Chapter 6

Emission Inventory of Air Pollutants and Trend Analysis Based on Various Regulatory Measures Over Megacity Delhi

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Additional information is available at the end of the chapter

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1. Introduction

An emission inventory is defined as an accounting of all air pollution emissions and associated data from sources within a specified area and over a specific time interval [1]. Air emissions inventory information assists in planning to reduce emissions to meet air quality goals and tracking progress of control initiatives towards pollution mitigation. The development of information for an emissions inventory can be carried out in one of two methods. One method is often referred to as the top-down approach. In the case of a top-down approach, generalized factors such as total fuel use, total population, total activity data, for example, are used as indicators of emissions. Emission factors are developed that predict emissions per unit of a process or fuel mass or per person or such. The product of the emission factor with the relevant emissions indicator provides an estimate of emissions. These emissions can be disaggregated sector wise. In other method, known as a bottom-up approach, the region of interest is divided into sectors of interest and specific information is developed for each sector. This information is then used to estimate the emissions that will occur in each sector [2].

Fast developing economy of Delhi, the capital city of India, has led to the rapid increase in its population. Consequently, urbanization and increasing numbers of vehicles in the city are causing high levels of air pollution. In response to the growing environmental concerns, various regulatory actions have also been initiated in Delhi over the past decade such as introduction of CNG, stringent emission norms, development of public transport etc. Construction of emission inventories is significant to understand sources of pollution so as to define priorities and set objectives for pollution management. Different groups have developed emission inventories for different parts of India such as Nagpur [3], Jamshedpur [4] and Delhi [5,6,7]. Similarly mathematical modeling tools aid in understanding the fate of various pollutants emitted into ambient air and estimations of their levels. In this context, emission inventories are gridded on urban scale [8] and applied for air quality modelling for varied purposes [9,10]

With this context, the objective of the present study is to develop an annual emission inventory of some selected air pollutants of Delhi and analyse the trends in light of various control measures enacted by the regulatory authorities. Emission data for different source categories has been calculated annually for Delhi for the year 2001-2008 using top to bottom approach. Estimated emissions have been used to compute ambient concentrations by air quality modeling and further compared with observed concentrations. In addition efforts are being made by various organizations to construct emission inventories for a particular sector, geographical location, specific pollutants and time span etc. This study also examines the various other emission inventories that are available in part or full over Delhi.

2. Study area and sources of air pollution

Delhi, the capital city of India, is located at 28.6 N and 77.2 E and geologically, this region is bounded by the Indo-Gangetic alluvial plains in the North and East, by Thar Desert in the West and by old Aravalli hill ranges in South. The city is the highest populated megacity of India with 16.3 million inhabitants belonging to different economic strata. The city also boasts of the highest number of registered motor vehicles in the nation [11]. The number of vehicles has increased by over 80 % from year 2000 to about 6 million in year 2008-09 [12] which can be sees in Figure 1. Consequently, vehicle fuel consumption has also increased. Major pollutants emitted from vehicles are CO, NOx, particulate matter and hydrocarbons. Upto year 2009, the city's power demand were met by four thermal power stations, three of which were coal based. The remaining one is gas based. Coal based thermal power stations are major sources of particulate pollution and some gases such as SO_2.

Delhi is the largest municipal solid waste producer in the country [13]. Treatment of waste and enteric fermentation in animals is source of emissions like methane while animal manure contributes towards gases like NH_3 and CH_4.

3. Emissions sectors

Emissions for the city have been calculated for transport sector, power plants, domestic sector and from animals using the emission factors approach for different pollutants. The pollutants considered for the assessment of emission inventory are criteria pollutants like SO_2, CO, NO_X, TSP and some other pollutants such as hydrocarbons (HC), methane (CH_4) and Carbon-di-oxide (CO_2).

3.1. Transport

Delhi city is home to the largest number of registered motor vehicles in India. The city has witnessed consistent increase in number of registered motor vehicles. Figure 1 shows the rise in increase in total number of registered motor vehicles in Delhi from 2001-2008 [12]. A consistent increase is observed in the number of vehicles in past years. The ever-rising number of vehicles is one of the major concerns for the city in terms of air pollution control.

The calculation of emission in Delhi from vehicles require the data on emission factor for the specific vehicle type, the distance traveled by a particular vehicle type and number of vehicles and their distribution in the type of the fuel used. The emission from vehicles is calculated using:

$$E_i = \sum (Veh_j \times D_j) \times E_{i;j;km}$$

where, E_i: emission of compound (i) ; Veh_j: number of vehicles per type (j) ;D_j: distance traveled in a year per different vehicle type (j) and $E_{i;j;km}$: emission of compound (i), vehicle type (j) per driven kilometer.

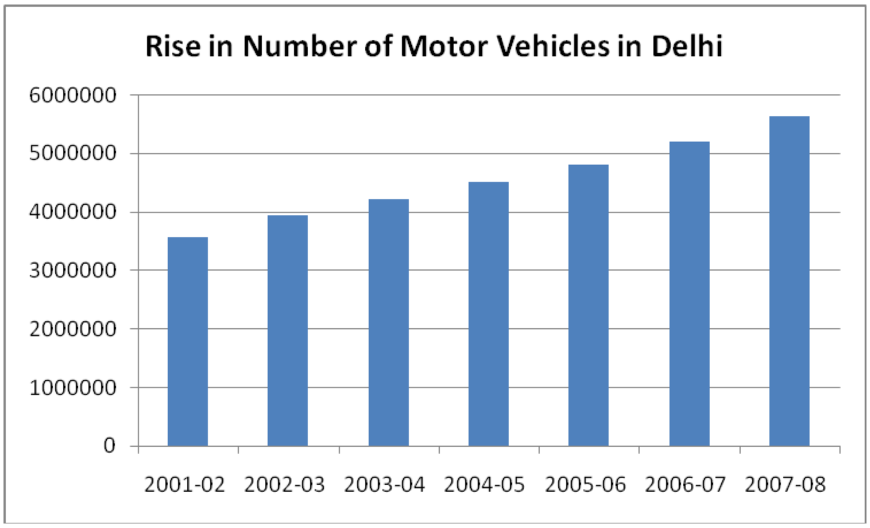

Figure 1. Vehicular population of Delhi

The emission factors are derived from Gurjar et al [6] which are based on sources such as EEA [14], Foell et al.[15] , Bouwman et al. [16] and Reddy and Venkataraman [17]. Cars in Delhi run on petrol, diesel and CNG. Phasing out of diesel based buses and petrol based autorickshaw (three wheeler) was initiated in year 2000 and by year 2002 all diesel based buses were phased out. Hence for buses and autorickshaw CNG consumption emission factors are considered. Two wheelers use gasoline while goods vehicles use diesel. The distance travelled by each vehicle is derived from surveys carried out in past studies [18,19].

Emissions have been estimated for four pollutants viz Carbon monoxide (CO), Hydrocarbons (HC), nitrogen oxides (NOx) and total suspended particulate matter (TSP). Figure 2 displays total annual emissions from vehicles for these four pollutants. The dominant pollutant is CO and among these four pollutants the least emitted pollutant is TSP. CO emissions have shown an increase till 2005 and then a decrease while other pollutants are showing an overall increase over the time period of 2001-2008.

