Environ Monit Assess (2007) 125:257–263
DOI 10.1007/s10661-006-9517-x

# Air Quality Assessment in Delhi: Before and After CNG as Fuel

**Asha B. Chelani · Sukumar Devotta**

Received: 11 September 2006 / Accepted: 15 September 2006 / Published online: 12 January 2007


**Abstract** A number of policy measures have been activated in India in order to control the levels of air pollutants such as particulate matter, sulphur dioxide ($SO_2$) and nitrogen dioxide ($NO_2$). Delhi, which is one of the most polluted cities in the world, is also going through the implementation phase of the control policies. Ambient air quality data monitored during 2000 to 2003, at 10 sites in Delhi, were analyzed to assess the impact of implementation of these measures, specifically fuel change in vehicles. This paper presents the impact of policy measures on ambient air quality levels and also the source apportionment. CO and $NO_2$ concentration levels in ambient air are found to be associated with the mobile sources. The temporal variation of air quality data shows the significant effect of shift to CNG (Compressed Natural Gas) in vehicles.

**Keywords** Air quality · Vehicular emission · CNG · Control policies

## 1 Introduction

A number of policy measures have been activated in India in order to control the levels of air pollutants such as particulate matter, sulphur dioxide ($SO_2$) and nitrogen dioxide ($NO_2$). These air pollutants cause adverse effects on health and environment. The harmful effects of these pollutants on human beings, ecosystem, historical monuments and building are well documented (Dockery & Pope, 1994). Particulates are considered to be responsible for respiratory diseases, morbidity and mortality (Schwartz, 1993; Vincent & Tan, 1997). The major anthropogenic sources of air pollutants are industrial emissions, domestic fuel burning, emissions from power plants and transportation activities. In India, specifically in Delhi, vehicular pollution contributes 67% of the total air pollution load, which is approximately 3,000 metric tones per day (Central Pollution Control Board, 1999). It is estimated that out of every 10 school children in Delhi, 1 suffers from asthma (Cropper et al., 1997). The figure is increasing due to the increased vehicular activities. It is remarkable that the vehicular population observed in 1993 was approximately 2.1 million and during 2001, it has increased to around 3.6 million. It is estimated that on an average, 370 to 600 vehicles are registered daily (Kathuria, 2002). The tremendous vehicular growth resulted in the high concentrations of air pollutants. It is estimated that the vehicles account for approximately 97% of total Hydrocarbons (HC), 48% of $NO_x$, 76% of CO, 10% of SPM and 6% of $SO_2$ emissions in Delhi (Sengupta, 2000). Diesel powered vehicles are one of the several vehicle sources of $NO_x$

A. B. Chelani (✉) · S. Devotta
National Environmental Engineering Research Institute,
Nehru Marg, Nagpur 440 020, India
e-mail: ashachelani@rediffmail.com

emissions. In diesel engines, a major part of the fuel remains unburnt that makes particulate emissions. According to the Central Pollution Control Board (CPCB), the concentration of PM10 (particulate matter of size less than 10 μm), $SO_2$, $NO_2$ and SPM (total suspended particulate matter) are exceeding the stipulated permissible limits for the respective pollutant.

Due to this, the major policies activated in Delhi are related to the emissions from transportation activity. To control the pollution levels in ambient air, standards for the vehicles and the fuel standards have been correspondingly improved. A few of recent initiative taken by government includes (Mashelkar, 2002); removal of lead from gasoline, phasing out of older commercial vehicles, introduction of EURO I and EURO II emission norms, check on adulteration of fuel, control of sulphur content in petrol and diesel, lowering of benzene content in petrol, change in automobile fuel, which led conversion of diesel fuel to CNG in the public transport and buses during 2001. CNG is introduced as it is a clean burning alternative fuel for vehicles and has a potential for reducing harmful emissions of air pollutants. It is estimated that diesel combustion emits 84 g/km of particulates as compared to 11 g/km in CNG (Nylund & Lawson, 2000).

