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UNDERSTANDING URBAN VEHICULAR POLLUTION PROBLEM VIS-A-VIS AMBIENT AIR QUALITY – CASE STUDY OF A MEGACITY (DELHI, INDIA)

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Abstract. Air pollution has become a growing problem in megacities and large urban areas through out the globe, and transportation is recognized as the major source of air pollution in many cities, especially in developing countries. Contribution of automobiles is reported in the range of 40 to 80% of the total air pollution. The challenge facing megacities is how to reduce the adverse environmental impacts and other negative effects of transportation without giving up the benefits of mobility. The dilemma becomes most pressing under conditions of rapid urban growth, which is likely to increase travel demand significantly.

The paper is aimed at understanding the problem of vehicular pollution vis-a-vis ambient air quality for a highly traffic affected megacity, Delhi, wherein, the contribution of transport sector was estimated to be as high as 72%. An effort has been made to review and evaluate the benefits (in terms of improved air quality) of the technological interventions/policies adopted for vehicular pollution control in Delhi. It also highlights the outcome of the efforts and suggests further improvements thereon. The importance of public participation and awareness are also discussed. The paper focuses on deriving the benefits of the implementation of management strategies, supported by scientific and technical data/ interpretation, so that the people can realize and participate in the government's endeavor for clean city drive in a more effective manner.

Keywords: ambient air quality, better air quality, control strategies, Delhi, inspection & maintenance, vehicular pollution

1. Introduction

The anthropogenic sources of urban air pollution are classified broadly into three categories; viz. point (industrial), area (mainly domestic cooking/heating) and line (vehicular). The main cause of air pollution is fuel combustion through any of these sources. In India, 25% of the total energy (of which 98% comes from oil) is consumed by transport sector only, which is reported to be contributing more than 50% of air pollution problem in most of the metro cities, and in some cases it was even up to 80%. As per an estimate, in 2001, air pollution contribution of transport sector was about 72% in Delhi and 48% in Mumbai. In Beijing and Guangzhou, automobile pollution contribution in terms of CO and NOx is estimated to be more than 80 and 40% respectively.

The population of Delhi has increased from 9.42 million in 1991 to 13.78 million in 2001, registering a decadal growth of 46.3%, against the national growth rate of 21.3%. The total area of National Capital Territory (NCT) of Delhi is 1483 km^2 with an urban segment of 685 km^2 (46.2%) in 1991. The population density has increased to 9294 persons/km^2 in 2001 as compared to 6352 persons/km^2 in 1991 (DoE, 2003).

The rapid population growth together with high rate of urbanization, industrialization and increase in motorized transport have resulted in an increased concentration of various air pollutants namely; Sulphur Dioxide (SO_2), Nitrogen Oxides (NOx), Suspended Particulate Matter (SPM), Respirable Suspended Particulate Matter (RSPM/PM10), Carbon Monoxide (CO), Lead (Pb), Ozone (O_3), Benzene, Hydrocarbons (HCs) etc. The adverse effect of pollution from vehicles gets revealed immediately through symptoms like cough, headache, nausea, and irritation of eyes, various bronchial problems and visibility impairment. Long-term exposure to the high level of pollutants is mainly responsible for respiratory and other ailments including lung cancer, asthma and in some cases leading to death. Vehicles in major metropolitan cities are estimated to account for 70% of CO, 50% of HC, 30–40% of NOx, 30% of SPM and 10% of SO_2 of the total pollution loads, of which about two third is contributed by two wheelers alone.

In the past couple of decades, considerable research and development efforts have been made towards improving engine efficiency and fuel quality together with adoption of emission reduction technologies (like catalytic converter). In addition, mechanisms for better traffic management have been evolved including construction of flyovers to ensure smooth traffic flow, thereby reducing traffic congestion at major traffic intersections and ultimately reducing emissions as well as travel time. If these measures are implemented effectively, the problem of air pollution due to transport sector could be managed to a greater extent.

This paper is aimed at understanding the problem of vehicular pollution vis-a-vis ambient air quality of Delhi, wherein several steps have been taken in the recent past to tackle the problem. An effort has been made to delineate action plans for further improvement in air quality of Delhi with public participation. In the following section, first the status of ambient air quality in Delhi has been presented, followed by understanding of vehicular pollution problem identifying the major vehicle category(ies) and pollutant(s) of concern. Impact of control measures on emission load and ambient air quality has been assessed and finally action plans for further improvement in air quality have been suggested.

