For a Breath of Fresh Air

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Ten Years of Progress and Challenges in Urban Air Quality Management in India

1993-2002

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Foreword

With robust economic growth raising living standards in urban areas and a growing number of people moving to cities, urban air quality in India is of increasing concern for the public and policy-makers. While a bold program of measures to ease air pollution has been implemented in Delhi and some other major metros, more remains to be done in urban centres across India in order to bring air quality to safe levels for public health, as set in national and international standards. Presently, many cities are at the crossroads, having recently been directed by the Supreme Court to develop air quality improvement action plans.

This report, prepared in collaboration with the Central Pollution Control Board (CPCB), is a contribution to the on-going efforts to assist cities with developing or updating their air quality management strategies. It attempts to analyze air quality trends and interventions implemented in the ten-year period between 1993 and 2002 in order to better inform future actions. Inevitably, the scope and power of the quantitative analysis presented in this report is constrained by data limitations. It is therefore important to view this report as one of the many contributions to a broader debate on what it will take for large Indian cities to have clean air.

The findings of this report need to be complemented by the findings of other studies, including a recently completed regional World Bank study on issues in urban air quality management in South Asia and a large body of work undertaken by other institutions in India and internationally. This report was discussed at a stakeholder workshop in October 2004, and presented at the regional Clear Air Initiative – Asia conference at Agra in December 2004.

We would like to express our gratitude to the CPCB, the State Pollution Control Boards, and many stake-holders from government and non-government organizations and civil society who contributed their time and knowledge in the preparation of this report.

Michael F. Carter
Country Director
India

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Sameer Akbar
Kseniya Lvovsky
Masami Kojima

Abbreviations and Acronyms

APPCB: Andhra Pradesh Pollution Control Board

AQM: Air Quality Management

Art. 21: Article 21 of the constitution of India which guarantees Right to Life and Liberty

BMC: Brihan Mumbai Corporation

°C: degree centigrade

CMC: Chennai Municipal Corporation

CNG: Compressed Natural Gas

Commercial Vehicles: as per MORTH definition these include the following: multi-axled/articulated buses and trucks, light motor vehicles (goods), buses, taxies, light motor vehicles (passengers) – autorickshaws

CPCB: Central Pollution Control Board

CSE: Center for Science and Environment

DDA: Delhi Development Authority

EPCA: Environmental Protection Control Authority

ESMAP: Energy Sector Management Assistance Program

FO: fuel oil

GEMS: Global Environment Monitoring System

GNI: Gross National Income

GSDP: Gross State Domestic Product

GOI: Government of India

HUDA: Hyderabad Urban Development Area

IMD: Indian Meteorological Department

km^2: Square kilometers

KMA: Kolkata Metropolitan Authority

KMC: Kolkata Municipal Corporation

KSPCB: Karnataka Pollution Control Board

Kmph: Kilometers per hour

LCV: Light Commercial Vehicle

LPG: Liquified Petroleum Gas

LSHS: Low Sulfur Heavy Stock

LMV: Light Motor Vehicle

MCD: Municipal Corporation of Delhi

MCH: Municipal Corporation of Hyderabad

Mil.: million

mm: millimeters

MMRDA: Mumbai Metropolitan Regional Development Authority

MoRTH: Ministry of Road Transport and Highways

MPCB: Maharashtra Pollution Control Board

MPD-20001: Master Plan of Delhi 2001

MT: Metric Tonne

NAAQS: National Ambient Air Quality Standards

NAMP: National Air Quality Monitoring Program

NCR: National Capital Region

NCT: National Capital Territory

NDMC: New Delhi Municipal Corporation

NEERI: National Environmental Engineering Research Institute

NGO: Non-governmental Organization

PIL: Public Interest Litigation

PM: Particulate Matter

$PM_{2.5}$: Particulate Matter less than 2.5 microns in aerodynamic diameter

PM_{10}: Particulate Matter less then 10 microns in aerodynamic diameter (used interchangeably with RSPM in this report)

Private Vehicles: as per MoRTH definition these include the following: two-wheelers, cars, jeeps, omni buses, tractors, trailers, and other vehicles

RSPM: Respirable Suspended Particulate Matter (used interchangeably with PM_{10} in this report)

RTV: Rural Transport Vehicle (a minibus with a good ground clearance)

SC: Supreme Court

SPCB: State Pollution Control Board

SPM: Suspended Particulate Matter

TD: Transport Department

TERI: The Energy Research Institute (formerly Tata Energy Research Institute)

TNPCB: Tamil Nadu Pollution Control Board

UAQM: Urban Air Quality Management

UNEP: United Nations Environment Program

VOSL: Value of Statistical Life

WBPCB: West Bengal Pollution Control Board

WHO: World Health Organization

WTP: Willingness to Pay

Note : Currency Conversion Rate used in the study
1 US dollar = Rs 45 approximately.

Profile of Sample Cities for this Study

Delhi: The national capital located in northern India with a population of approximately 9.8 million people and average population density of 7,021 people per square kilometer (km^2) is part of a larger national capital territory of 12.8 million inhabitants. It is located on the banks of the river Yamuna, and has a tropical semi-arid climate with hot summers and cold winters. The mean total annual rainfall is about 750 millimeters (mm), and low wind speeds prevail in winter months. Delhi has a per capita income of about Rs 24,450 (2000-01) which is almost twice the national average. Industry plays an important role in economic growth, though in recent years its share has gone down as compared to the services sector. The number of motor vehicles in Delhi, about 4 million, is the highest in the country, with two-wheelers constituting approximately 65 percent. It has the distinction of having all road-based public transport running on compressed natural gas (CNG) since 2002. With a past that was heavily influenced by the British Raj , New Delhi is considered a well-planned city with broad roads and green spaces. However, Old Delhi is characterized by mixed land-use and a large number of pedestrians and slow moving traffic.

Kolkata: The capital of West Bengal located in north-eastern India near the Bay of Bengal with a population of approximately 4.6 million people and average population density of 24,705 people per km^2 is part of a metropolitan area of 13.2 million inhabitants. It is divided into Howrah on the west and Kolkata city on the river Hoogly flowing in a north-south direction. It has a humid tropical climate with hot summers and moderate winters. The mean total annual rainfall is about 1,700 mm, and low wind speeds prevail in winter months. Kolkata has a per capita income of about Rs 10,636 (1998-99). Industry plays a very important role in economic growth. The number of motor vehicles in Kolkata is about 700,000, with two-wheelers constituting approximately 45 percent. However, the river also serves as an important waterway to the rural hinterland. With a past that was also heavily influenced by the British Raj, new Kolkata is considered a well planned city. However, the Old city is characterized by mixed land-use and a large number of pedestrians and slow moving traffic.

Mumbai: The capital of Maharashtra located on the west coast by the Arabian sea with a population of approximately 12 million people and average population density of 25,449 persons per km^2 is part of a metropolitan area of 16.4 million inhabitants. It has a humid tropical climate with hot summers and moderately cold winters. It has severe monsoons with mean total annual rainfall of about 2,300 mm, with a large diurnal variation in wind speeds. Mumbai has a per capita income of about Rs 31,922 (2000-01). It has always been famous as the commercial hub of the country, though it used to have a strong textile industry that has dwindled over the years. The number of motor vehicles in Mumbai is almost 1.1 million, with two-wheelers constituting approximately 45 percent . It has one of the most efficient public transport systems in India with rail-road carrying almost 70 percent of the traffic. From a urban planning perspective, Mumbai is a well-regulated city.

Hyderabad: The capital of Andhra Pradesh located on the Deccan plateau in south-central India with a population of approximately 3.4 million people and an average population density of 19,930 persons per km^2 is part of a metropolitan area of 5.5 million inhabitants. It has a hot steppe climate with hot summers and moderately cold winters. The mean total annual rainfall is about 900 mm, with high wind speeds persisting for large part of the year. Hyderabad has a per capita income of about Rs 10,590 (1998-99). It has developed in recent years as a significant Information Technology center in India with associated service sector becoming developed. The number of motor vehicles in Hyderabad is 1.3 million, with two-wheelers constituting approximately 75 percent. From a urban planning perspective, Hyderabad is a well-regulated city, although the old city is quite congested.

Chennai: The capital of the state of Tamil Nadu located on the east coast south India by the Bay of Bengal with a population of approximately 4.2 million people and an average population density of 24,138 persons per km^2 is part of a metropolitan area of 6.4 million inhabitants. It has a tropical marine climate with hot summers and moderate winters. The mean total annual rainfall is about 1,300 mm, with high wind speeds persisting for large part of the year. Chennai has a per capita income of about Rs. 36,138 (1998-99). Industry plays a very important role in economic growth. It has also developed a good service sector in recent years. The number of motor vehicles in Chennai is 1.3 million, with two-wheelers constituting approximately 75 percent. Like Hyderabad and Mumbai, Chennai has also had a well regulated growth over a period of time.

Executive Summary

1. Even as India experienced robust economic and urban growth in 1990s, air pollution in its major cities became a cause of national concern. The levels of airborne suspended particulate matter (SPM) recorded in a number of metro-cities far exceeded the ambient air quality standards that India had adopted along with many other countries. Two independent analyses estimated that urban air pollution in India could be responsible for a significant burden of ill-health (Brandon and Homman 1995, WHO 2002), primarily due to human exposure to elevated levels of respirable suspended particulate matter (RSPM), a finer fraction of SPM.

2. Taking cognizance of the situation, the government implemented a series of policy interventions. A special feature of decision making with regard to urban air pollution management in India has been a leading role by a vocal civil society and the judiciary. They have successfully directed the executive branch to act far more aggressively than would have been otherwise possible. Delhi, particularly, has set an example in this regard, undertaking a comprehensive and far-reaching program of measures. Of these, the most publicized is the conversion of the city's public transport to compressed natural gas (CNG) in 2000-2002. Following the success of getting these bold measures implemented in Delhi, the Supreme Court has directed a number of other highly polluted cities in India to prepare "action plans" to address the issue of urban air pollution, incorporating many of the measures adopted by Delhi.

Objectives of the Study

3. The study objective was to assess the impacts of ten years of actions and interventions in five metro-cities so as to enable these and other cities in India to design better-informed strategies and action plans for combating urban air pollution. The report presents a retrospective analysis of urban air pollution data with a focus on particulate air pollution from 1993 to 2002 in Delhi, Kolkata, Mumbai, Hyderabad and Chennai.

Methodology

4. The methodological framework followed in this study addressed four basic concerns:

(1) The efforts that have been made to address urban air pollution

(2) The effects of those efforts on air quality

(3) The key factors that affect air quality, and should be considered in future action programs

(4) The health impacts of changes in air quality.

Information on various interventions that could have affected urban air quality, directly or indirectly, in the period 1993- 2002, was collected from various secondary sources and through interviews of stakeholders knowledgeable about the developments in their cities. International experience in combating air pollution in other polluted cities around the world has been provided for comparison and drawing possible lessons. Air quality data collected by the National Environmental Engineering Research Institute (NEERI) between 1993 and 2002 were analyzed to assess spatial and temporal variation, as well as effects of policy interventions. The data were compared to those from other sources. As data were not always "consistent" within the same data set or between different data sources, only the data trends corroborated by different sources, have been used to the extent possible, for drawing conclusions.

5. Meteorological data acquired from the Indian Meteorological Department (IMD) have been used to assess the interaction between weather variables and air quality. To better understand sources of particulate air pollution, the air quality data have been analyzed in each city (also by land use: residential, commercial, and industrial), and the findings have been compared to those from another study on fine particulate source apportionment in Delhi, Kolkata, and Mumbai (ESMAP 2004). The air quality data have also been interpreted in the light of policy interventions implemented between 1993 and 2002 for air quality improvement. To understand the benefits of air quality improvement, the impact on public health of recent and potential future changes in ambient concentrations of particulate matter have been estimated.

Key findings

6. A potentially significant and encouraging finding of this study is that ambient concentrations of RSPM, the main pollutant of public health concern, appeared to fall between 1993 and 2002 in all the five cities. This decline in RSPM levels might have led to nearly 13,000 fewer cases of premature deaths and much greater reductions in the number of cases of respiratory illness in these cities on an annual basis by 2002, compared to the early 1990's. The levels of sulfur dioxide (SO_2) also declined during the same period. However, SPM levels did not fall in proportion to RSPM, implying—against the backdrop of generally falling RSPM levels—increasing concentrations of coarse particulate matter. This seems at first to be surprising. However, some factors have been identified which could perhaps explain this trend.

7. Despite substantial past progress and efforts to curb air pollution, RSPM pollution and the associated damage to health, remain elevated in all five cities. The levels of RSPM are the highest and significantly above the national standards in the northern cities of Delhi and Kolkata, especially in winter. Delhi continues to record the highest levels, notwithstanding the implementation of the most extensive program of air quality improvement. Alarmingly, data from the most recent years shows the reversal of a declining trend. Ambient concentrations of nitrogen dioxide (NO_2) have exhibited an increase in recent years, although still at relatively low levels. This calls for careful monitoring and, if the trend is not arrested, NO_2 control measures may need to be added to the city-level air quality management programs in the future.

8. Given that there is no established threshold for the health impacts from exposure to RSPM, all cities will gain substantial health benefits from further reductions to or even below the current national annual standard of 60 micrograms per cubic meter ($\mu g/m^3$) for residential areas, which seems a realistic target for Chennai and Hyderabad in the short to medium term. However, bringing the RSPM levels down to this standard is clearly a long-term target for Delhi and Kolkata. The potential benefits, however, are very large: about 10,000 lives can then be saved every year in these two cities alone.

9. This report investigates the main factors affecting air quality in each city as well as significant differences across the cities. Comparison of air quality trends with intervention measures implemented, indicates that reductions in RSPM concentrations have been achieved through a combination of measures, targeting industry, transport, and urban planning/development. Further, it is also possible that some developments, such as significant penetration of clean modern fuels in the household sector over the same period, and opening up of the economy to international automobile manufacturers who brought in more advanced technology vehicles, reinforced the benefits of these efforts. The table that follows (p.3) summarizes by sector, the key actions taken in the five cities that could possibly have helped improve air quality. While it is not possible to say (based on the available information) which of the interventions were relatively more effective, there seems to be some evidence linking measures targeted at industrial emissions with declining RSPM levels, particularly in industrial areas. However, beyond this the data analyzed do not provide evidence linking specific measures in any particular sector/subsector with measurable improvements in annual average air quality levels on a city-wide scale (although measurable improvements at the micro-level were likely, such as the impact of switching to CNG on air quality along traffic corridors). The need to target different sources, including domestic fuel use for cooking and space heating, is further supported by the recent source apportionment exercise for fine particulate matter ($PM_{2.5}$ particles smaller than 2.5 microns in diameter), discussed in this report, which has shown no single dominant source in Delhi, Kolkata, and Mumbai (ESMAP 2004).

10. The nature and magnitude of emission sources may vary between cities, and within a city with land-use. Mumbai offers a good example of the effect of attrition of industry and its consequent impact by way of reduction in RSPM and SO_2 levels in an industrial area. However, if land-use development is mixed, as in Delhi and Kolkata, then the effect of land-use on air quality is difficult to discern. Urban development with mixed land-use also challenges the current practice of having different National Ambient Air Quality Standards (NAAQS) within a city. Having differential standards is meaningful only if land-use regulation can be implemented

strictly. Otherwise, it could even lead to a perverse application of the regulation, whereby densely populated residential areas that exist in proximity to an industrial area are also classified as industrial, resulting in "legal" or "permissible" exposure of a large number of individuals to unhealthy levels of air pollution.

11. In addition to sources of air pollution, meteorological conditions play an important role in influencing ambient air quality. Meteorological conditions, which affect pollutant dispersion potential, differ significantly across the five cities. This study shows that the southern cities of Hyderabad and Chennai have much better dispersion characteristics all year round than Delhi, Kolkata, and Mumbai. This may partly account for lower RSPM levels recorded in Hyderabad and Chennai, with no significant variation in monthly averages. In contrast, Delhi, Kolkata, and to some extent Mumbai, see a three- to four-fold variation in monthly averages between summer/ monsoon and winter months. Further, since the temperature in southern cities does not drop as low as it does in the north during winter, there is unlikely to be much domestic and space heating. As solid fuel use for domestic and space heating is common in India, it is likely that the absence of the need for heating, helps to keep RSPM levels low in Hyderabad and Chennai in winters. As such, meteorological factors and RSPM sources also have an interactive effect on ambient air quality. Cities with a clear pattern of pollution peaking in winter, like in Delhi, may need to consider developing special programs to target "winter pollution".

A Way Forward. . .

12. Clearly, apart from there being a strong case, there is substantial scope for further improving urban air quality in India. Recently, the Supreme

Sector-wise summary of key actions taken in the five cities that could have helped in improving air quality

Intervention type	Industry	Urban	Transport
Clean fuels	Switching to cleaner fuels (reduction in Sulfur, gaseous alternatives)	Increasing share of domestic and commercial users of cleaner fuels (gas and kerosene for cooking, electricity for heating)	Use of cleaner fuels (gasoline lead elimination, Sulfur reduction in liquid fuels, use of gaseous fuels) Better lubricant quality and only pre-mixed 2T oil for two- and three-wheelers
Improved technology	More efficient and cleaner combustion technology	Better road infrastructure (road widening, traffic management, new flyovers)	Scrappage of old commercial vehicles and their replacement with a new fleet
Stronger and better enforced regulation	Tightened and better enforced emissions norms leading to installation of pollution control devices	Enforcement of land-use zoning regulations (closure and relocation of industry from non-conforming areas, development of green belts/areas)	Introduction and enforcement of new and more stringent emission norms for new and in-use vehicles*

* One consequence of opening up of the automobile market to international competition coupled with the introduction of increasingly tighter emission standards is a shift from two-stroke to four-stroke engines among two- and three-wheelers. According to the new vehicle sale figures, the sale of four-stroke engine two-wheelers increased from 21 percent in 1997-98 to 79 percent in 2000-04, with a corresponding decrease in the sale of two-stroke engine two-wheelers (SIAM 2004).

Court directed cities to formulate their own action plans, and drafts of action plans have been submitted by a number of cities. Given that as per the Air (Prevention and Control) Act 1981 section 19(1), State Pollution Control Boards (SPCBs) have the right to declare air pollution control area within their jurisdiction, the Central Pollution Control Board (CPCB) has recommended that many more cities should take up the action planning exercise, and not wait for directives from the Supreme Court to initiate it.

13. One of the key lessons from this analysis is that action plans, to be effective, should cut across the urban, transport and industry sectors. Furthermore, international experience shows a consistent pattern across all cities with very high particulate pollution (similar to that in Delhi) of significant pollution reduction, achieved by targeting solid fuel use by household and small establishments, a category of pollution sources largely ignored in India thus far. This category of sources warrants greater attention in future programs, especially in the northern cities where heating is needed in winter.

14. Another important lesson is that implementation of the same interventions in two cities with different meteorological conditions and mix of sources is unlikely to produce the same results. The choice of priority interventions to control urban air pollution needs to be city-specific, based on adequate local information. One of the critical requirements for formulating an effective strategy is that policymakers have access to adequate data and information.

15. The importance of strengthening data collection, management, and dissemination cannot be over-emphasized. Information on the effectiveness (or lack thereof) of interventions already undertaken across several cities in India can guide prioritizing interventions and establishing effective combinations in the future. For this, a stronger framework for monitoring and analyzing impacts of the interventions needs to develop. It should be noted that monitoring the "right" pollutants using correct protocols would not be informative unless accompanied by periodic analysis. Having such a framework becomes all the more important in a setting where civil society is very active, and actions driven by judicial directives have to be implemented, often at short notice.

16. The analysis points to a number of possible areas that cities can start working on to address their urban air quality concerns. These range from strengthening monitoring and information collection to developing and adopting a common framework for urban air quality management, to targeting a mix of relevant sectors (urban, transport, industry). Given the city-specific nature of the problem and the solution, undertaking action planning and interventions at the city rather than at the state or central government levels appears to be the best approach. This observation is also supported by feedback from various stakeholders involved in air quality issues in India who responded to a questionnaire survey conducted in parallel with this study.

Chapter 1

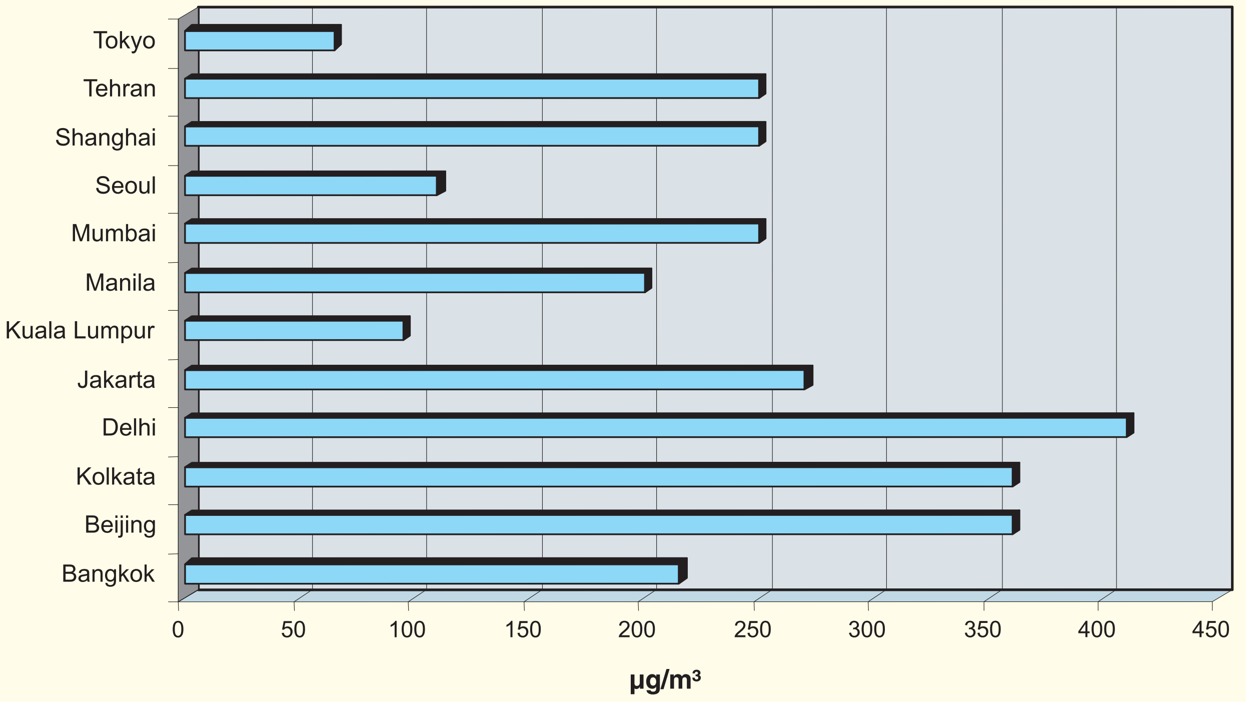
Introduction

1.01 In the 1990s, as India experienced robust economic and urban growth, air pollution in its major cities became a cause of national concern and generated worldwide attention. The levels of air-borne suspended particulate matter (SPM) recorded in the larger metro-cities, especially Delhi but also Kolkata and Mumbai, far exceeded the ambient air quality standards adopted by India and many other countries (see Figure 1. Also see Annex 4 for standards adopted by India). Two independent analyses estimated that urban air pollution in India could be responsible for about 40,000 premature deaths annually (Brandon and Homman 1995, WHO 2002), primarily due to human exposure to elevated levels of particulate matter. Delhi was identified as the city having the highest mortality figure of about 7,500 deaths per annum.

1.02 This situation clearly required urgent action, and a series of policy interventions followed. A special feature of decision-making insofar as urban air quality management (UAQM) in India is concerned, has been the leading role played by a vocal civil society and the judiciary in directing the executive branch to act far more aggressively than it would have otherwise done (Greenspan and others 2004). Delhi has set an example in this regard, by undertaking a comprehensive and far-reaching program of measures, of which the best known is the mandatory conversion of the city's public transport to compressed natural gas (CNG) in 2000-2002 (see Box 2 and Annex 1 for the chronology and a detailed description of the events in Delhi). The success with having these bold measures implemented in Delhi has led the Supreme Court to direct a number of other highly polluted cities to prepare action plans for addressing urban air pollution, incorporating many of the measures adopted by Delhi (see Box 1).

1.03 While a number of measures have already been implemented in Indian cities in the last few years, and new cities are being directed by the courts to follow suit, there is a debate among air quality experts in India and abroad about what the exact

Figure 1: Ambient Annual Averages of Suspended Particulate Matter in selected large cities in Asia and the Pacific in 1995 (UNESCAP 2000)



Box 1: Recent Supreme Court directions on Urban Air Pollution in India

I). The Honorable Supreme Court in a case [writ petition(civil) No 13029 of 1985, M C Mehta Vs Union of India and others] passed an order on 5 April 2002 for formulation and implementation of action plans for control of air pollution in critically polluted cities. Critically polluted cities were identified based on CPCB's report on air quality trends in India (CPCB 2000) as those that exceeded the annual National Ambient Air Quality Standard for SPM by 50 percent or more. The following nine cities were identified by the court:

- Agra
- Faridabad
- Jharia
- Jodhpur
- Kanpur
- Lucknow
- Patna
- Pune
- Varanasi

II). On 9 May 2002, the Honorable Supreme Court in continuation of the case mentioned above, passed an order for preparing a scheme for compulsory switchover to CNG/LPG as automotive fuel in cities which are equally or more polluted than Delhi. Based on RSPM, NO_2 and SO_2 annual average data of 2001 from CPCB, the following four cities were identified:

- Ahmedabad
- Kanpur
- Kolkata
- Pune

III). On 14 August 2003, the Honorable Supreme Court, in continuation of the same case above, directed the Union of India and respective states to draw an action plan for lowering the RSPM levels in the following nine cities, based on CPCB data from 2002, and submit it to the Environmental Protection Control Authority (EPCA):

- Ahmedabad
- Bangalore
- Chennai
- Hyderabad
- Kanpur
- Kolkata
- Lucknow
- Mumbai
- Solapur

impacts of specific measures have been and just how much the urban air quality has improved. It is in this context that this study was initiated by the World Bank in collaboration with the Central Pollution Control Board (CPCB). It attempts to take stock of the progress to date, both in terms of measures taken and changes in air quality, in order to better inform future actions.

1.04 This report presents a retrospective analysis of urban air quality interventions and trends for five major metros over ten years (1993 to 2002). It attempts to improve, within the limitations of the available data and analytical methods, the understanding of factors influencing ambient air quality in different cities so as to assist in the process of formulating future city-level strategies and action plans for addressing urban air pollution concerns in India.

Focus on Respirable Particulate Matter

1.05 Based on a large body of research, finer fractions of particulate matter, typically measured as PM_{10} (particles smaller than 10 microns in diameter) or $PM_{2.5}$ (particles smaller than 2.5 microns), are the major air pollutants of concern from the health viewpoint. The impacts on health manifest themselves in both increased morbidity (such as acute respiratory infections and chronic obstructive lung disease) and premature death, especially of the weak and infirm (Schwartz 1994, Pope and Dockery 1994). In India, a commonly used measure of finer fractions of SPM is respirable suspended particulate matter (RSPM), which in fact refers to PM_{10}. In this analysis RSPM has been used.

1.06 As Figure 2 shows, the concentrations of both SPM and RSPM are still high in Indian cities, so that PM is clearly the key pollutant of public health concern.[1] Gaseous pollutants—such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3)—also cause some adverse health effects. However, these impacts are less significant than those of RSPM, and the concentrations of these pollutants in Indian cities have normally been well below the prescribed national standards as well as health-based guidelines of the World Health Organization (WHO). SO_2 and NO_2, however, contribute to secondary particulate formation, which can be significant in some cities.

City Selection

1.07 This study covers five major cities in India—Delhi, Mumbai, Kolkata, Chennai and Hyderabad[2]—all with a population of more than 5 million inhabitants in the metropolitan area. In addition to the fact that these cities represent major metros with millions of people exposed to harmful levels of air pollution, the selection of these cities was also based on the following considerations: (a) these cities cover a wide range in the levels of PM pollution (see Figure 2); (b) geographically, they cover different locations (north, south, east and west), diverse climatic conditions, and represent both coastal and inland cities; (c) these cities have relatively more extensive data available; and (d) they represent a sample that has had policy interventions over the years, that could impact air quality. These cities are also on the list of the cities that have been asked by the Supreme Court to develop action plans to tackle PM pollution (except Delhi, which is treated as a special case on account of actions already taken; see Annex 1).

Methodological Framework

1.08 The methodological framework employed is a variation of the commonly used diagnostic framework of state-pressure-impact-response, used for assessing the "State of the Environment" in many countries (EEA 1999). Given its retrospective nature, the analysis starts with response as a "given" set of interventions that have taken place, and tries to assess whether the state of ambient air quality changed as a result of the interventions. It then tries to assess the health impacts stemming from the (current and possibly future) changes in the state of urban air quality. Furthermore, it presents an analysis of the pressures that affect the state of ambient air quality and that can also modify the response of interventions. More specifically, an attempt has been made to address the following concerns:

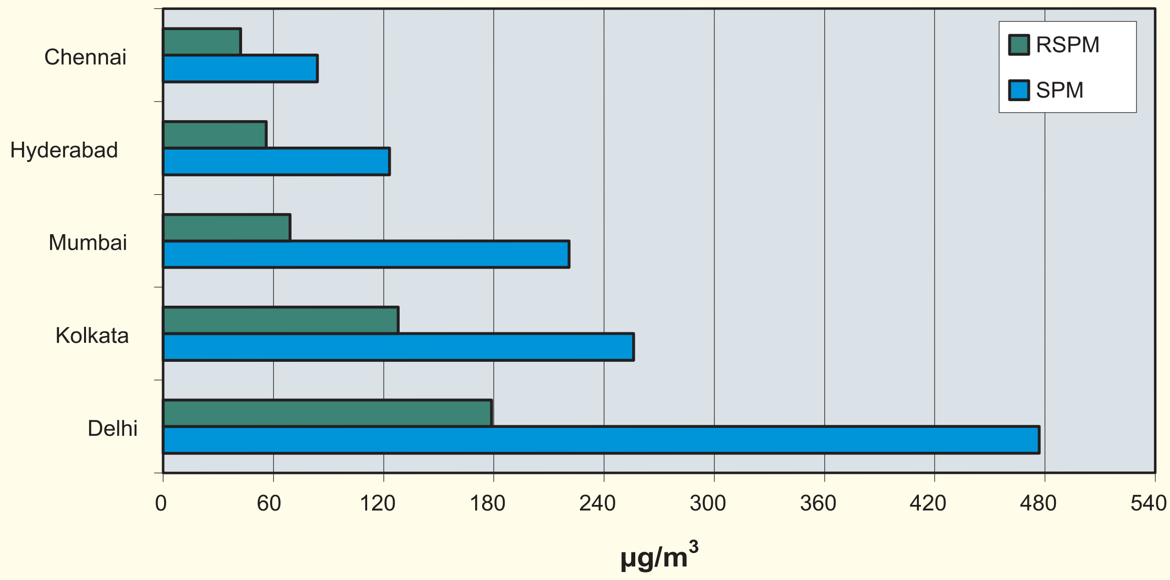
Efforts that have been made to address urban air pollution

1.09 Information on various interventions that could have affected urban air quality, directly or indirectly, in the ten years between 1993 and 2002 was collected from various secondary sources as well as by interviewing stakeholders knowledgeable about the developments in their cities. This included information on all interventions and initiatives that could possibly affect air quality, particularly with respect to RSPM levels. Experience of other (formerly) polluted cities around the world has also been summarized for comparison.

The effect of those efforts on air quality

1.10 Data on air quality for a period of ten years between 1993 and 2002 were analyzed for each of the five cities to assess the current status and changes over time, in order to determine the effects of programs that were undertaken to tackle urban air pollution. The data included the main regulated air pollutants—SPM, RSPM, SO_2 and NO_2—presented as time-series, as well as by land-use. Additional datasets for 2000-2003 were used for consistency check. It is important to stress that some of the data showed erratic patterns and were not necessarily consistent within the same data set or between

Figure 2: **Ambient Annual Averages of Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM) in five large Indian cities in 2002 (NEERI 2002)**



different data sources. Hence, only the air quality trends corroborated by different sources, to the extent possible, were used for drawing conclusions.

The key factors that affect air quality and need to be considered in future action programs

1.11 The analysis of determinants of air quality included the impacts of meteorological factors and different pollution sources. Meteorological data from 1991 to 2002 were collected from the Indian Meteorological Department (IMD) and analyzed to assess the interaction between weather variables and air quality. A number of information sources were used to improve the understanding of the relative significance of different sources[3] of air pollution, including a recent $PM_{2.5}$ source apportionment study conducted in Delhi, Kolkata, and Mumbai (ESMAP 2004). These findings are used for suggesting areas for future action, that have not yet been given sufficient attention.

The health impacts of changes in air quality

1.12 The changes in urban air quality in the 1993-2002 period were used to assess the health impacts in terms of incidence of illness and death, as well as the economic cost of these impacts using common valuation techniques. In order to compare health benefits from air quality improvements across cities, the benefits of 10 percent and 20 percent reductions in RSPM pollution were calculated for each of the five cities. Further, the health benefits of city-specific changes in RSPM between the first three years (1993-1995) and last three years (1999-2002) of the study period were estimated, as were the health benefits of declines in RSPM levels to meet the annual National Ambient Air Quality Standards (NAAQS).

Structure of the Report

1.13 The report is broadly structured to follow the methodological framework discussed above. Chapter 2 presents the set of interventions that have been implemented in the five cities, followed by Chapter 3 on the level of air quality including analysis of trends in the ten-year period between 1993 and 2002. Chapter 4 presents the role of determinants or variables that affect air quality, followed by Chapter 5 which estimates health impacts. Chapter 6 gives the conclusions and recommendations to strengthen future actions.

City-specific Interventions

2.01 All five cities implemented a significant number of interventions between 1993 and 2002 to address urban air quality concerns. In some cases these interventions were driven by the judiciary, while in other cases they were initiatives of the city and/or state governments. Some of the interventions initiated by the central government and/or mandated by the Supreme Court were common to a large number of cities. Annex 5 gives detailed notes on each city, provides data on the growth of key sectors—transport, industry and urban development—and lists key interventions that have been implemented and that may have had a positive impact on air quality.

Delhi

2.02 Amongst all cities, by far the largest number of programs to address urban air pollution have been implemented in Delhi. Box 2 provides the chronological sequence of the key policy interventions that have taken place in Delhi since the early 1990s (details in Annex 5A, Box A5A.3). It can be seen that while the majority of interventions are related to the transport sector, there have been significant interventions that also focused on industrial and urban sectors.

2.03 One of the major interventions targeting industry is the closure and relocation of more than 1,300 polluting industries, classified in the hazardous category in 1996-1997, including industries that emit particulate matter such as stone crushers, arc induction furnace units, hot mix plants, and brick kilns. The impact of industrial closures and relocation in 1996–1997 was seen on the annual index of industrial production compiled by the Delhi government, which showed a drop in 1996–97 (Delhi Government 2002). In addition, the 1996–1997 period coincided with the reduction in sulfur in diesel from 1 percent to 0.5 percent, and notification of sulfur content in fuel oil (FO) and low sulfur heavy stock (LSHS) at 1.8 percent and coal at 0.4 percent.[4] On the other hand, one activity that possibly contributed to a temporary increase in PM levels was the start of a major flyover construction program in 1998, which resulted in 19 flyovers being constructed by 2003, out of which nine were completed in 2001. In addition to industry, there are three coal-based thermal power plants and one gas-based power plant in Delhi (see Annex 5A, section 5). From the year 2000, much more environment-friendly beneficiated coal is being used in the thermal power plants.

2.04 The years 1999 and 2000 saw actions primarily targeted at the transport sector with introduction of pre-mixed 2T engine oil for 2-stroke engine vehicles, further reduction in diesel sulfur to 0.25 percent, and the phase-out of commercial/transport vehicles over 12 and 15 years of age, as the key interventions with potential to effect air quality.

2.05 Since 2000, the development that has dominated any debate on air quality in Delhi is the conversion of all public transport buses, taxis, and three-wheelers to CNG in 2000–2002. The conversion program targeted two most important sources of PM emissions in the transport sector: high annual mileage diesel vehicles and two-stroke engine gasoline vehicles. It was in response to a Public Interest Litigation against the government for not controlling air pollution adequately, that the Supreme Court directed the Delhi Government to convert the entire city bus fleet, autorikshaws, and taxis from liquid fuels to CNG or other gaseous fuels. Because liquefied petroleum gas (LPG) had not yet been authorized as an automotive fuel at the time, this led to the introduction of CNG starting in 1996 when an unsuccessful attempt was made to convert government vehicles to CNG. By the end of 2002, all public buses, taxis, and three-wheelers were running on CNG (see Annex 1 for details).

Kolkata

2.06 In Kolkata, significant interventions related to both the transport and industrial sectors (see Annex 5B, Box A5B.4). The major interventions that could have affected RSPM levels began to be implemented in 1997. An industrial siting policy for red (hazardous) category industries was introduced in

Box 2: Chronology of Key Actions Implemented in Delhi

- **1994-95: Transport**
  - Introduction of catalytic converters and unleaded petrol.
- **1996: Transport and Industry**
  - Fuel quality: 0.5% sulfur diesel introduced
  - CNG vehicles and catalytic converters for government petrol vehicles, excluding public transport introduced (but unsuccessful)
  - Closure of 168 hazardous industries, including stone crushers completed
  - Approved fuel notification issued for all activities (e.g. fuel oil [FO] and lower sulfur content in coal (LSHS) with 1.8% S; coal with 0.4% S).
- **1997: Industry**
  - Relocation of 513 industries
  - 337 hazardous category industries shifted (total of 1160 industries closed or relocated including hot mix plants, arc induction furnaces, brick kilns).
- **1998: Transport**
  - Pre-mix 2T engine oil mandated for 2-stroke engine vehicles; ban on supply of loose 2T oils
  - Phasing out of old commercial/transport vehicles (older than 15 years)
  - Start of Delhi Metro construction.
- **1999: Transport**
  - Diesel sulfur reduced to 0.25%
  - Registration of only EURO II three-wheelers and diesel taxis permitted
  - Restricting the plying of goods vehicles during the day
  - Taxis more than 12 year old phased out.
- **2000: Transport, Industry, and Urban**
  - Bharat Stage-II (Euro-II) emission norms for all private vehicles
  - Diesel and gasoline with 0.05% sulfur content made available in NCT (mandated for private vehicles)
  - Replacement of all pre-1990 three-wheelers and taxis with new vehicles on clean fuels (CNG in this case)
  - Buses more than 8 years old phased out or to ply on CNG or other clean fuel
  - The three coal-based power plants switched over to beneficiated coal
  - Piped natural gas by March 2000 to 1,311 domestic, 9 small, and 3 large commercial establishments.
- **2001: Transport, Industry, and Urban**
  - Bharat Stage-II (Euro-II) emission norms for all commercial vehicles by October
  - The sulfur content of diesel supplied to NCT Delhi further reduced to 0.05% with effect from October
  - Replacement of all post-1990 three-wheelers and taxis with new vehicles on clean fuels
  - Number of CNG vehicles as follows: 14,000 three-wheelers; 2,200 taxis; 400 buses; 250 Rural Transport Vehicles (RTVs); 9,500 private (26,350 total)
  - Piped natural gas by March to 2,821 domestic, 15 small , and 5 large commercial establishments
  - Hazardous industry closure/relocation continues: total of 2,210 closed/relocated between 1998-2001
  - Construction of 9 new flyovers completed.
- **2002: Transport and Urban**
  - 94 CNG stations established by March
  - All diesel buses phased out/converted to CNG.
  - Number of CNG vehicles as follows: 35,678 three-wheelers; 4,816 taxis; 4,231 buses; 2,165 RTVs; 10,350 private (57,240 total)
  - Piped natural gas by March to 4,111 domestic, 37 small, and 5 large commercial establishments
  - 16,340 non-destined good vehicles turned away from entering Delhi between July and November.

1997. Low smoke 2T oil for two-stroke engine gasoline vehicles was mandated in 1998, and pre-mixed 2T oil for two-wheelers was mandated in 1999. In 1996, 0.5 percent sulfur diesel was made mandatory, and the sulfur level was further reduced to 0.25 percent in 2000, and to 0.05 percent in 2001. In 2001, the government also made the use of cleaner fuels mandatory in industrial boilers, and by 2003 a large number of fuel conversions for industrial boilers had taken place.

Mumbai

2.07 The majority of interventions in Mumbai focused on the transport sector (see Annex 5C, BoxA5C.6). However, the industrial sector in Mumbai was affected by a shift in the city's economy towards the commercial and service sectors. The decline of the textile industry in Mumbai started in 1996, which led to the closure/relocation of a large number of textile mills and their ancillary units. The sulfur content of diesel in Mumbai was reduced following the same schedule as that in Kolkata: 0.5 percent sulfur in 1996, 0.25 percent in 2000, and 0.05 percent in 2001. The conversion of old taxis to CNG started in 1998, but picked up only in 2002 and the entire fleet of old and highly polluting taxis, as well as old three-wheelers, was phased out or converted to CNG/LPG by 2003. It is also worth noting that between 1995 and 2002, the number of natural gas consumers increased from about 100 to more than 100,000 in the domestic, commercial, and industrial sectors. However, as in Delhi, one activity that possibly contributed to a temporary increase in PM levels was the construction of 20-odd flyovers during the period 1997–2000.

Hyderabad

2.08 While the majority of interventions in Hyderabad targeted the transport sector, action was also taken against industries (see Annex 5D, Box A5D.7). Important interventions implemented included the reduction of sulfur in diesel to 0.5 percent in 1996 and to 0.25 percent in 2000, mandating of pre-mixed 2T oil for two-wheelers in 1999, and actions against air polluting industries in 2000. In 2001 and 2002, other than a restriction on the registration of three-wheelers, government actions focused primarily on road construction and maintenance, and better traffic planning and management.

Chennai

2.09 As in other cities, most interventions in Chennai related to the transport sector, including traffic management (see Annex 5E, Box A5E.8). The major interventions implemented were the lowering of sulfur in diesel to 0.5 percent in 1996, to 0.25 percent in 2000, and to 0.05 percent in 2001, and the mandating of pre-mixed 2T oil for two-wheelers in 1999. In January 2002, government prohibited the entry of old buses into the city center and diverted them to a new terminal on the outskirts of the city.

International Experience with Improving Urban Air Quality

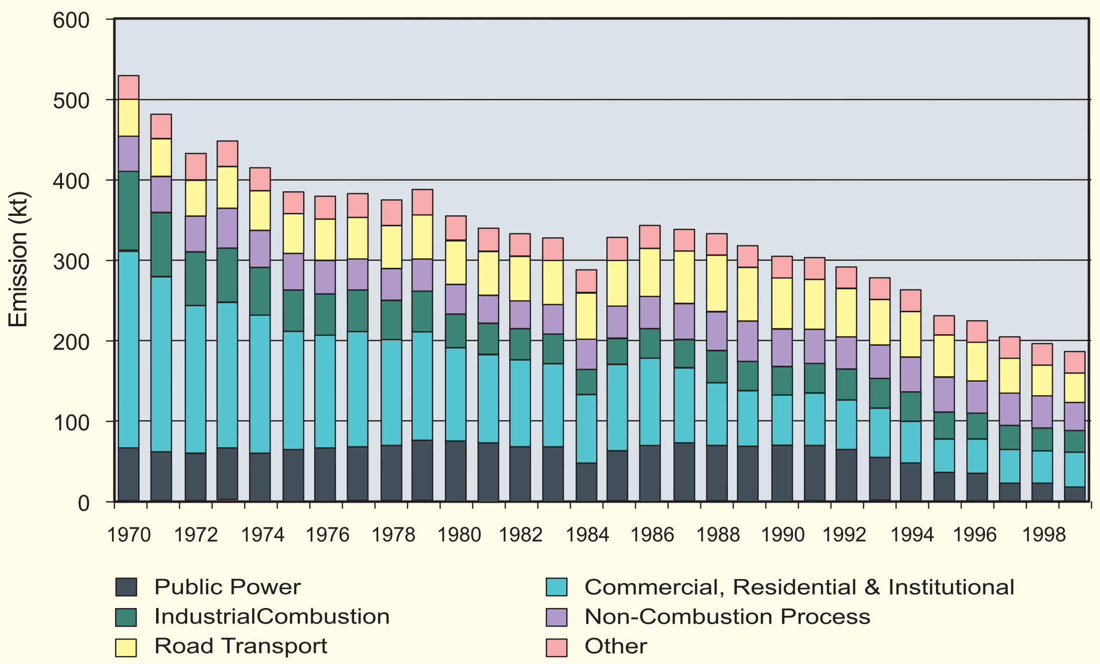
2.10 It is useful to compare the actions taken by the five cities with the once highly polluted cities in other parts of the world, which have managed to significantly improve air quality.

2.11 Historically, early efforts to combat urban air pollution (dating back to the middle of the 20th century) focused on the use of solid fuels (coal, wood) or high-sulfur content heavy fuel oil in household stoves and small municipal boilers for heating, and on industrial sources. Switching from coal to natural gas and/or developing district heating networks, successfully led to a significant reduction in PM and SO_2 air pollution in once highly-polluted cities such as London, Prague, Krakow, Seoul, and Beijing. Programs to address industrial pollution (using zoning, relocation, and mandated control technologies) also made a major contribution to improving air quality in Pittsburg in the United States, Manchester in the U.K., and many other highly industrialized cities and towns. All these cities made significant progress in reducing the levels of particulate matter in their air without doing much to deal with transport pollution, which was not considered an important source of urban air pollution until the 1970s–1980s.

2.12 The importance attached by policymakers to reducing emissions from commercial, residential, and institutional fixed sources in the U.K. can be seen in Figure 3 which shows the historical progression of PM_{10} emissions.

2.13 Against the backdrop of tightening emission controls for large industries and power plants and households switching to cleaner fuels, motorization

Figure 3: **Historical PM_{10} Emissions in the U.K.**



Source: National Atmospheric Emissions Laboratory, U.K.

grew and transport emissions became a key concern in urban air quality management. However, many cities, particularly in North America, undertook aggressive measures through the 1960s and 1970s to tackle transport emissions mainly in the context of ground-level ozone pollution, on account of significantly higher consumption of gasoline in transport as compared to India. Los Angeles and Mexico City are two notable examples. In Mexico City, gasoline fuel specifications were tightened much more than in the rest of the country, and a number of measures targeting gasoline vehicles were implemented. This included an extensive program of vehicle emissions inspection involving loaded dynamometer tests, progressive tightening of emission standards for in-use vehicles to drive out old-technology vehicles, and fewer restrictions on the use of cleaner vehicles as an incentive to encourage the replacement of old vehicles with new. While these measures were taken to combat ozone air pollution, there are some useful lessons from the Mexico City experience. These mainly relate to effectively monitoring and controling emissions from in-use vehicles, such as the decision to move from static to loaded tests for the purpose of identifying gross polluters.

2.14 On the policy front, the experience of Chile in public road passenger transport is informative for controlling emissions from diesel vehicles. Between 1979 and 1983, both entry to the market and fares were deregulated. The public sector operator was driven out of the market and total capacity more than doubled. But by 1985, regular bus fares had tripled, and the average age of buses had increased from 7 to 12 years. Competition concentrated on routes to the center of the city, which became congested and polluted by buses with too few passengers. Initial attempts to rectify the situation included banning 20 percent of the bus fleet from operation on each day of the week and banning buses more than 22 years old. But these measures gave little relief. In the early 1990s, the government introduced a system of competitive tendering for franchises to operate buses on routes entering the city center, limiting the capacity. The fare offered was one main criterion in selecting franchisees; another was the environmental characteristics of the vehicles offered. Congestion, air pollution, and fares all fell dramatically. By the mid-1990s, improved service, an important benefit of competition, had been retained, while the drawbacks associated with competition had been largely eradicated. In the 10-year period between 1993 and 2002, the number of buses fell from 14,000 to 7,500, and the average age of buses came down from 15 to 5 years.

2.15 In Asia, transport is believed to be a larger contributor to urban PM levels, as compared to cities in some other parts of the world, due to a special vehicle mix: a much larger share of two- and three-wheelers with highly polluting two-stroke engines, and a much higher proportion of diesel vehicles, many old and ill-maintained, compared to the Americas or the former Soviet Union republics. When two-stroke engine three-wheelers, which once numbered more than 50,000 were banned in Dhaka in December 2002, there was an immediate measurable reduction in PM_{10} levels. Contribution of emissions by transport are further exacerbated by road congestion and poor traffic management. Because particulate emissions occur predominantly during times of transient operation—during acceleration—smoothing traffic speed is a key consideration in reducing PM emissions. One very effective approach in this regard is to provide public transport priorities in the form of dedicated lanes or totally segregated busways. Experience in Curitiba, Brazil, and Bogotá, Colombia has demonstrated that, with good traffic management to minimize car delays, segregated bus systems can produce both efficiency gains and environmental benefits. While no single set of solutions are applicable across Indian metro cities, it may be worthwhile for some city authorities to take a closer look at the experience of the South American countries.

2.16 An important observation from international experience is a consistent pattern across all cities with very high particulate pollution (similar to that in Delhi) of significant pollution reduction achieved by targeting solid fuel use by household and small establishments, a category of pollution sources largely ignored in India thus far. Another observation is that most successful programs to control transport emissions have focused on ozone, rather than particulate pollution, so that those programs are not directly relevant to India (although certain principles of how to design and maintain an effective system for monitoring and enforcement of mandated emission limits apply).

Urban Air Quality: Levels and Trend Analysis

Air Quality Data

3.01 This study uses primarily the data collected by the National Environmental Engineering Research Institute (NEERI) between 1993 and 2002, since it is the only data set for RSPM available over that many years. It also uses, where available, the data obtained between 2000 and 2003 at monitoring stations not operated by NEERI to assess their correlation with the NEERI data set.[5]

3.02 NEERI operates three monitoring stations in each of the five cities on behalf of the CPCB as part of the network under the National Air Quality Monitoring Program (NAMP). These monitoring stations typically attempt to cover three types of land use: residential, commercial, and industrial. The stations are meant to register air pollution concentrations representative of a large area rather than peak concentrations at air pollution hot-spots, such as major traffic intersections, and are thus typically located at a significant distance from major roads. Details of NEERI's monitoring methodology and city-specific monitoring setup are provided in Annex 2. In addition to NEERI's monitoring stations, city authorities and state governments are free to have their own monitoring stations.

3.03 As discussed earlier, PM is the main pollutant of concern in Indian cities. As industrial countries shifted their monitoring efforts to PM_{10} and more recently to $PM_{2.5}$ on account of overwhelming evidence pointing to adverse health impacts from finer fractions of SPM, the CPCB started publishing RSPM data for select cities in 1999. However, monitoring of RSPM by NEERI had been started on behalf of CPCB as early as 1993 under the aegis of the NAMP and continues to date. The NEERI dataset presents a large and ready database to assess the urban RSPM pollution in select Indian cities.

3.04 A description of the monitoring network and quality assurance/quality control (QA/QC) procedures and protocols followed by NEERI is given in Annex 2. The monitoring procedures established by CPCB stipulate that PM be sampled twice a week, or a total of 104 days a year, for 24 hours at a time in three consecutive 8-hour intervals. The available data indicate that this requirement was seldom met by NEERI,[6] with some cities having fewer than 50 data points a year at each monitoring site even in recent years. The extremely limited number of measurements raises questions about the statistical significance of the data, including the question of whether the few measurements made are representative. In some cities where both the State Pollution Control Board (SPCB) and NEERI measured RSPM, the ambient concentrations measured in the same land use category area sometimes differed as much as two-fold. In the case of Chennai, this might have been at least in part on account of much fewer data points collected by NEERI. There is also room for improving monitoring procedures. A significant omission is the absence of anti-static measures—static charge on filters and other surfaces is the largest source of particulate measurement variability and microbalance instability. These limitations, treated in more detail in Annex 3, should be borne in mind when interpreting the data presented in this report. Annex 3A presents comparisons between NEERI and SPCB/CPCB data across cities for the period 2000 to 2003.

Air Quality Standards

3.05 Historically, the national ambient air quality standards have differed by land-use, with the most stringent standards set for "sensitive" areas, followed by "residential, rural, and other areas," and the most lenient standards set for "industrial" areas. The current national ambient air quality standards are summarized in Annex 4. All areas in the cities are classified according to these land-use categories. This practice carries an implicit assumption that land-use, and hence air quality, differ significantly by area in a given city. In the most recent revision of the national air quality standards in 1994, RSPM standards were included, and land-use categorizations were defined as follows: i) industrial, ii) residential, rural, and other use, and iii) sensitive areas.[7] The standards are most liberal for industrial areas, followed by the residential, rural and other areas, and most stringent for sensitive areas. However, in the case of the NEERI monitoring framework, the land-use classifications used were i) residential, ii) commercial, and iii) industrial, where commercial can be considered as the "other" category used by CPCB. This study uses the NEERI classification of areas.

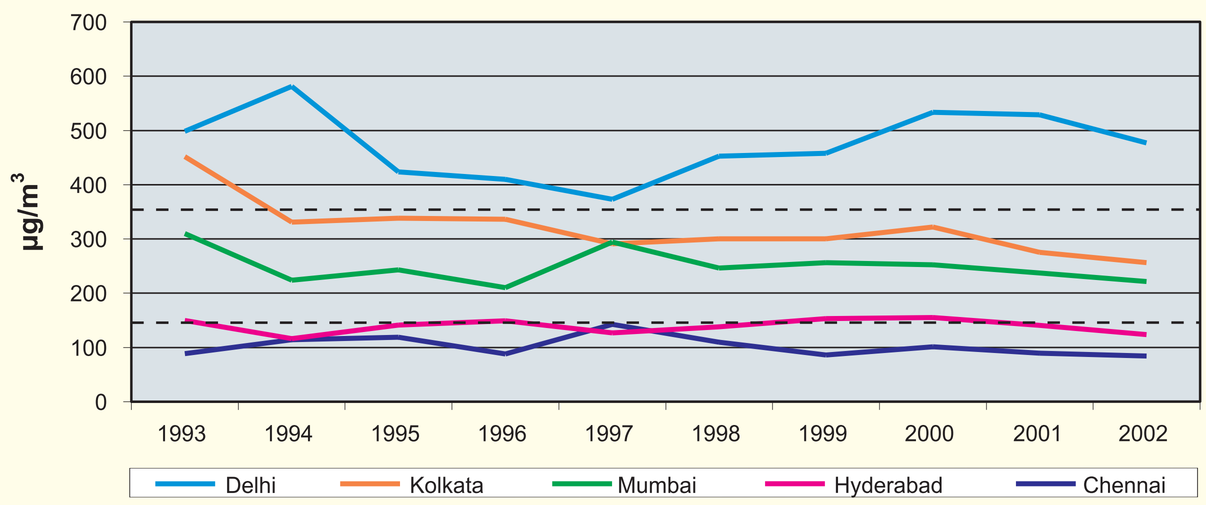
Levels and Overall Trends

3.06 For the most part, all the five cities were not in compliance with the national annual average air quality standards for particulate matter during the ten-year period 1993- 2002, and particulate pollution remains a cause of concern for all cities. Available data show that Delhi has the highest ambient concentrations of airborne particulate matter, followed by Kolkata, and then by Mumbai. Chennai and Hyderabad have the lowest ambient concentrations among the five cities studied. The difference in ambient concentrations between the most polluted and least polluted cities is about five-fold according to NEERI's data, but much smaller if the data collected by the CPCB and SPCBs are compared.

3.07 As mentioned above, different standards have been set for different land-use areas. The degree of non-compliance with the national annual average particulate standards for residential area remains most serious in Delhi and Kolkata for both SPM and RSPM, and for SPM in Mumbai. With respect to the national annual average particulate standards for industrial areas, which are much more lenient than those for residential areas, Delhi is in serious non-compliance with respect to SPM and RSPM, while Kolkata is in non-compliance for RSPM.

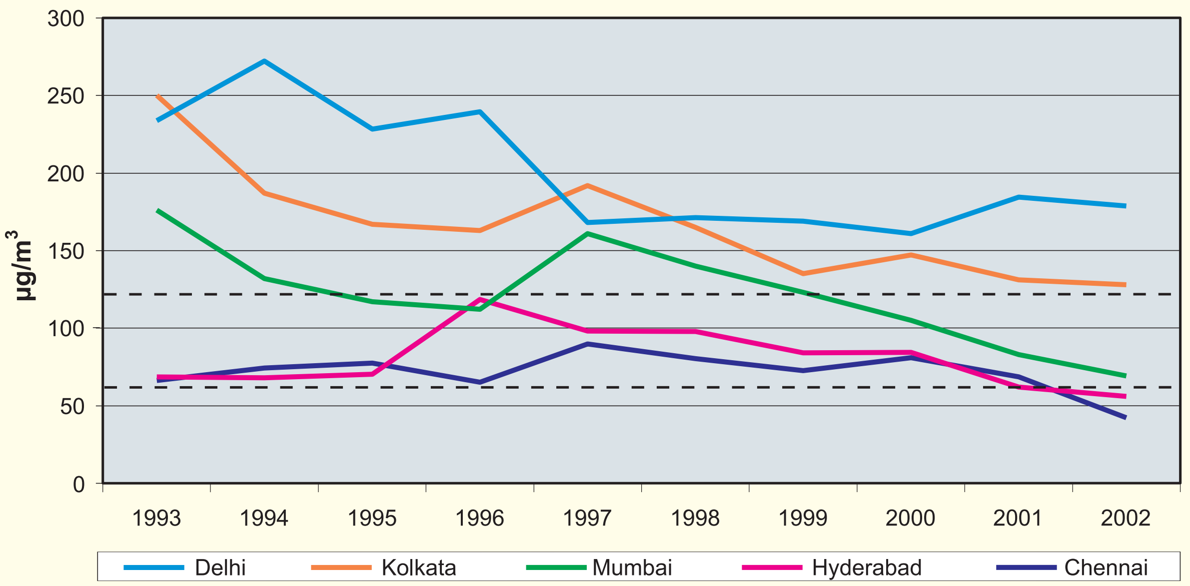
3.08 It is important to point out that while NEERI data for 2002 indicate that Hyderabad and Chennai are in compliance with the NAAQS for both residential and industrial areas, the SPCB data for 2002 shows that industrial areas of these cities are not in compliance while the residential area in Hyderabad is in compliance (in Chennai, the SPCB has no monitoring station in a residential area). One explanation for the differences could be that the locations of the monitoring stations and the days on which the data are collected by NEERI and SPCB are different. But it is doubtful whether these alone would account for the difference of as much as two-fold observed in Chennai in "industrial" areas (see Annex 3A). A closer examination of Chennai data revealed that NEERI carried out RSPM monitoring for less than half the number of days as SPCB (41 days as compared to 91 days), which raises questions about the representativeness of the data collected by NEERI. Given these very large differences in ambient pollutant concentrations in the same land-use area in the same city, it is not possible to draw conclusions about whether or not Chennai or Hyderabad might have met the national RSPM standards in 2002.