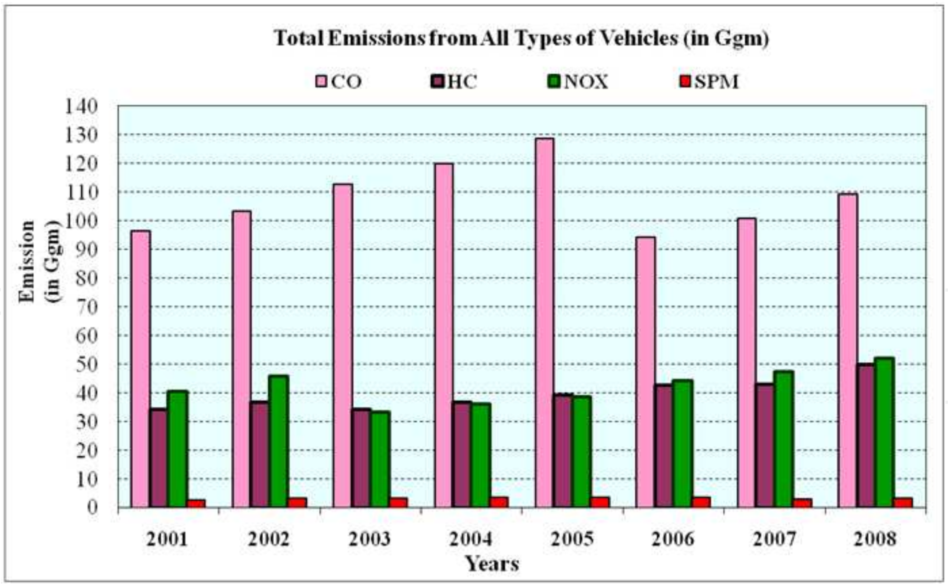

Figure 2. Emissions from transport sector

3.2. Power plants and fuel consumption in industries

Three coal-based Power Plants of Delhi (Badarpur, Indraprastha and Rajghat) have been considered in Delhi. The coal consumption for these Power Plants was collected from annual performance review reports of thermal power sector of India [20] . Using relevant emission factors, emissions from power plants are calculated as:

Total Emission= coal consumption (in 000′ ton) X emission factor for that power plant

Table 1 displays the annual coal consumption in the city from these power plants. As can be seen the total coal consumption has been increasing steadily from year 2001 to 2008. Figure 3 displays total emissions of NOX, SO_2, CO and TSP from power plants which are the dominant pollutants from this sector.

Sl. No.	Thermal Power Plants	Consumption in 000T							
		2001	2002	2003	2004	2005	2006	2007	2008
1.	Badarpur	3767	3818	3554	3605	3732	3768	3739	4104
2.	I.P. Stn.	695	650	495	639	789	934	946	982
3.	Rajghat	612	542	671	629	541	503	529	736

Table 1. Coal Consumption for year 2001-2008 for all the three thermal power plants [20]

Use of beneficiated coal was implemented in late nineties and early 2000s in Delhi for lower sulphur content to control TSP emissions [21]. There isn’t a consistent increase in emissions although overall increase in CO emissions has been observed.

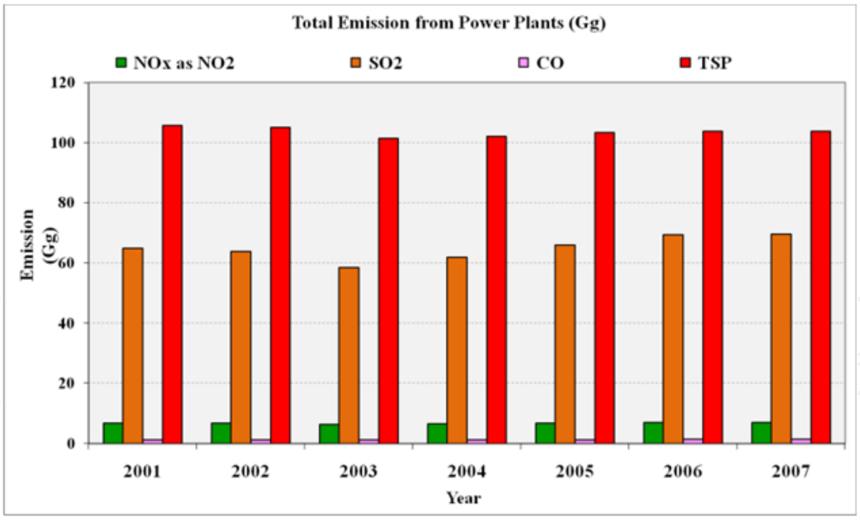

Figure 3. Emissions from power plants

Through a government regulation, a total of 2210 polluting industries were closed/relocated between 1998-2001 in Delhi [21]. Thus emissions from the industrial sector are mainly due to consumption of industrial fuels such as HSD and LDO. The emissions from industrial fuel consumption are calculated as:

$$E_i = \sum (Fuel_j \text{ X } EF_{ij}) \quad (1)$$

where, E_i: emission per compound (i) ; $Fuel_j$: consumption of fuel per fuel type (j) ; $EF_{i,j}$: emissions of compound (i) per unit of fuel (j) consumed.

The statistical handbook of Delhi [12] gives information on consumption of the HSD and LDO fuel. Emission factors for these fuels are as used in Delhi inventory preparation by Central Pollution Control Board [5] which are based on revised AP-42 emissions [5]. Figure 4 displays emissions from fuel consumption in industries for TSP, SO_2, NO_x and CO. Although, there is no consistent trend of increase or decrease, there is an overall decrease in emissions from 2001 to 2008.

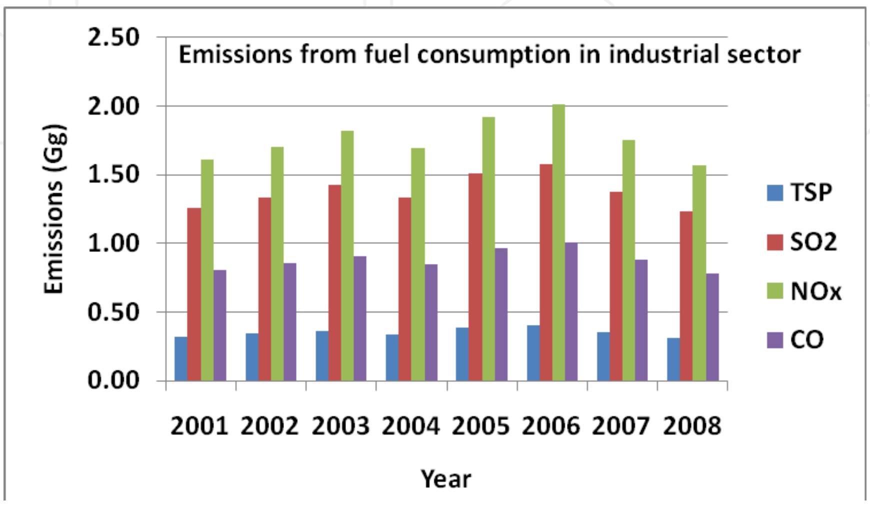

Figure 4. Emissions from industrial sector

3.3. Fuel consumption in domestic sector

The information on the fuel consumption in the government regulated statistical reports [12] does not provide detailed information regarding the energy use in power or industrial sector so assumptions were made that: petrol, high speed oil and light diesel oil are used in transport sector; Cooking gas and kerosene oil are burned in domestic sector other energy is assumed to be biomass such as fuel wood, crop waste and dung. The similar assumptions were used by earlier study [6]. The emissions have been calculated as

$$E_i = \sum (Fuel_j \ X \ EF_{ij}) \tag{2}$$

where, E_i: emission per compound (i) ; $Fuel_j$: consumption of fuel per fuel type (j) ; $EF_{i,j}$: emissions of compound (i) per unit of fuel (j) consumed. Emission factors of as used in [6] have been used. Figure 5 displays emissions for CO, NOx, SO2 and TSP from fuel consumption in domestic sector. Since fuel consumption in domestic sector is directly associated with population growth, a steady increase of emissions is observed in domestic sector.