2. Air Quality of Delhi – Past and Present Scenario

Presently, there are ten air quality monitoring stations in Delhi (under National Air Monitoring Programme) representing 6 residential/commercial activity zones, 3 industrial zones and one traffic activity (ITO, Bahadur Shah Zafar Marg). CPCB operates seven stations, while NEERI operates three. The air pollutants monitored regularly at all the sites are SPM, PM10, SO_2 and NO_2. SPM and PM10 are monitored 8 hourly for 24 h, whereas SO_2 and NO_2 are monitored 4 hourly for 24 h. Daily average concentration is calculated from the 3 observations of SPM and PM10, and 6 observations of SO_2 and NO_2. Monitoring frequency is twice a week.

Twenty four hourly annual average levels of criteria pollutants (SPM, SO_2 and NO_2) monitored at the seven locations by CPCB have been analysed for the years 1987 to 2003. Monitoring of PM10 was included in the early 1990's for the 3 stations operated by NEERI, whereas at other locations, it was included in the late 1990's. Air quality data at ITO was available since 1995 onwards (<http://www.cpcb.delhi.nic.in>). The data have been summarized according to activity zones, i.e. residential, industrial and traffic. Accordingly, annual data for four residential sites (Ashok Vihar, Sirifort, Janakpuri and Nizamuddinn), two industrial sites (Shahzada Bagh and Shahdara) and ITO are averaged, as presented in Figure 1 along with the corresponding CPCB standards (CPCB, 1994).

2.1. Suspended particulate matter (SPM)

Annual mean levels of SPM at residential and industrial sites have been in general in the range 280–420 and 300–450 $\mu g/m^3$ respectively. These levels were found higher than the corresponding CPCB standard of 140 and 350 $\mu g/m^3$. These levels were much higher compared to WHO guidelines of 60–90 $\mu g/m^3$ during all the years.

In general, an increasing trend was observed from 1988 to 1996, and thereafter a decreasing trend/consistent levels at residential and industrial sites was seen. At ITO, an increasing trend (in the range 409–531 $\mu g/m^3$) was observed since 1997. High SPM levels are attributed mainly to the natural sources, lifting of road dust and meteorological conditions, and to some extent the anthropogenic sources. The decline in SPM levels may be due to enforcement of various measures for air quality improvement and the growing awareness amongst industries for using emission control devices. However, due to significant variations observed in measured SPM levels, it is difficult to conclude precisely, and use the SPM data as an indicator of air pollution. As regards levels of PM10, WHO guideline of 40 $\mu g/m^3$ was found to exceed by a factor of 3 to 6 times. PM10 to SPM ratio was found to be around 50%.

2.2. Sulfur dioxide (SO_2)

Annual mean levels of SO_2 indicate that SO_2 has always been much below the prescribed standard of 60 $\mu g/m^3$ at all the sites. However, an increasing trend was observed at industrial area sites during 1989–1995, and thereafter a continuous declining trend was observed. At residential area sites, annual mean SO_2 concentration has been below 18 $\mu g/m^3$, maximum being during 1992. Thereafter, the levels were