Figure 4: **Annual average SPM concentrations in the five cities**



Note: The lower dotted line shows the national annual ambient standards for residential, rural, and other areas of 140 μg/m³. The upper dotted line shows the national annual ambient standards for industrial areas of 360 μg/m³. The concentrations shown are averaged across three monitoring sites with varying land-use.

Figure 5: Annual average RSPM concentrations in the five cities



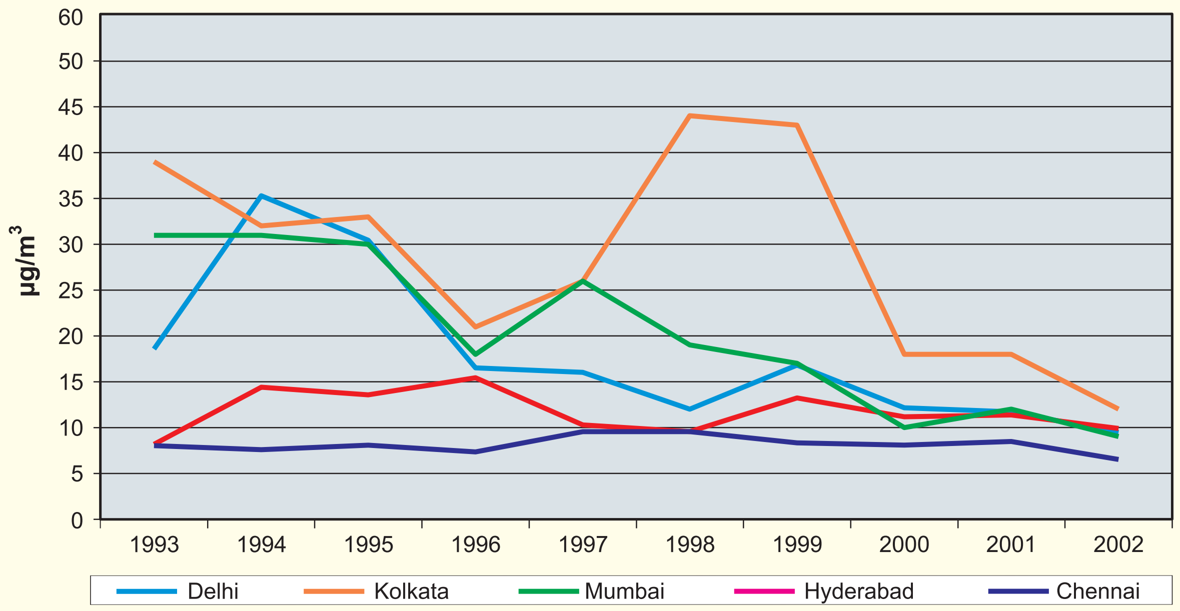
Note: The lower dotted line shows the national annual ambient standards for residential, rural, and other areas of 60 mg/m³. The upper dotted line shows the national annual ambient standards for industrial areas of 120 mg/m³. The concentrations shown are averaged across three monitoring sites with varying land-use.
There is a large amount of missing data, details of which are given in Annex 3; the residential site monitoring station in Delhi was moved to another location in 1994; the residential monitoring site in Kolkata was moved to another location in 1997; the residential site monitoring station in Mumbai was moved to another location in 2001; the monitoring equipment in Delhi was replaced with new equipment from a different manufacturer in between 1995 and 1997, while in Mumbai it

3.09 To examine how airborne particulate pollution has changed over time in each city on a city-wide scale, annual concentration averages, combining data from the three monitoring stations, were computed. The trends between 1993 and 2002 are shown for SPM in Figure 4 and for RSPM in Figure 5. With the exception of Delhi, there are no indications that particulate air pollution has worsened in recent years. SPM does not show a decline over time except in Kolkata. RSPM shows a slowly declining trend recently in Chennai, Hyderabad, and Kolkata, and a steady decline since 1997 in Mumbai. However, the overall trends need to be interpreted with caution since they hide a large number of significant data gaps, particularly in the case of Delhi and Kolkata (see Annex 3).

3.10 Comparison of Figures 4 and 5 shows that in the case of Delhi, while ambient SPM concentrations showed a marginal decline between 1995 and 1997 and began to increase in subsequent years, RSPM concentrations fell sharply from 1996 to 1997, remained steady until 2000, and rose slightly in 2001. In Hyderabad and Mumbai, RSPM showed a steady decline after reaching a maximum in 1996 and 1997, respectively, but SPM fell much less, if at all. While the ratio of RSPM to SPM is not static, the observed trend of increasing coarser particle fraction does not have a ready explanation, and calls for more rigorous data validation and quality control. However, annual average SPM levels in Delhi based on an independent source of data from CPCB have shown a similar pattern of variation, with a marginal decline occurring in 1997 followed by an increasing trend (CPCB 2001a). One possible reason for the lack of correlation between SPM and RSPM levels, particularly in Delhi, could be the increase in contribution of construction related PM (for example, 19 odd flyovers were under construction between 1998 and 2003, and the Delhi metro has been under construction since 1998), while there was a decrease in combustion-derived RSPM.

3.11 In contrast to particulate matter, annual average SO_2 concentrations were low during the same time period and in compliance with the national annual average standard of 60 µg/m³ for residential areas. NO_2 concentrations were also low

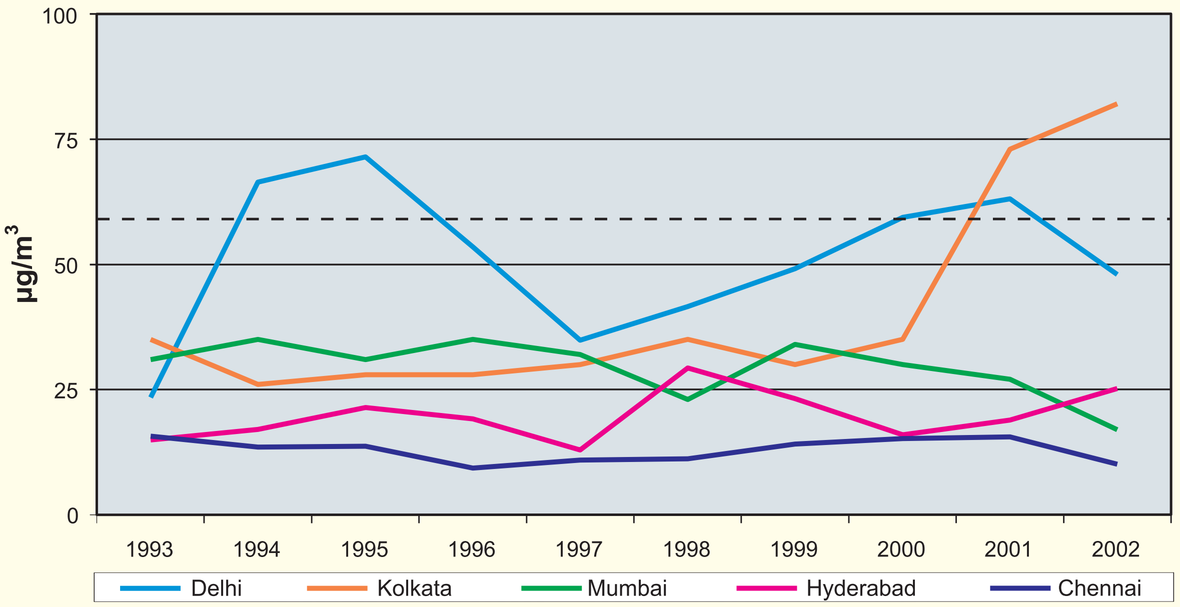
Figure 6: **Annual average SO_2 concentrations in the five cities**



Note: The national ambient standard for residential areas is 60 µg/m³ for SO_2. The concentrations are averaged across three monitoring sites with varying land-use.

except in Delhi and in Kolkata. The data are shown in Figures 6 and 7. The sharp increase in ambient SO_2 concentrations in 1998 followed by a sharp drop in 2000 in Kolkata is more likely to reflect problems with data than a sudden increase followed by a decrease in SO_2 emissions in the city. Similarly, the sharp increase in NO_2 concentrations in 2001–2002 in Kolkata and the large fluctuations in NO_2 concentrations between 1993 and 1997 in Delhi may indicate problems with data collection[8]. If these data points are excluded, Delhi, Kolkata, and Mumbai recorded falling SO_2 concentrations during this period. No particular trend could be observed with respect to ambient NO_2 concentrations.

Figure 7: **Annual average NO_2 concentrations in the five cities**



Note: The dotted line shows the national ambient standard for residential area of 60 µg/m³ for NO_2. The concentrations are averaged across three monitoring sites with varying land-use.

3.12 Overall, by comparison with PM, the two gaseous pollutants do not seem to be a (priority) problem. However, it appears that careful monitoring of the levels of NO_2 in Delhi and Kolkata is needed, as it is a precursor to secondary particulate formation, and also ground-level ozone, which may become a problem in the future.

City-specific Analysis

3.13 The observation in Figure 5 that RSPM levels do not seem to be rising, and in some cases may even be falling, suggests that targeted measures mentioned in the previous chapter (and in Annex 5) may have met with some success. It is also possible that this improvement in air quality is partially a "collateral benefit" of actions that have been undertaken at the city level, but without the explicit objective of air quality improvement, such as implementation of better town planning legislation or traffic management schemes to ease traffic congestion. The sensitivity to developments and interventions was assessed by superimposing them on the trend in ambient RSPM concentration. While it is not possible to assign causality in each case, some findings give stronger evidence of linkages (or lack thereof) to intervention measures than others.

Delhi

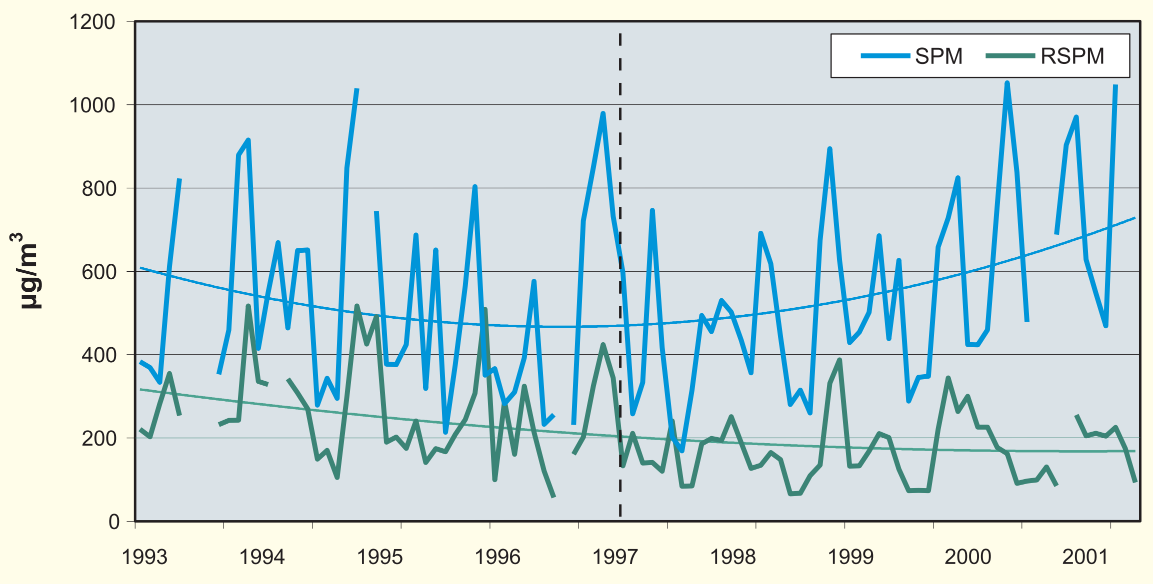
3.14 Although there are significant data gaps and questions about divergent trends shown by SPM and RSPM in Delhi, it is worth asking if there are corroborating circumstances to support a fall in ambient RSPM concentrations in Delhi between 1996 and 1997. When superimposed on the list of interventions (presented in Box 2 and Annex 5A Box A5A.3), this decrease parallels the closure and relocation of polluting industries, classified in the hazardous category, in 1996-1997. It also coincides with the reduction in sulfur in diesel and notification of sulfur content in fuel oil (FO) and low sulfur heavy stock (LSHS). However, it should be noted that the RSPM samplers were replaced with entirely new models (different manufacturer, different make) during 1995–1997. While cross-calibration with the prior samplers was carried out, instrument replacement could introduce additional data uncertainties.

3.15 Surprisingly, the annual ambient RSPM averages on a city-wide scale did not show a discernible impact of the penetration of CNG as an automotive fuel in 2000-02. One possible explanation is that the lower emissions from the previously diesel-fueled and two-stroke gasoline engine vehicles were offset by higher emissions from elsewhere, such as increasing overall vehicle use in Delhi, particularly of diesel vehicles (CSE 2004), and that ambient RSPM concentrations would have worsened in the absence of the CNG conversion programs. As a result, lower particulate emissions from the converted vehicles were registered as marginally, rather than dramatically, rising ambient concentrations.

3.16 Even if city-wide averages did not show a marked drop in ambient RSPM concentrations, heavy traffic intersections might be expected to show such a trend. Indeed, CPCB reported a 15 percent reduction in RSPM levels to 180 $\mu g/m^3$ at a busy traffic intersection (Income Tax Office crossing) in 2001 from approximately 210 $\mu g/m^3$ in 2000 (CPCB 2001b). However, the RSPM levels at the same location increased by almost 50 percent from 2001 in 2002 and then decreased by 10 percent from 2002 in 2003 (see Box 3). Similar observations have also been reported by others (CSE 2003). Meteorological data show that there were fewer calm days in 2002 than in 2001. However, what is not clear is whether meteorological parameters alone can account for such a large increase in RSPM between the two years. Nor is it clear why the number of calm days would have much more impact at the Income Tax Office crossing than in the rest of the city.

3.17 Another possible reason for the trend in ambient RSPM concentrations observed city-wide is that given multiple sources of air pollution in Delhi, the impact of the measures was not large enough to be reflected in the ambient RSPM concentrations, while a likely larger impact on $PM_{2.5}$ levels could not be detected because $PM_{2.5}$ is not currently being monitored. A third possibility, articulated by the Expert Committee on Auto Fuel Policy (GoI 2002), is that the reduction in PM emissions on account of CNG conversions was no more than 12 to 16 percent, while tighter emissions standards and better fuel quality were responsible for 84 to 88 percent of the reduction from vehicular emissions. This, however, would not explain the large rise in ambient RSPM concentrations between 2001 and 2002 at the Income Tax Office crossing (see Box 3). Finally, concerns about the quality of data discussed earlier and in Annex 3 cannot be discarded. One clear message

Figure 8: **Trend in monthly average concentration of SPM and RSPM in an industrial area of Delhi**



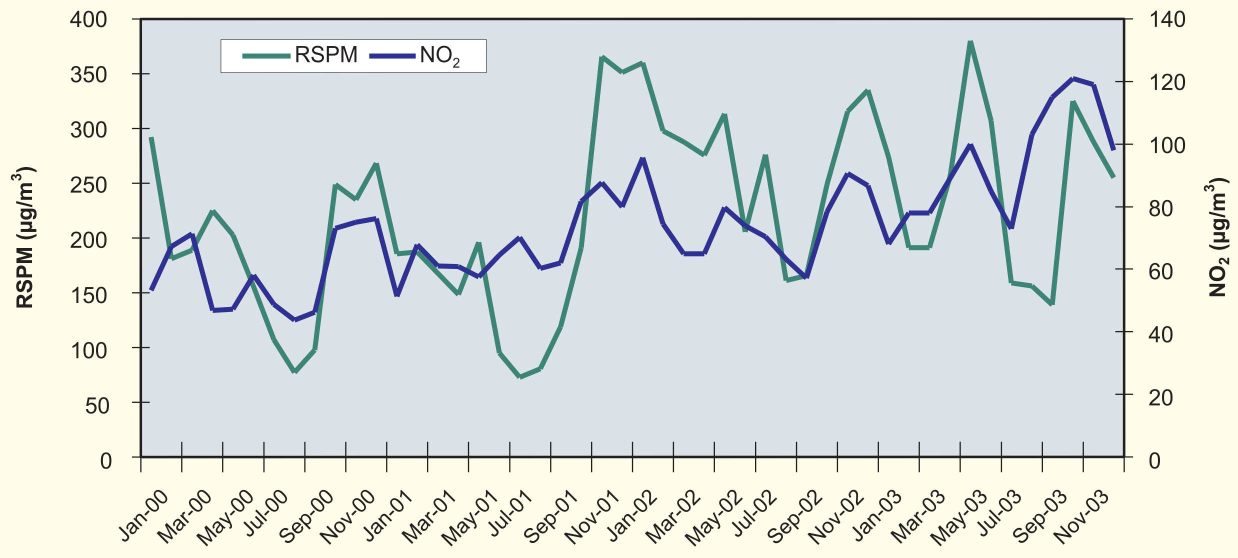
Note: The dotted line shows the time period in 1997 after which SPM started increasing again.

from this review of the Delhi experience is that future programs in Delhi and other cities should make an effort to improve the air quality monitoring program.

3.18 It is worth noting that, of the three land-use areas where air quality is measured, the maximum decline occurred in the industrial area. Figure 8 shows the trend line fitted to monthly RSPM and SPM data for the 1993–2001 time period in an industrial area (there was no monitoring by NEERI in the industrial area in 2002). The RSPM concentrations fell from about 320 µg/m³ in 1993 to less than 180 µg/m³ in 1999–2001, while the SPM concentration fell from

Box 3: **Air Quality at a busy traffic intersection in Delhi**

The CPCB has been monitoring air quality at the Income Tax Office (ITO) intersection for more than four years now, almost round-the-clock. It is also considered one of the best maintained air quality monitoring stations in Delhi. As expected, the major contributor to air pollution at ITO intersection, a classic example of an urban "hot spot," is vehicular emissions.



Note: Figure shows trends in RSPM and NO_2 concentrations at ITO intersection, 2000-2003.

about 600 μg/m³ to 420 μg/m³ in 1993–1997 but increased again to more than 600 μg/m³ in 1997–2001. It is quite likely that the impact of industrial closures and relocations resulted in a significant drop in RSPM concentrations, while the increase in SPM concentrations could have been temporarily influenced by the large-scale (on-going) construction activity related to nine flyovers and the Delhi metro in the 1998-2001 time period.

3.19 Comparing the NEERI data with those from CPCB showed that the SPM average from the six CPCB monitoring stations also showed a similar pattern of variation in 1993–2001 as the NEERI data (see Annex 3A).

Kolkata

3. 20 The ambient RSPM concentrations in Kolkata fell gradually from an average of 250 μg/m³ in 1993 to about 130 μg/m³ in 2002. However, as in the case of Delhi, because of a large amount of missing data (see Annex 3), the trends plotted should be interpreted with caution. If the 1993 data are removed, the decline in RSPM starts after 1997. As mentioned in the previous chapter (and detailed in Annex 5B), some of the major interventions targeting the transport and industrial sectors that could have affected RSPM levels began in 1997.

3.21 Data show that there is a generally decreasing trend in the commercial and industrial areas (Annex 5B). In the residential area, there was a break in monitoring on account of change in the location of the monitoring site in 1997, and higher concentrations were recorded subsequently. A similar trend is evident in the case of SPM, though it is not as pronounced. The decline in RSPM is comparable between commercial and industrial. As mentioned earlier, a large number of interventions in Kolkata have focused on the industrial sector.

3.22 When compared with RSPM data from the SPCB monitoring location between 2000 and 2002 it was found that the overall averages of NEERI and SPCB levels correspond very well to each other (Annex 3A).

Mumbai

3.23 Mumbai has seen a significant improvement in air quality over the years. From almost 180 μg/m³ in 1993, the RSPM levels fell in 2002 to 70 μg/m³—close to the national annual standard of 60 μg/m³ for residential areas. A decreasing trend is evident between 1993 and 1996, even if the high level in 1993 is discounted. There was a sharp increase in 1997, followed by a continuing decline in subsequent years. Similar trends are observed for SPM concentrations except between 1998 and 2000 where SPM levels remained stable but RSPM levels steadily declined.

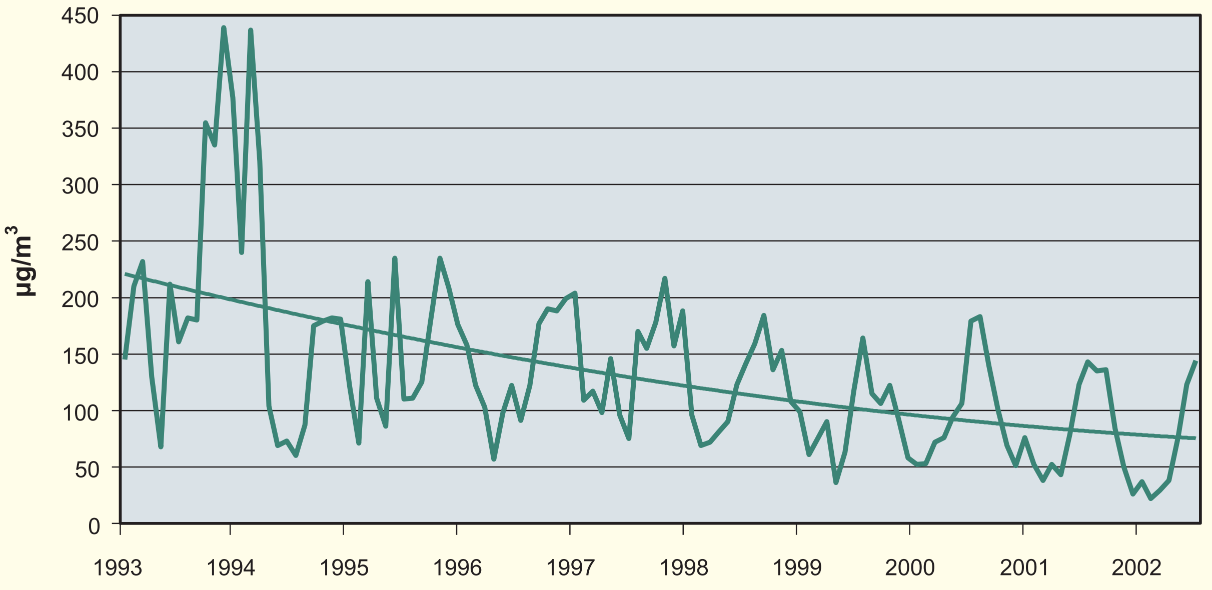
3.24 Overlaying the information from the list of interventions given in Annex 5C on the RSPM concentration data, it is likely that the large-scale construction activities related to flyover construction during 1997–2000 had an adverse impact on RSPM and SPM. The conversion of old taxis to CNG , according to estimates made by NEERI, could have contributed to a reduction in PM emissions of 385 tons, amounting to nearly 2.5 percent of the total PM emissions in Mumbai (NEERI 2004).

3.25 Ambient RSPM concentrations in the industrial area recorded the biggest reduction among the three monitoring sites, falling from about 220 μg/m³ in 1993 to about 75 μg/m³ in 2002. The declining trend in Mumbai between 1993 and 2002 mirrors the changes in economic activities in the city, wherein textile mills and their ancillaries either closed down or moved out of the city (see Figure 9). It is also worth noting that between 1995 and 2002, there was a large increase in the number of natural gas consumers in Mumbai.

Hyderabad

3.26 RSPM concentrations exhibit a decreasing trend in Hyderabad from 1996 onwards (Figure 5). The concentrations were more or less steady between 1993 and 1995 and increased sharply in 1996, with the monitoring site in the commercial making the greatest contribution to this rise (consistent with a large increase in SPM concentrations at the same site), as shown in Annex 5D. Increased traffic congestion near the commercial area, which had become a major traffic junction, could account for the sudden increase in levels. Traffic flows were rationalized by 2001. It is worth noting that the levels of both pollutants in the industrial area were the lowest, well below the annual national ambient standard for industrial areas throughout the study period, and

Figure 9: Trend in monthly average concentration of RSPM in industrial area of Mumbai



falling below the annual standard for residential areas in 2001 and 2002. As mentioned earlier, the interventions implemented in Hyderabad targeted primarily the transport sector.

3.27 However, comparison with data from the SPCB industrial monitoring location (Uppal) for 2001 and 2002 shows that the levels at the NEERI monitoring location (Nacharam), which is not too far from Uppal, are much lower. As per the SPCB data, the industrial area recorded annual average values nearly double of the NEERI industrial monitoring area. The overall trends in monthly averages from the NEERI and SPCB monitoring locations, tracked each other reasonably well till 2002, after which there seems to be a greater divergence in values (Annex 3A).

Chennai

3.28 As can be seen in Figure 5, RSPM concentrations in Chennai remained steady for the most part but there was a marked decrease in 2002, with the decrease at the commercial location making the greatest contribution (see Annex 5E). As mentioned earlier, the mitigation measures implemented in Chennai targeted primarily the transport sector. The decrease in annual average RSPM to below the annual national standard for residential areas at the three sites in 2002 coincided with the ban on entry of suburban buses into the city center.

3.29 It should be noted, however, that comparison with data from the SPCB industrial monitoring location for 2001 and 2002, which is located in the same area (Thiruvottiyur) as the NEERI industrial monitoring station, shows that the NEERI values are much lower. The lack of consistency in data between SPCB and NEERI, shown in Annex 3A, may be in part due to the number of data points obtained by NEERI being less than half of that obtained by SPCB; nevertheless, this inconsistency does not allow one to confidently conclude that residential values are indeed as low as reported by NEERI. This highlights the importance of following monitoring protocols so that proper comparison and verification of the data can be made.

Chapter 4

Understanding the Determinants of Urban Air Quality

4.01 A number of factors affect air quality. The knowledge of the direction and size of all these factors and their interaction is important for developing an effective mitigation strategy, particularly when there is no obvious dominant source of pollution. These factors include:

1. Composition and characteristics of emission sources, including

- *Absolute emission levels:* Everything else being equal, the higher the emissions, the higher the ambient concentrations. If the levels of industrial and transport activities are steady throughout the year but there is additional combustion of solid fuels in winter for space heating, absolute emission levels will increase in winter, worsening air quality.

- *Height of emissions:* The height at which emissions occur has a significant impact on ambient concentrations. Stack emissions from a very tall chimney tend to get dispersed over a much larger area, thereby diluting concentrations, than emissions from vehicles, small industries, and household sources occurring near ground level. Heights less than 20 meters (m) are generally considered low and those above 75–80 m high.

- *Location of emissions:* Emissions in the middle of a city are likely to increase ambient concentrations inside the city more than those occurring at the edge of the city, although this depends on wind direction and speed.

2. Meteorological parameters

Rainfall "washes away" pollutants, lowering ambient concentrations. High winds can help disperse pollutants while, at the same time, winds from polluting areas can increase ambient concentrations. For example, monitoring stations downstream of an area with high pollution will record higher ambient concentrations than those outside of such wind trajectories. Thermal inversion—whereby cold air is trapped under warm air—is prevalent especially in winter in northern India, and increases ambient concentrations because pollutants cannot "escape" from air near ground level. A human activity associated with low ambient temperature is combustion of solid fuels for space heating in winter. These observations suggest that low rainfall, low wind speed, and low ambient temperature worsen air quality.

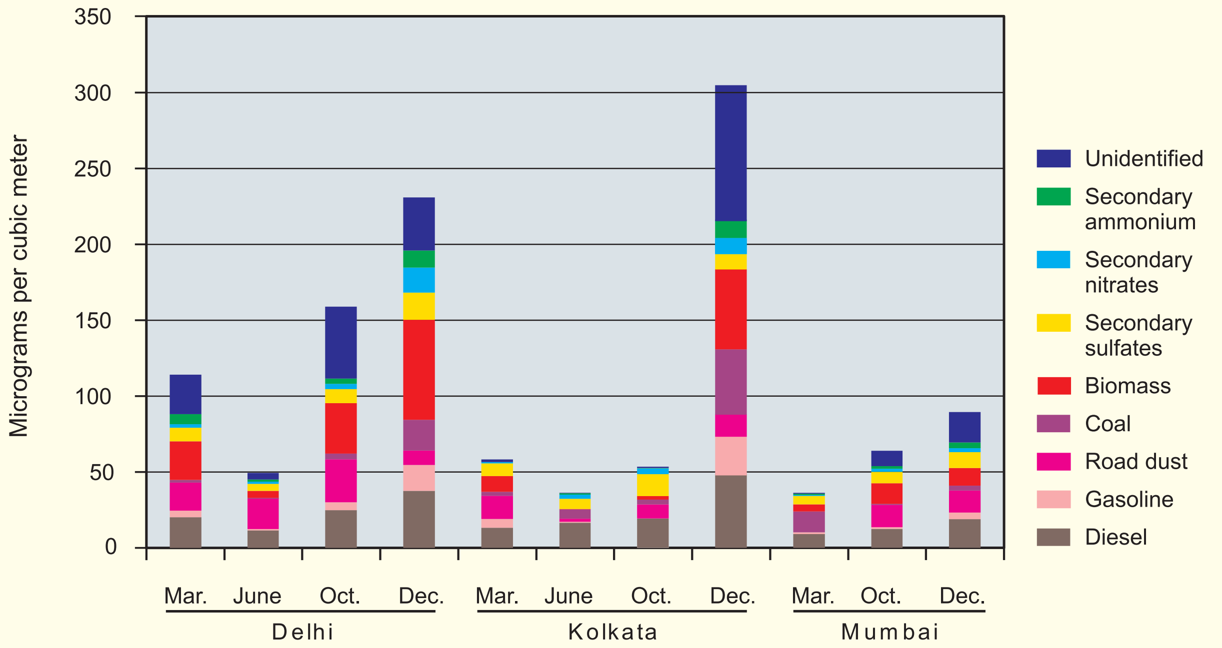
4.02 This chapter presents the available evidence of the impact of these factors, based on a recent source apportionment study – (ESMAP 2004, the first of its kind in India) for three of the sample cities, and the analysis of meteorological and air quality data over ten years for all five cities.

Evidence of Relative Contribution of Sources

4.03 In designing a policy package to reduce air pollution, one important question is the contribution of different sources of emissions to the overall ambient air quality. Those sources that are contributing significantly to particulate air pollution should ideally be the primary focus of policy intervention.

4.04 A recent study (ESMAP 2004) carried out an analysis of ambient $PM_{2.5}$ samples collected in March, June, October, and December in 2001 in Delhi, Kolkata, and Mumbai. The study used a technique called chemical mass balance receptor modeling. The particles were analyzed for organic carbon, elemental carbon, metals, and ions, and the hydrocarbons found in organic carbon were further subjected to detailed compound identification. The study represented one of the first detailed fine particulate matter source apportionment studies carried out in South Asia. The results indicated that there was no single dominant source in Delhi, Kolkata, and Mumbai, but rather three principal sources of particulate air pollution: vehicle exhaust, re-suspended road dust, and solid fuels, especially in cities with colder winters (see Figure 10). For example, mobile sources and biomass combustion appear to contribute substantially and in several cases approximately in equal proportions (spring and autumn in Delhi and autumn in Mumbai). The contribution of "road dust" can also be significant (summer in Delhi and spring and autumn in

Figure 10: Receptor Modeling of $PM_{2.5}$ in Delhi, Kolkata, and Mumbai



Note*:* Insufficient sample was collected in June in Mumbai to carry out hydrocarbon speciation.

Mumbai). Predictably, the combined contribution of biomass and coal is the highest in winter in Delhi and Kolkata, presumably as a result of heating. Contributions from solid fuel combustion are also significant in non-heating seasons: spring and autumn in Delhi and autumn in Mumbai, probably on account of considerable use of solid fuels in small-scale industries and by households for cooking.

4.05 Another study, sponsored by the Mumbai Metropolitan Regional Development (MMRDA) under the World Bank funded Mumbai Urban Transport Project (NEERI 2004), showed that the contribution of vehicular exhaust to RSPM was as high as 54 percent at kerbside locations and as low as 6 percent at an urban background location (an area with little activity away from any emission hotspot). Re-suspended road dust contributed 9 percent to 20 percent, while the contribution of industries varied from 6 percent to 42 percent, depending on the location (see Annex 5C for details). The overall results of source contribution to RSPM was in the same range as the findings of the URBAIR report for Greater Mumbai based on data collected in the early 1990s (World Bank 1997).

Meteorological Parameters

4.06 Monthly weather data for the period 1991-2002 were obtained from the Indian Meteorology Department. For each city, monthly rainfall and wind speed data were averaged over the 12-year period and categorized into those with **good, moderate,** and **poor** dispersion conditions. These criteria for good, moderate, and poor dispersion conditions were arrived at by the authors based on existing dispersion model classifications (Lvovsky et al 2001), and following qualitative analysis of variation in RSPM levels with rainfall and wind speeds[9] (see Annex 5 for details).

4.07 The analysis carried out in this study yielded the following observations:

- Poor dispersion conditions are encountered in Kolkata, Mumbai and Delhi for five, four, and three months respectively, a year.
- In Hyderabad, the higher wind speed stays for about 10 months of the year. This leads to better dispersion conditions over a long period of time.
- In Chennai, higher precipitation in October and November partially compensates for lower wind speeds during these months.

4.08 The results are summarized in Table 1. As mentioned above, Delhi, Kolkata, and Mumbai had several months in winter with poor dispersion

Table 1: Dispersion conditions and RSPM concentrations in five cities

City	Dispersion Condition for Pollutants			Comments
	Good	Moderate	Poor	
Delhi	June-Sept.	Jan.-May	Oct. – Dec.	Good dispersion for 4 months and poor for 3 months
RSPM in µg/m³	108	213	291	
Kolkata	Apr.-Oct.	NA	Jan.-Mar. Nov.-Dec.	Good dispersion for 7 months and poor for 5 months
RSPM in µg/m³	108	NA	242	
Mumbai	Jan., June-Oct.	Apr.-May	Feb.-Mar. Nov.-Dec.	Good dispersion for 6 months and poor for 4 months
RSPM in µg/m³	119	102	167	
Hyderabad	May-Oct.	Jan.-Apr. Nov.-Dec.	None	High average wind speed (6-16 kmph). Good or moderate dispersion all round the year
RSPM in µg/m³	74	87	NA	
Chennai	June-Dec.	Jan. - May	None	High average wind speed (6-16 kmph). Good or moderate dispersion all the year round
RSPM in µg/m³	72	71	NA	

NA – not applicable.
Note: **Good** corresponds to monthly rainfall more than 50 millimeters (mm). **Moderate** corresponds to rainfall more than 20mm and wind speed more than 5.4 kilometers per hour (kmph) or wind speed more than 7.2 kmph. **- Poor** corresponds to wind speed less than 5.4 kmph and rain less than 20mm or wind less than 3.6 kmph. Frequency of calm days could also be taken as a proxy for wind speeds. The two were found to be inversely related to each other.

conditions, whereas Chennai and Hyderabad had none. Also shown in the Table are RSPM concentrations corresponding to the months in question, averaged over the 10-year period covering 1993–2002. In Delhi, Kolkata, and Mumbai, there is a strong correlation between dispersion conditions and ambient concentrations of RSPM, with highly elevated concentrations observed in the winter months when poor dispersion conditions prevail. In contrast, the impact of dispersion conditions on RSPM concentrations in Chennai and Hyderabad is small. This relationship is also reflected in the seasonal variation in RSPM concentrations, as shown in Annex 5 for all the five cities.

4.09 However, it needs to be pointed out that the inverse relationship between RSPM and wind and amount of rainfall is qualitative and may not always hold. For example, if most of the rain falls on one or two days in a month, monthly RSPM levels are not likely to be lowered. Similarly, a few high wind days in a month are unlikely to lower the monthly RSPM level. This was seen in the case of Mumbai where during the month of January, the average dispersion condition can be considered good but the PM level is high as seen in Table 1, because only a handful of rainy days manage to contribute to raising the monthly average of dispersion conditions.

4.10 Another important contributing factor is ambient temperature. Historical data covering 1993–2002 show that temperatures in Delhi from November to February are markedly lower than those in other cities (see Figure 11). Kolkata had the next lowest temperature during the winter months. Cold winters in Delhi and, to a lesser extent, in Kolkata

Figure 11: Monthly average temperature based on the period 1993-2002

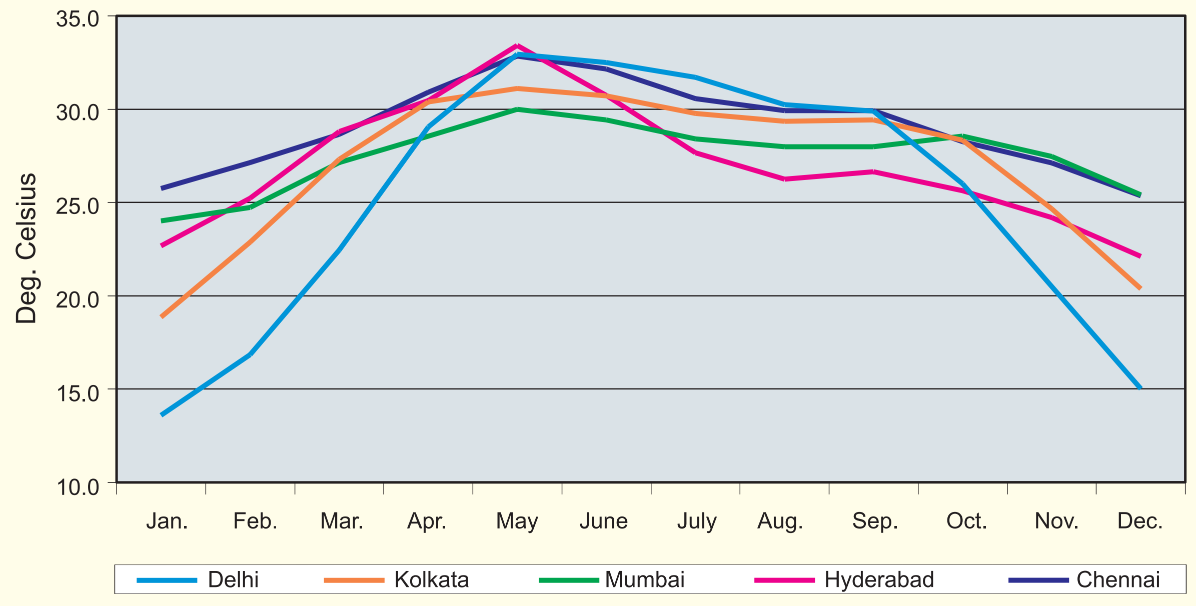
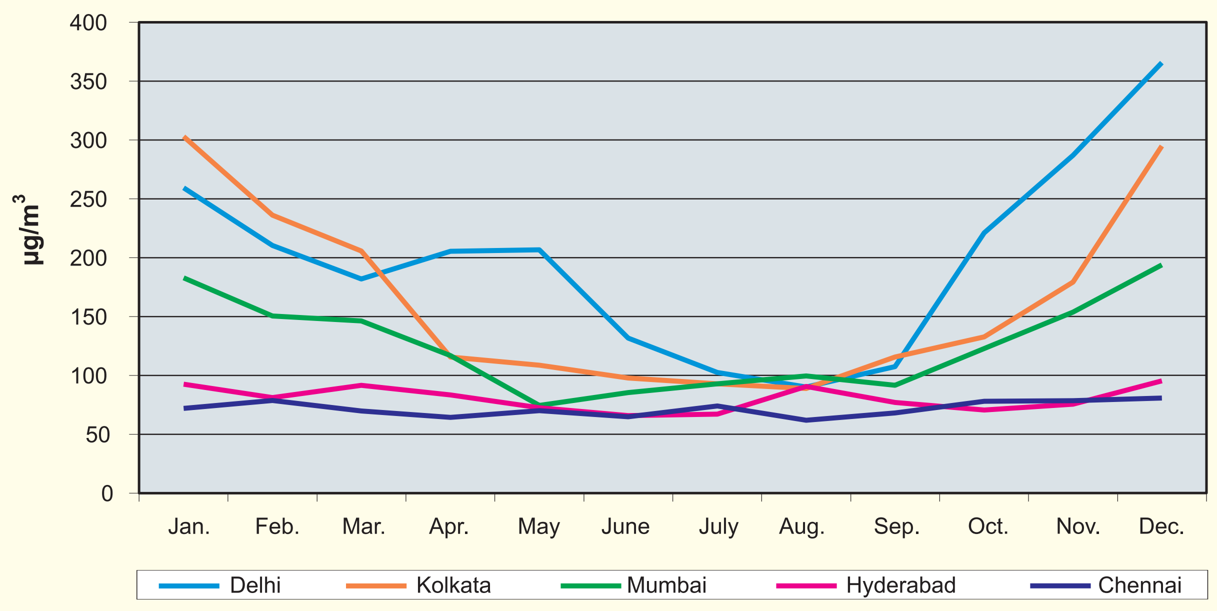


Figure 12: Combined (for all areas) monthly averages of RSPM, 1993-2002



lead to increased fuel usage for heating purposes. When solid fuels are combusted for domestic heating, particulate emissions increase. Biomass and coal combustion indeed seem to increase in winter months in Delhi and Kolkata (ESMAP 2004). This, together with poor dispersion conditions, are likely to be key contributors to high particulate air pollution in winter in these cities.

4.11 The seasonal variation of RSPM, showing higher levels of RSPM in winters in Delhi, Kolkata, and Mumbai is seen in Figure 12, which shows monthly data obtained by averaging over the 10-year period for each month. Chennai and Hyderabad, in contrast, show little seasonal variation. It is worth noting that the RSPM levels are similar between April and September in the five cities except Delhi in

April and May. The higher RSPM levels in Delhi during these months can be explained by the well known phenomenon of natural dust-laden winds from the desert in the neighboring state of Rajasthan in the north-west.[10] The monthly pattern of variation seen (see Figure 12) was evident, irrespective of land-use in all the cities, showing the strong effect of meteorological variables over any localized effect of land-use. The seasonal variation in RSPM levels during summer, monsoon, and winters is illustrated for all cities in Annex 5.

4.12 To summarize, meteorological conditions, which affect air pollution dispersion potential, differ significantly across the five cities. The southern cities of Hyderabad and Chennai have much better dispersion characteristics all year round than Delhi, Kolkata, and Mumbai. This may partly account for lower RSPM levels recorded in Hyderabad and Chennai. Further, since temperatures in southern cities do not drop as low as in the north during winter, there is unlikely to be much domestic-heating. Domestic-heating commonly uses "dirty" solid fuel and is a significant source of air pollution. RSPM levels are perhaps low in Hyderabad and Chennai in winters as there is no need for heating. As such, meteorological factors and RSPM sources also have an interactive effect on ambient air quality.

Chapter 5

The Health Impacts of Air Quality Improvement

5.01 Health impacts are the main impetus for air quality improvement policies worldwide, and India is no exception. In 1995, when the first-ever estimate of 40,000 lives lost annually in Indian cities on account of high particulate air pollution became available (Brandon and Homman 1995),[11] it provided the much needed stimulus to all the groups working on clean air in India.[12]

5.02 This chapter presents a quantification of the health benefits due to improvements in air quality in the five cities studied, using annual average RSPM data obtained by NEERI from 1993 to 2002. The likely health impacts as well as economic costs of different scenarios of improvement in RSPM levels are estimated using commonly used benefit-transfer techniques, as explained in Annex 6. In order to smooth out annual variations in average ambient concentration levels due to random fluctuations in meteorological and other factors, the scenarios were constructed using the three-year average annual concentrations of RSPM for 2000–2002 as the reference value.

5.03 The health benefits of air quality improvement have been calculated for the following scenarios:

Scenario 1: The difference between the three-year average concentrations for 1993–1995 and the reference value.

Scenario 2: A 10 percent reduction in RSPM from the reference value.

Scenario 3: A 20 percent reduction in RSPM from the reference value.

Scenario 4: A reduction from reference value to an annual average of 60 μg/m^3 (NAAQS for RSPM in residential areas) throughout the city.

5.04 Scenario 1 is meant to assess the health benefits that have been achieved by actions to improve air quality in the past decade, while Scenarios 2 to 4 aim to illustrate potential health benefits from further improvement in urban air quality in each city. Table 2 shows the reduction in RSPM levels to which the benefit calculations were applied for each of the four scenarios.

5.05 The health benefits, expressed as the number of lives saved and as monetary values of both averted premature death and illnesses per annum, are summarized in Table 3. Given data and methodological limitations discussed in Annex 3 and Annex 6, these estimates of averted deaths should be taken as leading order estimates of the magnitude of impacts, and not as exact numbers.[13] Furthermore,

Table 2: Three-year annual averages of RSPM in μg/m^3 and the levels corresponding to the four scenarios

	Delhi	Kolkata	Mumbai	Hyderabad	Chennai
Three year averages					
1993–1995	255	196	142	69	73
2000–2002 (reference value)	180	130	83	66	63
Reduction in RSPM for each scenario					
Scenario 1	75	66	59	3	10
Scenario 2	18	13	8.3	6.6	6.3
Scenario 3	36	26	16.6	13.2	12.6
Scenario 4	120	70	23	6	3

Table 3: Health benefits due to reduction in RSPM levels in five cities in India under four different scenarios

Cities	Pop.	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	(mil.)	Lives saved/ year	Econ value (mil.$/ year)	Lives saved/ year	Econ. value (mil. $/ year)	Lives saved/ year	Econ. value (mil.$/ year)	Lives saved/ year	Econ value (mil.$/ year)
Delhi	12.8	3629	432	871	104	1742	207	5806	691
Kolkata	13.2	3293	392	649	80	1297	154	3493	416
Mumbai	11.9	5308	409	747	57	1493	115	2069	159
Hyderabad	5.5	125	10	274	21	549	42	249	19
Chennai	6.4	484	37	305	23	610	47	145	11
TOTAL	49.8	12838	1279	3091	302	6182	603	11763	1296

Notes:
1. Economic value includes the benefits of both averted premature death and illness due to reduced exposure to RSPM. Gross national income (GNI) per capita of $470 (World Bank 1994) has been used for all cities for benefit-transfer estimates of WTP for reduced risks of death and illness.
2. Population figures are taken from the 2001 census
3. Population under 15 is assumed to be 36.9 percent (UNICEF 2004) and adults to be 63.1 percent.
4. Percentage of asthmatic population is assumed to be 5 percent.
5. Crude mortality rate per 1000 is assumed to be 9 (UNICEF 2004).
6. See Annex 6 for other details on the methodology.

monetary values of the health impacts reported here are based on the willingness-to-pay (WTP) approach as described in Annex 6, so that these values should be considered upper-bound estimates of the potential health benefits.

5.06 Not surprisingly, Delhi, Kolkata and Mumbai show the largest health benefits from improvements in air quality from 1993–95 to 2000–02 (Scenario 1) on account of large reductions in the RSPM levels and largest exposed populations. Mumbai shows the maximum number of lives saved, despite a smaller change in the RSPM levels compared to Delhi and Kolkata (see Table 1, chapter 4) because a higher concentration-response coefficient was used (see Annex 6 for an explanation).

5.07 Given the substantial scope for air quality improvement in all the five cities and no established threshold for adverse health impacts from exposure to RSPM (with effects detected at levels as low as 20 µg/m³), additional calculations were carried out to examine alternative scenarios. While 10 percent and 20 percent reductions seem realistic targets for all cities over the short and medium term, Scenario 4 (bringing the RSPM levels down to the annual national standard for residential areas) is clearly a long-term target for Delhi and Kolkata which have the highest ambient levels among the five cities, especially in winter. The potential benefits of lowering city-wide annual average RSPM concentrations to 60 µg/m³ are very high: as many as nearly 10,000 lives can be saved every year in these two cities, with the upper bound monetary estimates of the health benefits exceeding US$1.0 billion per annum.

5.08 The substantial health benefits that are likely to come from further air quality improvements in all the five cities establishes a strong case for continued efforts in urban air quality management in an accelerated and more effective way.

Chapter 6

Concluding Remarks

6.01 This study analyzed air quality data over the period 1993–2002 in five of the largest cities in India with a view to understanding recent trends, factors that influence these trends, and the associated effects on public health. As a retrospective study, it helps to draw lessons as also better understand repercussion of actions taken for urban air quality improvement.

6.02 The strength of this analysis to draw conclusions has been constrained by the limitations of the available data. Nevertheless, taking these constraints into account, a number of useful and interesting conclusions that can contribute significantly to the on-going policy discussions/dialogue on improving urban air quality in India emerged from the study.

6.03 A potentially significant and encouraging finding of this study is that ambient concentrations of RSPM, the main pollutant of public health concern, fell between 1993 and 2002. This decline in RSPM levels might have led to 13,000 fewer cases of premature deaths and much greater fall in the number of cases of respiratory illness annually in these cities by 2002, as compared to the early 1990s. SO_2 levels also declined during the same period. However, SPM levels remained steady, implying—against a backdrop of falling RSPM levels—increasing concentrations of coarse particulate matter, which is surprising. It would be important to confirm this trend by more systematic measurements with more rigorous data validation and quality assurance/control in the future.

6.04 Despite substantial progress and efforts in the past, RSPM pollution remains a cause for concern in all five cities. The levels of RSPM are the highest and dangerously above the national standards in the northern cities of Delhi and Kolkata, especially in winter. Delhi still displays the highest levels, notwithstanding the implementation of the most extensive program of air quality improvement measures. Ambient NO_2 concentrations have exhibited an increase in recent years, although at still relatively low levels, calling for careful monitoring. If the trend is not arrested, there would be a need for greater NO_2 control in the city-level air quality management programs in the coming years.

6.05 Given that there is no established threshold for health impacts from exposure to RSPM, all cities will gain substantial health benefits from further reductions to or even below the current national annual standard of 60 $\mu g/m^3$ for residential areas, which may be achievable in Chennai and Hyderabad in the medium term. However, bringing the RSPM levels down to this standard is clearly a long-term target for Delhi and perhaps Kolkata. Still, the potential benefits would be very high; it may save as many as 10,000 lives every year in these two cities alone.

6.06 There is substantial scope for further improving urban air quality in India. The two key questions are:

(i) What are the most effective strategies, that are also politically viable and socially acceptable, that need to be taken by each city to move forward?

(ii) What are the main factors affecting air quality in each city, as well as explaining significant differences across cities?

This study focuses on the second underlying question in order to inform the first.

6.07 Comparison of air quality trends with intervention measures implemented indicates that reductions in RSPM concentrations have been achieved through a combination of measures, targeting industry, transport, and better urban planning/development. It is also possible that some developments not directly aimed at improving air quality, reinforced the impact of these efforts. These would include significant penetration of clean modern fuels in the household sector over the same period[14] and opening of the economy to international automobile manufacturers, thus bringing in more advanced technology vehicles. Table 4 summarizes by sector the key actions taken in the five cities that possibly helped improve air quality. While it is not possible to say, based on the available information, which of the interventions were relatively more effective, there seems to be some evidence linking measures targeted at industrial emissions with declining RSPM level in industrial areas. However, beyond this the data analyzed do not provide evidence linking specific measures in any particular sector/subsector with measurable improvements in annual average air quality levels on a city-wide scale (although measurable improvements at the micro-level in the short-term were likely, such as the impact of switching to CNG on air quality along traffic corridors). The need to target different sources, including solid fuel use for domestic and space heating, is further supported by the recent source apportionment for $PM_{2.5}$ discussed in this report, which has shown no single dominant source in Delhi, Kolkata, and Mumbai (ESMAP 2004).

6.08 The nature and magnitude of emission sources may vary between cities, and within a city with land-use. Mumbai offers a good example of the effect of attrition of industry and its consequent impact by way of reduction in RSPM and SO_2 levels in an industrial area. However, if land-use development is mixed, such as in Kolkata and Delhi, then the effect of land-use on air quality is difficult to discern. Urban development with mixed land-use also challenges the current practice of having different National Ambient Air Quality Standards (NAAQS) within a city. The approach to having differential standards would make sense only if land-use regulation could be implemented strictly. Otherwise, it could even lead to a perverse application of the regulation, whereby densely populated residential areas that exist in proximity to an industrial area are also classified as industrial, resulting in "legal" exposure of a large number of individuals to unhealthy levels of air pollution.

6.09 Recently, the Supreme Court directed cities to formulate their own actions plans, and drafts of action plans have been submitted by a number of cities. Given that as per the Air (Prevention and Control) Act 1981 section 19(1), SPCB has the right to declare air pollution control areas within its jurisdiction, the CPCB is of the view that many more cities should take up the action planning exercise on their own. Hence it is recommending that many more cities take up the preparation of action plans in order to meet air quality objectives as notified under the Air Act 1981.

6.10 As cities undertake the preparation of action plans, it is important for them to learn from their own as well as international experience. One of the key lessons from this analysis is that such plans, to be effective, should cut across the urban, transport, and industrial sectors. Furthermore, international experience shows a consistent pattern across all cities with very high particulate pollution (similar to that in Delhi) of significant pollution reduction achieved by targeting solid fuel use by households and small establishments, a category of pollution sources largely ignored in India thus far. This category of sources warrants greater attention in future programs, especially in northern cities where heating is needed in winter.

6.11 In addition to sources of air pollution, meteorological factors plays an important role in influencing ambient air quality. Meteorological conditions, which affect air pollution dispersion potential, differ significantly across the five cities. Cities with a clear pattern of pollution peaking in winter, like in Delhi and Kolkata, may need to consider developing special programs to target "winter pollution".

6.12 An important lesson is that implementation of the same interventions in two cities with different meteorological conditions and/or mix of sources is unlikely to give the same results. The choice of priority interventions to control urban air pollution needs to be city-specific, based on adequate local information. One of the requirements for formulating an effective strategy is that policymakers have access to adequate data and information.

6.13. The importance of strengthening data collection, management, and dissemination cannot be over-emphasized. Information on the effectiveness (or lack thereof) of interventions already undertaken across several cities in India can guide prioritizing interventions and establishing effective combinations in the future. For this, a stronger framework for monitoring and analyzing impacts of the interventions needs to develop, so that policymakers have access to adequate quality data and information. It should be noted that monitoring the "right" pollutants using correct protocols would not be informative unless accompanied by periodic analysis. Having such a framework becomes all the more important in a setting where civil society is very

Table 4: Sector-wise summary of key actions taken in the five cities that could have helped in improving air quality

Intervention type	Industry	Urban	Transport
Clean fuels	Switching to cleaner fuels (reduction in sulfur, gaseous alternatives)	Increasing share of domestic and commercial users of cleaner fuels (gas and kerosene for cooking, electricity for heating)	Use of cleaner fuels (gasoline lead elimination, sulfur reduction in liquid fuels, use of gaseous fuels) Better lubricant quality and only pre-mixed 2T oil for two- and three-wheelers
Improved technology	More efficient and cleaner combustion technology	Better road infrastructure (road widening, traffic management, new flyovers)	Scrappage of old commercial vehicles and their replacement with a new fleet
Stronger and better enforced regulation	Tightened and better enforced emissions norms leading to installation of pollution control devices	Enforcement of land -use zoning regulations (closure and relocation of industry from non-conforming areas, devel opment of green belts/areas)	Introduction and enforcement of new and more stringent emission norms for new and in-use vehicles*

* One consequence of opening up of the automobile market to international competition coupled with the introduction of increasingly tighter emission standards is a shift from two-stroke to four-stroke engines among two- and three-wheelers. According to the new vehicle sale figures, the sale of four-stroke engine two-wheelers increased from 21 percent in 1997-1998 to 79 percent in 2000-2004, with a corresponding decrease in the sale of two-stroke engine two-wheelers (SIAM 2004).

active, and judicial directions have to be implemented often at short notice.

6.14 Given the city-specific nature of the air pollution problem and the solutions, targeting interventions at the city-level rather than at the state or central level appears to be the best approach. This is also supported by feedback from various stakeholders involved in air quality issues in India (see Box 4).

The analysis points to a number of possible areas that cities can start working on to address their urban air quality concerns. These areas range from strengthening monitoring and information collection to developing and adopting a common framework for urban air quality management to enable targeting a mix of relevant sectors (urban, transport, industry).

