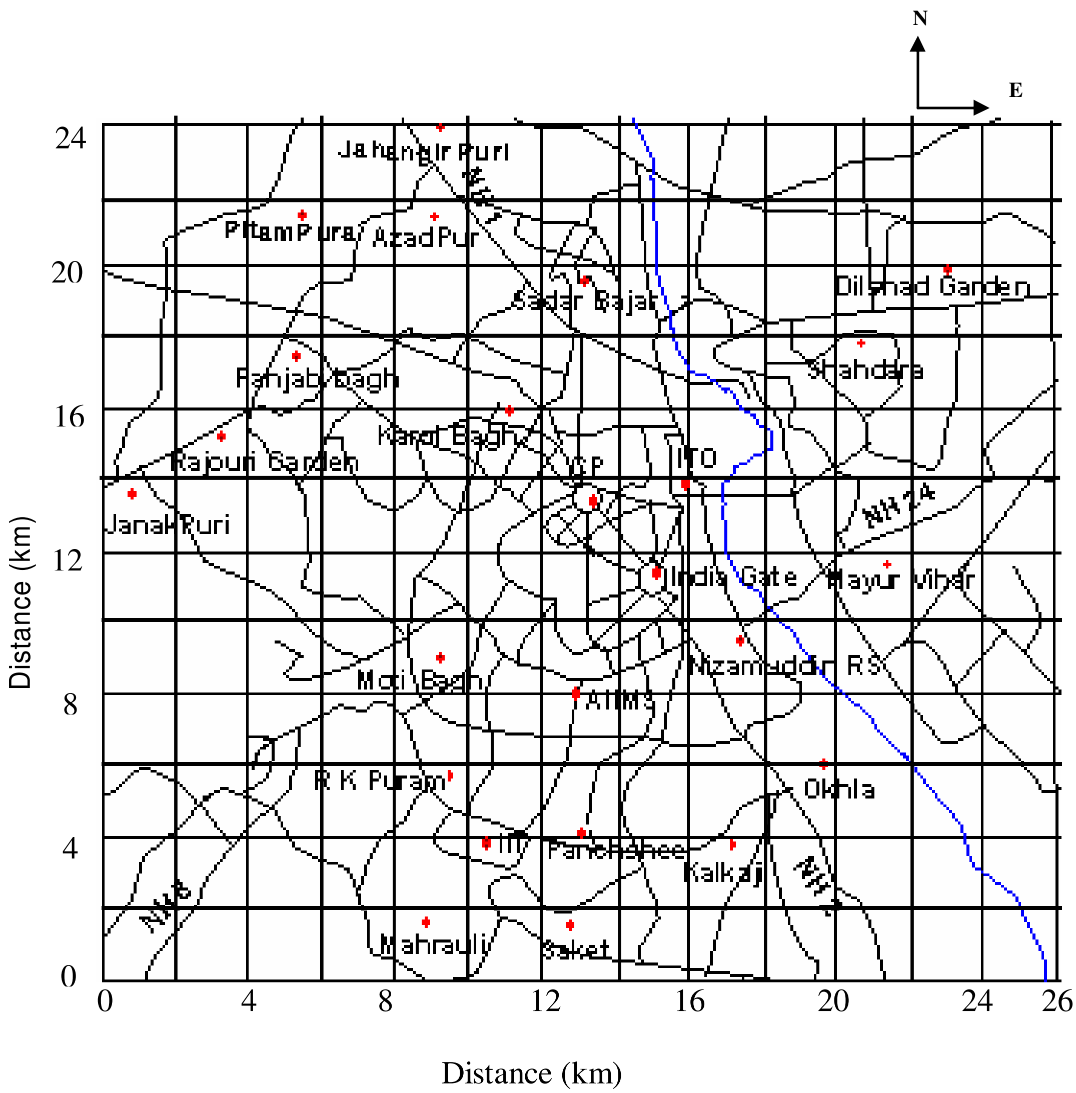

Figure 2b: Study area in the grided form showing the main receptor points

Rohini	Pitam Pura	Azadpur	Mukher-jee Nagar	Amam Vihar	Ram Vihar	Shalimar
Pash-chim Vihar	Panjabi Bagh	Shastri Nagar	Sadar Bajar	Kailash Nagar	Shahdara	Dilshad
Janak Puri	Pusa	Karol Bagh	Connaught Place	ITO	Shakar Pur	Anand Vihar
Kailash Puri	Kibby Place	Moti Bbagh	India Gate	Nizza-muddin R.S.	Mayur Vihar	Ashok Na
Airport	Vasant Vihar	R.K. Puram	AIIMS	Okhla	Abdul Fazal Enclave	Naur-anga-
Kapas Khera	Vasant Kunj	Mehrauli	Saket	Kalkajee	Okhla Indust. Estate	Sarita Vihar

Figure 3: Diurnal variation of vehicles at ITO during winter season in 2004

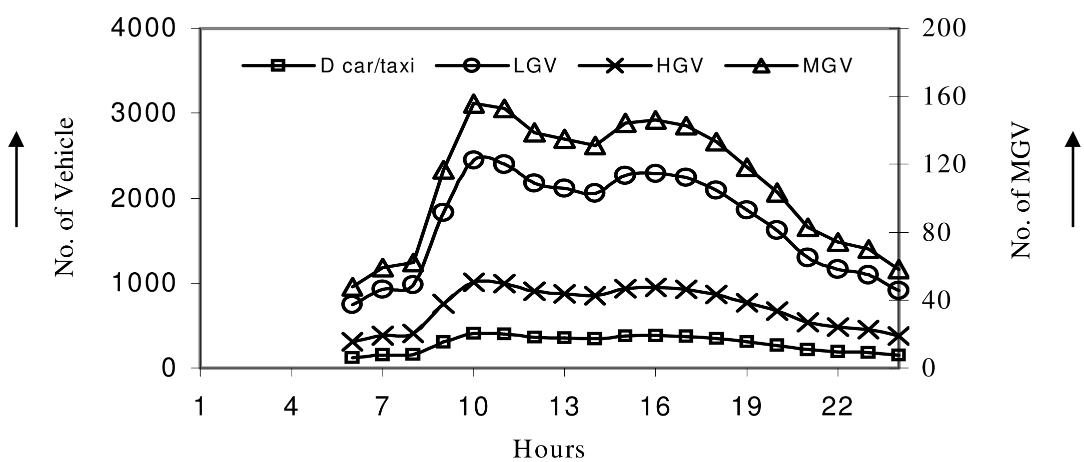

Figure 4: Spatial distribution of NOx emissions (tonnes/day) from commercial diesel vehicles over the study area in winter season.