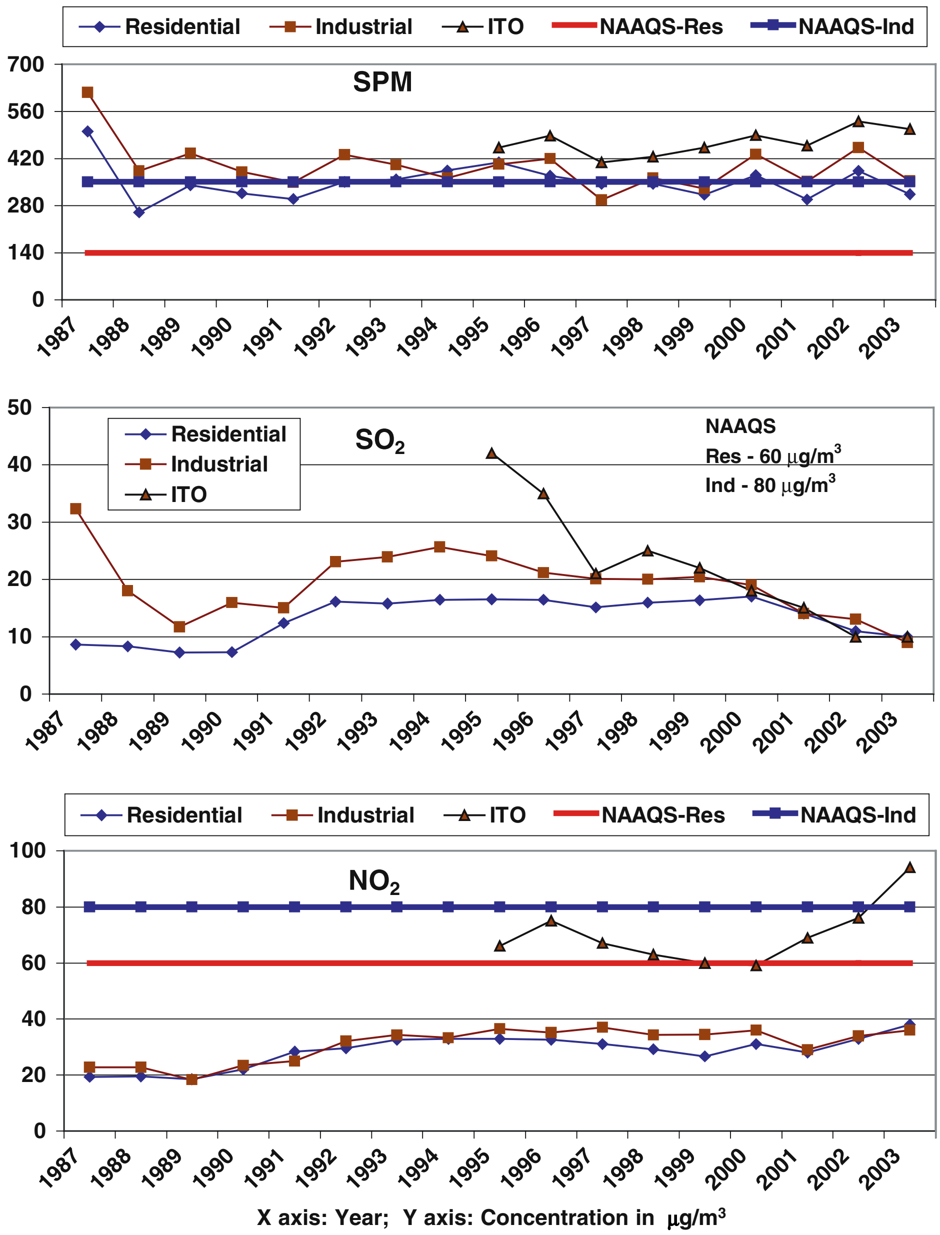

Figure 1. Annual mean levels of SPM, SO_2 and NO_2 in Delhi: 1987–2003.

stabilized and declined subsequently at all the locations after 2000. This may be attributed to various pollution control measures, particularly adopted in different industrial sectors, and also due to reduction in sulfur content in the diesel (from 1 to 0.05%) used in automobiles. This is also evident by the declining SO_2 levels at ITO, traffic intersection site.

2.3. Nitrogen dioxide (NO_2)

Annual mean levels of NO_2 indicate that NO_2 has mostly been in the range 20–40 μg/m^3, much below the prescribed standard of 60 μg/m^3 during all the years at residential and industrial area sites. However, a consistent increase in NO_2 levels has been observed during 1989 to 1995, and thereafter levels stabilized during 1996–2000. An increasing trend was observed after 2001 at all the sites. Considerable increase in vehicular traffic could be considered as major cause for high NO_2 levels.

At ITO, NO_2 levels declined during 1996–2000, which was considered as the positive impact of various pollution control measures in vehicular sector. However, in the subsequent years, NO_2 levels rose at a faster rate, exceeding the CPCB standard of 60 μg/m^3. Increased traffic, traffic congestion and implementation of CNG in auto, taxis and buses in Delhi are considered as the factors responsible for increase in NO_2 levels at ITO.