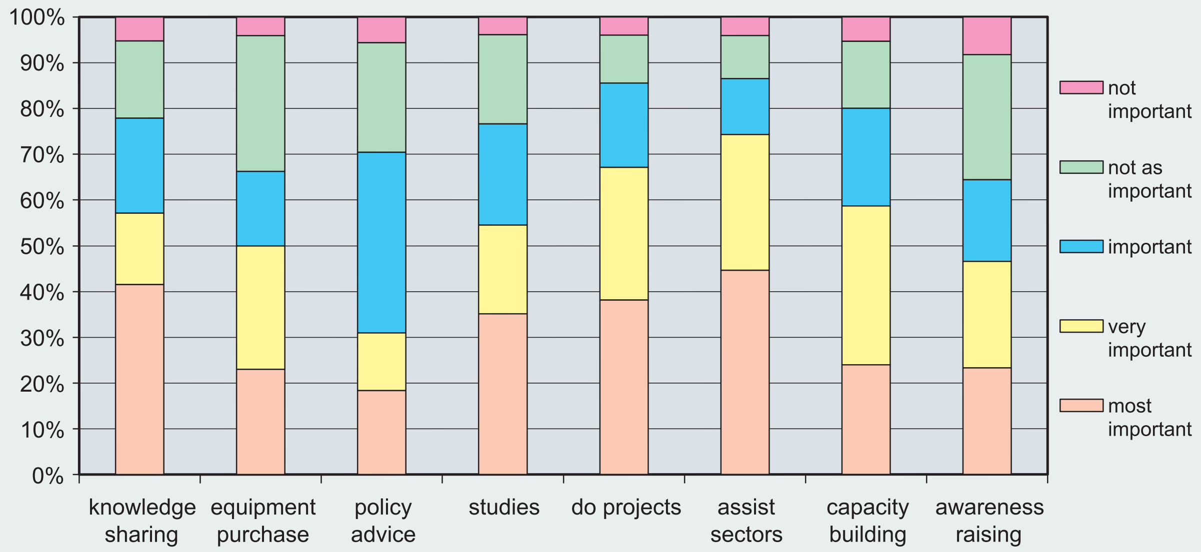
Box 4: Stakeholder Feedback on the Role of the World Bank in UAQM

A questionnaire survey was conducted over the internet (using the Clean Air Initiative – Asia website and listserver) in parallel with this study as a means of soliciting stakeholder perceptions on urban air quality as well as seeking stakeholder views on the role of agencies such as the World Bank in urban air quality management (UAQM). A total of 80 people replied, representing a wide cross-section of stakeholders (29 percent government, 24 percent private sector, 15 percent academia, 13 percent NGOs, 6 percent development agencies, and 13 percent others). The responses to questions on the role of agencies such as the World Bank in UAQM complement the findings presented in this report. A copy of the questionnaire used is given in Annex 7. A separate briefing note on the findings of the survey is available via the internet (www.worldbank.org/sarurbanair).

An overwhelming 97.5 percent of the respondents thought that agencies such as the World Bank had a role to play in addressing urban air quality concerns in India. In response to whom agencies like the World Bank should support, 49 percent cited the city/local administration, 27 percent cited the state government, 18 percent cited the central government, and the remaining 6 percent were not sure about the answer. In response to the question on where people saw the role of agencies such as the World Bank in urban air quality management, the answer is shown in the figure below (all responses ranked 1 and 2 were treated as most important; 3 and 4 were treated as very important; 5 and 6 were treated as important; 7 and 8 were treated as not as important; 9 and 10 were treated as not important).

It is interesting to note that of those who responded to each category of the questions, more than 40 percent respondents saw knowledge sharing and assistance through other sectors (such as transport, energy, urban) as the "most important," although doing stand-alone projects was not far behind at 38 percent; a little over 30 percent saw capacity building as a "very important" area of engagement; and almost 40 percent saw policy advice as an "important" area of engagement. At an aggregate level, about 85 percent respondents saw an important (or above) role for agencies like the World Bank in doing stand-alone projects and assisting through other sectors. In contrast, the respondents did not see much of a role in procuring air quality monitoring equipment and awareness-raising.

Response to question of where people saw the role of the World Bank in UAQM



Cleaning the Air in Delhi: Chronicle of Events, 1985 –2002

- A Public Interest Writ petition was filed in **1985** by Mr M. C. Mehta in the Supreme Court against the Government of India, requesting the court's intervention to ensure the fundamental right to clean air (under Article 21 of the Constitution of India which guarantees Right to Life).

- During the pendency of this writ, the court passed several orders/directions to deal with the problem of vehicular pollution, but with little effect. For example, in **1989** government said it would raise penalty on owners of polluting vehicles; in **1990** it announced vehicular emission standards for smoke.

- Meanwhile, the second master plan for Delhi was approved in **1990**. It identified hazardous industries for removal from Delhi by 1993.

- One of the court orders led to formation of a committee on vehicular pollution under a retired judge (Mr Justice K. N. Saikia). This committee submitted a set of recommendations to the court in **1991**. It also recommended the introduction of CNG as a vehicular fuel.

- In **1991**, the government appointed a committee under a distinguished academician (Prof. H. B. Mathur) to evolve mass emission standards for motor vehicles for the year 1995 and 2000.

- In **1992**, the Ministry of Environment and Forests brought out a document (Development and Policy Statement for Abatement of Pollution) which acknowledged that SPM in metro cities were higher than prescribed limits especially during summer time. It recommended various actions vis-à-vis the transport sector, including introduction of clean fuels.

- In **1993**, the Government announced the first set of vehicular mass emission standards for India, based on the Mathur Committee's recommendations, which also recommended introduction of unleaded petrol by 1995. However, a different version of the norms were notified after extending the deadline to 1996.

- In **1994**, revised ambient air quality standards (including for RSPM) were notified.

- In **1994**, the Supreme Court passed the order that unleaded petrol be made available to the entire country by December 1996, but in selected metros, including Delhi, by April 1995. It also said that new vehicles should be equipped with Catalytic Converters by April 1995. These orders were implemented on the said dates.

- In **1996**, a World Bank internal document entitled "Cost of Inaction", estimated upto 7,500 deaths in Delhi on account of particulate matter air pollution.

- In **1996**, the Center for Science and Environment (CSE) – a prominent NGO - brought out *Slow Murder: The Deadly Story of Vehicular Pollution in India*, which made the case that Delhi's air pollution was causing severe health impacts, and argued that the fault lay in backward vehicle technology and maintenance, poor fuel quality, and non-existent traffic planning.

- In **1996**, the Supreme Court issued a notice telling the Delhi government to submit an action plan for controlling the city's pollution. In response the Delhi and Central governments developed their first action plans (in 1996 and 1997 respectively).

- In **1996**, Supreme court issued order for compulsory conversion of all petrol driven government vehicles to CNG or to be fitted with catalytic converters. Only a very limited vehicles followed the order.

- In **1997**, there was large-scale closure of hazardous industries in non-conforming areas as per the second Master Plan. About 1160 industries were closed or relocated.

- In **1997**, policy paper on control of automotive exhaust pollution was prepared by the CPCB. It talked about phasing out of 15 year old vehicles.

- In October **1997**, after being prodded by the Supreme Court, the Delhi government announced that 15 year-old and older vehicles commercial vehicles be phased out by March 1998. But with elections round the corner the government withdrew that announcement. In July 1998 the court gave a deadline of October 1998 to implement the policy, which was extended to December 1998 in response to a plea by government.

- In **1997**, the Delhi government announced it would introduce new vehicular emission norms in the capital in 1998 instead of 2000.

- In **1997**, the central government issued its own "White Paper on Pollution in Delhi with an Action Plan".

- In **1998**, a massive program of flyover construction started.

- In **1998**, physical work on the construction of the Delhi Metro (underground) started.

- The Supreme Court used the release of the White Paper as an opportunity to direct the central government to establish a committee to monitor the implementation of the White Paper and to suggest other policies to control pollution. This led to the formation of the Environmental Protection Control Authority (EPCA) in January 1998, with membership of government officials, one semi-government automobile manufacturer, and an NGO (CSE). The EPCA met once a week and followed the implementation of the court order and the action plans. It reported back to the court at regular intervals. The court relied heavily on the EPCA for technical inputs. Based on EPCA's input the following key directions were issued by the court in July **1998** :

  - Augmentation of public transport to 10,000 buses by 1 April 2001

  - Supply of only pre-mix petrol by 31 December 1998 for two-stroke engines of two wheelers and autos

  - Elimination of leaded petrol from National Capital Territory of Delhi by 1 September 1998

  - Replacement of all pre-1990 autos and taxis with new clean vehicles on clean fuels by 31 March 2000

  - No 8-year old buses to ply except on CNG or other clean fuels by 1 April 2000

  - Entire city fleet (Delhi Transport Corporation and private) to be converted to single fuel mode on CNG by 31 March 2000

  - New Inter-State Bus Terminal to be built at entry point in north and south west to avoid pollution due to entry of interstate buses by 31 March 2000

  - Gas Authority to expedite and expand from 9 to 80 CNG supply outlets by 31 March 2000

  - Proper inspection and maintenance facilities to be set up for commercial vehicles with immediate effect

  - Comprehensive inspection and maintenance programme to be started by transport department and private sector by 31 March 2000

  - Government to set up a few more monitoring stations and strengthen the air quality monitoring stations for monitoring critical pollutants by 1 April 2000.

- In **1998**, the EPCA suggested phasing out of diesel private vehicles. This led to the Supreme Court order that private non-commercial vehicles registered after June 1999 should adhere to EURO II norms. That led to the process of introduction of BHARAT II norms for other categories of vehicles and in other cities, which came into force in October 2001.

- In **2000**, the Supreme Court ordered closure / relocation of all, except light service industry, from non-conforming areas after initiation of contempt proceedings.

- In **2000**, extensions were granted to the CNG program since progress was slow, citing problems with supply of CNG and availability of conversion kits for vehicles.

- In September **2001**, the Dr Mashelkar Committee on Auto-Fuel policy was created. It recommended that the government should not mandate type of fuel or technology. It should decide on emission standards. Supreme Court rejected this recommendation and extended the CNG deadline to March 2002.

- In April **2002**, frustrated by delays, the court ordered immediate introduction of 1500 CNG buses and replacement of 800 diesel buses per month beginning May 2002. Fines were imposed for delays.

- By December **2002**, all public transport in Delhi was converted to CNG.

Air Quality Monitoring by NEERI

Table A2.1: Monitoring procedures for all pollutants

Particulars	Pollutants			
	SPM	PM_{10}	SO_2	NO_2
Equipment	High Volume Sampler	Respirable Dust Sampler	Tapping in the Hopper	Tapping in the Hopper
Flow measuring device	Pressure drop across orifice in the hopper	Pressure drop across orifice in the hopper	Rotameters/Orifice Manometers	Rotameters/Orifice Manometers
Flow rate	0.8-1.3 m^3/min	0.8-1.3 m^3/min	1 l/min	1 l/min
Sampling period	8 hourly (round the clock)	8 hourly (round the clock)	4 hourly (round the clock)	4 hourly (round the clock)
Sampling frequency	Twice a week	Twice a week	Twice a week	Twice a week
Analytical method	Gravimetric	Gravimetric	West & Gaeke	Jacobs & Hochheiser
Min. detection limit	1 µg/m³	1 µg/m³	0.04 µg/ml	0.03 µg/ml
Min. reporting value	10 µg/m³	10 µg/m³	6 µg/m³	3 µg/m³
Absorption wavelength (max)	NA	NA	560 nm	550 nm

Methodology

A2.01 The primary pollutants measured are SPM, PM_{10}, SO_2 and NO_2. The sampling frequency for all measurements is 24 hourly, undertaken twice a week. While for SPM and PM_{10} it entails three sampling periods of 8-hour each using two co-located monitors, for SO_2 and NO_2 it entails six sampling periods of 4-hour each. The standard monitoring procedures for each of the pollutants is given in Table A2.1.

City-specific Monitoring Networks[15]

NEERI has three monitoring stations each in the cities taken up in this study. They attempt to cover the three kinds of land use: industrial, commercial and residential.

Delhi

Industrial:

A2.02 This sampling station was located at a height of about 6 m on the top of Employees State Insurance (ESI) dispensary building in Najafgarh industrial area till 2001. From three sides it was surrounded by industries including an insecticide factory, chemical works, cotton mill, rubber factory, factories manufacturing paints and chemicals, and foundries. Factory workers occupied residential areas to its southwest. A new multi-storey shopping complex and a cinema hall came up within 1 km radius of this site. Some major industries in the area, namely Delhi Cloth Mills and Swatantra Bharat Textile Mills, were closed down by order of the Supreme Court during 1996-97, following which other industries in the vicinity were also closed down/relocated by 2001. This station was moved to nearby Mayapuri in 2003.

Commercial:

A2.03 The sampling station is located at a height of about 6 m on the terrace of the Ayurvedic Dispensary building in the Town Hall. This site is surrounded by the main commercial area of Chandni Chowk. The Old Delhi Railway Station is located at a distance of about 0.4 km to its north. No appreciable change has been noticed in the vicinity except for an increase in traffic.

Residential:

A2.04 In November 1994, this was moved to the

Delhi

Location	Najafgarh (Industrial)	Townhall (Commercial)	Sarojini Nagar (Residential)
Height from ground level	6 m	6 m	10 m
Major sources of pollution in the vicinity	Industries like an insecticide factory, cloth mill, chemical works, cotton mill, rubber factory, paint factories, and chemicals, and foundries which were closed down in 1996-97.	Vehicular traffic (all around sampling station).	No specific source as this is purely a residential area.

terrace of the Navayug School building, Sarojini Nagar from the post office in Netaji Nagar. This move had become necessary due to the construction of a multi-storey building nearby. The new location is surrounded by residential quarters provided by government for its staff. There is a bus depot about 200 m away and a railway station for local trains about half a kilometer away. An electrified railway track for goods trains is about 500 m away from this site.

Kolkata

Industrial:

A2.05 This site is located at Cossipore police station, on Barrakpore Trunk road. There are schools, a railway station, a thermal power plant, and industries manufacturing hosiery, electric goods, and guns and ammunition in the vicinity. Also, there are godowns and police barracks nearby.

Commercial:

A2.06 This site is located at Lalbazar police headquarters, Lalbazar Street, formerly known as Dalhousie Square. There are commercial and residential buildings, the Dalhousie Square bus terminus, small-scale textile printing, bakery, hotels, and shopping complexes around.

Residential:

A2.07 From 1992 to 1996 this site was located at Mandville Garden. It was then moved to Salt Lake where it is located at the NEERI zonal laboratory, Kasba, since 1998.

Mumbai

Industrial:

A2.08 Major changes have taken place around the Parel sampling station, which is an industrial site. There were originally 13 textile mills in the Parel area in 1978 which were gradually closed down over the years and at present only 6 are working and that too, partly. There are 823 small-scale industries in the area, out of which 18 have smoke stacks. Two flyovers have been constructed near this site during the last decade.

Commercial:

A2.09 In the Kalbadevi area there has been no development activity during the past ten years with the exception of the construction of three multi-storeyed buildings.

Residential:

A2.10 Till 2000, the residential sampling station was located in Bandra and then moved to Worli in 2001. At Bandra, the height of the sampling station was 5 m and there was some light vehicular activity around due to nearby Bandra reclamation, Vinoba Bhawan, and Swami Vivekanand roads. Construction of a Marine outfall, Bandra sewage treatment and disposal facility, and the sewage pumping station continued till 1999.

A2.11 The height of the Worli station is 5 m. The site is about 250 m from the coast and 100 m from a wastewater treatment. Construction of one flyover and on-going construction of another are

Kolkata

Location	Cossipore (Industrial)	Lalbazar Street (Commercial)	Kasba (Residential)
Height from ground level	5 m	14 m	3 m
Major sources of pollution in the vicinity	School, railway station, hosiery factory building to the east. Cossipore gun & shell factory, a thermal power station, Barrackpore Trunk road, godowns, and Hoogly river to the west. Tala canal, Kar hospital, railway yard for goods, offices and buildings to south. Khaitan fan factory, Rabindra Bharati University, Indian Statistical Institute, and police barracks to the north.	Commercial and residential buildings, small cloth printing factory, and small bakery to the east. Commercial buildings and offices, Hoogly river, traffic junction at Dalhousie square to the west. Bus terminus, offices and commercial buildings, metro station to south. Office building, hotels, and shops to the north.	By-pass road, engineering college, electric industries, bakery, and residential buildings to the east. Canal, slums, and residential building to the west. Residential plots and building to the south. Kolkata State Transport Bus Depot, and residential building to the north.

Mumbai

Location	Parel (Industrial)	Kalbadevi (Commercial)	Bandra (Residential)
Height from ground level	15 m	20 m	5 m
Major sources of pollution in the vicinity	Textile mills (all around sampling station). Ambedkar Road (major arterial road adjacent to sampling station).	Mumbai harbour (east of sampling station). Road traffic (all around sampling station as this is a major commercial area).	Construction site of marine outfalls (temporary till year end of 1999). At Worli from 2001, construction of a flyover was in progress. No other source as this is purely a residential area.

two major development activities. Two parks have been developed in the area during the last ten years.

Hyderabad

Industrial:

A2.12 This site is located at the Indian Institute of Chemical Technology pilot plant in the Nacharam industrial area. There are non air polluting small-scale industries such as electronics, engineering, and leather goods.

Commercial:

A2.13 This site is located on the terrace of the

Hyderabad

Location	Nacharam (Industrial)	Abids (Commercial)	Tarnaka (Residential)
Height from ground level	10 m	10 m	8 m
Major sources of pollution in the vicinity	Small-scale industries such as electronics, engineering and leather goods.	Multi-storeyed buildings, shopping complexes, increase in 2- and 3-wheelers, light vehicles and buses.	Multi-storeyed buildings, vehicular traffic on the nearby national highway.

general post office building in Abids. A number of multi-storeyed buildings have come up with increased commercial activities. The roads around this site were also repaired. There has been a considerable increase in public and private vehicular traffic constituting two- and three-wheelers, light vehicles, and buses.

Residential:

A2.14 This site is located on the terrace of the NEERI zonal laboratory building in the Indian Institute of Chemical Technology campus at Tarnaka. A number of multi-storeyed buildings and four-storey residential flats have come up around this site. There has been a substantial increase in vehicular traffic around this site.

Chennai

Industrial:

A2.15 This sampling site is located at the municipal office in Thiruvottiyur. It is at a distance of 1.7 km from the centre of the city. Air sampling is carried out on the open terrace of the municipal council's building at a height of 8-10 meters. The Manali industrial area is at a distance of 1.5-2 km on the western side of the sampling site. The Bay of Bengal is to the east at a distance of about 750 km. Ennore Thermal Power House is 2.5-3 km to the north of the sampling site. The Manali industrial area consists of large chemical and petrochemical industries like Madras Refineries Ltd., Madras Fertilizers Ltd, Manali Petrochemicals,

Chennai

Location	Thiruvottiyur (Industrial)	EVR Periyar Salai (Commercial)	Santhome (Residential)
Height from ground level	10 m	15 m	15 m
Major sources of pollution in the vicinity	Manali industrial area at a distance of 1.5 -2 km on the western side of the sampling site consisting of large chemical and petro-chemical industries. Ennore thermal power house to the north of the sampling site at 2.5-3 km distance. During 1988-98, repairs and re-laying of storm water drain and roads, opening new container godowns along the beach road had taken place. This increased movement of heavy vehicles like trucks.	Sampling site close to Chennai central station and Chennai Port Trust. During 1988-99, construction of Metropolitan Rapid Transport System (MRTS) took place. Construction of multi-storeyed commercial and residential buildings.	During 1992-98, heavy construction activity took place in the area. Bay of Bengal is at a distance of 750 meters to the east and residential localities are spread in the remaining three sides.

Madras Petrochemicals, Kothari Industrial chemical, and Chlor-alkali plant. During 1988-92, the expansion of Madras Refineries included SO_2 control. During 1993-98, three to four chemical and petrochemical industries came up in the Manali Industrial area. During 1988-98, repairs and re-laying of storm water drain and roads, and the opening of new container godowns along the beach road had taken place. This increased movement of heavy vehicles and trucks.

Commercial:

A2.16 This site is situated at Madras Medical College, right in the heart of the city. Air sampling is carried out on the open terrace of the pharmacology building of the Madras Medical College at a height of 15 meters. During 1988-99, the construction of Metropolitan Rapid Transport System (MRTS) on an elevated bridge structure took place at a distance of 7.0 km as well as construction of multi-storeyed commercial and residential buildings. During 1992-98, the main vegetable market in Kothwal Chavadi near Parry's Corner was moved to a new place in Koyambedu in the outskirts of the city. This reduced the number of trucks, lorries, three-wheelers and vans plying in the Parry's Corner area that is within 1 km of the sampling site.

Residential:

A2.17 This site is located at a height of about 15 meters, on the open terrace of Zoological Survey of India, Santhome High Road. This road connects south Chennai to the north along the beach road. Regular road strengthening and repairs are observed, as it is the road for VIPs and Governor to reach the Secretariat. During 1988-92, a number of multi-storeyed buildings were constructed both for residential and commercial purposes. Nearby marshy land was reclaimed by filling with municipal solid waste. During 1992-98, there was heavy construction activity in this residential area. The Bay of Bengal is 750 meters to its east and residential localities are spread in the remaining three sides.

Data Quality Issues[16]

Data Recording

A3.01 Ambient air quality monitoring is carried out manually using high volume samplers and respirable dust sampler with gaseous attachments. The site operators manually record the flow rates every hour and the time period of operation at the site, and note down such weather conditions as dust storm and rainfall in a specified format which in turn is passed on to the laboratory after the sampling. The samples are analyzed in the laboratory and the 4-hourly and 8-hourly concentrations are recorded in the CPCB specified format and sent to Pollution Assessment Monitoring and Survey (PAMS) division of CPCB. All the data recording and reporting are manual up to this point, hence adding a human interface which increases the likelihood of error in data recording.

A3.02 The data received by CPCB are checked and outliers are removed, and data are entered into a computer database. In case of any questions, clarifications are sought from the monitoring agencies. The values obtained through monitoring for less than 16 hours a day are not considered for analysis. CPCB has a software for data storage and management which compiles daily average, monthly average, annual average, standard deviation, percentage violation of National Ambient Air Quality Standards (24-hour average), number of observations, and categorizes air quality in terms of low, moderate, high, and critical levels.

A3.03 This method of data recording has been in existence for a number of years and there have not been major changes other than the data collection format becoming a little more detailed and introduction of the software. For example, since 2001, CPCB has started asking for qualitative information on weather and other local conditions (cloudy/rainy/dusty/smoky). Weather data are obtained from the Indian Meteorological Department in most cases.

Instrument Calibration

A3.04 The frequency of calibration varies between agencies. CPCB carries out calibration once every year or two years for the ambient air quality stations in Delhi. (However, for the monitoring station at the Income Tax Office traffic intersection, calibration is carried out every 6 months.) CPCB recommends to the SPCBs to undertake calibration at least once a year. The frequency of calibration reported by NEERI is once every 2 to 3 months. Calibration is conducted using top loading calibrator and the recording of calibration data is not uniform across the different agencies.

A3.05 CPCB engaged a consultant in 1996 to carry out service, repair, and calibration of all high volume samplers throughout the country. A similar exercise is being undertaken at present.

Data Validation

A3.06 The data are checked at CPCB where the 4-hourly and 8-hourly values are scrutinized for outliers, parametric correlation, and other items, taking into account data from previous years. However, there are no reference samplers used, and there is no systematic cross-calibration or comparison of CPCB/SPCB and NEERI samplers using co-located monitors in the same city.

Standard Operating Manual

A3.07 Recently CPCB has compiled a report titled *Guidelines for Ambient Air Quality Monitoring* (CPCB 2003c) which includes monitoring methods, guidelines for locating stations, and quality control and quality assurance in air quality monitoring. At the time of sanctioning new stations in the 1990s, CPCB provided various monitoring agencies with terms, conditions, and guidelines for monitoring and measurement methods. CPCB also holds periodic workshops on monitoring methods for the SPCBs.

Handling of Filter Papers

A3.08 The new guidelines (CPCB 2003c) provide detailed instructions on handling filter papers. However, these guidelines were not in use during the period that is the focus of this study; instead measurement methods were provided to the monitoring agencies, which included filter handling procedures.

A3.09 Filter papers are normally desiccated for 24 hours before being used. After being used they are desiccated for another 24-48 hours depending on the next shift at that monitoring station. All CPCB stations have precision balances while NEERI and SPCBs normally have a single precision balance located at a central laboratory to which samples are transported (after being folded and kept in envelopes). All the precision balances can record values up to 5 decimal places. The monitoring stations do not have temperature or humidity controls. At monitoring stations, temperature of absorbing solutions for gaseous pollutants is maintained by using ice, and in the laboratory desiccators are used for moisture control of PM samples.

A3.10 One serious omission is the absence of anti-static measures. Static charge on filters and other surfaces is the largest source of particulate measurement variability and microbalance instability, with its adverse impact increasing with decreasing particulate deposition on a given filter. Not adopting anti-static measures is, therefore, likely to have greater adverse effects on PM data quality in lower-pollution cities than in Delhi or Kolkata, and also in summer much more than in winter. Anti-static measures include:

- Dissipation of the static charge from the sample filter by passing the filter over an alpha-emitter source (such as Po-210 "microspot") prior to weighing.

- Grounding of the operator of the microbalance to prevent transfer of the electrical charge to the PM sample filter (by using, for example, a grounding wrist strap similar to that used by microelectronics technicians)

Change in Equipment for RSPM Monitoring

A3.11 While the CPCB has been using the same make of equipment since they started RSPM monitoring in the late 1990s, NEERI replaced its equipment in the mid- to late-1990s in all cities (before that, due to non-availability of standardized indigenous equipment for RSPM monitoring in the country, NEERI was using equipment developed in-house). In Delhi, the instruments were replaced between 1995 and 1997, while in Mumbai they were replaced in 1998 and 1999. NEERI reports that the new samplers were compared (and cross-calibrated) with the old samplers before being deployed in the field.

Location of Monitoring Stations and Days of Monitoring

A3.12 The monitoring stations are located in areas with varying land use. While NEERI has three monitoring stations per city—one each for industrial, commercial, and residential areas—CPCB/SPCBs have many more monitoring stations also meant to cover different land-use areas. However, in the case of Chennai, all SPCB monitors are in industrial areas.

A3.13 In cities where both CPCB/SPCB and NEERI have monitoring stations, their locations are different, and they do not necessarily conduct monitoring on the same days. In addition, the monitoring stations are operated by different sets of operators contracted by each agency.

A3.14 While currently all monitoring agencies try to adhere to a protocol of gathering 8 samples per month for both SPM and RSPM (on the same days), in the 1990s NEERI used to run SPM samplers for 4 days and RSPM samplers for a different set of 4 days. As a result, in addition to having only 4 samples for each of these pollutants, the two PM readings at that time could also not be directly compared. Furthermore, on a handful of days when RSPM and SPM were measured at the same time, it was not unusual to find that RSPM concentrations were higher than SPM concentrations, clearly indicating serious problems.

A3.15 With respect to the number of days data were captured, there are many months during the 10-year study period when no data are available at a given monitoring stations. Important features of missing data are highlighted below (full details are given in Table A3.1).

- In Delhi, data from June to August in 1993 are missing entirely at the three monitoring stations. Because RSPM and SPM concentrations are low during these months, these missing data would artificially elevate the annual average RSPM level for that year. In 1994, the residential area had data from only November and December. Since RSPM concentrations are high during these months, the "annual average" would once again be artificially high. In August 1996, a "low RSPM" month, all the three sites are missing data, elevating the annual average. In November 2000, two monitoring stations are missing data, lowering the annual average since RSPM tends to be high in November. During the second half of 2001 and all of 2002, no data were collected at the industrial site.

- In Kolkata, a large amount of data is missing between 1993 and 1997; at the residential site there are no data for the entire year in 1997. The first year in which some data are available for every month of the year in Kolkata was 1999.

- In Mumbai, the residential area had no data in 1993 except January, and data were also missing in six months out of twelve in 1994.

- In Hyderabad, the three monitoring stations missed a few months of data collection in 1995–1997.

- In Chennai, every monitoring station had some RSPM data in every month during the relevant period but SPM data were not collected at the industrial site during the first seven months of 2003.

A3.16 Missing data affect the results in two ways. Few data points make the data less representative under all circumstances. If RSPM concentrations vary markedly between land-use areas, which monitoring stations are missing data matters in the calculation of city-wide averages. In addition, in cities where ambient RSPM concentrations exhibit strong seasonal dependence, the months in which data are missing can raise or lower annual averages artificially.

Overall Uncertainty in Data

A3.17 There is no systematic estimation of uncertainty or error in the data. However, based on knowledge of various sources of error, the monitoring agencies report an estimated error of about ±20 percent in readings today. Given that there have been gradual improvements in data collection over the years, errors in the past were most probably greater.

CPCB Initiatives to Ensure Data Quality

A3.18 Recognizing the need to improve the quality of data, CPCB has initiated several measures in recent years. These are:

- Monitoring stations are inspected by Zonal Offices of CPCB. Deficiencies found are communicated to the monitoring agencies.

- Training programmes on ambient air quality monitoring are organized for field and laboratory staff of various monitoring agencies.

- Analytical quality control exercises using Ring Test Facility are organized regularly every year at CPCB in which various monitoring agencies including NEERI have participated.

- Review meetings are held at Zonal Offices of CPCB in which problems and deficiencies with the data are discussed with the monitoring agencies.

- Training programmes on software for data management have been held for monitoring agencies. CPCB has also developed an environmental data bank in which all the monitoring agencies are requested to enter data online on the CPCB website and the data will be disseminated to public on a daily basis. Some of the data checks on data validation are incorporated in the software.

Table A3.1: Missing SPM and RSPM data in each city

Year	Months	SPM Data missing for	RSPM data missing for
DELHI			
1993	February	Residential area	
	June – August	All areas	All areas
	December		Residential area
1994	January – October	Residential area	Residential area
	March	Commercial area	Industrial area
	December	Industrial area	
1995	November	Residential area	
1996	August	All areas	All areas
1998	January	Commercial area	
2000	August	Industrial area	
	September	Industrial area	Residential area
	November	Residential	Industrial and Residential areas
2001	May	Industrial area	Industrial area
	July – December	Industrial area	Industrial area
2002	January – December	Industrial area	Industrial area
2003	January – February		
KOLKATA			
1993	April – May	Industrial and Commercial areas	Industrial and Commercial areas
	June – July	All areas	All areas
	August	Industrial and Commercial areas	Industrial and Commercial areas
	September	Industrial area	Residential area
	October		All areas
	November		Industrial and Residential areas
	December		Industrial and Residential area
1994	January	Commercial area	Residential
	February – March	Industrial and Commercial areas	All areas
	April	Industrial and Commercial areas	Industrial and Commercial areas
	May	Commercial area	Commercial area
	July		All areas
1995	March-April		Residential
	October-December		Residential
1996	January-February	All areas	Residential
	June		All areas
	July		Industrial
	August		Industrial and Commercial areas
	September	Commercial area	Commercial and Industrial areas
	October		Commercial area
	November		Commercial and Residential areas
	December	All areas	Industrial and Residential area
1997	January	All areas	All areas
	February		Industrial and Residential areas
	March – December		Residential area
	August	Industrial area	Commercial and Residential areas
1998	January – February		Residential area
	February	All areas	Industrial area
	March	Industrial area	
	July	Industrial area	Commercial area
	September –October	Residential area	
MUMBAI			
1993	February - December	Residential area	Residential area
	December		Commercial area
1994	January	Commercial area	Commercial and Residential
	February – April	Commercial and Residential	Residential area
	August – September	Residential area	Residential area
HYDERABAD			
1995	April – May		Industrial area
1996	March		Residential area
	August – November	Commercial area	Commercial area
1997	January		Industrial area
	February		Commercial area
CHENNAI			
1993	January – July	Industrial area	

Box A3.1: Structural Issues with NAMP and Implications for Data Quality

In 2000, a "needs assessment" for procurement of air quality monitoring equipment for the CPCB was commissioned under the World Bank funded Environmental Management Capacity Building (EMCB) project. The report, delivered in 2002, highlighted three fundamental structural issues:

- There is inadequate financing for maintenance and operation of the instruments
- There is inadequate infrastructure for supporting analytical work
- There is a very serious shortage of skilled technical staff.

The conclusion that followed was not that more equipment ought to be purchased, but that some of the fundamental structural issues need to be addressed as a first priority.

In 2001, the World Bank commissioned The Energy Research Institute (TERI) to undertake a review of past and on-going work on UAQ in India. They reported that "there are no significant efforts towards quality control or harmonizing the data generated by different agencies involved in monitoring network." This is also acknowledged by CPCB which earlier stated that "the involvement of several agencies increase the probability of variations and personal biases reflecting on the data. Therefore the air quality statistics are indicative rather than absolute" (CPCB 2000). Further, the TERI review also reported the results of an unpublished NEERI report prepared for the UNEP/WHO, shown in the table below.

Integrated mean error in pollutant monitoring

City	Overall Error Range (%)		
	SPM	SO_2	NO_2
Bangalore	+8 to –25	+14 to –20	+14 to –19
Kolkata	–3 to –14	+24 to –37	+13 to –28
Chennai	+1 to +4	+22 to –31	+28 to –38
Delhi	–7 to –12	+16 to –27	+11 to –22
Mumbai	+17 to +26	+12 to –45	–3 to –30

Source: Unpublished report by TERI for UNEP/WHO, "Review of GEMS air monitoring network in operation in certain cities of South East Asia."

To quantify the uncertainties shown in the table a parallel sampling was done at the same place with centrally calibrated equipment and following a strict quality control protocol.

Reference: TERI 2001

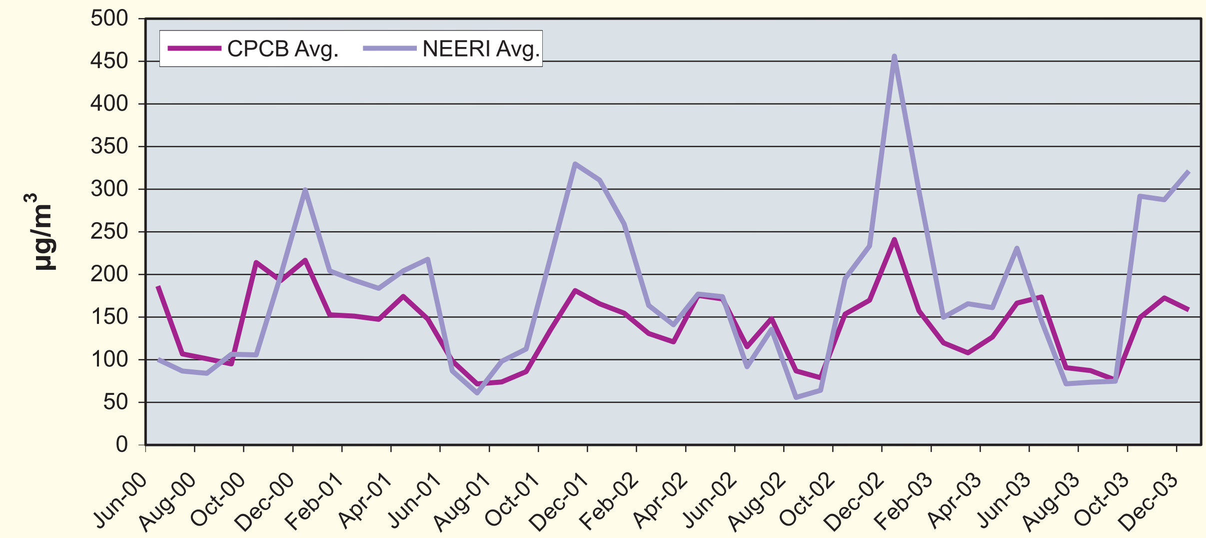
Comparison of NEERI and CPCB/SPCB Data

A3A.01 In the absence of a formal quality assurance/quality control (QA/QC) system, there are only limited checks that can be performed to assess the validity of the data collected in the past. Such checks include comparison of data obtained from different agencies in the same city, checking inherent variability in the data, and inter-comparison of data collected at different sites in the same city.

A3A.02 Comparison of RSPM data from different agencies in the same city is the focus of this annex. For brevity, the data were averaged across all monitoring stations for each agency. The results shown here need to be interpreted with caution since averaging across different monitoring stations can lead to calculation artifacts. Only in two cases is the comparison presented for areas with similar land use but at different locations in the same city.

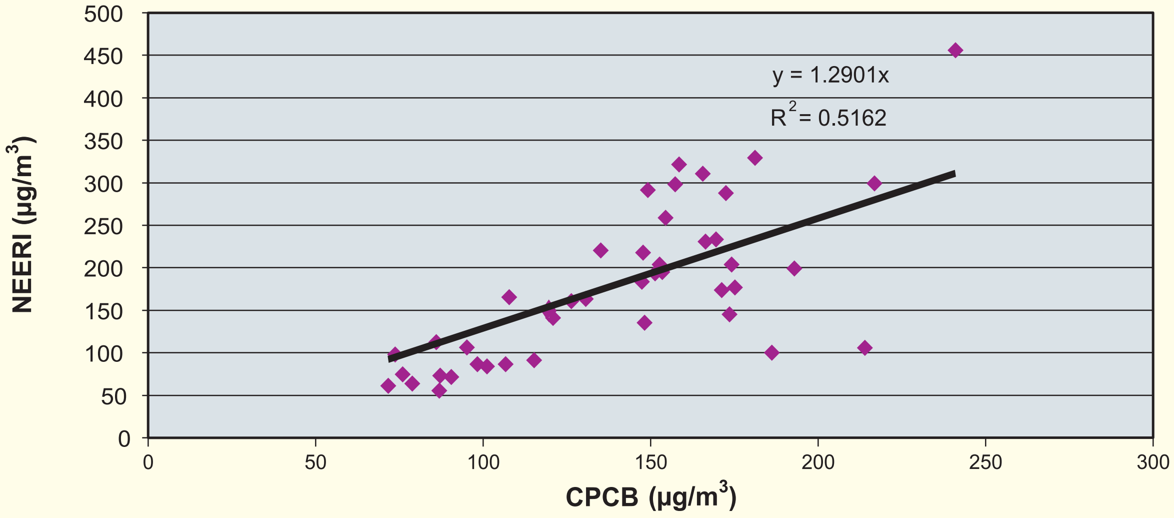
A3A.03 In addition, although not reported in detail, this study also examined frequency distribution plots and correlations between two sites in the same city using the data obtained in the year 2000. Frequency distribution plots of data points indicate if any set of data deviated substantially from the patterns observed elsewhere. At its simplest, theory suggests that if a pollutant is generated at a constant rate and its variance is affected by dispersion and scavenging, the pollutant concentration would be expected to form a normal distribution. If there is a large step change in the source, the distribution would be expected to be bimodal (being the sum of two normal distributions with widely separated medians). In the case of smaller changes, the distribution may be skewed. In the case of large and rapid changes in the pollution levels, the observed distributions may even be log normal. Large seasonal changes in the pollution mean that deviations from the expected normal distribution could be common. Monthly averaged data can be used for this purpose, and may in fact be better than daily average data because some of the short-range fluctuations due to changes in the inventory and dispersion conditions are smoothed out, thereby magnifying equipment performance and calibration problems. This examination found that SO_2 and NO_2 data might be more problematic than RSPM data. More specifically, RSPM tended to give smoother distribution curves

Figure A3A.1: Comparison between CPCB and NEERI RSPM data for 2000-2003 (Delhi)



Note: The values represent monthly averages for three NEERI stations and six CPCB stations. No data available at the NEERI industrial site during the second half of 2001 and all of 2002.

Figure A3A.2: Linear regression between NEERI and CPCB RSPM data, 2000-2003 (Delhi)



than SO_2 and NO_2 plots, some of which tended to resemble randomly generated numbers.

A3A.04 Data collected at different sites in the same city were also plotted to see the level of correlation. At any given time, it would be reasonable to expect pollution levels at different monitoring stations to be correlated, although to varying degree depending on dispersion conditions and proximity to major emission sources. The extent of correlation would be indicated by R-squared for a scatter plot of data from two locations.

Delhi

A3A.05 In Delhi, data from the two agencies track similar trends but with significant differences in magnitude in the winter months, as shown in Figure A3A.1. When compared with the data monitored by CPCB between 2000 and 2003 it was found that the overall monthly averages of three NEERI stations [Najafgarh Road (I), Town Hall (C), Sarojini/Netaji Nagar (R)] and six CPCB stations [Nizamuddin (R), Ashok Vihar (R), Shahzada Bagh (I), Shahdara (I), Janakpuri (R), Siri Fort (R)][17] correspond reasonably well. Regression analysis between the two datasets returned an R-squared values of 0.52 (on forcing the linear regression line through the origin)[18] as shown in Figure A3A.2.

A3A.06 Further, when the data from the two residential monitoring stations located close to each other were analyzed, regression analysis returned an R-squared values of 0.42 as shown in Figure A3A.3, indicating that there is moderate correlation in the dataset between the two sites.

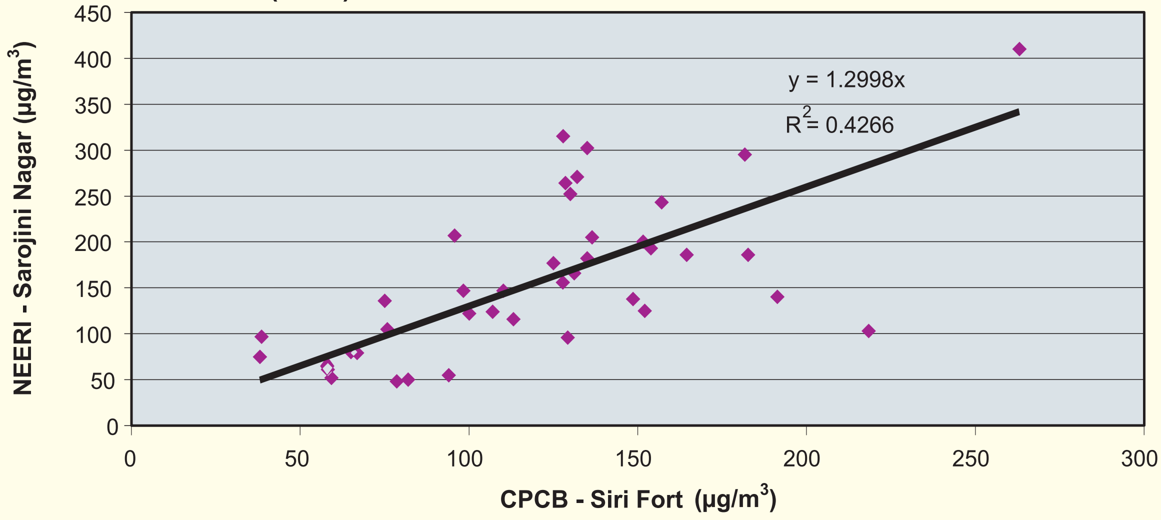
Relationship between SPM and RSPM data

A3A.07 Figure A3A.4 shows the comparison between SPM measurements by NEERI and CPCB. The values shown are overall averages of values recorded at the three NEERI stations and six CPCB stations between 1994 and 2003. It can be observed that while there is much greater scatter in the case of NEERI data (perhaps on account of fewer data points compared to CPCB data), the overall SPM averages followed similar trends of a slight initial decrease followed by a slight increase.

A3A.08 The CPCB has been conducting ambient monitoring of RSPM at six locations in Delhi since June 2000, along with SPM, using co-located monitors. Figure A3A.5 shows the overall averages of SPM and RSPM based on data from the six monitoring locations, operated at the same time. Both SPM and RSPM show a slight decrease in mid-2001, after which SPM shows a slight increase in 2002 while RSPM remains stable.

A3A.09 Regression analysis between RSPM and SPM returned an R-squared values of 0.38 (on forcing the linear regression line through the origin)[19] as shown in Figure A3A.6. The area-specific values ranged from a minimum of – 0.76 (in one of the industrial areas) to a maximum of 0.50 (in one of the residential areas). These variations could indicate that sources of RSPM and SPM differ significantly in different parts of a city. For example, impact of the

Figure A3A.3: Linear regression between RSPM data from NEERI and CPCB residential areas, 2000-2003 (Delhi)



large number of flyovers being constructed since 1998 (see Annex 5A Box A5A.3) on ambient concentrations at each monitoring station could vary markedly. Some of the variation could also be a result of calculation artifacts: regression should be carried out on RSPM and SPM concentrations measured at the same site at the same time, but monthly averages were used, introducing a source of error. Lastly, experimental artifacts cannot be ruled out.

A3A.10 Figure A3A.7 shows that the ratio of RSPM to SPM declined from June 2000, when it used to be 0.6 to about 0.4 at the end of December 2003.

While the ratio decreased substantially in 2002, it again increased in 2003.

Kolkata

A3A.11 In Kolkata, the NEERI data correspond very well to SPCB data as shown in Figure A3A.8. Regression analysis between the two datasets returned an R-squared value of 0.79 as shown in Figure A3A.9.

A3A.12 Figure 3.10 shows that the ratio of RSPM to SPM stabilized from 2002 onwards at about 0.5 after having fluctuated widely earlier.

Figure A3A.4: Comparison between CPCB and NEERI SPM data, 1994-2003 (Delhi)

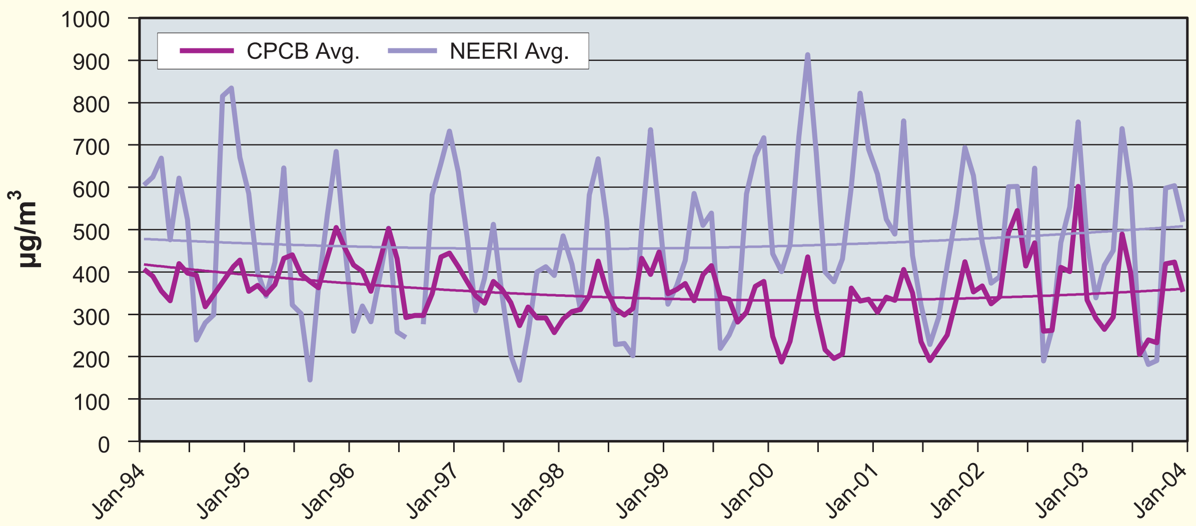
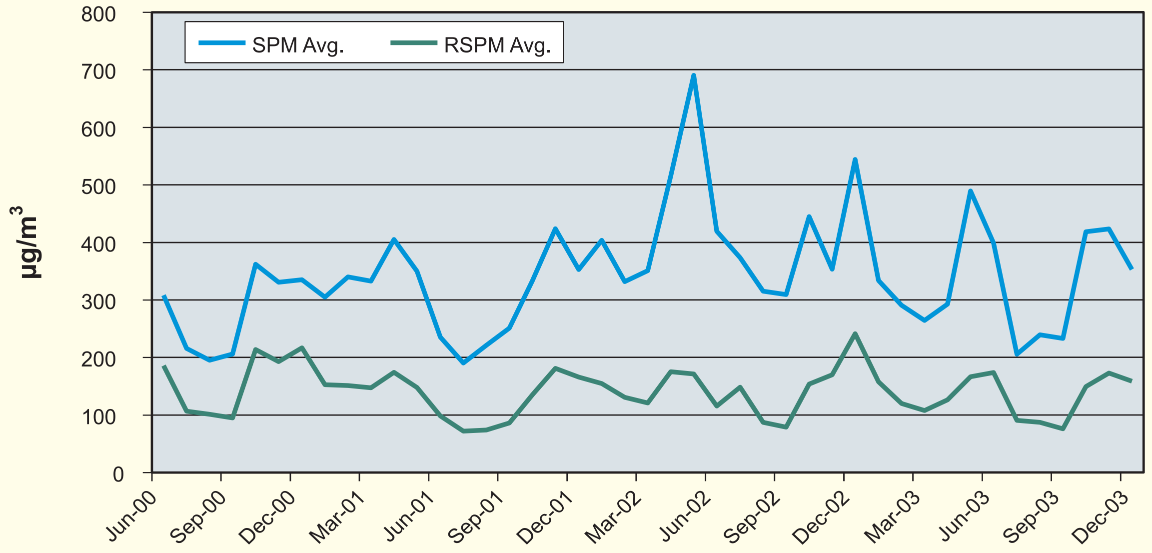


Figure A3A.5: **SPM and RSPM monitored by CPCB 2000-2003 (Delhi)**



Note: The values represent monthly averages for six CPCB stations.

Figure A3A.6: **Linear regression between RSPM and SPM monitored by CPCB, 2000-2003 (Delhi)**

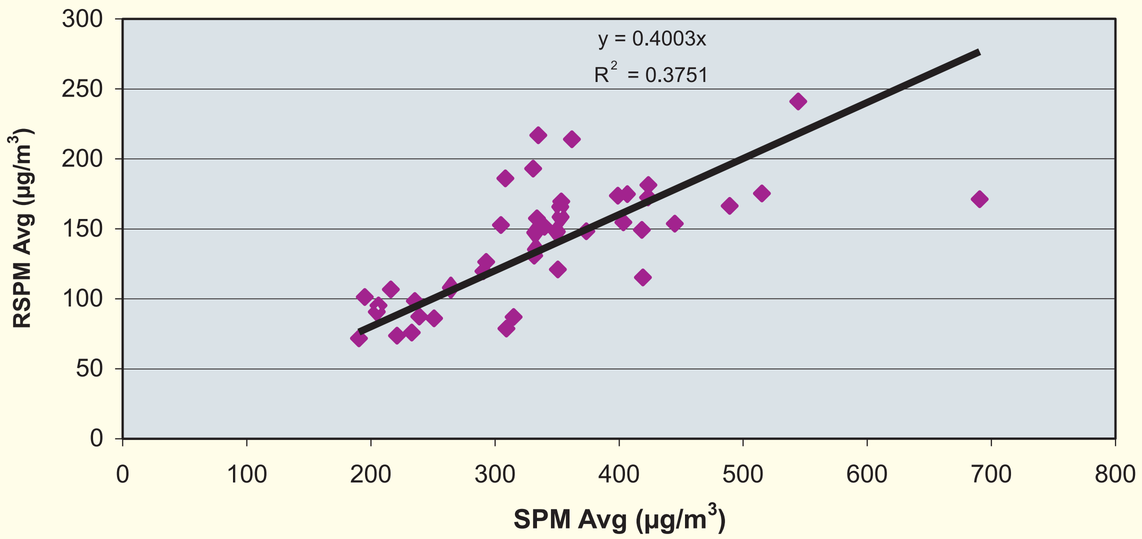


Figure A3A.7: **Ratio of RSPM to SPM monitored by CPCB, 2000-2003 (Delhi)**

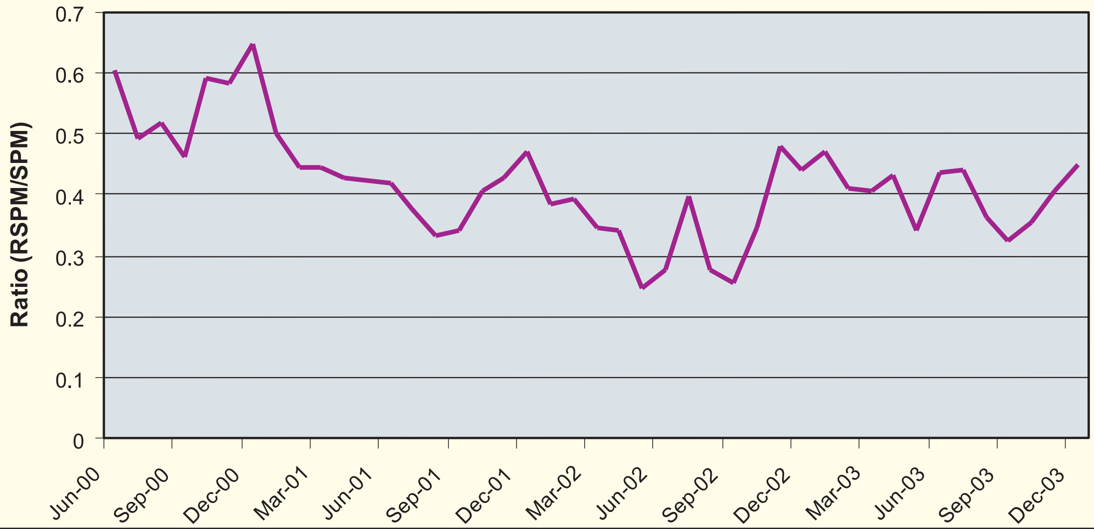


Figure A3A.8: Comparison between NEERI and SPCB RSPM data for 1999-2002 (Kolkata)

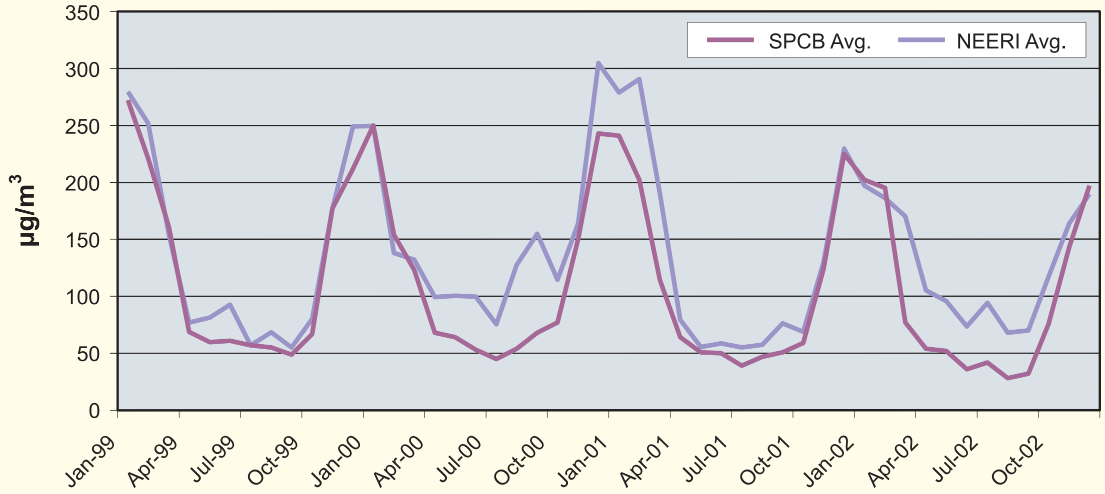


Figure A3A.9: Linear regression between NEERI and SPCB RSPM data, 1999-2002 (Kolkata)

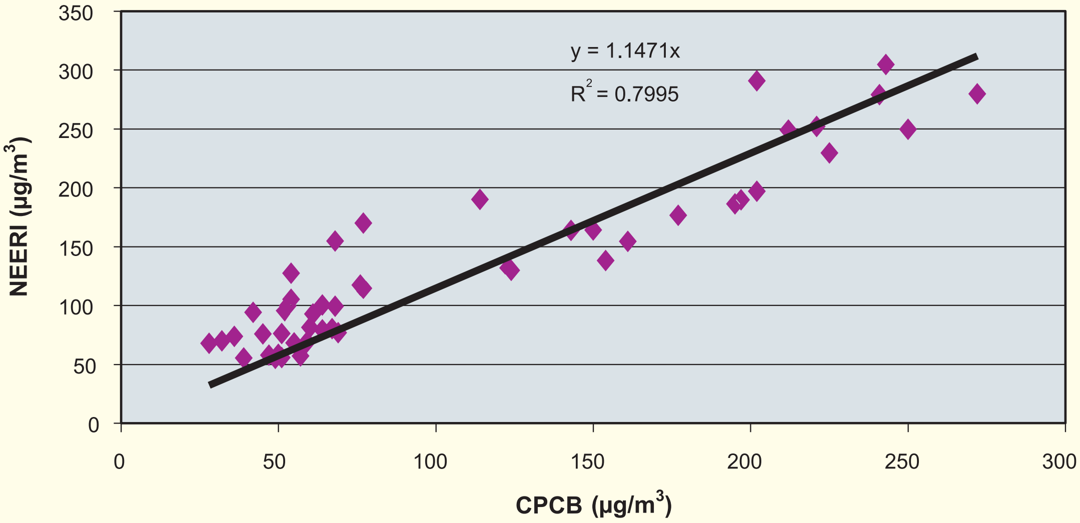
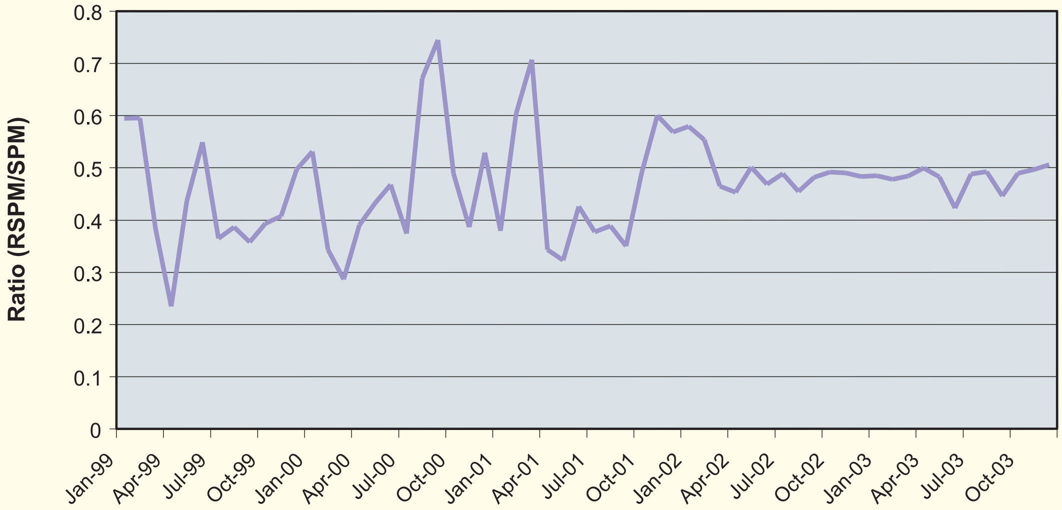


Figure A3A.10: Ratio of RSPM to SPM monitored by NEERI, 1999-2003 (Kolkata)



Hyderabad

A3A.13 In Hyderabad, SPCB data consistently showed higher values compared to NEERI data, as shown in Figure A3A.11. However, the overall trends in monthly averages from the NEERI and SPCB monitoring locations tracked each other reasonably well till 2002 after which there seems to be a greater divergence in values. Regression analysis between the two datasets returned an R-squared value of 0.19 as shown in Figure A3A.12.