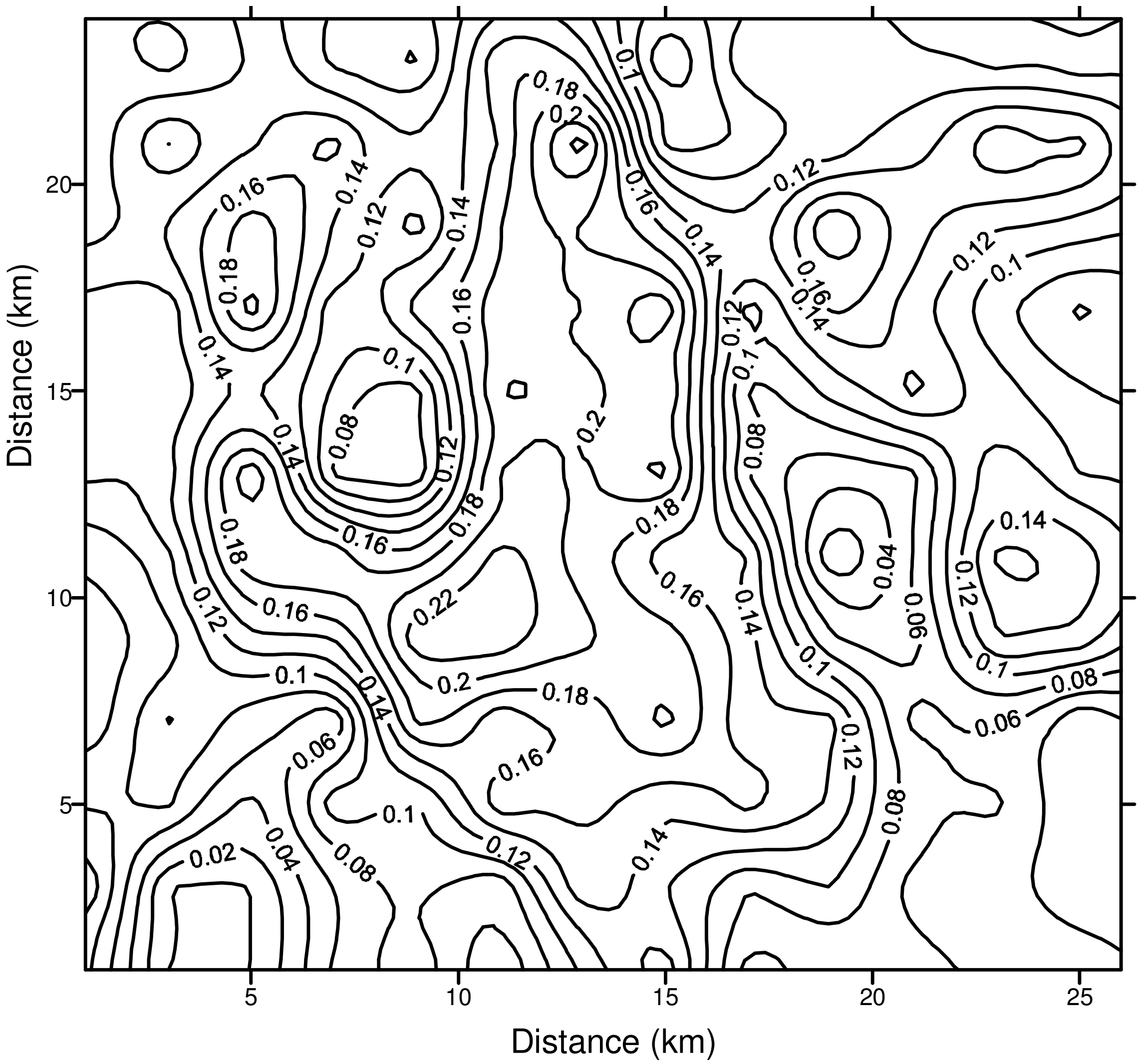

Figure 5: Spatial distribution of PM emissions (tonnes/day) from commercial diesel vehicles over the study area in winter season.