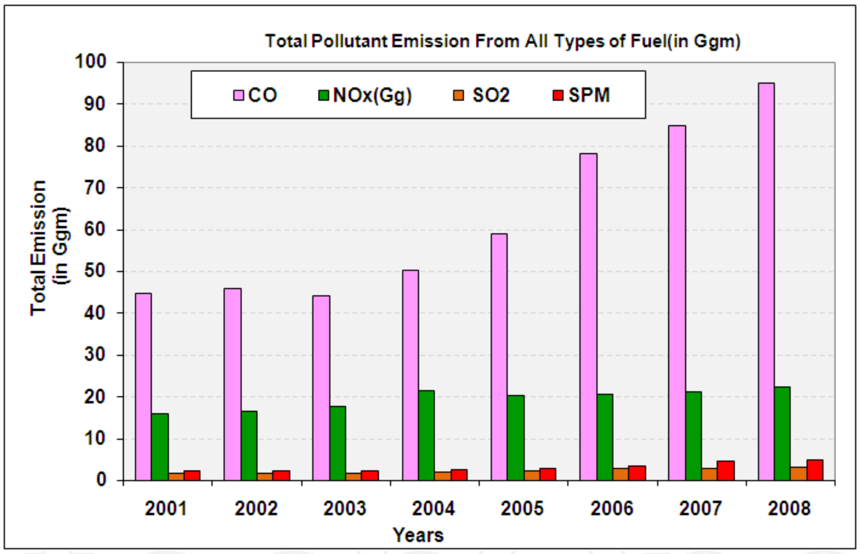

Figure 5. Emissions from fuel consumption in domestic sector

3.4. Emissions from animals

Enteric fermentation and treatment of animal manure are main processes contributing to methane, N_2O and ammonia emissions from animal sector. These emissions have been calculated using the formulation and emission factors in IPCC tier I methodology [22]. Livestock count has been taken from statistical reports [12] .

CH_4 emissions from enteric fermentation are calculated using

$$Emission_{CH4} = \sum (Number \ of \ animals_j \ X \ EF_{CH4 \ j}) \tag{3}$$

Here, j denotes the animal type.

N_2O and NH_3 emissions are calculated using equation given below, assuming unmanaged livestock keeping and non-treatment of manure.

$$\text{Emission}_{N2O/NH3} = \sum (\text{Number of animals}_j \text{ X Nitrogen-excretion}_j \text{ X } EF_{N2O/NH3j}) \quad (4)$$

Figure 6 shows annual emissions of CH_4, NH_3 and N_2O from animal sector. With increasing urbanization, the agricultural activities in Delhi are on decline. The agricultural land has decreased by 27 % in the decadal period of 2001-2010 [23]. This has had an influence on animal population as well which has declined by 18 % from 2001 to 2008. Thus the emissions also show a gradual decline especially in case of ammonia.

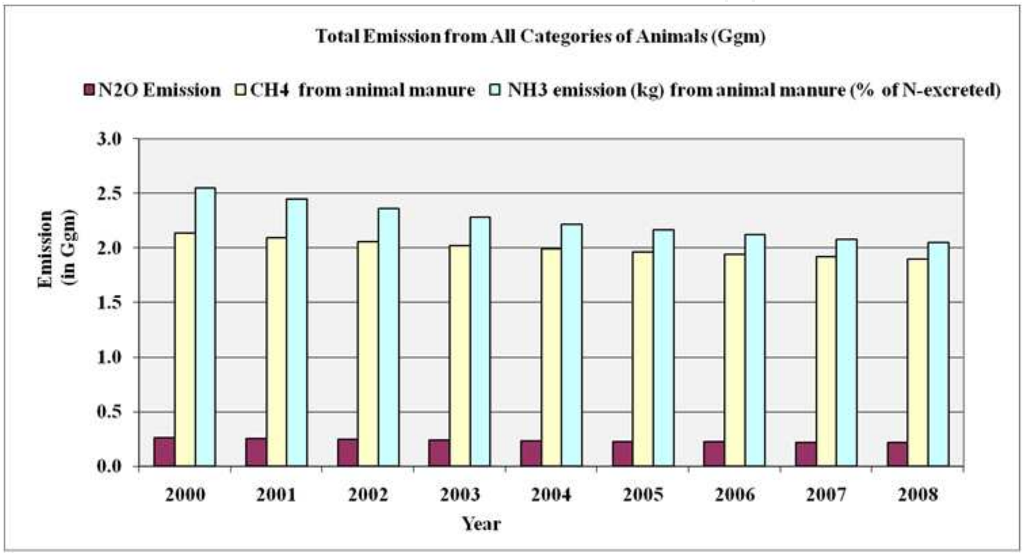

Figure 6. Emissions from animals

3.5. Emissions from waste sector

About 6500 - 7000 tons of municipal solid waste (MSW) is generated each day in Delhi with per capita generation rate of 0.47 kg day-1. MSW mainly comprises of biodegradable materials, which undergo anaerobic decomposition in landfills generating landfill gas (LFG) consisting of about 60% methane (CH_4) together with small quantities of non-methane organic compounds and other trace gases [24] . Major processes in the waste treatment sector are treatment of municipal solid waste and wastewater which leads to leads to CH_4 emission from landfills. NH_3 emissions are resulted from waste composting. Further some waste is left out on streets for open burning which also leads to emission of several pollutants.

CH_4 emissions from solid waste disposal are calculated using the following formula [25,6].

$$\text{Total Emission } CH_4 = [(\text{MSW X MCF X DOC X } DOC_f \text{ X F X } (16/12) - R] \text{ X } [1 - OF] \quad (5)$$

where, MSW = Municipal Solid Waste [per capita waste produced X Delhi population] ; MCF = Methane Correction Factor ; DOC = Degradable Organic Carbon ; DOC_f = Fraction of DOC dissimilated ; F = Fraction of CH4 in landfill gas and OF = Oxidation factor

Figure 7 shows annual emissions of three major pollutants from waste treatment sector viz CH_4, NH_3 and N_2O. Contribution of waste sector for NH_3 and N_2O emissions is very small in comparison to methane emissions. Again, as in the case of fuel consumption in domestic sector, waste generation is also related to population and thus emissions from waste sector have also shown a consistent increase during 2001-2008.

Methane estimations can have different methodologies yielding different estimations. Chakraborty et al [24] estimated methane emission estimations using different methods viz. the in-situ CH_4 measurements, IPCC 1996 default methodology (DM), Modified Triangular Method (MTM) and First Order Decay (FOD) method based on data collected between 2008-2009. The annual average methane emission rates from three landfills were 45.7 Gg by IPCC method, 31.1 Gg y^{-1} by the FOD; 41.1 Gg y-1 by the MTM respectively.