A3A.14 Frequency distribution plots of data obtained by NEERI at its three sites showed that the data from the residential and commercial sites, although close in location, differed significantly, with the data obtained at the industrial area monitoring site being markedly skewed to lower concentrations than those at the commercial site. The commercial and residential sites, although much farther apart than commercial and industrial, showed similar frequency distribution patterns. These observations suggest that it may be possible that there are common sources of emissions in the residential and commercial areas (for example, vehicular traffic).

A3A.15 Figure A3A.13 shows that the ratio of

Figure A3A.11: Comparison between NEERI and SPCB RSPM data for 2001-2003 (Hyderabad)

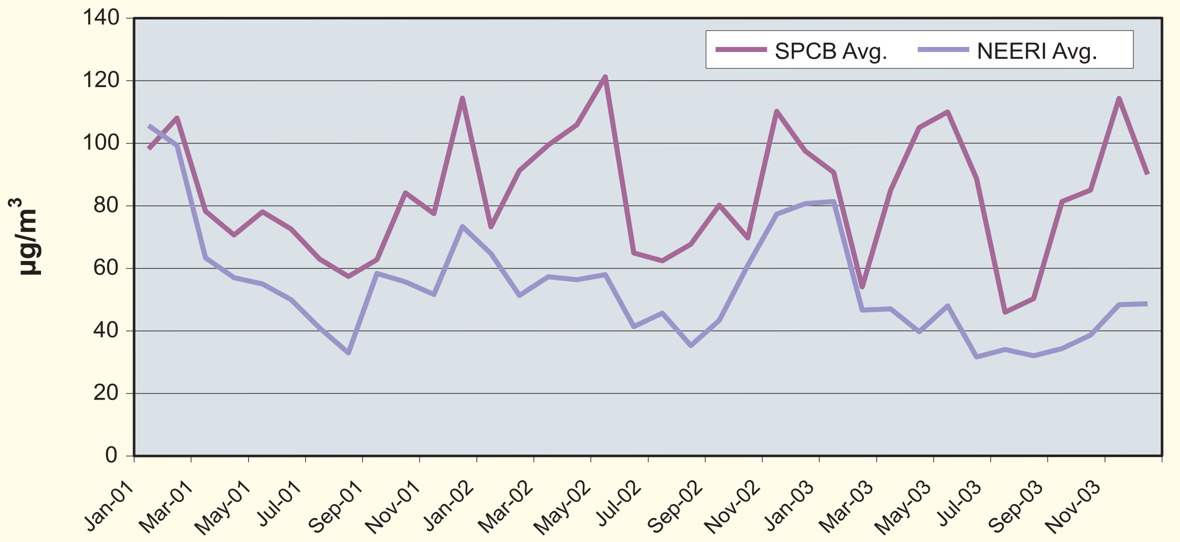


Figure A3A.12: Linear regression between NEERI and SPCB RSPM data, 2001-2003 (Hyderabad)

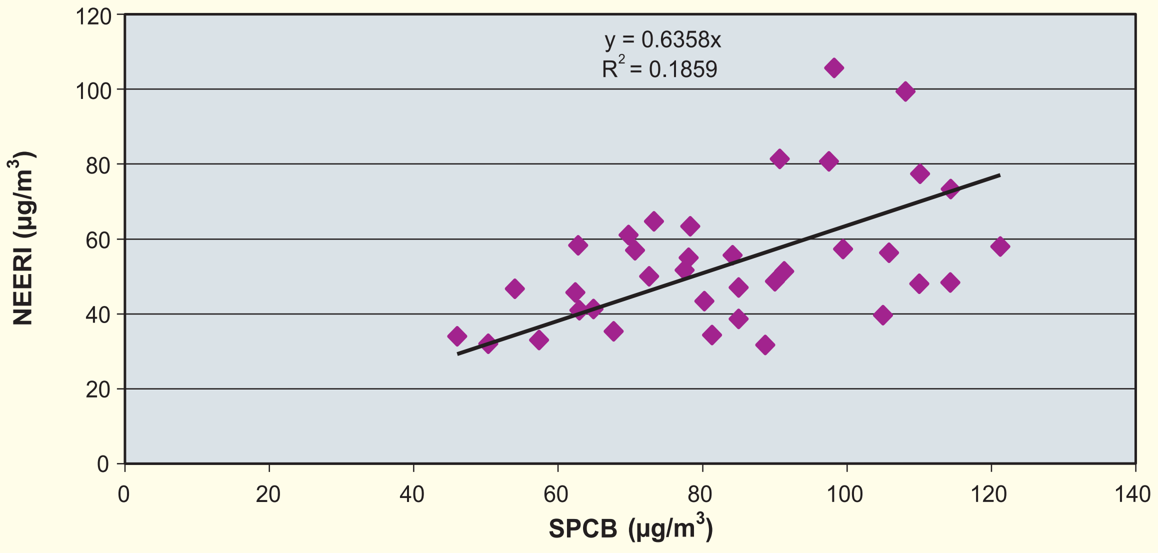


Figure A3A.13 : Ratio of RSPM to SPM monitored by NEERI, 2001-2003 (Hyderabad)

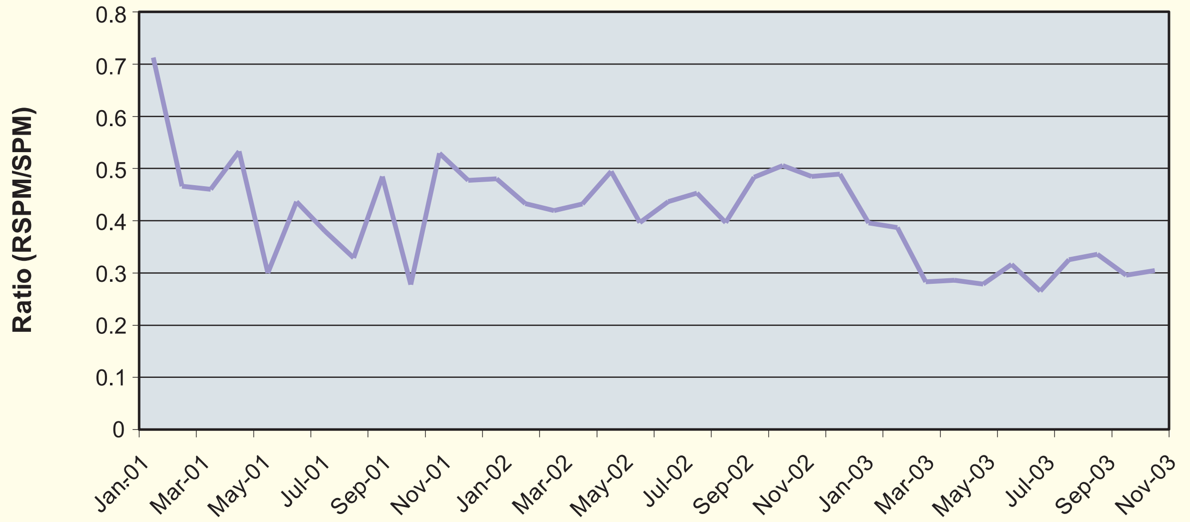


Figure A3A.14: Linear regression between RSPM data from NEERI and SPCB residential areas, 2001-2003 (Hyderabad)

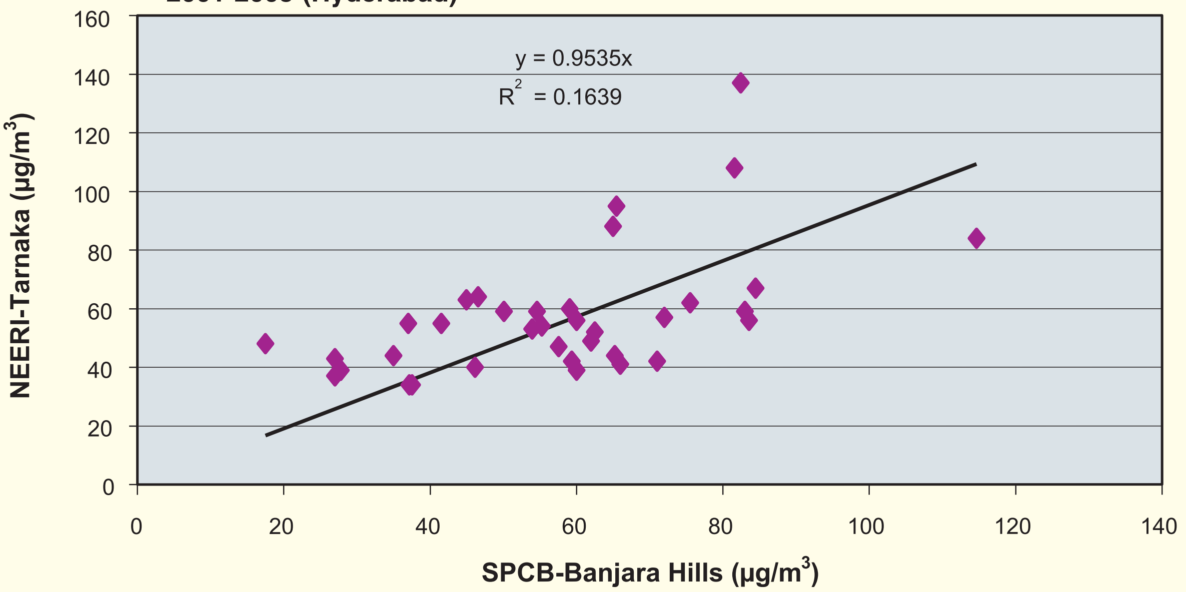


Figure A3A.15: Comparison between NEERI and SPCB RSPM data for 2001-2003 (Chennai)

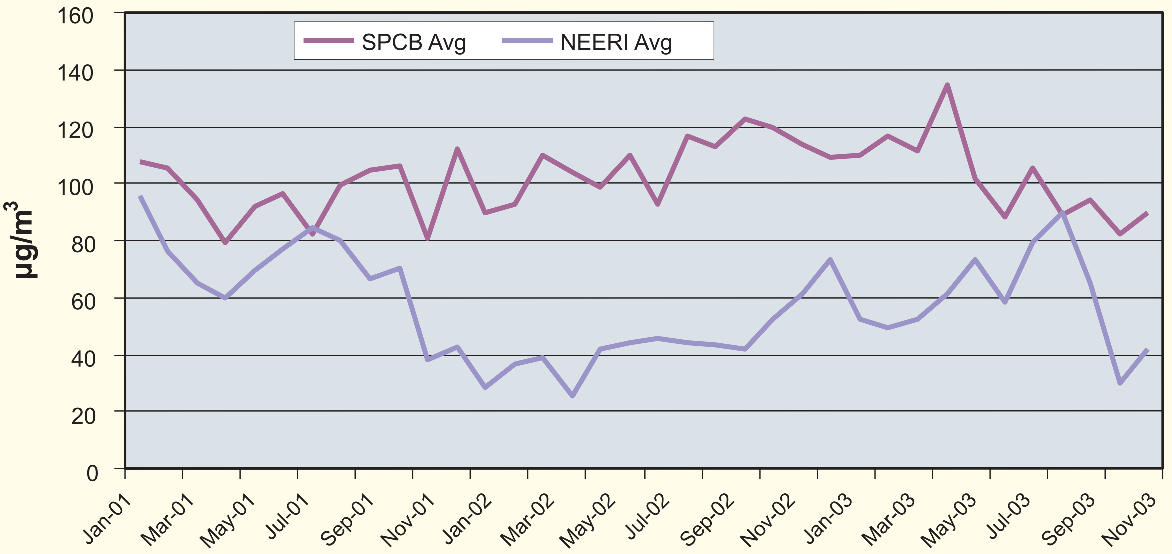


Figure A3A.16: Linear regression between NEERI and SPCB RSPM data, 2001-2003 (Chennai)

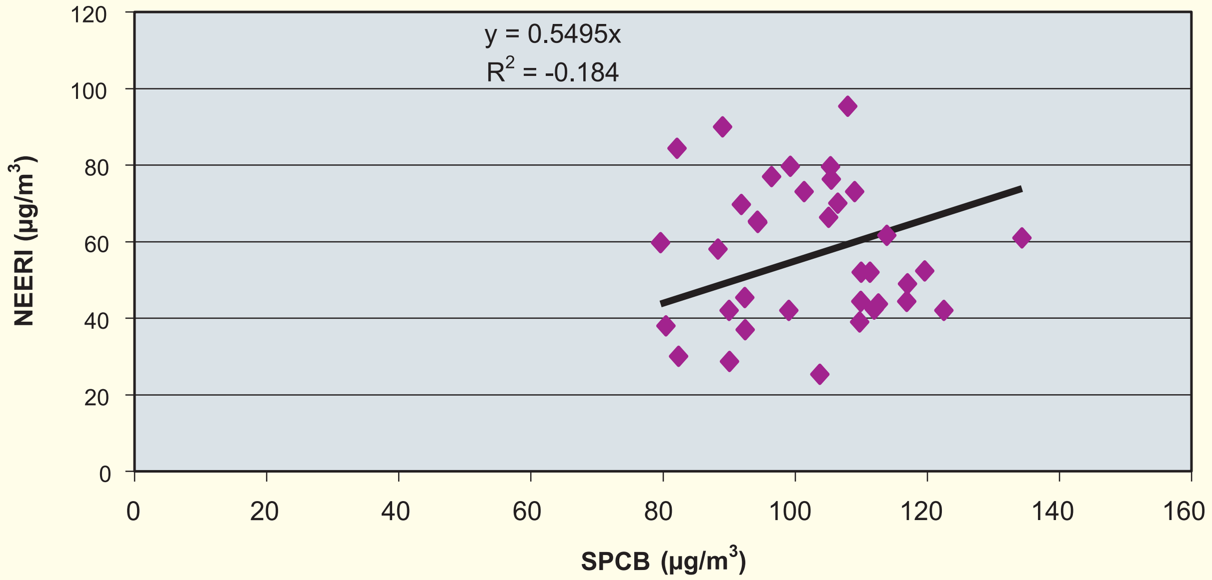
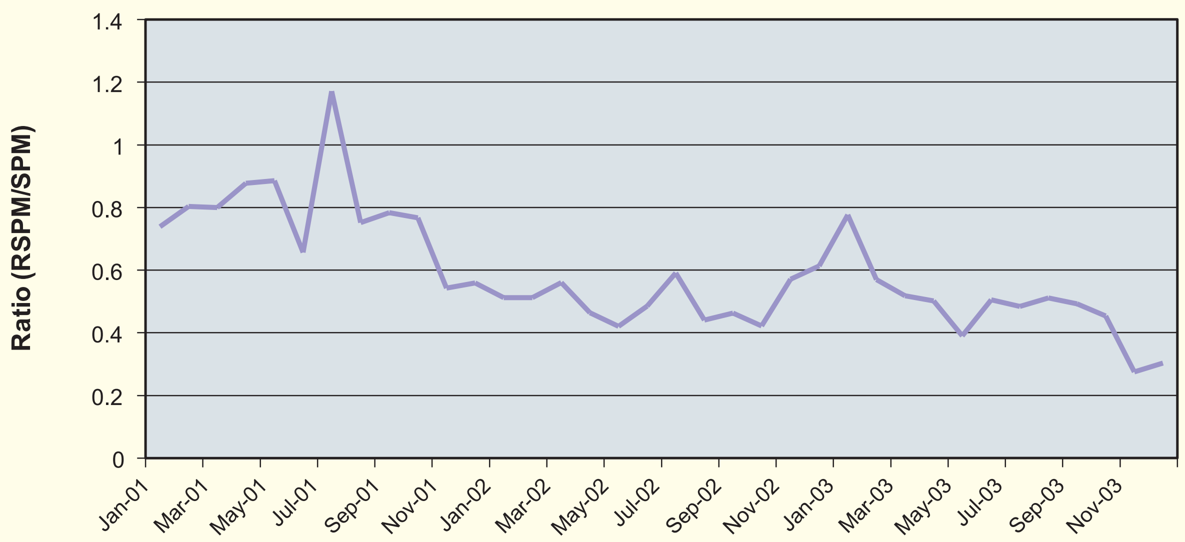


Figure A3A.17 : Ratio of RSPM to SPM monitored by NEERI, 2001-2003 (Chennai)



RSPM to SPM declined from about 0.5 in 2001-2002 to about 0.3 in 2003.

A3A.16 Further, when data from the two residential monitoring stations (located far from each other) were analyzed, regression analysis returned an R-squared values of 0.16 as shown in Figure A3A.14, indicating that there is poor correlation in the dataset between the two sites. Given Hyderabad seems to have good dispersion conditions, this level of discrepancy in the data from two agencies may be on account of experimental problems with RSPM monitoring or differences in monitoring protocols, such as the number of days monitored.

Chennai

A3A.17 The data from Chennai exhibit almost divergent trends at times between SPCB and NEERI as shown in Figure A3A.15. The lack of agreement was evident even when data from two closely located monitoring stations in an industrial area (Thiruvottiyur) were compared. Regression analysis between the two datasets returned an R-squared value of -0.18 as shown in Figure A3A.16. The lack of consistency in data between SPCB and NEERI may be in part due to the number of data points obtained by NEERI being less than half of that obtained by SPCB. This highlights the importance of following

Figure A3A.18: SPM and RSPM monitored by NEERI 2000-2003 (Mumbai)

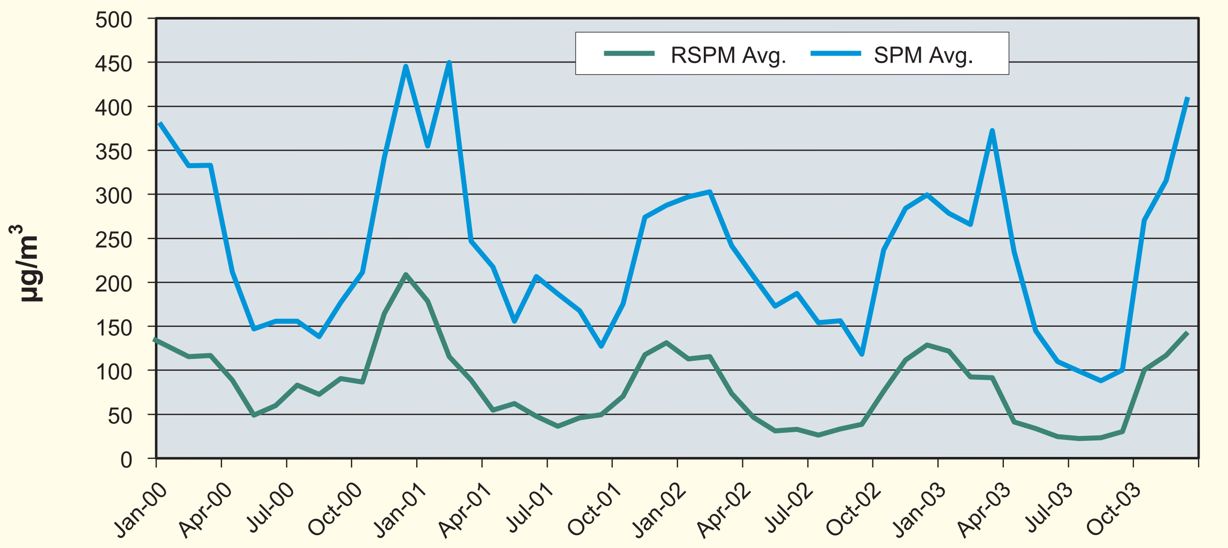
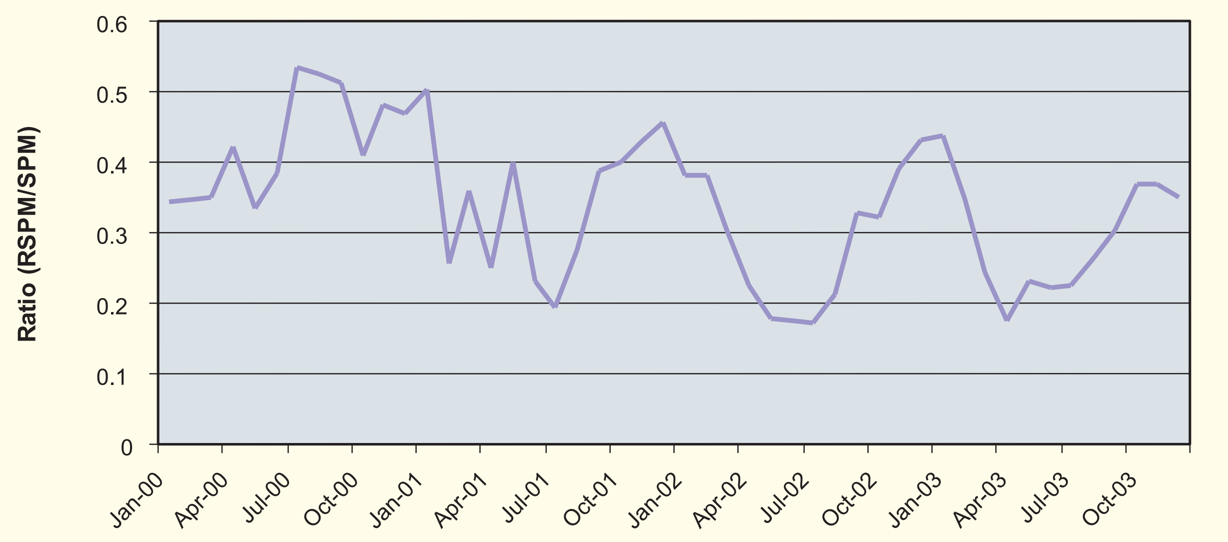


Figure A3A.19: Ratio of RSPM to SPM monitored by NEERI, 2000-2003 (Mumbai)



monitoring protocols so that proper data comparison can be made.

A3A.18 Figure A3A.17 shows that there is a decreasing trend in the ratio of RSPM to SPM over the years. While in 2001 it was close to 0.5, it decreased to 0.3 by the end of 2003.

Mumbai

A3A.19 In Mumbai all monitoring is undertaken by NEERI. Figure A3A.18 shows the overall averages of SPM and RSPM based on data from the three monitoring locations. The seasonal variation in levels of both pollutants is evident from the figure.

A3A.20 Figure A3A.19 shows that unlike other cities there seems to be a seasonal trend in the ratio of RSPM to SPM, with the ratio between 0.4 and 0.5 in winter months and close to 0.2 in the summer and monsoon months. Overall, there appears to be a slightly decreasing trend in the ratio of RSPM to SPM over the years.

General Observations

A3A.21 The higher R-squared values between NEERI and SPCB data in Delhi and Kolkata strengthen the notion about sources being more uniformly dispersed across these two cities on account of mixed land-use, as compared to

Hyderabad where land-use regulation is better implemented and hence mixed-use is less common (unfortunately a similar comparison can be made with Chennai since all SPCB monitoring stations in Chennai are in industrial areas). This is one possible explanation for the observation that, even though the monitoring locations are not the same, there is better correlation between the data from two different agencies in Delhi and Kolkata than Hyderabad.

National Ambient Air Quality Standards

National Ambient Air Quality Standards (NAAQS), 1994					
		Concentration in Ambient Air			
Pollutant	**Time Weighted**	**Sensitive Area**	**Industrial Area**	**Residential Rural & Other Areas**	**Method of Measurement**
Sulfur Dioxide (SO_2)	Annual*	15 µg/m³	80 µg/m³	60 µg/m³	Improved West and Gaeke Method
	24 hours**	30 µg/m³	120 µg/m³	80 µg/m³	Ultraviolet Flurescence
Oxides of Nitrogen as NO_2	Annual*`	15 µg/m³	80 µg/m³	60 µg/m³	Jacob & Hochheiser Modified (Na-Arsenite) Method
	24 hours**	30 µg/m³	120 µg/m³	80 µg/m³	Gas Phase Chemiluminescence
Suspended Particulate Minute) Matter (SPM)	Annual*	70 µg/m³	360 µg/m³	140 µg/m³	High Volume Sampling, (Average Flow Rate not Less Than 1.1m³/minute
	24 hours**	100 µg/m³	500 µg/m³	200 µg/m³	
Respirable Particulate Matter (RPM) Size Less Than 10 µm	Annual*	50 µg/m³	120 µg/m³	60 µg/m³	Respirable Particulate Matter Sampler
	24 hours**	75 µg/m³	150 µg/m³	100 µg/m³	
Lead (Pb)	Annual*	0.50 µg/m³	1.0 µg/m³	0.75 µg/m³	AAS Method After Sampling Using EPM 2000 or Equivalent Filter Paper
	24 hours**	0.75 µg/m³	1.5 µg/m³	1.00 µg/m³	
Carbon Monoxide (CO)	8 hours**	1.0 mg/m³	5.0 mg/m³	2.0 mg/m³	Non-Dispersive Infrared Spectroscopy
	1 hour	2.0 mg/m³	10.0 mg/m³	4.0 mg/m³	

Note : * Annual arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform intervals.

** 24-hourly/8-hourly values should be met 98% of the time in a year. However, 2% of the time, it may exceed but not on two consecutive days.

Source : Air Quality Status and Trends in India. CPCB, 1994

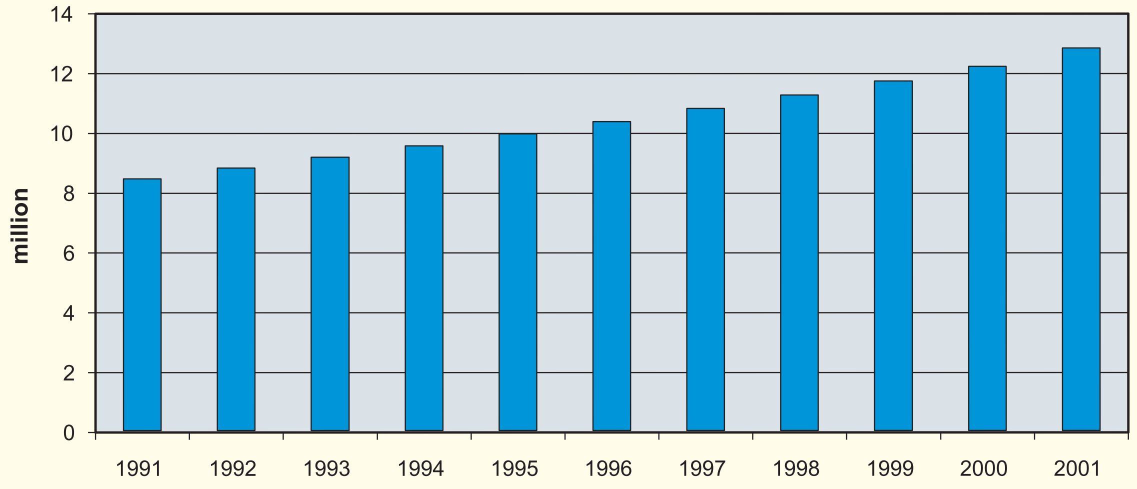
Delhi

1. Geographical Location

A5A.01 Delhi, the National Capital of the country, is surrounded by the state of Haryana on the north, west and south and by Uttar Pradesh on the east, separated by river Yamuna flowing in a north-south direction. The growth of the city has been concentrated between the river Yamuna in the east and the

Figure A5A.1: Approximate location of NEERI monitoring stations in industrial, commercial and residential areas.

Figure A5A.2: Population growth in NCT of Delhi between the last two census periods (Pandey 2003)



Aravalli hills in the west. The area of National Capital Territory (NCT) of Delhi is 1,397 square kilometers (km^2). The urban area in 2001 was 891.1 km^2 compared to 685.3 km^2 in 1991 (GoNCTD 2002). Figure A5A.1 shows approximate location of the pollution monitoring stations.

2. Demography

A5A.02 Delhi is one of the most rapidly growing metropolitan cities in India. As per 2001 census, the population of the NCT area was 12.8 million compared to 8.4 million in 1991. This shows a decennial growth rate of 51.9 percent between 1991 and 2001. The annual growth rate of population of Delhi during 1991-2001 was 4.18 percent, almost double the national average (Maps of India 2003). The average population density was 7,021 persons per km^2 in 2001. Figure A5A.2 shows the annual population growth rate in Delhi.

Table A5A.1: Monthly average values of key meteorological parameters for 1991-2002

	Mean Max. Temp. (°C)	Mean Min. Temp. (°C)	Mean Wind Speed (kmph)	No. of Calm Days		Relative Humidity %		Total Rainfall (mm)
				0830 hrs	1730 hrs	0830 hr	1730 hrs	
January	20.4	7.4	6.8	11	4	85	52	24
February	23.8	10.2	7.3	8	2	78	42	22
March	29.4	15.2	8.2	6	1	64	35	11
April	36.1	20.9	8.0	3	1	45	22	10
May	40.0	26.0	9.1	3	3	43	25	37
June	38.9	27.8	9.0	3	3	58	43	94
July	35.6	27.6	8.5	3	3	74	62	150
August	33.8	26.6	7.8	5	4	79	68	240
September	34.1	25.0	6.9	5	4	75	59	122
October	32.7	19.1	3.8	14	10	70	47	14
November	28.2	12.7	4.0	15	17	74	50	5
December	22.9	8.1	4.8	15	16	81	57	10
Total/year				91	66			740

Note: Data on calm days and relative humidity are collected twice a day.

Figure A5A.3: **Growth in commercial motor vehicles in Delhi (MoRTH 2003)**

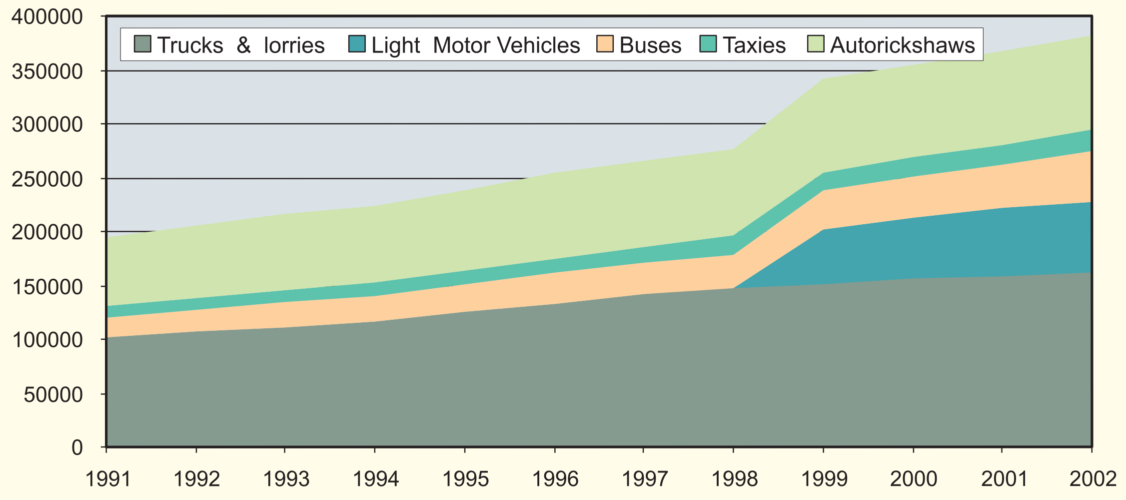
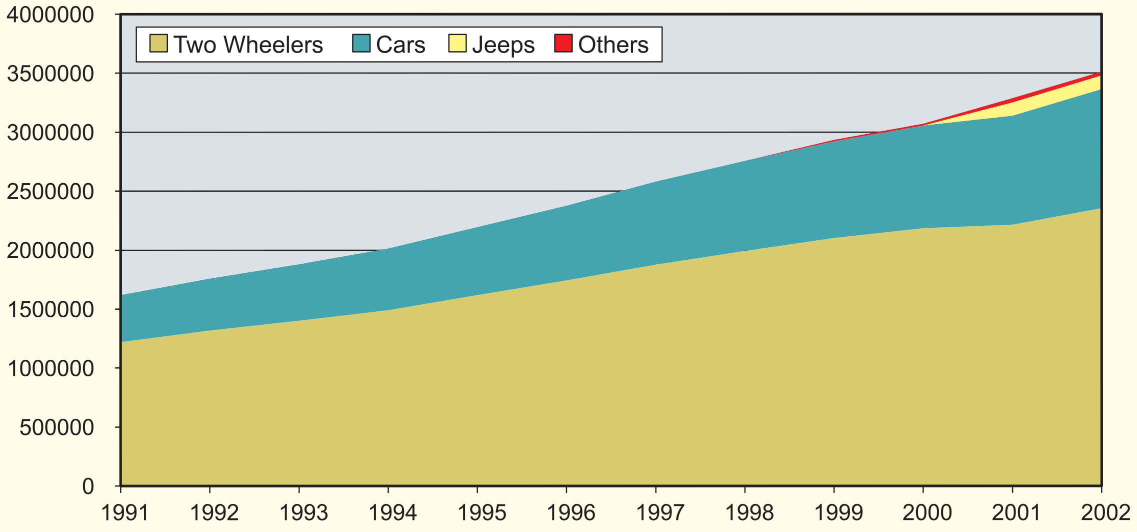


Figure A5A.4: **Growth in private motor vehicles in Delhi (MoRTH 2003)**



3. Climate

A5A.03 The weather profile for Delhi is shown in Table A5A.1, based on 12 years of data. The city experiences a tropical semi-arid climate. It is characterized by hot and dry summer (February to June), moderate monsoon (July to September), and a cool winter (October to January). The mean monthly temperature ranges from 7.4°C in winters to 40°C in summer months. Dust storms occur frequently during summer months, leading to build-up of particulate matter in the atmosphere. The heavy monsoon rains following summer months act as a "scrubber" that removes the particulate matter.

Wind speeds are typically higher in the summer and monsoon periods; in winter, calm conditions are frequent.

4. Economy

A5A.04 The annual per capita income of Delhi was Rs 24,450 in 2000-01, more than twice the national average. The gross state domestic product (GSDP) was Rs 366.85 billion in 2000-01. An analysis of the sectoral composition of GSDP shows that the share of the primary sector[20] had gone down significantly from 3.9 percent during 1993-94 to 1.4 percent during 2000-01. In contrast, the tertiary sector,

Box A5A.1 : Supreme Court Directions for Industrial Closures

(i) Hazardous/Noxious heavy and large industries

The Supreme Court vide its order dated **8/7/1996** directed that 168 industries falling in hazardous categories under the Master Plan of Delhi – 2001 (MPD-2001), should stop functioning in the city of Delhi from 30/11/1996. However, those industries could relocate/shift themselves to any other industrial estate in the National Capital Region (NCR) or outside of it.

(ii) The Supreme Court vide its order dated **6/9/1996** ordered that 513 industries falling under hazardous 'H' category under the MPD-2001, should stop functioning and operating in the city of Delhi from 31/1/1997. However, those industries could relocate/shift themselves to any other industrial estate in NCR.

(iii) Hot Mix Plants

The Supreme Court vide its order dated **10/10/1996** directed that 43 Hot Mix Plants operating in Delhi close down and stop operating in Delhi from 28/2/1997, and be relocated to any other industrial estate in the NCR.

(iv) Brick Kilns

The Supreme Court vide its order dated **26/11/1996** directed that 246 brick kilns operating in the Union Territory of Delhi falling under hazardous category under the MPD–2001, should close down and stop functioning from 30/6/1997 in Delhi and relocate/shift within NCR. The Supreme Court further directed the brick kiln owners to indicate before 31/1/1997 in writing to the Delhi Government and Delhi Pollution Control Committee that the concerned brick kilns intended to shift to the new technology of manufacturing bricks by using flyash-sand-lime technology. The Delhi Pollution Control Committee was directed to monitor the setting up of the new project of the concerned brick kilns. After obtaining the consent and no objection certificate from the Delhi Pollution Control Committee and also from the Central Pollution Control Board, the concerned brick kilns would be permitted to operate at the same site, if it is permitted under MPD-2001. The Court further directed the Delhi Government to render all possible assistance to the concerned brick kiln owners to changeover to the new technology and in the setting up of the modern plants with flyash- sand-lime technology.

(v) Arc/Induction Furnaces

The Supreme Court vide its order dated **26/11/1996** directed that the 21 arc/induction furnaces falling under hazardous category under the MPD-2001 close down and stop operating from 31/3/1997 in Delhi. However, these arc/induction furnaces could relocate/shift themselves to any other industrial estate in the NCR.

(vi) The Supreme Court vide its order dated **19/12/1996** directed that 337 industries falling under hazardous category under the MPD–2001 close down and stop operating from 30/6/1997 in Delhi. However, those industries could relocate/shift themselves to any other industrial estate in the NCR.

(vii) All industries located in residential area (except light service industries)

The Supreme Court vide its order dated **12/9/2000** directed and appointed the Ministry of Urban Development to act as the Nodal Agency for the matter of relocating/shifting of industries as per MPD-2001 functioning and operating in residential areas of Delhi. The court on **7/12/2000** directed that under the supervision of the Nodal Agency, the Government of National Capital Territory of Delhi, the Municipal Corporation of Delhi and the Delhi Development Authority would close all the polluting units functioning in non-conforming/residential areas or zones within a period of four weeks from the date of the order.

References: CPCB 2003a, GoNCTD 2003.

Note : Dates to be read as day/month/year.

which contributed 70.5 percent to state economy during 1993-94, increased its share to 78.4 percent during 2000-01. The share of the secondary sector in the GSDP of Delhi declined from 25.6 percent in 1993-94 to 20.2 percent during 2000-01 due to closure of polluting industrial units on environmental grounds (GoNCTD 2002).

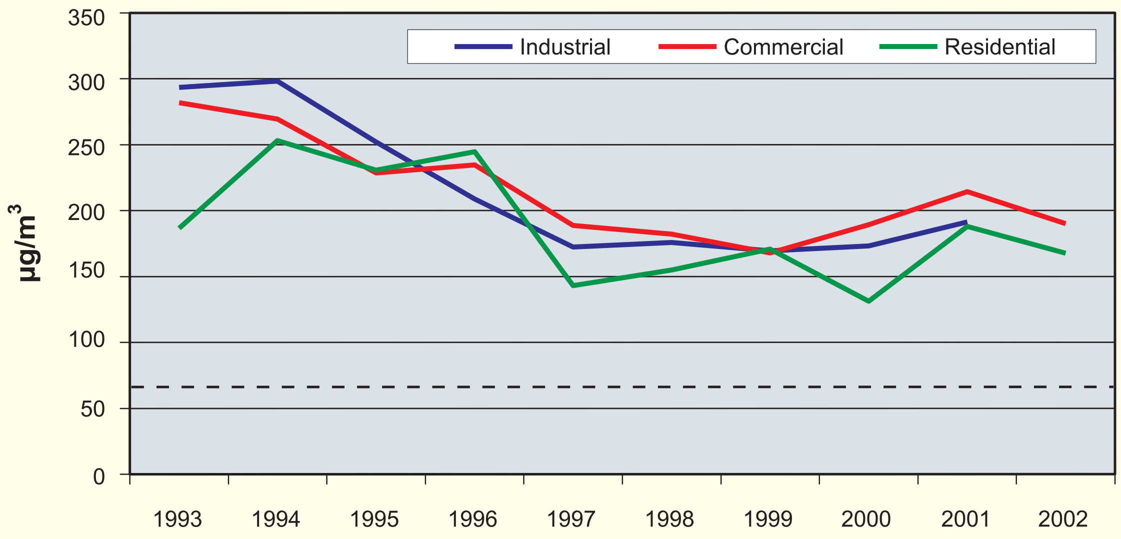
5. Industry

A5A.05 The economic census of 1998 indicates that there were 129,363 manufacturing enterprises in Delhi. The manufacturing sector provided employment to 1.44 million people. The Master Plan of Delhi prohibits setting up of large and heavy industries. There is, however, scope for expanding small scale industries. As a result, industrial growth is mainly in the small-scale sector.

A5A.06 The Delhi government issued an industrial policy statement in 1982, which emphasized the promotion of sophisticated industries that could achieve optimum levels of production using less space and power, while generating employment.

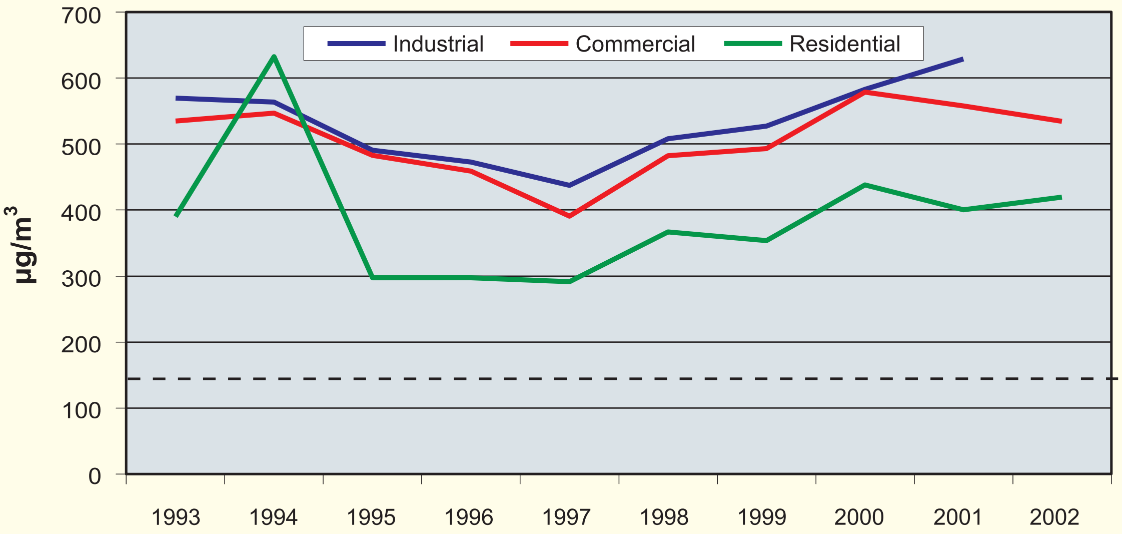
Household industries were permitted and 73 types of industries were identified that could be run in residential houses with a maximum powerload of 5 kilo-watts (kW), provided that the industry did not cause pollution or congestion and could be operated within a space of 30 square meters. However, this policy led to a proliferation of industries in non-conforming areas. According to a survey by the Delhi Government in 2000, out of a total of 125,000 regis-tered industries, 98,000 industries were located in non-conforming areas in violation of the Master Plan of Delhi. Industries had been set up in unauthorized colonies, urban villages, resettlement colonies, the walled city, and other residential pockets (TERI 2002). As a result of a writ petition filed in the Supreme Court in 1985 (M. C. Mehta versus

Figure A5A.5: Trend in RSPM levels in three areas of Delhi.



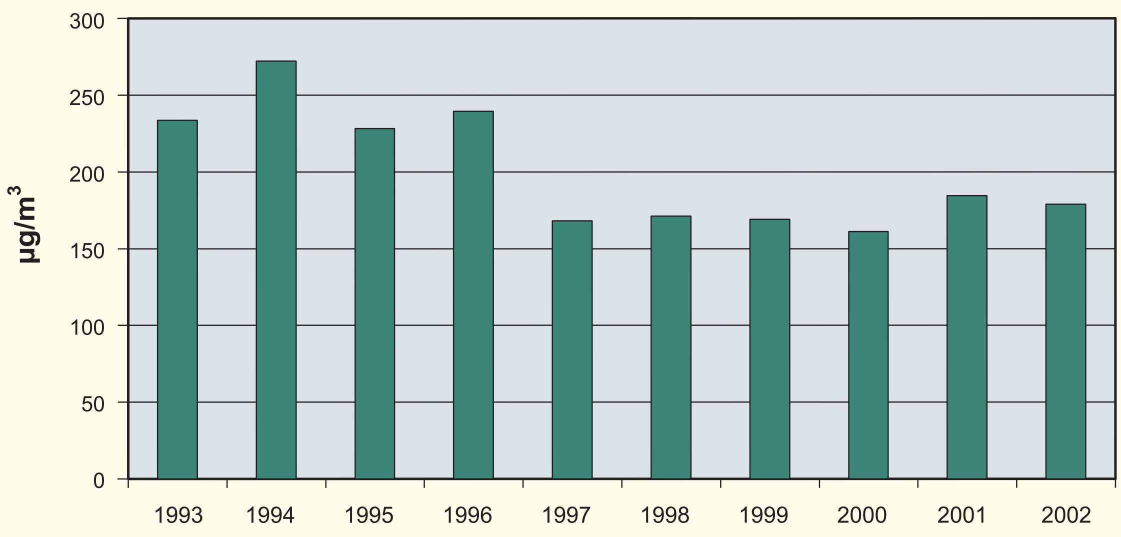
Note: The dotted line shows the annual national ambient standard of 60 µg/m³ for RSPM for residential areas.

Figure A5A.6: Trend in SPM levels in three areas of Delhi



Note: The dotted line shows the annual national ambient standard of 140µg/m³ for SPM for residential areas. There is a large amount of missing data. Examples include no data from June to August in 1993 at the three monitoring sites, no data from January to October 1994 at the residential monitoring site, no data in August 1996 at the three monitoring sites, and no data available at the industrial site in the second half of 2001 and all of 2002; the residential site monitoring station was moved to another location in 1994; the monitoring equipment was replaced with new equipment from a different manufacturer in between 1995 and 1997.

Figure A5A.7: Trend in overall average RSPM concentration in Delhi



Government of India), and in July 1996, the Supreme Court ordered the closure and shifting of industrial units in Delhi that were considered to be polluting and/or operating in non-conforming areas in violation of Delhi Master Plan. The index of industrial production also showed the effect of industrial closures and relocation. Box A5A.1 details the Supreme Court orders for industrial closures, which are also discussed in Box A5A.3.

A5A.07 Delhi has 28 industrial estates where about 25,000 industrial units are located. In addition, approximately 26,000 industries that were earlier permitted in residential/non-conforming areas are being rehabilitated and relocated in the conforming use zones. Government has acquired approximately 1,865 acres of land for development of industrial estates, where infra-structure development is on-going (GoNCTD 2002).

A5A.08 In addition to industry, there are three coal-based thermal power plants (at Indraprastha and Rajghat in central Delhi, and Badarpur in the south), and one gas-based power plant (at Indraprastha) in Delhi, which have a combined generation capacity of about 1,300 MW. As per data for the year 2000, almost 5,000 metric tons (MT) of coal was consumed per day in Delhi at these power plants, in addition to small quantities of furnace oil/light diesel oil, in progressively decreasing quantities, at two of the power plants.

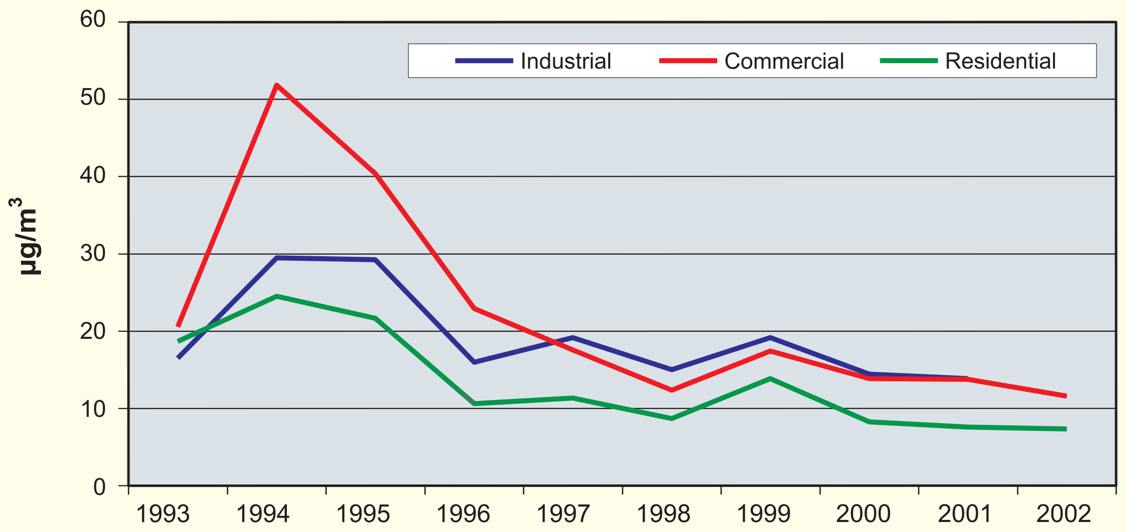
6. Transport

A5A.09 Delhi is still predominantly dependent on road transport, though the metro started functioning on a limited stretch in 2002. Buses constitute only 1.2 percent of the total vehicle population, but cater to about 60 percent of the total travel demand while personal vehicles account for about 30 percent. Motorcycles and scooters comprise about 65 percent of the total vehicle population, while cars and jeeps account for almost 27 percent. In addition, registered human- and animal-driven vehicles constitute almost 5 percent of the total vehicle population, out of which about 52 percent are cycle rickshaws. The number of cars and jeeps increased by about 5 percent per year between 1991 and 2001 (MoRTH 2003).

A5A.10 Figures A5A.3 and A5A.4 show the increase in vehicle population in Delhi between 1991 and 2002. While trucks and lorries make up the majority of (commercial) transport vehicles, two-wheelers dominate non-transport (private) vehicles.

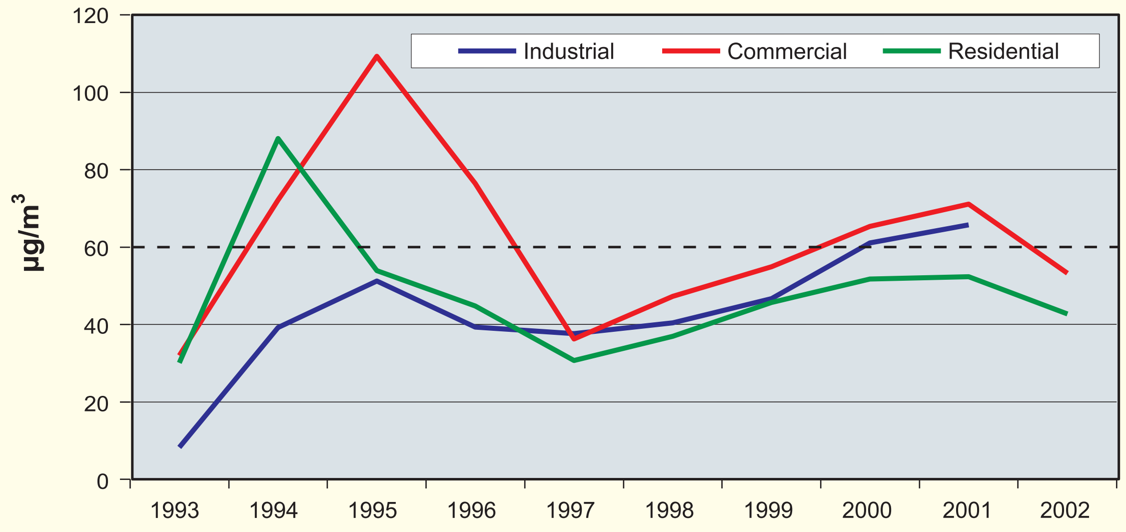
A5A.11 Delhi's registered vehicular population nearly doubled to about 4 million between the two census periods of 1991 and 2001, registering a growth rate of approximately 200,000 vehicles per annum. In terms of per capita vehicle numbers this translates to about 250 vehicles for every 1000 residents in 2001 compared to the corresponding figure of about 190 in 1991. The percentage distribu-tion of categories of motor vehicles shows that there

Figure A5A.8: Trend in SO_2 levels in Delhi



Note: The annual national ambient standard for SO_2 in residential areas is 60 µg/m³.

Figure A5A.9: Trend in NO_2 levels in Delhi



Note: The annual national ambient standard for NO_2 in residential areas is 60 µg/m³

has been a rapid rise in the number of cars and jeeps in recent years, while the increase in relative share of two-wheelers has shown a slightly declining trend (GoNCTD 2002). It is also worth noting, though not evident from Figure A5A.4, that while the share of petrol cars in all cars registered in Delhi stagnated, the share of diesel cars increased from 4 percent in 1998-1999 to 16 percent in 2002-2003 (CSE 2004).

A5A.12 However, there is controversy about the number of vehicles on Delhi roads since a large number of vehicles are from neighboring states, as is obvious from their registration records and number plates. Further, a recent survey indicates that the average age of the vehicle fleet is also much younger than the registration data suggests (GoI 2002a).