3. Vehicular Population and Pollution Scenario

3.1. Vehicular growth pattern

The total number of vehicles in 1985 was 0.841 million, which increased to 3.552 million in 2002 (4.2 times increase). Growth in total number of vehicles is projected in Figure 2, along with the annual growth rate (GoI, 2002). Though the total number of vehicles had increased, but the annual growth rate was found to decrease from 19% during 1985–90 to 9.7% during 1990–1995 and to 6.6% during 1995 to 2002. Two wheelers and cars are the two major types of vehicles

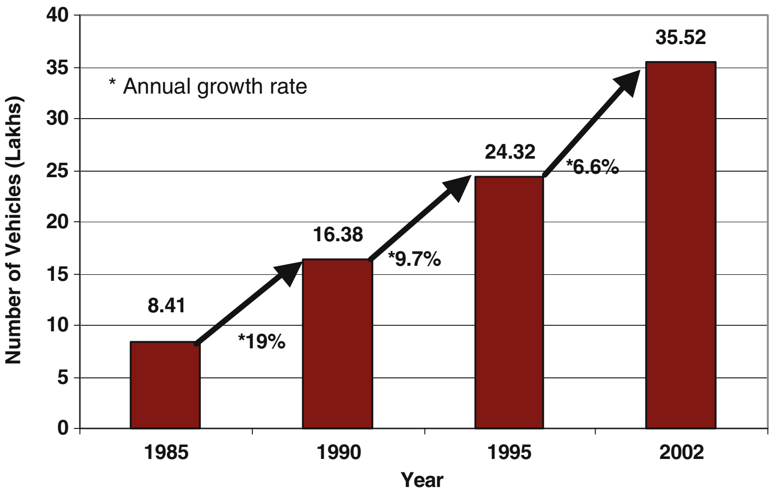

Figure 2. Growth in number of registered vehicles in Delhi: 1985–2002.

TABLE I
Percentage share of different types of vehicles in Delhi (1985–2002)

Year	2-Wheelers	3-Wheelers	Cars/Cabs	Buses	Goods vehicles
1985	68.8	3.6	19.8	1.6	6.2
1990	68.0	3.6	21.7	1.1	5.7
1995	66.5	3.1	24.2	1.1	5.1
2002	63.8	2.4	27.9	1.3	4.6

Source. Estimate based on data given in Auto Fuel Policy Report, 2002.

used in Delhi and together account for about 90% of the total vehicles. Percent share of different categories of vehicles during different time periods is presented in Table I. The total number of 2 wheelers decreased from 68.8% (in 1985) to 63.8% in 2002, whereas share of cars increased from 19.8% (in 1985) to 27.9% in 2002.

3.2. Vehicular movement and emission load

As per CRRI (2002) estimate, total daily traffic movement in Delhi is 79.2 million kilometers. Share of 2-wheelers and cars are about 43 and 38% of the total fleet, respectively. The share of 3-wheelers is about 12%, whereas remaining type of vehicles travel about 7%. Total daily emission load by transport sector is estimated to be 422 MT of CO, 110 MT of NOx, 184 MT of HC and 13 MT of particulate matter (PM). Major contributor (vehicle category) in terms of different pollutants is presented in Figure 3.

In terms of percentage of the total pollution from different category of vehicles, two wheelers contribute about 40% CO, 3.5% NOx, 60.4% HC and 38.6% PM. The other major contributor is private cars which account for about 47% CO, 39% NOx, 19% HC and 26% PM. In terms of HC and PM, two wheelers contribute more than the cars, whereas for CO and NOx, cars are the major contributors. These two types of vehicles hold major share of pollution equally and together contribute nearly 87% CO, 43% NOx, 80% HC and 65% PM. Buses and LCVs (light commercial vehicles) contribute about 39% and 10.7% NOx and 13% and 15% PM respectively. Depending upon the parameter of interest, specific vehicle category may be targeted for control of emissions.

4. Impact of Vehicular Pollution Control Measures

4.1. Impact on emission load

Under the directives of Hon'ble Supreme Court, various pollution control measures were taken in Delhi towards vehicular pollution reduction (available at