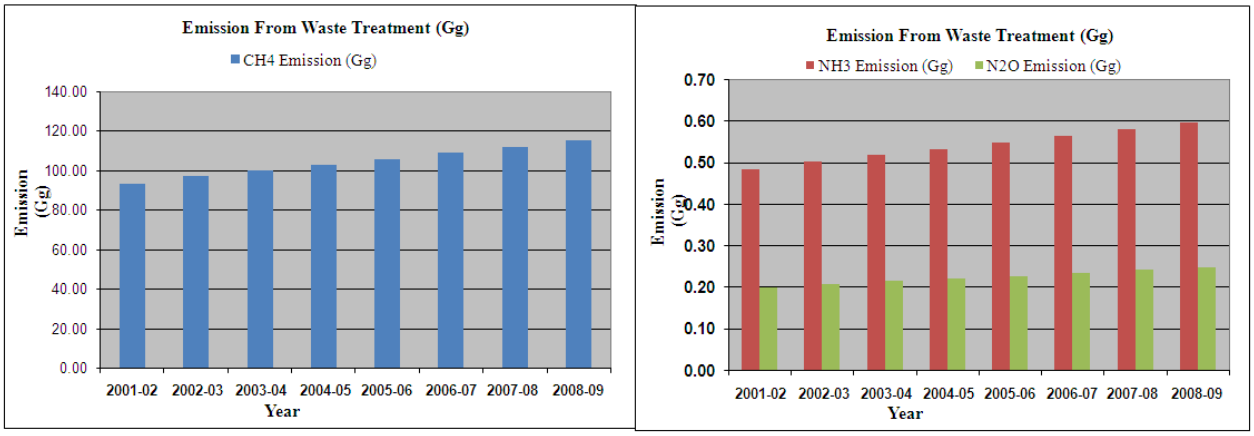

Figure 7. Annual emissions from waste treatment

4. Sectoral contribution towards emissions

Different sources have varying contribution towards different pollutants. Figures 8-11 display sector wise contribution and total emissions for CO, NOx SO_2 and TSP respectively. It is found that CO is mainly emitted from domestic sector and transport sector. Main contributor of SO_2 and TSP is power plants. NO_2 is mainly emitted from transport, domestic sector and power plants and the contribution of transport sector has increased for NOx emissions from 2001-2008. Waste treatment is main contributor of CH_4 followed by enteric fermentation and then domestic sector. NH_3 emissions are mainly contributed by animal and waste sector. The sudden drop in CO emissions in the year 2006 could have been due to application of Euro –III emission norms in 2004-2005. The percentage increase in CO in past 8 years is 37%; the main contribution of CO is from Transport sector and as the numbers of vehicles are increasing every year the emission of CO is increasing. CH_4 has increased 21% in the past 8 years, mainly contributed from Waste Treatment Sector followed by Domestic Sector which is again a result of increasing population and the demands.

Figures 9, 10 and 11 also show observed annual average ambient concentrations of NOx, SO_2 and TSP along with emissions.

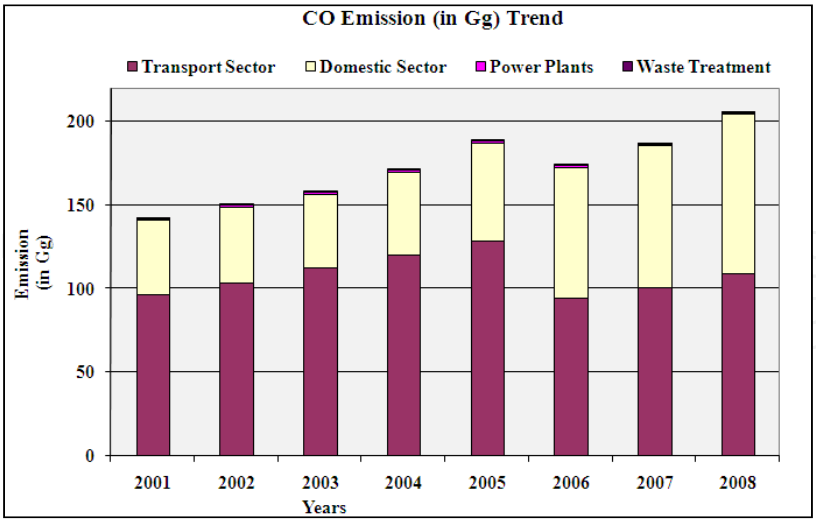

Figure 8. CO Emission Trends, 2001-2008

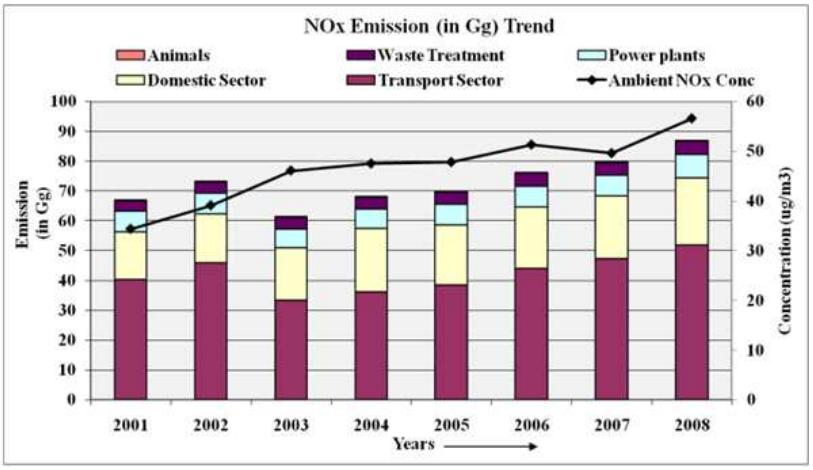

Figure 9. NOx Emission Trends, 2001-2008

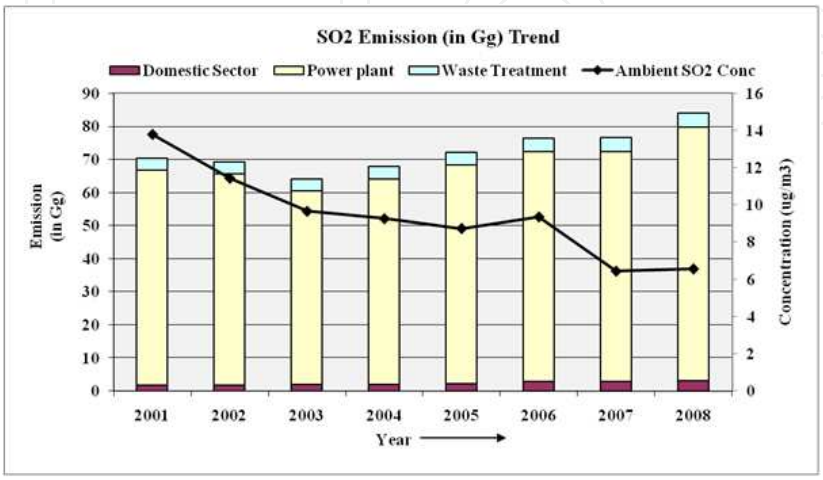

Figure 10. SO_2 Emission Trends, 2001-2008

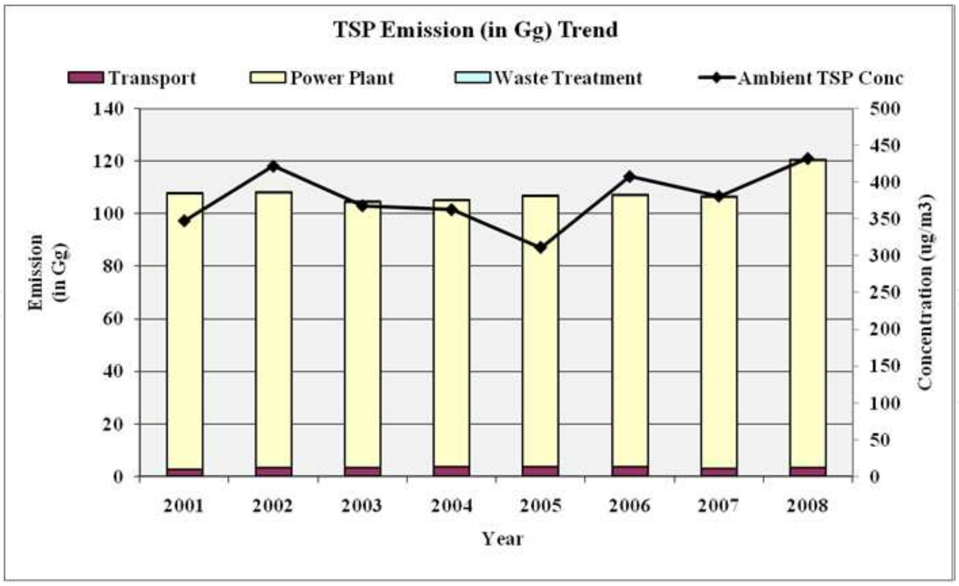

Figure 11. TSP Emission Trends, 2001-2008

5. Emission trends vis-à-vis control options

From time to time different regulatory actions have been initiated in Delhi for control of air pollution scenario. The major initiatives that have been undertaken are phasing out of old commercial vehicles, successive implementation of stringent emission norms, use of CNG and introduction of mass rapid transport means such as Delhi Metro and Bus Rapid Transit. In the period of year 2000-2001 many major initiatives were taken for control of air pollution such as introduction of Bharat Stage II (Euro-II equivalent) emission norms, reduction of Sulphur content in diesel and gasoline, replacement of pre 1990 three wheelers and taxis with new vehicles on CNG, phasing out of more than 8 year old buses and switch over to beneficiated coal in three coal based power plants. Table 2 shows timeline of interventions taken by government for abatement of air pollution [21]