It is argued that the conversion of fuel in vehicles to CNG reduces the pollutants levels, as it is less hazardous, environmental friendly and cost effective in terms of operational cost (Goyal & Sidhartha, 2003). The studies have already been conducted to assess the air quality levels and the effect of shift to cleaner fuel. In this line, Kathuria (2002) observed insignificant impact of change in fuel quality on air quality levels. The study was however confined to the air quality data observed during 1999 to 2001 and at only one station. Contrary to Kathuria, Goyal and Sidhartha (2003) observed significant impact of CNG implementation in Delhi. They utilized the air quality data during 1995–2001, collected at the same station as that of Kathuria. In a study on emission trends of air pollutants from various sources and effects on air quality in Delhi, Gurjara et al. (2004) observed that the impact of several control measures on air quality is not very large (World Bank, 2005). A significant reduction in various air pollutant levels at several residential, industrial and commercial areas and also at traffic intersections has been reported (Central Pollution Control Board, 2000). On the contrary, Center for Science and Environment (CSE) study has reported increase in the levels of air pollutants in Delhi (Center for Science and Environment, 2001).

Results of the above studies vary in their interpretations and yield messages, which may be misleading for the policy makers and public. Therefore, there is a need for a more comprehensive study, which is based on increased spatial and temporal coverage. This would help in integrated assessment of the air quality levels before and after the implementation of CNG in motor vehicles. This will ultimately result in providing the comprehensive solutions to the air quality concerns of the city. The objective of the study is, therefore, to examine whether the control measures mainly the use of CNG in vehicles reduced the air quality levels in Delhi.

## 2 Study Area

The city is located in central India and approximately 715 ft above the mean sea level. The population of Delhi has increased from 9.5 to 13.8 million during the last decade. The region has a semi-arid climate that is often described as tropical plain, with extremely hot summers, heavy rainfalls in the monsoon months, and cold winters. The summer months witness dust storms. In winter months, mornings are foggy and evenings cause poor natural ventilation with high emission loads during peak traffic hours. Temperature generally varies from 46°C in summer to 10°C in winter. This area is under the influence of monsoon winds generally NE–NW in winter and SE–SW in summer with average yearly rainfall of approximately 73 cm. Low wind speed and temperature inversion conditions lead to accumulation of air borne pollutants over the city, particularly in winter months. Existing industries, power plant, vehicular activities and frequent dust storm mainly contribute high concentrations of the pollutants in Delhi. Among the industries, thermal power plants are the most prominent contributors to air pollution. There are 126,000 industrial (small- and medium-scale) units in Delhi, out of which 98,000 units are categorized as non-conforming (Ministry of Environment & Forests, 1997). The Supreme Court of India directed government to either shift or close down the hazardous industries. After the shifting or closing of industries, vehicular pollution remains to be dominating in Delhi.