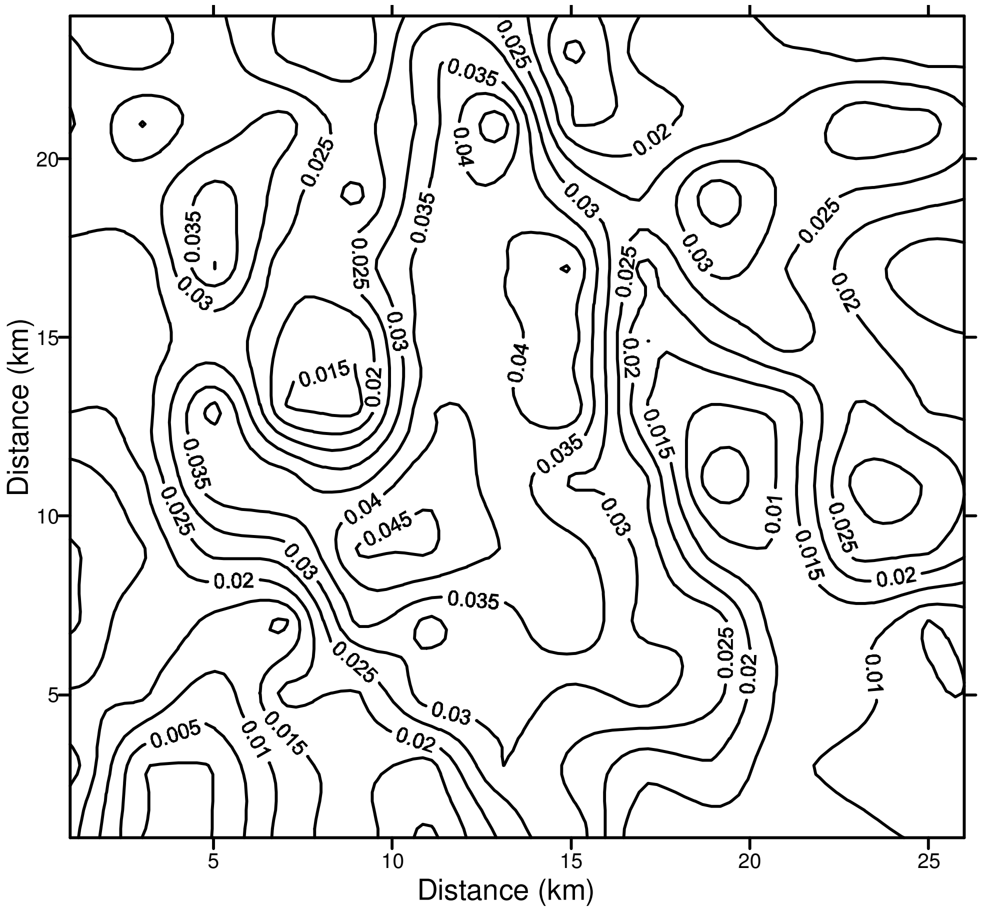

Figure 6: Isopleths of 24-hourly averaged concentration (μg m^{-3}) of NOx due to Commercial diesel vehicles in winter season

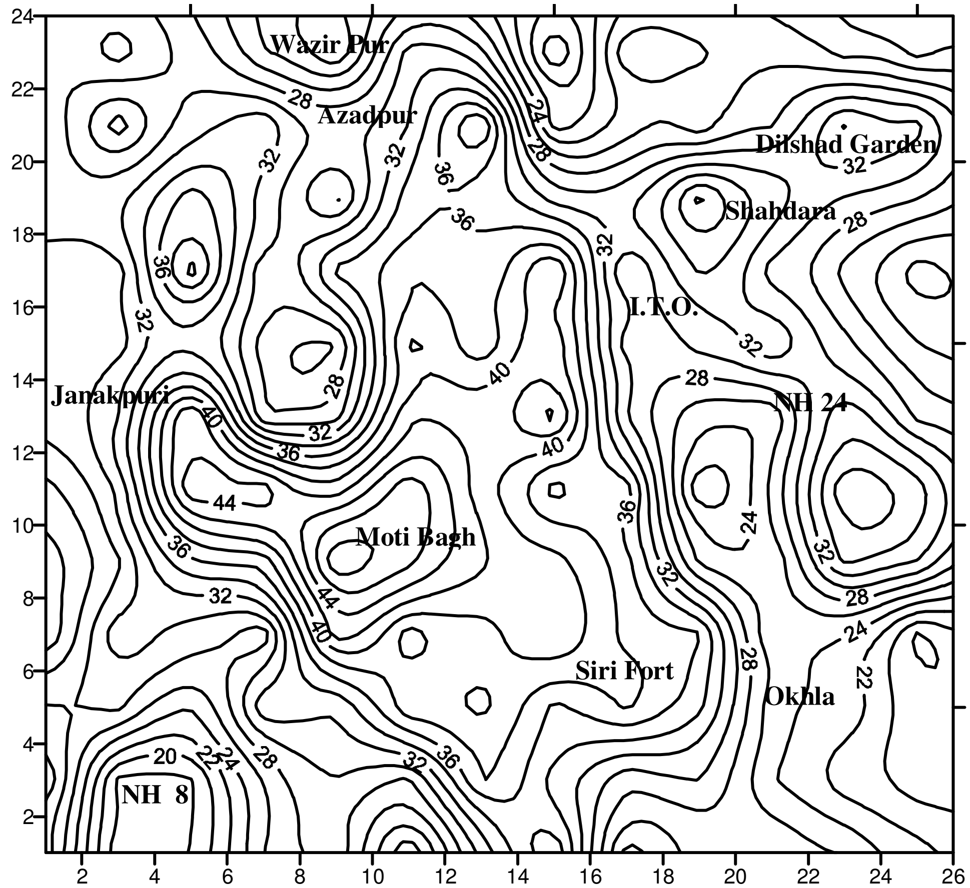

Figure 7: Hourly variation of NOx concentration (μg m^{-3}) from Diesel vehicles at Moti Bagh in winter season

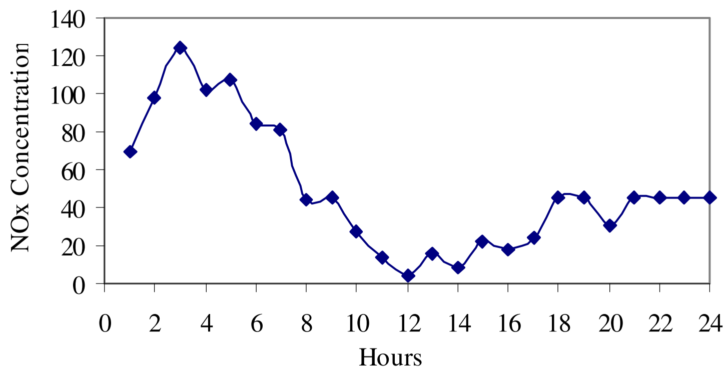

Figure 8: Isopleths of 24-hourly averaged concentration (μg m^{-3}) of PM due to Commercial diesel vehicles in winter season