Major problem due to dominance of transport sector

To some extent, the impact of control options is reflected in the emissions scenario. The period of 2001-2003 shows decrease in NOx, SO2 and TSP emissions. However, in the later years 2007-2008, an increasing trend emerges due to rise in number of vehicles on the road. Application of Euro –III emission norms on 2004-2005 has led to a marginal decrease in 2006-2007 emissions. Specially, in the transport sector, often introduction of a policy initiative like CNG, EURO-III norms are followed by decrease in emissions, but the ever increasing vehicles on road again leads to an increase. In terms of concentrations also, introduction of CNG fuel has been observed to be followed by a decrease in SO_2 and CO concentrations, while the NOx level was increased in comparison to those before the implementation of CNG. Further, total suspended particulate matter showed no significant change after the implementation of CNG [26]. Despite the rise of METRO ridership, the number of private and commercial vehicles are also increasing thereby negating the impact of control initiatives.

Year	Steps taken
2000	• Bhar at Stage II (Euro-II equivalent) emission norms introduced for all private vehicles • Sulphur content in diesel and gasoline reduced to 0.05 % • Replacement of all pre 1990 three wheelers and taxis with new vehicles on CNG • Switch over to beneficiated coal in three coal based power plants • Buses more than 8years old phased out or to ply on CNG
2001	• Bharat Stage II (Euro-II equivalent) emission norms introduced for all commercial vehicles • Replacement of all post 1990 three wheelers and taxis with new vehicles on CNG • Increase in number of CNG vehicles • Total 2210 industries closed/relocated between 1998-2001 • Piped natural gas to limited domestic and commercial establishment
2002	• All diesel buses phased out/converted to CNG • Increase in number of CNG vehicles • Increase in supply of Piped natural gas to more domestic and commercial establishment
2002-2003	• First route of METRO becomes operational
2003-2008	• Further increase in number of CNG vehicles
2005	• Euro-III emission norms introduced for all private vehicles, city public service vehicles and city commercial vehicles • Bharat Stage II emission norms introduced for 2/3 wheelers • Sulphur content in gasoline reduced to 0.035 % and 0.015% respectively • Phase I of metro rail project completed
2006	• Work of Bus Rapid Transit project started
2009	• 37 % completion of work on Phase II of metro rail started in 2006 • Construction of two new gas based power plants 330 MW and 1000 MW

Table 2. Regulatory actions taken by government for control of air pollution

CNG and NOx emissions

Ravindra et al [26] analysed impact of introduction of CNG on criteria pollutants by observing annual average ambient concentrations at Bahadur Shah Zafar Marg, one of the monitoring sites of CPCB. The introduction of CNG was followed by decrease in SO_2 and CO levels, however TSP and NOx levels were observed to have an increasing trend. The high CO/NOx ratio and low SO2/NOx ratio at BSZ indicated toward dominance of vehicular emission sources for CO and NOx while dominance of other sources for SO_2. Increasing NOx concentration were explained by [26] in relation to flash point of CNG (540°C) which is higher than that of diesel (232–282 °C). Thus due to higher temperature, combustion chamber of CNG vehicles allows more formation of nitrogen oxides.

Low levels of SO_2 in Delhi

A significant fall in SO_2 concentrations despite increase in emissions can be attributed to the use of refined (low S) coal in power stations, the reduction of the S content in diesel and the shifting/relocation of industries from residential to industrial sites [26].

Biswas et al [27] analysed CO concentrations at three monitoring sites in Delhi and observed that CO does not exhibit noticeable inter-annual variability at any of the three sites, signifying that there is not much variation in impact of emission sources from one year to the next. Table 3 discusses the trends of emissions of certain pollutants.

Pollutant	**Years**	**Trend in emission**	**Remark**	**Corresponding Change in ambient concentration**
SO_2	2001-2008	Increase	Main contributor is power plants. As the fuel consumption is increasing so the emission based on the fuel consumption in power plants is also increasing.	Decrease due to Improvement in coal quality combined with the fact that thermal power plants emit at a height thereby have lower contribution to surface level concentrations. Introduction of low sulfur diesel is also another cause.
NOx	2001-2002	Increase	The main cause is increasing number of vehicles.	Increasing emission have led to increase in concentrations also.
NOx	2002-2003	Decrease	This is outcome of outcome of decreasing number of taxies, three-wheelers, buses and goods vehicles based on diesel and gasoline which were phased out due to introduction of CNG	Even though fuel emissions have decreased , NOx concentration has increased due to facilitation of more formation of N oxides in high temperature CNG combustion chambers
NOx	2003-2008	Increase	As the number of all the types of vehicles are increasing (transport sector being the major contributor) also the fuel consumption in domestic sector, Power Plant fuel consumption and emission from Waste Treatment is also increasing.	Consistent increase in NOx emission as well as introduction of CNG is leading to increase in ambient NOx concentrations also.

Pollutant	Years	Trend in emission	Remark	Corresponding Change in ambient concentration
TSP	2001-2004	Decrease	Phasing out of diesel vehicles and introduction of CNG vehicles have led to an initial decrease in TSP emission.	Decrease followed by increase in 2001-2002. shows impact of CNG introduction in vehicles and beneficiated coal in power plants.
TSP	2005-2008	Increase	Consistent increase in number of vehicles as well coal consumption together led to an increase in overall TSP emissions.	No certain trend.
CO	2001-2004	Increase	The major source of CO is transport and Domestic sector. As the number of on road vehicles and fuels used in domestic sector is increasing, CO emission shows an increasing trend.	Decrease at traffic intersection [26]. Increase of CNG fuels usage and introduction of BS-II norms in 2001 leads to decrease in ambient levels.
CO	2004-2005	Decrease	The decrease in emission of CO is mainly from transport sector due to the different emission factors used in 2005 taking in view implementation of Euro IV standards.	No certain trend. Increase in number of vehicles counter the effect of EURO-IV norms and CNG introduction.
CO	2005-2008	Increase	The reason for increasing trend is the consistent increase in number of vehicles and domestic fuel consumption.	

Table 3. Emission Trends for year 2001 to 2008

6. Comparison with other inventories

6.1. Local city based data studies

Central Pollution Control Board along with National Environmental Engineering Research Institute prepared an emission inventory for Delhi based on data of collected between year 2006-2007 implying a bottom-up approach [5]. The emission inventory was based on revised USEPA AP-42 emission factors and those formulated by Automotive Research Association of India. Figure 12 displays emissions as estimated from present study with emission factors from various sources as described in section 3, and those using emission factors as per CPCB report [5]. It can be seen that emissions estimated from present study and those based on CPCB emissions are quite comparable. Moreover, the actual estimates of CPCB report emissions (from bottom up approach) are compared in Table 4 with those estimated in present study using a top down approach. Again the estimates from two approaches are of the same order with largest difference being in case of CO. While, bottom up approach incorporates detail sector information in an emission inventory, top down approach estimated are based on many assumptions. This can lead to differences in emission estimates. However, the present study shows the estimates from the two approaches are comparable.