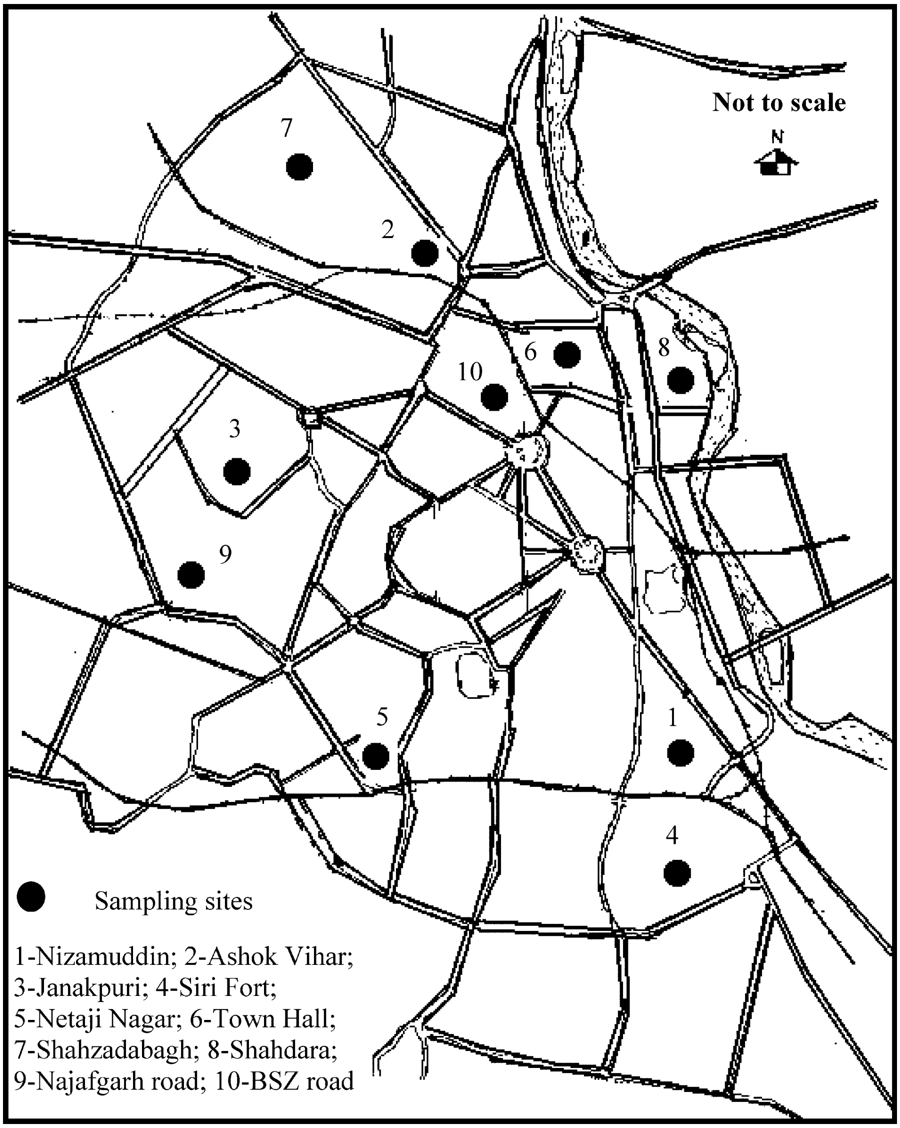


**Fig. 1** Location map of sampling sites in Delhi

For assessing the impact of introduction of CNG, the air quality data collected during 2000 to 2003 was considered. This data set represents the before and after the fuel change scenario, as CNG was introduced in 2001. CPCB is monitoring various criteria pollutants such as $SO_2$, $NO_2$, PM10 and SPM at 10 sites located at Nizamuddin, Ashok Vihar, Janakpuri, Siri Fort, Netaji Nagar, Town Hall, Shahzadabagh, Shahdara, Najafgarh road and Bahadur Shah Zafar (BSZ) road in Delhi. The data at all the 10 sites is utilized for the present study. Out of these 10 sites, first six are categorized as residential and next three are industrial and the remaining one represents the busiest traffic intersection site. Due to data limitations, carbon monoxide (CO) was analyzed only at one site i.e. BSZ road. The map showing the location of each of the sites is plotted in Fig. 1. The data were obtained from the CPCB web site (http://www.cpcb.nic.in).

## 3 Results and Discussion

In the past few years, a number of policies have been enacted in Delhi to control and abate air pollution. Emission inventory indicated that vehicular emission is the main source of pollution in Delhi. Private vehicles include two wheelers and cars, whereas mass