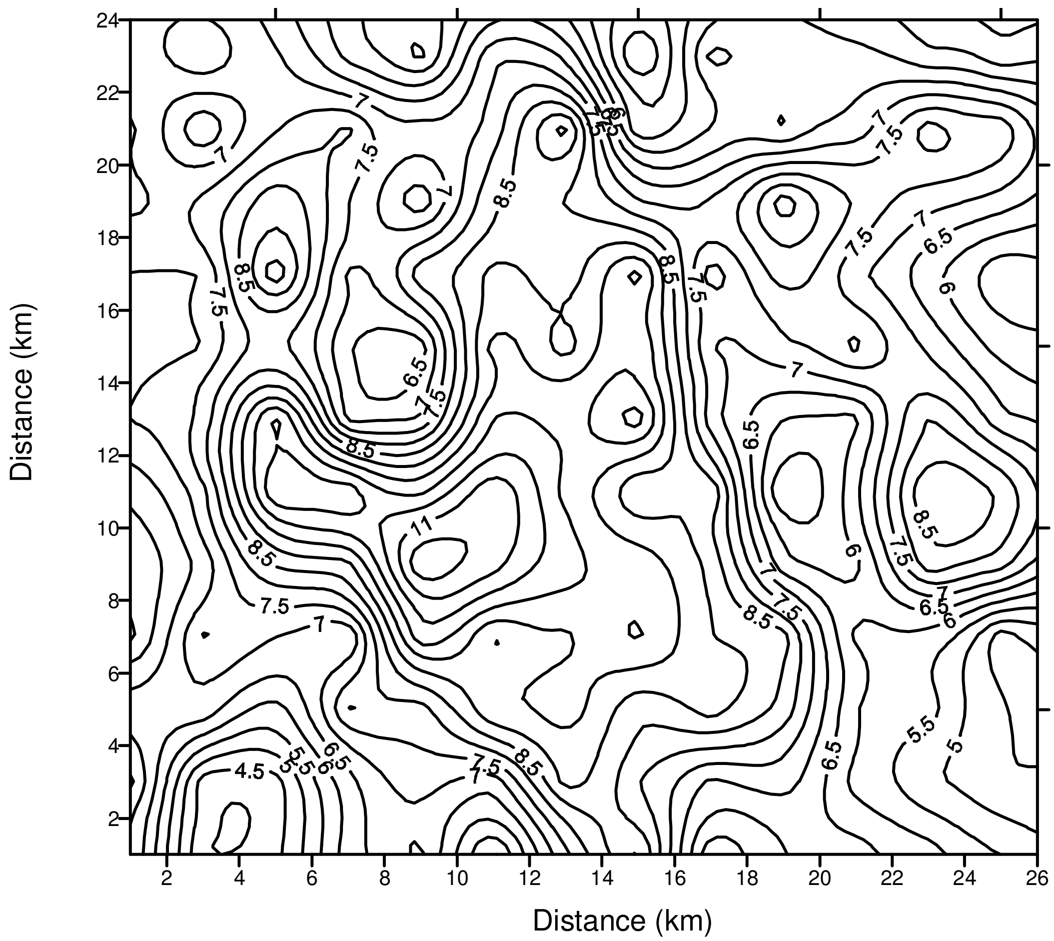

Figure 9: Hourly variation of PM concentration (μg m^{-3}) due to Diesel commercial Vehicles at Moti Bagh during winter season

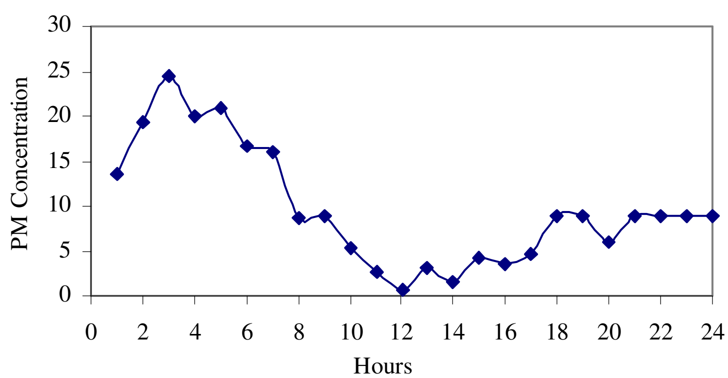

Figure 10: 24-hourly averaged NOx Concentration ($\mu g\ m^{-3}$) due to **Tempos** in winter season