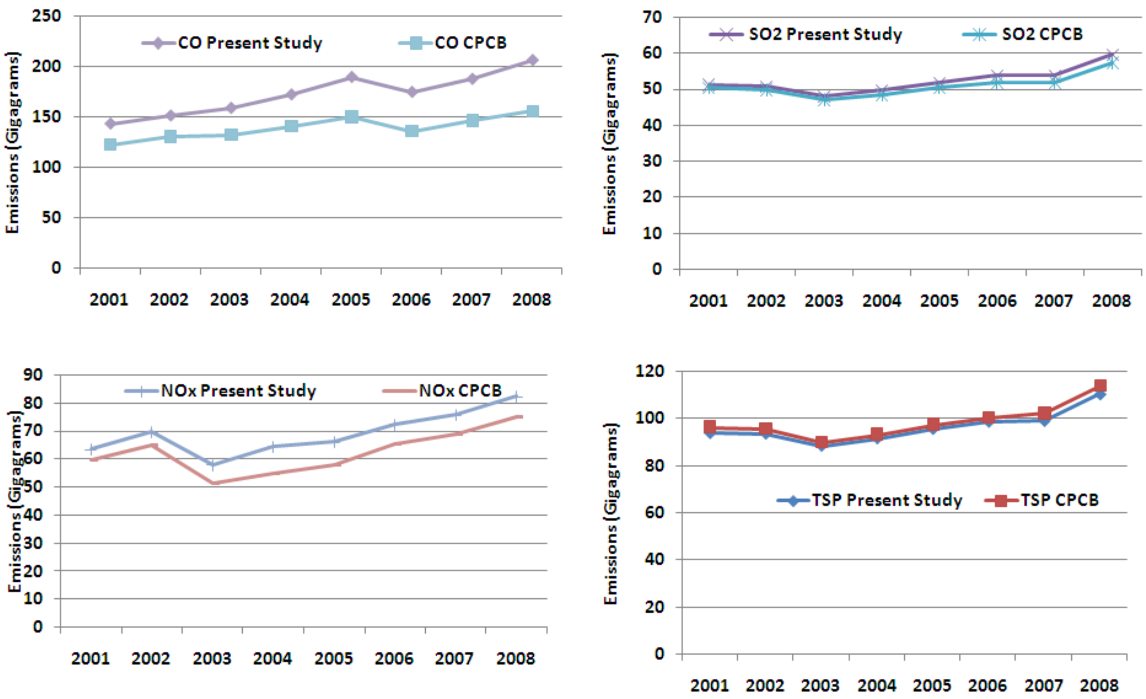

Figure 12. Comparison of emission estimates of some pollutants from present study and CPCB report.

Further, the differences between various emissions are largely attributed to emission factors. Emission factors developed for anthropogenic processes in one region at a certain time may not be applicable for other regions. Kansal et al [28] estimated emissions from power plants, vehicles and industries based on data of period 2005-2006. It was estimated that Vehicular emissions are the major sources of TSP concentrations (54%), followed by Thermal power plants (32%). For SO_2, the major contributors are TPPs (67%) and vehicles (33%). Further, vehicles and TPPs contribute 90% and 10% of NO_2 concentrations, respectively. However in this study transport emissions were considered only around certain monitoring sites of Delhi and emissions from power plant were based on stack monitoring and not on coal consumption which are likely to result into major differences between the two approaches for the power plant sector. The domestic and industry sectors emissions of Kansal et al 2010 are comparable with those of present study. Ramchandra et al, [29] developed a decentralized emission inventories for vehicular transport sector of India for different metropolitan cities based on various data of period 2003-2006. It was estimated that for the Delhi city annually 284.43×10^6, 87.74×10^6, 129.99×10^6, 9.13×10^6 and 42.38×10^6 g/km^2 for CO, HC, NOx, PM and SO_2 are emitted respectively. Table 4 lists some of these period specific studies for different pollutants and their comparison with emissions from present study. Results are comparable with other local studies.

Study	Pollutant-(Sector)	Based on data of Year	Emissions (Gg yr^{-1})	Corresponding emissions estimated in present study
CPCB, 2010 [5]	CO (Transport+Power Plants+Industries+Domestic)	2006-07	136	174
	NOx (Transport+Domestic)		41.7	64.8
	SO_2 (Transport+Power Plants+Industries+Domestic)		73.3	76.2
Chhabra et al [30]	CH_4 (Livestock)	2003	2.1	2.06
Jalihal et al [31]	TSP (Transport)	2002	4.6	3.3
	NOx (Transport)		40.3	45.9
	CO (Transport)		154	103
Kansal et al,[28]	SO_2 (Domestic+Industries)	2005-06	1.9	2.2
	NOx as NO_2 (Domestic+Industries		12.0	20.2
Ramchandra et al [29]	CO (Transport)	2003-06	122	101 (Year 2006)
	NOx (Transport)	2003-06	56	47 (Year 2006)
	TSP (Transport)	2003-06	4	3.7 (Year 2006)

Table 4. Comparison of emissions with other local studies

6.2. Global and regional inventories

Global inventories like EDGAR (Emission Database for Global Atmospheric Research) give emissions at 0.1 ° resolution for CO, SO_2 and NOx. EDGAR emissions calculated at country level for different sectors relevant to that country. These parameter data are based on evaluation of scientific literature, inventory guidance, inventory reports, industry reports, dataset documentation. Emissions by country and grid are allocated on a spatial grid to provide gridded emissions dataset for atmospheric modeling. the emissions are then spatially allocated using grid maps with 0.1°x0.1° resolution based on data such as location of energy and manufacturing facilities, road networks, shipping routes, human and animal population density and agricultural land use (EDGAR, 2008). Similarly REAS (Regional Emission Inventory in Asia) emissions use country region-specific emission factors for several emission species from subdivided source sectors to estimate emissions on state or and country levels. These emissions are divided into a 0.5 ×0.5 grid by using index databases, i.e. population data; information on the positions of large point sources; land cover data sets; and land area data sets [32]. GAINS-Asia emission inventories are calculated at country and sub-region level for China and South Asia (GAINS-Asia, 2011). Figure 13 compares emissions for CO, NOx and SO_2 for the city of Delhi as extracted from these databases for common sectors along with emissions estimated in present study.