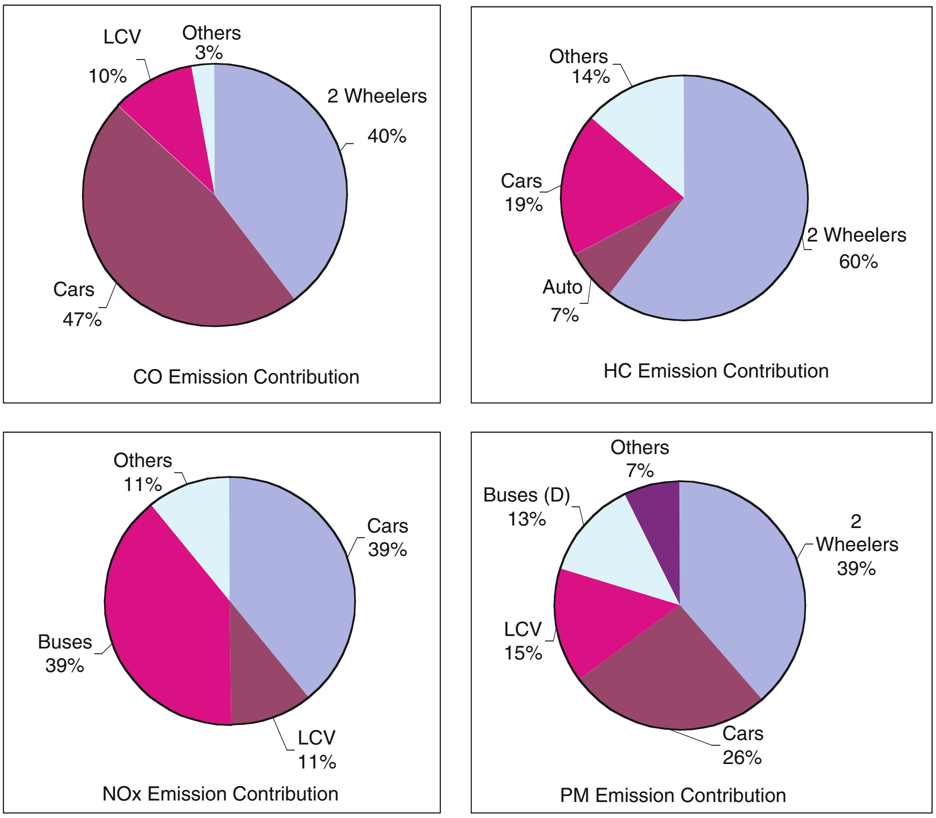

Figure 3. Pollutant-wise major contributors to vehicular pollution.

www.delhigovt.nic.in). One of the major steps was phasing out of old vehicles and use of clean fuel (CNG) in auto, taxis and buses. The impact of phasing out vehicles in terms of pollution load reduction has been estimated, to understand the likely positive impact on ambient air quality.

4.1.1. *Phasing out More than 15 Years Old Commercial/Transport Vehicles*

The total number of commercial/ transport (trucks and LCVs) was 52370 in 1985 and 161650 in 2002. The following emission scenarios have been generated and emission load in terms of CO and NOx have been estimated using the CPCB emission factors.

- Base Scenario – all trucks and LCVs were operating in 2002
- Case 1 – all vehicles registered by 1985 were replaced by similar type of vehicles, but conforming to 2001–2005 emission norms
- Case 2 – all vehicles registered during 1985–1990 were also replaced by similar type of vehicles, but conforming to 2006–2010 emission norms.

Ban/replacement of pre-1985 vehicles is estimated to reduce the CO and NOx emission load by about 13.3 and 13.9% respectively as compared to the base scenario. Further, in case of replacement of pre-1990 vehicles, the corresponding reductions in CO and NOx emission load would be 33 and 28% respectively in 2007.

4.1.2. *Conversion of Auto, Taxi and Buses to CNG*

The total number of auto and taxi in 2002 were 86,985 and 20,628 respectively. Considering all the autos have switched over to CNG, the emission load reduction in terms of CO is estimated to be about 99%, whereas the NOx load would increase by about 4.2 times as compared to the present level (before CNG conversion). This increase in NOx emissions would be because of the higher emission factors for CNG, as compared to petrol for 3-wheelers.

Conversion of all the taxis to CNG would reduce CO emission load by about 85% and NOx by 57%. Conversion of all the buses (47,578) to CNG by 2002 would have reduced CO emission load by about 71% and NOx by 88%. Thus, a positive impact in terms of CO emission is expected in ambient air, whereas NOx level should also reduce or may remain consistent. The reduction in NOx due to trucks, LCV, Taxi and buses may get offset by the increase in NOx emissions from autos.