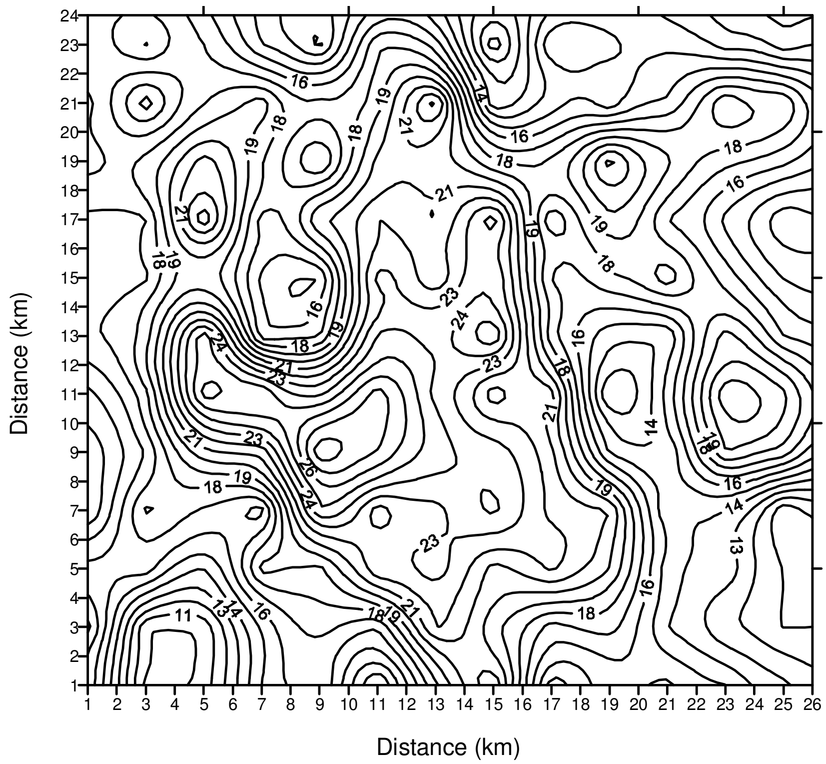

Figure 11: 24-hourly averaged PM Concentration ($\mu g\ m^{-3}$) due to **Tempos** in winter season

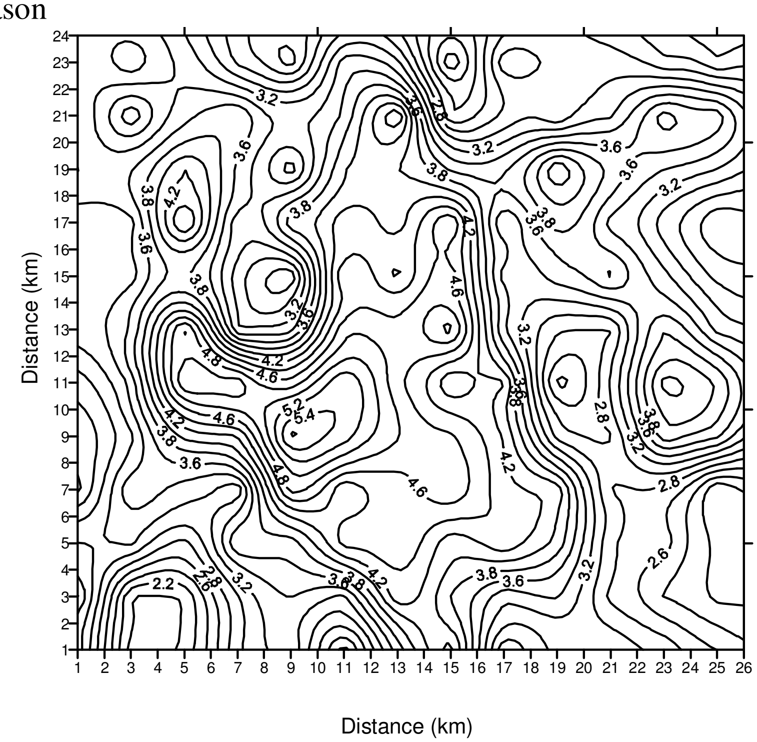

Figure 12: 24-hourly averaged NOx concentration (μg m^{-3})due to **M.T.V. and Small Trucks** in winter season

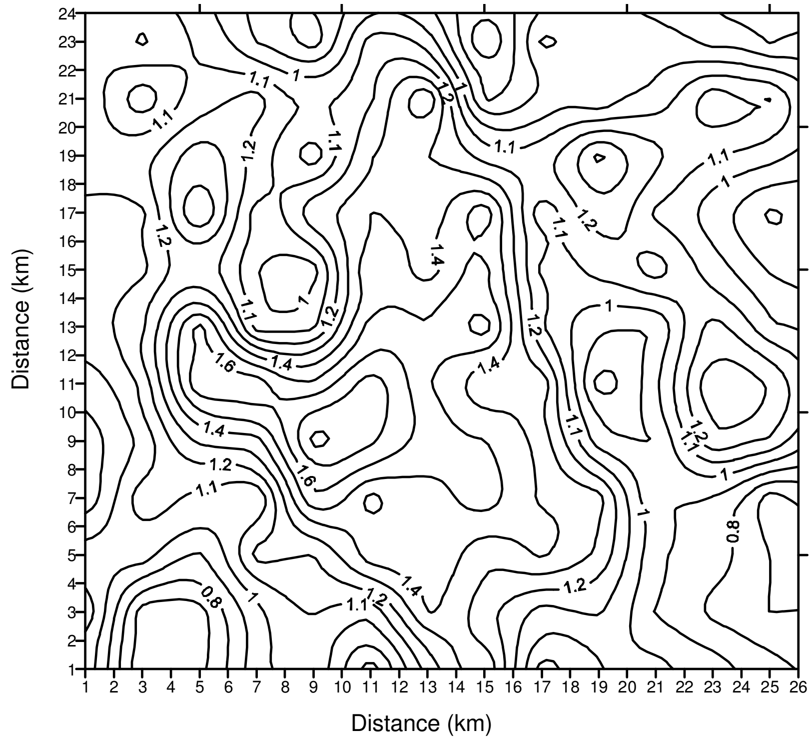

Figure 13: 24-hourly averaged PM concentration (μg m^{-3})due to **M.T.V. and Small Trucks** in winter season