A5A.13 Delhi had 1749 km of road length per 100 km² area compared to national average of 73 km per 100 km² in 1995-96. Since 1971-72, the road network has increased three-fold while the number of vehicles has increased sixteen-fold, and the result is evident on the roads of Delhi. One of the reasons for Delhi's traffic problem is that it is the epicenter for wholesale trade in north India. It is estimated that 78 percent of the vegetables and fruits, 49 percent of fuel, 44 percent of iron and steel, and 47 percent of foodgrains traded in Delhi are destined for other

Figure A5A.10: Trend in RSPM monthly concentration at the residential, commercial and industrial area monitoring location (there was no monitoring at the industrial area in 2002)

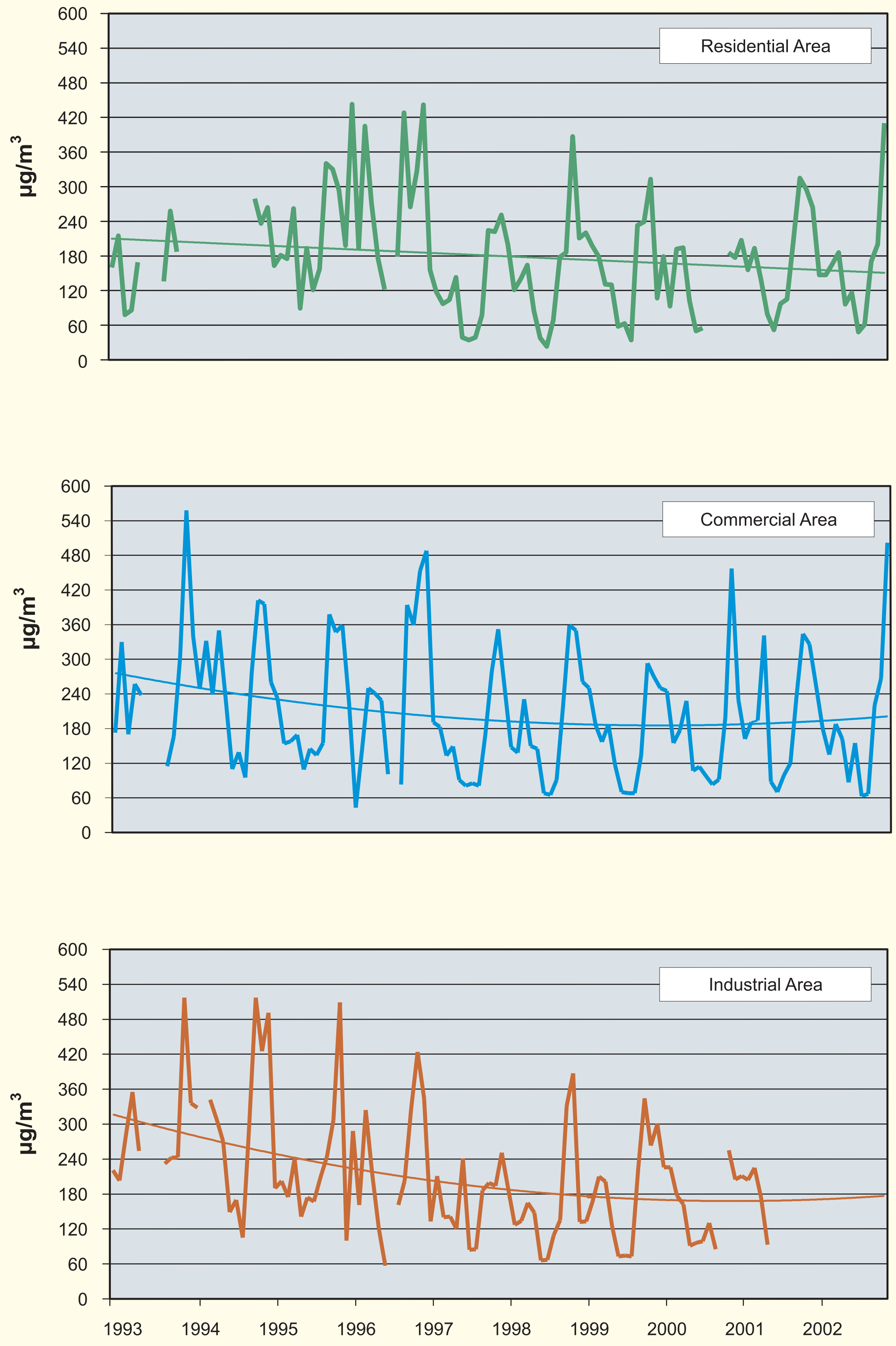


Figure A5A.11: **Monthly average total rainfall and mean wind speed**

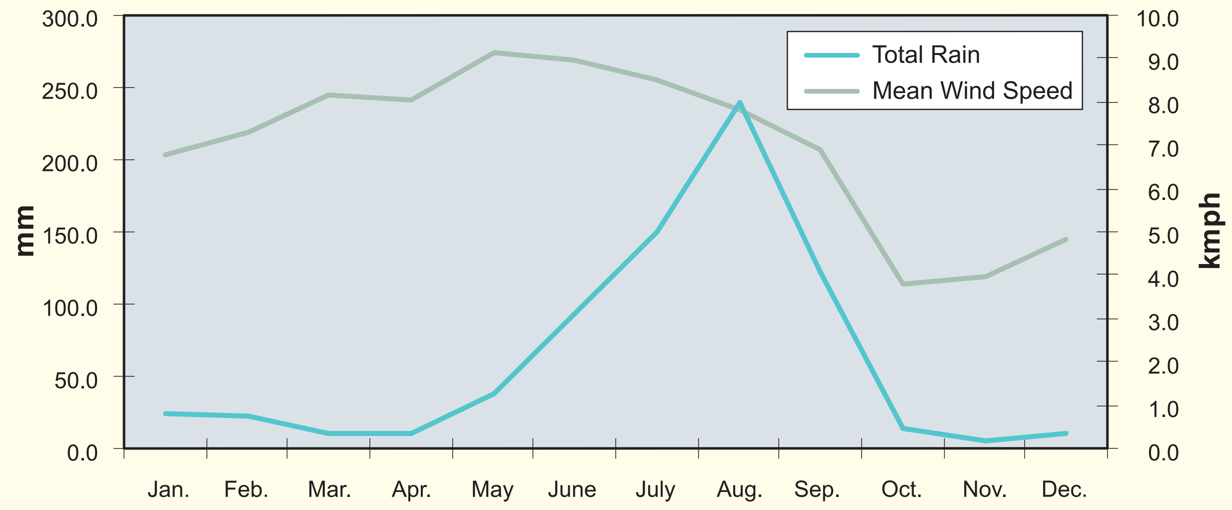


Figure A5A.12: **Monthly average total rainfall and RSPM concentration**

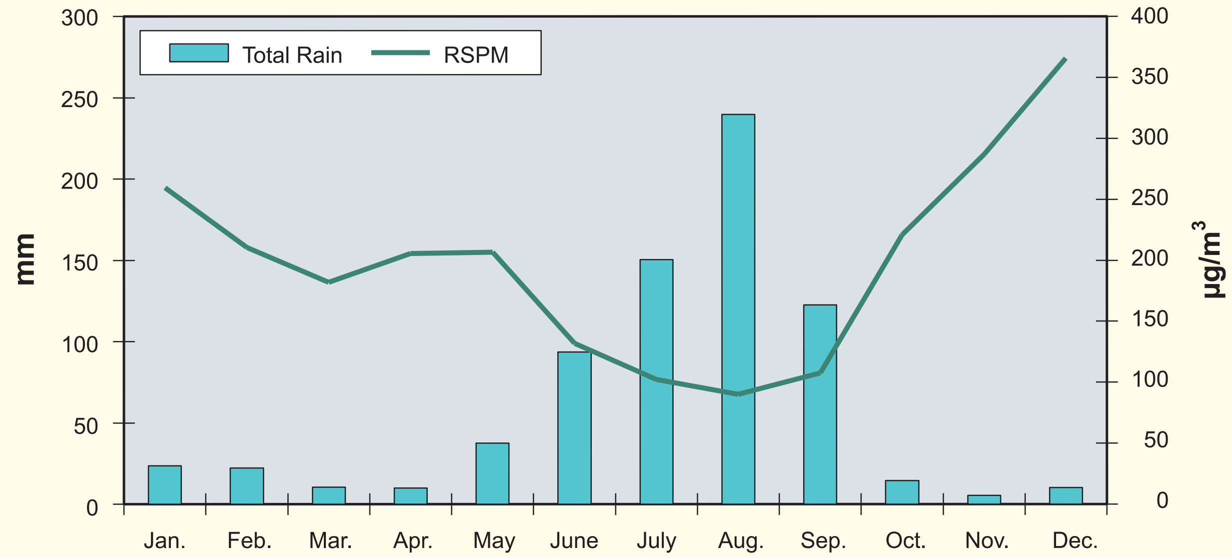


Figure A5A.13: **Monthly mean wind speed and RSPM concentration**

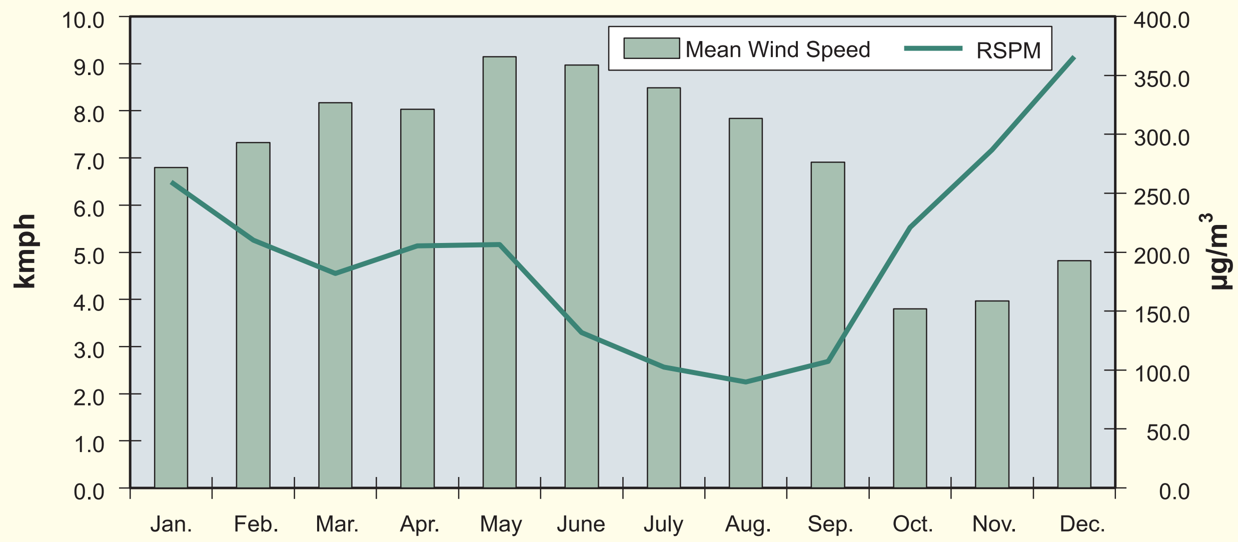
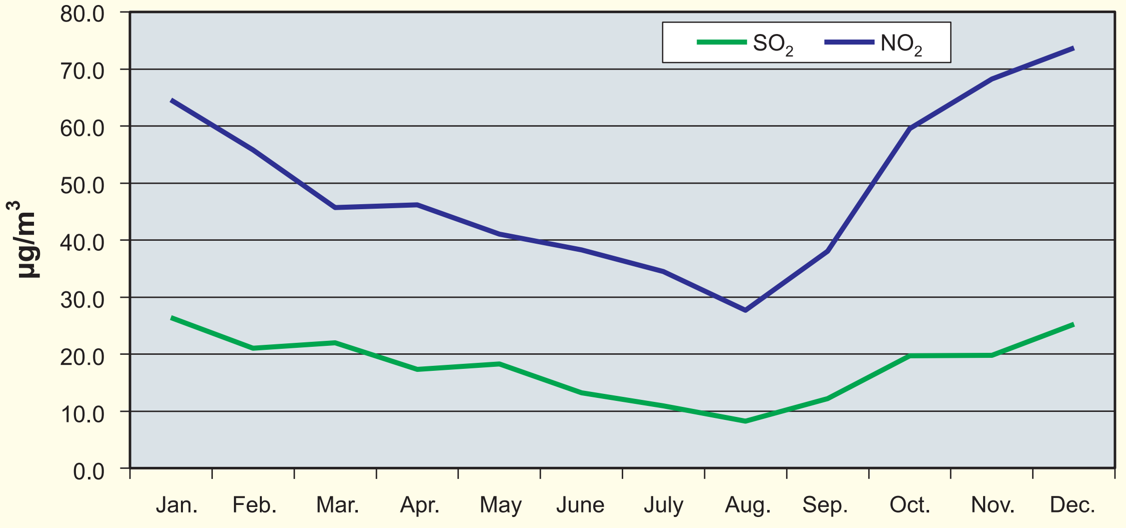


Figure A5A.14: Variation in monthly averages of SO_2 and NO_2

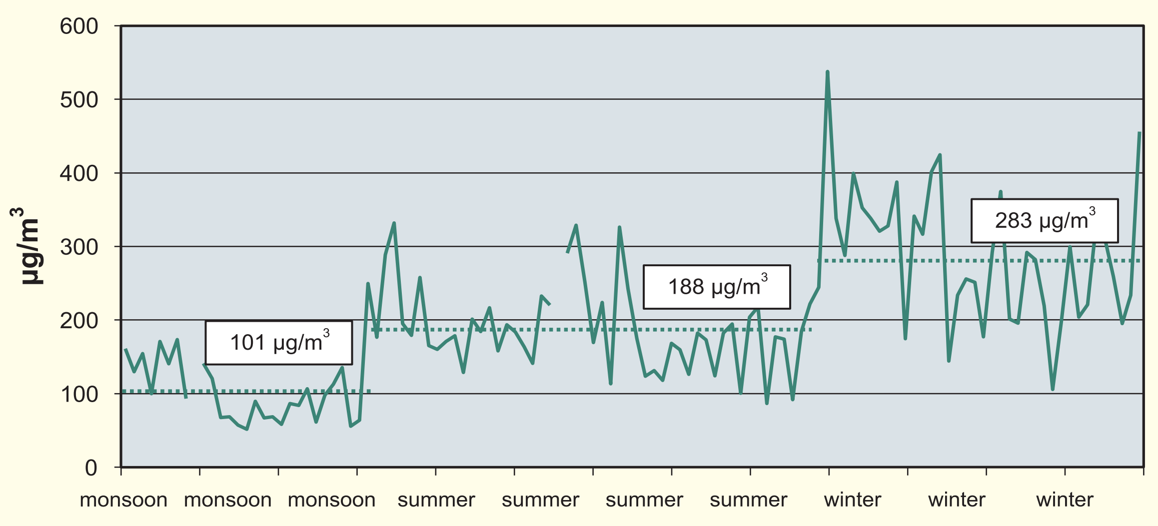


states. The convergence of five national highways, while facilitating transport, aggravates the traffic congestion in the city (GoNCTD 2002).

A5A.14 In response to a Public Interest Litigation against the government for not controlling air pollution adequately, the Supreme Court directed the Delhi Government to convert the entire city bus fleet, autos and taxis from liquid fuel to CNG or other gaseous fuels. Because LPG had not yet been authorized as an automotive fuel at the time, this led to the introduction of CNG starting in 1996 when an unsuccessful attempt was made to convert government vehicles to CNG. By the end of 2002, all public buses, taxis, and three-wheelers were running on CNG.

A5A.15 In addition to addressing the ever-growing traffic problem, the city government is constructing a large number of flyovers, introducing high capacity buses on select corridors, speeding up the introduction of additional lines on the metro, and discussing the need for a unified metropolitan transport authority.

Figure A5A.15: Overall variation in RSPM with seasons (Monsoon: July to September; Summer: February to June; Winter: October to January)



7. Urban

A5A.16 The city of New Delhi shows a strong influence of its colonial past. It has broad tree-lined boulevards and a large number of open green spaces. On the other hand, Old Delhi pre-dates the period of the Raj and is densely populated. The post-partition influx of refugees from Pakistan altered the landscape of New Delhi considerably, since a large number of refugee housing colonies came into existence with little regard for any land use regulation or environmental sanitation. The latest Master Plan of Delhi, MPD 2001, made provisions for various land-use categories and zones. However, it could only be implemented in limited measure, and in the case of non-confirming industrial development, with the help of the Supreme Court, as mentioned earlier. Unplanned settlements are common in Delhi to this day.

A5A.17 In administrative terms, Delhi is a Union Territory with its own legislature and a council of ministers. However, a number of agencies that directly affect the urban governance, such as Municipal Corporation of Delhi (MCD), the New Delhi Municipal Corporation (NDMC), and the Delhi Development Authority (DDA), are not under the administrative ambit of Delhi government. This has had effects on the implementation of politically unpopular decisions.

A5A.18 Delhi Government's revenue receipts comprise its own revenue receipts (tax and non-tax) and grants from the Centre. The revenue receipts increased from Rs 19.80 billion in 1994-95 to Rs 54.43 billion in 2000-01, registering an annual growth rate of 17.6 percent during 1994-2001. The revenue expenditure increased from Rs 14.30 billion in 1994-95 to Rs 36.96 billion in 2000-01 with an average annual growth rate of 17.2 percent in 1994-2001. As a result, the revenue account of Delhi government has a significant surplus. The major expenditure stream indicative of expenditure on capital works (such as water works, drainage / sewerage, solid waste management, roads, etc) more than trebled between 1994-95 and 2000-01, indicating spending by the government on construction of new infrastructure as well as operation and maintenance of capital infrastructure.

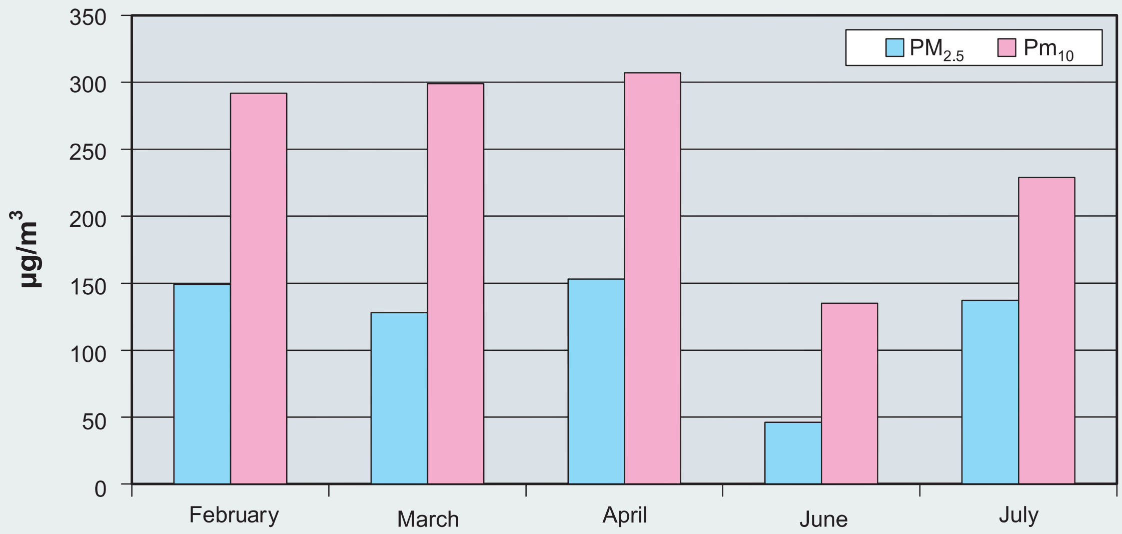
8. Urban Air Quality

Trends

A5A.19 Figures A5A.5 and A5A.6 show annual

Box A5A.2 : $PM_{2.5}$ in Ambient Air in Delhi

The CPCB conducted $PM_{2.5}$ monitoring employing portable samplers between February and July 2002 at a busy traffic intersection (Income Tax Office crossing).



The results illustrated above showed alarmingly high concentration of $PM_{2.5}$. Monthly mean concentration of $PM_{2.5}$ between February and July 2002 ranged between 46 µg/m³ and 153 µg/m³. On average, $PM_{2.5}$ constituted 50 percent of PM_{10} and 25 percent of SPM.

average ambient RSPM and SPM concentrations, respectively, between 1993 and 2002 in the three different land-use areas. However, because of a large amount of missing data (see Annex 3), the trends plotted should be interpreted with caution. The nature of missing data is such that it could affect the averages shown in the figures markedly. For example, focusing on RSPM, the averages in 1993 are most likely to be artificially elevated, since the three months in which ambient concentrations are generally low, June to August, are excluded from annual average calculations. In the residential area, there were no data in December 1993, lowering the annual average but unlikely to compensate for missing data in June–August.

A5A.20 RSPM shows a generally decreasing trend in the commercial and industrial areas until 1997 after which the levels stabilize and even show a slight increase. In the case of SPM, the minimum level recorded is in 1997, followed by an increasing trend in subsequent years. The sharp rise in RSPM and SPM in 1994 in the residential area seems to be an experimental artifact because only the data from November and December are available and taken as the "annual average." It is also worth noting that the residential monitoring site was shifted from the terrace of a post office in Netaji Nagar to the terrace of a school in the neighboring Sarojini Nagar in 1994.

A5A.21 RSPM averaged over the three areas as shown in Figure A5A.7. The averages for 1996 and 1997 were 239 $\mu g/m^3$ and 168 $\mu g/m^3$ respectively, showing that the decline is quite large (even with missing data in 1996 for the month of August). When the chronology of interventions listed in Box A5A.3 were matched with Figure A5A.7, it appears that the closure of about 1,300 polluting industries in 1996 and 1997 time period may have contributed significantly to the decrease in RSPM levels, as would have the various other interventions mentioned in Box A5A.3. However, these findings need to be interpreted with caution given the data quality issues discussed in Annex 3, especially the fact that the 1995-1997 period also coincided with the replacement of RSPM samplers. Although NEERI reports cross-calibration with the previous samplers before deploying new ones to ensure consistency in measurements between the old and new instruments, the changes made were significant: the first generation samplers were developed in-house by NEERI, the second generation instruments were manufactured by a commercial manufacturer.

A5A.22 When compared with the data monitored by the CPCB between 2000 and 2003 it was found that the overall monthly averages of (three) NEERI stations and (six) CPCB stations correspond reasonably well in non-winter months, as shown in Annex 3A.

A5A.23 The overall average levels of SO_2 and NO_2 are shown in Figures A5A.8 and A5A.9. While SO_2 has been below the annual national standard, and showed a decreasing trend in all three areas, the levels of NO_2 showed a sharp decrease in 1997, and then increased in all three areas to reach levels in the vicinity of the annual national air quality standard for residential areas in 2001-02. The fluctuations in NO_2 concentrations between 1993 and 1997 in Delhi may indicate problems with data collection.

A5A.24 Figure A5A.10 shows the monthly averages of RSPM in the three areas over the years. As can be seen, there is a wide range of RSPM levels in all three areas, with an overall maximum just above 540 $\mu g/m^3$, and minimum going down to approximately 20 $\mu g/m^3$. Further, the RSPM levels were not found to be significantly different between the three areas (at the 10 percent level) as indicated by analysis of variance results, pointing to the possibility that sources of RSPM may be similar in all three areas. However, it is important to note that there are data gaps, and these gaps are particularly serious in the residential area in 1994 and in the industrial area in 2001 and 2002.

9. Seasonality

A5A.25 From empirical evidence, it is known that the two parameters which directly impact concentrations of pollutants are rainfall and wind speed, since higher precipitation leads to lower concentration of pollutants, and higher wind speeds lead to better dispersion.

A5A.26 As can be seen in Figure A5A.11, relatively low wind speeds and rainfall are encountered in Delhi for almost 3 months in a year. This is likely to lead to poor dispersion over that time period. An empirical classification[21] of the dispersion conditions was attempted based on the meteorological data.

Box. A5A.3 **Major Technical and Policy Interventions in Delhi (1991-2004) that Impacted Air Quality**

Year	Action
1991	*1) Mass emission norms for new petrol vehicles introduced on 1/4/1991*
1992	*1) Mass emission norms for new diesel vehicles introduced on 1/4/1992*
	2) Start of closure of stone crushers
1993	N.A.
1994	*1) Lead in petrol reduced to 0.15 gm/litre in June*
1995	*1) Catalytic converters for 4-wheeled petrol driven vehicles mandated with effect from April*
	2) Unleaded petrol introduced to compliment the introduction of catalytic converters
1996	*1) Mass emission norms for new vehicles made more stringent on 1/4/1996*
	2) Fuel quality: 0.5% S diesel mandated in December
	3) Benzene in petrol reduced to 5%
	4) CNG vehicles and catalytic converters (unsuccessfully) introduced for government vehicles, excluding public transport.
	5) Closure of 168 hazardous industries, including stone crushers completed by 30 /11/1996
	6) Approved fuel notification issued for all activities (e.g. FO and LSHS with 1.8% S; coal with 0.4% S)
1997	1) Relocation of 513 industries by 31/1/1997
	2) Closure of 43 Hot mix plant by 28/2/1997
	3) Closure of 21 Arc/induction furnaces by 31/3/97
	4) Closure and relocation of 246 Brick Kilns outside Delhi by 30/6/1997
	5) Installation of pollution control devices by all air polluting industries by 31/12/1997 mandated
	6) Ban on registration of army disposal vehicles, government auctioned vehicles
	7) Commercial goods and passenger vehicles (LCVs) beyond a specified life span by 31/12/1997
	8) 337 hazardous category industries shifted on 30/6/96 (total of 1160 industries closed or relocated in 1997)
1998	*1) Emission Norms for catalytic converter fitted passenger vehicles from 1/4/1998*
	2) Benzene in petrol reduced to 3%
	3) Ban on alteration of vehicles by replacing petrol engines with diesel engines with effect from 1/4/98
	4) Low smoke 2T oil mandated
	5) Pre-mix 2T engine oil mandated for two-wheelers by 31/12/1998; ban on supply of loose 2T oils from 31/12/1998
	6) Phasing out/ban on plying of old commercial/transport vehicles more than 20 years old by 2/10/1998
	7) Phasing out/ban on plying of old commercial/transport vehicles more than 17 years old by 15/11/1998
	8) Phasing out/ban on plying of old commercial/transport vehicles more than 15 years old by 31/12/1998
	9) Start of construction of Delhi metro (underground) and a major flyover construction program
	10) Leaded petrol phased out by 1/9/1998
1999	*1) India Stage-I (Euro-I) emission norms mandated for all category of new vehicles*
	2) Emission norms for tractors introduced
	3) Taxis older than 12 years phased out by 31/3/99
	4) Registration of Autorickshaws and diesel taxis only if they conform to Bharat Stage-II (Euro II) norms with effect from 29/4/1999
	5) Fuel quality: 0.25% S diesel made mandatory
	6) Restriction on the plying of goods vehicles during the day from August 1999
2000	1) Taxis older than 10 years phased out by March
	2) Replacement of all pre-1990 autorickshaws and taxis with new vehicles on clean fuels by 31/3/2000
	3) Conversion of 3-wheelers to CNG initiated
	4) Expansion of the number of CNG supply outlets from 8 to 30 by 31/3/2000
	5) All new private (non commercial) 4-wheeled vehicles to conform to Euro II norms by 1/4/2000
	6) Buses more than 8 years old phased out or to ply on CNG or other clean fuels

Year	Action
	7) Number of CNG vehicles as follows: 3983 3-wheelers; 877 taxis; 61 buses; 13 Rural Transport Vehicles (RTVs) (total of 4834 minus private vehicles)
	8) Low Sulfur petrol & diesel (0.05%) mandated from 1/4/2000 for private vehicles
	9) The three coal based power plants switched over to use of beneficiated coal
	10) Petrol with 1% benzene mandated from November 2000
	11) Piped natural gas made available by March 2000 to 1311 domestic, 9 small, and 3 large commercial establishments
	12) Bharat Stage-II (Euro-II) emission norms for all non-commercial vehicles by April
2001	*1) Bharat Stage-II (Euro-II) emission norms for all commercial vehicles by October*
	2) The Sulfur content of diesel supplied to NCT Delhi further reduced to 0.05% with effect from October 2001 (to go with the above measure)
	3) Replacement of all post-1990 autorickshaws and taxis with new vehicles on clean fuels (Court also allowed usage of conversion kit on such vehicles) by 31/3/2001
	4) Entire city bus fleet (DTC and private) to be converted to single fuel mode on CNG by 31/3/2001 (started but not completed by deadline)
	5) Augmentation of public transport to 10,000 buses by 1/4/2001
	6) Total of 3538 hazardous category industries closed
	7) Number of CNG vehicles as follows: 14000 3-wheelers; 2200 taxis; 400 buses; 250 Rural Transport Vehicles (RTVs); 9500 private (26350 total)
	8) Piped NG available by March to2821 domestic, 15 small , and 5 large commercial establishments
	9) Construction of 9 flyovers completed
	10) Emission norms for LPG vehicles introduced from May 2001
2002	1) Extension of deadline for conversion of entire city bus fleet to CNG mode till 31/1/2002 (started but not completed by deadline)
	2) 94 CNG stations set up by March
	3) All diesel buses phased out by November
	4) Fresh registration of 5000 new CNG based 3-wheelers in Delhi from 20/12/2002
	5) Number of CNG vehicles as follows: 35678 3-wheelers; 4816 taxis; 4231 buses; 2165 Rural Transport Vehicles(RTVs); 10350 private (57240 total)
	6) Piped NG available by March to 4111 domestic, 37 small , and 5 large commercial establishments
	7) 16340 non-destined good vehicles turned away from entering Delhi between July and November
	8) Emission norms for CNG vehicles (all categories) and LPG vehicles (heavy duty) with effect from May 2002 and October 2002 respectively
2003	*1) Supreme Court order for preparation of Action Plan for lowering ambient RSPM levels on 14/8/2003*
	2) Construction of 19 flyovers completed.
2004	*1) Notification issued by Government of India revising the emission norms of in use vehicles with effect from 1/10/2004.*

N.A. – Not applicable.

Notes (1): Interventions common to all five cities are shown in Italics. However, all common interventions were not implemented in the same year in all cities. (2) : Dates to be read as day/month/year.

It was found that good dispersion conditions exist from June to September, moderate conditions from January to May, and poor dispersion conditions exist from October to December. Further evidence of the effect of relatively poor dispersion from October to November can be seen in the monthly variation of RSPM.

A5A.27 As can be seen in Figure A5A.12 and A5A.13, there is a strong effect of meteorological parameters, with very high levels being recorded at the end of the year. Figure A5A.14 shows that SO_2 and NO_2 levels also show a strong effect of meteorological factors, with fairly high NO_2 concentrations recorded in the winter months. However, given the cold temperatures in Delhi compared to southern states in winters, the high RSPM and gaseous pollutant levels in winters are also in part a result of increased solid fuel use for domestic and space heating purposes.

A5A.28 The commonly used definitions of summer, winter, and monsoon seasons were used to aggregate the months, in order to further explore any seasonality in the variation of RSPM levels.

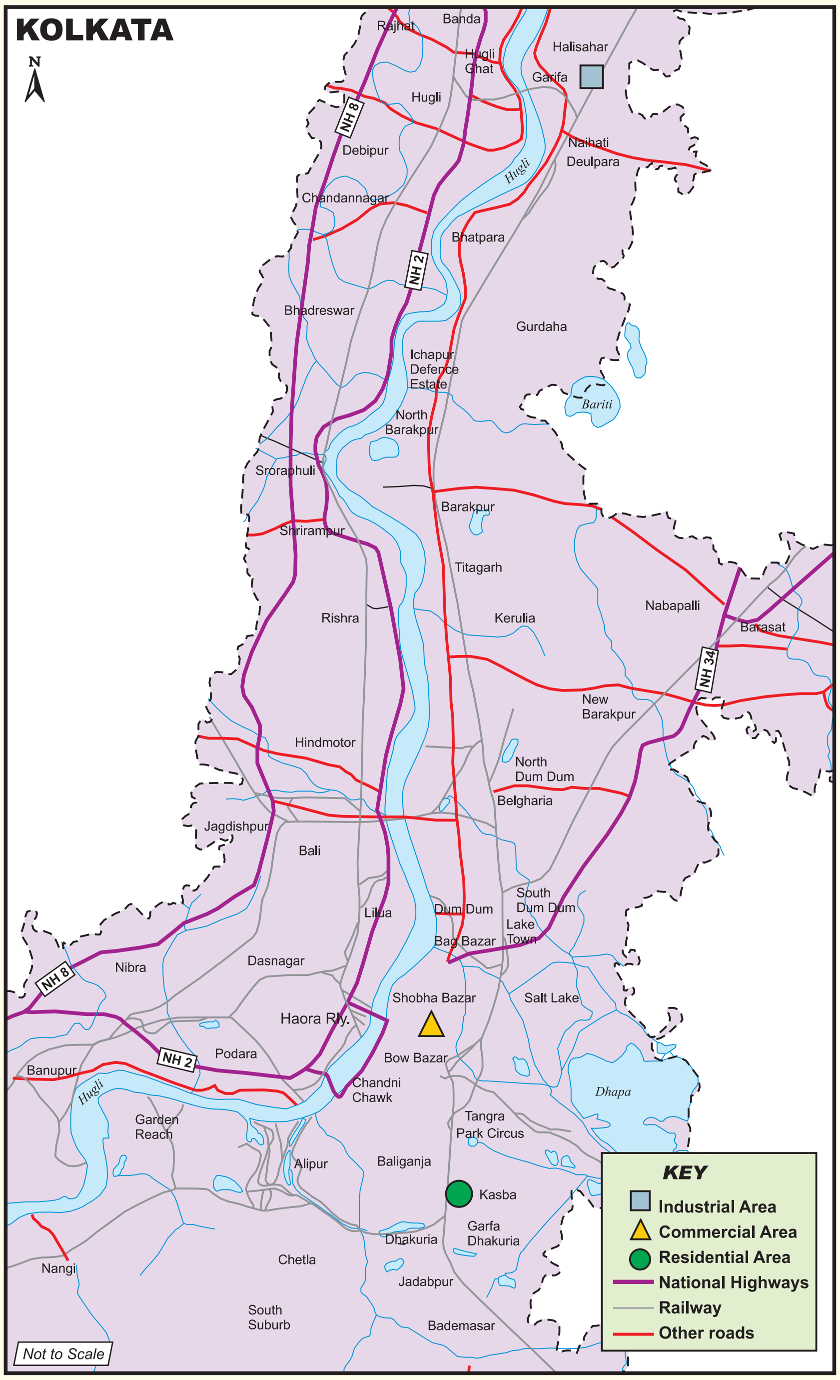
A5A.29 The effect of seasons on RSPM is clearly visible in Figure A5A.15. The averages for monsoon, summer, and winter months were 101 $\mu g/m^3$, 188 $\mu g/m^3$, and 283 $\mu g/m^3$, respectively. However, since the summer, winter and monsoon classification shown is subjective in nature, the empirically derived classification of dispersion conditions discussed at the beginning of this section was also used to assess seasonality in RSPM variation. It was found that there was a strong effect of the three dispersion classifications. The RSPM averages for the good, moderate, and poor dispersion classifications were 108 $\mu g/m^3$, 213 $\mu g/m^3$, and 291 $\mu g/m^3$, respectively.

Kolkata

1. Geographical Location

A5B.01 Kolkata and Howrah are twin cities situated on the eastern and western sides of the river Hoogly respectively (about 150 kms upstream from the Bay of Bengal). The boundary of Kolkata is contiguous with Kolkata Municipal Corporation (KMC), which has an area of 104 km^2 (GoI 1999). Figure A5B.1 shows the approximate location of the pollution monitoring stations.

Figure A5B.1: Approximate location of NEERI monitoring stations in industrial commercial and residential areas



2. Demography

A5B.02 The KMA accounts for less than 20 percent of West Bengal's population. As per 2001 census, the population of KMA grew at an annual growth rate of 1.8 percent from 11.02 million in 1991 to 13.2 in 2001 as against 11.02 million in 1991 at an annual growth rate of 1.82 percent. During the same period, the population of the KMC grew from 4.39 to 4.58 million, which shows that most of the growth in the decade between 1991 and 2001 occurred outside of KMC.

A5B.03 Figure A5B.2 shows the annual population between the two census periods. The population density of the municipal corporation area in 2002 was 24,705 persons per km^2 making Kolkata one of the most densely populated cities in India.

3. Climate

A5B.04 The weather profile for Kolkata is shown in Table A5B.1, based on data from 1991 to 2002. The city experiences a humid and tropical climate. It is characterized by hot and dry summer from February to April, monsoon from May to October, and a moderately cool winter between November and January. The mean monthly temperature ranges from 12.6°C in the winters to 35.6°C in summer months. Calm conditions prevail frequently during winter months, and are more common in the evening hours. Relative humidity remains quite high throughout the year.

4. Economy

A5B.05 The KMA accounts for 25 percent of the state's income with less than 20 percent of the state's population. In terms of employment, KMA accounts for about 43.5 percent and 48 percent of workers in secondary and tertiary sectors respectively[22]. Out of the total registered small-scale units in West Bengal, KMA houses around 56 percent, providing about 61 percent employment. For the KMA as a whole, the ratio of formal to informal employees is about 10.9, which shows that there is a large informal sector in Kolkata.

A5B.06 The economic base of the city contributes substantially to the total revenue collection of both the central and state governments. Kolkata city alone shares about 80 percent of annual sales tax collection and about 97 percent of annual income tax collection of the State (GoI 1999).

A5B.07 The per capita net state domestic product (2000-01 at current prices) was Rs 18,021. Annual per capita income of the city was Rs 10, 636 (1998-99).

5. Industry

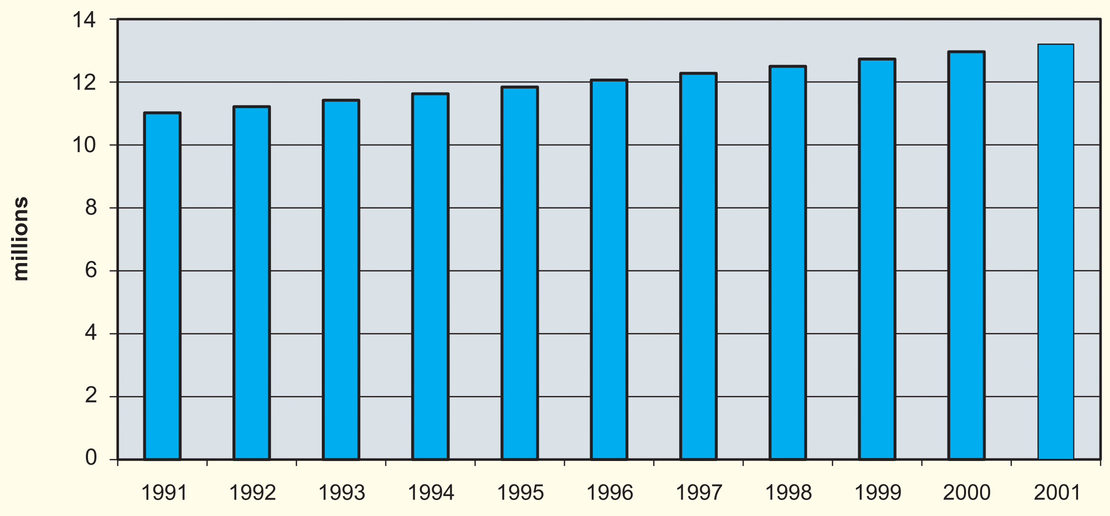
A5B.08 Kolkata forms the commercial and industrial hub of eastern India. Due to the availability of infrastructural facility which includes river fronts, a port and an abundance of water and raw materials for industrial activity, industrial development took place predominantly along the river (GoWB 2001).

A5B.09 Kolkata's traditional industries include jute manufacturing, light and heavy engineering, leather products and tea trading. However, it has a range of other industries including textiles, paper, pharmaceuticals, chemicals, tobacco, railway wagons, automobiles, heavy machinery, and steel. A large number of industrial estates have come up in the metropolitan area, and approximately 329 small-scale units of varying capacities are operating within the metropolitan area of Kolkata. There are approximately 297 small but hazardous industrial units operating in densely populated residential areas. Many of these industries use coal-fired boilers for generation of steam. Other polluting units include coal-fired power generating units, such as the New Cossipore thermal power plant, Southern power generating station (Watgung) in the city and Budge Budge, Titagarh, Mulajore, and Bandel thermal power plants in the suburbs or in the nearby areas. According to the State Pollution Control Board, industries are major contributors of air pollutants in the city. About 32 tons of small particulates are released to the atmosphere by the industries in Kolkata: 16 tons from New Cossipore thermal power plant, 14 tons as uncontrolled emissions from small boilers, and 2 tons from Southern power generating station and other large industries (GoWB 2001). Recognizing that industries contribute disproportionately to air pollution in Kolkata, the government has taken a number of steps against polluting industries (see Box A5B.4).

6. Transport

A5B.10 Public transportation is the predominant form for transport of passengers in Kolkata,

Figure A5B.2: Population in Kolkata metropolitan area between the last two census periods (Pandey 2003).



including trams, taxis, three-wheelers, local trains, metro-rail, circular rail, and ferry service, coupled with non-motorized vehicles such as cycle-rickshaws. Over the last decade the number of registered automobiles in Kolkata has increased by about 52 percent. The effective road area available in Kolkata is less than 5 percent of the total area, leading to very high automobile density, disproportionately low percentage of road network, congestion and traffic jams. The traffic movement in the city is also affected by poor standard of maintenance of the roads, old vehicles, and a mixture of traffic including auto-rickshaws, trucks, hand carts, hand rickshaws, stray animals and a large number of pedestrians. High population density also results in a large number of pedestrians per unit area, which affects traffic movement.

A5B.11 The vehicular growth in Kolkata as shown in Figure A5B.3 and A5B.4 shows that there has been a steady increase in the number of vehicles in the city since 1991. The number of registered vehicles in 2001 was more than 750,000, out of which two-wheelers constituted about 44 percent, cars 37 percent, three-wheelers 2 percent, goods carriages 9 percent, and buses, taxis, jeeps constituting the rest. The average growth rate of the vehicle population has been between 3 and 5 percent per annum in the last decade (MoRTH 2003).

Figure A5B.3: Growth in commercial motor vehicles in Kolkata (MoRTH 2003)

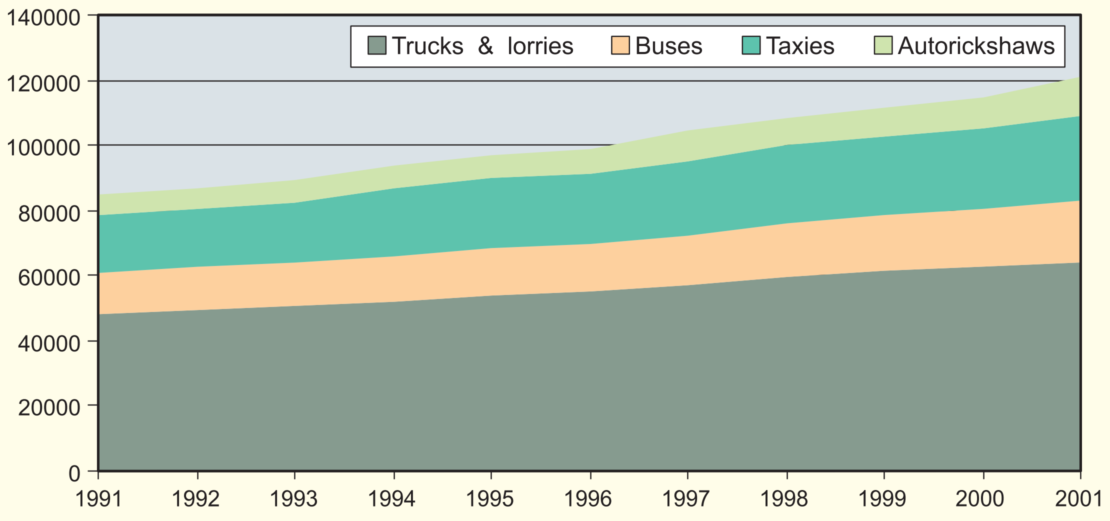


Table A5B.1: Overall monthly average values of key meteorological parameters

	Mean Max. Temp. (°C)	Mean Min. Temp. (°C)	Mean Wind Speed (kmph)	No. of Calm Days		Relative Humidity %		Total Rainfall (mm)
				0830 hrs	1730 hrs	0830 hrs	1730 hrs	
January	25.4	12.6	3.4	12	23	75	61	18
February	28.8	16.6	4.2	9	14	72	55	28
March	33.6	21.4	5.3	7	11	66	48	47
April	35.6	24.6	7.3	3	3	70	58	52
May	35.6	25.9	8.7	3	2	73	68	146
June	34.2	26.4	7.8	3	3	80	78	260
July	33.1	26.2	7.0	4	4	83	82	318
August	32.8	26.3	6.3	4	5	83	83	351
September	32.9	25.8	5.4	6	8	81	81	284
October	32.4	24.0	3.8	9	17	76	76	153
November	30.0	19.3	3.0	11	25	72	69	32
December	26.8	13.7	3.0	12	27	73	65	7
Total/year				83	142			1696

Note: Data on calm days and relative humidity are collected twice a day.

A5B.12 A large number of highly polluting old vehicles (about 54 percent of total) are presently plying in the city streets. Of the old vehicles, 56 percent of cars, 55 percent of trucks, 56 percent of buses, 46 percent of taxis, and 25 percent of two-wheelers are more than 15 years old (GoWB 2001). The exhaust emissions from old and slow-moving traffic contribute heavily to atmospheric pollution. A number of steps, some as part of country-wide measures, were undertaken in the last few years to address emissions from motor vehicles (see Box A5B.4).

7. Urban

A5B.13 The land-use breakdown in 1998 included 45 percent residential areas, 6 percent major industrial areas, 2 percent organized open space and recreational areas, 8 percent transportation space, and 33 percent vacant (including cultivable) land, forest and waste land, water body and swampy land (GoWB 2001).

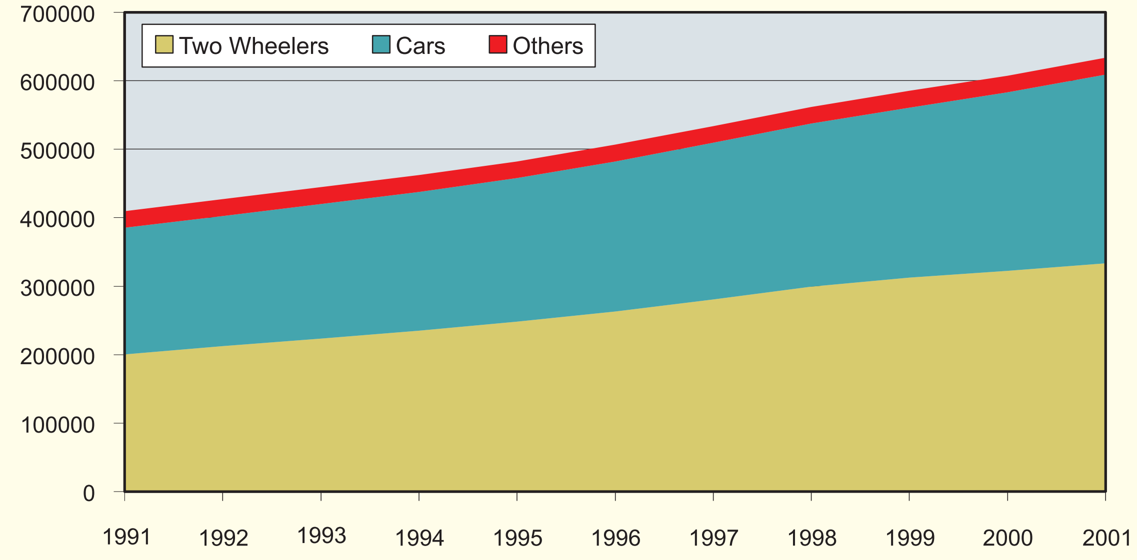
A5B.14 The KMC managed to raise its own revenues by almost Rs 700 million during 2002-03, an increase of 27 percent over the previous year. Both tax and non-tax revenues have increased substantially in recent years. In particular, water charges, amusement fees, building sanction fees, and commercial markets have seen substantial growth, with the result that in 2002-03, self-generated revenues outscored the government grants.

8. Urban Air Quality

Trends

A5B.15 Figures A5B.5 and A5B.6 show annual average ambient RSPM and SPM concentrations, respectively, between 1993 and 2002 in the three different land-use areas. However, as in the case of Delhi, because of a large amount of missing data (see Annex 3), the trends plotted should be interpreted with caution. The nature of missing data is such that it could affect the averages shown in the figures markedly. RSPM shows a generally decreasing trend in the commercial and industrial areas. In the residential area, there was a break in monitoring on account of change in location of the monitoring site in 1997, and higher concentrations were recorded subsequently. A similar trend is evident in the case of SPM, though it is not as pronounced. The decline in

Figure A5B.4: Growth in private motor vehicles in Kolkata (MoRTH 2003)

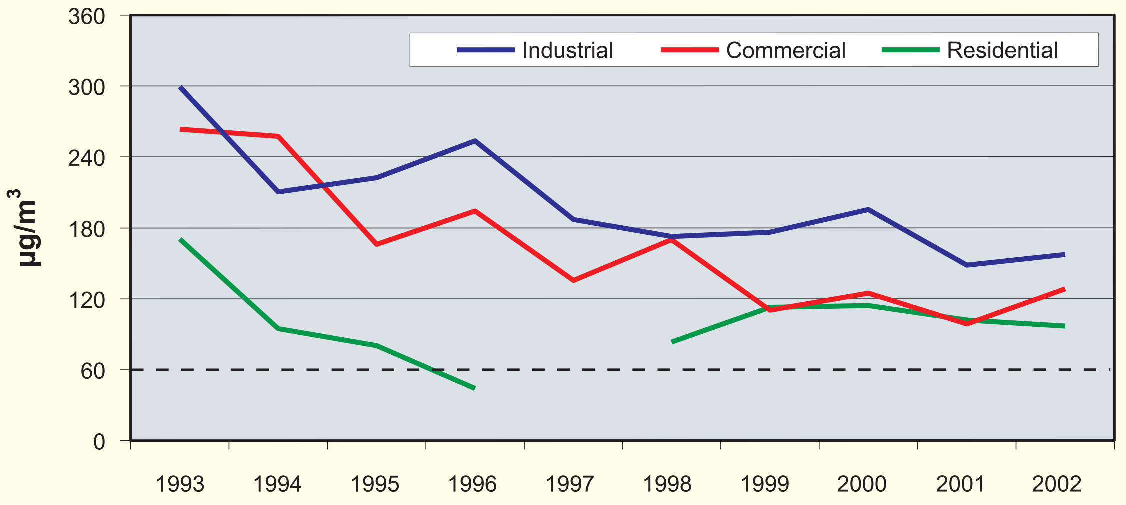


RSPM is comparable between the commercial and industrial sites. As seen in Box A5B.4 a large number of interventions in Kolkata have focused on the industrial sector.

A5B.16 When compared with RSPM data from the SPCB monitoring location between 2000 and 2002, it was found that the overall averages of NEERI and SPCB levels correspond very well to each other, as shown in Annex 3A. Regression analysis between the two datasets returned a R-squared value of 0.80. However, this result needs to be interpreted with caution since averaging across different monitoring stations can lead to calculation artifacts.

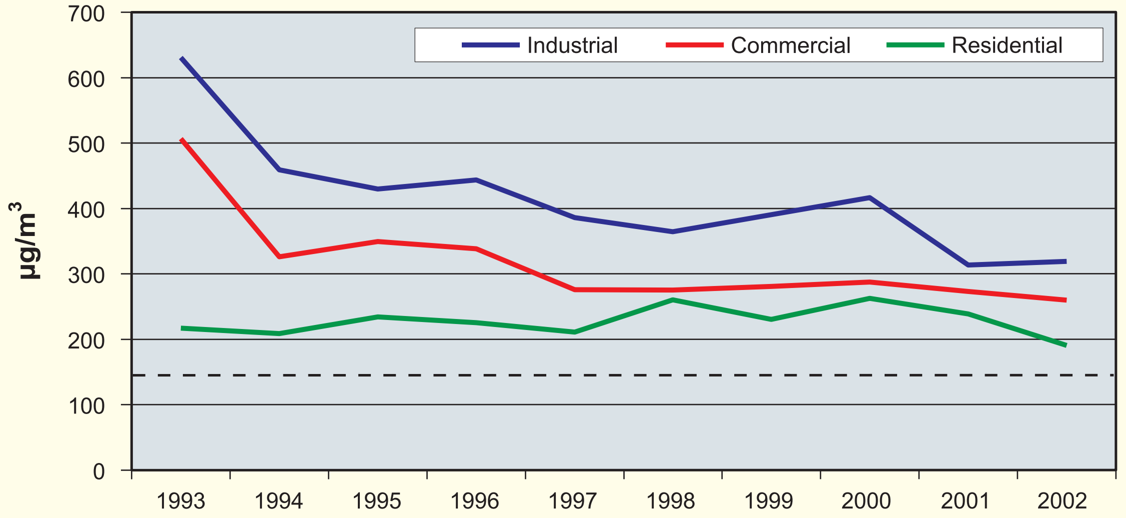
A5B.17 The overall averages of SO_2 and NO_2 are shown in Figures A5B.7 and A5B.8. While the ambient concentrations of SO_2 were broadly steady in the residential area, it showed a significant increase in the commercial and industrial areas in 1998-99, followed by a decrease in 2000. There is no obvious explanation for this trend between 1998 and 2000, since lower sulfur limits were being implemented during this period. NO_2 remained largely steady in all the three areas until about 2000, after which it showed a significant increase. The levels of NO_2 in all three areas violated the annual national standard for residential areas in 2002. There are no obvious

Figure A5B.5: Trend in RSPM levels in three areas of Kolkata



Note: The dotted line shows the annual national ambient standard of 60 µg/m³ for RSPM for residential areas.

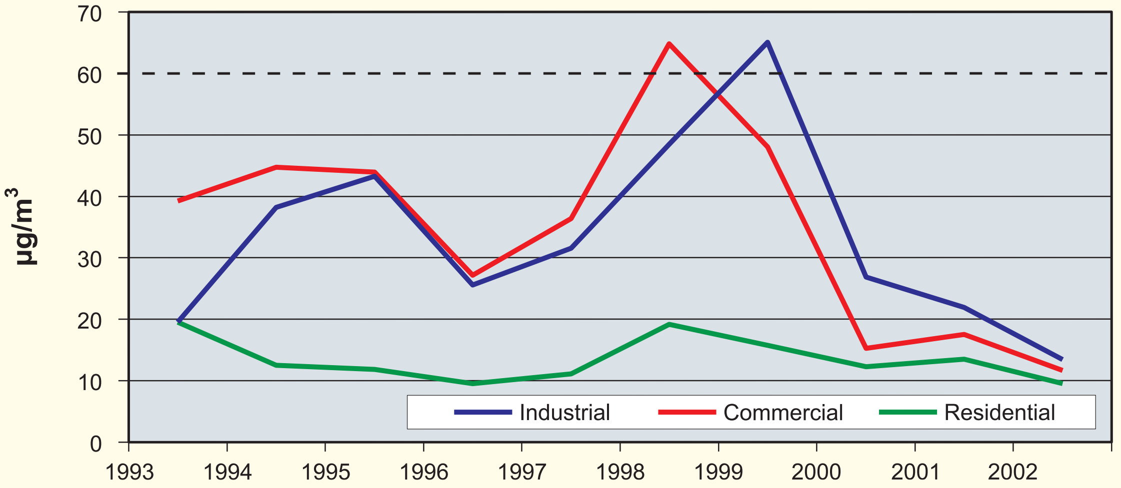
Figure A5B.6: Trend in SPM levels in three areas of Kolkata



Notes: The dotted line shows the annual national ambient standard of 140mg/m³ for SPM for residential areas.

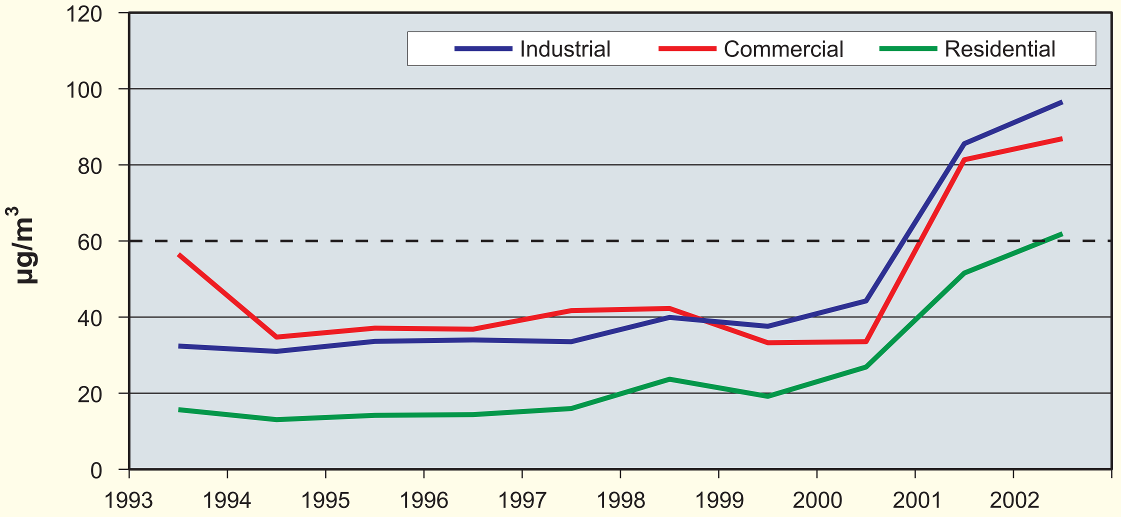
A large amount of data are missing between 1993 and 1997, including no data at the residential site for the entire year in 1997, when the monitoring site was being moved to another location. The first year in which some data are available for every month of the year in Kolkata was 1999.

Figure A5B.7: Trend in SO_2 levels in Kolkata



Note: The annual national ambient standard for SO_2 in residential area is 60 µg/m³.

Figure A5B.8: Trend in NO_2 levels in Kolkata



Note: The annual national ambient standard for NO_2 in residential area is 60 µg/m³.

Box A5B.4.: Major Technical and Policy Interventions in Kolkata (1991-2004) that Impacted Air Quality

Year	Action
1991	1) *Mass emission norms for new petrol vehicles introduced on 1/4/1991*
1992	N.A.
1993	1) In-use emission standards for smoke density on 26/3/1993
	2) *Mass emission standards for new diesel vehicles introduced on 15/9/1993*
1994	1) *Lead in petrol reduced to 0.15 gm/litre in June*
1995	1) In reference to the court case of Mr. M. C. Mehta versus Government of India, the Supreme Court directed air polluting industries to install air pollution control devices within a stipulated time period, failing which such industries will be liable for closure. The directions of the Court were implemented
	2) *Catalytic converters for 4-wheeled petrol drivenvehicles mandated with effect from April*
	3) *Unleaded petrol introduced to complement the introduction of catalytic converters*
1996	1) *Mass emission norms for new vehicles made more stringent on 1/4/1996*
	2) *Fuel Quality: 0.5% S diesel mandated in December*
	3) *Benzene in petrol reduced to 5%*
1997	1) Some buses of State Transport Corporation ordered off the road by the Calcutta High Court on grounds of air and noise pollution.
	2) Implementation of industrial siting policy restricting setting up of polluting industries (red category) in municipal areas of Kolkata Metropolitan, Authority (KMA)
1998	1) *Emission norms for catalytic converter fitted passenger vehicles from 1/4/1998*
	2) 0.25% Sulfur diesel mandated in Kolkatta Metropolitan Area from 1/4/1998
	3) *Low smoke 2T oil mandated*
	4) Environmental Bench of High Court ordered that before starting any project environmen tal clearance is mandatory, and the order was implemented.
1999	1) Euro-I (India 2000) norms in KMA with effect from 1/11/1999 for new private non commercial vehicles
	2) *Pre-mixed 2T engine oil made mandatory for two-wheelers with effect from 1/4/1999.*
2000	1) *India Stage-I (Euro-I) emission norms man dated for all category of new vehicles with effect from 1/4/2000*
	2) *Fuel quality: 0.25% S diesel mandated from 1/4/2000*
	3) *Leaded petrol phased out by February*
	4) Reduction of Benzene content in petrol to 3% in Kolkata from 1/4/2000
2001	1) *Bharat Stage-II (Euro-II) emission norms for all new non-commercial vehicles by July*
	2) *Low Sulfur petrol and diesel (0.05%) mandated from 1/7/2001*
	3) Introduction of stricter emission standard for boilers, ceramic kilns, foundries and rolling mills of KMA with effect from 11/5/2001
	4) Cleaner fuel made mandatory for boilers (< 2 ton/hr capacity), ceramic kilns and rolling mills
	5) All small boilers (steam generation capacity < 2 ton) of KMC area and ceramic kilns of KMA were directed to convert the boiler/ ceramic kilns to cleaner fuel (low Sulfur oil or gas) fired ones
	6) *Bharat Stage II (Euro-II) emission norms mandated for all new commercial vehicles with effect from 23/10/2001 in KMA*
	7) Supply, distribution and selling of loose 2T oil in KMA banned with effect from 1/10/2001
	8) *Emission norms for LPG vehicles intro duced from May 2001*
2002	1) Bharat Stage-II (Euro-II) emission norms for all commercial vehicles by October
	2) Regularly complying industries felicitated with the Environmental Excellence Award by SPCB and other cleaner production partners

Year	Action	Year	Action
	3) Emission norms for CNG vehicles (all categories) and LPG vehicles (heavy duty) with effect from May 2002 and October 2002 respectively		5) 5% ethanol blended gasoline mandated from January
			6) Supreme court order for preparation of Action plan for lowering ambient RSPM levels on 14/8/2003
2003	1) Most of the ceramic kilns and small boilers have been converted from coal fired to oil/gas fired system	**2004**	*1) Notification issued by Government of India revising the emission norms of in-use vehicles with effect from 1/10/2004.*
	2) Closure order has been given to the units not taken any step towards conversion from coal to cleaner fuel		
	3) About 67 percent of the coal fired boilers and about 78 percent of the coal fired ceramic kilns have already been converted to oil fired ones		
	4) Only LPG driven three wheelers are registered in Kolkata from June 2003		

N.A. – Not applicable

Notes : (1) Interventions common to all five cities are shown in italics. However, all common interventions were not implemented in the same year in all cities.
(2) Dates to be read as day/month/year.