4.2. Impact on Ambient Air Quality

Impact of pollution control measures (PCM) on ambient air quality of Delhi has been analyzed into three time periods, i.e. 1989–1996 (when the air pollution problem was identified or pre-implementation period), 1997–2000 (when several control measures in vehicular and industrial sector were taken or during implementation period), and 2001–2003 (when the outcome of the control measures are expected to reflect in the resultant ambient air quality or during post-implementation period). Summary of annual average concentrations of SO_2, NO_2, CO, SPM and PM10 observed at residential (average of 4 sites), industrial (average of 2 sites) and traffic intersection sites are presented in Table II. Following observations are made from the above analysis:

- Annual average concentration of SO_2 during PCM implementation stage was 16, 20, and 22 μg/m^3 respectively in residential, industrial and traffic activity zones, which got stabilized at 12 μg/m^3 during post-implementation period. A very positive indicator of pollution control measures.
- Annual average concentration of NO_2 during PCM implementation stage was 30, 36 and 62 μg/m^3 in respective activity zones. Uniform distribution of NO_2 concentration is observed in residential and industrial activity zones, average concentration being 33 μg/m^3 in both the zones. However, a steep rise was observed at traffic intersection, the average concentration being 80 μg/m^3 during 2001–2003. At the same time, CO levels have decreased considerably (3479 from

TABLE II
Summary of air quality status in Delhi: Pre, during and post-implementation period of pollution control measures

		1989–1996		1997–2000		2001–2003	
Parameter	Zone/Site	Range	Avg.	Range	Avg.	Range	Avg.
SO_2	Residential	7–17	13	15–17	16	10–14	12
	Industrial	12–26	20	19–21	20	9–14	12
	ITO	–	–	18–35	22	10–15	12
NO_2	Residential	19–33	29	27–31	30	28–38	33
	Industrial	18–36	30	34–37	36	29–36	33
	ITO	–	–	59–67	62	69–94	80
CO	ITO	3259–5587	4032	4241–5450	4855	2598–4619	3479
SPM	Residential	300–409	354	312–370	343	298–383	332
	Industrial	362–432	398	298–433	356	352–453	386
	ITO	–		409–490	444	458–531	499
PM10	Residential	–	–	154*	154	113–142	126
	Industrial	–	–	155*	155	140–165	150
	ITO	–	–	191–222**	210**	171–270	228

All values are in μg/m^3.
*For 2000 only.
**March 1998 to December 2000.

4855 μg/m^3 during 1997–2000), indicating a positive impact of PCM on vehicular pollution. This may be possibly due to introduction of CNG vehicles and reduction in 2-sroke vehicles in Delhi. However, the possibility of other sources contributing to high NO_2 levels at ITO may not be ruled out, and this requires a detailed investigation.

- Annual average concentration of SPM in residential, industrial and traffic activity zones were observed to be 343, 356 and 444 μg/m^3 during 1997–2000 respectively. This has shown a marginal decrease (3.2%) at residential sites, but slight increase at industrial (8.4%) and traffic (12.4%) sites. Substantial variation is observed in SPM levels due to number of factors, and it cannot be attributed to any specific activity.
- During 2001–2003, PM10 levels at residential, industrial and ITO were 126, 150 and 228 μg/m^3 respectively, which were much higher than the corresponding CPCB standards. During PCM implementation stage, PM10 data was available from March 1998 to December 2000. In this period, the average value was 210 μg/m^3, which was found to increase (by 8.6%) to 228 μg/m^3 during post implementation period. No positive impact of control measures was observed on PM10 at ITO. At residential sites, PM10 levels decreased by about 18%, whereas, at industrial site, the reduction was marginal (3%).

- PM10 data collected by NEERI during 1993–2002 was also analyzed, to ascertain the effect of various pollution control measures adopted primarily in transport and industrial sector (Akbar, 2004). PM10, the main pollutant of public health concern was found to decline, indicating the positive impact of various interventions. Annual PM10 levels in Delhi decreased from 255 to 180 μg/m^3 during 2000–2002, as compared to the levels measured during 1993–95.

The above analysis indicates that NO_2 is going to be the pollutant of concern in future, and needs to be given due attention, along with particulate matter. NOx is mainly contributed by cars (39%), buses (39.3%) and LCVs (10.7%), amounting to 89%. 2-wheelers contribute less than 4% NOx emissions, but high CO.

Replacement of 2-stroke 2-wheelers (2S-2W) by 4-stroke 2-wheelers (4S-2W) may further increase NO_2 levels in ambient air due to higher emission factor (0.3 g/km for 4S-2W as against 0.07 g/km for 2S-2W).

5. Major Concerns

The main source of vehicular pollution is the fuel itself. The way it undergoes combustion inside the engine determines the amount of pollutant emissions from the engine. Any strategy then has to aim at the use of cleaner fuel, reduction in fuel consumption, adoption of efficient engines and installation of pollution control device at the tail end pipes of vehicles. Use of adulterated fuel and poor inspection and maintenance practices are identified as the two major cause of vehicular pollution, which are to be tackled by Government as well as the people of Delhi. These two aspects are discussed below.