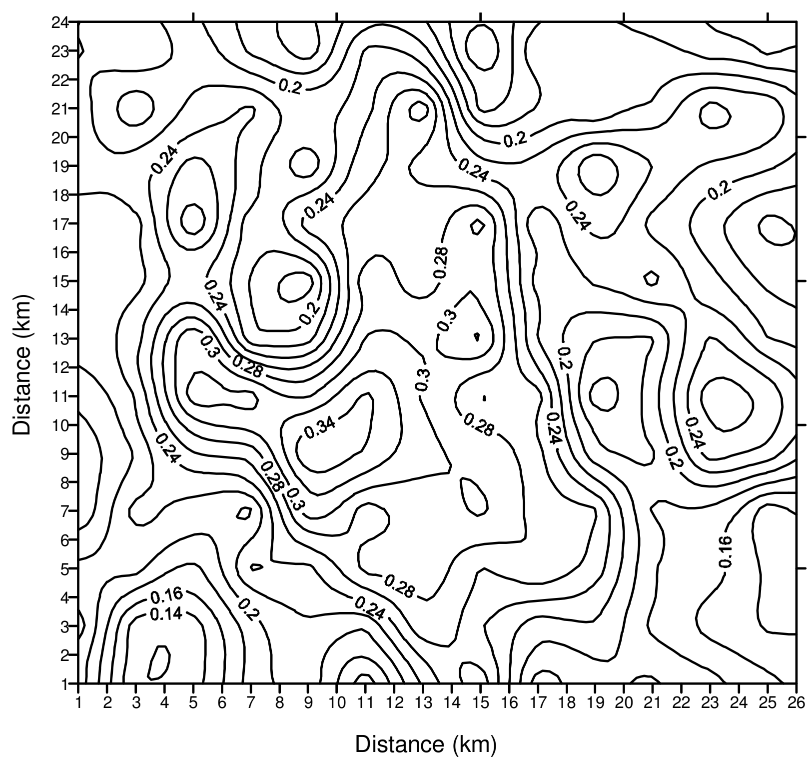

Figure 14: 24-hourly averaged NOx concentration (μg m^{-3}) due to **Trucks** in winter season

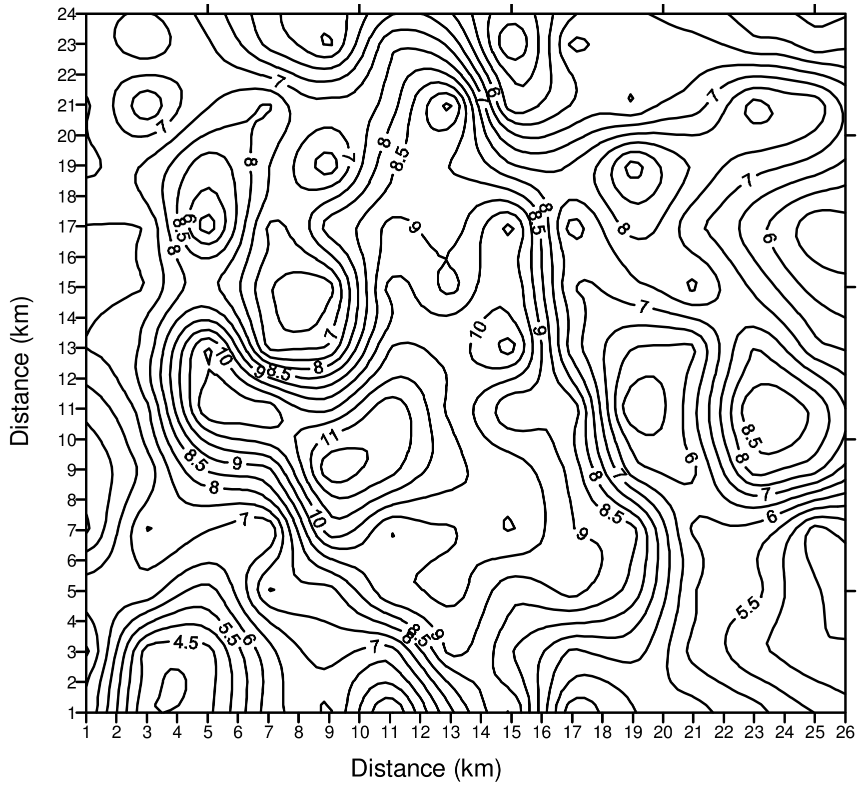

Figure 15: 24-hourly averaged PM concentration (μg m^{-3}) due **Trucks** in winter season

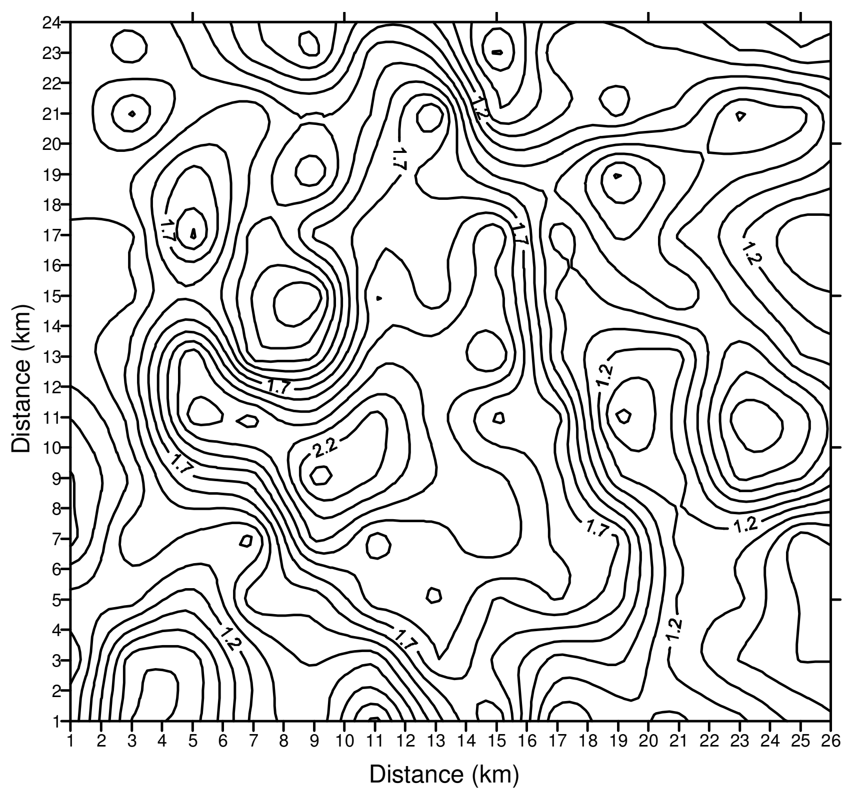

Figure 16: 24-hourly averaged NOx concentration ($\mu g\ m^{-3}$) due to **Tractor, Trailors and others** in winter season