Figure A5B.9: **Trend in RSPM monthly concentration at the residential, commercial and industrial area monitoring locations.**

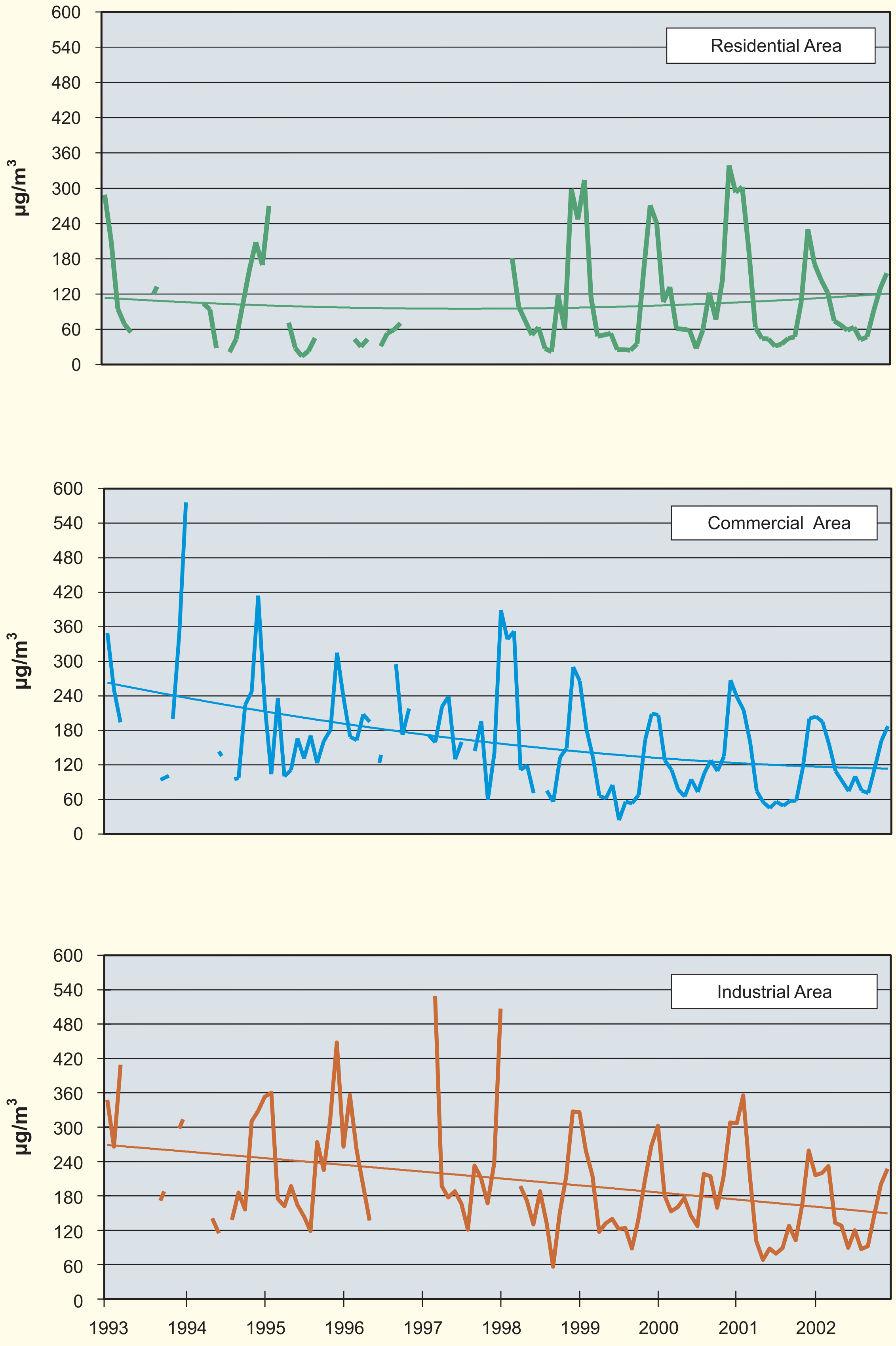


Figure A5B.10: **Monthly average total rainfall and mean wind speed**

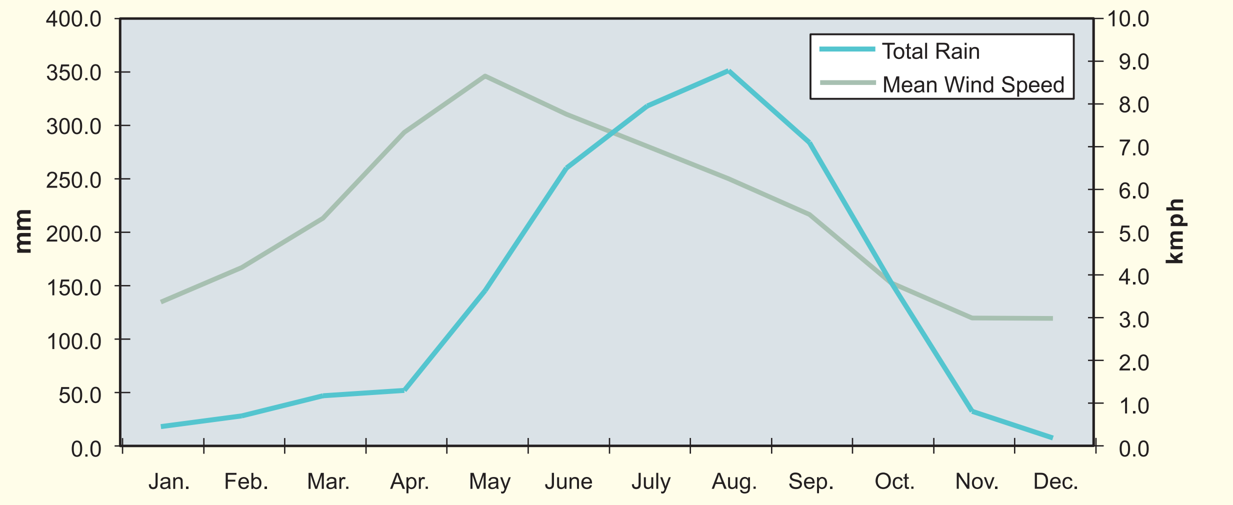


Figure A5B.11: **Monthly average total rainfall and RSPM concentration**

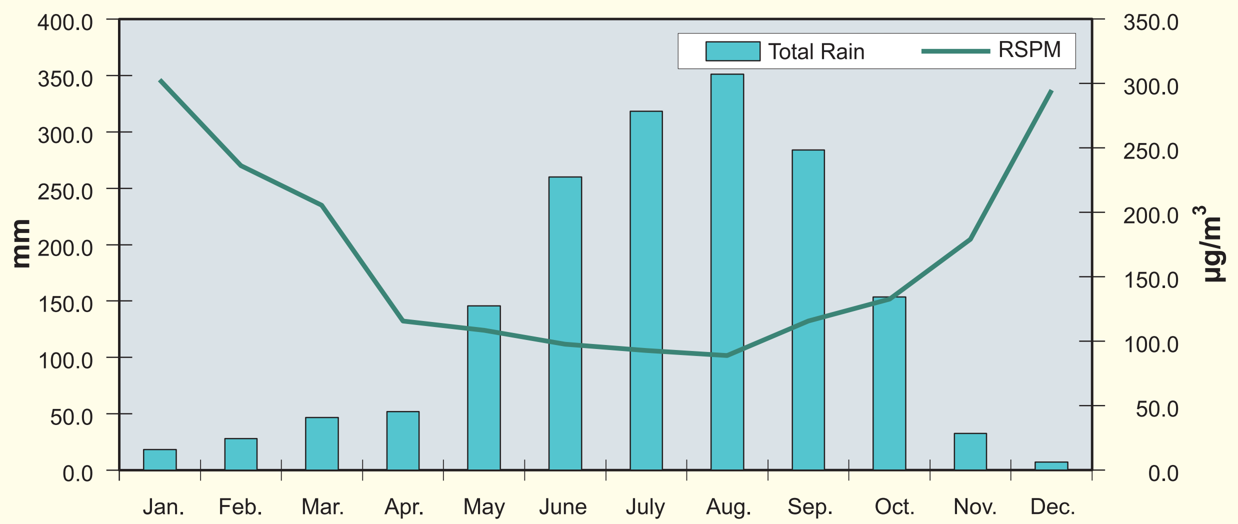


Figure A5B.12: **Monthly mean wind speed and RSPM concentration**

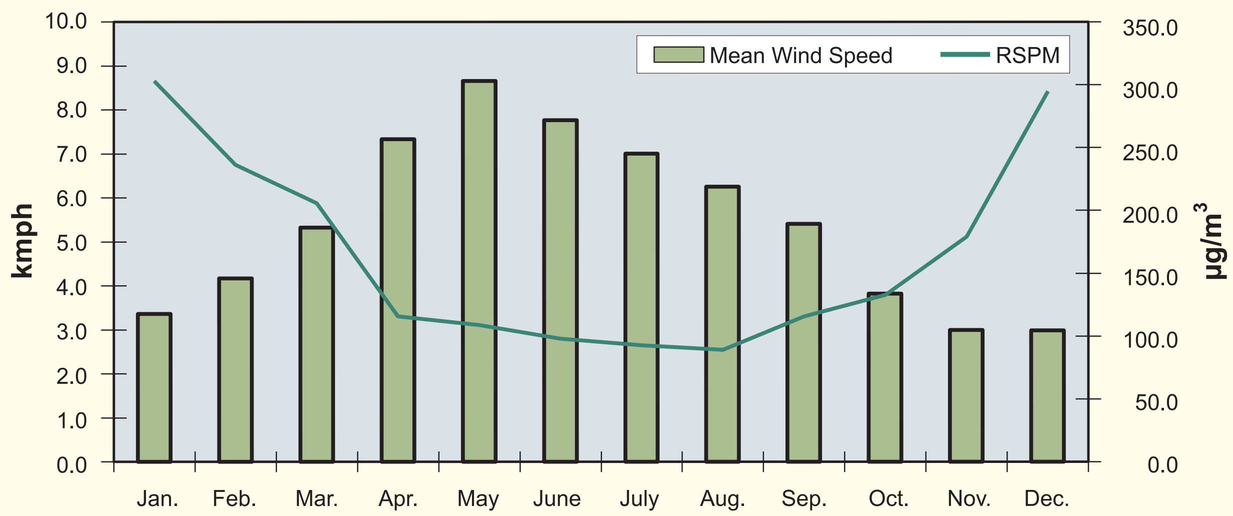
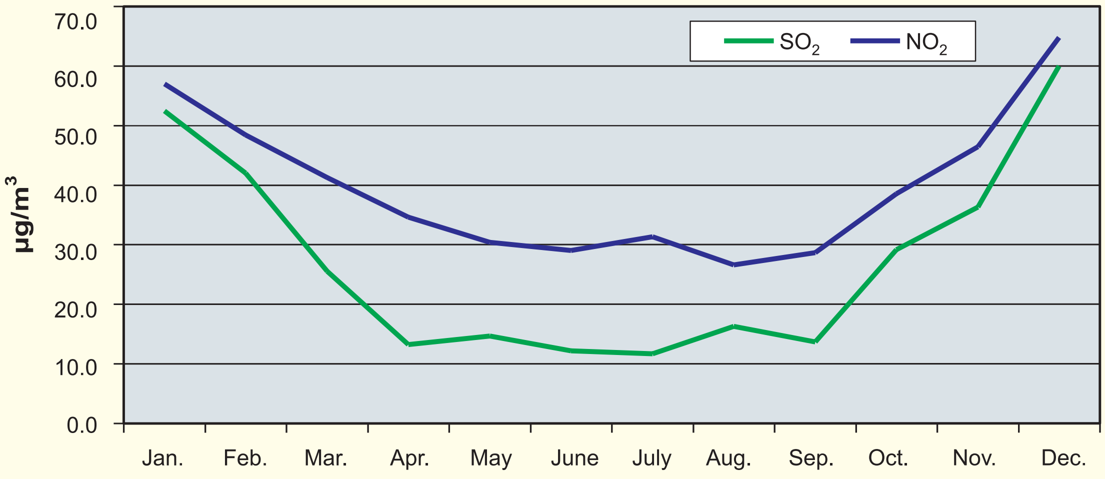


Figure A5B.13: Variation in monthly averages of SO_2 and NO_2.



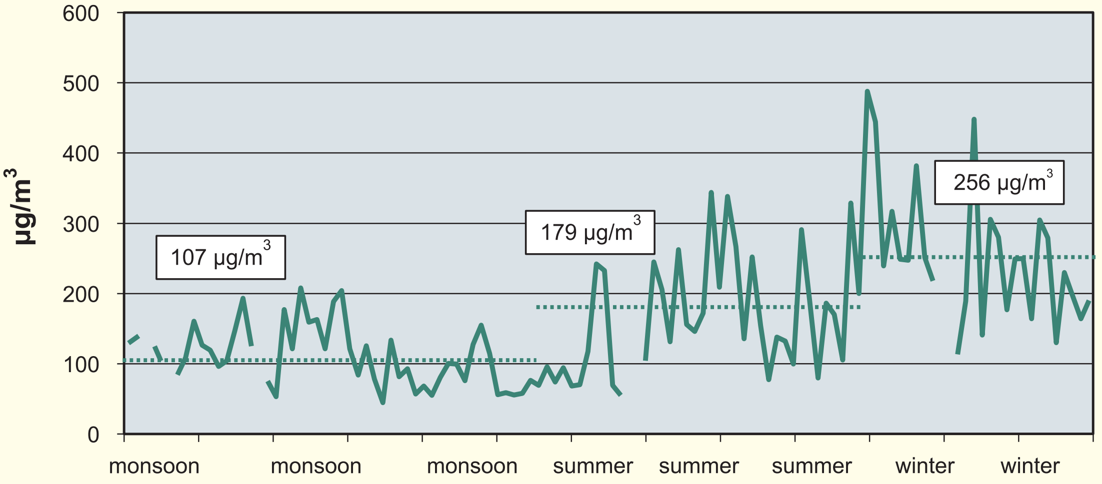
explanations for the increasing trend in NO_2 after 2000.

A5B.18 Figure A5B.9 shows the monthly average concentrations of RSPM at the three monitoring locations in Kolkata. However there are a lot of gaps in the data until 1998, which makes it difficult to draw meaningful conclusions concerning trends in the 1993 to 1998 period. Focusing on the data after 1998, Figure A5B.9 shows that RSPM levels in the residential area remained steady compared to the commercial and industrial areas, both of which showed a decreasing trend. The range of RSPM levels was large, with a maximum of about 600 µg/m³ and a minimum of about 20 µg/m³. However, the difference in RSPM levels across the three areas was not found to be significant (at the 10 percent level) as indicated by analysis of variance, indicating the possibility that sources of RSPM may be scattered across the city.

9. Seasonality

A5B.19 From empirical evidence, it is known that the two parameters that directly impact concentrations of pollutants are rainfall and wind speed,

Figure A5B.14: Overall variation in RSPM with seasons (Monsoon: May to October; Summer: February to April; Winter: November to January)



since higher precipitation leads to lower concentrations of pollutants, and higher wind speeds lead to better dispersion.

A5B.20 As can be seen in Figure A5B.10, relatively low wind speeds and rainfall are encountered in Kolkata for almost five months in a year. This is likely to lead to poor dispersion over that time period. An empirical classification (see endnote #21) of the dispersion conditions was attempted based on the meteorological data. It was found that good dispersion conditions exist from April to October, while poor dispersion conditions exist in the rest of the year. Further evidence of the effects of dispersion conditions can be seen in the monthly variation of RSPM.

A5B.21 As can be seen in Figure A5B.11 and A5B.12, there is a strong effect of meteorological parameters, with very high levels being recorded at the beginning and the end of the year.

A5B.22 As Figure A5B.13 demonstrates, SO_2 and NO_2 levels show a strong effect of meteorological factors. However, given the lower winter temperature compared to southern states, the high RSPM and gaseous pollutant levels are also likely to be confounded by increased solid fuel use for domestic heating purposes.

A5B.23 The commonly used definitions of summer, winter, and monsoon seasons were used to aggregate the months, in order to further explore any seasonality in the variation of RSPM levels.

A5B.24 As can be seen in Figure A5B.14, effects of seasons are clearly evident. The averages for monsoon, summer, and winter months were 107 $\mu g/m^3$, 179 $\mu g/m^3$, and 256 $\mu g/m^3$, respectively.

A5B.25 Since the summer, winter, and monsoon classification shown is subjective in nature, the empirically derived classification of dispersion conditions discussed at the beginning of this section was also used to assess seasonality in RSPM variation. It was found that there was a strong effect of the two dispersion classifications. The RSPM averages for the good and poor dispersion classifications were 108 $\mu g/m^3$ and 242 $\mu g/m^3$, respectively.

Mumbai

1. Geographical location

A5C.01 Mumbai is situated on the Arabian Sea, with much of it being a low-lying plain at the mean altitude of sea level. The plain is flanked by two ridges of low hills on the east and the west. The western ridge terminates in Malabar hill which is the highest point in the city rising to 55 m above the sea level. Mumbai or Greater Mumbai with an area of 437 km^2, stretches longitudinally for 42 km (north to

Figure A5C.1: Approximate location of NEERI monitoring stations in industrial, commercial and residential areas.

Figure A5C.2: Population in Mumbai between the last two census periods (Pandey 2003)

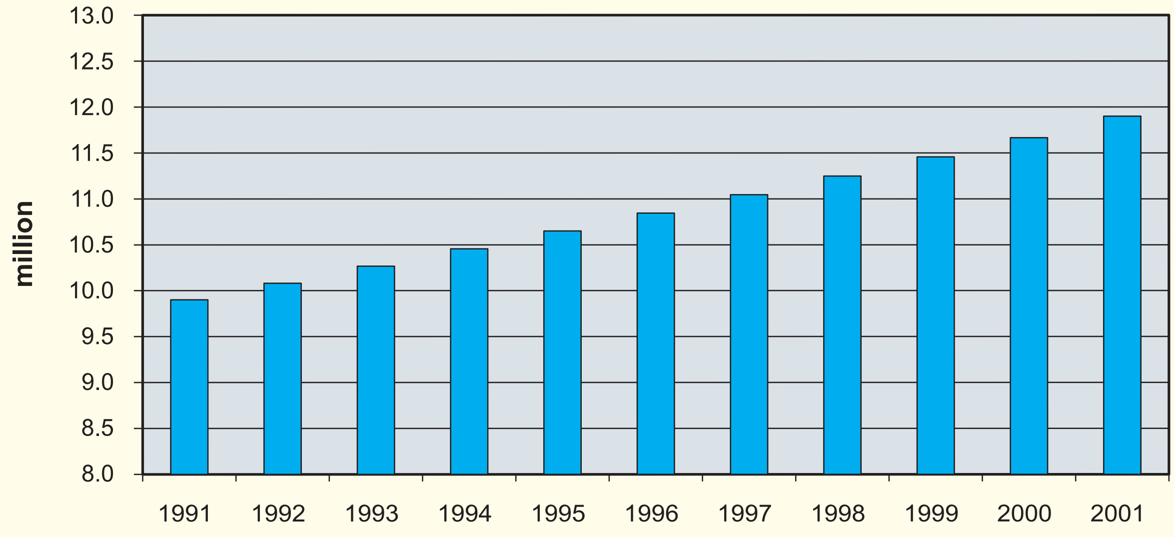


Table A5C.1: Overall monthly average values of key meteorological parameters

	Mean Max. Temp. (⁰C)	Mean Min. Temp. (⁰C)	Mean Wind Speed (kmph)	No. of Calm Days		Relative Humidity %		Total Rainfall (mm)
				0830 hrs	1730 hrs	0830 hrs	1730 hrs	
January	31.0	16.9	5.9	20	0	71	49	66
February	31.2	17.9	6.6	18	0	70	49	0
March	32.9	21.0	7.2	19	0	71	52	0
April	32.9	24.0	7.6	12	0	69	60	0
May	33.3	26.8	9.3	10	0	70	66	42
June	32.4	26.8	11.2	6	1	79	74	438
July	30.6	25.8	12.6	4	2	85	81	777
August	30.3	25.4	11.3	7	1	86	80	484
September	30.8	24.8	7.0	17	2	85	76	354
October	33.3	23.9	5.7	22	1	76	66	115
November	33.8	21.3	5.3	15	1	63	53	8
December	32.4	18.1	5.1	18	1	64	50	3
Total/year				169	11			2287

Note: Data on calm days and relative humidity is collected twice a day.

Figure A5C.3: Growth in commercial motor vehicles in Mumbai (MoRTH 2003)

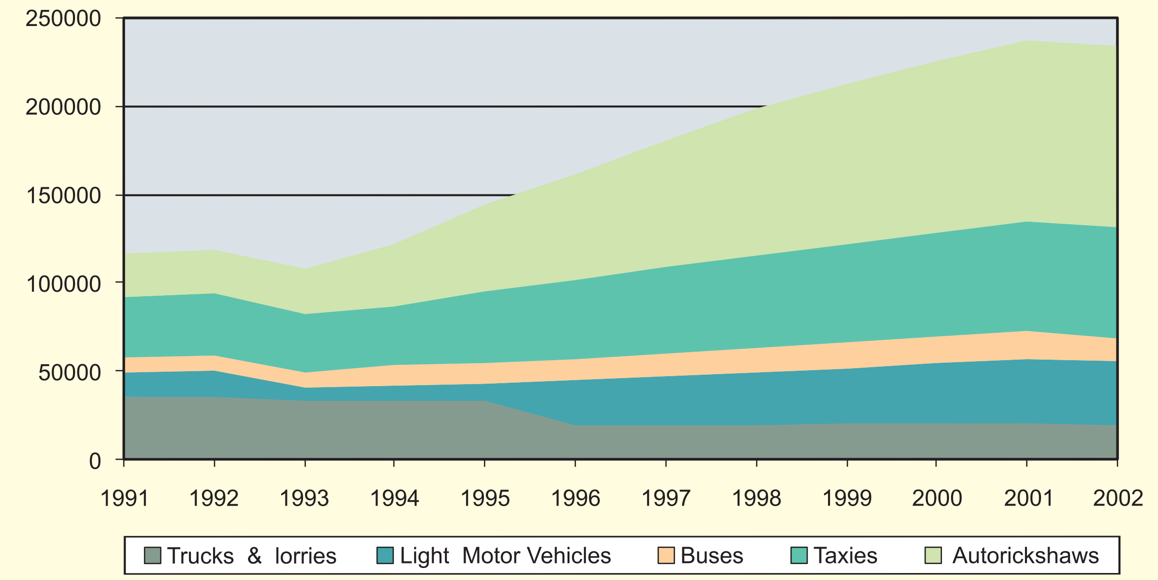
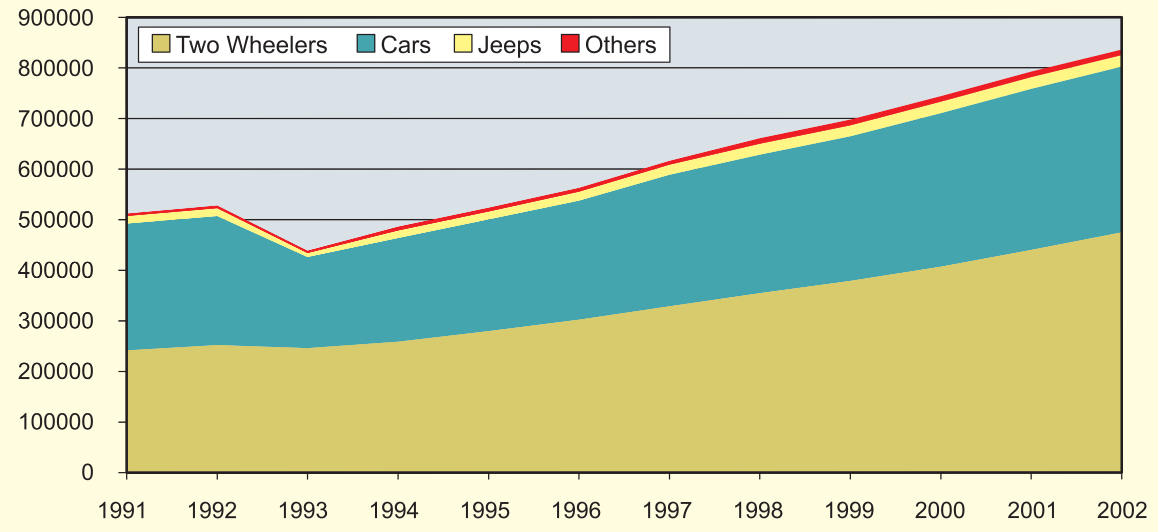


Figure A5C.4: Growth in private motor vehicles in Mumbai (MoRTH 2003)



south) and has a maximum width of only 17 km (Bombay First 2004). Figure A5C.1 shows approximate location of NEERI pollution monitoring stations in Mumbai.

2. Demography

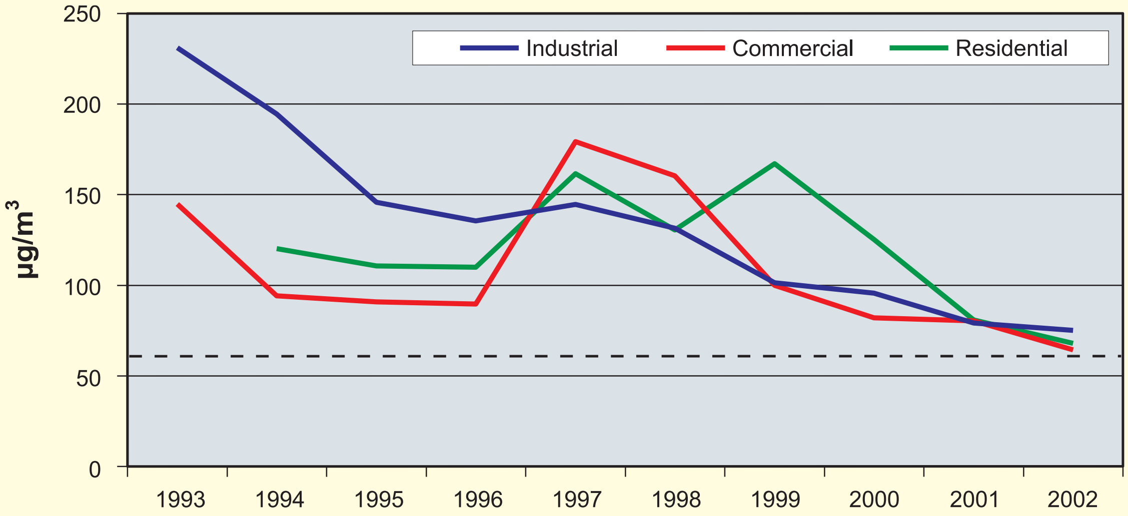
A5C.02 Mumbai accounts for 12 percent of Maharashtra's population and for 1.1 percent of the country's population. As per 2001 census, the population of Mumbai grew by 16.7 percent from 9.9 million in 1991 to 11.9 million in 2001. The annual growth rate of population during 1991-2001 was 1.9 percent.

A5C.03 Figure A5C.2 shows the population between the last two census counts. A possible reason of nearly constant population growth in the last decade could be the developments in surrounding areas of Mumbai and the declining rate of migration into city. The population density of urban area is 25,449 persons per km², making it one of the most densely populated cities in India. As of 1991, the average number of persons per household was 4.8 and the average number of persons living per room was 3.4 (Bombay First 2004).

3. Climate

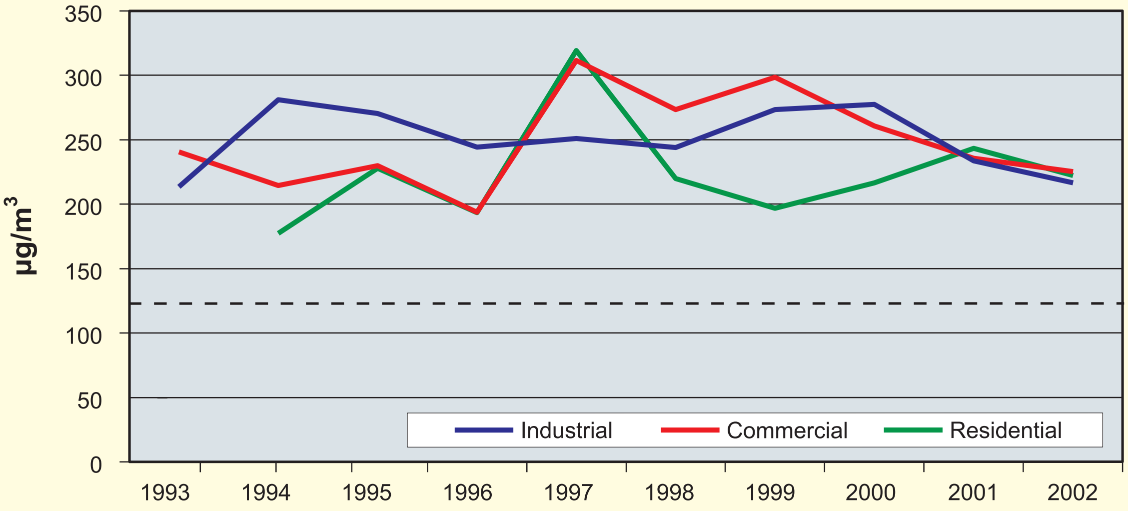
A5C.04 The weather profile in Mumbai between

Figure A5C.5: Trend in RSPM levels in Mumbai



Note: The dotted line shows the annual national ambient standard of 60 µg/m³ for RSPM for residential areas.

Figure A5C.6: Trend in SPM levels in Mumbai



Notes: The dotted line shows the annual national ambient standard of 140µg/m³ for SPM for residential areas.

There are missing data in 1993 and 1994. In particular, there are no data at the residential site except January in 1993 and for six months out of twelve in 1994. The monitoring equipment was replaced with new equipment from a different manufacturer in between 1998 and 1999. The residential site monitoring station was moved to another location in 2001.

1991 and 2002 is shown in Table A5C.1. The city experiences a warm tropical climate. The mean temperature ranges from 16.9 °C in winter (October to February) to 33.3 °C in the summer (March to May). Winds are generally moderate, but increase in force during monsoon months. The city receives heavy rainfall during monsoon (June to September). Calm conditions prevail generally in the morning hours, but the winds pick up in the evening. The relative humidity is higher in the morning hours, complementary to calm conditions.

4. Economy

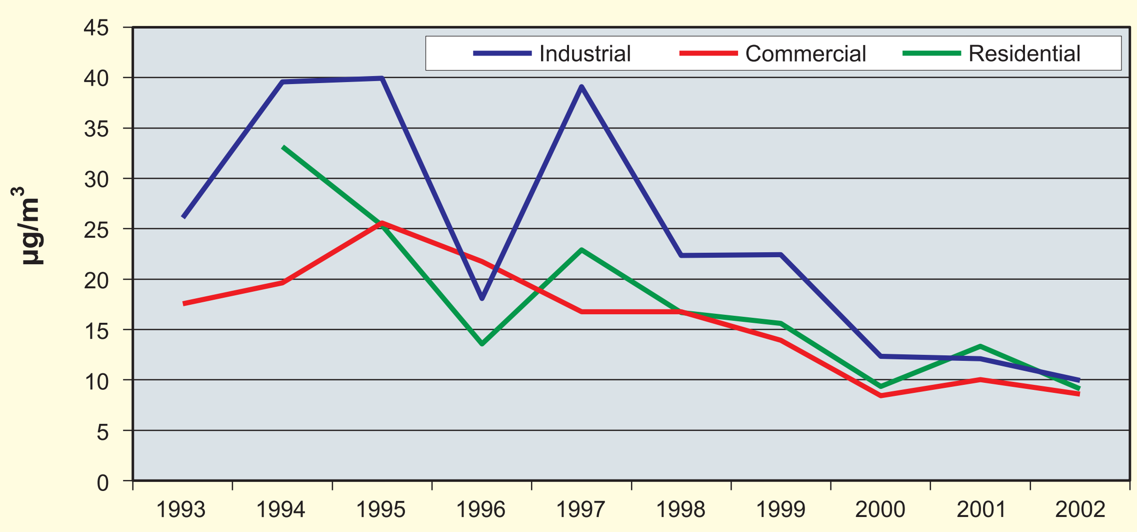
A5C.05 Mumbai's annual per capita income in 2000-01 was Rs 31,922, which was twice that of Maharashtra. At the same time, the GSDP was Rs 414 billion with the tertiary sector accounting for more than 60 percent of the income generated in Mumbai. Interestingly, while the share of the tertiary sector in the income of Mumbai has increased in the last decade, the share of the secondary and primary sectors (see endnote #20) has remained almost static (Bombay First 2004).

5. Industry

A5C.06 Most of the industries are located in the eastern and northeastern corridor of Greater Mumbai, with a few in the western region. The number of factories in Mumbai declined from 7,832 in 1991 to 6,986 in 1999, and so did Mumbai's share of factories in the state. As per the available fuel-use data for Mumbai the use of furnace oil (which is used mainly in industry) also declined from 1,441,888 to 1,352,567 kiloliters between 1998-99 and 2001-02. Among the large and medium industries in Maharashtra, while there was a slight increase in absolute numbers (1,069 to 1,129), overall there was a decrease from 44 percent to 34 percent in the number of industries located in Mumbai between 1993 and 2000. A large part of the decline was in the textile industry (Bombay First 2004).

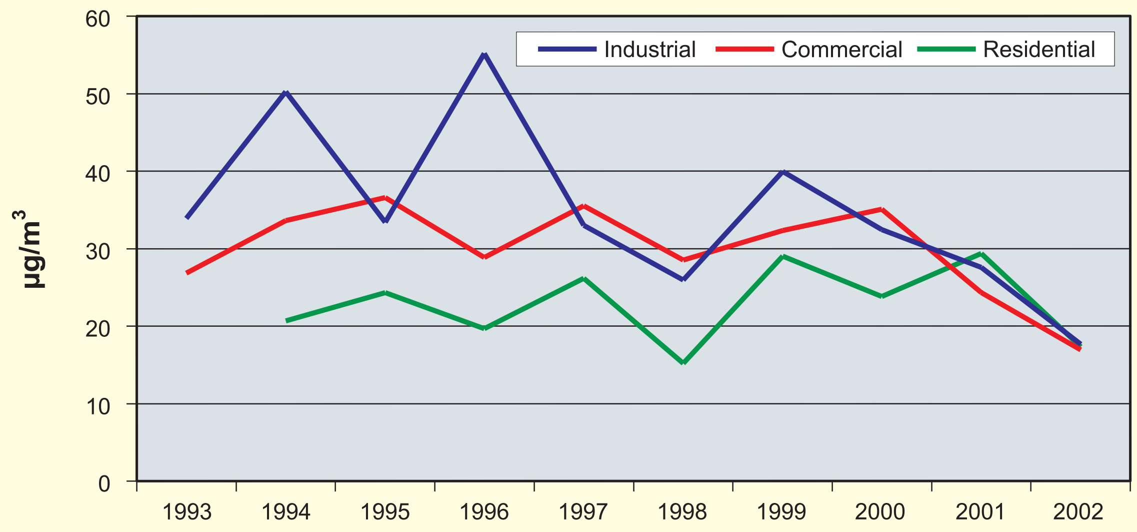
A5C.07 Industries in the air polluting category include textile mills, chemicals, pharmaceuticals, engineering, and foundries. Out of 183 air polluting industries in the Mumbai region, 70 are large scale, 37 are medium scale and 76 are of small scale. In addition, there are 32 stone crushers in the north-eastern parts of city, and a giant fertilizer/chemical complex and thermal power plant in Chembur. However, industrial fuel use has been shifting to

Figure A5C.7: Trend in SO_2 levels in Mumbai



Note: The annual national ambient standard for SO_2 in residential areas is 60 µg/m³.

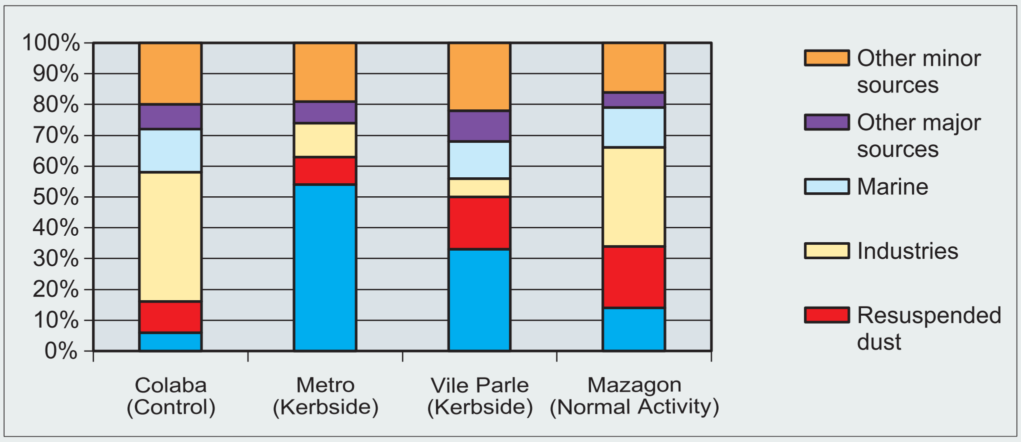
Figure A5C.8: Trend in NO_2 levels in Mumbai



Note: The annual national ambient standard for NO_2 in residential areas is 60 µg/m³.

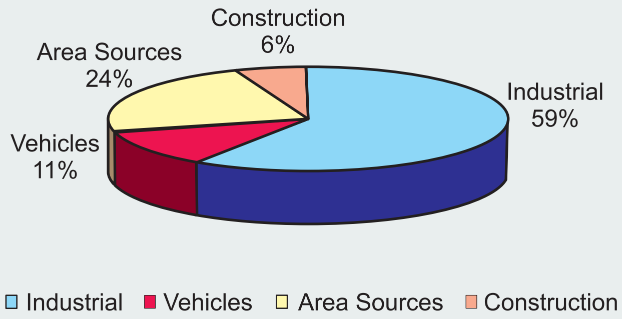
Box A5C.5: Results of RSPM Source Apportionment in Mumbai

As part of the World Bank funded Mumbai Urban Transport Project (MUTP), a source apportionment study based on dispersion modeling was conducted with a focus on RSPM emissions from vehicular sources. Air quality monitoring was conducted at various locations in Mumbai in 2001-2002 to cover areas with different levels of vehicular movement. While the methodology used for source apportionment was not state-of-the-art, and hence could not resolve all sources in detail, the results provide reasonable order-of-magnitude estimates of the contribution of different sources to RSPM levels, as shown below.



While the kerbside sites illustrate dominance of vehicular emissions, the control (an urban area with little activity away from any emission hot spot) and normal activity sites show that industrial sources can be major contributors to RSPM pollution in ambient air. Resuspended road dust seems to contribute significantly in all areas.

The study also used secondary data to construct an overall emissions inventory as shown below. It was estimated that out of the 16,550 tonnes of RSPM emission per year emissions from industrial sources dominated, followed by area sources, vehicles, and construction activities.



Reference: NEERI 2004

natural gas over the years. The number of industrial natural gas users increased from 0 to 40 between 1995 and 2002, while the number of commercial natural gas users increased to almost 420 in the same time period (Mahanagar Gas 2003).

6. Transport

A5C.08 Mumbai accounts for 17 percent of the vehicle population of the state and about 50 percent of the car population. The total number of vehicles in Mumbai in the year 2002 was close to 1.1 million. Their composition was 45 percent two-wheelers, 30 percent cars, 6 percent taxis, 6 percent heavy vehicles, 10 percent three-wheelers, and 3 percent other vehicles (jeeps, omni-buses, tractors, and trailers).

A5C.09 The bulk of the growth of vehicle population has been on account of two-wheelers and three-wheelers as can be seen in Figures A5C.3 and A5C.4. Since 1995 the number of trucks and lorries registered in Mumbai has shown a decreasing trend. The increasing trend in the number of light motor

Box A5C.6: Major Technical and Policy Interventions in Mumbai (1991 -2004) that Impacted Air Quality

Year	Action
1991	*1) Mass emission norms for new petrol vehicles introduced on 1/4/1991*
1992	*1) Mass emission norms for new diesel vehicles introduced on 1/4/1992*
1993	1) Policy framed to restrict the industrial growth in and around Mumbai called as "Mumbai Metropolitan Region"
1994	*1) Lead in petrol reduced to 0.15 gm/litre in June*
1995	*1) Catalytic converters for 4-wheeled petrol driven vehicles mandated with effect from April*
	2) Unleaded petrol introduced to compliment the introduction of catalytic converters
1996	*1) Mass emission norms for new vehicles made more stringent on 1/4/1996*
	2) Fuel quality: 0.5% S diesel mandated in December
	3) Benzene in petrol reduced to 5%
	4) Textile industries decline started after the strikes of textile workers
1997	1) CNG conversion of taxis started
	2) Construction of large number of flyovers started
1998	*1) Emission Norms for catalytic converter fitted passenger vehicles from 1/4/1998*
	2) Low smoke 2T oil mandated
	3) CNG conversion of taxis on a large scale
	4) Construction of flyovers continues
1999	1) Emission norms for tractors introduced
	2) Pre-mixed 2T engine oil made mandatory for two-wheelers
2000	*1) India Stage-I (Euro-I) emission norms mandated for all category of new vehicles by 1/4/2000*
	2) Fuel quality: 0.25% S diesel mandated from 01/04/2000
	3) Leaded petrol phased out in February
	4) Closure of bulk drugs and pesticides manufacturing units
	5) A number of industries were converted to natural gas available from a terminal near Mumbai
	6) Construction of flyovers ends (about 36 in number)
2001	*1) Bharat Stage-II (Euro-II) emission norms for all new non-commercial vehicles man dated by July*
	2) Low Sulfur diesel and petrol (0.05%) mandated
	3) Emission norms for LPG vehicles introduced from May 2001
2002	*1) Bharat Stage-II (Euro-II) emission norms for all commercial vehicles mandated by October*
	2) All taxis over the age of 15 years phased out, unless converted to run on CNG/ LPG
	3) All taxis of Premier 137D model phased out unless converted to run on CNG/LPG with effect from 1/3/2002
	4) All three wheelers over the age of 10 years phased out, unless converted to run on CNG/ LPG with effect from 1/3/2002
	5) 35,000 CNG vehicles plying
	6) Emission norms for CNG vehicles (all categories) and LPG vehicles (heavy duty) with effect from May 2002 and October 2002 respectively
2003	1) All taxis over the age of 8 years phased out, unless converted to run on CNG/LPG with effect from 1/1/2003
	2) Some 3-wheelers over the age of 8 years phased out or, converted to run on CNG/ LPG with effect from 1/1/2003
	3) All transport vehicles over the age of 15 years, with the exception of BEST buses, phased out or converted to run on CNG/ LPG with effect from 1/1/2003
	4) 5% ethanol blended gasoline mandated with effect from January 2003
	5) Supreme court order for preparation of Action Plan for lowering ambient RSPM levels on 14/08/2003
2004	1) All transport vehicles over the age of 8 years, with the exception of BEST buses, phased out or converted to run on CNG/ LP with effect from 1/2/2004
	2) Notification issued by Government of India revising the emission norms of in-use vehicles with effect from 1/10/2004.

N.A. – Not applicable

Notes: 1). Interventions common to all five cities are shown in Italics. However, all common interven tions were not implemented in the same year in all cities. 2). Dates to be read as day/month/year.

Figure A5C.9: **Trend in RSPM monthly concentration at the residential, commercial and industrial area monitoring locations**

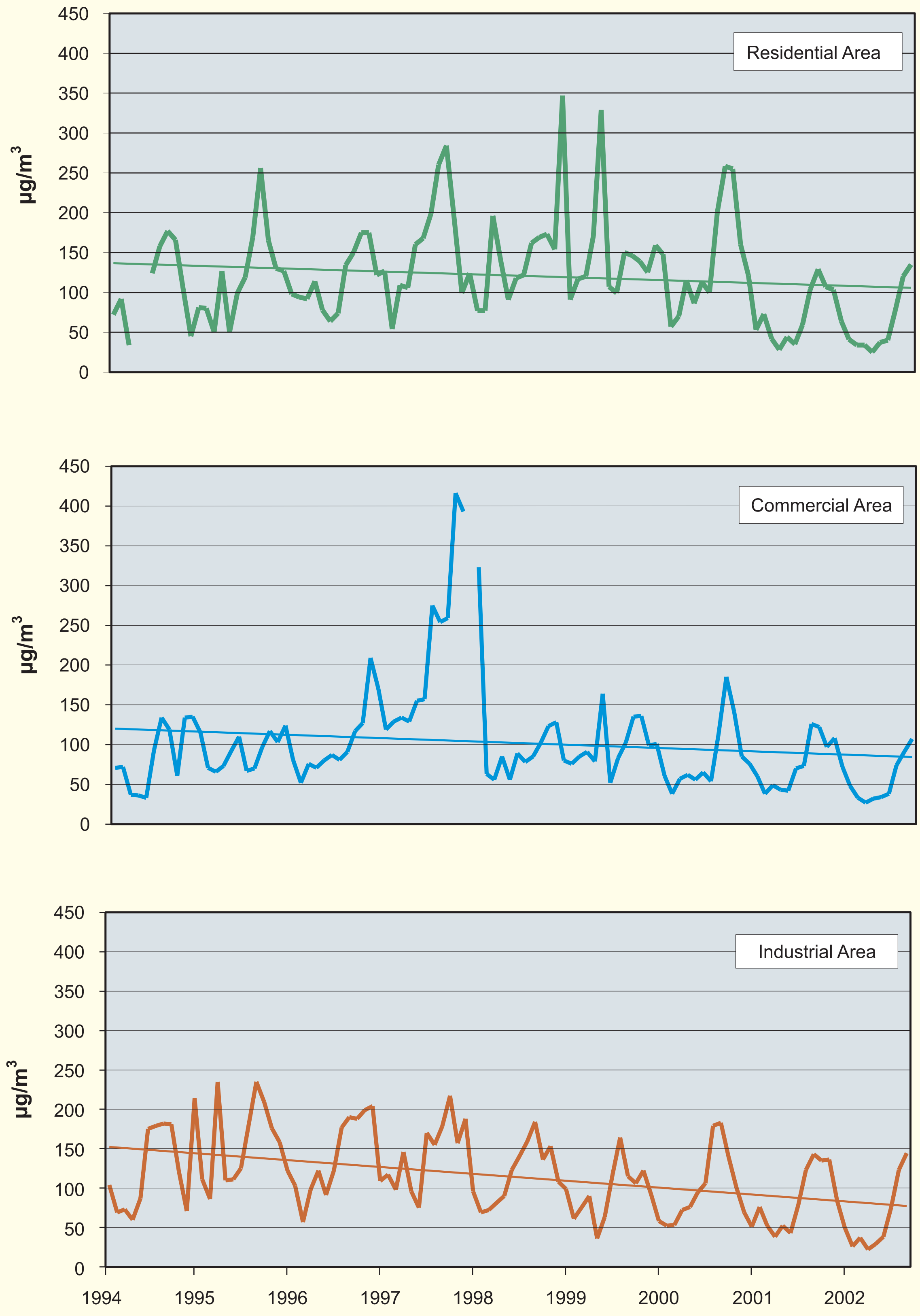
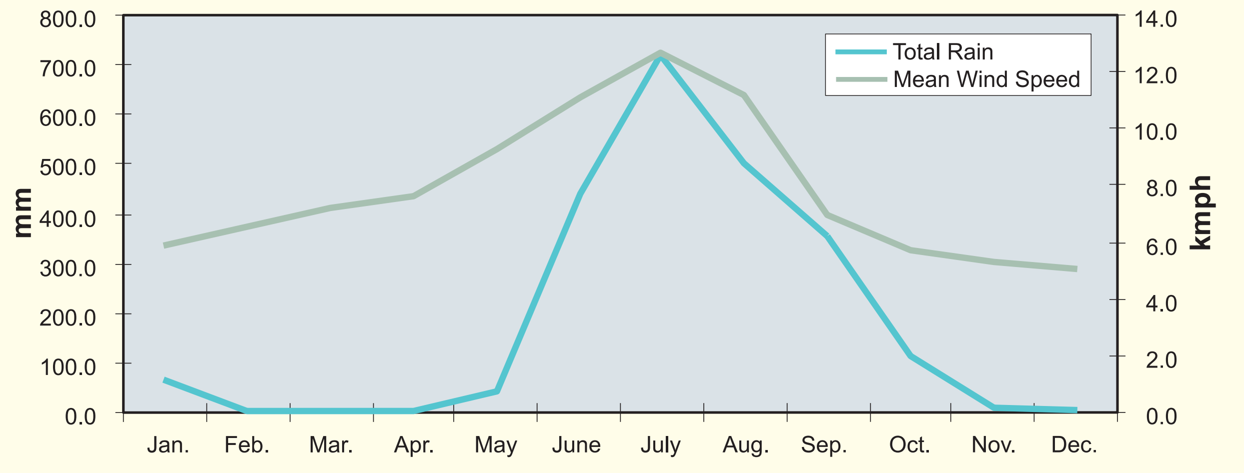


Figure A5C.10: Monthly average total rainfall and mean wind speed



vehicles, taxis and three-wheelers since 1993 seems to have stopped in 2001. However, two-wheelers and cars seem to have continued on a steep increasing trend. In addition to the vehicles registered within Mumbai, it is well known that a large number of commercial vehicles that ply in Mumbai are registered in the neighboring district of Thane.

A5C.10 The road network in Mumbai comprises three main corridors: Western Express Highway, Eastern Express Highway, and the Central Corridor. The total length of roads in Mumbai is 1,889 km (507 km in the city, 914 km in western suburbs, 468 km in eastern suburbs). However, the road network has become very congested over the years with increasing number of vehicles, and more people traveling to and from the city. As a result of the growing traffic congestion, Mumbai embarked on a very aggressive program of flyover construction, and 36-odd flyovers were constructed between 1997 and 2000.

A5C.11 It is acknowledged that vehicular emissions contribute significantly to the air pollution in Mumbai. Various initiatives, some voluntary and others mandated, have been implemented in Mumbai in the last few years to address vehicular emissions, as shown in Box A5C.6. One of the major developments was the appointment of a committee (referred to as the Lal Committee) in December 1999, to look into various issues pertaining to air pollution in the city. This was in response to a Public Interest Litigation filed in the High Court (Smoke Affected Residents Forum Vs Municipal Corporation of Greater Mumbai and others). The recommendations of the Lal Committee have formed the basis of a number of interventions that have taken place in Mumbai since 1999 (NEERI 2004).

Figure A5C.11: Monthly average total rainfall and RSPM concentration

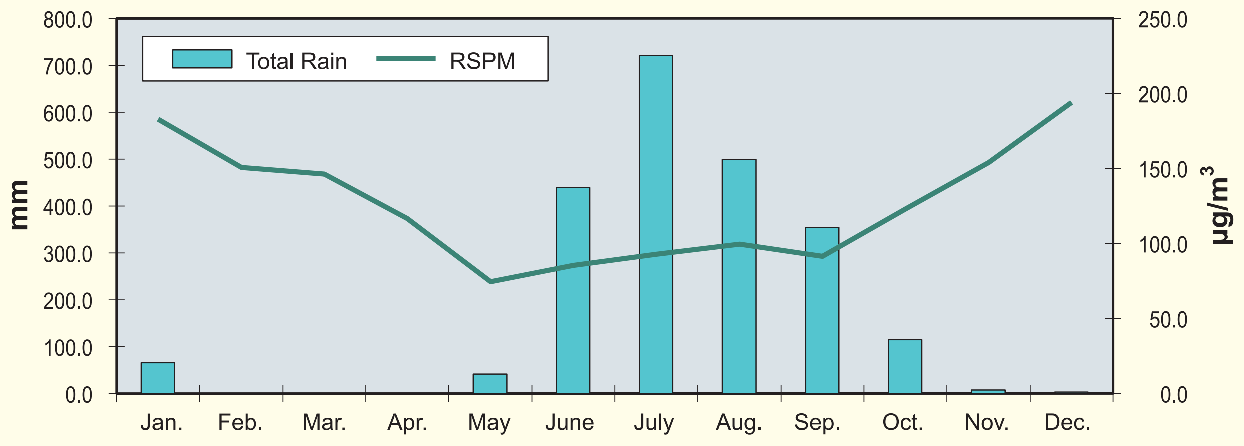
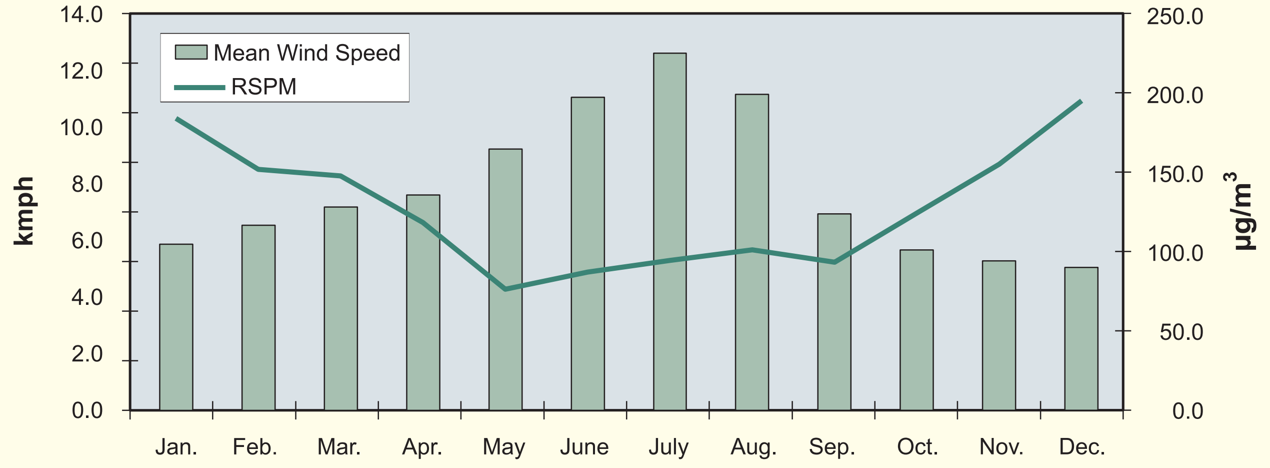


Figure A5C.12: Monthly mean wind speed and RSPM concentration



7. Urban

A5C.12 Mumbai was the first City Corporation to adopt the concept of a development plan. The land in the industrial zone are allowed to be used for residential/commercial purposes. The overall land use breakdown includes 44 percent residential area, 3 percent commercial area, 12 percent industrial area, and 41 percent no development zone. The land-use structure of Mumbai has undergone major changes in the past. Massive housing developments have been undertaken in previously non-urban belts along the western corridors. New district centers have emerged in the northern suburbs (BMC 2003).

A5C.13 The municipal limits of Mumbai come under the jurisdiction of the Brihan Mumbai Municipal Corporation (BMC). According to data between 1991-92 and 1995-96, the BMC maintained an operating ratio the ratio of revenue expenditure to receipts between 0.99 and 1.02, which is indicative of good financial health of the municipality. One of the major revenue stream for BMC is octroi (tax) collection, levied on goods coming into the city, which quadrupled from Rs 6.4 million in 1993 to Rs 25.6 million, and taxes on land and buildings also showed a steep increase in the same time period (as per the detailed financial operating plan of BMC). Both, octroi and taxes on land and buildings are also good indicators of economic growth of the city.

A5C.14 Capital expenditure on water works, drainage/sewage, solid waste management, roads, storm water drains, and street lighting more than doubled in between 1993 and 2002. The total (capital) expenditure on infrastructure increased

Figure A5C.13: Variation in monthly averages of SO_2 and NO_2

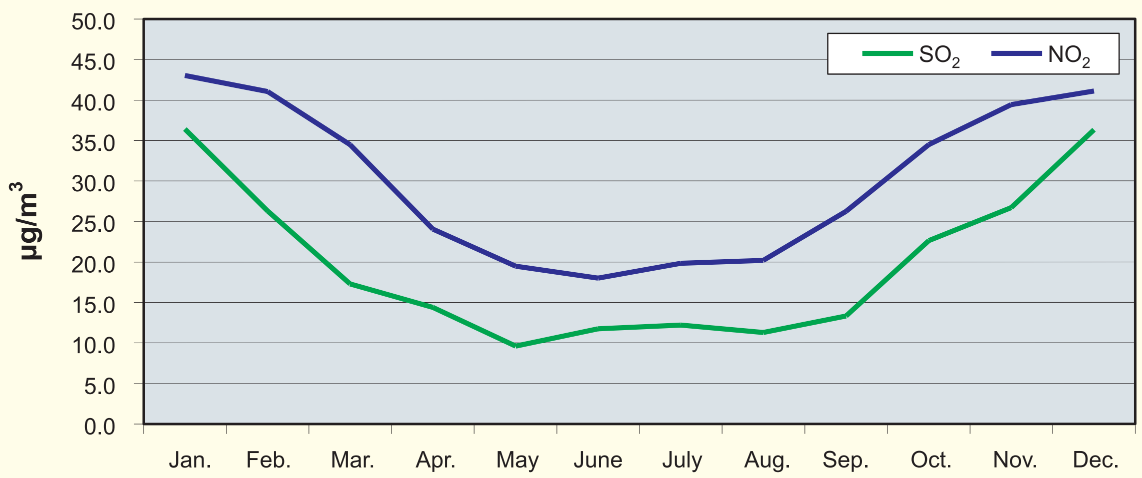
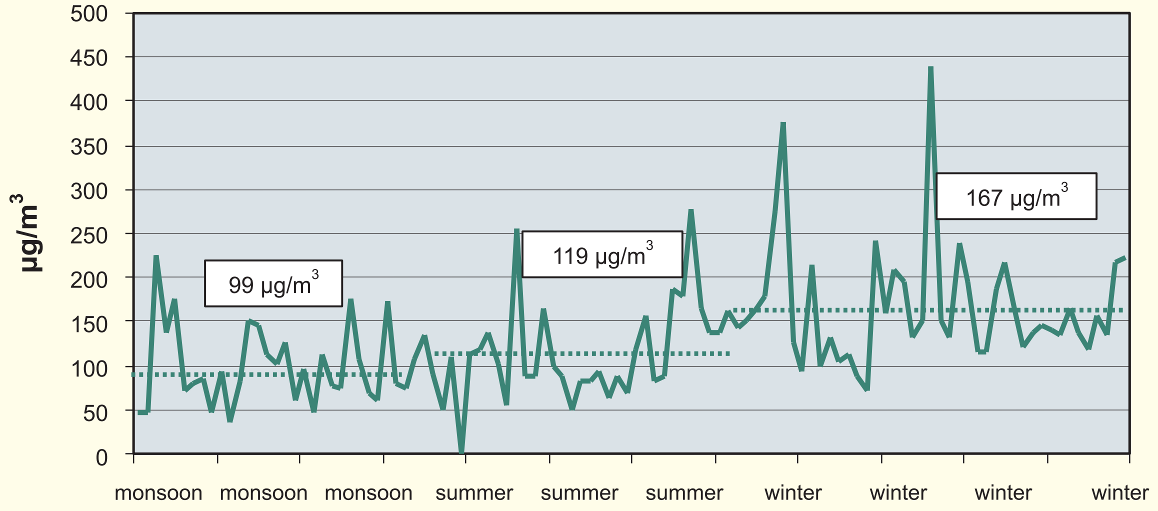


Figure A5C.14: Overall variation in RSPM with seasons (Monsoon: June to September; Summer: March to May; Winter: October to February)



significantly between 1997 and 1999. The major capital-intensive infrastructure development that happened during that period in Mumbai was the construction of 36-odd flyovers in the metropolitan area. This possibly contributed significantly to elevated concentrations of particulate matter on account of traffic congestions and the construction related activities.