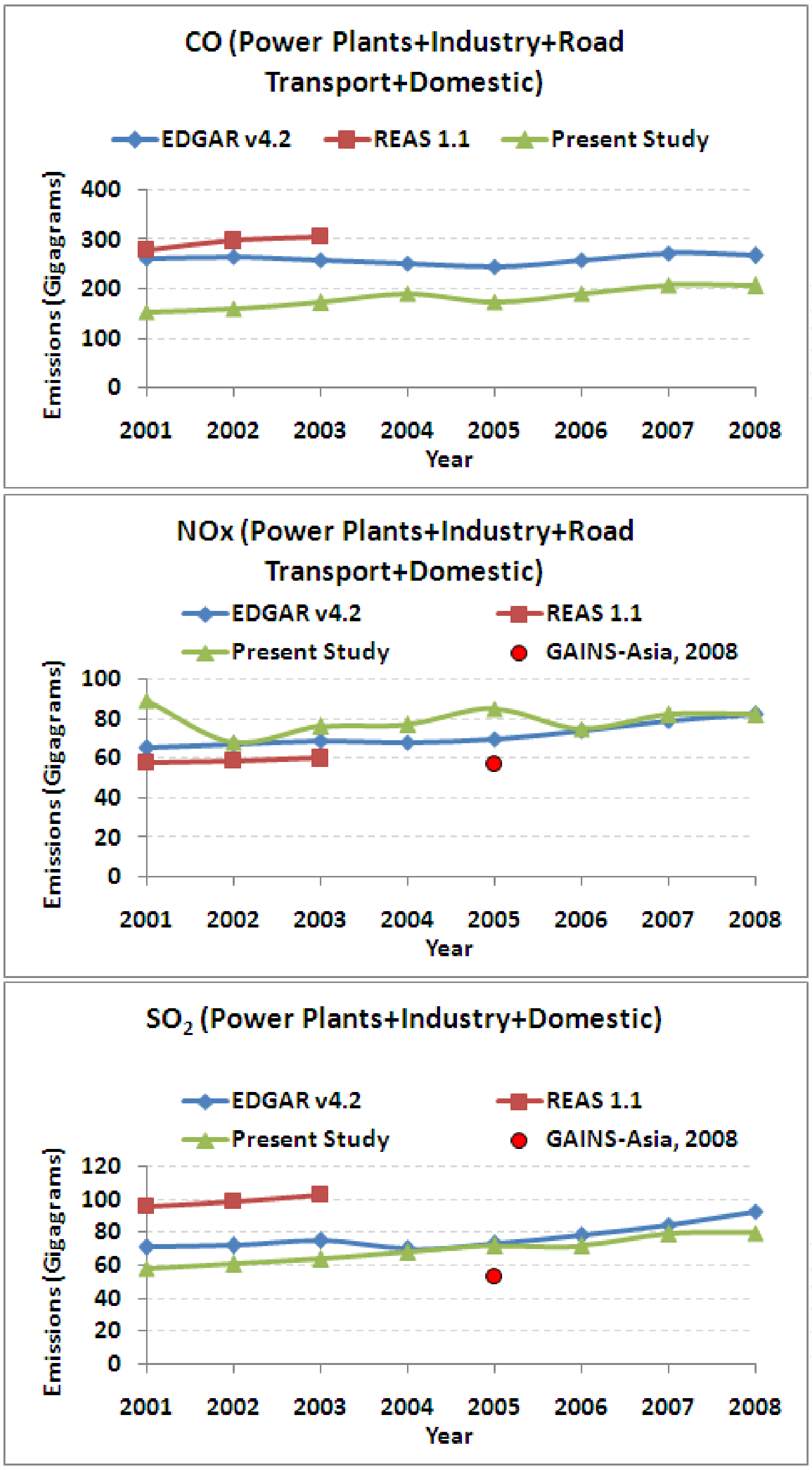

Figure 13. Emission estimates (Gigagrams yr^{-1}) for Delhi extracted from different global/regional inventories

Estimates of global inventories range from a resolution of 0.1° to 1°. At these resolutions representation of emissions is usually average of a large region. Hence emission estimates of global inventories may be different when scaled to city level as compared to an emission inventory based on local data sources of a city. Granier et al,[33] compared global and regional inventories like EDGAR, REAS etc for different regions of the world and concluded that the identification of all the reasons for the differences between the inventories is difficult to establish quantitatively. One of the reasons could be that different inventories are updated at different intervals and therefore their respective reference activity data and emission factors could be significantly dissimilar. They observed that specially for India, there are large discrepancies between different inventories. For SO_2, CO and NOx emissions, the differences between global and regional scale inventories were largest for India. In India, the largest emissions were estimated from REAS database. Thus for the city of Delhi also, these features are being reflected in the present study.

7. Air quality analysis

Emission inventories are based on basic assumptions, available statistical data and formulations. Thus there are no standard methods for validation of emission inventories. In such cases, a qualitative validation can be attempted by making use of air quality models. Concentrations output of the models using estimated emissions as input can be compared with observed concentrations. Air quality models range from simple empirical relationships to sophisticated dispersion and chemical models. The latter ones are required for estimation of concentration levels on a fine temporal and spatial scale. However, in some cases, where relevant input data is not available or average concentrations are required, simple urban pollution models have also been found applicable [34]. The present study makes use of a simple fixed box model to estimate concentrations. The box model is applicable here as concentrations are being estimated for the city as whole on an annual average scale as a qualitative validation of emission trends in correspondence to total emissions per year for the entire city. In Delhi, frequent exceedence is observed in case of TSP and NOx. Thus in the present study, these pollutants have been considered for comparison with box model estimations. Figure 14 displays annual trend of observed concentrations of TSP and NOx with those estimated from box model.

Both TSP and NOx concentrations show reasonable trend with estimated concentration. The correlation coefficient for TSP observed and estimated concentration is 0.41 while that for NOx is 0.69. Both the trends and correlation coefficient are reasonable in case of NOx estimates.

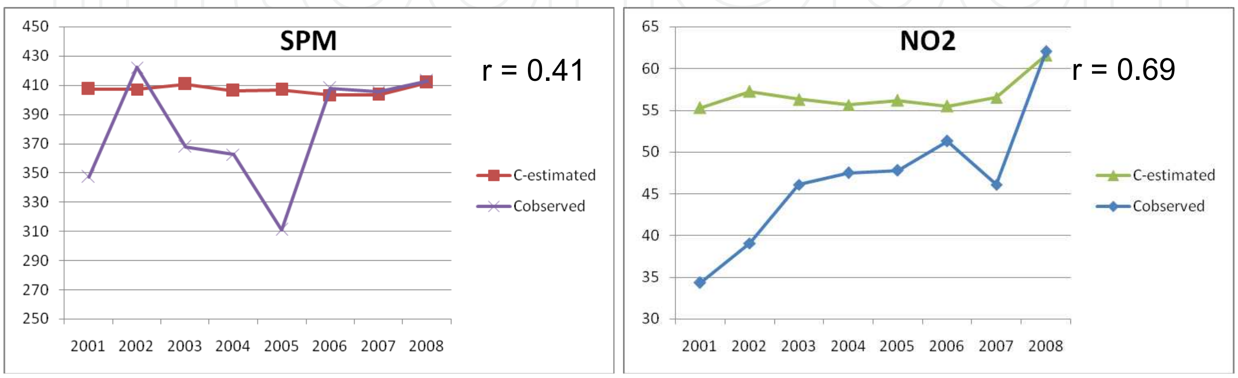

Figure 14. Comparison of TSP and NOx observed concentrations with estimated concentrations.

8. Conclusions and recommendations

An annual inventory for a period of 2001-2008 has been developed for major pollutants for the city of Delhi and compared with several global regional and national level local inventories including the one based on a bottom up approach. The results are comparable to these inventories barring one or two. Hence the methodology adopted here based on top down approach seems to have worked well and is promising in future for this purpose. The advantage here is that data requirements are less in comparison to bottom-up approach.

Emission estimates are for several years during the period when majority of the policy and control measures are implemented in Delhi and therefore the impact of these on emission trends is successfully studied. All criteria pollutants like CO, NOx , SO_2 and TSP have shown an overall increase in emissions. The major contributors remain the ever growing activities related to motor vehicle, and fuel consumption corresponding to population rise. High increase in number of vehicles often eliminates the influence of several other control options and requires a major policy intervention to circumvent this cause as also indicated by other studies [35]. This necessitates the augmentation of public transport and accessibility to modes of public transport as the need of the hour. Adoption of alternate fuel in vehicles and pollution free systems like electric vehicles also needs to be promoted. Studies have indicated that with adoption of electric vehicles cars in Delhi, an amount of Rs. 1225.25 crores (Approx. USD 28,16,663) can be reduced, which is now being annually spent on petrol [36]. Further, passage norms of vehicles from other states through Delhi also need to be made more restricted.

Coal based power plants are the major source of TSP and SO_2 emissions. However, SO_2 levels are under control in Delhi due to better fuel quality implemented through policy interventions. Methane levels from waste treatment in landfills are expected to increase as waste generation is increasing with rise in population. Shift of coal based power plants to natural gas will lead to further decrease in SO_2 and TSP emissions. The government is already in process of complete shift to natural gas in all power plants and new power plants are also coming up. Further, due to its high population density and a high percentage of people living in the slums, the extent of usage of cooking fuel in the form of biomass and kerosene is considerably high leading to high level of emissions from domestic sector also. Thus increase in supply of piped natural gas (PNG) and LPG to domestic sector is also recommended especially cleaner fuels are required in unorganized commercial sectors and slum areas.

Number of polluting industries in Delhi is decreasing due to their relocation. However, a large number of remaining industries still needs technology interventions like installation of electrostatic precipitator and venturi-scrubbers [5].

Delhi continues to be one of the most polluted megacities. However, the control measures are also being implemented in timely manner. Control strategies need to be in synchronization with other urban centers around Delhi so as to improve the efficacy of the regulatory measures.

Finally it is recommended that in future gridded emissions are estimated and air quality modeling be performed to study the impact of proposed policy interventions.