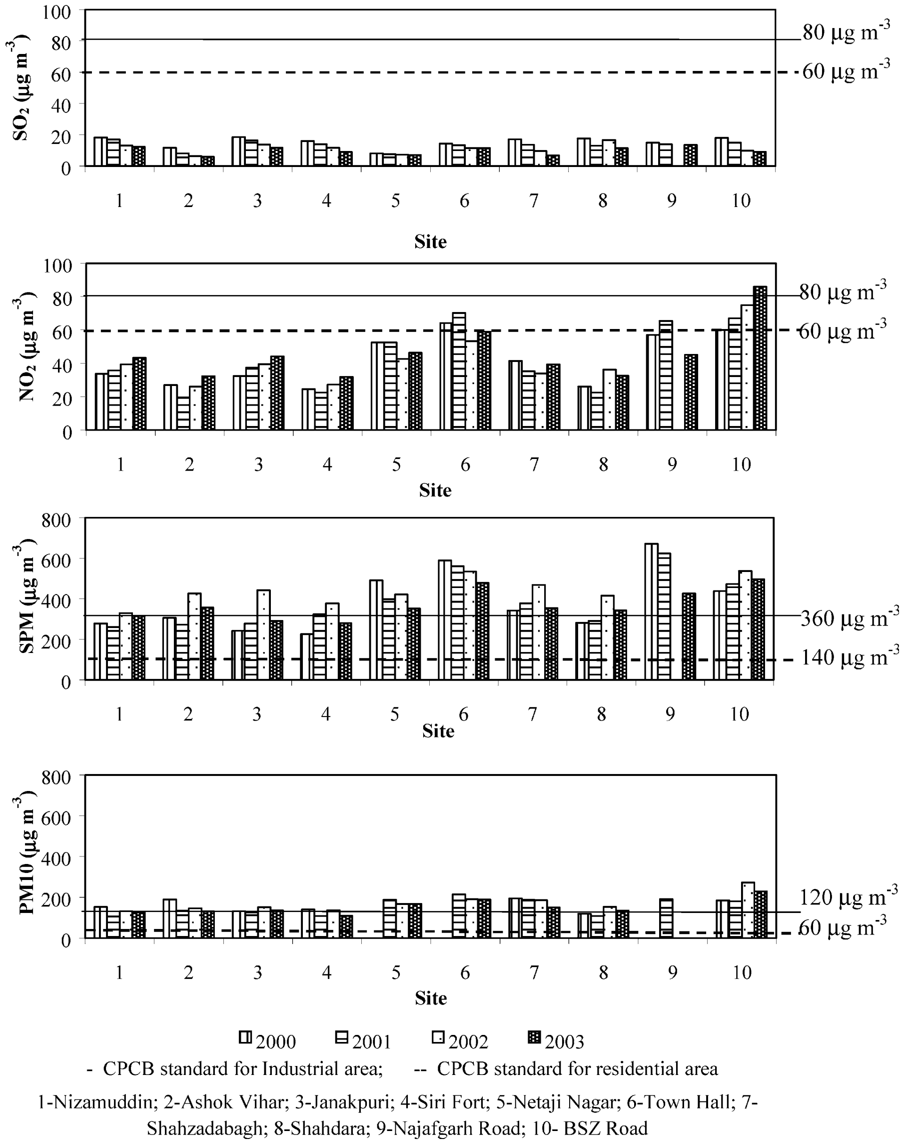


**Fig. 2** Air quality data observed during 2000 to 2003 at 10 sites in Delhi

transport is through buses. Though buses constitute less than 1% of the vehicle fleet, they serve about half of all travel demand (Tiwari, 2002). Two and three wheelers are two- or four-stroke gasoline-powered engines. Pollution control depends a lot on the quality of the fuel. For example, the sulphur content of diesel is generally assumed to be associated with SPM and $SO_2$ emissions (Central Pollution Control Board, 1999). Due to this, several policies were enacted to change the quality of the fuel. Use of CNG as a cleaner fuel in vehicles is one of them and was implemented in late 2001. CNG vehicles are shown to be emitting fewer amounts of air pollutants than the diesel vehicles even with Euro IV norms (Nils & Alex, 2000). CNG vehicles emit 85% less $NO_x$, 70% less reactive hydrocarbons and 74% less CO than gasoline vehicles (http://daq.state.nc.us/motor/cng). With these advantages, it is obvious that the activation of CNG in vehicles should reduce the concentration of pollutants in ambient air at the receptor sites. To investigate this, the ambient air quality data of $SO_2$, $NO_2$, PM10 and SPM for the 10 sites during 2000 to 2003 in Delhi was considered.