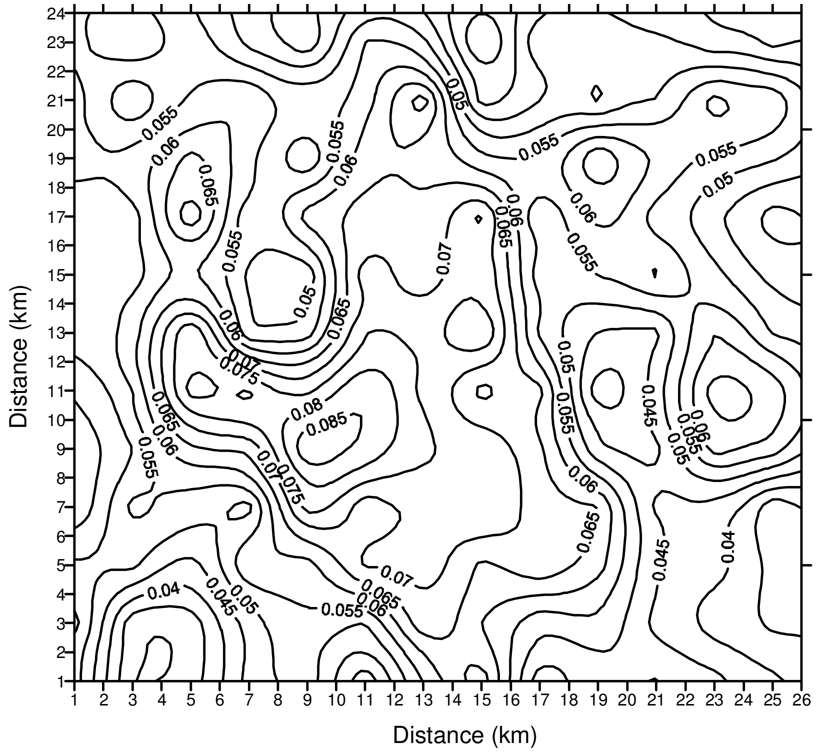

Figure 17: 24-hourly averaged PM concentration ($\mu g\ m^{-3}$) due to **Tractor, trailors and others** in winter season

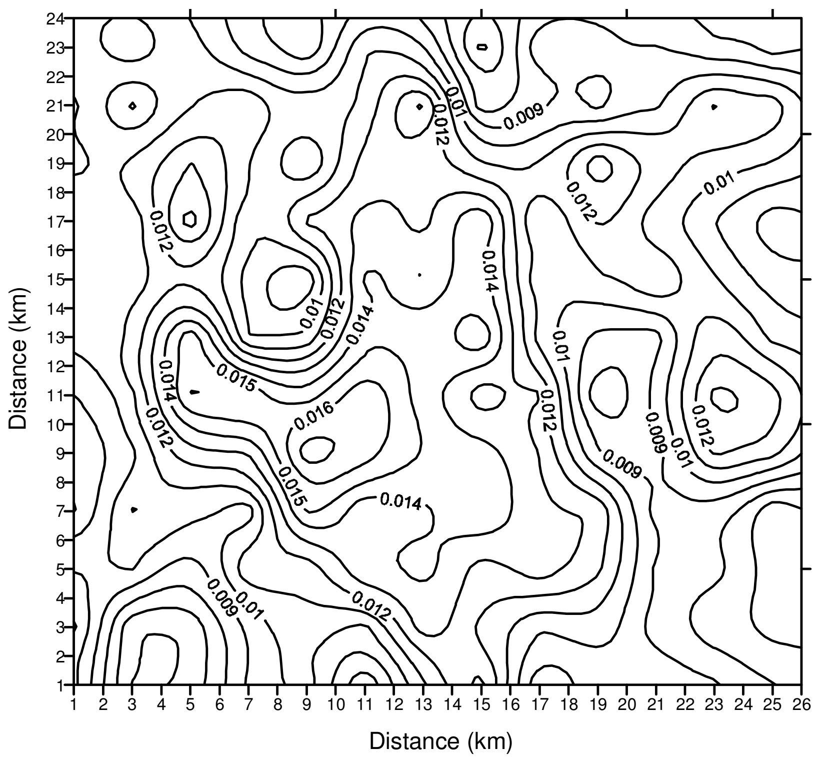

Figure 18: 24-hourly averaged NOx concentration ($\mu g\ m^{-3}$) due to **Cars/Taxis** in winter season