5.1. Adulteration of fuel and fuel products

The possibility of adulteration could be at three points: during transportation from refinery outlet/storage to petrol pump, at the petrol pump and by the consumers. Adulteration by commercial vehicle owners (auto and taxi) is ruled out due to shifting to CNG. No private vehicle owner would adulterate the fuel at the cost of his/her vehicle. The best check point is at the petrol pump. Adequate facilities should be established and the petrol pump owner should ensure receipt and distribution of un-adulterated fuel. Some guidelines in this regard should be formulated with the direct responsibility on the petrol pump owner.

5.2. Inadequacy of inspection and maintenance (I&M) practices

Tendency of not to go for servicing unless the vehicle develops some problem deteriorates the mechanical condition of even the new vehicles over a period of time and thus emit more pollutants than at the time of their designing. Plying older vehicles on roads is not a problem but plying older vehicles that are not properly maintained is a problem. Newer vehicles can also pollute equally in absence of regular maintenance and repairing practices. In India one-time registration procedure at the time of purchase of a new vehicle is followed, whereas countries like Japan have a mandatory renewal registration system inter-locked with compulsory I&M system in which the owner has to get his registration renewed only after necessary I&M formalities are complete.

Automotive Research Association of India (ARAI) conducted various tests on all categories of on-road vehicles to study the effect of I&M on emissions. The study proved substantial reduction in various types of pollutants after I&M. The results are given in Table III. After I&M, reduction in CO emissions were about 77, 66 and 40% for 2, 3 and 4 wheelers respectively. In case of hydrocarbons, corresponding reductions were 36, 23 and 40%.

In order to promote better I&M practices, it is proposed to have free pollution checking facility along with minor servicing, at petrol pumps. People should get the vehicle checked while re- fuelling the vehicle. A certificate ensuring that the vehicle meets the emission norms could be issued, with a validity of 2 months (initially for the first year). Fuel should be given only after check and ensuring that the vehicle meets the norms.

All the vehicles entering Delhi from nearby States should also have this certificate. Necessary arrangement for this may be created at the petrol pumps located in the outskirts of Delhi. Similar kind of facility may also be created at major parking places. Vehicles not having PUC and I&M certificate should be parked separately

TABLE III
Effect of I&M practices on emissions from 2, 3 and 4 wheelers

Vehicle/Status	CO	HC
2 Wheelers		
Before I&M (g/km)	7.67	3.99
After I&M (g/km)	1.79	2.54
Reduction (%)	76.7	36.3
3 Wheelers		
Before I&M (g/km)	6.01	8.77
After I&M (g/km)	2.02	6.77
Reduction (%)	66.4	22.8
4 Wheelers		
Before I&M (g/km)	12.18	2.3
After I&M (g/km)	7.27	1.38
Reduction (%)	40.3	40.0

Source. Parivesh, CPCB, May 2003.

and be charged more for parking. A detailed methodology applicable to different category of vehicles can be worked out to ensure strict follow up by the people.

Recommendations given by various experts on fuel quality improvement, engine technology upgradation, awareness and vehicle maintenance, and traffic management etc. need to be quantified in terms of cost, time and comfort and then publicized through various media to bring about change in the mindset of people to realize the importance of pollution control measures proposed by the Government.

6. Conclusions

The population of Delhi is going to increase further which will require more infrastructure and transport facilities. More movement of vehicles will result into more emissions, which will ultimately deteriorate the air quality of Delhi.

Analysis of impact of pollution control measures on ambient air quality indicated that SO_2 levels have decreased considerably. CO levels measured at traffic intersection also decreased significantly by about 28% during 2001–2003 as compared to 1997–2000 levels. SPM and PM10 levels have increased by about 10%. NO_2 levels were found to stabilize in residential and industrial activity zones but increased alarmingly at ITO representing traffic activity, which needs to be investigated in detail.

In order to restore and improve the air quality of Delhi, concerted efforts have to be made by Government as well as by the people of Delhi. Besides, consistent improvements in fuel quality and engine technology, petrol pump owners and parking places have to play an important role in this endeavor. A detailed methodology applicable to different category of vehicles needs to be worked out to check the adulteration of fuel and follow up of I&M practices by the people to make the city clean and pollution free.

Acknowledgments

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