Figure 2 shows the spatial and temporal variation of air quality. It can be observed that $SO_2$ and $NO_2$ levels were below the permissible limits set by CPCB

(60 μg $m^{-3}$ for residential area and 80 μg $m^{-3}$ for industrial area for $SO_2$ and $NO_2$). However, at Najafgarh road and Town Hall, $NO_2$ had exceeded the limits in 2001. At BSZ road also, $NO_2$ had exceeded the limits stipulated by CPCB. As per the US national ambient air quality standards (US NAAQS), both were well below the standards (80 μg $m^{-3}$ for $SO_2$ and 100 μg $m^{-3}$ for $NO_2$). $SO_2$ concentration varied from 6 to 19 μg $m^{-3}$, whereas $NO_2$ varied from 19 to 86 μg $m^{-3}$. In Delhi, most of the vehicles are gasoline powered and these vehicles hardly emit $SO_2$. The average $SO_2$ and $NO_2$ concentration at all the sites in Delhi were 12 and 43 μg $m^{-3}$ with standard deviation of 4 and 16 μg $m^{-3}$, respectively. It can also be observed that the levels of $SO_2$ had decreased from 2000 to 2003, whereas $NO_2$ levels were increasing at six sites (Nizamuddin, Ashok Vihar, Janakpuri, Siri Fort; Shahdara, BSZ road). The trend in $NO_2$ is not monotonic at the remaining four sites (Netaji Nagar, Town Hall, Shahzadabagh, Najafgarh road). During 2003, the $NO_2$ concentration was mostly higher as compared to the levels in the preceding years. As CNG was implemented in 2001 and the vehicles with CNG fuel facility were more in 2003 than 2000, the $NO_2$ levels have increased in 2003. In a study by Gurjara et al. (2004) on emissions from various sources in Delhi, transport sector was found to be the dominant source of $NO_2$. CNG has a higher flash point (540°C) than diesel (232–282°C) and at such high temperature, more nitrogen from air reacts with oxygen in the combustion chamber of CNG-driven vehicle in comparison to petrol-driven vehicle and thus produces more $NO_2$ (Gulati, 2001).

To identify the sources of $SO_2$ and $NO_x$, an approach used by Aneja, Kim, and Chameides (1997) is followed. They characterized the point source emissions by high $SO_2$ and $NO_x$ concentrations and mobile source emissions by high CO and $NO_x$ concentrations and low $SO_2/NO_x$ concentrations. Mobile sources generally have low $SO_2/NO_x$ and high $CO/NO_x$ ratios and point sources typically have high $SO_2/NO_x$ and low $CO/NO_x$ ratios. Therefore, the relationship between these air pollutants was investigated by the ratio analysis (Aneja et al., 1997). It is observed that at all the 10 sites, the ratio of $SO_2/NO_x$ is approximately <0.5, which indicates that point sources were not contributing to $SO_2$ in Delhi. The results are however, contrary to the findings obtained by Goyal and Sidhartha (2003) and Aneja et al. (2001), where they observed point sources as the contributors of $SO_2$. In their study, the air quality data were limited to one site that was located at BSZ road. From the ratio analysis, the relative source strengths and background concentrations can be determined by examining the slope and intercept of the regression line fitted to $SO_2$ and $NO_x$ levels. The average of intercepts and slopes of the fitted straight lines is 12.8 and 0.9 μg $m^{-3}$ for $SO_2$ and $NO_x$, respectively. The regression curves reveal average background $SO_2$ concentration of approximately 12.8 μg $m^{-3}$, whereas the minimum, maximum and average concentrations of $SO_2$ are 6, 18.6 and 12.4 μg $m^{-3}$, respectively. This indicates that ambient $SO_2$ levels were not dominated by a specific point or mobile source. The levels below the CPCB limits also indicate that it is not a significant problem in Delhi at all the 10 sites. The same analysis was also carried out for CO and $NO_2$ but for a single site at BSZ road as the CO data were not available at other nine sites. It is observed that the straight line, $CO = 10.644\ NO_2 + 1,166$, best fits the data for 2000 to 2003. The background concentration of CO was therefore 1,166 μg $m^{-3}$ at this site. The $CO/NO_2$ ratios were observed to be 7.9, 8, 4, 2.8 for 2000, 2001, 2002 and 2003, respectively. Aneja et al. reported the ratio of 50 for Delhi at the same site of BSZ road for 1997 and 1998 and reasoned the mobile sources as the major contributor of CO and $NO_2$ in Delhi. They also compared the ratios of 8.4, 7.8 and 10.2 in Eastern US, where too the mobile sources are the predominant contributors of CO and $NO_2$. Comparing the results with ratios observed in Eastern US, mobile sources were dominant contributors of CO and $NO_2$ during 2000 to 2002, but in 2003 the ratio was too low indicating that some other sources were also influencing in the area. Also, the observed value of CO at this site decreased during 2002 and 2003 as compared to 2000 and 2001. As discussed above, CNG vehicles emit less CO than similar gasoline and diesel-driven vehicles and this may be the reason for lower $CO/NO_2$ ratio and lower concentration of CO. The $NO_2$ levels were however increasing during the study period at the concerned site. As discussed above, implementation of CNG might be responsible for increased concentration of $NO_2$ in ambient air. However, more investigation for other sites is needed to confirm the sources of CO and $NO_2$.