8. Air Quality

Trends

A5C.15 Figures A5C.5 and A5C.6 show annual ambient RSPM and SPM concentrations, respectively, between 1993 and 2002 in the three different land-use areas. The RSPM levels declined between 1999 and 2002, with the levels in 2002 in all the three land-use areas reaching close to the annual national ambient standard of 60 µg/m³ for residential areas. The largest improvement in RSPM levels took place in the industrial area, indicating a possible systematic attrition of industrial source(s). However, SPM levels did not mirror the variation in RSPM, suggesting that the sources of RSPM and SPM may be different in Mumbai, especially given the large flyover construction program that was undertaken in Mumbai till 2000 (see Box A5C.6), or possible data quality problems. However, these findings need to be interpreted with caution given the 1998-1999 period also coincided with the replacement of RSPM samplers. Although NEERI reports cross-calibration with the previous samplers before deploying new ones to ensure consistency in measurements between the old and new instruments, the changes made were significant: the first generation samplers were developed in-house by NEERI while the second generation instruments were manufactured by a commercial manufacturer.

A5C.16 The average levels of SO_2 and NO_2 are shown in Figures A5C.7 and A5C.8. SO_2 tended to decline in all three areas; the levels of NO_2 showed greater fluctuation. A declining trend in NO_2 is not discernible until 1999 in the industrial and commercial areas.

A5C.17 Figure A5C.9 shows the monthly averages of RSPM between 1994 and 2002 in the three areas (1993 is excluded because of missing data for residential area). The maximum and minimum values vary quite a lot between the three areas. The overall maximum was just above 400 µg/m³, and the minimum about 20 µg/m³. However, the RSPM levels were not found to be significantly different between the three areas (at the 10 percent level) as indicated by analysis of variance results, suggesting that sources of RSPM may be similar in all three areas.

A5C.18 It is important to note that the sudden decline in the RSPM concentration in 2001 in the residential area coincides with a shift in the monitoring station from Bandra to Worli (see Annex 2). Further examination by overlaying the information in Box A5C.6 on the RSPM data indicates that the relatively high values between 1997 and 2000, as seen in Figure A5C.5, coincides with the period of a construction program for 36-odd flyovers.

9. Seasonality

A5C.19 From empirical evidence, it is known that the two parameters that directly impact concentrations of pollutants are rainfall and wind speed, since higher precipitation leads to lower concentrations of pollutants, and higher wind speeds lead to better dispersion.

A5C.20 As can be seen in Figure A5C.10, relatively low wind speeds and rainfall are encountered in Mumbai for almost four months in a year. This is likely to lead to poor dispersion over that time period. An empirical classification (see endnote #21) of the dispersion conditions was attempted based on the meteorological data. It was found that good dispersion conditions exist from June to October and in January, moderate dispersion conditions exist in April and May, and poor dispersion conditions exist in the rest of the year. Further evidence of the effects of relatively better dispersion over longer period of time can be seen in the monthly variation of RSPM.

A5C.21 While Mumbai gets a good strong sea breeze since it is located by the sea, it is worth noting that the monsoon months are also the months that experience strong winds, indicating that these two weather variables, both of which have an inverse relationship with air pollution, are in-phase in Mumbai.

A5C.22 The effects of rain and wind are evident in Figures A5C.11 and A5C.12. The same pattern of variation is seen with gaseous pollutants in Figure A5C.13, with the highs occurring in the winter months and lows occurring in the monsoon months. The effect of weather parameters was found to be consistent across all three land-use areas.

A5C.23 The commonly used definitions of summer, winter, and monsoon seasons were used to aggregate the months, in order to further explore any seasonality in the variation of RSPM levels.

A5C.24 Figure A5C.14 clearly shows effects of seasons. The averages for monsoon, summer, and winter months were 99 $\mu g/m^3$, 119 $\mu g/m^3$, and 167 $\mu g/m^3$, respectively. However, since the summer, winter, and monsoon classification is subjective in nature, the empirically derived classification of dispersion conditions discussed at the beginning of this section was also used to assess seasonality in RSPM variation. It was found that the effects of moderate dispersion classification were not distinctly different from those of good dispersion classification. The RSPM averages for the good, moderate, and poor dispersion classifications were 119 $\mu g/m^3$, 102 $\mu g/m^3$, and 167 $\mu g/m^3$, respectively.

Hyderabad

1. Geographical Location

A5D.01 The twin cities of Hyderabad and Secunderabad are located in Hyderabad district in the heart of the Deccan plateau in south-central India. The contour level falls gradually from west to east creating almost a trough near the Musi river which runs through the city (GoAP 2003a). Figure A5D.1 shows approximate location of NEERI monitoring stations at Hyderabad.

Figure A5D.1: **Approximate location of NEERI pollution monitoring stations in industrial, commercial and residential areas**

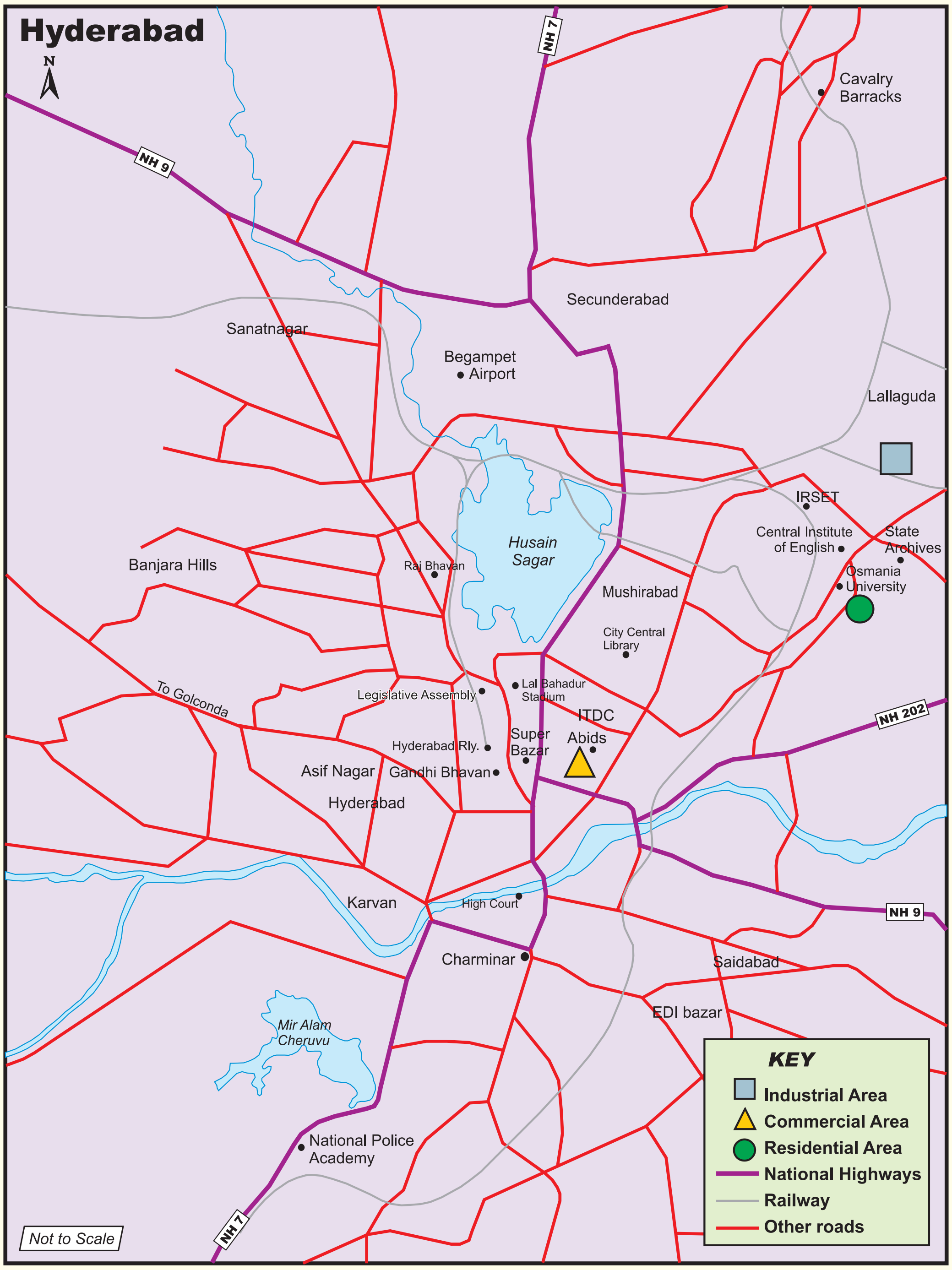
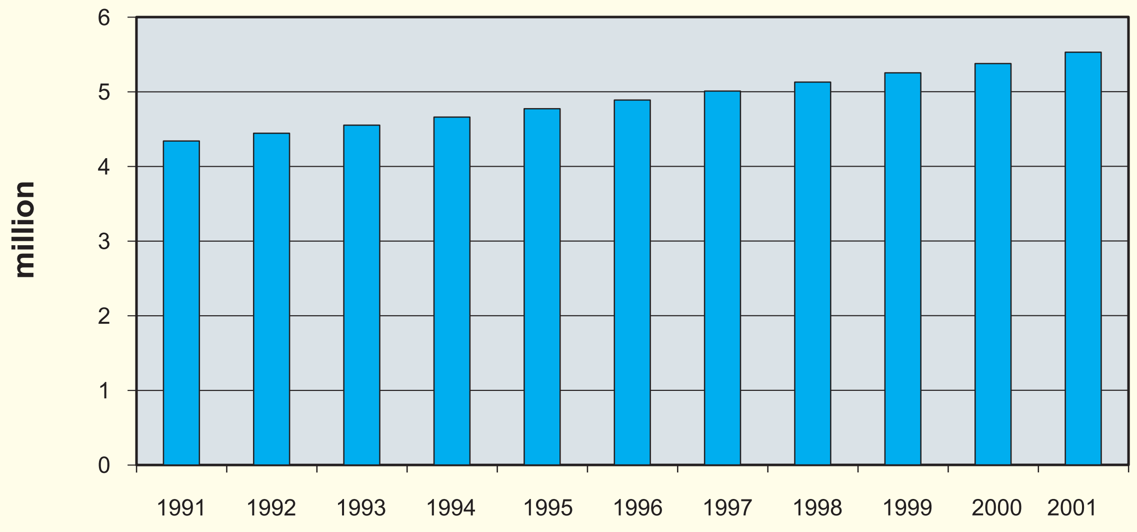


Figure A5D.2: Population in Hyderabad Development Area between 1991 and 2001 (Pandey 2003)



2. Demography

A5D.02 The Hyderabad Development Area includes 80 percent of the district of Hyderabad (173 km²), 20 percent of neighboring Ranga Reddy District (1526 km²), and 2 percent of neighboring Medak District (166 km²). The Municipal Corporation of Hyderabad (MCH) governs only Hyderabad district but accounts for approximately 65 percent of the population of the Development Area.

A5D.03 Figure A5D.2 shows the historical population in the Hyderabad Development

Table A5D.1: Overall monthly average values of key meteorological parameters

	Mean Max. Temp. (°C)	Mean Min. Temp. (°C)	Mean Wind Speed (kmph)	No. of Calm Days		Relative Humidity %		Total Rainfall (mm)
				0830 hrs	1730 hrs	0830 hrs	1730 hrs	
January	29.2	15.7	6.3	16	2	73	41	11
February	32.0	18.2	7.2	10	1	64	32	10
March	35.8	21.5	7.5	10	2	53	27	8
April	37.4	24.4	8.0	5	2	53	30	22
May	39.4	26.4	11.1	2	2	51	31	36
June	35.4	24.2	15.3	1	1	70	53	102
July	32.0	22.8	16.1	1	1	79	64	160
August	30.2	22.1	13.9	1	2	83	71	237
September	31.3	22.1	10.3	5	3	79	65	111
October	30.8	20.8	7.2	12	3	76	60	125
November	29.7	17.6	7.0	12	2	69	50	29
December	28.8	14.4	5.9	19	3	69	42	8
Total/year				93	25			859

Note: Data on wind speed and relative humidity is collected twice a day.

Figure A5D.3: Growth in commercial motor vehicles in Hyderabad (MoRTH 2003, GoAP 2003b)

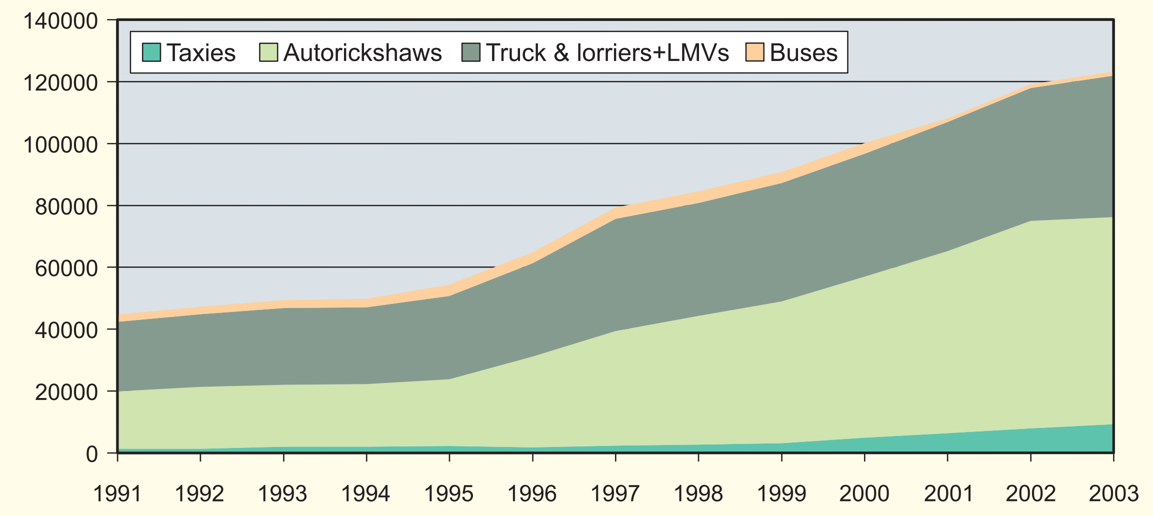
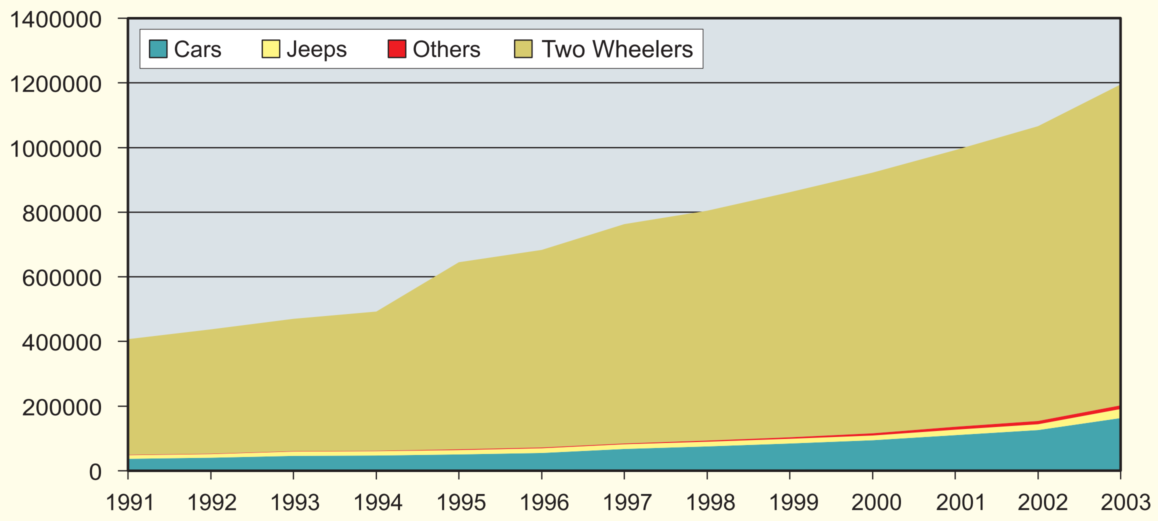


Figure A5D.4: Growth in private motor vehicles in Hyderabad (MoRTH 2003, GoAP 2003b)



Area, which grew from 4.34 million in 1991 to 5.53 million in 2001 at an annual growth rate of 2.41 percent. The decadal growth rate was more than 27 percent. At the same time, the population of MCH grew from 3.04 million to 3.43 million at a cumulative growth rate of 18 percent, indicating that the development area and surrounding municipality absorbed a large part of the growth in population. The population density of Hyderabad in 2001 was 19,930 persons per km^2.

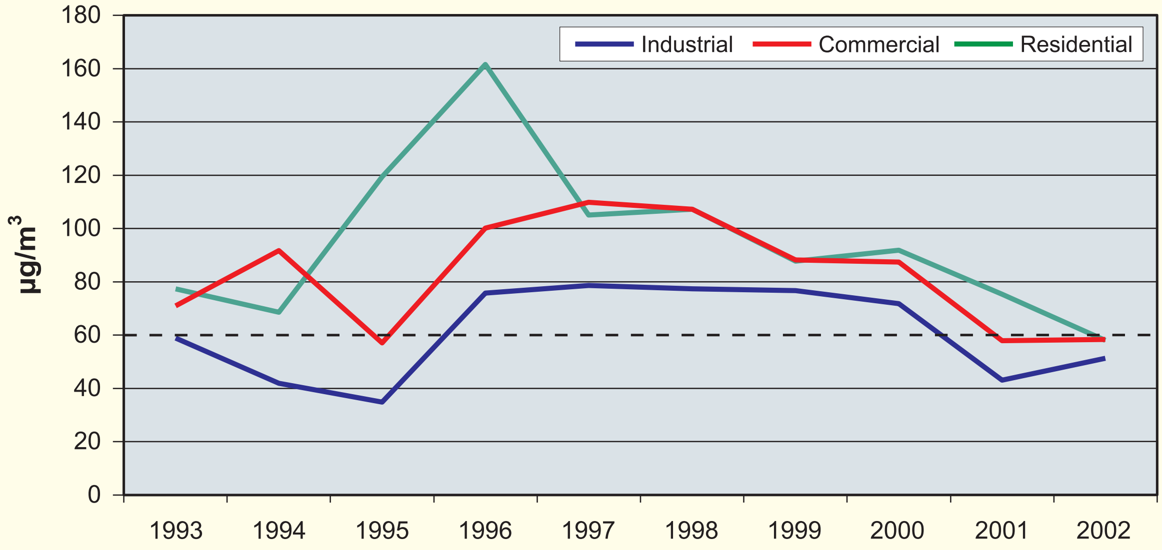
3. Climate

A5D.04 The weather profile between 1991 and 2002 in Hyderabad is shown in Table A5D.1. Hot steppe type climate prevails over Hyderabad. The mean monthly temperature varies from 14.4 °C in winter (November to January) to 39.4 °C in summer (February to May). The city receives rainfall in the monsoon months (June to October). Calm conditions mostly prevail in the morning hours, but the winds pick up later in the day. The period of relatively high wind speeds lasts for 10 months, barring December and January. The relative humidity is higher in the morning hours, complementary to calm conditions.

4. Economy

A5D.05 The percentage of main workers in the population of the MCH area in 2001 was 26.9 percent with a slight increase from the previous census of 1991 in which it was 26.6 percent. Almost 72 percent of the workforce in 1994 was employed in the service sector and about 18 percent in the

Figure A5D.5: Trend in RSPM levels in three areas of Hyderabad



Note: The dotted line shows the annual national ambient standard of 60 µg/m³ for RSPM for residential areas.

manufacturing industry. Of the rest, 8 percent were employed in the construction sector and the remaining in household industries and the agricultural and allied sector. The annual per capita income (1997-98) was Rs 10,590.

5. Industry

A5D.06 The city is characterized by an economic base that is now dominated by the service industry, primarily in the information technology (IT) sector. Earlier it had a highly diversified economic base with trading and manufacturing being the most important activities. The major industry sector besides IT includes cotton and silk textiles, cigarettes, paper, pottery, tourism, health services, electronics, and biotechnology. Amongst the polluting industries that remain in and around Hyderabad, pharmaceutical and bulk drugs, textiles, chemicals, and leather dominate. As per the categorization of the Andhra Pradesh (AP) Pollution Control Board, there were 333 air polluting industries in the larger Hyderabad Urban Development Area in early 2004, out of which 301 were meeting the emission norms (GoAP 2003a).

6. Transport

A5D.07 The number of vehicles more than doubled between 1992 and 2002, from .48 million to 1.08 million. The vehicular growth trends are shown in Figures A5D.3 and A5D.4. The percentage of two-wheelers in Hyderabad makes up around 75 percent of the vehicle population. Motor cars make up about 12 percent and three-wheelers another 5.5 percent of the vehicle population. The remaining population is made up of taxis, trucks and lorries, buses, and jeeps. However, like other cities in India, there is a significant difference between the number of vehicles registered and the actual number on the road, since vehicles retired or moved out of the city are not de-registered.

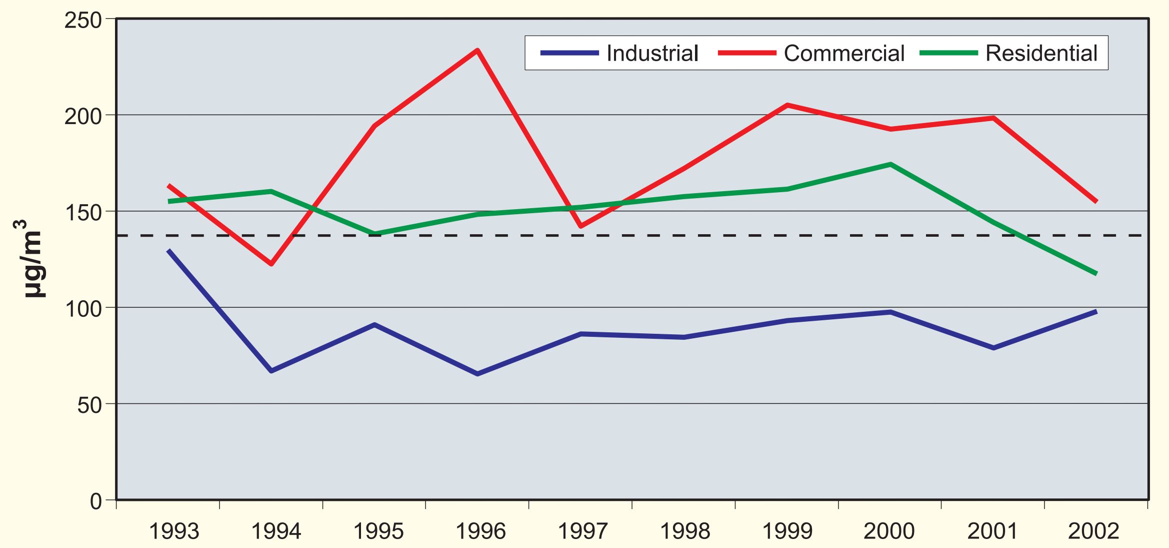
A5D.08 Motor vehicles are considered the major source of air pollution in Hyderabad, and most of the actions taken against air pollution in the city have focused on the transport sector, as illustrated in Box A5D.7. Traffic movement at the major traffic junction in the commercial area of Abids was rationalized in 2001 in order to ease congestion.

A5D.09 A public interest litigation was filed in the Andhra Pradesh Court on vehicular pollution in Hyderabad city in 1997, following a study that showed that 29 percent of those working at high traffic junctions were affected by respiratory problems. According to the SPCB, there is relatively higher increase in the number of respiratory patients than in the increase in human population or the number of vehicles (GoAP 2003a).

7. Urban

A5D.10 The existing land use for MCH area in 2000-2001 was 75.2 km^2 of residential and plotted area, 20.6 km^2 of commercial including mixed-use area, 3.07 km^2 of manufacturing area, 23.8 km^2 of

Figure A5D.6: Trend in SPM levels in three areas of Hyderabad



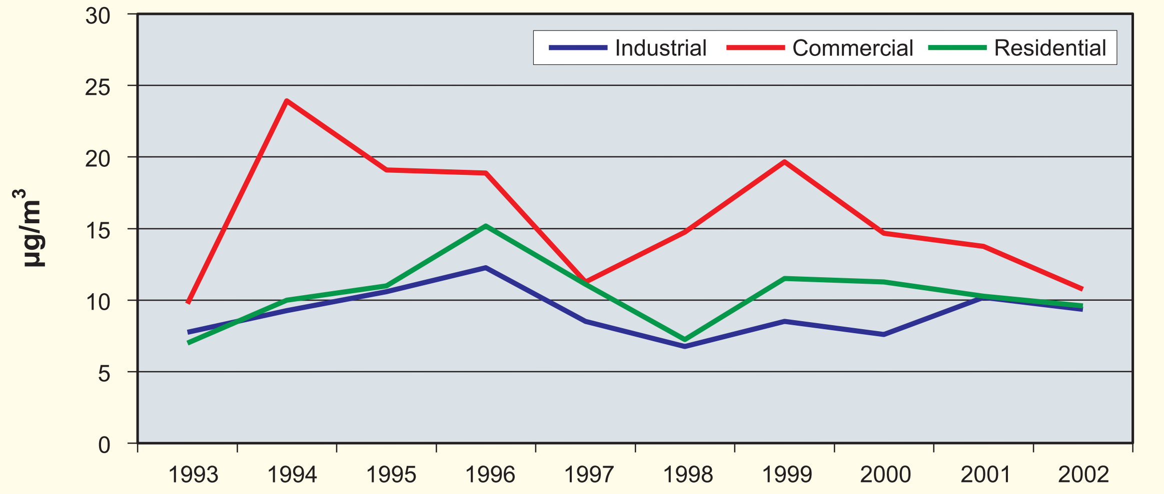
Note: The dotted line shows the annual national ambient standard of 140µg/m³ for SPM for residential areas.The three monitoring stations missed a few months of data collection in 1995–1997.

public and semi-public area, 7.6 km² of open area including urban forest area, 20.1 km² of agricultural and other areas, 8.6 km² of water bodies (8.63), and 13.5 km² area for transport and communications (HUDA 2003). Compared to 1998, the residential area increased by almost 9 percent and the commercial area increased by almost 2.7 percent.

A5D.11 The revenue of MCH increased from Rs 1.8 billion in 1998 to Rs 2.6 billion in 2001. The revenue receipts included taxes, fees and user charges, and income from estates and grants. Maintenance of civil works health and sanitation together accounted for about 75 percent of the revenue expenditure. Overall, the MCH had revenue savings of Rs 623 million (MCH 2003).

A5D.12 Hyderabad also won the Cleanest City award given by the Housing and Urban Development Corporation (HUDCO) and Government of India in 1999 and 2000. A noticeable feature of Hyderabad municipality is the sweeping of all major roads at night, which is likely to lower ambient concentrations of resuspended dust.

Figure A5D.7: Trend in SO_2 levels in Hyderabad



Note: The annual national ambient standard for SO_2 in residential area is 60 µg/m³.

Box A5D.7: Major Technical and Policy Interventions in Hyderabad (1991-2004) that Impacted Air Quality

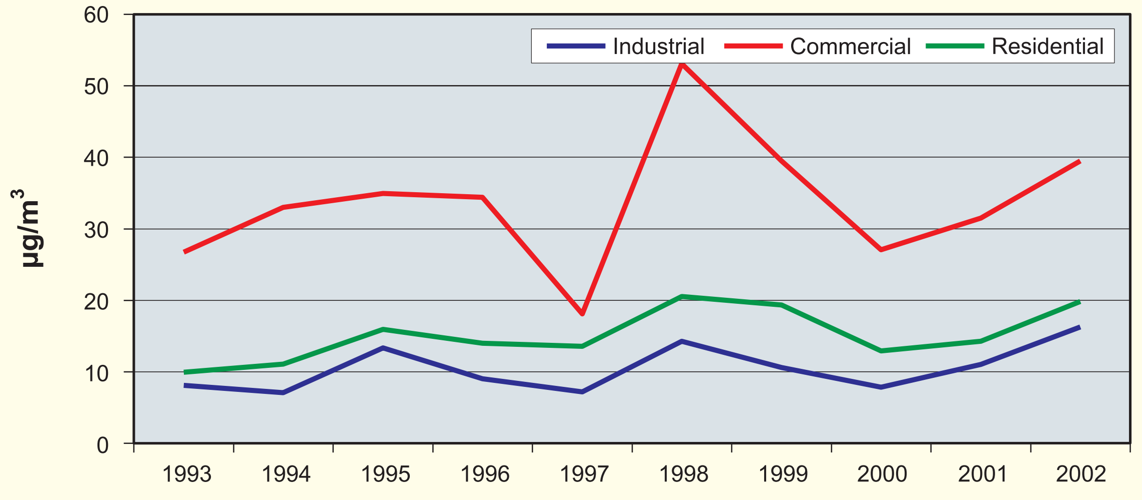
Year	Action
1991	*1) Mass emission norms for new petrol vehicles introduced on 1/4/1991*
1992	*1) Mass emission norms for new diesel vehicles introduced on 1/4/1992*
1993	N.A.
1994	N.A.
1995	N.A.
1996	*1) Mass emission norms for new vehicles made more stringent on 1/4/1996*
	2) Fuel quality: 0.5% S diesel mandated in December
	3) Benzene in petrol reduced to 5%
	4) Lead in petrol reduced to 0.15 gm/litre
1997	N.A.
1998	*1) Emission Norms for catalytic converter fitted passenger vehicles from 1/4/1998*
	2) Low smoke 2T oil mandated
	3) Catalytic converters for 4-wheeled petrol driven vehicles mandated with effect from April.
	4) Unleaded petrol introduced to complement the introduction of catalytic converters
1999	*1) Pre-mixed 2T engine oil made mandatory for 2-wheelers with effect from 1/4/1999*
2000	*1) India Stage-I (Euro-I) emissions norms mandated for all category of new vehicles with effect from 1/4/2000*
	2) Fuel quality: 0.25% S diesel mandated from 01/04/2000
	3) Leaded petrol phased out by February
	4) Construction of flyovers started.
	5) Action against air-polluting industries initiated.
2001	1) Construction of by-pass roads for heavy vehicles started
	2) Widening of roads undertaken
	3) Emission norms for LPG vehicles introduced from May
2002	1) Stopping of permit to new autorickshaws
	2) Emission norms for CNG vehicles (all categories) and LPG vehicles (heavy duty) with effect from May 2002 and October 2002 respectively.
2003	*1) Bharat Stage-II (Euro-II) emission norms for both new non-commercial and commercial vehicles mandated from 1/4/2003*
	2) Phasing out of old Government vehicles started
	3) Low Sulfur petrol & diesel (Sulfur 0.05%) mandated
	4) 5% ethanol blended gasoline mandated from January, 2003
	5) Introduction of LPG stations
	6) Insistence of the local administration to provide cover at the construction sites to avoid dispersion of dust
	7) Supreme court order for preparation of Action Plan for lowering ambient RSPM levels on 14/8/2003
2004	1) Introduction of Multi Modal Transport System
	2) Notification issued by Government of India revising the emission norms of in-use vehicles with effect from 1/10/2004.

N.A. – Not applicable

Notes: (1) Interventions common to all five cities are shown in Italics. However, all common interventions were not implemented in the same year in all cities.

(2) Dates to be read as day/month/year.

Figure A5D.8: Trend in NO_2 levels in Hyderabad



Note: The annual national ambient standard for NO_2 in residential areas is 60 µg/m³.

8. Urban Air Quality

Trends

A5D.13 Figures A5D.5 and A5D.6 show RSPM and SPM levels, respectively, between 1993 and 2002 in the three different land-use areas. The data collected at the monitoring stations run by NEERI show that the RSPM levels in 2001 and 2002 were generally below the annual national ambient standards for residential areas, and SPM levels were also meeting the annual residential area standard in 2002 except for the commercial monitoring site. However, it should be noted (see Annex 3A) that the data collected by SPCB do not show this trend. On the contrary, the ambient RSPM concentrations rose between 2001 and 2002, and remained above 80 µg/m³ on average at SPCB's three monitoring sites.

A5D.14 The sudden increase in levels in 1996 could be explained by the increased traffic congestion near the commercial area, which had become a major traffic junction, until the traffic flow was rationalized in 2001. It is worth noting that the levels of both pollutants in the industrial area were the lowest, and well below the national ambient standards for industrial areas in 2001 and 2002. In one sense, this is not surprising given that non-polluting industries occupy the area surrounding the site (see Annex 2). However, comparison of the 2001 and 2002 data at the industrial site with those collected at another industrial site not too far from it, SPCB's Uppal site, shows that the concentrations measured by NEERI are much lower. The overall trends in monthly averages from the NEERI and SPCB monitoring locations, shown in Figure A3A.12 in Annex 3A, tracked each other reasonably well till 2002 after which there seems to be a greater divergence in values. Regression analysis between the two datasets returned a R-squared value of 0.19. However, this result needs to be interpreted with caution since averaging across different monitoring stations can lead to calculation artifacts.

A5D.15 The average levels of SO_2 and NO_2 are shown in Figures A5D.7 and A5D.8. The values of both gaseous pollutants remained well below the national annual ambient standards for all land-use areas with no significant trends discernible. The commercial area showed the largest fluctuations for both gases, whereas the other two sites showed fairly steady SO_2 and NO_2 concentrations over the last 10 years.

A5D.16 Figure A5D.9 shows the monthly average concentration of RSPM at the three monitoring locations in Hyderabad. As can be seen in Figure A5D.9, RSPM increased between 1993 and 1996 and showed a decreasing trend after 2000 in all three areas. The overall maximum did

Figure A5D.9: **Trend in RSPM monthly concentration at the residential, commercial, and industrial area monitoring locations (trend line shown)**

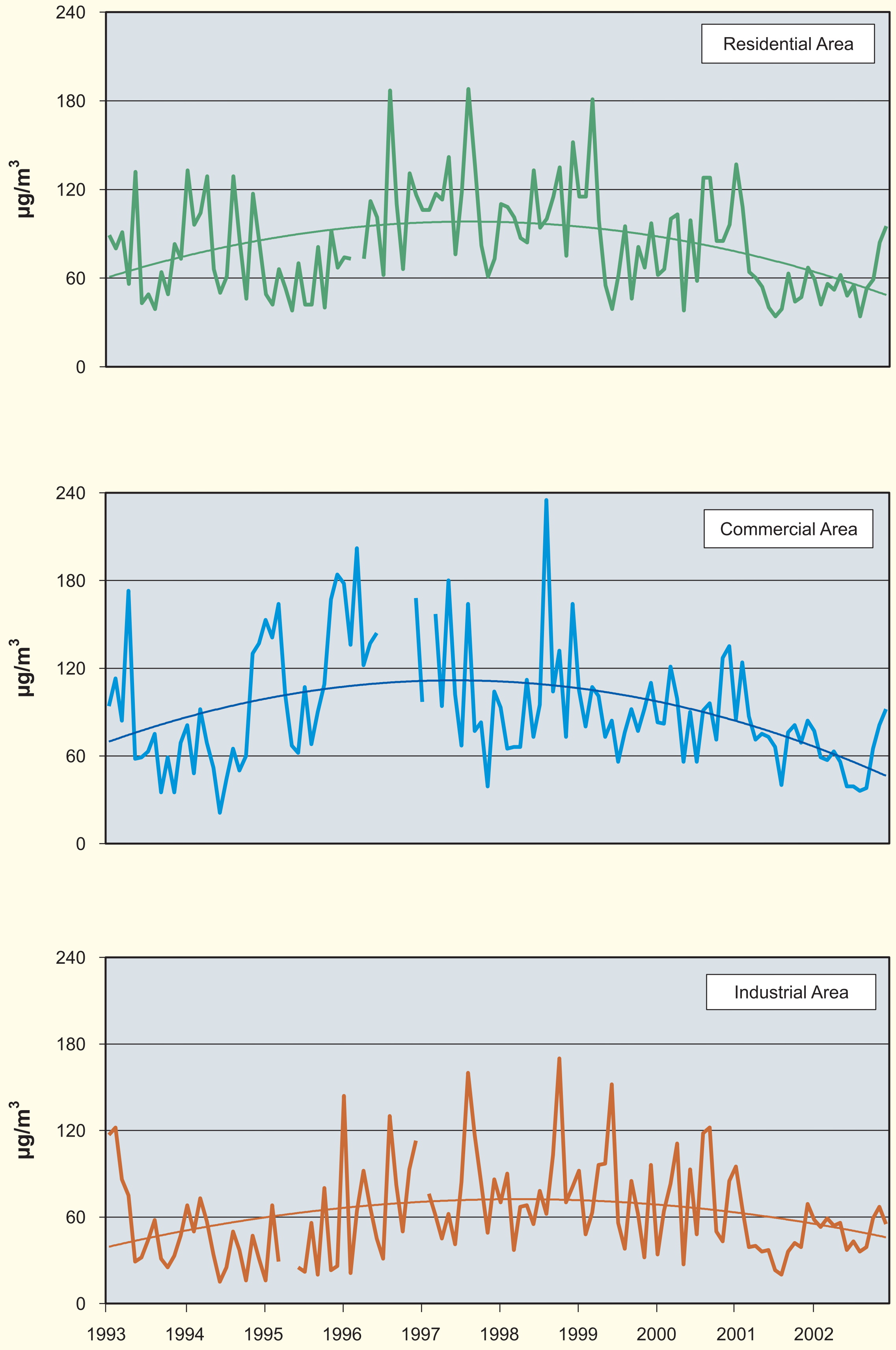


Figure A5D.10: Monthly average total rainfall and mean wind speed

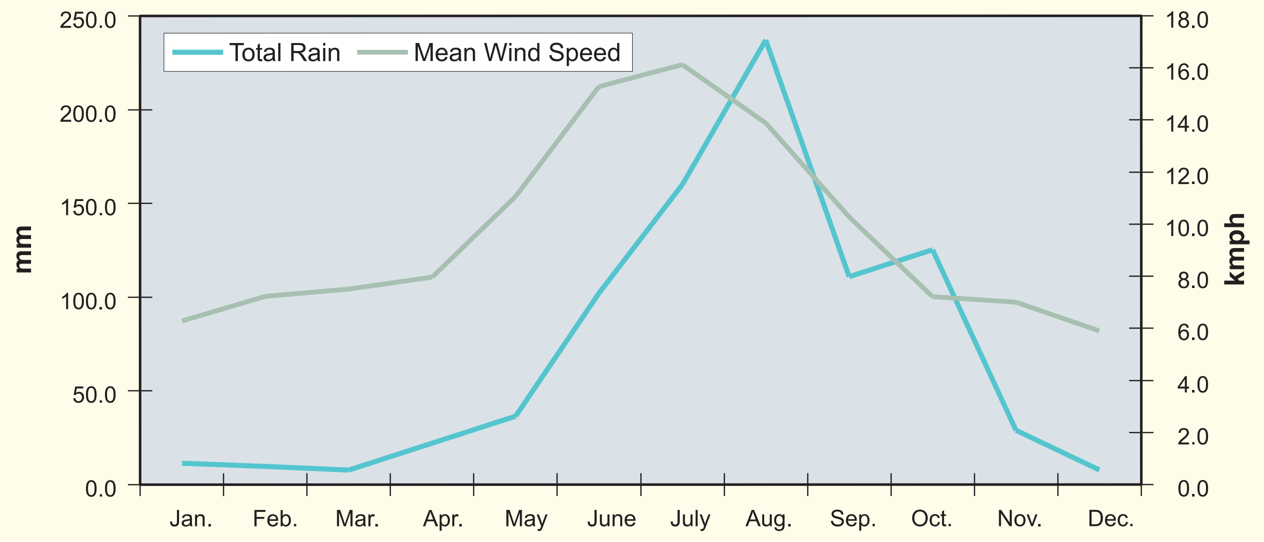


Figure A5D.11: Monthly average total rainfall and RSPM concentration

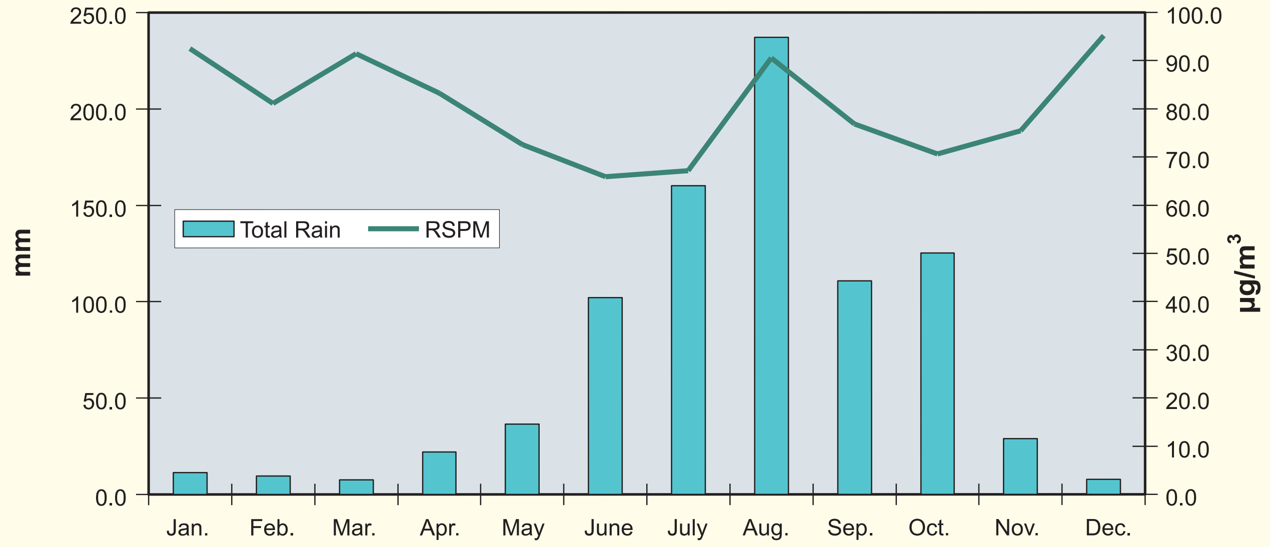


Figure A5D.12: Monthly mean wind speed and RSPM concentration

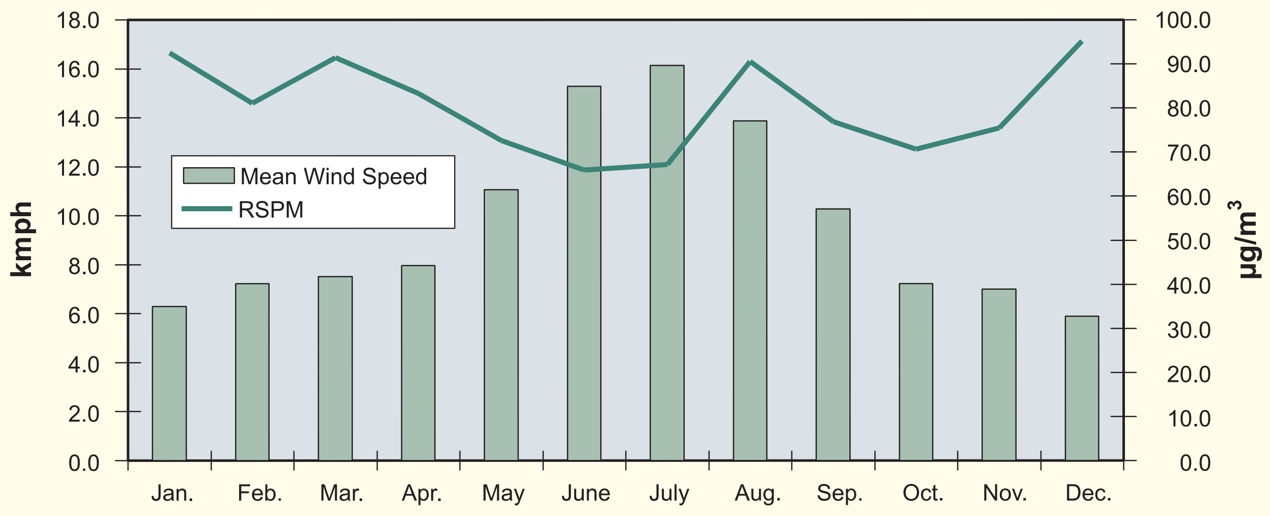


Figure A5D.13: **Variation in monthly averages of SO_2 and NO_2**

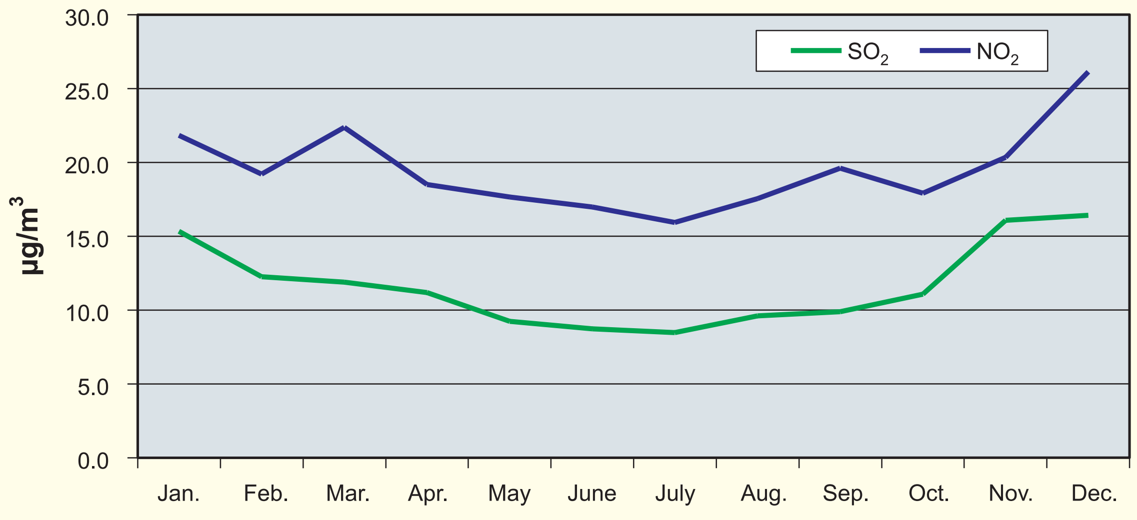
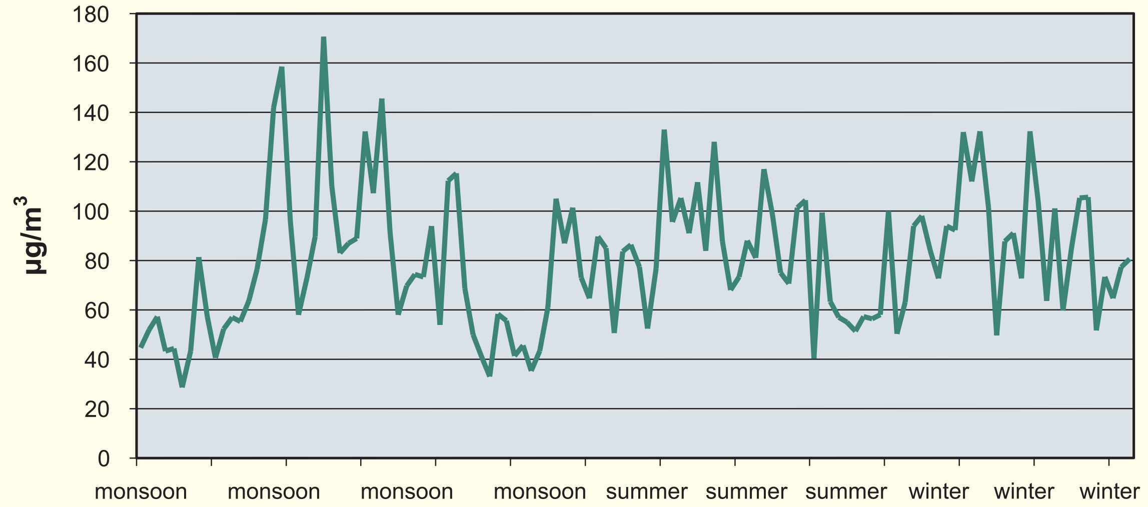


Figure A5D.14: **Overall variation in RSPM with seasons (Monsoon: June to October; Summer: February to May; Winter: November to January)**



not exceed 240 µg/m³, and the minima went down to approximately 20 µg/m³. The RSPM levels were found to be significantly different between the three areas (at the 10 percent level) as indicated by analysis of variance results, suggesting that sources of RSPM may not be the same in three areas.

9. Seasonality

A5D.17 From empirical evidence, it is known that the two parameters which directly impact concentration of pollutant are rainfall and wind speed, since higher precipitation leads to lower concentration of pollutants, and higher wind speeds leads to better dispersion.

A5D.18 Figure A5D.10 shows that relatively higher wind speed stays in Hyderabad for about 10 months of the year. This is likely to lead to better dispersion conditions over a longer period of time. An empirical classification (see endnote # 21) of the dispersion conditions was attempted based on the meteorological data. It was found that good dispersion conditions exist from May to October, while moderate dispersion conditions exist between January and April and November and December. Further evidence of the effects of relatively better dispersion over a longer period can be seen in the monthly variation of RSPM.

A5D.19 Figures A5D.11 and A5D.12 show that there is hardly any impact of the two meteorological parameters—total rainfall and mean wind speed—on ambient RSPM levels. However, if the RSPM level in August is excluded, a slight effect of wind speed and rainfall could be discerned. From

Figure A5D.13, it is seen that SO_2 and NO_2 show a small effect of meteorological factors, although the levels remain quite low in each month.

A5D.20 The commonly used definitions of summer, winter, and monsoon seasons were used to aggregate the months, in order to further explore any seasonality in the variation of RSPM levels.

A5D.21 As Figure A5D.14 shows, the effect of seasons is not strong. The averages for monsoon, summer, and winter months were 74 $\mu g/m^3$, 82 $\mu g/m^3$, and 88 $\mu g/m^3$, respectively. However, since the summer, winter, and monsoon classification shown is subjective in nature, the empirically derived classification of dispersion conditions discussed at the beginning of this section was also used to assess seasonality in RSPM variation. It was found that there was a small effect of the two dispersion classifications. The RSPM averages for the good and moderate dispersion classifications were 74 $\mu g/m^3$ and 87 $\mu g/m^3$, respectively.

Chennai

1. Geographical Location

A5E.01 Chennai district is situated in the north east of Tamil Nadu on the coast of Bay of Bengal. It stretches over an area of 174 km^2, for nearly 25.6 km along the coast. The city is intersected by two rivers, Coovam and Adyar, which pass through the center and north of the city, respectively, and enter the sea. Chennai city is a separate district, covering the Chennai Municipal Corporation area (NEERI 2003b).

Figure A5E.1: Approximate location of NEERI monitoring stations in industrial, commercial and residential areas

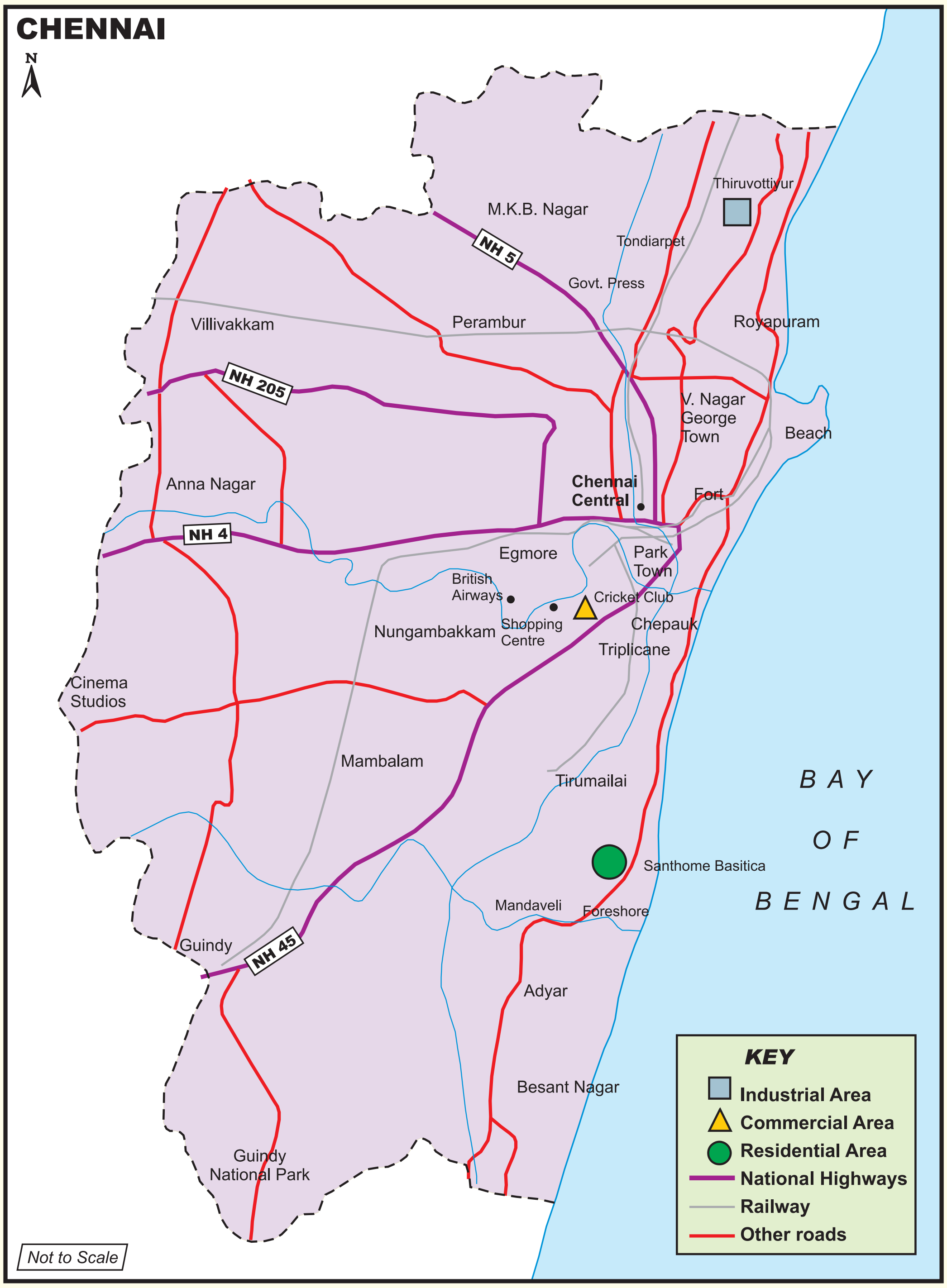


Figure A5E.1 shows a map of Chennai with location of NEERI pollution monitoring stations.

2. Demography

A5E.02 In 1991, the total population of Chennai Metropolitan area was 5.42 million which increased to 6.42 million in 2001 as a decadal growth rate of 18.4 percent. Figure A5E.2 shows the historical population in the Chennai Metropolitan area between 1991 and 2001. The population in Chennai city increased from 3.84 to 4.21 million during the same period, a growth of less than 1 percent per annum. Most growth occurred in the periphery and small and medium towns in the Metropolitan Area.

A5E.03 Chennai city was the most densely populated district in the state with 24,138 persons per km^2 compared to a 22,077 persons per km^2 in 1991. While this was mainly due to migration from other parts of the state and country, it also shows that much of the population growth took place in the larger metropolitan area which reflected a cumulative growth rate of 18.4 percent.

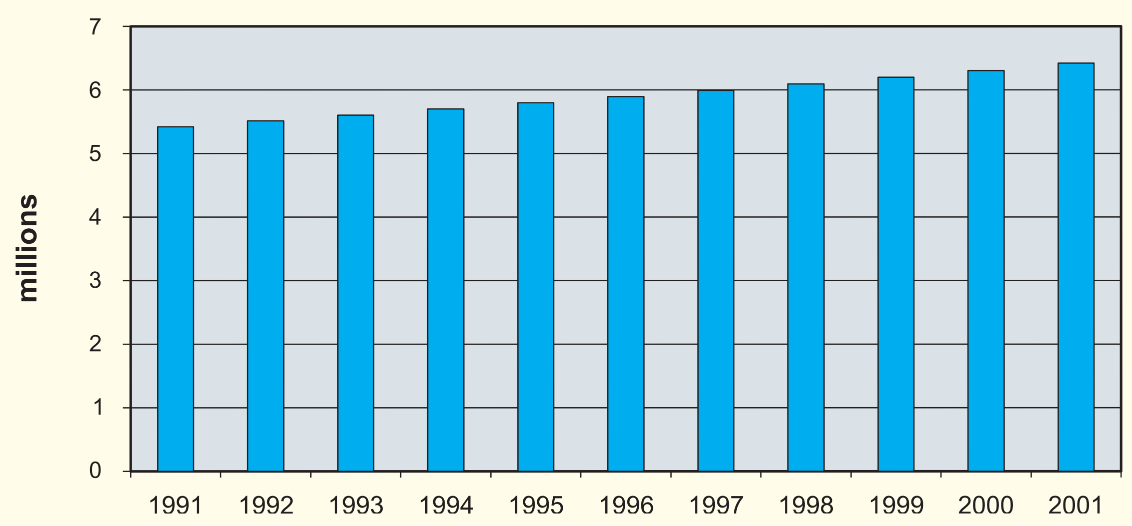
3. Climate

A5E.04 The weather profile for Chennai (Table A5E.1), is based on 12 years of data (1991 and 2002). Chennai has a hot climate, which can be termed as tropical maritime monsoon type. The mean monthly temperature ranges from 21.3°C (December to February) to 37.2 °C in summer months (March to August), the city receives quite a lot of rain during the monsoon (September to November) months. Calm conditions mostly prevail in the morning hours, but then the winds pick up and average wind speeds are on the higher side. The relative humidity is higher in the morning hours, complementary to calm conditions.