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9. References

[1] Utah DEQ (2012) Emissions Inventory: Definitions. Available: http://www.airquality.utah.gov/Planning/Emission-Inventory/Define.htm. Accessed 2012 Mar 31.

[2] Lents J, Walsh M, He K, Davis N, Osses M, Tolvett S, Liu H (2012) Estimating Emissions from Sources of Air Pollution. In: Handbook of Air Quality Management. Available: http://www.aqbook.org/read/?page=72. Accessed 2012 Mar 29.

[3] Majumdar D, Gajghate DG (2011) Sectoral CO_2, CH_4, N_2O and SO_2 emissions from fossil fuel consumption in Nagpur City of Central India. Atmos. environ. 45: 4170 – 4179.

[4] Bhanarkar AD, Goyal SK, Sivacoumar R, Rao CVC (2005) Assessment of contribution of SO_2 and NO_2 from different sources in Jamshedpur region, India. Atmos. environ. 39: 7745-7760.

[5] Central Pollution Control Board (2010) Air Quality Monitoring, Emission Inventory & Source Apportionment Studies for Delhi. Available: http://www.cpcb.nic.in/Delhi.pdf. Accessed 2011 Sep 16.

[6] Gurjar BR, van Aardenne JA, Lelieveld J and Mohan M (2004) Emission estimates and trends (1990–2000) for megacity Delhi and implications. Atmospheric Environment. 38: 5663-5681.

[7] Sharma C, Pundir R (2008) Inventory of green house gases and other pollutants from the transport sector: Delhi. Iranian j. environ. health sci. eng. 5: 17-124.

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[8] Mohan M, Dagar L and Gurjar B (2007) Preparation and Validation of Gridded Emission Inventory of Criteria Air Pollutants and Identification of Emission Hotspots for Megacity Delhi. Environ. Moni.t assesst. 130: 323-339.

[9] Mohan M, Bhati S, Sreenivas A, Marrapu P (2011) Performance Evaluation of AERMOD and ADMS-Urban for Total Suspended Particulate Matter Concentrations in Megacity Delhi. Aerosol and air quality research 11: 883-894.

[10] Mohan M, Bhati S and Rao A (2011) Application of air dispersion modelling for exposure assessment from particulate matter pollution in mega city Delhi. Asia-Pacific Journal of Chemical Engineering. 6: 85-94.
Ministry of Statistics and Programme Implementation (MOSPI) (2010) Number of motor vehicles registered in India. Available:
http://mospi.nic.in/Mospi_New/site/India_Statistics.aspx?status=1&menu_id=14.
Accessed 2011 Aug 19.

[11] Govt. of NCT of Delhi (2009) Delhi Statistical Handbook. Available:
http://www.delhi.gov.in/wps/wcm/connect/doit_des/DES/Our+Services/Statistical+Hand+Book. Accessed 2010 Oct 15.

[12] Talyan V, Dahiya RP, Anand S, Sreekrishnan TR (2007) Quantification of methane emission from municipal solid waste disposal in Delhi. Resour. conserve. recycle. 50: 240-259.

[13] EEA (European Environment Agency), 2001. Joint EMEP/ CORINAIR Atmospheric Emission Inventory Guidebook, third ed. European Environment Agency, Copenhagen.

[14] Foell W, Amann M, Carmichael C, Chadwick M, Hettelingh J, Hordijk L, Dianwu Z (1995) Rains-Asia: an assessment model for air pollution in Asia. Report on the World Bank sponsored project ''Acid rain and emission reductions in Asia.''

[15] Bouwman AF, Lee DS, Asman WAH, Dentener FJ, van der Hoek KW, Olivier JGJ (1997) A global high resolution emission inventory for ammonia Global Biogeochemical Cycles 11: 561–587.

[16] Reddy MS, Venkataraman C (2002) Inventory of aerosol and sulphur dioxide emissions from India Part II—biomass combustion. Atmos. Environ. 36: 699–712.

[17] Central Pollution Control Board (2001) Transport Fuel Quality for Year 2005. PROBES/78/2000-01.

[18] Sahu SK, Beig G and Parkhi NS (2011) Emissions inventory of anthropogenic PM2.5 and PM10 in Delhi during Commonwealth Games 2010. Atmos. environ. 45: 6180-6190.

[19] Central Electricity Authority (CEA) (2002-2009) Annual Thermal Performance Review. Available http://www.cea.nic.in/report.html. Accessed 2011 Sep 12.

[20] Govt of NCT of Delhi (2010) State of Environment Report for Delhi, 2010. Available http://www.delhi.gov.in. Accessed 2012 Feb 20.

[21] IPCC/OECD/IEA (1997). Revised 1996 IPCC Guidelines for National Greenhouse Inventories. OECD, Paris.

[22] Mohan M, Pathan SK, Narendrareddy K, Kandya A, Pandey S (2011) Dynamics of Urbanization and its Impact on Land-Use/Land-Cover: A Case Study, of Megacity Delhi. J. environ. prot. doi:10.4236/jep.2011.29147.

[23] Chakraborty M, Sharma C, Pandey J, Singh N and Gupta PK (2011) Methane emission estimation from landfills in Delhi: A comparative assessment of different methodologies. Atmos. environ. 45: 7135-7142.

[24] Mor S, Ravindra K, De Visscher A, Dahiya RP and Chandra A (2006) Municipal solid waste characterization and its assessment for potential methane generation: A case study. Sci. total environ. 371: 1-10.

[25] Ravindra K, WautersE, Tyagi SK, Mor S (2006) Assessment of air quality after the implementation of compressed natural gas (CNG) as fuel in public transport in Delhi, India. Environ. monit. assess. 115: 405–417.

[26] Biswas J, Upadhyay E, Nayak M, Yadav AK (2011) An Analysis of Ambient Air Quality Conditions over Delhi, India from 2004 to 2009. Atmos. climate sci. 1: 214-224.

[27] Kansal A, Khare M, Sharma CS (2011) Air quality modelling study to analyse the impact of the World Bank emission guidelines for thermal power plants in Delhi . Atmos. pol. res. 2: 99-105.

[28] Ramachandra TV and Shwetmala (2009) Emissions from India's transport sector: Statewise synthesis. Atmos. environ. 43: 5510-5517

[29] Chhabra A, Manjunath KR, Panigrahy S, Parihar JS (2009) Spatial pattern of methane emissions from Indian livestock. Current Science. 96: 683-689.

[30] Jalihal SA and Reddy TS (2006) Assessment of the Impact of Improvement Measures on Air Quality: Case Study of Delhi. Journal of Transportation Engineering. 132: 482-488. Ahmad I and Dewan KK (2007) Electric vehicle: a futuristic approach to reduce pollution (A case study of Delhi). World Review of Intermodal Transportation Research. 1: 300-312

[31] Ohara T, Akimoto H, Kurokawa J, Horii N, Yamaji K, Yan X, et al (2007) An Asian emission inventory of anthropogenic emission sources for the period 1980-2020. Atmos. Chem. Phys. 7: 4419-4444.

[32] Granier C, Bessagnet B, Bond T, D'Angiola A, Denier van der Gon H, Frost G, et al (2011) Evolution of anthropogenic and biomass burning emissions of air pollutants at global and regional scales during the 1980–2010 period. Climatic Change. 109: 163-190.

[33] Venegas LE, Mazzeo N.A., Rojas A.L.P. (2011) Evaluation of an Emission Inventory and Air Pollution in the Metropolitan Area of Buenos Aires. Air Quality-Models and Applications, Nicolas Mazzeo (Ed.), ISBN: 978-953-307-307-1, InTech.

[34] Mohan M, Kandya A (2007) An Analysis of the Annual and Seasonal Trends of Air Quality Index of Delhi. Environ. monit. assess. 131: 267-277.

[35] Ahmad I and Dewan KK (2007) Electric vehicle: a futuristic approach to reduce pollution (A case study of Delhi). World Review of Intermodal Transportation Research. 1: 300-312.