Considering the variations in SPM and PM10 concentrations, both vary from 225 to 671 and 107 to 272 μg $m^{-3}$ with average concentrations of 394 and 159 μg $m^{-3}$, respectively. PM10 and SPM were exceeding the limits at all the sites during the study period. PM10 levels were also exceeding the limits (50 μg $m^{-3}$) of US NAAQS. The exceeded levels of SPM and PM10 highlight the significant problem of dust pollution in Delhi. It can be observed from Fig. 2 that SPM levels increased from 2000 to 2002 with a sudden decrease in 2003, which is although beyond the limits at seven sites (Nizamuddin, Ashok Vihar, Janakpuri, Siri Fort, Shahzadabagh, Shahdara, BSZ road). At the remaining three sites (Netaji Nagar, Town Hall, Najafgarh road), however, a reverse pattern is observed. Considering the trend in PM10 concentration, it was decreasing during the study period, except at BSZ road, the increased concentration was observed in 2002. In 2003, SPM and PM10 were relatively lower, but beyond the CPCB limits than the preceding three years.

The effect of CNG conversion in vehicles, though not in a sustained manner, is evident on SPM, PM10 and $SO_2$. The average percentage change in levels from 2000 to 2003 was −34.8% for $SO_2$, 13.7% for $NO_2$, −2.8% for SPM and −7% for PM10, respectively. This shows that the CNG conversion has resulted in the decrease of SPM, PM10 and $SO_2$ and increase in $NO_2$ levels. Though the air quality levels for $SO_2$, PM10 and SPM decreased, the concentration of particulates was still exceeding the CPCB limits (Fig. 2). The scenario of number of vehicles using CNG fuel in 2003 was 85,920 vehicles including 15,001 buses, 5,337 taxis, 10,481 private cars and 55,101 three wheelers which had been converted to CNG mode (Transport Department, 2004). It appears that only a very small fraction of 1.5% of 3.6 million vehicles have been converted into CNG mode. If CNG had implemented in more number of vehicles, then this would have resulted in better reduction in the pollutant levels.

## 4 Conclusion

The study was carried out to assess the effect of fuel shift specifically CNG conversion on levels of air pollutant concentrations. Several measures were introduced and implemented in order to control emission levels in Delhi. The study shows the significant impact of CNG conversion in vehicles with reference to particulates and $SO_2$. The reduction in the levels of these pollutants from 2000 to 2003 was 34.8% for $SO_2$, 2.8% for SPM and 7% for PM10. The increase in $NO_2$ level was observed with an increase of 13.7%. It is also observed that $SO_2$ pollution is not a major problem in Delhi and CO in ambient air was contributed by mobile sources during 2000 to 2002, whereas in 2003, concentration of CO decreased due to CNG. The results show that use of CNG in vehicles reduced the levels of air pollutants that are generally contributed by vehicular sources. The implementation is however limited to few of the vehicles in Delhi. The public transport also needs to be encouraged to use CNG. The policies related to proper management of transport system utilizing the benefits of public transport and discouraging the use of private vehicles such as two wheelers and cars should also be initiated.