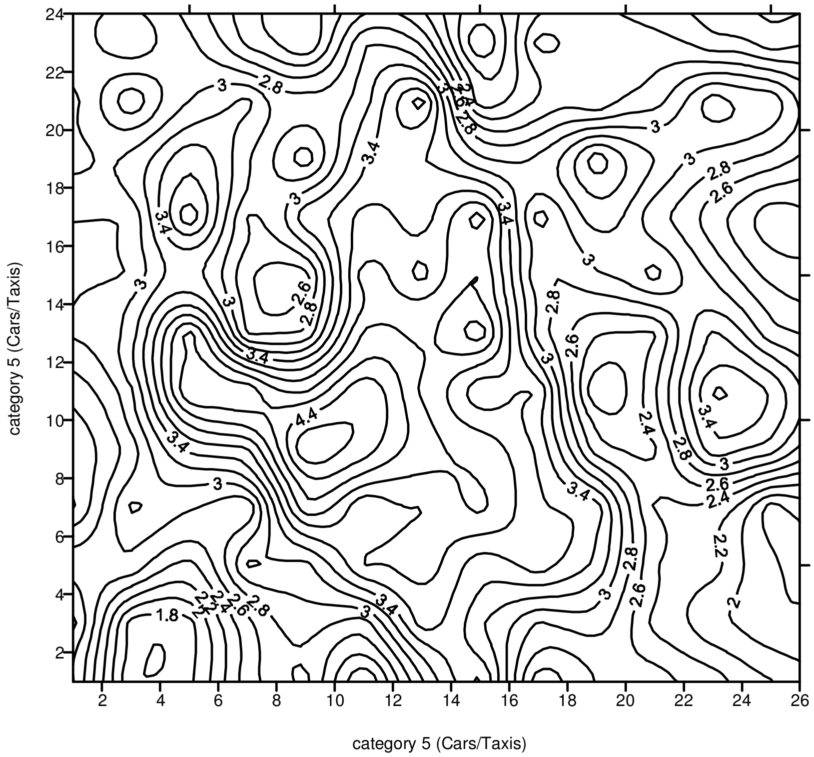

Figure 19: 24-hourly averaged PM concentration ($\mu g\ m^{-3}$) due to **Cars/Taxis** in winter season

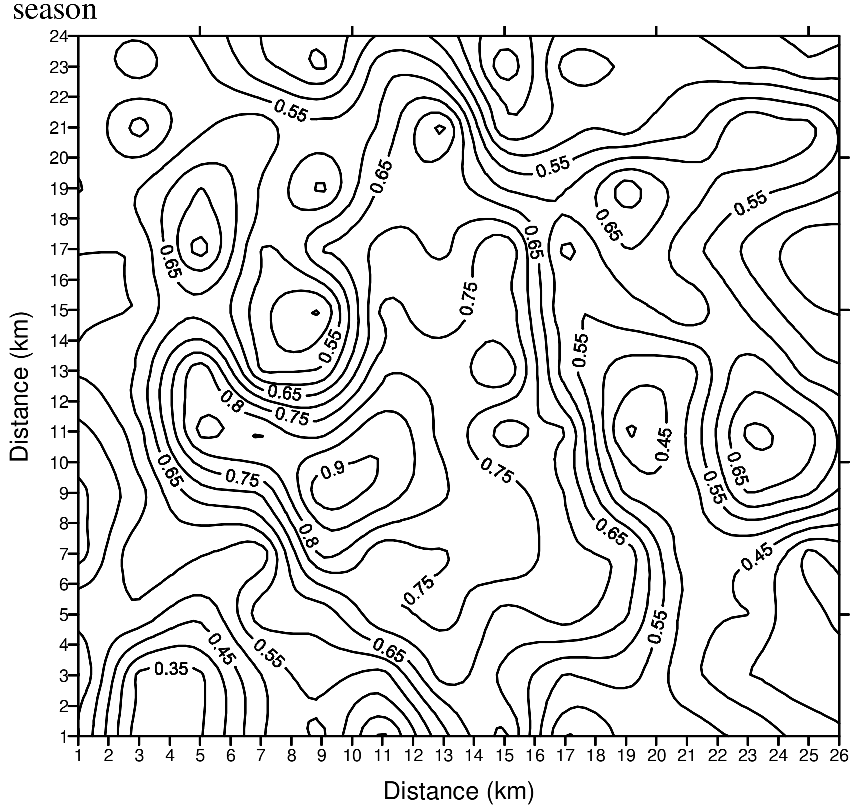

Figure 20: 24-hourly averaged NOx concentration ($\mu g\ m^{-3}$) due to **Buses** in winter season

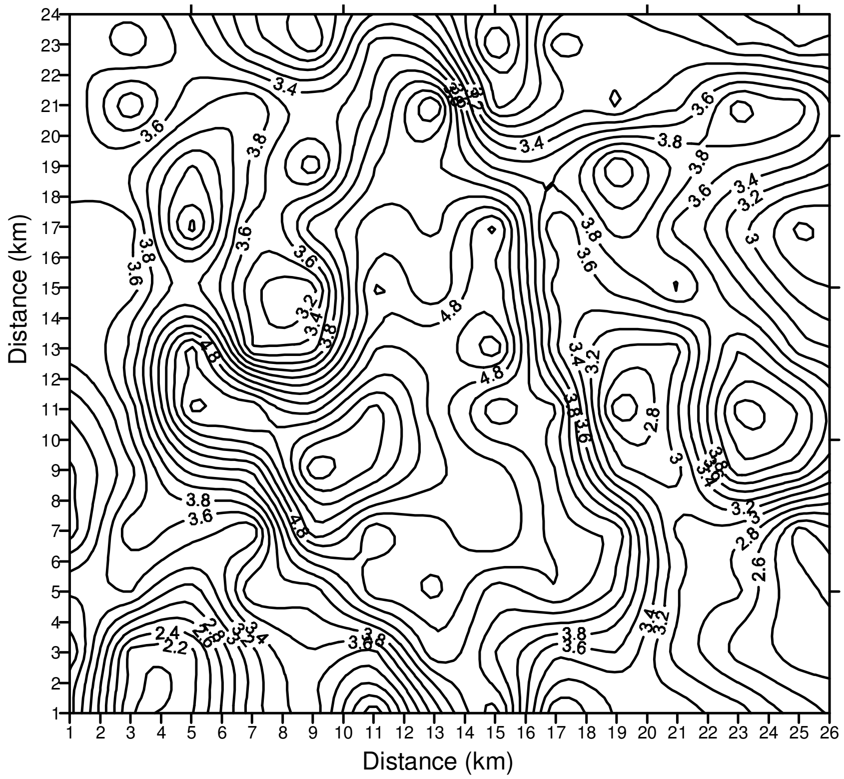

Figure 21: 24-hourly averaged PM concentration ($\mu g\ m^{-3}$) due to **Buses** in winter season