4. Industry

A5E.05 Chennai has a mix of large, medium and small-scale industries. There are about 35 medium and large-scale industries manufacturing a variety of products. The development of small-scale industries has been influenced by the needs of medium and large industrial units. As of March 1991, there were 16,326 permanently registered small-scale units in Chennai which grew to 40,300 by March 2001. These units are in the fields of automobile, hosiery and readymade garments, paper and paper products, machinery parts, metal products, food processing, rubber and plastic products, and chemicals. An information technology park named "Tidel Park" has also been set up by the state government across eight acres of land to boost the electronic

Figure A5E.2: Population growth in Chennai metropolitan area between the last two census periods (Pandey 2003)



telecommunications and information technology industry (GoI 2002b).

A5E.06 In terms of air pollution, industry is not much of a concern other than the Chennai Port Trust and the power generating units of the Power Corporation in Chennai due to good dispersion conditions. In addition, there are more than 900 diesel generators, which are used if and when there are power outages. The two principal operations of the Port Trust which lead to particulate pollution are handling of coal and export of iron ore. However, all the coal handling activities are in the process of being shifted out of the port by end of 2004. The ore handling is also supposed to be shifted out by end 2005. The Power Generating units use LSHS (low sulfur heavy stock) and naptha as fuels, and are monitored quite rigorously for air emissions (GoTN 2004).

5. Economy

A5E.07 Small-scale industries play a major role in the economy of the state. The employment generated directly by the registered small-scale industrial units in Chennai as of March 2001 numbered almost 3 million. Higher employment is generated in textile and textile-based industries and auto ancillaries. The contribution of the small-scale sector to the economy can be gauged from the fact that it accounts for 40 percent of the industrial production, 35 percent of direct exports, and 45 percent of overall exports. The average annual per capita income was Rs 36,138 (1998-99).

6. Transport

A5E.08 Chennai has a combination of three modes of public transport within the city: Metropolitan Rapid Transport System (MRTS), suburban railway, and Transport Corporation buses. The buses run by the Metropolitan Transport Corporation are the predominant mode of public transport in Chennai. The rail and roads to a large extent run in parallel.

A5E.9 Vehicular growth in Chennai as shown in Figure A5E.3 and A5E.4 shows that there has been a steady increase of vehicles in the city over the past two decades. The number of registered vehicles in 2002 was 1.35 million. About 75 percent of vehicles were two-wheelers, 18 percent were cars, 3 percent

Table A5E.1: Overall monthly average values of key meteorological parameters

	Mean Min. Temp. (°C)	Mean Max. Temp. (°C)	Mean Wind Speed (kmph)	No. of Calm Days		Relative Humidity %		Total Rainfall (mm)
				0830 hrs	1730 hrs	0830 hrs	1730 hrs	
January	29.5	21.3	4.4	14	3	83	68	22
February	31.2	22.5	4.7	10	2	81	66	23
March	33.2	24.0	5.0	6	1	78	66	3
April	34.7	26.6	5.8	5	1	74	69	21
May	37.2	28.0	6.8	3	1	67	66	30
June	36.6	27.4	7.1	2	2	64	62	81
July	35.4	26.6	5.6	4	3	68	63	99
August	34.3	25.9	5.0	3	5	72	64	109
September	34.6	25.6	5.2	5	5	76	70	142
October	32.1	24.5	3.9	11	7	83	76	297
November	30.0	23.3	4.6	9	4	85	78	374
December	28.9	21.5	5.4	9	1	81	70	139
Total/year				79	34			1342

Note: Data on wind speed and relative humidity is collected twice a day.

Figure A5E.3: Growth in commercial motor vehicles in Chennai (MoRTH 2003)

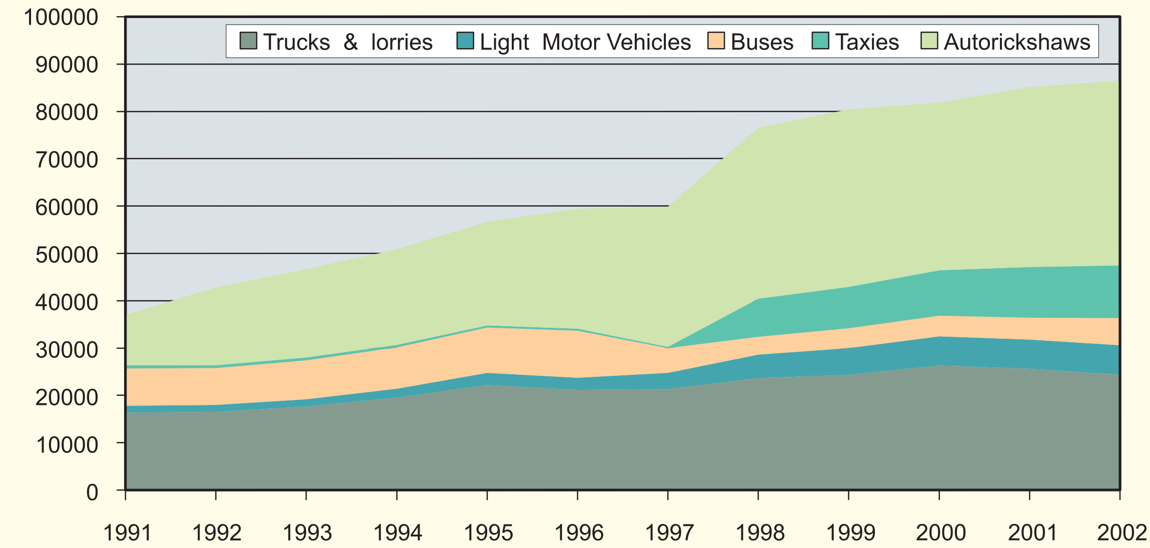
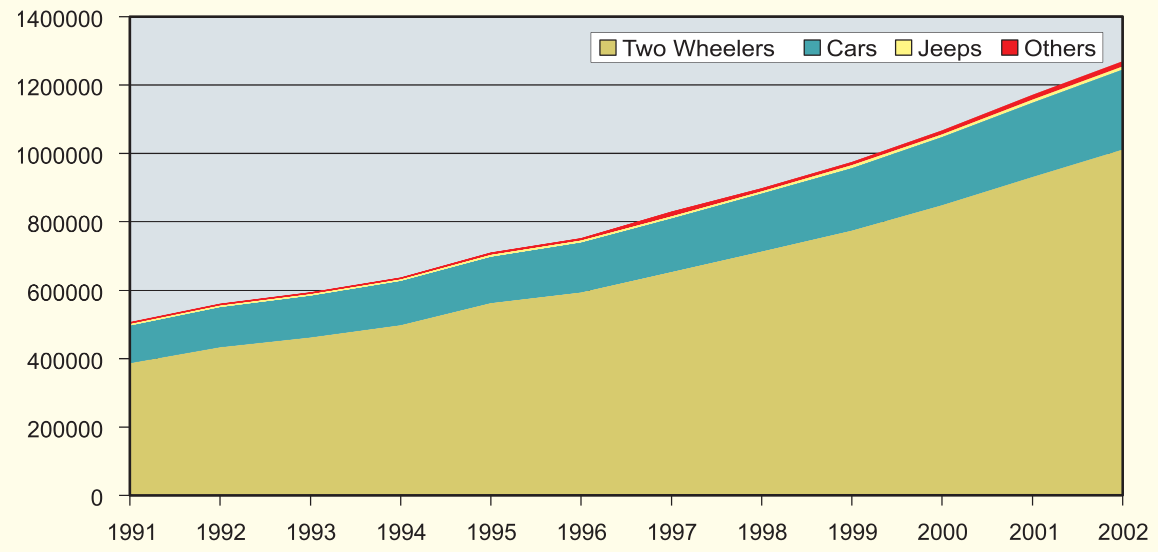


Figure A5E.4: Growth in private motor vehicles in Chennai (MoRTH 2003)



were three-wheelers, 2 percent were goods carriages, and the rest were a mix of buses, taxis and jeeps. The average growth rate in vehicle population has been between 7 and 9 percent per annum in the last decade (MoRTH, 2003).

A5E.10 The unprecedented increase in the number of private vehicles, particularly two-wheelers, has led to congestion on the roads and is a likely cause of air pollution in the city. Most of the actions being undertaken and proposed to address urban air pollution, target vehicular emissions as shown in Box A5E.8.

A5E.11 In 2002, the government banned the entry of suburban buses into the city center, close to the commercial monitoring location, and diverted them to a new terminal on the outskirts of the city.

7. Urban

A5E.12 The geographical area of Chennai City was 174 km^2. The green cover decreased from 1.7 percent of the geographical area in 1998-99 to 0.7 percent in 1999-2000 (Chennai Corporation 2004). Chennai has reached a level of saturation in terms of growth and most changes have been in terms of land-use or by way of densification. As outlined above, most growth has been in the metropolitan area. This growth has been radial, following the major road-rail network. Unlike other cities such as

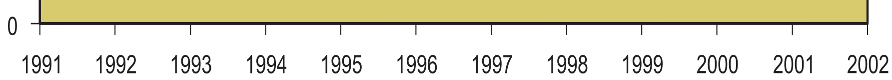
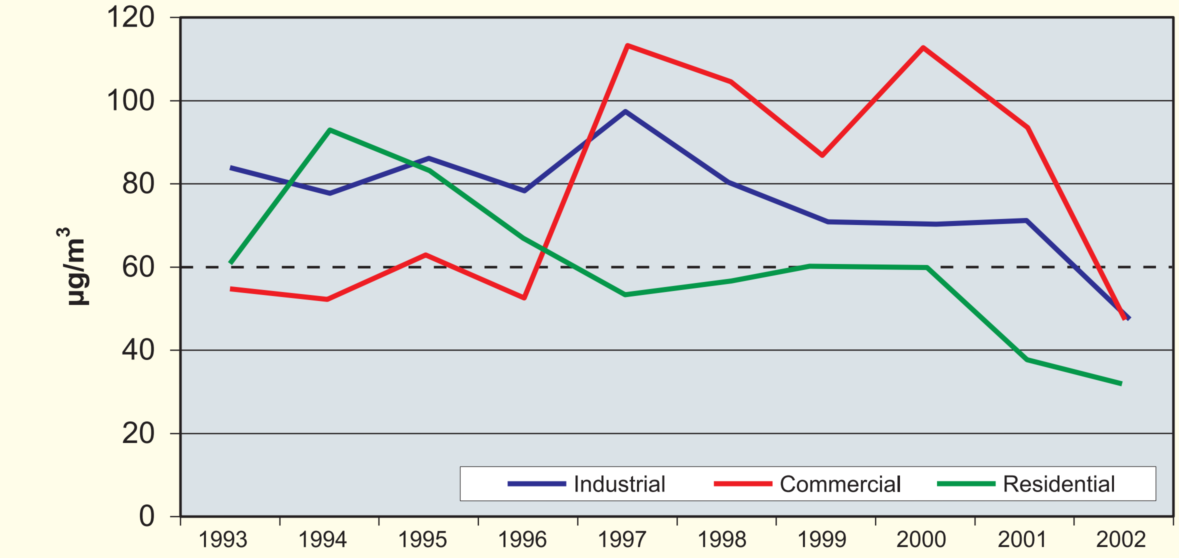


Figure A5E.5: Trend in RSPM levels in three areas of Chennai



Note: The dotted line shows the annual national ambient standard of 60 mg/m³ for RSPM for residential areas.

Delhi or Bangalore, the Chennai Metropolitan Development Authority regulates growth rather than developing land.

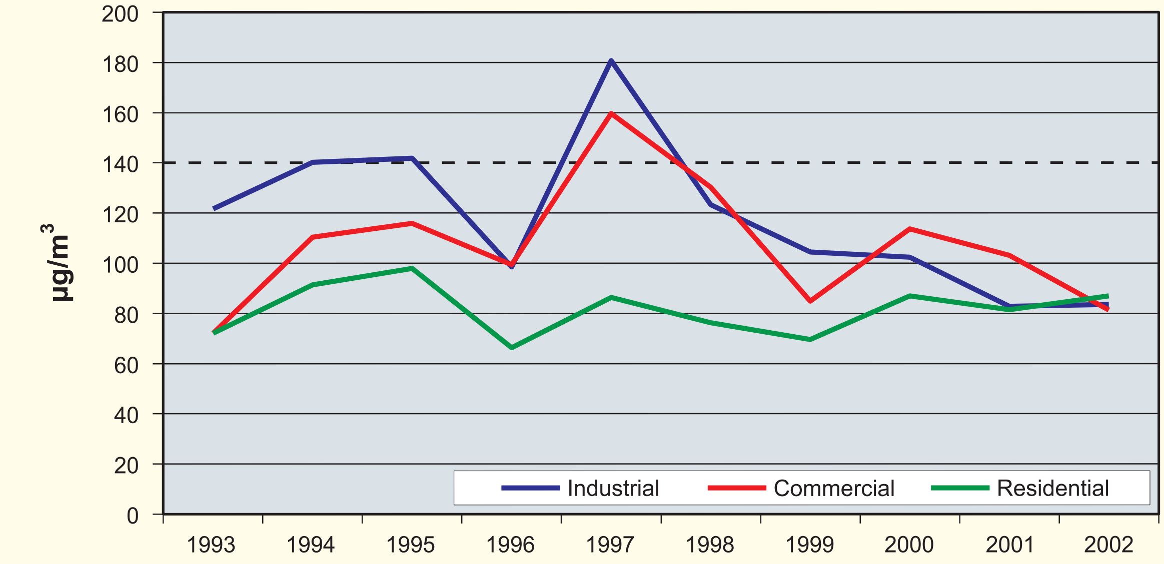
A5E.13 The Chennai Corporation is the oldest municipal corporation in the country formed in 1688. The revenue receipts in 2003-04 were Rs 5.1 billion in which the major contribution was from the property tax (Rs 2.4 billion). The revenue expenditure in 2003-04 was Rs 5.1 billion. The operating expenses were Rs 5.7 billion and repairs and maintenance cost was Rs 3.5 billion (Chennai Corporation 2004). Capital expenditure in 2002-03 amounted to Rs 1.6 billion with maximum expenditure on roads which was 1 billion. In the late 1990s, Chennai invested substantial resources in improving vehicle circulation by implementing 12 flyover schemes apart from major road rehabilitation works.

8. Urban Air Quality

Trends

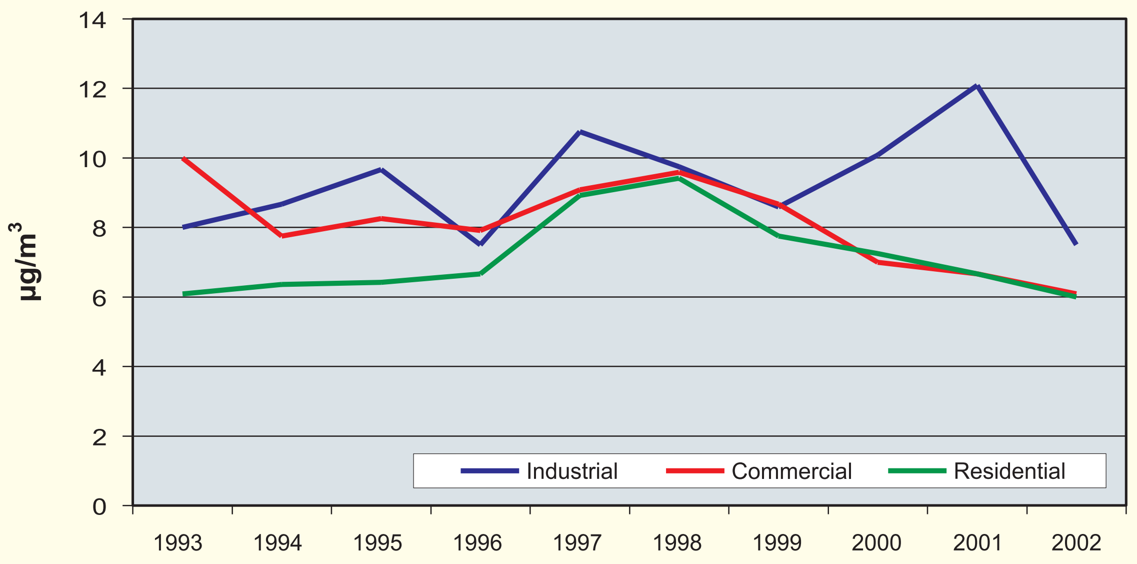
A5E.14 Figures A5E.5 and A5E.6 show annual

Figure A5E.6: Trend in SPM levels in three areas of Chennai



Note: The dotted line shows the annual national ambient standard of 140µg/m³ for SPM for residential areas.
No SPM data during the first 7 months of 1993 at the industrial site.

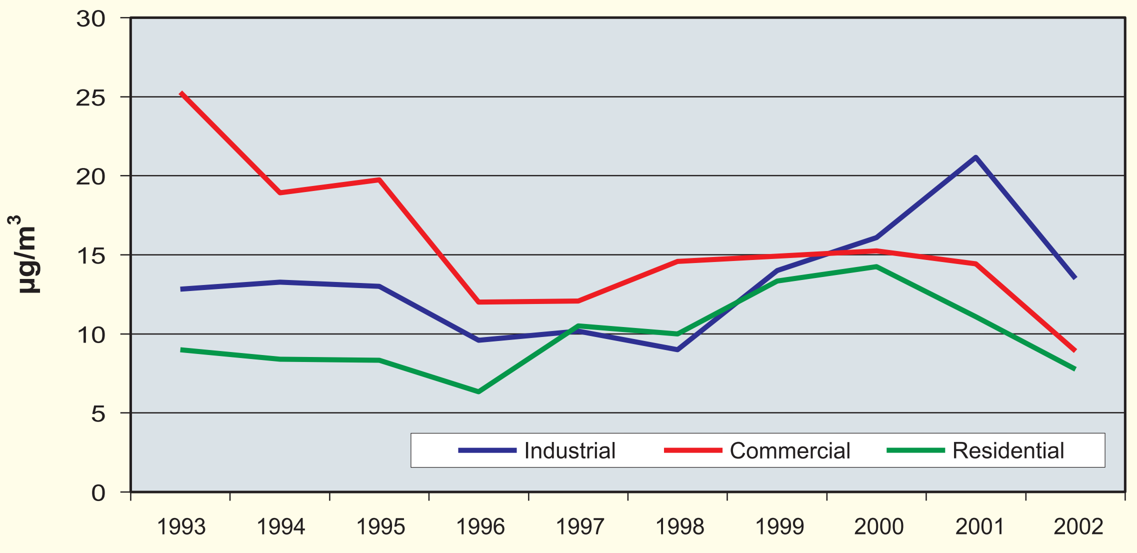
Figure A5E.7: Trend in SO_2 levels in Chennai



Note: The annual national ambient standard for SO_2 in residential areas is 60 μg/m³.

ambient RSPM and SPM levels, respectively, between 1993 and 2002 in the three different land-use areas. The data collected by NEERI indicate that the levels for both pollutants in all three areas were below the annual national ambient standards in 2002. Increased construction activities in the city center might account for the sudden increase in levels in 1997 at the commercial monitoring site. The decrease in annual average RSPM to below the national standards in 2002 coincided with the ban on entry of suburban buses into the city center. However, when compared with data from the SPCB industrial monitoring location for 2001 and 2002, which is located in the same area (Thiruvottiyur) as the NEERI industrial monitoring station, it was found that the NEERI values were much lower. Furthermore, the number of data points collected by SPCB was more than double NEERI's, rendering greater statistical significance to SPCB's data than NEERI's. Given the available data, the observation that all the three sites by 2002 were in compliance with the annual National Ambient Air Quality Standard for residential areas does not appear to hold across the city.

Figure A5E.8: Trend in NO_2 levels in Chennai



Note: The annual national ambient standard for NO_2 in residential areas is 60 μg/m³.

Box A5E.8: Major Technical and Policy Interventions in Chennai (1991-2004) that Impacted Air Quality

Year		Action
1991	*1)*	*Mass emission norms for new petrol vehicles introduced on 1/4/1991*
1992	*1)*	*Mass emission norms for new diesel vehicles introduced on 1/4/1992*
1993		N.A.
1994	*1)*	*Lead in petrol reduced to 0.15 gm/litre in June*
1995	*1)*	*Catalytic converters for 4-wheeled petrol driven vehicles mandated with effect from April*
	2)	*Unleaded petrol introduced to compliment the introduction of catalytic converters*
1996	*1)*	*Mass emission norms for new vehicles made more stringent on 1/4/1996*
	2)	*Fuel quality: 0.5% S diesel mandated in December*
	3)	*Benzene in petrol reduced to 5%*
1997	1)	Emission norms for in-use vehicles implemented from 1/1/1997
1998	*1)*	*Emission norms for catalytic converter fitted passenger vehicles from 1/4/1998*
	2)	*Low smoke 2T oil mandated*
1999	*1)*	*Pre-mixed 2T engine oil made mandatory for two-wheelers with effect from 1/4/1999*
2000	*1)*	*India Stage-I (Euro-I) emission norms mandated for all categories of new vehicles with effect from 1/4/2000*
	2)	*Fuel quality: 0.25% S diesel mandated from 01/04/2000*
	3)	*Leaded petrol phased out by February*
2001	*1)*	*Bharat Stage-II (Euro-II) emission norms for all categories of new non-commercial vehicles mandated by July*
	2)	*Low Sulfur diesel and petrol (0.05%) mandated from 1/7/2001*
	3)	*Emission norms for LPG vehicles introduced from May*
2002	*1)*	*Bharat Stage-II (Euro-II) emission norms for all new commercial vehicles introduced by October*
	2)	Entry of old buses into the center of the city prohibited, and old buses diverted to new bus terminal at Koyambedu in the outskirts of the city from 18/1/2002.
	3)	*Emission norms for CNG vehicles (all categories) and LPG vehicles (heavy duty) with effect from May 2002 and October 2002 respectively*
2003	1)	5% ethanol blended gasoline mandated with effect from January
	2)	Green tax levied for vehicles more than 15 years old from August
	3)	*Supreme court order for preparation of Action Pan for lowering ambient RSPM levels on 14/8/2003*
2004	1)	MRTS introduction in selected areas of Chennai since 26/1/2004
	2)	*Notification issued by Government of India revising the emission norms of in-use vehicles with effect from 1/10/2004.*

N.A. – Not applicable

Notes: (1) Interventions common to all five cities are shown in Italics. However, all common interventions were not implemented in the same year in all cities. (2) Dates to be read as day/month/year.

Figure A5E.9: **Trend in RSPM monthly concentration at the residential, commercial and industrial area monitoring locations**

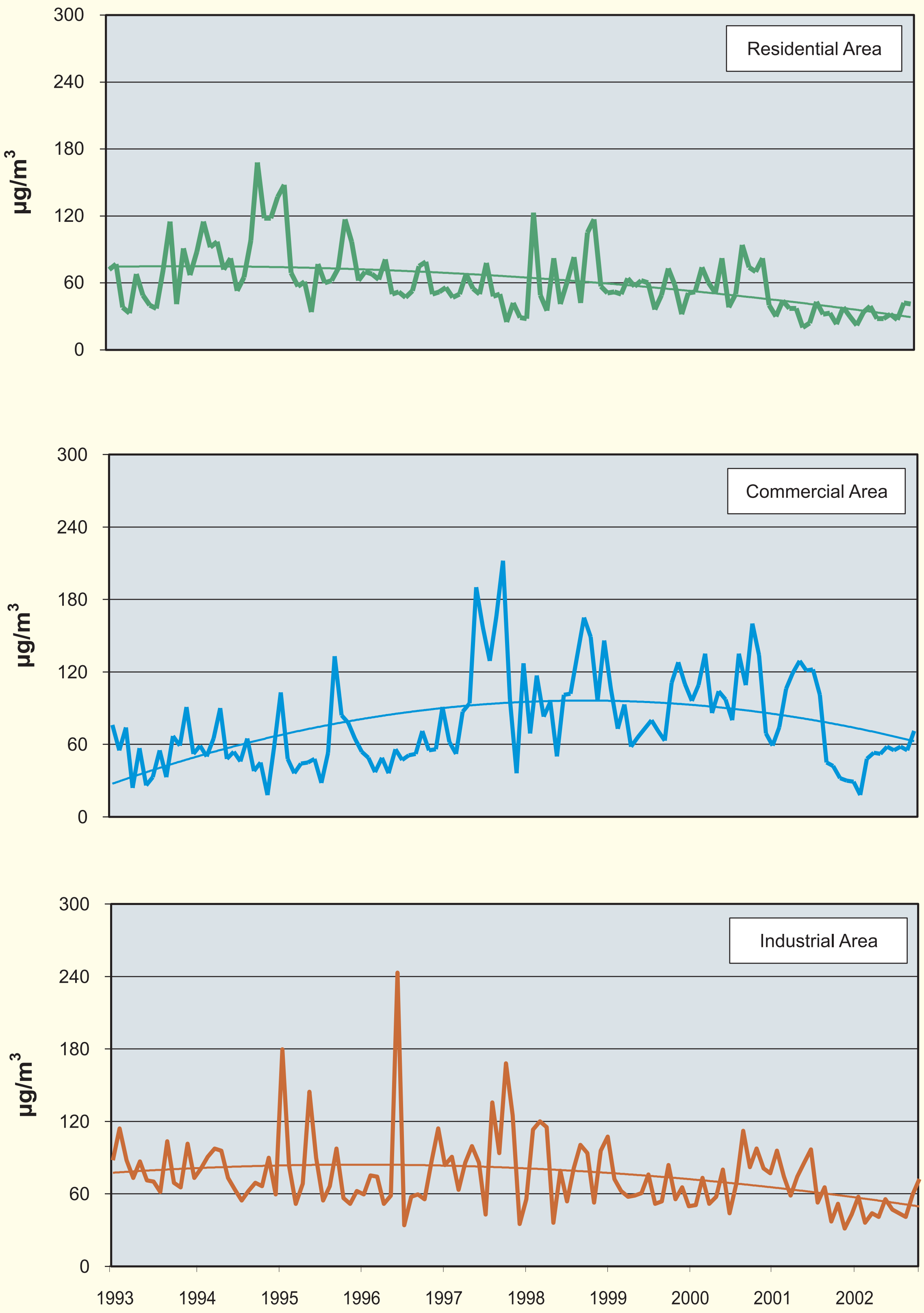
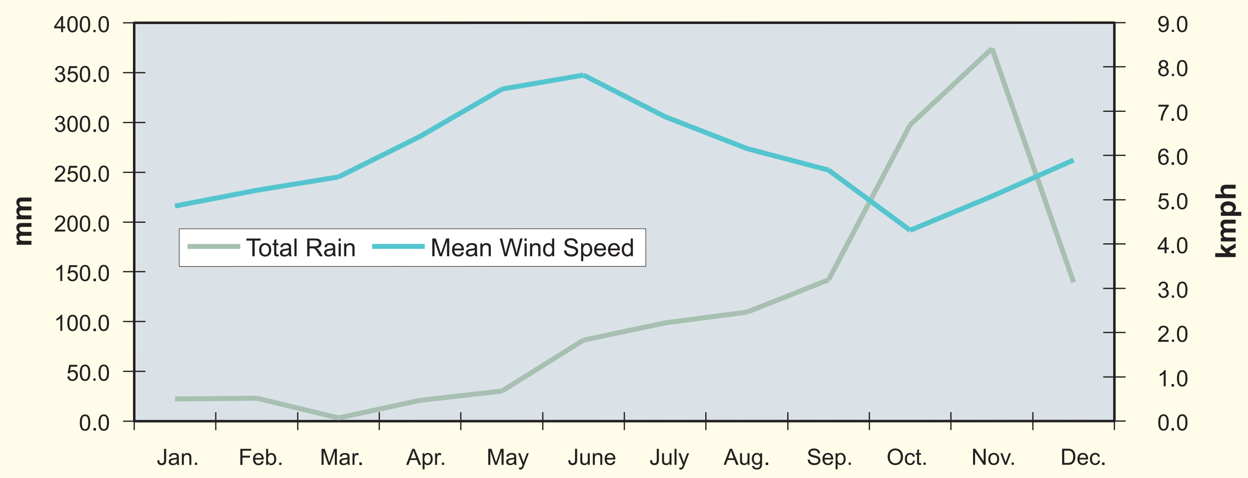


Figure A5E.10: Monthly average total rainfall and mean wind speed



A5E.15 The average levels of SO_2 and NO_2 are shown in Figures A5E.7 and A5E.8. The levels observed were well below their respective annual national standards and there was no particular trend in their variation. The levels of NO_2 were lower in the period 1996 -98 than in other years.

A5E.16 Figure A5E.9 shows the monthly averages of RSPM in the three areas over the years. The maximum and minimum values did not vary too much between the three areas. The overall maximum was just above 240 µg/m³, and the minimum went down to approximately 20 µg/m³. Further, the RSPM levels were found to be significantly different between the three areas (at the 10 percent level) as indicated by analysis of variance results, suggesting that the sources of RSPM may not be similar across the three areas.

9. Seasonality

A5E.17 From empirical evidence, it is known that the two parameters which directly impact concentration of pollutant are rainfall and wind speed, since higher precipitation leads to lower concentration of pollutants, and higher wind speeds leads to better dispersion.

A5E.18 As Figure A5E.10 shows, higher precipitation and higher wind speed seasons follow each other sequentially in Chennai. Such a situation is likely to lead to better dispersion conditions over a longer period of time. An empirical classification (see endnote # 21) of the dispersion conditions was attempted for all the cities based on the meteorological data. It was found that good dispersion conditions exist from June to December, while

Figure A5E.11: Monthly average total rainfall and RSPM concentration

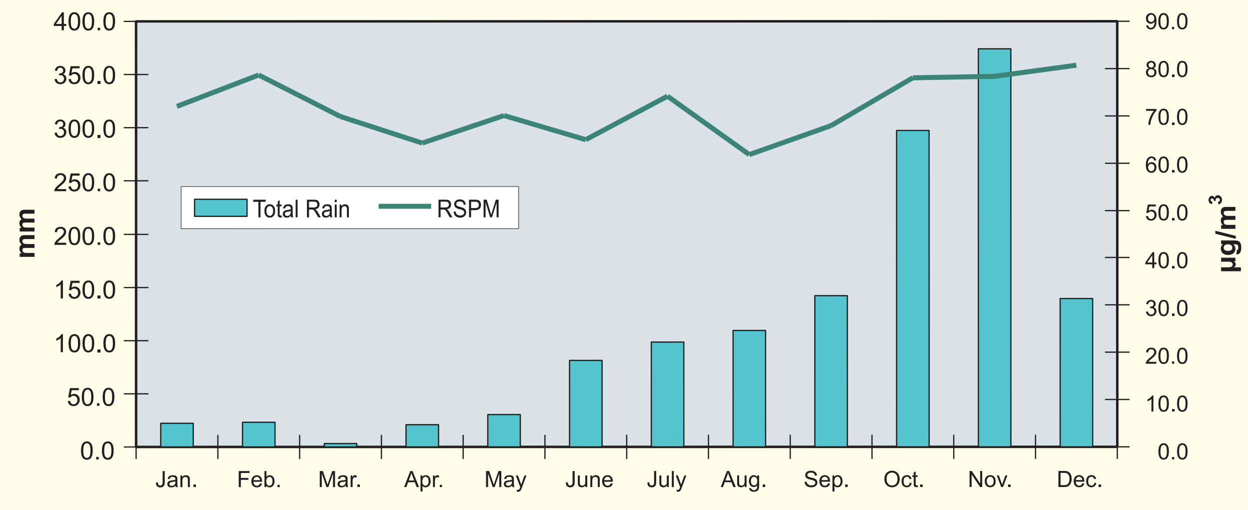


Figure A5E.12: Monthly mean wind speed and RSPM concentration

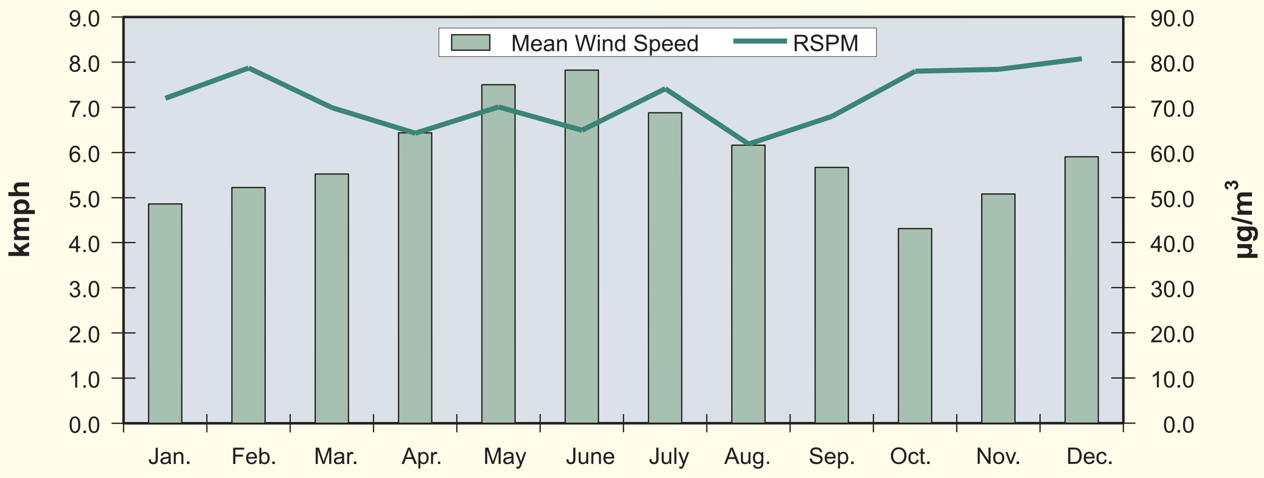


Figure A5E.13: Variation in monthly averages of SO_2 and NO_2

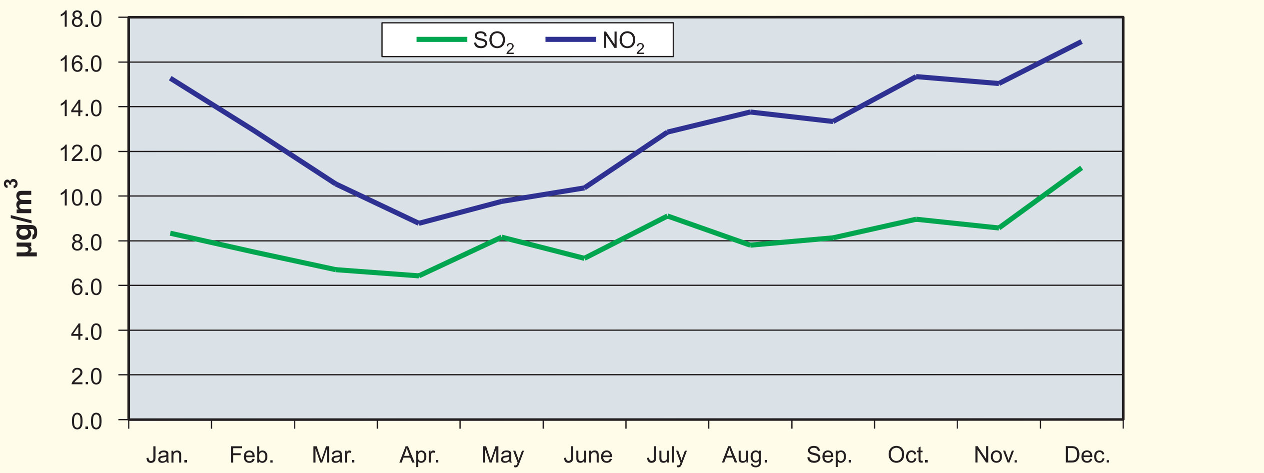
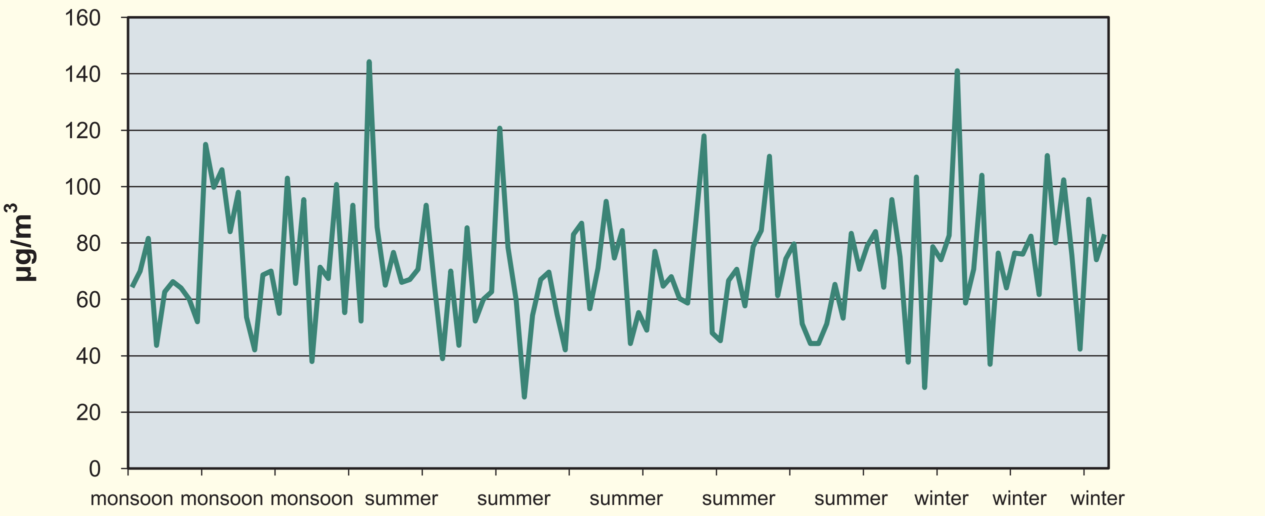


Figure A5E.14: Overall variation in RSPM with seasons (Monsoon: September to November; Summer: March to August; Winter: December to February)



moderate dispersion conditions exist between January and May. Further evidence of the effects of better dispersion over a longer period of time can be seen in the monthly variation of RSPM.

A5E.19 As seen in Figures A5E.11 and A5E.12, there is hardly any impact of the two meteorological parameters—total rainfall and mean wind speed—on RSPM levels.

A5E.20 The variation in monthly averages of SO_2 and NO_2 is shown in Figure A5E.13. It can be seen that NO_2 does show a slight effect of wind speed as it decreases between January and April as wind speeds increase.

A5E.21 The commonly used definitions of summer, winter, and monsoon seasons were used to aggregate the months, in order to further explore any seasonality in the variation of RSPM levels.

A5E.22 As Figure A5E.14 shows, there are no discernible effect of seasons. The averages for monsoon, summer, and winter months were 75 $\mu g/m^3$, 68 $\mu g/m^3$, and 77 $\mu g/m^3$, respectively.

A5E.23 Since the summer, winter, and monsoon classification is subjective in nature, the empirically derived classification of dispersion conditions discussed at the beginning of this section was used to assess seasonality in RSPM variation. It was found that there was no effect of the two dispersion classifications. The RSPM averages for the good and moderate dispersion classifications were 72 $\mu g/m^3$ and 71 $\mu g/m^3$, respectively.

Health Cost of Exposure to RSPM Pollution

A6.01 A large number of epidemiological studies have linked exposure to PM_{10} concentrations to health end-points, making it possible to conduct a meta-analysis of the different studies. Given that most of the studies have been conducted in industrialized countries, application of their results to a developing country like India raises legitimate concerns. However, recent studies undertaken in Mexico city, Santiago, and Bangkok provide support to the case for extrapolation of results. Further, the fact that epidemiological studies provide information on percent change in mortality due to absolute change in ambient levels, makes a case for extrapolation since the change is predicted with respect to the area-specific baseline mortality. Furthermore, meta-analysis enables one to derive "best estimates" of the relationship between air pollution and health end-points, which can be applied with greater confidence to other situations/countries/cities than an estimate from an individual study. While epidemiological studies using PM_{10} or RSPM do not exist in India, a study in Delhi found an association between SPM levels and changes in mortality rates (Cropper et al, 1997). In this assessment, both meta-analytical estimates from Lvovsky et al (2000) and estimates from Cropper et al (1997) are used, as explained below.

Estimates for Mortality and Morbidity

A6.02 Hence, this study uses the pooled estimate of 0.84 percent change in all-cause mortality relative to a 10 µg/m³ change in RSPM concentration, derived from a number of acute exposures studied in an earlier World Bank review (Lvovsky et al. 2000), and summarized in Table A6.1. However, this estimate is used only for Mumbai, Hyderabad, and Chennai, since they had levels that were close to those recorded in cities from which the estimates have been derived. In the case of Delhi and Mumbai, which show much higher ambient levels, more conservative estimates of 0.42 from Cropper et at (1997) are used. [23]

A6.03 Similar to estimates of mortality, concentration-response functions are also derived for morbidity impacts such as respiratory hospital admissions, chronic bronchitis, cough, asthma, etc. However, there are much fewer concentration-response functions available for morbidity end-points from developing countries than for mortality. The pooled estimates used for morbidity end-point from an earlier World Bank review (Lvovsky et al, 2000) are used in this study. It needs to be borne in mind that these estimates implicitly incorporate the baseline incidence of the morbidity end-points (such as chronic bronchitis) in the location where the studies were conducted, and as a result they are likely to underestimate the morbidity impacts for Indian cities (since the baseline incidence in Indian cities can be expected to be higher than in cities in industrialized countries where most of the studies have been conducted).

Methodology for the Estimation of Health Impacts

A6.04 Health impacts are calculated using the equation

$$\Delta H_i = b_{ij} * \Delta A_j * P \quad \ldots\ldots (1)$$

Where: Δ stands for change; H_i is the health impact of type i per year; b_{ij} stands for the slope of the concentration response function of health effect i for exposure to pollutant j per year; A_j is the ambient concentration of pollutant j and P is the population exposed to the pollutants.

The quantity ΔA_j is defined as

$$\Delta A_j = \max [\, 0, A_j^1 - \max(A_j^0 , S_j)] \quad \ldots\ldots(2)$$

Where: A_j^1 is the observed concentration; A_j^0 is the background concentration and S_j is the relevant threshold or air quality standard.

The coefficients b_{ij} used in this study are shown in Table A6.1 (except that 0.42 was used for assessing the impact of mortality in Delhi and Mumbai). It was assumed that the dose-response

Table A6.1: Air pollution concentration-response function slope (b_{ij}) per 1 μg/m³ change in the mean annual level of PM_{10}

Health Effects	Units	b_{ij}
Mortality	Percentage change	0.084
Chronic Bronchitis	Per 100,000 adults	6.12
Respiratory Hospital admission	Per 100,000 population	1.2
Asthma attack	Per 100,000 asthmatics	3,260
Emergency room visits	Per 100,000 population	23.54
Restricted day activities	Per 100,000 adults	5,700
Lower respiratory illness	Per 100,000 Children	169
Respiratory symptoms	Per 100,000 adults	18,300

Source: Lvovsky et al. 2000

ambient RSPM concentrations were obtained from NEERI measurements.

A6.05 In the case of mortality, the slope refers to percentage change in the mortality and hence it has to be multiplied by the crude mortality rate to get the absolute number of cases. Similarly, the other slopes have to be multiplied by the adult or children fraction of the population as appropriate. In the case of asthma attacks, the slope has to be multiplied by the fraction of asthmatics in the population.

Economic Valuation of the Health Impacts

A6.06 Economic valuation of health impacts in this study is based on the approach of Willingness-to-Pay (WTP) to reduce the risk of getting sick or dying prematurely. In valuing the mortality costs, this approach uses the Value of Statistical Life (VOSL), which is not the same as valuing actual life, but instead involves placing a value on reduction in overall risk that people face. The VOSL used in this study was also adjusted for a difference between an average number of years lost by people dying due to air pollution and an average number of years lost by people surveyed by the labor market studies, on which the majority of VOSL estimates are based. Valuation of morbidity in this report is also based on WTP estimates for avoiding suffering and inconvenience associated with an illness of a given severity (see Lvosky et al 2000 for details).

A6.07 The major uncertainty that complicates the transfer of WTP estimates from industrialized countries to a country like India is the difference in income levels, since WTP estimates are known to rise with income. Hence, VOSL estimates were adjusted for income effects before applying to India (see Table A6.2).

Scaling the Costs of Health Effects

A6.08 The WTP-based values for the cost of health effects including the VOSL have been obtained through extensive research mostly in the United States. These values are of course related to economic indicators and these have to be scaled by per capita GNP (Gross National Product) for variation in time and space. It has been shown that country specific variation can be scaled by using the relation:

$$\text{Log}\ (V_k) = r * \log\ (Y_k\ /\ Y_{us}) + \log(V_{us}) \ldots\ldots\ldots\ldots..(3)$$

Where: V is the valuation parameter for given country; k and Y is the per capita GNI. Various values of r in the range of 0.4 to 1.2 have been reported but it has been observed that r=1 provides conservative estimates (Lvovsky et al., 2000). With this approximation, the relation for any given city (C) becomes linearized to:

$$V_C = V_{us} * (Y_C\ /\ Y_{us}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

This simplified relation is used in the calculations here and are shown in Table A6.2 (next page) .

Table A6.2: Willingness-to-Pay based health effect costs per case derived for in Delhi

Health Effects	WTP US (1990)	India (2003) US$	India (2003) Indian Rs.
Mortality (VOSL)	1,620,000	34,943	1,572,419
Chronic Bronchitis	195,000	4,206	189,273
Respiratory Hospital admission	4,225	91.13	4,101
Asthma attack	63.00	1.36	61
Emergency room visits	126.00	2.72	122
Restricted day activities	53.00	1.14	51
Lower respiratory illness	44.00	0.95	43
Respiratory symptoms	44.00	0.95	43

Note: GNP per capita for India is $470; GNP per capita for US for 1990 is $ 21790; 1$=Rs.45

Source: Lvovsky et al, 2000

Annex 7

Questionnaire Survey for Stakeholder Input

The World Bank has been engaged in air quality management issues in India for almost ten years. For the first time in 1995, an assessment by the World Bank assigned monetary values[24] to the health impacts of urban air pollution – an effort that contributed to the movement for clean air in Indian cities. Since then the political economy of decision making with regards to urban air quality management (UAQM) in India has evolved, with an active role being played by civil society and judiciary in influencing policy decisions. In recent years, a number of cities have started to clean-up their act! However, cities continue to grow in size and population, with a consequent increase in sources of air pollution – particularly the number of motor vehicles and the vehicle-kilometers traveled.

While in 1995 the World Bank helped provide impetus to the movement for clean air in urban India, it has made limited efforts to scale-up its engagement on urban air quality management since then. With a large and growing portfolio of projects in India – across sectors which are likely to present many challenges and opportunities for addressing urban air quality concerns – it is important for the World Bank to take stock, and understand the key issues and challenges. That is the purpose of the attached questionnaire, which is part of a study to assess the status of Urban Air Quality in India. The study is being conducted by undertaking an assessment of air quality in five major cities, namely – Delhi, Mumbai, Chennai, Hyderabad and Kolkata.

Your time and effort in completing the questionnaire will be appreciated.

Questionnaire

Name: ....

Address: ....

City: ....

Telephone Number & Email Address: ....

1. Whom do you work for?

Government ☐ Private Sector ☐

Academia ☐ Development agency ☐

NGO ☐ Others (specify) ☐

2. How would you describe your area of work? (can check more than one box)

Policy formulation / analysis ☐

Legal Issues ☐ Enforcement ☐

Information dissemination ☐

Research ☐ Air Pollution Related ☐

Advocacy ☐ Others (specify) ☐

3. In your opinion, what is the status of air pollution in your city of residence?

Serious ☐ Not Serious ☐

Moderately Serious ☐ Others (specify) ☐

4. What is your primary source of information on air pollution in your city of residence?

Newspaper/ TV ☐ Technical reports ☐

Friends & Colleagues ☐ Other (specify) ☐

5. Please rank[25] (on a scale of 1 to 6) the air pollutants of concern in your city of residence:

Respirable Particulate Matter / PM_{10} ☐

Carbon Monoxide ☐

Sulfur Dioxide ☐ Ozone ☐

Nitrous Oxides ☐ Others (specify) ☐

6. In your opinion, in the last 10 years, air quality in your city of residence:

Improved initially then deteriorated ☐

Has been deteriorating ☐

Deteriorated initially then improved ☐

Has been Improving ☐

Has not changed ☐ Others (specify) ☐

7. Please rank (on a scale of 1 to 4) the sources of air pollution in your city of residence by sector:

Transport ☐ Urban[26] ☐

Industry[27] ☐ Others (specify) ☐

8. In your opinion, over the last 10 year which of the following have had positive (+), negative (-), or neutral (0) impact on air quality in your city of residence (put a mark in the box; leave blank if the activity has not occurred in your city or you do not know about it):

New roads and flyovers (exclude period of construction) ☐

Closure of air polluting industries ☐

Construction practices in the city ☐

Public Transport ☐

Relocation of air polluting industry ☐

Zoning to segregate different land-uses ☐

Use of cleaner transport fuels ☐

Cleaner fuel use in industry

Maintenance of urban infrastructure such as roads and pavements

Phase-out of old vehicles

Overall shift in nature of industry towards service sector

Use of cleaner fuels for domestic use

Newer vehicles on the road

Compliance of industry with regulation

Ban on open burning of garbage etc

Others (specify)

9. Do you agree that effect on human health is the single, most important manifestation of the impact of urban air pollution ?

Yes No

Others (specify)

10. Please rank (on a scale of 1 to 7), the involvement of following in efforts to address air quality concerns in your city of residence:

Government Academia

NGOs Judiciary

Private Sector Others (specify)

International agencies

11. Please rank (on a scale of 1 to 8), the impediments to effective urban air quality management in your city of residence:

Corruption Lack of political will

Poor laws and regulations

Lax standards

Lack of information / knowledge at the decision-making level

Poor decision-making structure

Poor/outdated technologies

Others (specify)

12 Should donor-agencies like the World Bank be active in addressing urban air quality concerns in Indian cities?

Yes No

13. If agencies like the World Bank were to support urban air quality management efforts, should they:

Support the central government

Support the state government

Support city /local administration

Others (specify)

14. Please rank (on a scale of 1 to 10), where you see the role of agencies like the World Bank in urban air quality management :

Knowledge sharing based on international experience

Stand-alone environment projects (e.g. cleaner public transport, industrial emissions control etc.)

Provision of equipment for air quality monitoring

Assistance through sectors that impact air quality (e.g. transport, energy, and urban development)

Formulation of policies, standards and regulations

Training and capacity building

Technical studies

Awareness generation

Others (specify) No role

A Request (only if you have the time): As part of this study we are trying to put together a list of all actions[28] that have taken place in your city of residence which may have affected air quality since 1993 (along with the year and month). It would be appreciated if you could take the time to provide us a list of relevant actions based on your knowledge/ memory (attach a separate sheet of paper if necessary). Your effort will be acknowledged in the study report.

Thank you !

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Notes

1. The national annual ambient air quality standards for residential areas are 140 µg/m³ for SPM and 60 µg/m³ for RSPM. Furthermore, WHO sets no threshold for the health impacts of exposure to RSPM, as such impacts have been detected even at very low levels of exposure.

2. Bangalore was originally proposed to be included in the study, but it had to be excluded due to inadequate data on key air pollution parameters, particularly RSPM.

3. The sources of urban air pollution are many, and can broadly be classified into transport, industrial, domestic/municipal, and fugitive sources. Specific examples include: motor vehicles, large, medium and small scale industries, thermal power plants, garbage burning, domestic cooking and heating, and re-suspended road dust.

4. The notification was issued by the Delhi Pollution Control Committee as part of the list of approved fuels under the Air Act. There was no prescribed limit for sulfur in these fuels before that.

5. All the data were made available by the CPCB. See Annex 3A.

6. Even CPCB measurements of RSPM, started in 1999, seldom meet the requirement of 104 measurements in a year. This is a major issue with data collection irrespective of the agency collecting the data.

7. The sensitive area classification refers to protected areas and eco-sensitive zones such as the area around the Taj Mahal.

8. According to CPCB the high levels of NO_2 in Delhi may be attributed to two natural gas based thermal power plants emitting high levels of NO_2, plying of non-optimized converted CNG vehicles, poor performance of three-way catalytic converters in gasoline vehicles, and an overall increase in the vehicle population.

9. The usual classifications for wind speed in dispersion model calculations are less than 2, 2-5, 5-7.5 and greater than 7.5 meters/sec (m/s) (Lvovsky et al. 2000). From the analysis of the present data, it was observed that the dispersion situation is substantially changed when wind speed is combined with precipitation. So, the first classification (0-2 meters/sec) has been divided into three, less than 1, 1-1.5 and greater than 1.5 m/s. All the other classifications are included in the >2 m/s group. These sub-divisions when combined with precipitation provided reasonable qualitative description for observed variation in PM levels in all the cities with some exceptions that arise from outliers in the data sets.

10. These winds are locally called the "loo."

11. The numbers for five cities being studied were 7,491 in Delhi, 5,726 in Kolkata, 4,477 in Mumbai, 768 in Hyderabad, and 863 in Chennai.

12. The CSE followed up on the study with its own assessment of premature mortality and estimated higher numbers. TERI also did a similar exercise using a modified methodology and computed even higher numbers.

13. Additional caution should be exercised in using estimates for Delhi and Kolkata for Scenario 4, when concentration-response coefficients were applied over a wide range of concentrations, which is unusual for concentration-response studies which typically measure the impact of marginal changes in air quality.

14. For example, LPG uptake for cooking gas rose nation-wide from 26 percent of urban households in 1993-1994 to 45 percent in 1999-2000, while the use of wood dropped significantly (See World Bank 2003). The consumption of LPG in the domestic sector almost doubled in 1998-199 as compared to 1990-1991 (TERI 2001)

15. Information on city-specific monitoring networks for each of the five study cities has been provided by NEERI.

16. Based on site visit and input from NEERI and CPCB staff in Delhi.

17. Where R, C, and I refer to residential, commercial, and industrial areas respectively.

18. When the concentrations of RSPM or SPM measured at the same site at the same time are plotted against each other, the regression line must go through the origin. If the monitoring stations are different and /or data are not taken on the same days, as in this case, then the line does not necessarily have to go through the origin. However, since RSPM data are collected in the same city, provided there is reasonable dispersion across the city, it is unlikely for RSPM concentrations to be zero in one place and non-zero in another place, and therefore the line is forced through the origin throughout this annex.

19. The concentration of RSPM must be zero if SPM concentration is zero. In theory, it is possible for SPM to be non-zero and RSPM to be zero, but in practice such a situation is extremely unlikely, if not impossible. Therefore, when plotting RSPM against SPM, the plot is forced through the origin throughout this annex.

20. The primary sector comprises of agriculture, livestock, forestry, fishing, mining and quarrying; the secondary sector comprises of manufacturing electricity, gas and water supply and construction; and the tertiary sector comprises of trade, hotels and restaurants, transport, storage, communications, financing, insurance, real estate, business services, community and social and personal services.

21. "Good dispersion" conditions correspond to monthly rainfall more than 50 mm. "Moderate" corresponds to rainfall more than 20 mm and wind speed more than 5.4 km/hr (1.5 m/sec) or wind speed more than 7.2 km/hr (2 m/sec). "Poor" corresponds to wind speed less than 5.4 km/hr and rain less than 20 mm or wind less than 3.6 km/hr (1 m/sec). This classification is not based on proper dispersion model calculations. The usual classifications for wind speed in dispersion model calculations are <2, 2-5, 5-7.5 and >7.5 meters/sec (Lvovsky et al. 2000). From the analysis of the present data, it was observed that the dispersion situation is substantially changed when wind speed is combined with precipitation. So, the first classification (0-2 meters/sec) has been divided into three, <1, 1-1.5 and >1.5 m/s. All the other classifications are included in the >2 m/s group. These subdivisions when combined with precipitation provided reasonable qualitative description for observed variation in PM levels in all the cities with some exceptions that arise from outliers in the data sets.

22. The secondary sector comprises of manufacturing electricity, gas and water supply and construction; and the tertiary sector comprising of trade, hotels and restaurants, transport, storage, communications, financing, insurance, real estate, business services, community and social and personal services.

23. The value is derived taken a change in mortality relative to a change of 10 $\mu g/m^3$ in SPM levels from Cropper et al (1997) and using the RSPM/SPM ration of 0.55.

24. The cost of urban air pollution was calculated to be equivalent to 0.63 % of GDP, or 14 % of the cost of environmental degradation of US$9.7 billion.

25. All ranking should use number 1 as the high-end of the scale, with following numbers signifying reduction.

26. Includes construction, open burning of garbage, and household fuel use

27. Including power plants

28. These could range from technical / policy interventions driven by court orders, to initiatives that may have taken place for reasons other than air quality improvement, but ended up affecting air quality (e.g. change in industrial base from manufacturing to the service sector due to economic reasons).