## References

Aneja, V. P., Agarwal, A., Roelle, P. A., Philips, S. B., Tong, Q., Watkins, N., et al. (2001). Measurement and analysis of criteria pollutants in New Delhi, India. *Environmental Modelling & Software, 27*(1), 35–42.

Aneja, V. P., Kim, D.-S., & Chameides, W. L. (1997). Trends and analysis of ambient NO, $NO_3$, CO and ozone concentration in Raleigh, North Carolina. *Chemosphere, 34*(3), 611–623.

Center for Science and Environment (2001). *Inside story of how the government institution and groups have conspired to compromise the Delhi's public health*. New Delhi: Down to Earth, CSE September 30.

Central Pollution Control Board (1999). *Parivesh: Newsletter*. Delhi: Ministry of Environment and Forests.

Central Pollution Control Board (2000). *Parivesh highlights*. New Delhi: Ministry of Environment and Forest, Government of India.

Cropper, M. L., Simon, N. B., Alberini, A., Arora, S., & Sharma, P. K. (1997). The health benefits of air pollution control in Delhi. *American Journal of Agricultural Economics, 79*, 1625–1629.

Dockery, D. W., & Pope, C. A. (1994). Acute respiratory effects of particulate air pollution. *Annual Review of Public Health, 15*, 107–132.

Goyal, P., & Sidhartha. (2003). Present scenario of air quality in Delhi: A case study of CNG implementation. *Atmospheric Environment, 37*, 5423–5431.

Gulati, A. R. (2001). *Director transport engineering*. Delhi: Bureau of Indian Standards.

Gurjara, B. R., Aardennea, J. A., Lelievelda, J., & Mohanb, M. (2004). Emission estimates and trends (1990–2000) for mega city Delhi and implications. *Atmospheric Environment, 38*, 5663–5681.

Kathuria, V. (2002). Vehicular pollution control in Delhi. *Transport Research, D 7*, 373–387.

Mashelkar, R. A. (2002). Report of Its Expert Committee on Auto Fuel Policy, Gov. of India, New Delhi. www.autofuelpolicy.org.

Ministry of Environment & Forests (1997). *White paper on pollution in Delhi with an action plan*. New Delhi: Ministry of Environment & Forests, Government of India.

Nils, O. N., & Alex, L. (2000). Exhaust emissions from natural gas vehicles: Issues related to exhaust emissions and environmental impacts. *A Report Prepared for the International Association for Natural Gas Vehicles (IANGV) Technical Committee*.

Nylund, N. O., & Lawson, A. (2000). *Exhaust emissions from natural gas vehicles*. Helsinki: International Association of Natural Gas Vehicles, VTT Energy.

Schwartz, J. (1993). Particulate air pollution and chronic respiratory diseases. *Environmental Research, 62*, 7–13.

Sengupta, B. (2000). Steps taken to control vehicular pollution in India. The paper presented in international workshop organized by Society of India Automobile Manufacturers (SIAM), New Delhi, Dec. 4–5.

Singh, A., Sharma, N., Sharma, K., & Bhan, C. (2001). Emission characteristics of in-use CNG vehicles in Delhi. Workshop on Land Use, Transportation and the Environment, Pune, Dec. 3–4.

The World Bank (2005). For a breath of fresh air. Ten years of progress and challenges in urban air quality management in India 1993–2002. Environment and Social Development Unit, South Asia Region. www.worldbank/sarurbanair.

Tiwari, G. (2002). Urban transport priorities – Meeting the challenges of socio-economic diversity in cities, a case study of Delhi, India. *Cities, 19*(2), 95–103.

Transport Department (2004). Gov. of NCT of Delhi, New Delhi.

Vincent, J. R., & Tan, C. Y. (1997). *Air pollution and health. Environment and development in a resource-rich economy: Malaysia under the new economic policy*. Harvard: Harvard University Press.